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Sustainability assessment of an apartment building containing reinforced concrete or cross-laminated timber (CLT)


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3 Preface

We prepared this master's thesis at the Department of Engineering Science at the Faculty of Technology and Science, University of Agder. Collaboration partner for this thesis is the Construction Department, Rambøll in Skien.

This report is written in the fourth and final semester, and it constitutes the last 30 credit points of the civil engineering program in Construction, the subject BYG 508.

We want to thank our internal supervisor Bjørn Kittelsen, who has contributed with excellent help and guidance throughout the master's thesis in addition to the preliminary project written as an initial assignment for the master thesis.

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Last but not least, a big thank to our families who have supported us and been patient while we have worked at the Master's thesis.

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4 Summary

Today, the construction industry contributes to 40% of the world's energy consumption and greenhouse gas emissions (GHGs). According to the Intergovernmental Panel on Climate Change's (IPCC) report, the greenhouse gas emissions must be reduced by 40-50 percent to limit Global Warming to 1.5 degrees rather than 2 degrees by 2030. The United nation's (UN) Sustainability Goals are the world's common work plan to stop climate change by 2030. To achieve the above goals, it is crucial for the construction sectors to look for better, alternative construction materials as top concern to sustainability and environmental issues.

In this study, a methodology for determining a sustainable solution for a structural system of an apartment building has been investigated.
The study has proposed and compared three structural systems options with more focus on the environmental issue. The options are: Option 1: Timber structural system including walls and foundations made of normal concrete. Option 2: Timber structural system including walls and foundations made of low carbon concrete and option 3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.

Then a comparative life cycle assessment (LCA) was carried out, as well as an analysis of construction cost. The ReCiPe LCA method is utilized to assess the impacts of the three structural systems options using SimaPro software based on the midpoint characterization.

The findings of this study show that, the Global Warming Potential (GWP) of option 3 appears to be much lower, compared to the other two options; followed by option 2 and option 1. However, Land use in option 3 is found to be 9% higher than the option 1 and option 2. GWP of option 3 was 11% and 5% lower than option 1 and option 2 respectively.

It is important to note that replacing normal concrete with low carbon concrete in option 2 has reduced the GWP by 6 %. Furthermore, in option 3, replacing some of the low carbon concrete walls with CLT has reduced the GWP by 5%. Based on these LCA results, it can be concluded that structural systems containing low carbon concrete and CLT would have the lowest environmental impact - of the three options studied.

When it comes to construction costs, option 2 was slightly more expensive than the other two options. This option was 1.3% more expensive. Surprisingly, construction cost of low carbon concrete is only 2-3% more expensive than normal concrete.

Based on an overall assessment, option 3 is preferred in regard to environmental concerns; it has more positive properties than the other alternatives if one regard energy consumption, greenhouse gas emissions and construction costs. Thus, construction sectors can achieve higher sustainability by implementing measures to reduce GWP, by for example replacing the normal concrete with sustainable concrete (low carbon concrete, preferably class A) and by using timber structures (CLT and glulam) as much as practically and structurally possible. Low carbon concrete has more positive properties and its construction cost is very close to normal concrete, as mentioned it is in fact only 2-3% higher.

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8 List of Abbreviations

Symbol	Description
F_k	characteristic value for an impact(load)
γ_{GJ}	load factor for permanent load no j
γ_{Qi}	load factor for variable load no i
γ_P	load factor for PR restressing
$Q_{k,1}$	the characteristic value for the leading variable load.
$\gamma_{Q,1}$	the partial safety factor associated with $Q_{k,1}$
$f_{t,o,k}$	characteristic tensile strength along the fiber direction
$f_{t,9o,k}$	characteristic tensile strength perpendicular to the fiber direction
$f_{v,k}$	characteristic shear strength
$f_{c,o,k}$	characteristic compressive strength along the fiber direction
$f_{c,9o,k}$	characteristic compressive strength perpendicular to the fiber direction
$f_{m,k}$	characteristic bending strength
k_{mod}	the modification factor for duration of load and moisture content
k_h	depth factor
γ_M	a partial factor for material properties
$E_{g,mean}$	mean value of modulus of elasticity for GLT
$E_{g,0.05}$	fifth percentile value of shear modulus for GLT
$G_{g,mean}$	mean value of shear modulus for GLT
$G_{g,0.05}$	fifth percentile value of shear modulus for GLT
$\rho_{g,k}$	characteristic density for GLT
$\rho_{g,mean}$	mean density for GLT
$f_{m,y,d}$ and $f_{m,z,d}$	design bending strength about the principal y-axis and design bending strength about the principal z-axis respectively
$\sigma_{t,0,d}$	design tensile stress along the grain
$\sigma_{t,90,d}$	design tensile stress perpendicular to the grain
$\sigma_{c,0,d}$	design compressive stress along the grain
$\sigma_{c,90,d}$	design compressive stress perpendicular to the grain
$\sigma_{m,y,d}$ and $\sigma_{m,z,d}$	design bending stress about the principal y-axis and design bending stress about the principal z-axis respectively
k_m	factor considering re-distribution of bending stresses in a cross-section
$f_{v,d}$	design shear strength
$\tau_{v,d}$	design shear stress
V_{Ed}	design shear force
b_{ef}	effective width
k_{crit}	factor accounting for the effect of lateral buckling
$M_{y,Ed}$ and $M_{z,Ed}$	design bending moment about the principal y-axis and design bending moment about the principal z-axis respectively
W_y	section modulus about axis y
$\lambda_{rel,m}$	relative slenderness ratio in bending.
L_{ef}	effective length of the beam

b, h	b, h width and height of section respectively
k_{cr}	a crack factor for shear resistance
N_{Ed}	design tensile force
A_{eff}	effective cross-section of the component
$F_{c,90,d}$	design compressive strength perpendicular to the fibre direction
$k_{c,90}$	a factor that takes into account the load configuration
A_{ef}	the effective contact area for compression perpendicular to the fiber direction.
λ	slenderness ratio
L_k	an effective buckling length of the member
V_{Ed}	design shear force
i	radius of gyration of the cross-section
I	the second moment of area
A	the cross-sectional area of the member
P_E	Euler load
P_{kr}	the critical load that column is subjected to
$\lambda_{rel,y}$ and $\lambda_{rel,z}$	Relative slenderness ratio corresponding to bending about the y-axis and relative slenderness ratio corresponding to bending about the z-axis
$k_{c,y}$, $k_{c,z}$ and k_y	instability factors.
β_c	straightness factor
$f_{0,T,d}$	design value of torsional strength
$f_{V,R,d}$	design value of rolling shear strength
$w_{inst,qp}$	an initial deformation in the quasi-permanent design situation
M_{Ed}	design bending moment
k_{def}	deformation factor
$Z_s = Z_0$	distance of the top edge fiber to the overall center of gravity S
E_i	modulus of elasticity for the individual layer for CLT
b_i , d_i	dimensions of the individual layer for CLT
o_i	distance from center of gravity of individual layer and the upper edge of CLT element
E_c	reference modulus due to the different moduli of elasticity
n	number of longitudinal layers
$A_{0,net}$	net area of the section
$I_{0,net}$	net moment of inertia
$W_{0,net}$	net section modulus
$S_{R,0,net}$	static moment
$I_{0,ef}$	the effective moment of inertia
W_T	moment of torsional resistance
k_{sys}	system strength factor
SLS	serviceability limit state
ULS	ultimate limit states
σ_{gd}	an allowed design soil pressure
q_{Ed}	Soil pressure
b_0	the effective foundation width
h_f	the thickness of the foundation (height)

a	the width of foundation outside wall edge
f_{ck}	the characteristic cylinder pressure strength of the concrete after 28 day
b	the width of foundation
d	the effective height of the cross section
M_{Rd}	Moment capacity for concrete pressure zone
f_{yd}	design yield strength of the reinforcement
z	the inner moment arm of the cross-section
f_{ywd}	f_{ywd} is the shear reinforcement design yield strength
θ	the angle between the concrete pressure bar and the beam axis perpendicular to the shear force
A_{sw}	the cross-sectional area of shear reinforcement
S	the center distance between shear reinforcement units
v_1	a strength reduction factor for concrete elevation due to shear force
A_{sL}	the cross-sectional area of the tension reinforcement
A_s	Cross sectional area of reinforcement
γ_c	a partial factor for concrete
$V_{Rd,c}$	the design value for the shear resistance
e	Eccentricity
$M_{c,Rd}$	design resistance for bending about one principal axis of a cross-section
$M_{b,Rd}$	design buckling resistance of the compression member
M_{cr}	the elastic critical moment for lateral-torsional buckling
$N_{pl.Rd}$	the design plastic resistance of the gross cross-section
$N_{u.Rd}$	the design ultimate resistance of the net cross-section at holes for fasteners, respectively
$M_{y,Ed}$	design bending moment, y-y axis
$M_{z,Ed}$	design bending moment, z-z axis
f_y	yield strength
γ_{MO}	partial factor for resistance of cross-sections whatever the class is
$V_{pl,Rd}$	design plastic shear resistance
$V_{c,Rd}$	design shear resistance
γ_{M2}	partial factor for resistance of cross-sections in tension to fracture
A_{eff}	effective cross-section
$N_{c,Rd}$	design resistance to normal forces of the cross-section for uniform compression
N_{Rk}	characteristic resistance to normal force of the critical cross section
N_{cr}	elastic critical force for the relevant buckling mode based on the gross cross sectional properties
$N_{b,Rd}$	design buckling resistance of a compression member
ε	strain
$\bar{\lambda}$	non dimensional slenderness
$\chi_{LT,mod}$	modified reduction factor for lateral-torsional buckling
W_y	elastic section modulus
χ_{LT}	reduction factor for lateral-torsional buckling
γ_{M1}	partial factor for resistance of members to instability assessed by member checks

f	modification factor for χ_{LT}
$\bar{\lambda}_{LT}$	relative slenderness for torsional or torsional-flexural buckling
ϕ_{LT}	value to determine the reduction factor χ_{LT}
ϕ	value to determine the reduction factor χ
α and α_{LT}	Imperfection factor
L_{cr}	the buckling length in the buckling plane
λ_1	slenderness value to determine the relative slendemcss
M_{cr}	elastic critical moment for lateral-torsional buckling
z_g	the distance between the load application point and the beam shear center
I_w	warping constant
k_c	a correction factor
χ_z and χ_y	reduction factor due to flexural buckling (y-y axis) and reduction factor due to flexural buckling (z-z axis)
$V_{c,Rd}$	the design value of shear resistance
K_{bi}	bending stiffness of wall "i"
K_{si}	shear stiffness of wall "i"
k_b and k_s	stiffness coefficients
δ_b	deflection due to bending
δ_s	deflection due to shear
H	horizontal force on the selected shear wall
K_{xi}	rigidity of the wall in the x-direction
K_{yi}	rigidity of the wall in the y-direction
G_i	shear modulus of wall "i"
E_i	elastic modulus of wall "i"
A_i	area of wall "i" that resists the load
I_i	height of the wall segment under consideration
$F_{ax,\alpha,Rk}$	characteristic withdrawal capacity of the connection at an angle a to the grain
$f_{ax,k}$	the characteristic withdrawal strength perpendicular to the grain
n_{ef}	the effective number of screws
l_{ef}	the penetration length of the threaded part
α	the angle between the screw axis and the grain direction
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
EU	Europe
Option 1	Timber structural system including walls and foundations made of normal concrete
Option 2	Timber structural system including walls and foundations made of low carbon concrete.
Option 3	Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.
GWP	Global Warming
EC, EK	Eurocode

1. Introduction

Sustainable development concerns meeting today's needs without compromising the ability of future generations to satisfy their own needs. The three essential factors that form the basis of sustainable development are economic, environmental and social dimension as shown in Figure 1.1. Sustainability is a balancing act among these three conditions. These three must work together and simultaneously [18].

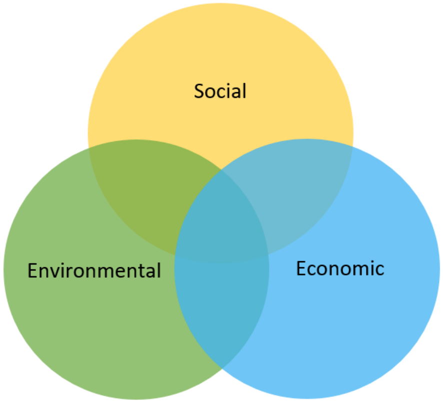


Figure 1.1: Sustainable development consists of three dimensions: economic, environmental and social [18].

Social sustainability in the construction industry is about reducing disease, ensuring higher productivity and creating appropriate cities and buildings adapted to people and giving them a high quality of life.

Environmental sustainability in the construction industry is about building and renovating cities and buildings with as little ecological footprint as possible.

Economic sustainability in the construction industry is about securing long-term financial interests and investments in buildings and establish appropriate conditions for resource optimization.

Sustainable construction can be considered as a combination of the three dimensions: social, environmental and economic conditions, in combination with building technical conditions and process thinking that make it possible to balance all the above aspects.

Sustainable construction can thus be regarded as a combination of the three dimensions: Social, environmental and economic conditions. Furthermore, building materials, material performance, construction technology and processes, energy and resource efficiency in building, high-tech solutions in the building body are some of the issues of sustainable construction [21] [22].

The United nation’s (UN) Sustainability Goals are the world's standard work plan to eradicate poverty, combat inequality and stop climate change by 2030. We must work continuously with solutions that balance the environmental impact of our consumption and economy [18].

Since 40% of the energy consumption and greenhouse gas emissions in the world are related to the construction industry, it is crucial to implement the measures that are possible to reduce the overall environmental footprint. Based on this, this master’s thesis focuses on choosing the right materials that use less energy and have lower emissions of harmful greenhouse gases [22].

Recently, October 8, 2018, Intergovernmental Panel on Climate Change (IPCC) released a new and shocking report. IPCC has now seen the gain by reducing the 2-degree target to 1.5 degrees, and the difference is enormous. To decrease Global Warming to 1.5 degrees, greenhouse gas emissions must be reduced by 40-50 percent by 2030. The goal requires very rapid and extensive changes in most sectors of society [23].
The concrete industry has difficulty in achieving the environmental aspect. For all ordinary (normal) concrete works where sustainability is appropriate to take into account, the usage of low-carbon concrete plays a significant role. This type is of concrete significantly reduce the environment-degrading footprint that current developments take into account in the long run.

Wood is a climate-friendly building material. Increased use of wood as a building material will not just provide value added in the forest industry, but also contribute positively to the reduction of greenhouse gas emissions. Wood is a renewable raw material that requires little energy to produce and also binds CO2 in its life cycle. It can replace non-renewable building materials such as concrete and steel that have a much larger carbon footprint during production and when used [24] [25].

The use of wood as a building material can be an essential contribution to achieving the Norwegian Government's goal of being carbon neutral by 2030. Furthermore, wood provides an excellent indoor environment, and it is easy to recover and reuse. [26].
In order to achieve a type of construction that is sustainable, it is crucial to balance the basic principles of sustainability, i.e. environmental, economic and social aspects [27].

This paper is going to focus on the environmental part of sustainability by emphasizing sustainable solutions so that environmental properties are taken into consideration when choosing materials and construction parts. This master’s thesis studies the sustainability assessment of reinforced concrete or cross-laminated timber.

Previously, a preliminary project has been studied for this master’s thesis. In the preliminary project, three structural systems options of an apartment building were compared and summarized. The options were a timber structural system, a concrete structural system, and a steel structural system with prefabricated concrete elements. In the preliminary project the timber structural system was pointed out as a sustainable solution

In this master’s thesis, the project mentioned above has been extended with a focus on environmental issues. Here, timber structural system is taken initially. Previously, the timber structural system had normal concrete in all structural walls and foundations. This study explores how sustainable materials such as low carbon concrete can replace the normal concrete.

In this master’s thesis, we have proposed the following options for the structural systems:
Option 1: Timber structural system including walls and foundations made of normal concrete
Option 2: Timber structural system including walls and foundations made of low carbon concrete.
Option 3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.

A detailed 3D digital models of above options are developed and assessed based on the following criteria:

1. Structural design
2. Life cycle assessment (LCA)
3. Construction cost

2. Significance of the work

"Social perspective" is about the public. The public perspective represents the society's need to safeguard the interests of the community. The environment and similar issues that one must relate better to must be considered when planning construction projects. The needs of society must be prioritized and safeguarded in order to avoid possible negative consequences of various construction projects. It is also important to identify limitations in a project. Furthermore, one must evaluate the possibilities of being able to adapt various framework conditions and solutions in larger social tasks. This can be in the form of projects, both within the public sector and in the business sector in general. According to «fasenormen, Neste Steg» (Building 21), eight steps have been described which must be reviewed in the implementation of a construction or construction project. The steps cover everything from start to use or demolition. The eight steps highlight four different perspectives, which are owner, user, executive and public perspective (social perspective). The public perspective should ensure that players who are not part of the project are involved. These players will be able to make decisions that will affect the outcome. It must be ensured that the project is carried out within the laws and boundaries defined in the public planning processes. In Table 2.1, it is made clear how the step concerning the public sector can be involved in the project - starting from step 3, and moving to step 6 [28].

Table 2.1: Main features in «Neste Steg»

	Requirement (1)	concept development (2)	concept preparation (3)	detailed engineering (4)	Production (5)	Handover (6)	Use (7)	Termination (8)
Owner	Association plan and drift	work plan	Basis of Investment	Status control parameter.	Status control parameter.	Product evaluation in relation to project goals	Evaluation in relation to the work plan for the measure	verification of work results
		concept Selection						
User	Requirements analysis	Function program	Space program	Final program	As built documentation	FDV documentation	Evaluation building in use	documentation termination of commitment
		draft project		specification solution		Performance evaluation	operational evaluation	
Excutive		Management document	Assessment Method of Construction	production documents	Performance measurements	process evaluation		
			implementation Model	Plans for implementation		final settlement		
Public			Frame Application	building application	Declaration of conformity	certificate of completion	Social perspective	
				legal liability				

According to Samset (2008), two benefits are described for a project to be successful. It's tactical performance and strategic performance. Strategic performance concerns the social perspective. Tactical performance deals with the project, such as concerns regarding cost, time and quality. Strategic performance focuses on relevance, efficiency, and viability. The success lies in that we have all the parameters as illustrated in the circles in the figure below [29].

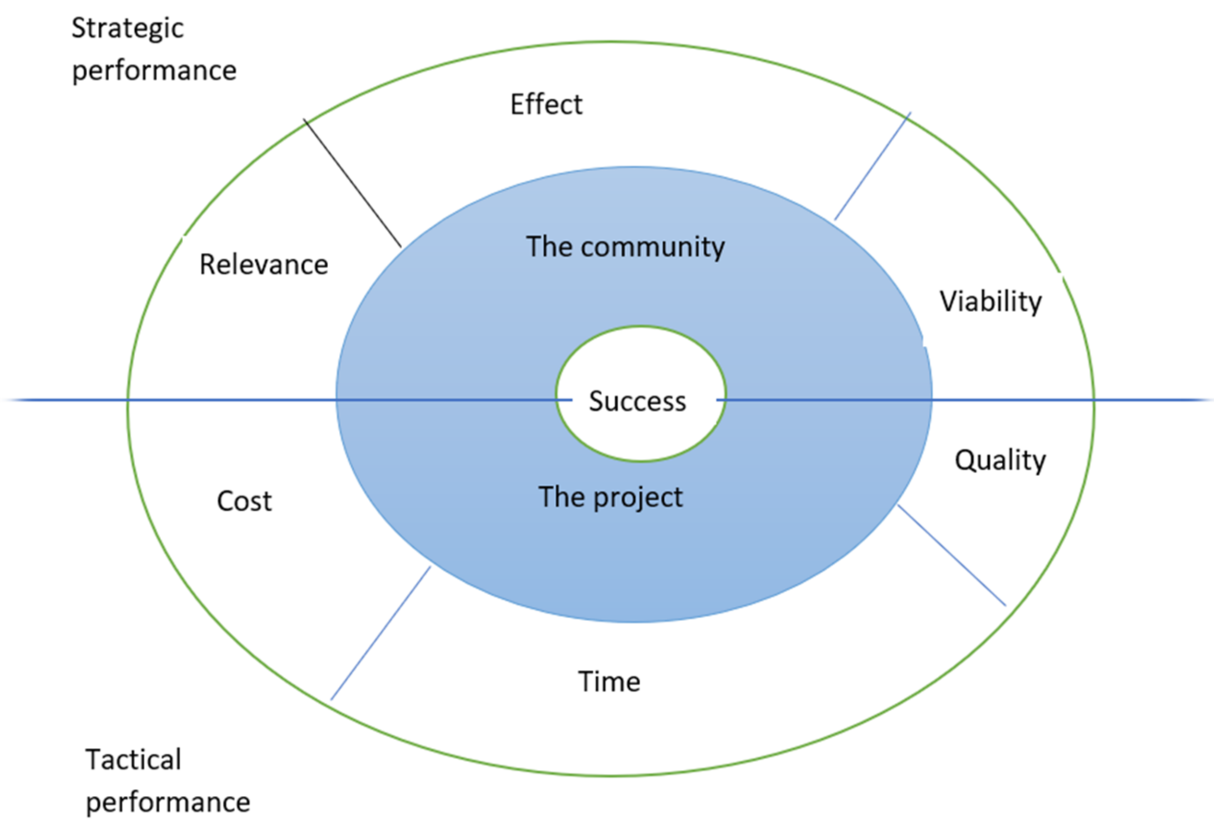


Figure 2.1: Strategic and Tactical Performance

3. Theory

3.1. Structural design

General

Different types of construction frame can be found. Their engineering requirements depend on several causes and conditions such as economy, environment, climate, owner's willingness and aesthetic considerations. Beams, slabs, and columns are considered such as structural system. Structural system resists vertical forces that affect elements of construction. To stabilize this construction against horizontal forces which are coming from winds and earthquake the supporting system is required. Shear walls and shafts are good examples that can be given to understand the meaning of supporting system.

3.1.1. Timber

Wood and stone were the primary building materials until the industrial revolution. Then, cast iron, steel, and reinforced concrete played a good functional role in the building market. Therefore, both stone and wood were reduced as building materials. Nevertheless, timber was still a valuable building material resource. It was used for small projects that were carried out without the supervision of engineers.

Timber working up and development have given it an excellent opportunity to come back to its place as a building material. Glulam, cross-laminated timber (CLT), and other types of wood are good examples for mentioned development. The use of timber is not limited to small projects , but has become the load-bearing construction part in huge projects [30] Figure 3.1 shows an example of an old timber construction and an example of a modern one. The first is Heddal stavkirke in Notodden, while the other is modern wooden building in Bergen.

Figure 3.1: An example of timber construction in Norway: old Heddal stave church in Notodden and modern timber building in Bergen, respectively

As a construction material, timber can be divided into two main groups, softwoods, and hardwoods. Spruce, pine, and larch are examples of(softwoods) conifers wood. Birch , aspen and oak are examples of hardwood.

The two groups above are mentioned in Standards as symbols C and D. In Norway, C18, C24, and C30 are mostly used. Regarding the second type, it is brought in the qualities D30, D35, D40, D50, D60, and D70. In Norway, pine and spruce are mainly used as construction materials, while the proportion of pine is somewhat more abundant in our neighboring countries Finland and Sweden [30]. The most used types of trees as construction materials, spruce, and pine are shown in Figure 3.2:

Figure 3.2: Example of two softwood species. Left: Spruce, right: Pine

Advantages and disadvantages of timber:
Positive and negative properties should be known to use timber efficiently as possible . Some positive properties:

- Environmentally friendly, renewable: Timber doesn't need high production energy requirements. Also, it is a net CO2 absorber. Of course, if the forests of the earth are managed sustainably, then tree species become renewable.
- Has good strength compared to its light weight. Regarding the proportion of strength for weight, it is higher 20 percent compared with steel. The strength of timber is 4-5 times better than unreinforced concrete in compression. In addition, heavy machines are not required for installation of timber especially for limited projects [30].
- Safe: timer has low toxicity; therefore special preventive measures are not required to work with it. Since timber has low electrical conductivity, an advantage can be mentioned in terms of electrical safety.
- The installation process is easy: Fast and sure assembly can be achieved by using modern technique prefabrication. Moreover, the heavy lifting machines are not required to lift timber construction materials and frame.
- Recyclable and flexible: Timber disassembly is uncomplicated, and many timber elements could be reused after demolition. Many structural components can simply be changed, joined and modified if it is necessary. In addition to recyclability and flexibility, timber has a suitable property of thermal insulation and small thermal conductivity [13].

Although timber has positive properties, the negative properties should not be ignored. Some of these properties are:

- Timber can be damaged by fungi, rot, and insects. Therefore, preventive measures must be taken into account.

- Different proportion of moisture absorption and excretion create volume changes, shrinkage, and swelling.
- Timber has low Young's modulus E (modulus of elasticity, for birch, is 14700 MPa) compared with other building materials, with steel for example (210000 MPa). Therefore, it has a large deformation.
- Different strength properties can be found due to moisture content.
- Many safety measures are required due to flammability and combustibility.
- Steel connections are needed to connect timber components due to difficulties of connection between timber elements.[13, 30]

Timber protection:

Engineered wood products (EWP):
The reason for finding Engineered Wood Product or EWP is getting a type of timber that has larger dimensions because the dimensions of standard sawn timber are curtained. EWPs are consisting of wood in form. This form can be veneers, sawn timber boards fibers glued with particular types of adhesives or joined together with screw and nails. Glued laminated timber – glulam, Cross-laminated timber – X-Lam, Laminated veneer lumber – LVL, Plywood, Oriented strand board – OSB, Chip, particle or fiberboard, Built up structures – I-beams[4]. The types are shown in Figure 3.3:

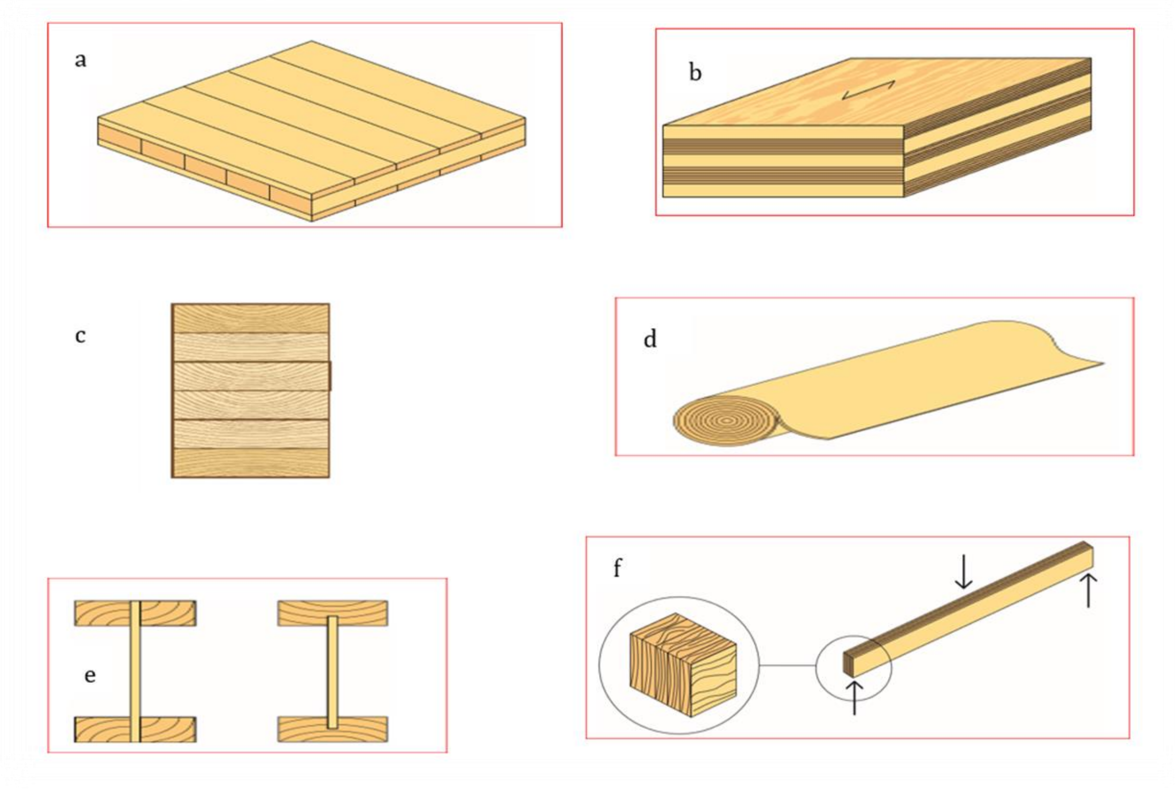


Figure 3.3: Types of Engineered wood products(EWP): a) Cross-laminated timber – X-Lam, b) Plywood c) Glued laminated timber – glulam, d) Veneer production from logs, e) I-beams with flanges of solid timber and a web of a board material, f) Laminated-veneer lumber – LVL, all veneers with the same fiber orientation [4]

In the master's thesis, it will be focused on two types of EWP. The first type is Glued laminated timber – glulam for beams and columns and the second is Cross-laminated timber (CLT) for slabs and walls.

Glue laminated timber (GLT):

Glulam is made of many lumber (laminations) joined together with glue. The number of laminations should be at least four. In addition, laminations should be lain parallel to the fiber direction. Glue -laminated timber was firstly detected by inventor Otto Hetzer that could get the patent for it in 1906[4]. In Norway, the Norwegian engineer Guttorm Brekke got the patent after he spent some time at the company of Otto Hetzer. In the standard 14080, glulam was mentioned as 2 or more than two laminations with a thickness from 6 to 45 mm. The thickness varies from spruce to pine. Where it is 45 mm in terms of spruce, but the 33 mm for pine[13]. Glulam manufacturing is shown in the following Figure 3.4:

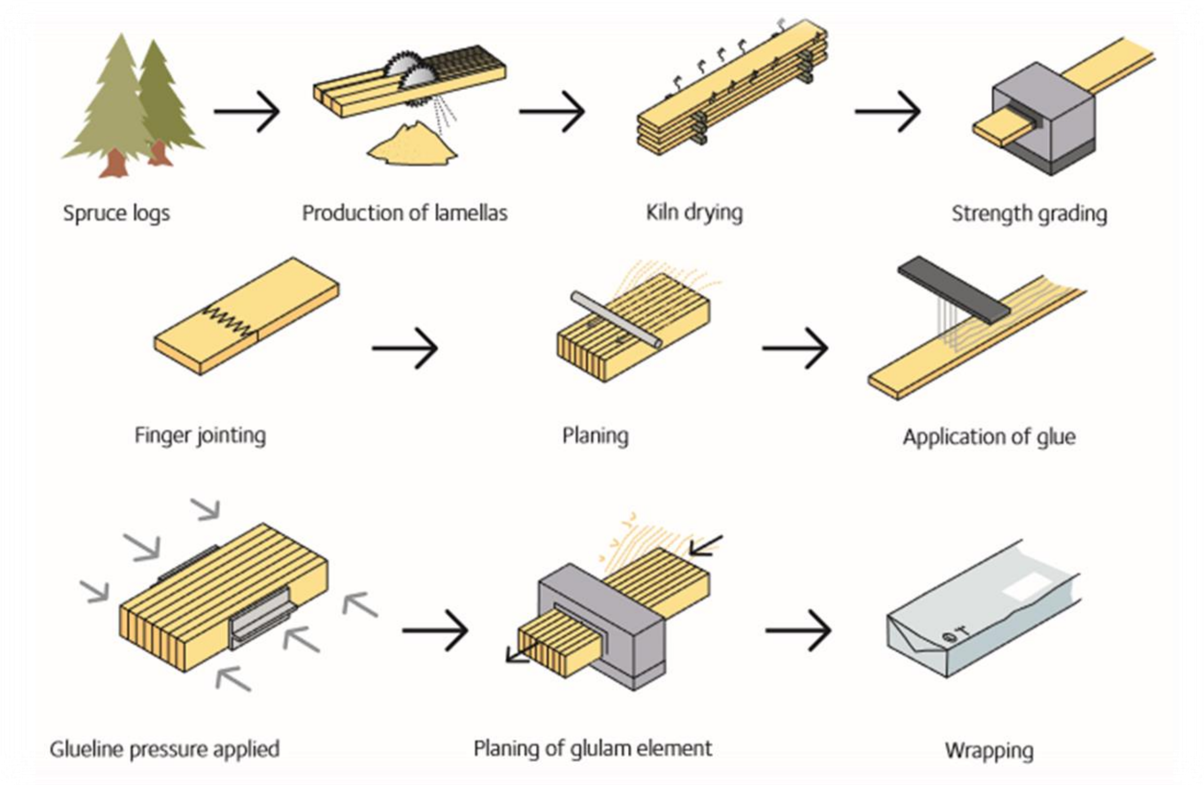


Figure 3.4: Production of glulam [4]

When wider beams are needed, these beams can be produced by gluing two or more glulam beams together. Glulam can either be homogeneous, where the laminations have the same strength. The second is nonhomogeneous or combined glulam—in this case, the glulam consists of laminations with different strength. The higher strength laminations are in the outer higher stressed regions of the beam[4]. The two mentioned types of glulam are denoted by GLxxh and Glxxc, respectively, where xx is a number, for example, 20. Letters h and c represent respectively homogenous and combine[13]. The Combined glulam is illustrated in Figure 3.5:

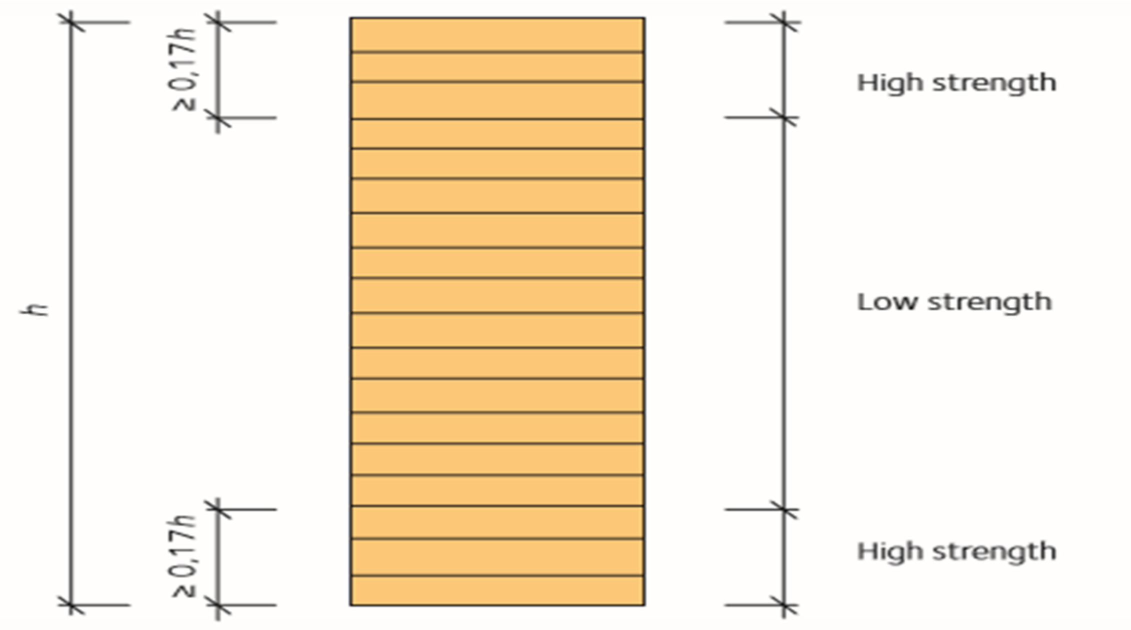


Figure 3.5: The combined glulam, where the high strength laminations are lain in both outer regions, while the low strength laminations are put in the inside region.[4, 13]

Through tests and by comparing the glued -laminated timber and solid beams that have the same size, it could be found that solid beams are stronger than laminated ones. But on the other hand, the glued -laminated timber has lower variability in strength compared by solid beams[4]. There are many failures in a glulam beams .The most common is a tensile failure parallel to the grain of outer lamination. This failure occurs when the glulam beam is subjected to bending and generates in two regions, a finger-joint, and a knot. Therefore, the high tensile stresses perpendicular to the fiber direction should be considered, especially in beams with holes or notches and curved arcs.

Design of structural timber elements:

a) Beams: A beam is a horizontal structural element that is designed to resist external loads . The most common external loads include self-weight of the beam and dead loads and live loads from slabs. It is shown that timber loses its strength remarkably over a certain period of time. Therefore, load duration classes were determined in the Standard to simplify the design process. The duration classes are shown in Table 3.1:

Table 3.1: Load duration classes and an example of loading[8]

Load duration classes	Accumulated duration	Examples of loading
Permanent (P)	> 10 years Self weight	Self-weight
Long-term (L)	6 months – 10 years	Storage
Medium-term (M)	1 week – 6	Traffic loads, Snow load
Short-term (S)	< 1 week	Wind load, Snow load
Instantaneous (I)		Wind load, Accidental load

These loads lead to bending moment, shear force and torsion on the cross-section. It must be proved based on the standard that load effects(E) are less than or equal to the resistance or capacity (R). Mathematically, this following equation should be verified :

$$E \leq R \tag{3.1}$$

Two limit states are defined by Eurocode, Ultimate limit state and serviceability limit state. They are denoted by ULS and SLS, respectively. The first is related to breakdown or similar forms of construction failure. ULS includes loss of equilibrium, rupture due to large displacement or fatigue, breaks in individual cross-sections, and so forth. The second is related to constructional functionality, and is mainly related to deformations, vibrations, and cracks.[4]

Generally, Forces are mentioned by Standard as influences and indicated with the letter F. Designed force for an impact F_d is defined as:

$$F_d = \psi \cdot \gamma \cdot F_k \tag{3.2}$$

Where
F_k characteristic value for an impact(load)
(γ) and (ψ) are the load factor and combination factor respectively. Values for load combination factors (ψ) are given in Table 3.2:

Table 3.2: Load combination factors where ψ_0 is a factor for combination value of a variable action, ψ_1 is a factor for the frequent value of a variable action, ψ2 is a factor for the quasi-permanent value of a variable action[31]

Load (Live load categories in buildings) based on EC1-1-1	ψ_0	ψ_1	ψ_2
Category A: Residential areas	0,7	0,5	0,3
Category B: Office areas	0,7	0,5	0,3
Category C: Assembly areas	0,7	0,7	0,6
Category D: Shopping areas	0,7	0,7	0,6
Category E: Storage areas	1,0	0,9	0,8
Category F: Traffic area, vehicle weight ≤ 30 KN	0,7	0,7	0,6
Category G: Traffic area, 30 KN ≤ vehicle weight ≤ 160	0,7	0,5	0,3
Category H: Roofs	0	0	0
Snow load (EC1-1-3)	0,7	0,5	0,2
Wind load (EC1-1-4)	0,6	0,2	0
Thermal load (non-fire) in buildings (EC1-1-5)	0,6	0,5	0
Note: EC is an abbreviation for Eurocode			

regarding the load factors (γ), the following definitions are used:

γ_{GJ} load factor for permanent load no j

γ_{Qi} load factor for variable load no i

γ_{P} load factor for prestressing [13]

The load factor (γ) looks after the uncertainty of the representative value of an impact and the uncertainty related to the modeling of load and load effect. While the combination factor (ψ) takes care of the probability that loads work simultaneously.[13]

The load combination rules and the different design situations are defined in Eurocode NS-EN 1990 (EC 0). In Ultimate limit state ULS, the four types of limit state should be taken into account when related. These limit states are:
EQU: It involves loss of static equilibrium for a construction or a structural member that is considered as a rigid body.
STR: failure, or too large deformations in the construction or member of construction, includes foundations, piles, basement walls.
GEO: failure or too large deformations in soil or rocks.
FAT: fatigue failures in the structure or structural parts. [4]

Design load effects (E_d) will be given in the following equations based on second ultimate limit state (STR):

$$E_d = \sum_{J\geq 1} \gamma_{G,j}\, G_{k,j} + \gamma_{Q,1}\psi_{0,1}\, Q_{k,1} + \sum_{i>1} \gamma_{Q,i}\psi_{0,i}\, Q_{k,i} \tag{3.3}$$

$$E_d = \sum_{J\geq 1} \xi_j \gamma_{G,j}\, G_{k,j} + \gamma_{Q,1}\, Q_{k,1} + \sum_{i>1} \gamma_{Q,i}\psi_{0,i}\, Q_{k,i} \tag{3.4}$$

Where
Index j indicates to permanent load component
Index i indicates to variable load component

$Q_{k,1}$ is the characteristic value for the leading variable load.

$\gamma_{Q,1}$ is the partial safety factor associated with $Q_{k,1}$.

$\gamma_{G,j}\, G_{k,j}$ presents the permanent loads

$\gamma_{Q,1}\psi_{0,1}\, Q_{k,1}$ presents dominant variable load

$\gamma_{Q,i}\psi_{0,i}\, Q_{k,i}$ presents other variable loads. These loads are mentioned in Table 3.2.

In Norwegian standard the following values for ξ and γ are used:

$$\gamma_{G,j} = \begin{cases} 1{,}35 & \text{if unfavorable} \\ 1{,}0 & \text{if favorable} \end{cases}$$

$$\gamma_{Q,1} = \begin{cases} 1{,}5 & \text{if unfavorable} \\ 0 & \text{if favorable} \end{cases}$$

$$\gamma_{Q,i} = \begin{cases} 1{,}5 & \text{if unfavorable} \\ 0 & \text{if favorable} \end{cases}$$

$\xi = 0{,}89$. Therefore the value of $\xi \cdot \gamma_G = 0{,}89 \times 1{,}35 = 1{,}20$ [31]

In serviceability limit state SLS, all partial coefficients related to the different loads are normally set to 1.0. This means $\gamma_{G,j} = \gamma_{Q,1} = 1{,}0$. In NS-EN 1990, three load combinations for SLS are defined. General case for mentioned load with several variable loads($Q_{k,i}$)is given by the following:

Characteristic combination:

$$\sum_{J\geq 1} G_{k,j} \ + Q_{k,1} + \sum_{i>1} \psi_{0,i}\, Q_{k,i} \tag{3.5}$$

Where $\psi_{0,i}\, Q_{k,i}$ is the combination value of the variable loadA high value on the dominant variable load is given by this combination. Therefore, it is used in order to determine the short-term displacements.

Frequent combination:

$$\sum_{J\geq 1} G_{k,j} \ + \psi_{1,1}\, Q_{k,1} + \sum_{i>1} \psi_{2,i}\, Q_{k,i} \tag{3.6}$$

Where
$\psi_{1,1}\, Q_{k,1}$ is the frequent value of the load $Q_{k,1}$
And
$\psi_{2,i}\, Q_{k,i}$ is the quasi-permanent value of the variable load $Q_{k,i}$.
This combination is applied to estimate the effects that occur with a specific frequency, but the effects will be reduced when the load decreases again.

Quasi-permanent combination:

$$\sum_{J\geq 1} G_{k,j} \ + \sum_{i>1} \psi_{2,i}\, Q_{k,i} \tag{3.7}$$

Where $\psi_{2,i}\, Q_{k,i}$ is the quasi-permanent value of the variable load $\mathrm{Q_{k,i}}$.
This combination is applied to evaluate long-term (creep) effects.[13]

When the design loads are found based on mentioned load combinations, accordingly design load effects (M_{Ed} , V_{Ed} , N_{Ed}) are calculated based on these design loads. To understand how stresses in glulam work, one must first define the characteristic strength of it. Therefore 6 strengths are mentioned as follows:

Table 3.3: Characteristic Strength for glulam and their location

Characteristic strength	Characteristic Strength direction
$f_{t,o,k}$	Characteristic tensile strength along the fiber direction
$f_{t,90,k}$	Characteristic tensile strength perpendicular to the fiber direction
$f_{c,o,k}$	Characteristic compressive strength along the fiber direction
$f_{c,90,k}$	Characteristic compressive strength perpendicular to the fiber direction
$f_{m,k}$	Characteristic bending strength
$f_{v,k}$	Characteristic shear strength

Characteristic shear strength is divided into three types:
The first is the strength against interception perpendicular to the fiber direction, it is called by (interception rupture), and it is bigger than two other types. The second is the strength located along the fiber direction and it is called by (displacement rupture). The third is called by rolling shear. They are shown in Figure 3.6(3.6.f,3.6.g,3.6,h)[13]:
The characteristic strengths are illustrated in Figure 3.6:

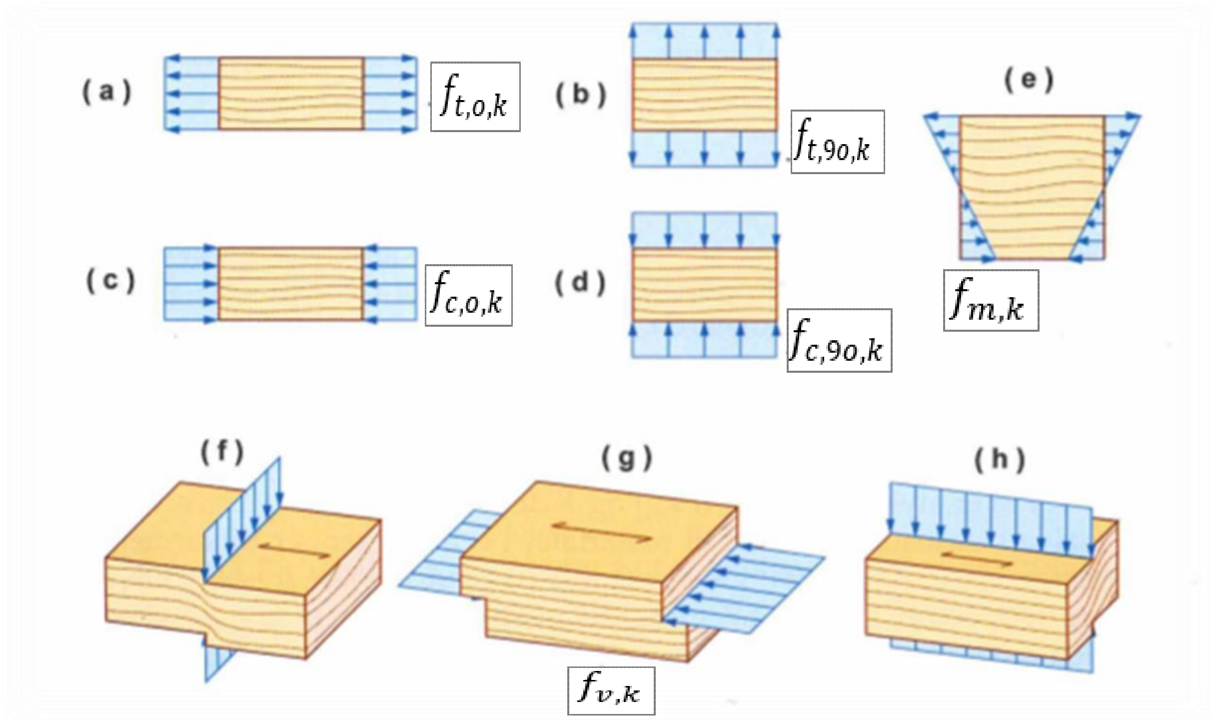


Figure 3.6: Characteristic strengths for glulam where: a) characteristic tensile strength along the fiber direction b) characteristic tensile strength perpendicular to the fiber direction c) characteristic compressive strength along the fiber direction d)characteristic compressive strength perpendicular to the fiber direction e) characteristic bending strength f,g,h) characteristic shear strength[13]

After finding design load effects,, the characteristic strengths could be defined and found to include it in the control step . The design material strength is given by the following equation:

$$f_d = f_k \frac{k_{mod}}{\gamma_M} \quad (3.8)$$

Where

f_k *is* characteristic strength. Values are shown in Table 3.4 and Table 3.5

γ_M is a partial factor for material properties. The value of this factor is decided to be $\gamma_M = 1{,}15$ for glulam.[13]

k_{mod} is the modification factor for duration of load and moisture content

Characteristic bending strength and characteristic tensile strength along the fiber direction depends on dimensions. Therefore, design material strength can be increased by multiply the equation by height factor (depth factor) k_h .

$$f_d = (k_h\, f_k) \frac{k_{mod}}{\gamma_M} \quad (3.9)$$

Table 3.4: Characteristic strength and stiffness properties in MPa and densities in kg/m3 for homogeneous (h) glulam [13]

Properties	Symbol	Glulam strength class						
		GL20h	Gl22h	GL24h	GL26h	GL28h	GL30h	GL32h
Bending strength	$f_{m,g,k}$	20	22	24	26	28	30	32
Tension strength	$f_{t,0,g,k}$	16	17,6	19,2	20,8	22,3	24	25,6
	$f_{t,90,g,k}$	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Compression strength	$f_{c,0,g,k}$	20	22	24	26	28	30	32
	$f_{t,90,g,k}$	2,5	2,5	2,5	2,5	2,5	2,5	2,5
Shear strength	$f_{v,g,k}$	3,5	3,5	3,5	3,5	3,5	3,5	3,5
Rolling shear strength	$f_{r,g,k}$	1,2	1,2	1,2	1,2	1,2	1,2	1,2
Elastic modulus	$E_{0,g,mean}$	8400	10500	11500	12100	12600	13600	14200
	$E_{0,g,0.05}$	7000	8800	9600	10100	10500	11300	11800
	$E_{90,g,mean}$	300	300	300	300	300	300	300
	$E_{90,g,0.05}$	250	250	250	250	250	250	250
	$G_{g,mean}$	650	650	650	650	650	650	650

Shear modulus	$G_{g,0.05}$	540	540	540	540	540	540	540
Rolling shear modulus	$G_{r,g,mean}$	65	65	65	65	65	65	65
	$G_{r,g,0.05}$	54	54	54	54	54	54	54
Density	$\rho_{g,k}$	340	370	385	405	425	430	440
	$\rho_{g,mean}$	370	410	420	445	460	480	490

Table 3.5: Characteristic strength and stiffness properties in MPa and densities in kg/m3 for homogeneous (c) glulam[13]

Properties	Symbol	Glulam strength class						
		GL20c	Gl22c	GL24c	GL26c	GL28c	GL30c	GL32c
Bending strength	$f_{m,g,k}$	20	22	24	26	28	30	32
Tension strength	$f_{t,0,g,k}$	15	16	17	19	19,5	19,5	19,5
	$f_{t,90,g,k}$	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Compression strength	$f_{c,0,g,k}$	18,5	20	21,5	23,5	24	24,5	24,5
	$f_{t,90,g,k}$	2,5	2,5	2,5	2,5	2,5	2,5	2,5
Shear strength	$f_{v,g,k}$	3,5	3,5	3,5	3,5	3,5	3,5	3,5
Rolling shear strength	$f_{r,g,k}$	1,2	1,2	1,2	1,2	1,2	1,2	1,2
Elastic modulus	$E_{0,g,mean}$	10400		11000	12000	12500	13000	13500
	$E_{0,g,0.05}$	8600	8600	9100	10000	10400	10800	11200
	$E_{90,g,mean}$	300	300	300	300	300	300	300
	$E_{90,g,0.05}$	250	250	250	250	250	250	250
Shear modulus	$G_{g,mean}$	650	650	650	650	650	650	650
	$G_{g,0.05}$	542	542	542	542	542	542	542
Rolling shear modulus	$G_{r,g,mean}$	65	65	65	65	65	65	65
	$G_{r,g,0.05}$	54	54	54	54	54	54	54
Density	$\rho_{g,k}$	355	355	365	385	390	390	400
	$\rho_{g,mean}$	390	390	400	420	420	430	440

The value of strength modification factor k_{mod} for glulam is given in the following table below:

Table 3.6: k_{mod} based on Norwegian standard[8]

Climate Classes	Load duration class				
	P Permanent load	A Long-term	B Medium-term	B Short-term	I Instantaneous
1	0,6	0,7	0,8	0,9	1,1
2	0,6	0,7	0,8	0,9	1,1
3	0,5	0,55	0,65	0,7	0,9

Depth factor for glulam (k_h) is determined based on the following equation

$$k_h = min\begin{cases}(600/h)^{0.1} \\ 1{,}1\end{cases} if\ h < 600 \quad (3.10)$$

But when h>600 becomes k_h =1

When design material strength is completely determined, design stresses could be calculated and controlled by satisfying the following expresses:

Bending stress:

$$\frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1 \quad (3.11)$$

$$k_m \frac{\sigma_{\mathrm{m,y,d}}}{f_{\mathrm{m,y,d}}} + \frac{\sigma_{\mathrm{m,z,d}}}{f_{\mathrm{m,z,d}}} \leq 1 \quad (3.12)$$

Where

$\sigma_{m,y,d} = \frac{6M_{y,Ed}}{bh^2}$ and $\sigma_{m,z,d} = \frac{6M_{z,Ed}}{hb^2}$ are design bending stress about the principal y-axis and design bending stress about the principal z-axis respectively if section is rectangular

$f_{\mathrm{m,y,d}}$ and $f_{\mathrm{m,z,d}}$ are design bending strength about the principal y-axis and design bending strength about the principal z-axis respectively.

k_m is the factor considering re-distribution of bending stresses in a cross-section.

k_m = 0,7 for rectangular cross section and 1,0 for another cross sections

$M_{y,Ed}$, $M_{z,Ed}$ are design bending moment about the principal y-axis and design bending moment about the principal z-axis respectively.

B and h are width and height of section respectively.

The equations (3.11) and (3.12) are used when the beam is subjected to bending about both axes of the cross section. But when the glulam beams are only subjected to bending moment, the following equation will be satisfied[13]:

$$\sigma_{m,d} = \frac{M_{y,Ed}}{W_y} \leq k_{crit} f_{m,d} \tag{3.13}$$

Where
$\sigma_{m,d}$ is design bending stress.
$f_{m,d}$ is design bending strength
k_{crit} is the factor accounting for the effect of lateral buckling and it can be found by following:

$$k_{crit} = \begin{cases} 1 & \text{for } \lambda_{rel,m} \leq 0,75 \\ 1,56 - 0,75\lambda_{rel,m} & \text{for } 0,75 < \lambda_{rel,m} \leq 1,4 \\ \dfrac{1}{(\lambda_{rel,m})^2} & \text{for } \lambda_{rel,m} > 1,4 \end{cases} \tag{3.14}$$

Where
$\lambda_{rel,m}$ relative slenderness ratio in bending. For glulam this ration is found from the following equation:

$$\lambda_{rel,m} = \frac{\sqrt{hL_{ef}}}{16,5b} \tag{3.15}$$

Where *b and h* are width and height of section respectively
L_{ef} is effective length of the beam, depending on support conditions and load configuration, can be found by using Table:

Table 3.7: Effective length L_{ef} comparing with the span (L)[8]

Beam type	Load type	$\frac{L_{ef}}{L}$
Simply supported	Constant moment	1,0
	Uniformly distributed load	0,9
	Concentrated force at midspan	0,8
Cantilever	Uniformly distributed load	0,5
	Concentrated force at the free end	0,8

It is crucial to note the method for calculating L_{ef} . Where the proportion $\frac{L_{ef}}{L}$ is brought from Table 3.7 then *2h* is added

Shear stress:

$$\tau_d = \frac{3}{2} \cdot \frac{V_{Ed}}{b_{ef} \cdot h} \leq f_{v,d} \tag{3.16}$$

$f_{v,d}$ is design shear strength

$\tau_{v,d}$ is design shear stress where the equation that is given in equation (3.9) is related to rectangular cross-section.

V_{Ed} is design shear force

$b_{ef} = k_{cr} b$ is effective width.

k_{cr} is a crack factor for shear resistance. $k_{cr} = 0{,}8$ for glulam

Illustration for design bending stress and design shear stress is shown in Figure 3.7 and Figure 3.8:

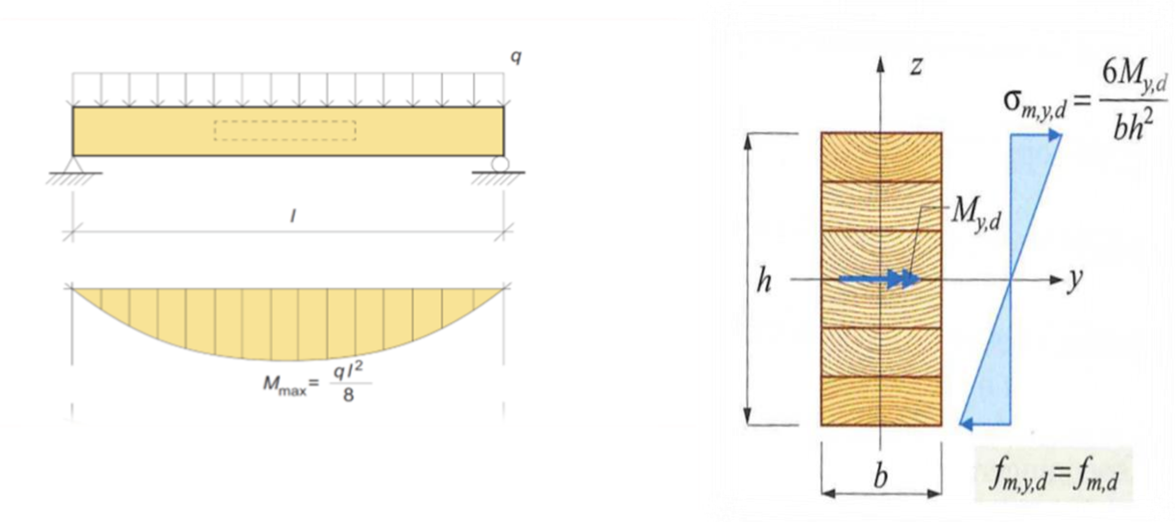


Figure 3.7: Free supported glued wooden beam with a uniformly distributed load. Bending moment about an axis (y)and its effect on the cross-section is also shown.[2]

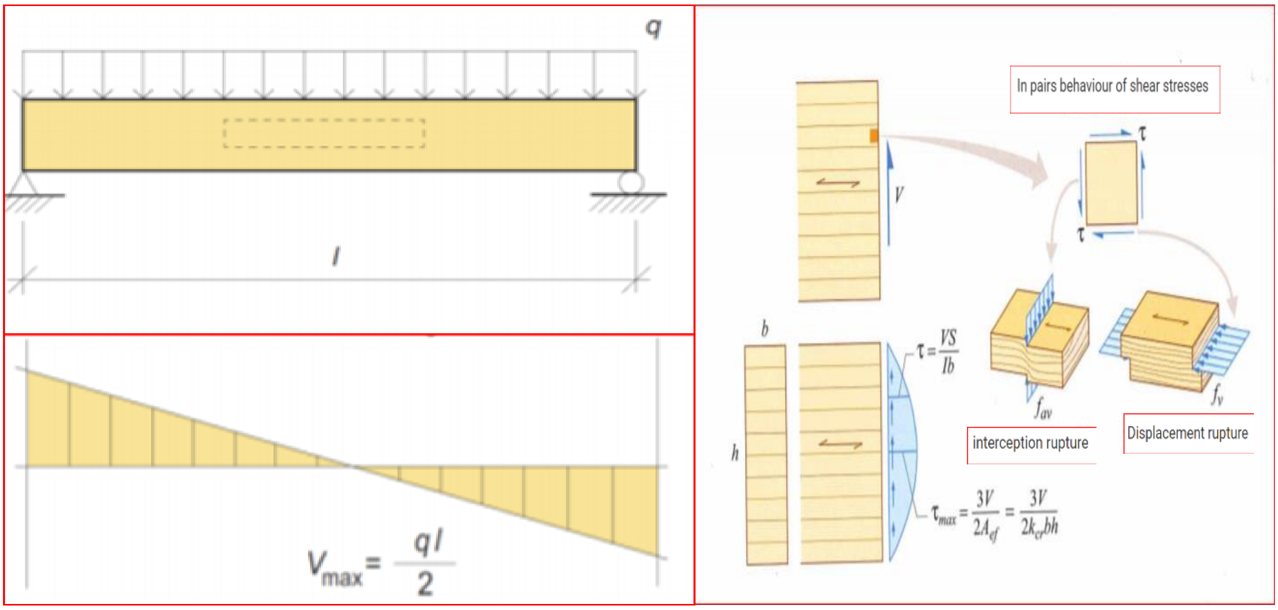


Figure 3.8: Shear force in a rectangular cross-section of a free supported glued wooden beam with a uniformly distributed load. In addition, it is shown how shear force is divided into two types of ruptures, Interception rupture and displacement rupture.[2, 13]

Regarding the normal stresses, it is assumed that the glulam cross-section belongs to a straight component of constant cross-section. It is also assumed that fiber direction is approximately parallel to the component axis x. This mentioned assumption is related to both bending stresses and shear stresses[13]. The following conditions for normal stress are found:

Tension parallel to the fiber direction: The strength of wood in this state ($f_{t,o}$) is very high; The stress is given as follows:

$$\sigma_{t,0,\text{d}} = \frac{N_{Ed}}{A_{eff}} \leq f_{t,0,d} \qquad (3.17)$$

Where
$f_{t,0,d}$ is design tensile strength along the fibre direction
$\sigma_{t,0,\text{d}}$ is design tensile stress along the fibre direction
N_{Ed} is design tensile force
A_{eff} is effective cross – section of the component. Some holes will be taken into account and be calculated. This means that the area of these holes will be deducted from the gross area of the component's cross-section when the distance between these holes are within the half minimum distance(a_{min})for the concerned bonding agent.The screws and nails with diameter less than 6mm or less than 6mm will not be deducted from the gross area of the cross section. This is illustrated in the following Figure 3.9:

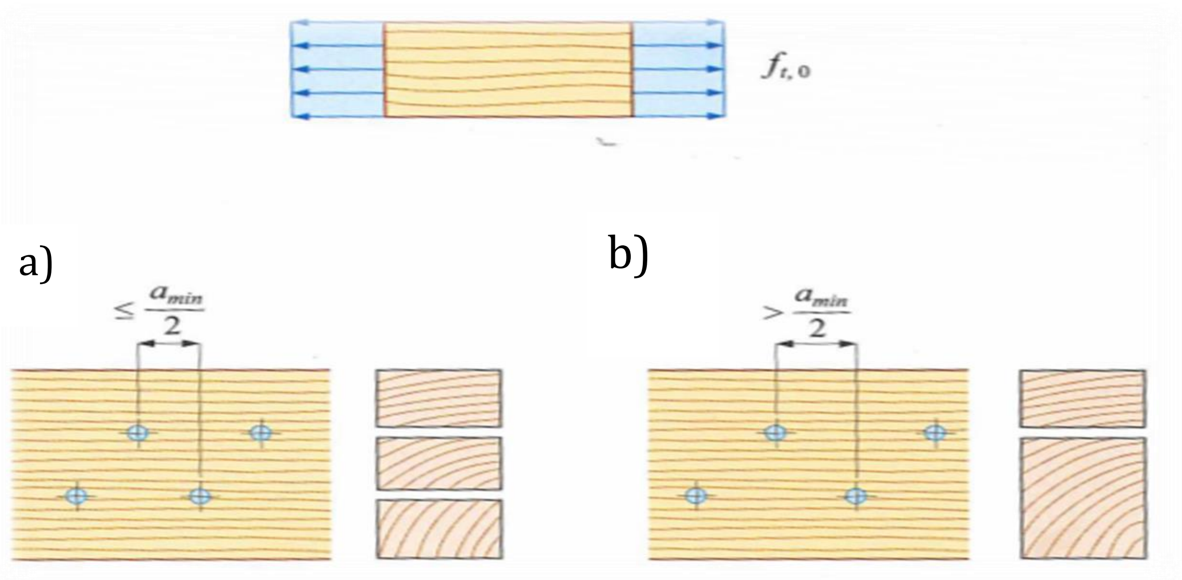


Figure 3.9: Effective cross-section(A_{eff}) for tensile stress. In the case a) the holes are subtracted from the total area b)the holes are not subtracted from the total area[13]

Tension perpendicular to the fiber direction: The strength of timber in this case ($f_{t,o}$)is very low. This may occurs only in some quite specific component forms(gable roof beams).It can therefore be avoided.

Compression parallel to the fiber direction: This stress state is analogous to the state of tension. The stress is given by:

$$\sigma_{c,0,d} = \frac{N_{Ed}}{A} \leq f_{c,0,d} \tag{3.18}$$

Where

$f_{c,0,d}$ is design compressive strength along the fibre direction

$\sigma_{c,0,d}$ is design compressive stress along the fibre direction

N_{Ed} is design compressive force

A is gross area of the component's cross section

Compression perpendicular to the fibre direction: The stress is given by:

$$\sigma_{c,90,d} = \frac{F_{c,90,d}}{A_{ef}} \leq k_{c,90} f_{c,90,k} \tag{3.19}$$

Where

$k_{c,90}$ is a factor that takes into account the load configuration, the possibility of splitting and the size of the pressure deformation. $1 \leq k_{c,90} \leq 1.75$ this value is usually is 1,0 but in specific cases can be different. These cases are mentioned in NS-EN:1995 as such as:

- For structural parts resting on continuous supported structural parts, where $l_1 \geq 2h$,), the value of $k_{c,90}$ for glulam can be assumed 1,5. This is shown in Figure 3.10.

- For structural parts resting on simply supported structural parts, ($l_1 \geq 2h$, (is shown in figure (3.10a), the value of $k_{c,90}$ for glulam can be assumed 1,75 with taking account into contact length $l \leq 400mm$.Where *h* is the height of the cross-section[8].

$\sigma_{c,90,d}$ is design compressive stress perpendicular to the fiber direction
$F_{c,90,d}$ is design compressive force perpendicular to the fiber direction
A_{ef} is the effective contact area for compression perpendicular to the fiber direction.
The effective area should be calculated by getting pay attention to an effective contract length(l_{ef})
along the fiber direction.Then $A_{ef} = b \cdot l_{ef} = b(d + l + d)$
Where *l* is relevant to contact length and $d = \min\{30 \text{ mm}, a, l, {}^{l_1}/_2\}$
The relevant contact length $l, a, l,$ and l_1 are illustrated in Figure 3.10

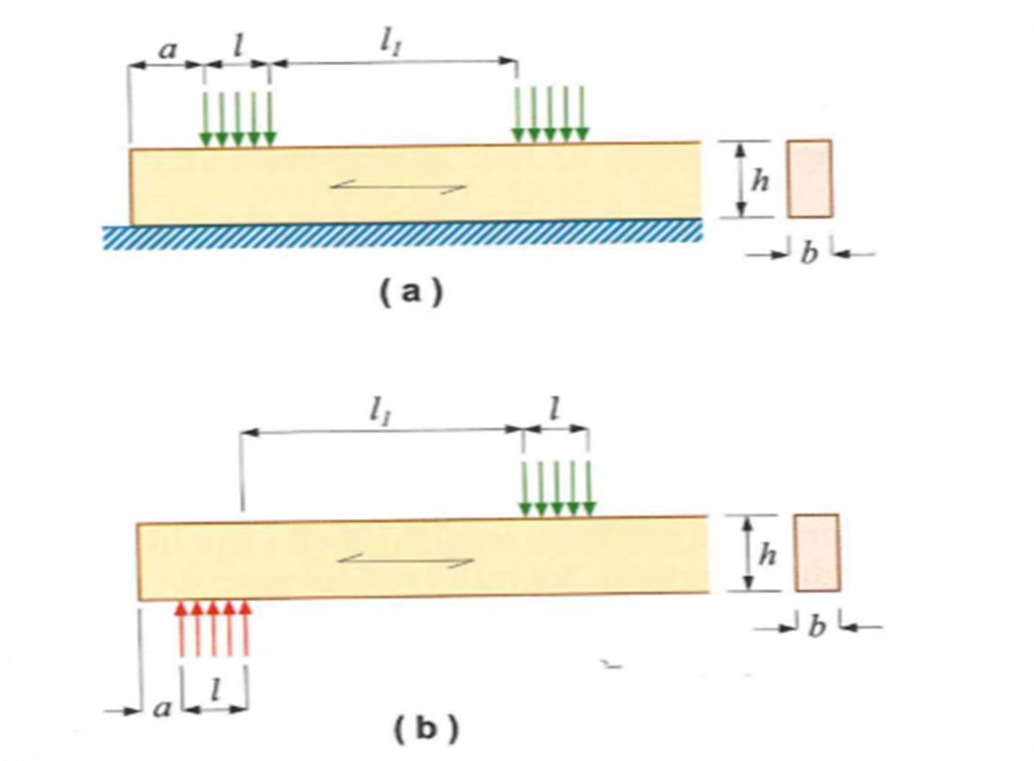


Figure 3.10: Illustration of concepts l, a, l_1 for a) component on continuous case and b) separated case[8]

a) Columns:

a vertical structural element which is usually designed to transmit a pressure load of the above structure (beams, plates) to other structural elements below (basis, for example). During the design procedure, the slenderness ratio of the columns has to be taken into consideration in order to avoid problems concerning of stability. [4]
The slenderness ratio is defined by the following equation:

$$\lambda = \frac{L_k}{i} = \frac{\beta L}{i} \tag{3.20}$$

Where

L_k is an effective buckling length of the member. Illustration of L_k and recommended values for β are shown in Figure 3.11:

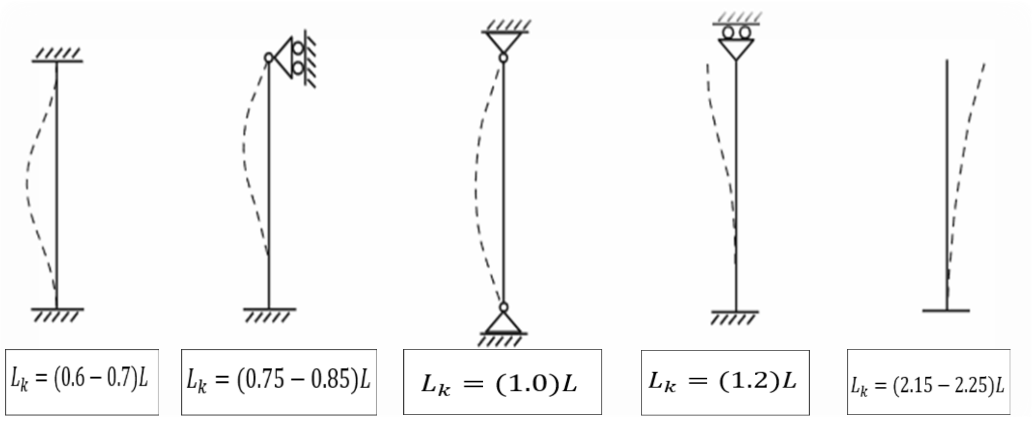


Figure 3.11: Effective buckling length L_k for different end conditions and values of β. L is factual column length [2]

i is radius of gyration of the cross-section. This can be defined as:

$$i = \sqrt{\frac{I}{A}} \tag{3.21}$$

I is the second moment of area, A is the cross-sectional area of the member [13]
For a straight and simply supported columns with following characteristics(classic column): constant cross-section, is only affected by a central axial force P, homogeneous and isotropic, has no load eccentricity. Based on Euler buckling load, the critical load for the mentioned classic columns is given by[13]:

$$P_{kr} = P_E = \frac{\pi^2 EI}{L^2} \tag{3.22}$$

By applying the concept buckling length on the equation (3.22), the critical load for all columns can be written by:

$$P_{kr} = P_E = \frac{\pi^2 EI}{(L_k)^2} \tag{3.23}$$

Where
P_E is Euler load
P_{kr} is the critical load that column is subjected to
The critical stress is defined by the following:

$$\sigma_{kr} = \frac{P_{kr}}{A} = \frac{\pi^2 EI}{A(L_k)^2} = \frac{\pi^2 E}{(\lambda)^2} \tag{3.24}$$

Last equation (3.24) could be found by substituting two equations(3.20) and (3.21) in the equation(3.23).

Norwegian standard(NS-EN 1995) mentions that two equations should be satisfied to control stresses in columns when relative slenderness ratio is equal to or less than 0,3 ($\lambda_{\mathrm{rel,y}} \leq 0{,}3 \; and \; \lambda_{\mathrm{rel,z}} \leq 0{,}3$). In this case, the columns are subjected to compression. At the same time, are subjected to moments of both the strong and weak axis. The two equations are:

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1 : \text{ to control buckling about y-axis} \tag{3.25}$$

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + k_m \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1 : \text{ to control buckling about z-axis} \tag{3.26}$$

When the relative slenderness ratio is more than 0,3, then the following equations should be satisfied :

$$\frac{\sigma_{c,0,d}}{k_{c,y}\, f_{c,0,d}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1 : \text{ to control buckling about y-axis} \tag{3.27}$$

$$\frac{\sigma_{c,0,d}}{k_{c,z}\, f_{c,0,d}} + k_m \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1 : \text{ to control buckling about z-axis} \tag{3.28}$$

Where

$k_{c,y}$ and $k_{c,z}$ are instability factors. These two factors are given by:

$$k_{c,y} = \frac{1}{k_y + \sqrt{(k_y)^2 - (\lambda_{rel,y})^2}} \tag{3.29}$$

$$k_{c,z} = \frac{1}{k_z + \sqrt{(k_z)^2 - (\lambda_{rel,z})^2}} \tag{3.30}$$

Relative slenderness ratio corresponding to bending about the y-axis, as well as relative slenderness ration corresponding to bending about the z-axis, are given by the following ::

$$\lambda_{rel,y} = \frac{\lambda_y}{\pi} \sqrt{\frac{f_{c,0,k}}{E_{0,05}}} \tag{3.31}$$

$$\lambda_{rel,z} = \frac{\lambda_z}{\pi} \sqrt{\frac{f_{c,0,k}}{E_{0,05}}} \tag{3.32}$$

Both the slenderness ratio($\lambda_y = \frac{L_k}{i_y}$ and $\lambda_z = \frac{L_k}{i_z}$) can be found based on equation (3.20) with taking account into $i_y = 0{,}289h$ and $i_z = 0{,}289b$ based on equation(3.21).

The other instability factors(k_y, k_Z) are calculated as follows:

$$k_y = 0{,}5\left[1 + 2\beta_c \left(\lambda_{rel,y} - 0{,}3\right) + (\lambda_{rel,y})^2\right] \tag{3.33}$$

$$k_z = 0{,}5\left[1 + 2\beta_c \left(\lambda_{rel,z} - 0{,}3\right) + (\lambda_{rel,z})^2\right] \tag{3.34}$$

Straightness factor $\beta_c = 0{,}1$ for glulam, factor considering re-distribution of bending stresses in a cross-section ($k_m = 1$)for glulam

Cross-laminated timer (CLT):

Cross-laminated timer elements consist of a board layer that should be three layers at least. The board layers are oriented at the right angles to one another and then joined together to form structural panels. The joining is carried out by screws, nails, wood dowels, glue and prestressed steel. Finally, the wood panel with exceptional strength, dimensional stability, and rigidity can be obtained[7]. Some examples of CLT building are shown in the Figure 3.12:

Figure 3.12: Examples for CLT constructions. Multi-family building Berlin, Germany(above).Viken skog BA, Hønefoss, Norway(down)[7]

A typical CLT-plate has an odd number (from 3-7) of layers with crossed boards, symmetrical about the middle layer. The largest plate size is normally 3m wide and 18m long, and the thickness can vary from 50 to 500 mm, depending on the application area[13]. The difference between CLT and plywood is the layer thickness and dimensions. A great advantage of gluing cross-laminated boards together is that you will get a much more dimensionally stable product which also has got more isotropic mechanical properties[7]. In the mid-1990s, industry, and academia in Austria cooperate together to develop the modern CLT which is now being manufactured and used in large parts in Europe, Canada USA, and Australia. The goal was to produce a timber element that could utilize much of the lumber that sawmills could not find any turnover (sales) for[13]. The configuration of CLT panel, cross-sections of CLT panel and CLT direction of fibers of the top layers are shown in Figure 3.13 below:

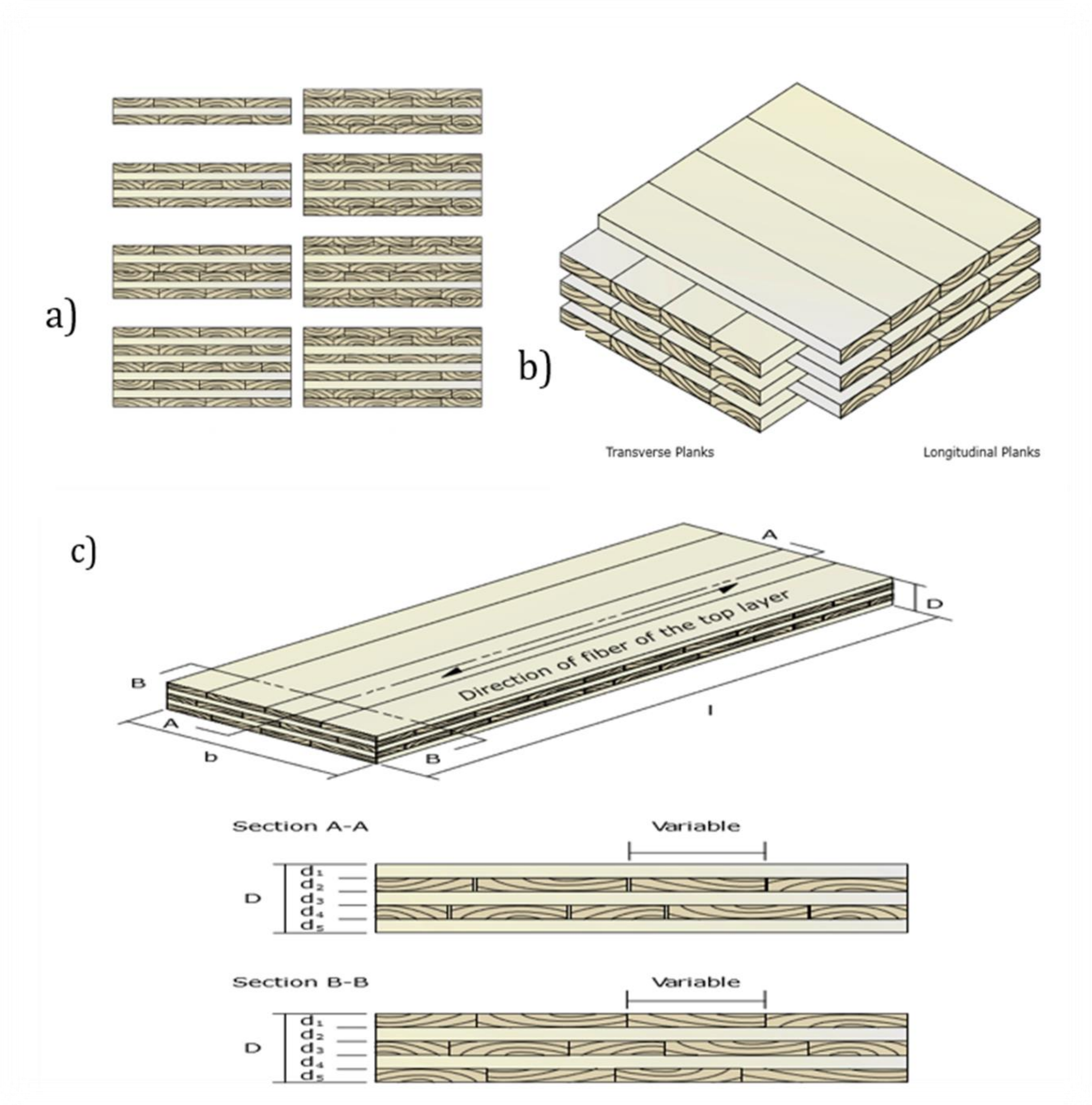


Figure 3.13: a)CLT panel cross- sections b)configuration of CLT panel c)direction of fibers of top layer of CLT panel [7]

The high stiffness plates (board) are arranged on the main direction of the load-bearing capacity(0°) where the main direction matches the direction of top layers. The lower stiffness plates are arranged on the perpendicular direction of load-bearing capacity (90°)[12]. This is illustrated in Figure 3.13. In addition, the performance of stress and mean value of modulus of elasticity can be seen in Figure 3.14:

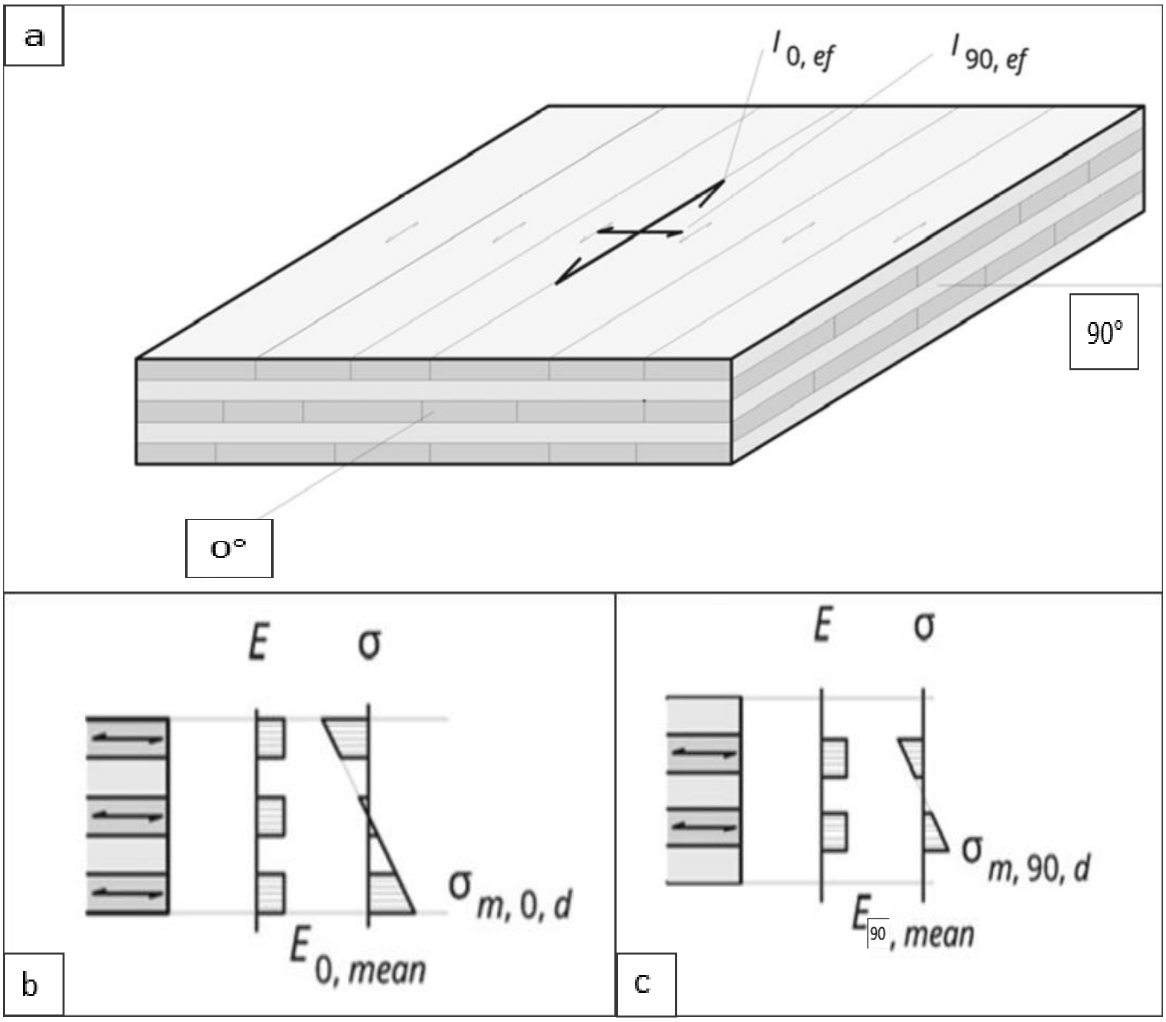


Figure 3.14: a)Location of the main direction of the load-bearing capacity (0°) and ancillary direction of the load-bearing capacity b)Bending stresses σ, mean value of modulus of elasticity E in the main direction (fibre direction) c) Bending stresses σ, mean value of modulus of elasticity E in the ancillary direction (perpendicular to fibre direction).[12]

Two designations of CLT are determined based on the orientation of the top layer and the long element side. The first designation is L or DL. In this case, the elements have a top layer longitudinal to the long element side. L or DL are usually used as roof, ceiling, and girder elements. The second designation is Q or DQ; the top layer of elements is perpendicular to the long element side. Q or QD are used as wall elements. Orientation of the top layers and examples for two designations of CLT are shown in Figure 3.15 and Figure 3.16:

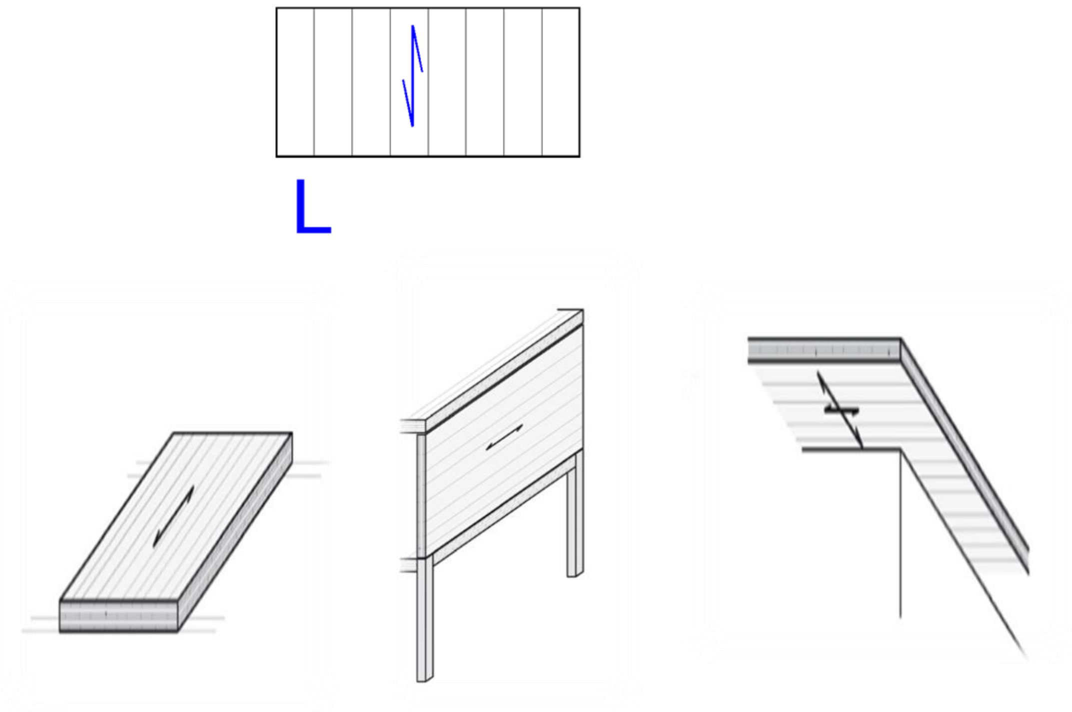


Figure 3.15: L or DL elements, the top layer longitudinal to the long element side (above).Ceiling, grinder, and roof are respectively examples for L or DL designation (down)[12]

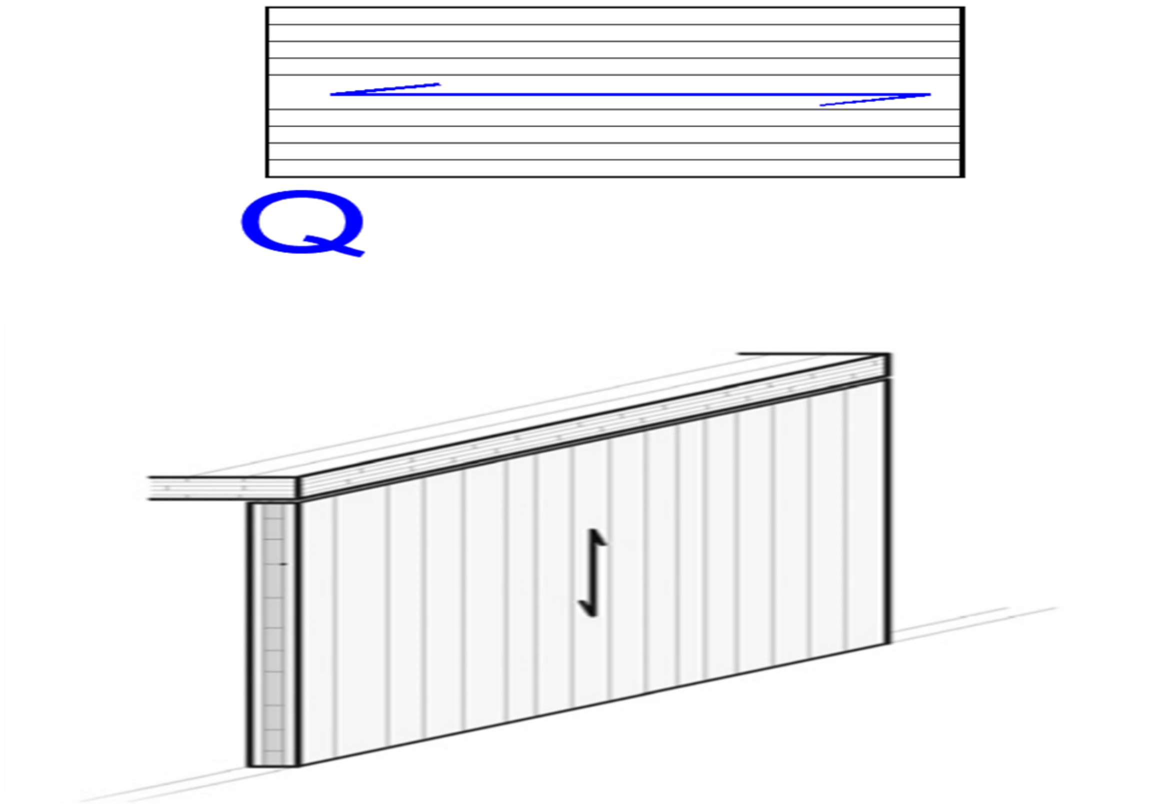


Figure 3.16: Q or DQ elements, the top layer transverse to the long element side (above).Ceiling, grinder, and roof are respectively examples for Q or DQ designation (down)[12]

Design of cross-laminated timber(CLT) elements:

In general, the CLT are approved for two types of effects: static and quasi-static. Dead loads, live loads, wind loads, and snow load are mentioned as characteristic values in the specific parts of NS-EN: 1991. Measurements and load models are main sources for obtaining the characteristic values of impacts (E_K), with taking into account the reference period that is 50 years.

For verifying the structural safety of cross-laminated timber construction, the design value (impact) of stress (E_d) should be equal or less than the design value of resistance(R_d) [12]. It means :

$$E_d \leq R_d \tag{3.35}$$

Based on Ultimate limit state (Load-bearing capacity), the Design value of impact (E_d) and design value of resistance(R_d), respectively are given as following[12]:

$$E_d = \sum \gamma_G \cdot E_{G,i,k} + \gamma_Q \cdot E_{Q,1,k} + \sum \psi_0 \cdot \gamma_Q \cdot E_{Q,i,k} \text{ with estimate } E_d = 1{,}5 \cdot E_k \tag{3.36}$$

$$R_d = k_{mod} \frac{R_k}{\gamma_M} \quad \text{with estimate } R_d = \frac{R_k}{1{,}5} \tag{3.37}$$

Where

The partial factor for material properties ($\gamma_M = 1{,}25$)

Modification factor for the duration of the load(medium load duration) and moisture content($k_{mod} = 0{,}8$), for another load duration it is mentioned in Table 3.6.

Strength and stiffness properties and densities for cross-laminated timber upon use as panels are given in Table 3.8 and Table 3.9:

Table 3.8: Coefficient of strength for CLT upon use as panel(Suggested design values for($k_{mod} = 0{,}8$)and$\gamma_M = 1{,}25$) , coefficient of stiffness for CLT upon use as panel and general characteristic building material values [12]

Properties	Symbol	Suggested design values	
		Value	Unit
Flexural strength	$f_{m,d}$	15,3	N/mm^2
Tension strength in the direction of fibre	$f_{t,0,d}$	9,00	N/mm^2
Compression strength in the direction of the fibre	$f_{c,0,d}$	13,4	N/mm^2
Compression strength perpendicular to fibre direction	$f_{c,90,d}$	1,6	N/mm^2
Shear strength	$f_{V,d}$	1,6	N/mm^2
Rolling shear strength	$f_{V,R,d}$	0,7	N/mm^2
Torsional strength	$f_{0,T,d}$	1,6	N/mm^2

Elastic modulus(Normal stress)	$E_{0,mean}$	11000	N/mm^2
	$E_{0,05}$	9160	N/mm^2
Modulus of elasticity (Transverse to fiber)	$E_{90,mean}$	370	N/mm^2
Shear modulus	$G_{0,05}$	690	N/mm^2
	$G_{0,mean}$	570	N/mm^2
Rolling shear modulus	$G_{R,mean}$	50	N/mm^2
Density (for load assumptions)	γ	5,5	KN/m^3
Characteristic minimum value of bulk density	ρ_k	400	Kg/m^3
Mean bulk density	ρ_{mean}	450	Kg/m^3

Table 3.9: Coefficient of strength for CLT upon use as a plate (Suggested design values for$(k_{mod} = 0{,}8) and \gamma_M = 1{,}25)$ *, coefficient of stiffness for CLT upon use as plate. The CLT layer that is under stress is made up of continuously finger-jointed board layers [12]*

Properties	Symbol	Suggested design values	
		Value	Unit
Flexural strength	$f_{m,d}$	15,3	N/mm^2
Tension strength in the direction of fibre	$f_{t,0,d}$	9,00	N/mm^2
Compression strength in the direction of the fibre	$f_{c,0,d}$	13,4	N/mm^2
Compression strength perpendicular to fibre direction	$f_{c,90,d}$	1,6	N/mm^2
Shear strength	$f_{V,d}$	1,6	N/mm^2
Shear strength of the plate	$f_{V,S,d}$	3,2	N/mm^2
Torsional strength of the glued joint	$f_{V,T,d}$	1,6	N/mm^2
Rolling shear strength	$f_{V,R,d}$	0,7	N/mm^2
Elastic modulus(Normal stress)	$E_{0,mean}$	11000	N/mm^2
	$E_{0,05}$	9160	N/mm^2
Modulus of elasticity (Transverse to fiber)	$E_{90,mean}$	370	N/mm^2

Shear modulus	$G_{0,05}$	690	N/mm^2
	$G_{0,mean}$	570	N/mm^2
Rolling shear modulus	$G_{R,mean}$	50	N/mm^2

Partial safety factor(γ) for ULS, Modification factor for the duration of load k_{mod} that match up the values for plywood based on EN 1995, and combination factors based on EN.1990 are collected in the following table.

Table 3.10: Load categories and related factors [12]

<table>
<tr><th>Group</th><th>Category</th><th>Load ab-bre-via-tion</th><th>γ_{sup}</th><th>γ_{inf}</th><th>KLED</th><th>k_{mod} NKL 1, 2</th><th>ψ_0</th><th>ψ_1</th><th>ψ_2</th></tr>
<tr><td colspan="2">Permanent loads</td><td>G</td><td>1,35</td><td>1,00</td><td>permanent</td><td>0,60</td><td colspan="3">–</td></tr>
<tr><td rowspan="9">Live loads in building construction</td><td>A: Living areas</td><td>NA</td><td rowspan="9">1,50</td><td rowspan="9">0,00</td><td>medium</td><td rowspan="2">0,80</td><td rowspan="4">0,70</td><td rowspan="2">0,50</td><td rowspan="2">0,30</td></tr>
<tr><td>B: Office areas</td><td>NB</td><td>medium</td></tr>
<tr><td>C: Accumulations of people</td><td>NC</td><td>brief</td><td>0,90</td><td rowspan="2">0,70</td><td rowspan="2">0,60</td></tr>
<tr><td>D: Sales areas</td><td>ND</td><td>medium</td><td>0,80</td></tr>
<tr><td>E: Storage and industrial utilisation</td><td>NE</td><td>long</td><td>0,70</td><td>1,00</td><td>0,90</td><td>0,80</td></tr>
<tr><td>F: Traffic and parking areas (light)</td><td>NF</td><td>medium</td><td rowspan="2">0,80</td><td rowspan="2">0,70</td><td>0,70</td><td>0,60</td></tr>
<tr><td>G: Traffic and parking areas (medium)</td><td>NG</td><td>medium</td><td>0,50</td><td>0,30</td></tr>
<tr><td>H: Roofs</td><td>NH</td><td>brief</td><td rowspan="2">0,90</td><td>0,00</td><td>0,00</td><td>0,00</td></tr>
<tr><td>Balconies, accesses, etc.</td><td>N1</td><td>brief</td><td>0,70</td><td>0,50</td><td>0,30</td></tr>
<tr><td rowspan="2">Snow loads in building construction</td><td>Locations above 1.000 m above sea level</td><td>S1</td><td rowspan="2">1,50</td><td rowspan="2">0,00</td><td>medium</td><td>0,80</td><td>0,70</td><td>0,50</td><td>0,20</td></tr>
<tr><td>Locations below 1.000 m above sea level</td><td>S2</td><td>brief</td><td>0,90</td><td>0,50</td><td>0,20</td><td>0,00</td></tr>
<tr><td>Wind loads in building construction</td><td></td><td>W</td><td>1,50</td><td>0,00</td><td>brief</td><td>0,90</td><td>0,60</td><td>0,20[1]</td><td>0,00</td></tr>
</table>

Regarding deformation impact(creep deformation) it is calculated by taking account into factor k_{def} based on the following equation:

$$w_{creep} = k_{def}\, w_{inst,qp} \tag{3.38}$$

Where

$w_{inst,qp}$ is initial deformation in the quasi-permanent design situation

k_{def} can be found in the Table 3.11

Table 3.11: k_{def} for different types of timber based on utilization class[12]

Building material	k_{def} for utilization class		
	1	2	3
Solid wood	0,6	0,8	2,0
Glued-laminated timber			
Cross laminated timber	0,8	1,00	Not approved

To satisfy stresses in the cross-section of CLT, the engineering properties of these sections should firstly be determined with considering that the outer transverse layer is not evaluated.
To calculating the center of gravity for cross -section of CLT, two of cross section will be determined: **Symmetrical** cross section: the center will be calculated with the axis of symmetry. Regarding **unsymmetrica**l cross-section with different properties including strength classes, the distance between the overall center of gravity and the upper edge of the element should be calculated based on the following equation:

$$Z_s = \frac{\sum_{i=1}^{n} \frac{E_i}{E_c} \cdot b_i \cdot d_i \cdot o_i}{\sum_{i=1}^{n} \frac{E_i}{E_c} \cdot b \cdot d_i} \quad (3.39)$$

Where
$Z_s = Z_0$ Distance of the top edge fiber to the overall center of gravity S
E_i Modulus of elasticity for the individual layer
b_i, d_i Dimensions of the individual layer
o_i Distance from center of gravity of individual layer and the upper edge of CLT element
E_c reference modulus due to the different moduli of elasticity
n number of longitudinal layers
Later, the distance between the center of gravity of the individual layer and the overall center of gravity S will be determined by:

$$a_i = o_i - Z_s \quad (3.40)$$

Distances, stresses and overall center of gravity *S* are clearly illustrated in Figure 3.17b:

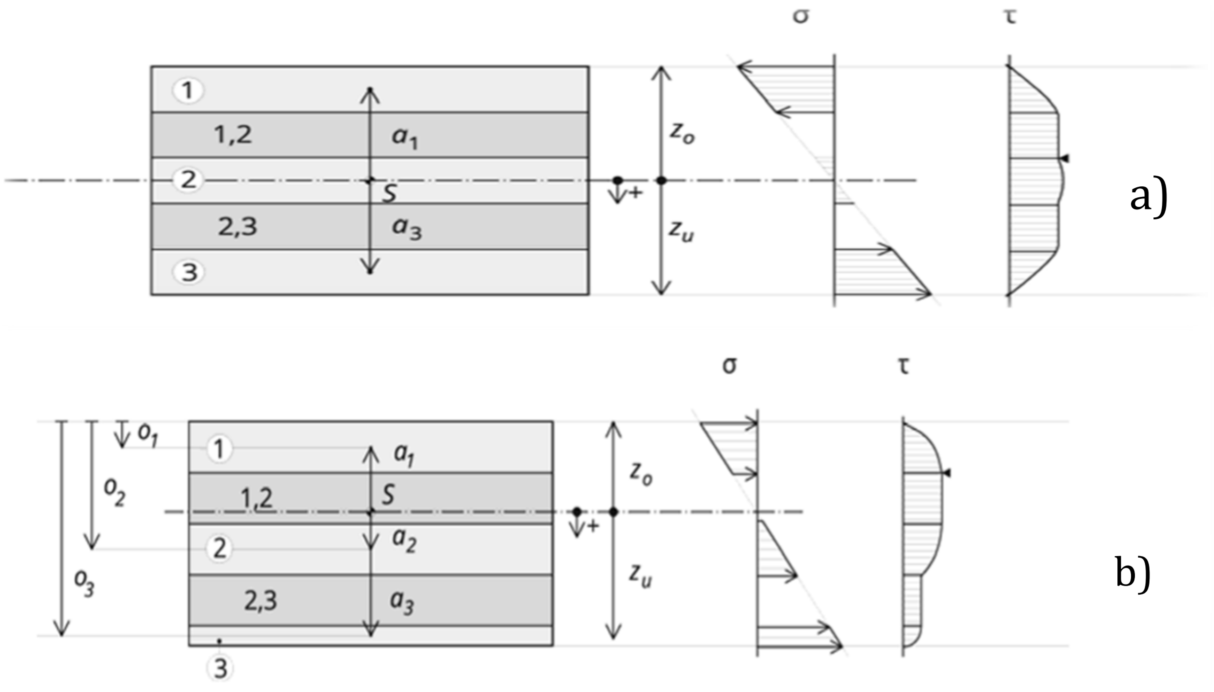


Figure 3.17: Determination of centre of gravity for cross-section of cross-laminated timber element, distances and stresses .a) symmetrical cross-section b) unsymmetrical cross-section

The **net area of the section** in the main direction of span(*0*) is determined as follows[12]:

$$A_{0,net} = \sum_{i=1}^{n} \frac{E_i}{E_c} \cdot b \cdot d_i \tag{3.41}$$

Net moment of inertia is given by:

$$I_{0,net} = \sum_{i=1}^{n} \frac{E_i}{E_c} \cdot \frac{b \cdot d_i{}^3}{12} + \sum_{i=1}^{n} \frac{E_i}{E_c} \cdot b \cdot d_i \cdot a_i{}^2 \tag{3.42}$$

Then, **net section modulus** is determined:

$$W_{0,net} = \frac{I_{0,net}}{\max\{|z_0|; |z_u|\}} \tag{3.43}$$

Where
$z_u = d - |z_s|$ is the distance of the bottom edge fiber to the overall center of gravity
Whereas the **static moment** is determined as follows:

$$S_{R,0,net} = \sum_{i=1}^{m_L} \frac{E_i}{E_c} \cdot b \cdot d_i \cdot a_i \tag{3.44}$$

m_L Index of that longitudinal layer closest to the position of the center of gravity as seen from the top edge of the cross-section[12].

The effective radius of inertia i_{ef} should be taken into account to avoid the buckling from the structural element plane[12]. Then it is given by :

$$i = \sqrt{\frac{I_{0,ef}}{A_{0,net}}} \tag{3.45}$$

Where
$I_{0,ef}$ is the effective moment of inertia

For determination the torsional moment, two factors will be considered: cross section build up and width of the element. Therefore, the **moment of torsional resistance** for rectangular and homogenous cross-section is given by[12]:

$$W_T = \frac{c_1}{c_2} \cdot \frac{h\,d^{\,2}}{3} \tag{3.46}$$

where

$$c_1 = 1 - 0{,}63 \cdot \frac{d^{\,2}}{h} + 0{,}052 \cdot \left(\frac{d}{h}\right)^5 \tag{3.47}$$

$$c_2 = 1 - \frac{0{,}65 \cdot \left(\frac{d}{h}\right)^3}{1 + \left(\frac{d}{h}\right)^3} \tag{3.48}$$

After determination of the cross-sectional properties of cross-laminated timber, the stresses must be satisfied based on ULS. The following cases will be discussed upon the panel load and stressing as upright girder[12]:
Bending in the main direction of load -bearing capacity: This is illustrated in in Figure 3.18:

$$\sigma_{m,d} = \frac{M_{0,d}}{W_{0,net}} \leq f_{m,d} = k_{mod} \cdot k_{sys} \cdot \frac{f_{m,k}}{\gamma_M} \tag{3.49}$$

Where
k_{sys} is system strength factor. The value varies from 1 until 1,2 and depends on the number of boards that are subjected to stress [8]

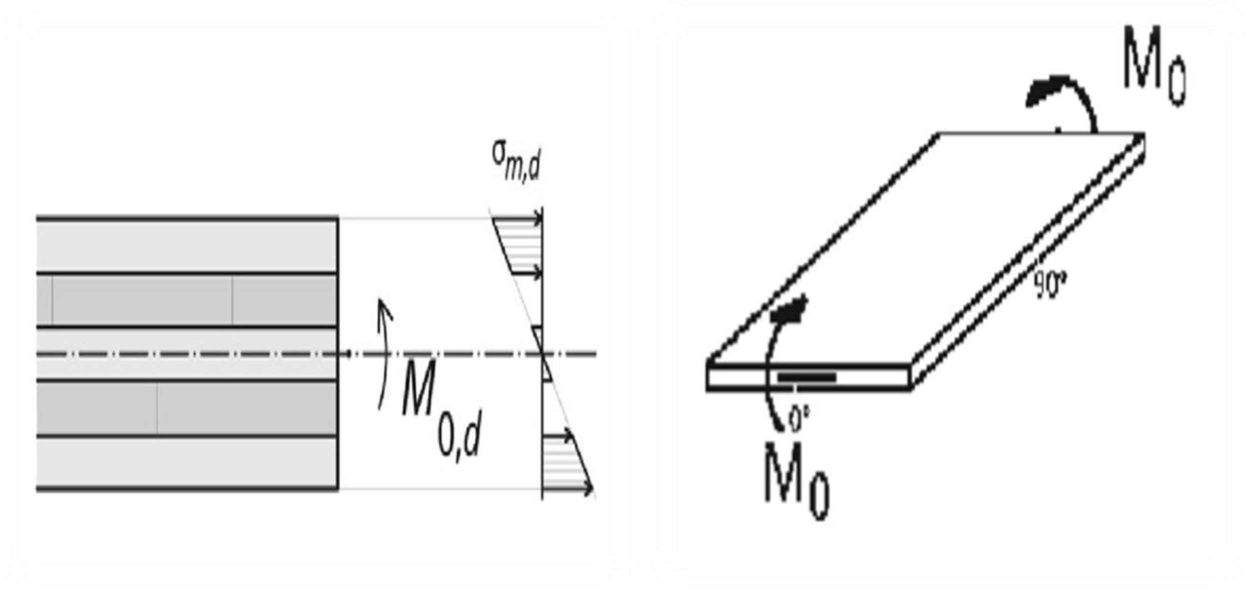


Figure 3.18:Bending in the main direction of load-bearing capacity[12]

Bending in the ancillary direction of the load-bearing capacity: An illustration is shown in Figure 3.19:

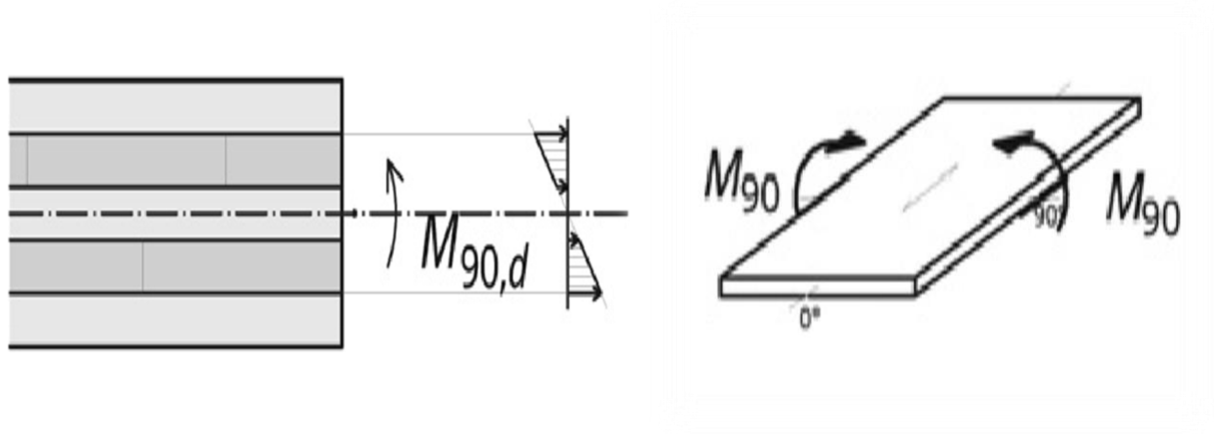


Figure 3.19: Bending in the ancillary direction of load-bearing capacity[12]

$$\sigma_{m,d} = \frac{M_{90,d}}{W_{90,net}} \leq f_{m,d} = k_{mod} \cdot k_{sys} \cdot \frac{f_{m,k}}{\gamma_M} \tag{3.50}$$

When bending occurs upon stressing as an upright girder, following cases will be determined:
The top layer in the direction of load-bearing capacity:

$$\sigma_{m,z,d} = \frac{M_{z,d}}{W_{z,0,net}} \leq f_{m,d} = k_{mod} \cdot \frac{f_{m,k}}{\gamma_M} \tag{3.51}$$

Where net section modulus is given by:

$$W_{z,0,net} = \frac{\sum d_0 \cdot h^2}{6} \tag{3.52}$$

The direction of the moment, bending stresses, the net thickness of layers subjected to impact, and the height of elements is shown in Figure 3.20.

Top layer transverse to the direction of load -bearing capacity: Illustrated in Figure 3.20.c:

$$\sigma_{m,z,d} = \frac{M_{z,d}}{W_{z,90,net}} \leq f_{m,d} = k_{mod} \cdot \frac{f_{m,k}}{\gamma_M} \tag{3.53}$$

Where net section modulus is given by:

$$W_{z,90,net} = \frac{\sum d_{90} \cdot h^2}{6} \tag{3.54}$$

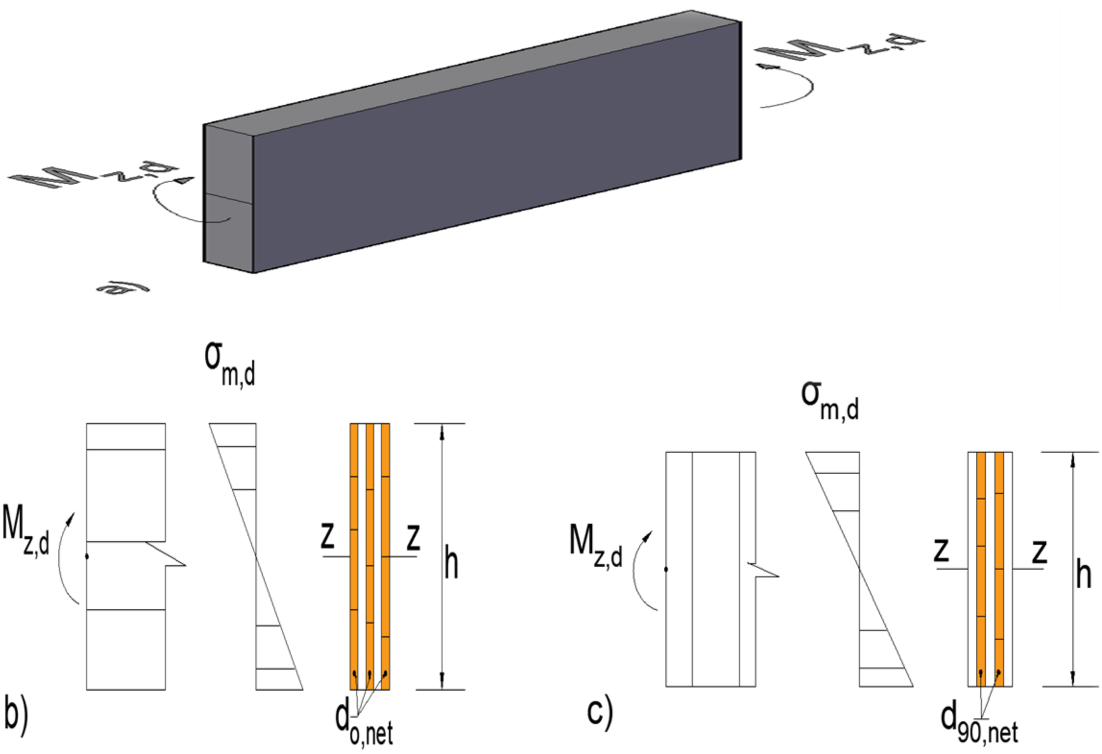


Figure 3.20:Bending stress for girder in the direction of load-bearing capacity (b) and transverse to the direction of load bearing capacity (c)[12]

Concerning to the shear stresses, the first case depends on direction of load-bearing capacity relative to plane. First, the stress in the main direction of the load-bearing capacity is shown in Figure 3.21.b:

$$\tau_{V,R,d} = \frac{V_{0,d} \cdot S_{0,R,net}}{I_{0,net} \cdot b} \leq f_{V,R,d} = k_{mod} \cdot \frac{f_{V,R,k}}{\gamma_M} \quad (3.55)$$

Secondly, **stress in the ancillary direction of load-bearing capacity:** Illustration is shown in Figure 3.21.c.

$$\tau_{V,R,d} = \frac{V_{90,d} \cdot S_{90,R,net}}{I_{90,net} \cdot b} \leq f_{V,R,d} = k_{mod} \cdot \frac{f_{V,R,k}}{\gamma_M} \quad (3.56)$$

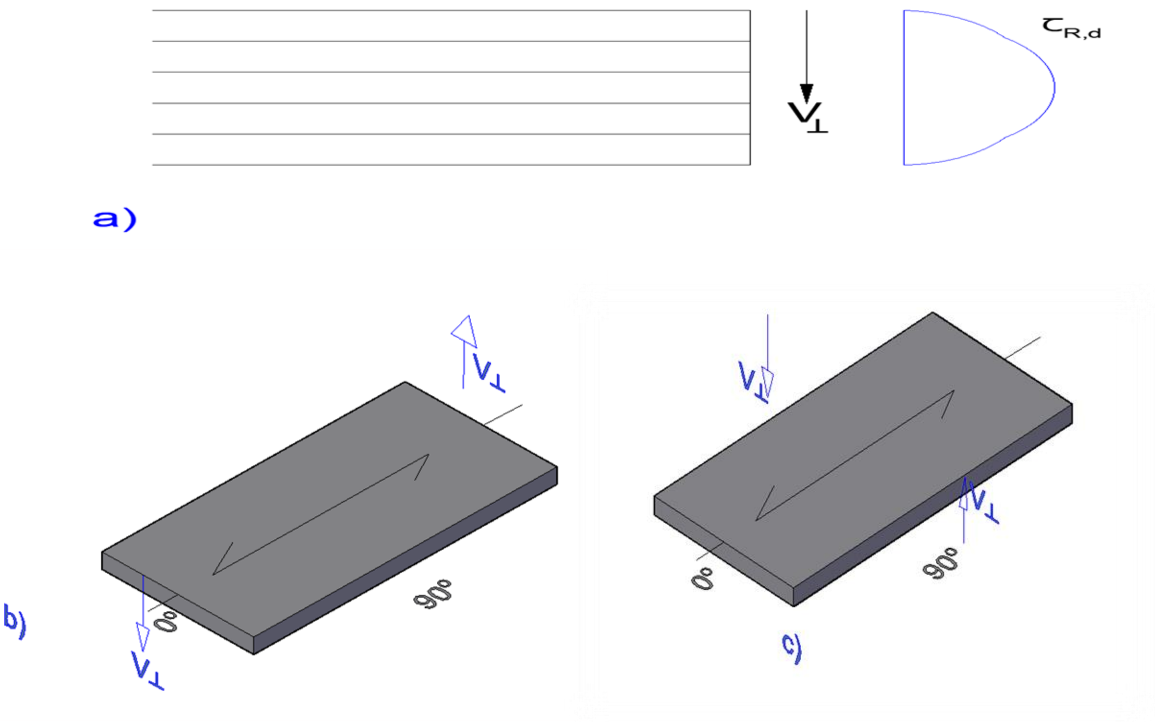


Figure 3.21:Shear stress in the main direction of load bearing capacity and in the ancillary direction of load-bearing capacity ,b and c respectively.[12]

Tension in the direction of the top layers: The following requirements should be satisfied:

$$\sigma_{t,0,d} = \frac{N_{0,d}}{A_{0,net}} \leq f_{t,0,d} = k_{mod} \cdot k_{sys} \cdot \frac{f_{t,0,k}}{\gamma_M} \quad (3.57)$$

Illustration of relative tensile force and tensile are shown in Figure 3.22.a and Figure 3.22.*b*

Tension in the direction of the transverse layers:

$$\sigma_{t,0,d} = \frac{N_{90,d}}{A_{90,net}} \leq f_{t,0,d} = k_{mod} \cdot k_{sys} \cdot \frac{f_{t,0,k}}{\gamma_M} \tag{3.58}$$

Figure 3.22.c and Figure 3.22.d show how force and stresses act in the direction of transverse layers

Tension perpendicular to the element plane: In this case, a decrease of the tensile load -bearing perpendicular to the element plane should be taken into account .Therefore, certain connections are recommended in order to transfer the force through the elements.

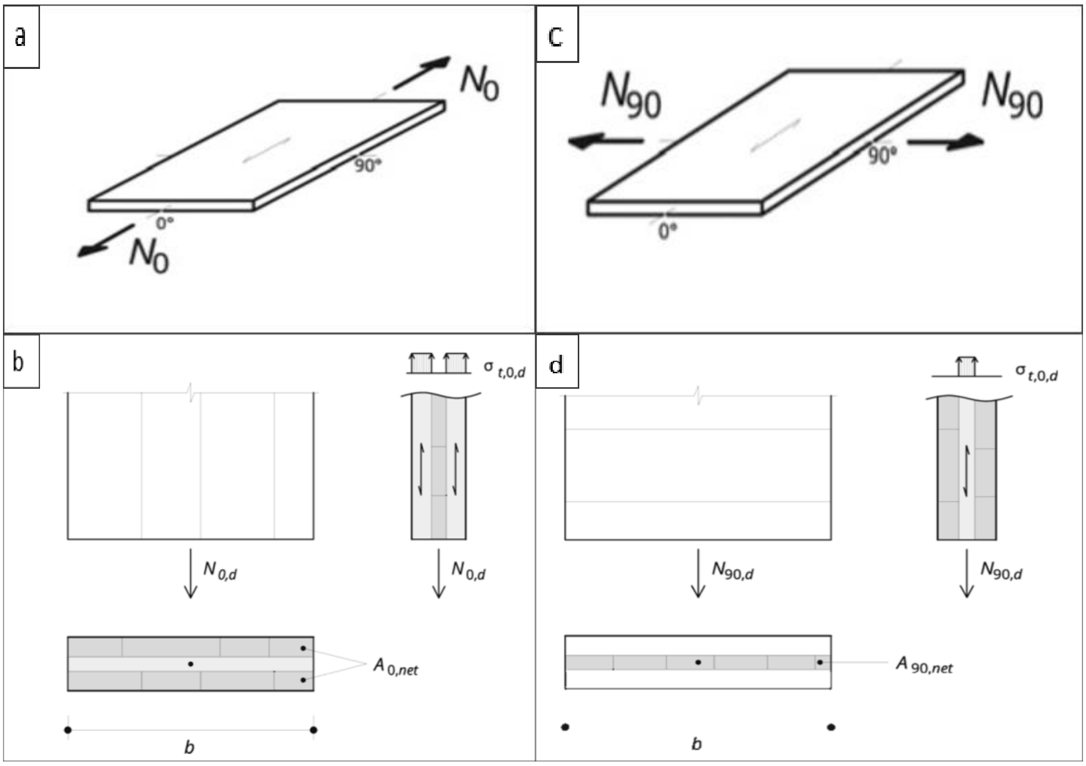


Figure 3.22: Tension in direction of top layer (a, b), and tension in direction of transverse layer(c, d). In addition, the net areas in both directions are also illustrated [12]

Compression in the direction of the top layers: Figure 3.23.a and Figure 3.23.b:

$$\sigma_{c,0,d} = \frac{N_{0,d}}{A_{0,net}} \leq f_{c,0,d} = k_{mod} \cdot \frac{f_{c,0,k}}{\gamma_M} \tag{3.59}$$

Compression in the direction of the transverse layers: Figure 2.23.c and Figure 3.23.d:

$$\sigma_{c,0,d} = \frac{N_{90,d}}{A_{90,net}} \leq f_{c,0,d} = k_{mod} \cdot \frac{f_{c,0,k}}{\gamma_M} \tag{3.60}$$

Where $A_{0,net} = b.d_0$ End pressing area for both relative compression cases is illustrated in Figure 3.23

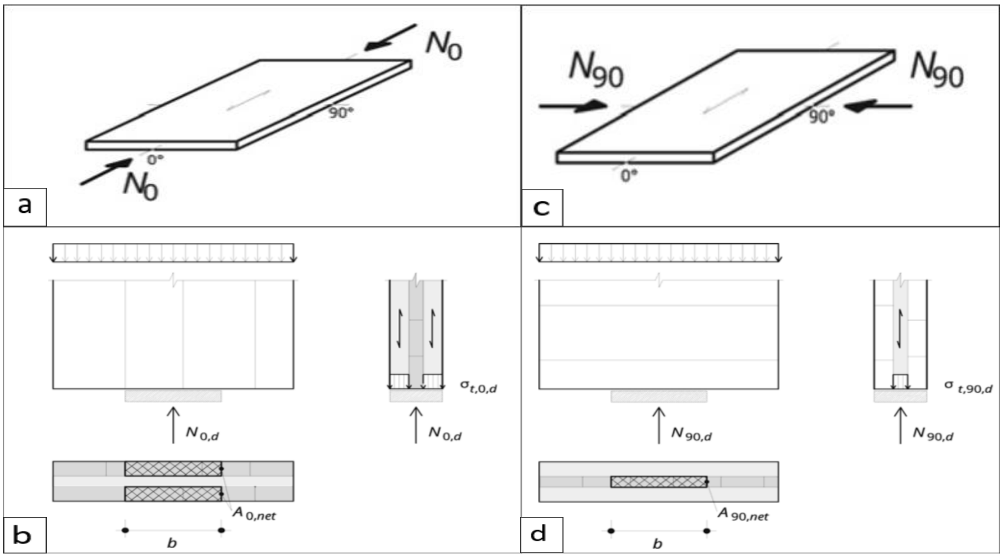


Figure 3.23: Compression in the direction of the top layers and transverse layer (a, b) and (c, d), respectively. Net area in both cases are shown[12].

Compression transverse to the element plane: Figure 3.24.aand Figure 3.24.b

$$\sigma_{c,90,d} = \frac{N_{90,d}}{k_{c,90} \cdot A_{ef}} \leq f_{c,90,d} = k_{mod} \cdot \frac{f_{c,90,k}}{\gamma_M} \tag{3.61}$$

Where

$f_{c,90,d}$ is design compressive strength perpendicular to the element plane.

$k_{c,90}$ is a factor that takes into account the load configuration. $1{,}4 \leq k_{c,90} \leq 1.90$ (see Figure 3.24.c)

$\sigma_{c,90,d}$ is design compressive stress perpendicular to the element plane

$N_{90,d}$ is design compressive force perpendicular to the element plane

A_{ef} is the effective contact area.

The effective area should be calculated by getting pay attention to an effective contract length. This length is increased by 3 cm on both sides in the direction of the fibre of the top layer (Figure 3.24.d)

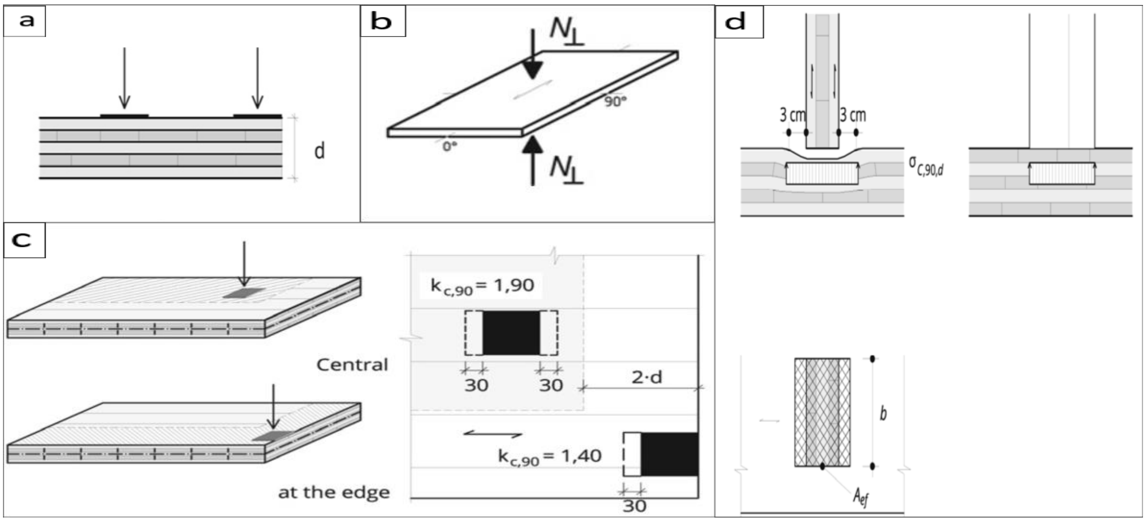


Figure 3.24: Compressive force perpendicular to the element plane (a, b). $k_{c,90}$ values based on orientation of compressive forces (c). Illustration of effective area(d)[12]

Buckling upon compression in the direction of the top layers is given by:

$$\frac{\sigma_{c,0,d}}{k_{c,y}\, f_{c,0,d}} + \frac{\sigma_{m,d}}{f_{m,d}} \leq 1 \tag{3.62}$$

$$\frac{\frac{N_d}{A_{net}}}{k_{c,y}\, f_{c,0,d}} + \frac{\frac{M_d}{W}}{f_{m,d}} \leq 1 \tag{3.63}$$

The slenderness ratio is defined by the following equation:

$$\lambda_y = \frac{L_{k,i}}{i_{y,0,ef}} \tag{3.64}$$

Where

$L_{k,i}$ is effective buckling length, can be determined based on Figure 3.11

$i_{y,0,ef}$ is effective radius of inertia. This can be defined as:

$$i_{y,0,ef} = \sqrt{\frac{I_{y,0,ef}}{A_{o,net}}} \tag{3.65}$$

$k_{c,y}$ is the buckling factor:

$$k_{c,y} = \frac{1}{k_y + \sqrt{(k_y)^2 - (\lambda_{rel,y})^2}} \tag{3.66}$$

Relative slenderness ratio corresponding to bending about the y-axis is given

$$\lambda_{rel,y} = \frac{\lambda_y}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} \tag{3.67}$$

The other instability factors k_y

$$k_y = 0{,}5\left[1 + 2\beta_c\left(\lambda_{rel,y} - 0{,}3\right) + (\lambda_{rel,y})^2\right] \tag{3.68}$$

Straightness factor $\beta_c = 0{,}1$ for CLT

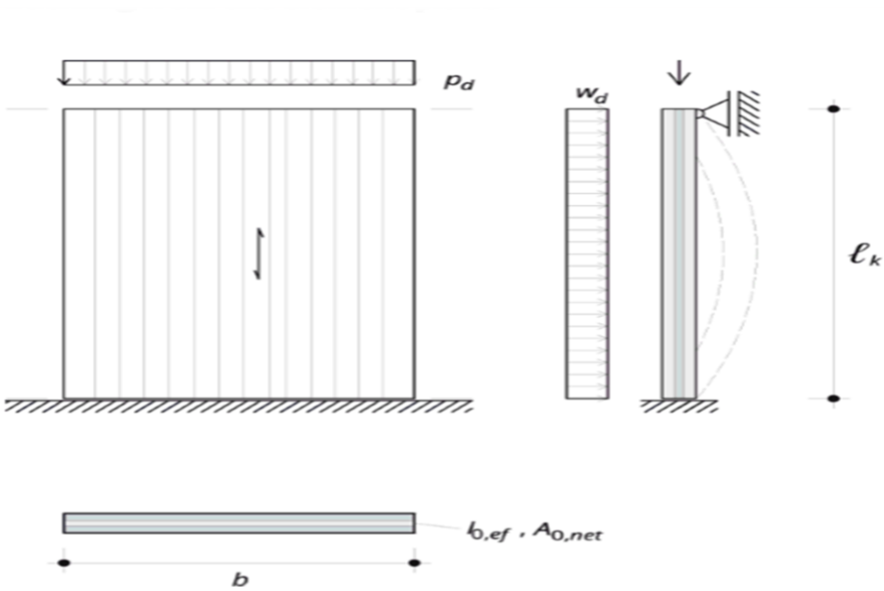


Figure 3.25: Buckling from the element plane. Net area and net moment of inertia in the main direction of load bearing capacity and effective buckling length [12]

Benefit and Drawbacks s of CLT

Benefits [24] [25] [32]**:**

- Solid wood floors combine the beneficial properties of the wood with the possibility of prefabrication that result in short construction time.
- Solid wood provides a good indoor climate as the tree breathes while being able to regulate moisture and temperature.
- Wood is a renewable raw material that requires little energy to produce which results in lower CO2 emissions and in addition binds CO2 in its life cycle.
- It is easy to recover and reuse
- Wood has properties that can contribute to making the use of the finished building environmentally friendly, by reducing the energy requirement for heating.
- And so forth.

Drawbacks:
Wood is basically problem-free when used correctly inside buildings. CLT elements must be prevented from being exposed to high humidity for long periods. Stresses must be assessed against the properties of CLT elements such as temperature variations, moisture variations and precipitation. Like timber or glulam, CLT elements may also have similar weaknesses. Usually, CLT needs protective measures in the same way as for wood or glulam. There may be various forms of constructive protection of the building, which protects the wood materials from direct water stress and moisture. Examples of such measures are [33]:

- Good roof protrusions or equivalent protection from other protruding building parts
- Sufficient distance between wood and terrain
- Proper connections and details
- Aerated and drained exterior cladding

In addition, special care should be taken when designing the external part of the building with CLT. It requires good solutions. Some of the solutions are:

- Avoid details which can lead to water traps
- Rainwater must be led down and away without dampening the elements.
- Cover with waterproof coating on elements used in hallways or balconies and proper slope
- Adequate shielding and protection against flames by fire.
- Pressure impregnation of exposed wood in the elements for improving the resistance to rot fungi when the elements are used outside.

Nevertheless, it is recommended not to use solid wood outside (exterior) so that horizontal surfaces are exposed to direct rainfall or water spilling from overhead surfaces [33].

3.1.2. Reinforced concrete (RC)

Concrete is one of the world's most commonly used building materials consisting of cement, aggregate, water, and possibly admixtures. When these different constituents of a concrete mixture are mixed , a chemical reaction between the cement and water will begin. Thereby starting the curing process. For the next 28 days, the curing process will lead to significant changes in the concrete properties, where most of these will be taken place within the first seven days. After these 28 days, the concrete will have achieved most of its properties, and its properties will be considered representative of what it will achieve as a fully hardened concrete[34].

Foundations:
A foundation is defined that is a structural element that through it the loads are transmitted from other structural elements to soil. It can be designed and constructed by concrete, steel or wood [9]. Foundations can be shallow where the ratio of the embedment depth to the width (B) is less than 2,5. A deep foundation (pile) is a slender structural part designed and installed in the ground to transfer the structural loads to a solid deep layer of soil. In general, foundations are designed to satisfy the stability conditions called "ultimate limit state" and "serviceability limit state".

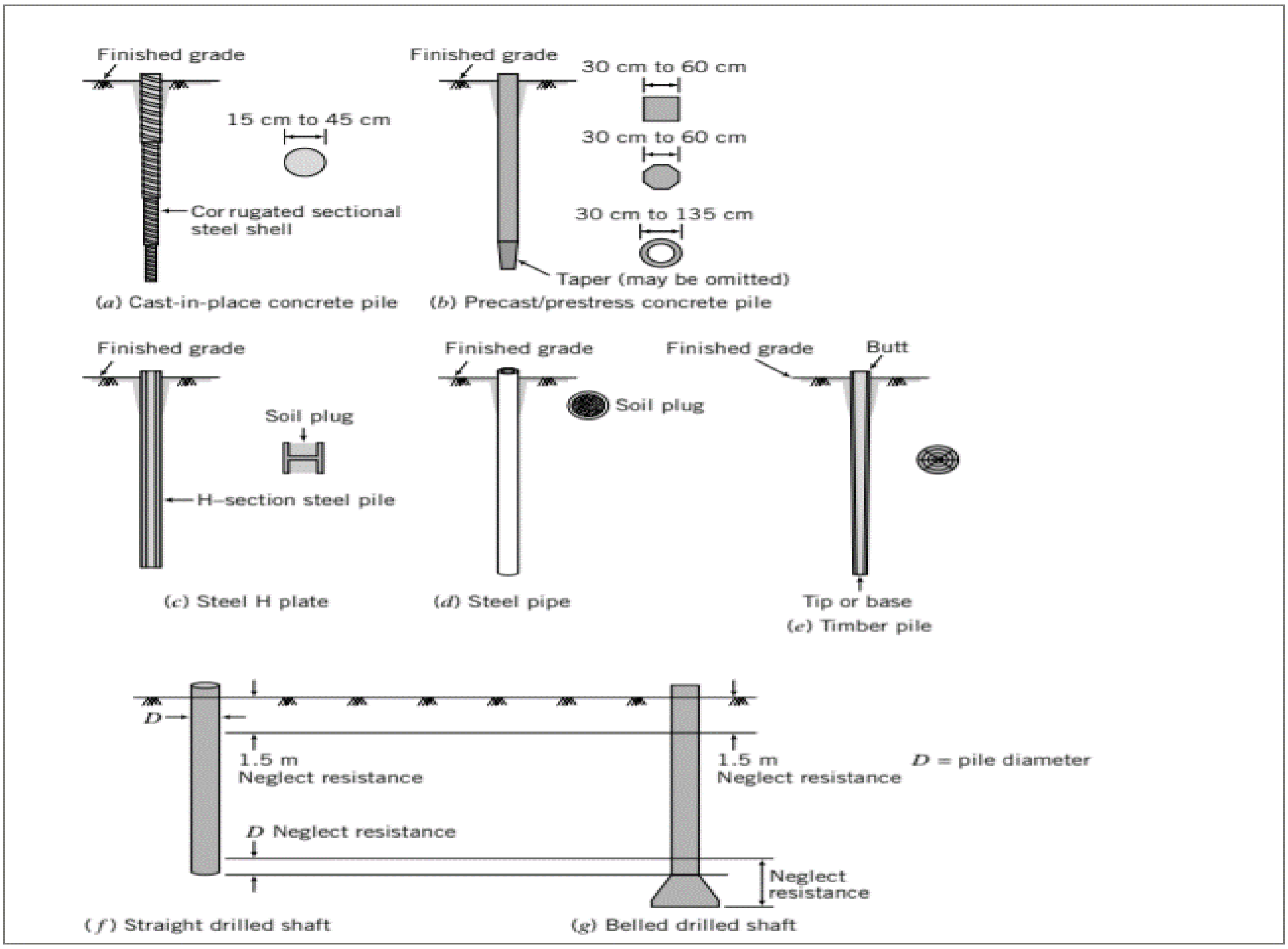


Figure 3.26: Types of piles: a) Cast -in-situ concrete pile b)Precast concrete pile c) steel pile (H-section) d)steel pipe (circle section) e) timber pile[9]

The ultimate limit state means that the collapse of foundation and instability must not occur under any potential force. Serviceability, on the other hand, means that stability of the construction should be within acceptable limits to avoid damage to the construction (deformation must not exceed acceptable limits)[17]. Shallow and deep foundations are shown in Figure 3.26 and Figure 3.27:

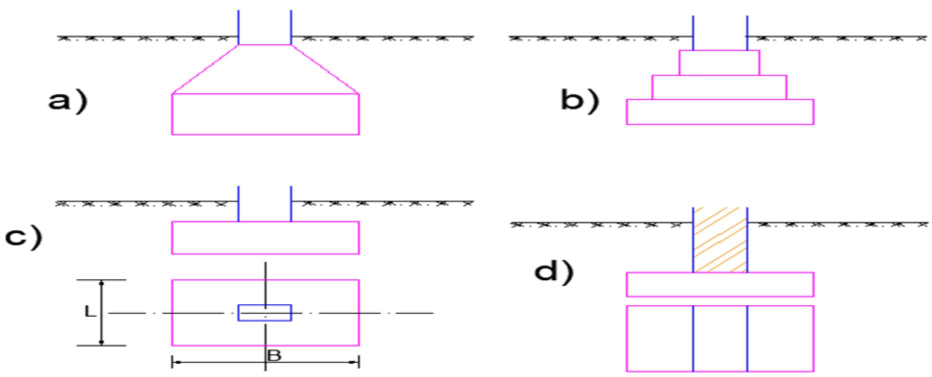


Figure 3.27: Some types of shallow foundations: a) plain concrete foundation b) stepped reinforced concrete foundation c) reinforced concrete rectangular foundation d) reinforced concrete wall foundation[17]

When a long footing supports two or more columns in one row, it is called a "combined footing". This type is constructed when columns are near to private adjoining property and the foundations must build in limits of this property. When the footing is large and supports more than two columns located in two or more rows, it is called a raft foundation or a mat. Raft foundation or mat is performed when sensitive construction is built on soft soil, has a low bearing capacity, and when the total area of separated footing is more than 50 % of the foundation area[9]. These types are illustrated in Figure 3.28.

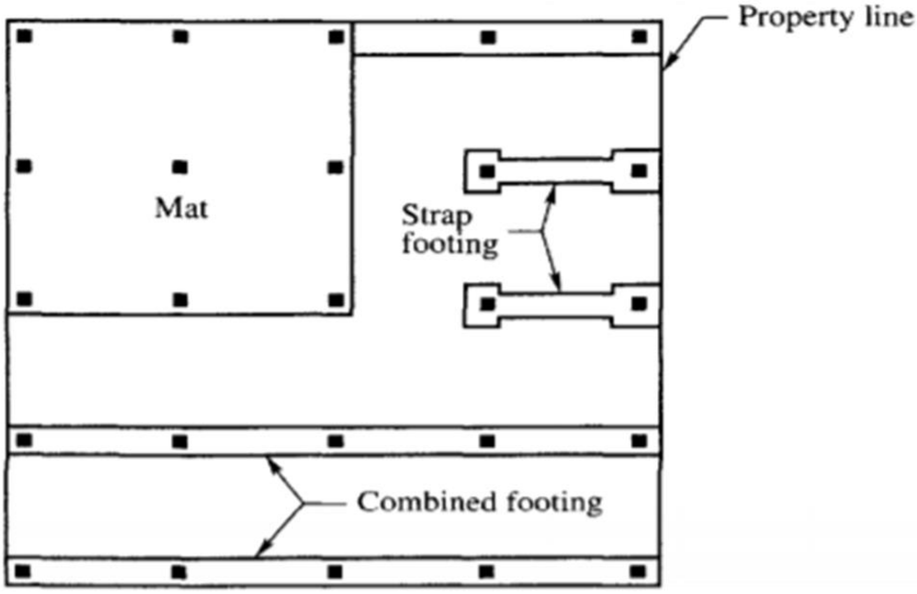


Figure 3.28: Raft foundation or mat and combined footing. Strap footing can be a special case of combined footing[17]

When the design of the foundation is carried out, it is crucial to determine the subsoil bearing capacity. This can be mentioned by an allowed design soil pressure, σ_{gd} . Many factors can affect the value of σ_{gd} , including the type of soil, depth of foundation sole, and foundation surface. Therefore, these factors should be assessed by a geotechnical consultant. Some values for σ_{gd} are shown in the Table 3.12 below:

Table 3.12: values for σ_{gd} for different types of soil[13]

Type of soil	σ_{gd} (KN/m$^{2)}$
Gravel, stone	400
Coarse solid stored sand	300
Fine solid stored sand	200
Fine loose stored sand	100
wet gravel, wet (coarse /fine) sand	100-200
Dry solid clay	200-300
Loose less solid clay	50-200
Soft clay, strongly clay-mixed sand	20-100

In this project will be focused on two types of foundations:

a) Wall foundations:

When wall foundation is subjected to axial load, the required foundation width can be determined by using the following[15], See Figure 3.29:

$$b \geq \frac{N_{Ed}}{\sigma_{gd}} \tag{3.69}$$

This is carried out based on:

$$q_{Ed} = \frac{N_{Ed}}{b} \leq \sigma_{gd} \tag{3.70}$$

Where

N_{Ed} is a central load from the structure that the wall foundation is subjected to

b is the width of the wall foundation

q_{Ed} is soil pressure

However, the foundation should often transfer moment in addition to vertical load to the underlying soil. This occurs when the foundation is subjected to an eccentric load. Then the effective foundation width can be determined as following[15]:

$$b_0 = \frac{N_{Ed}}{\sigma_{gd}} \tag{3.71}$$

Then the total foundation width is given:

$$b = b_0 + 2e \qquad \textit{when the wall foundation is symmetric} \tag{3.72}$$

$$b = \frac{b_0}{2} + \frac{b_0}{2} + e_{max} = b_0 + \frac{M_{Ed,max}}{N_{Ed}} \qquad \textit{when the foundation is asymmetric} \tag{3.73}$$

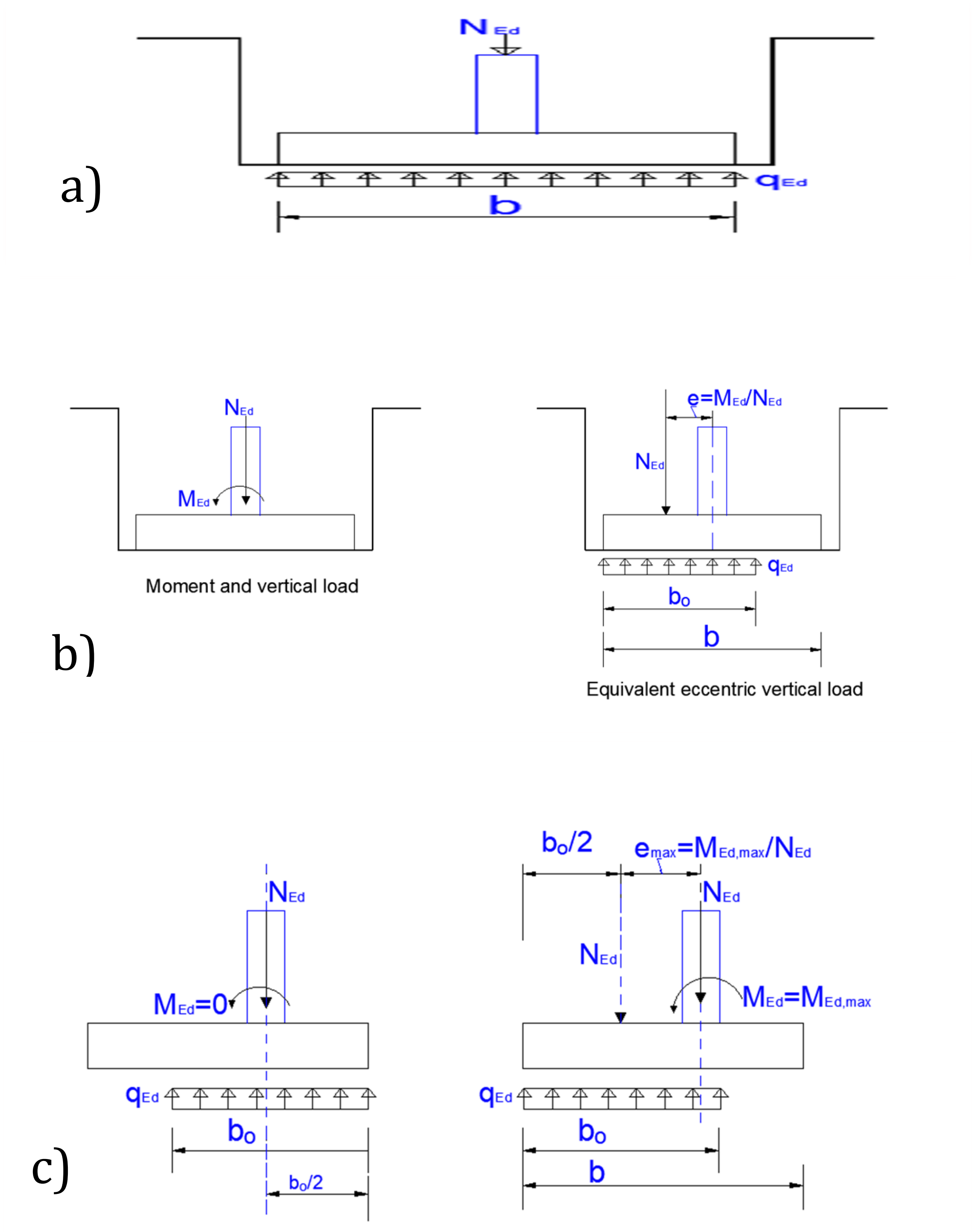


Figure 3.29: a) Wall foundation is subjected to centrical load b) symmetrical wall foundation subjected to eccentrical vertical load c) asymmetrical wall foundation subjected to eccentrical vertical load[15]

As stated, the determination of the required foundation dimensions ensures that the soil's bearing capacity is not exceeded. After that, the required height of foundation and reinforcement will be determined. Based on the Eurocode 2, the wall foundation doesn't need reinforcement if the following requirement is satisfied [35]:

$$\frac{h_f}{a} \geq 2 \qquad (3.74)$$

Where

h_f is the thickness of the foundation (height)

a is the width of foundation outside wall edge (see figure below)

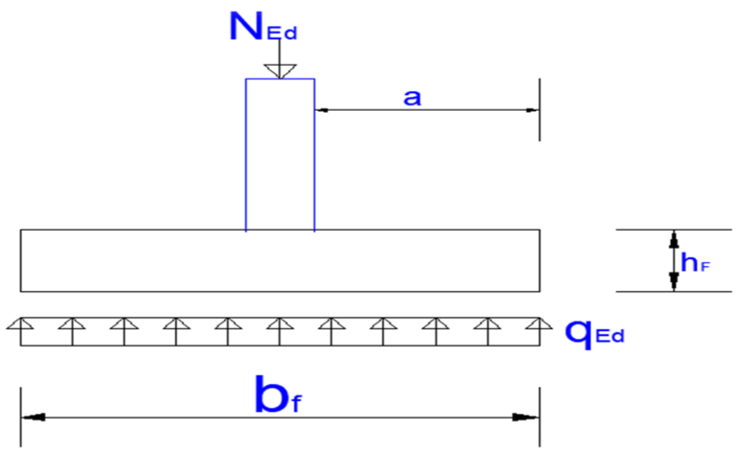


Figure 3.30: Unreinforced foundation

When mentioned requirement in equation (3.74) is not satisfied, then the wall foundations must be reinforced. To design and control the foundation's reinforcement, the requirements of EC2 must be satisfied so that the minimum bar diameter for the main reinforcement is 8mm.
Two sections through the foundation are taken, one of them can be at the face of the wall (edge) and others at distance (d)from the wall face. Bending moment and shear force are calculated at two sections. For a simple design, the foundation is assumed a cantilevered plate with some special standard requirements that concern the foundation. To sections are illustrated in Figure 3.31:

Moment capacity for concrete pressure zone at normally reinforced cross-sections is given by:

$$M_{Rd} = 0{,}275 \cdot f_{cd} \cdot b\, d^2 \qquad (3.75)$$

$f_{cd} = 0{,}85 \cdot \frac{f_{ck}}{\gamma_c}$ is design concrete strength

f_{ck} is the characteristic cylinder pressure strength of the concrete after 28 days

b is the width of foundation (it is taken as 1 m)

d is the effective height of the cross section

The necessary reinforcement cross-section to withstand the bending moment at the bottom of the foundation is given by:

$$A_s = \frac{M_{Ed1}}{f_{yd} \cdot z} \tag{3.76}$$

Where

$M_{Ed1} = \frac{q_{Ed} \cdot a^2}{2}$ is the bending moment at section 1 (Figure 3.31)

f_{yd} is design yield strength of the reinforcement

$z \approx (1\text{-}0{,}17 \cdot \frac{M_{Ed1}}{M_{Rd}})d$ is the inner moment arm of the cross-section

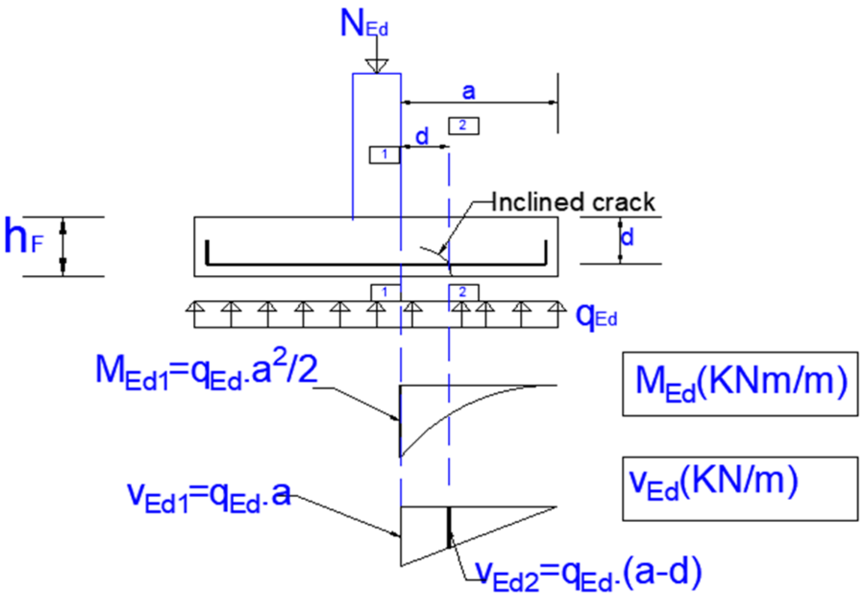


Figure 3.31: Reinforced foundation with design load effect(M_{Ed})and V_{Ed} at two sections, at wall face and distance d from wall face

Regarding the shear force, forces at two sections (V_{Ed1}, V_{Ed2}) will be controlled as mentioned:

$V_{Ed1} = q_{Ed} \cdot a$ is the shear force at the edge of support, is controlled based on EC2, 6.2.3 [35].

$$V_{Rd,max} = \nu_1 f_{cd}\, b_w z \frac{1}{\cot\theta + \tan\theta} \tag{3.77}$$

When $V_{Rd,max} > V_{Ed1}$ Then shear pressure capacity is sufficient and shear reinforcement is not needed.

However, when $V_{Rd,max} < V_{Ed1}$ Then shear pressure capacity is not sufficient and shear

reinforcement is needed and it is calculated based on following [35]:

$$\frac{A_{sw}}{s} \cdot z\, f_{ywd} \cdot \cot\theta \geq V_{Ed1} \tag{3.78}$$

Where

f_{ywd} is the shear reinforcement design yield strength
z = 0.9 d is inner moment
ϑ is the angle between the concrete pressure bar and the beam axis perpendicular to the shear force limit values for cot θ are given in expression (6.7N): 1 ≤ *cot* ϑ ≤ 2,5
A_{sw} is the cross-sectional area of shear reinforcement
S is the center distance between shear reinforcement units
ν_1 is a strength reduction factor for concrete elevation due to shear force it is given in EC2, NA.6.2.3(3) as:
ν_1 = 0,6 for $f_{ck} \leq$ 60 MPa
ν_1 = 0,9 – f_{ck}/200 > 0,5 for $f_{ck} \geq$ 60 MPa

$V_{Ed2} = q_{Ed} \cdot (a - d)$ is shear force at distance d from the edge of support. It will be controlled based on EC2,6.2.1(8), 6.2.2 and 6.2.3[35]:

$$V_{Rd,c} = \left[C_{Rd,c} . k\ (100\ \rho_L\ f_{ck})^{\frac{1}{3}}\right] b_w\ d \tag{3.79}$$

Where '

$k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$ and *d* is in mm.

$\rho_L = \frac{A_{sL}}{b_w\ d} \leq 0{,}02$

A_{sL} is the cross-sectional area of the tension reinforcement (moment reinforcement)

$b_w = b_{foundation} = 1\text{m of foundation}$

d the effective height of the cross section

$C_{Rd,c}$ *=0,18/γ_c*

γ_c = 1,5 is partial factor for concrete

When
$V_{Rd,c} > V_{Ed2}$ the shear tension capacity is sufficient. If not, shear tension reinforcement is required and is calculated based on (3.78) with substituting (V_{Ed2}) in stead for(V_{Ed1}).

b)Columns foundations:
Regarding foundations that are subjected to axial load (Figure 3.32.a); the required foundation width (quadratic foundation) will be found by:

$$b^2 \geq \frac{N_{Ed}}{\sigma_{gd}} \quad then\ b \geq \sqrt{\frac{N_{Ed}}{\sigma_{gd}}} \tag{3.80}$$

In case of eccentrically loaded columns foundation, the two required foundation dimensions (length and width) are determined by the following equation—taking into account that the moment is transmitted in one direction (Figure 3.32.b)[15]:

$$b_x = b_0 + 2e = \sqrt{\frac{N_{Ed}}{\sigma_{gd}}} + 2 \cdot \frac{M_{Ed}}{N_{Ed}}$$ for symmetric foundations (3.81)

$$b_y = b_0 = \sqrt{\frac{N_{Ed}}{\sigma_{gd}}}$$ for symmetric foundations (3.82)

$$b_x = b_0 + \frac{M_{Ed,max}}{N_{Ed}}$$ for asymmetric foundations (3.83)

$$b_y = b_0 = \sqrt{\frac{N_{Ed}}{\sigma_{gd}}}$$ for asymmetric foundations (3.84)

For foundations that are eccentrically loaded and moment is transmitted in two directions (Figure 3.32c), two the required foundation dimensions (length and width) become :

$$b_x = b_0 + e_{x,max} = b_0 + \frac{M_{Edx,max}}{N_{Ed}}$$ for asymmetric foundations (3.85)

$$b_x = b_0 + e_{y,max} = b_0 + \frac{M_{Edy,max}}{N_{Ed}}$$ for asymmetric foundations (3.86)

The design method of column foundation is in many ways similar to that of a wall foundation, including design of bending moment , requirements for cover and cross-sectional height. But the critical section for shear pressure is calculated as [15]:

$$V_{Ed1} = q_{Ed} \cdot \frac{b_f + b}{2} \cdot a$$ (3.87)

Cover requirements for both column foundation and wall foundation, distribution of bottom edge reinforcement in column foundation and a critical section for shear pressure in column foundation are shown in Figure 3.33:

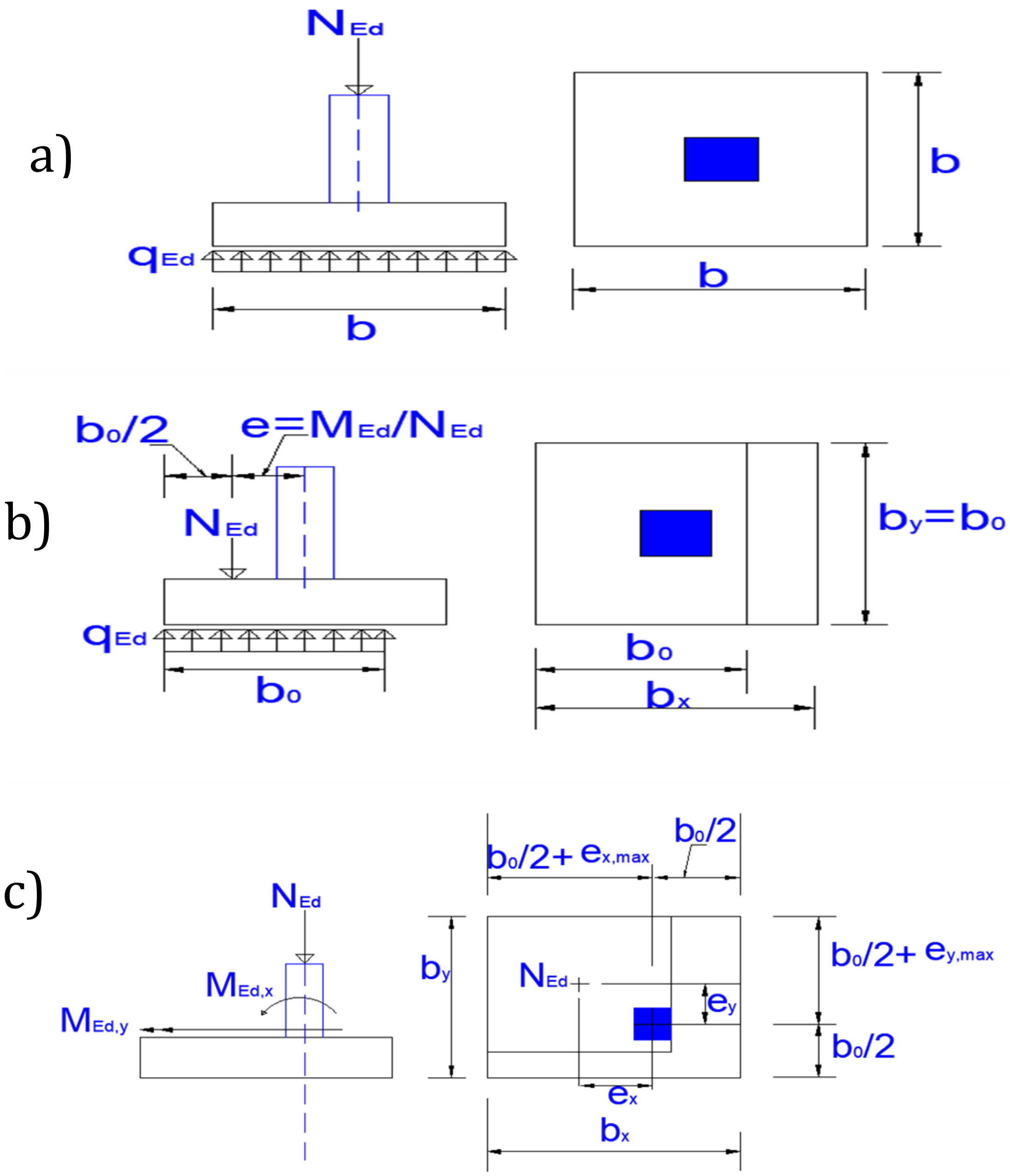


Figure 3.32: a) column foundation subjected to centric load b)eccentrically loaded column foundation (moment in one direction) c) asymmetric column foundation with moment in two direction [15]

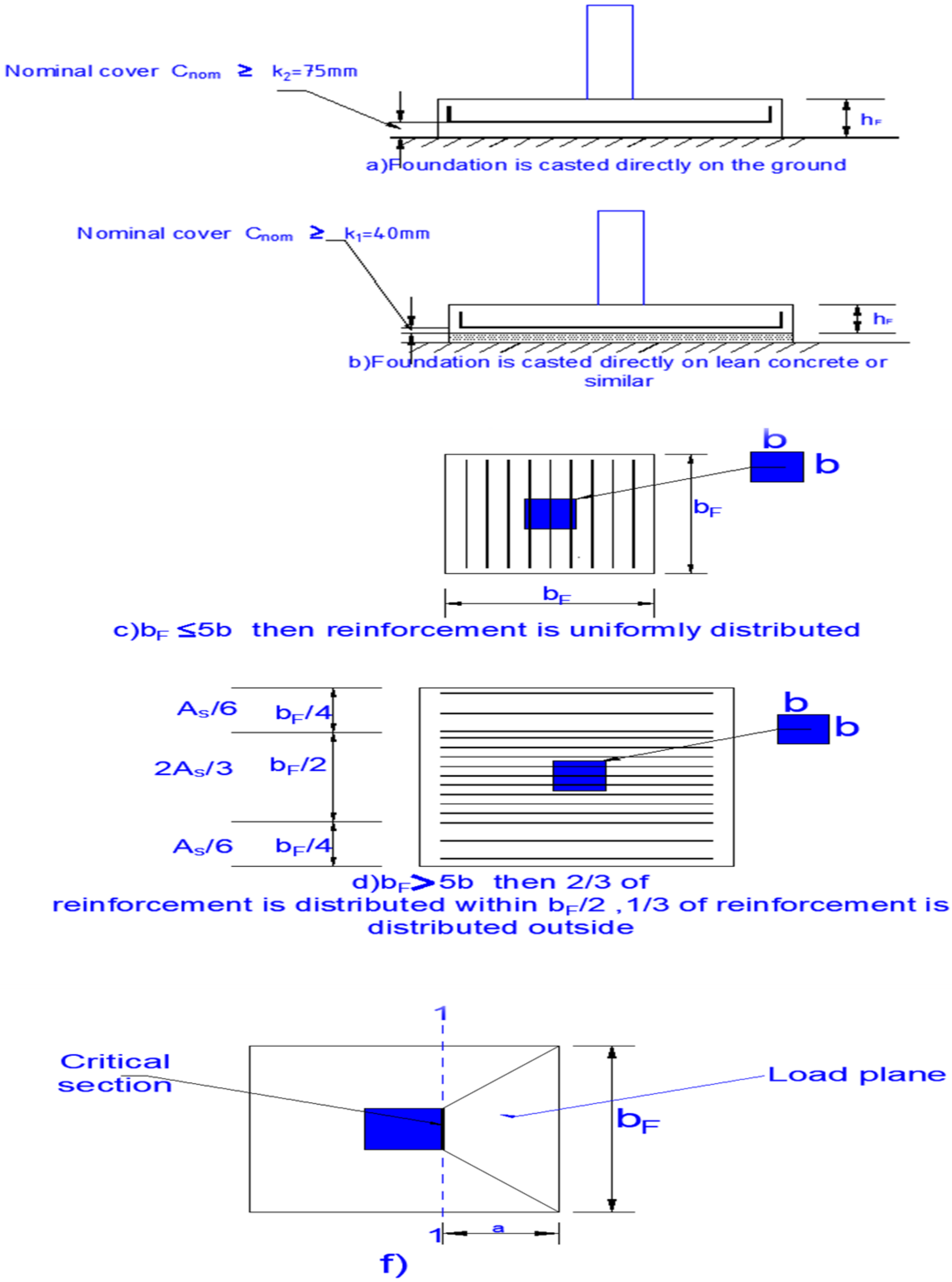


Figure 3.33: a and b) Cover requirement for wall foundation and column foundation based on EC2 c and d) Distribution of reinforcement for column foundation f) Critical section for shear pressure in column foundation [15]

Walls:

A wall is a vertical structural element that has a length increases four times of its thickness. Therefore; Base on this definition, the difference between walls and columns depend on their dimensions. The resistance of loads, partitioning of construction, and keeping heat inside the construction, are examples of functions of the walls as a construction element.[36]

A concrete wall is divided into a reinforcement wall, that has at least a minimum quantity of reinforcement, and plain wall, that has no reinforcement or a minimum quantity of reinforcement that is not satisfied. In addition, walls can also be categorized into braced or non-braced. According to the ratio of the effective height (L_e) and thickness (h), walls are classified as a slender or a stocky wall. If the ratio is ($L_e/h < 15$), the wall is classified as a stocky wall. If the ration is ($L_e/h < 10$), the wall is classified as a slender wall[36]. The figure below shows one type of walls that is used in the project.

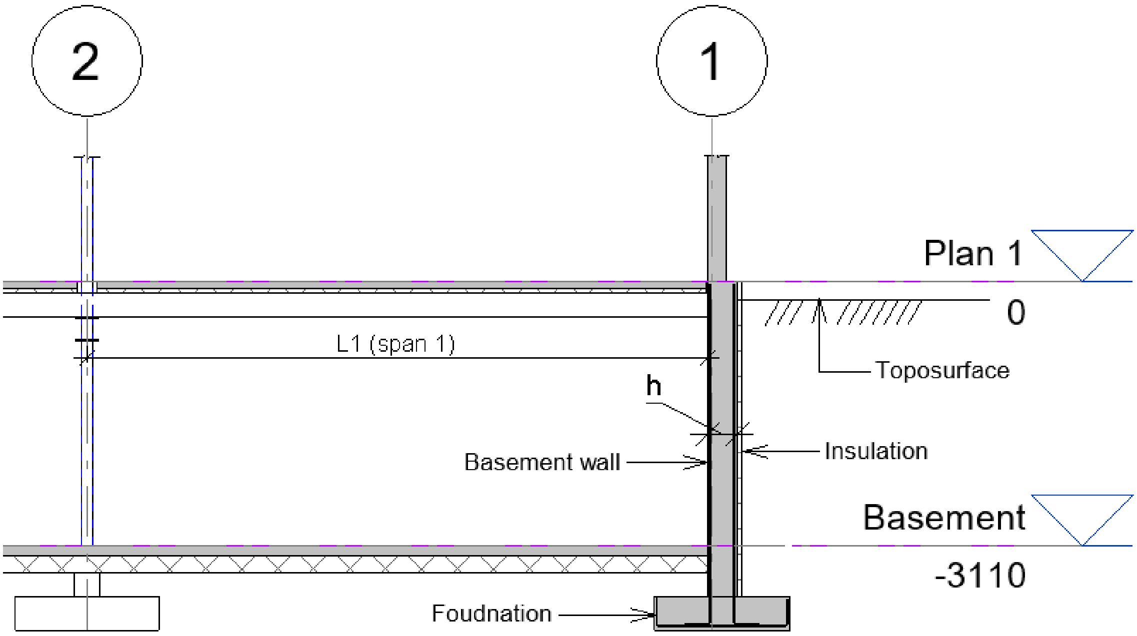


Figure 3.34: Basement wall of the project

Based on EC2,NA.9,6,2 and NA. 9,6,3, minimum required vertical reinforcement is

$A_{S,vmin} = 0{,}002A_c$: is an area of one meter of wall

Whereas, the minimum required horizontal reinforcement area on each side in double-armed walls is:

$A_{S,h\,min} = max\{0{,}25A_{sv}\,; 0{,}3A_c f_{ctm}/f_{yk}\}$

Strut and tie models may be used to design and calculate high beams or free bearing walls. Free-bearing walls and high beams can be examples of a method called the discontinuity region[15]. Strut-and-tie models consist of struts representing compressive stress fields, of ties representing the reinforcement, and of the connecting nodes. Strut and tie models are illustrated in the figure below:

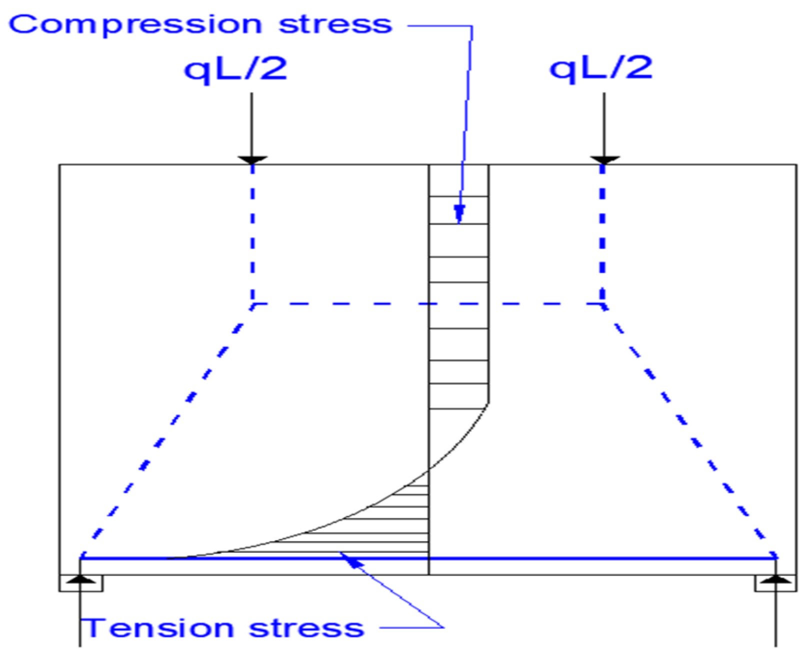


Figure 3.35: Strut and tie models

The design strength for a concrete strut in a region with transverse compressive stress or no transverse stress may be calculated from equation [35]:

$$\sigma_{\mathrm{Rd,max}} = \mathrm{f_{cd}} \tag{3.88}$$

In cracked compression zone, the design strength of a concrete strut should be reduced and the following equation is used[35]:

$$\sigma_{Rd,max} = 0{,}6\, \nu`\, f_{cd} \tag{3.89}$$

Where:

$$\nu` = 1 - \frac{f_{cd}}{250} \tag{3.90}$$

Force in horizontal reinforcement (ties) is calculated based on:

$$S_h = \frac{M_{Ed}}{z} \tag{3.91}$$

Where

M_{Ed} the maximum moment in the span

z inner moment arm that can be determined based on different cases illustrated in the following Figure:

Then, the required cross-section area of the horizontal reinforcement is calculated as follows:

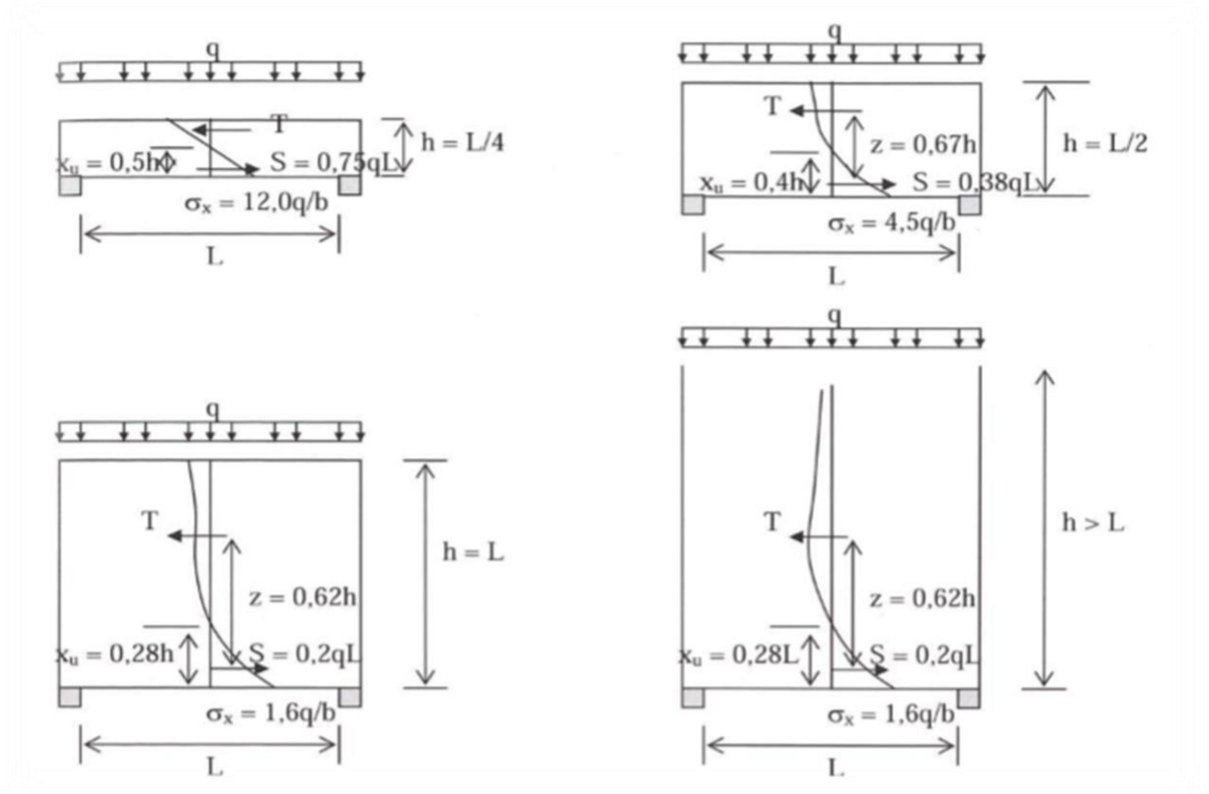


Figure 3.36: Inner moment arm for different cases. In addition, tensile forces and compressive forces and stresses in middle in section of simply supported wall are illustrated [15]

$$A_{sh} = \frac{S_h}{f_{yd}} \tag{3.92}$$

Total force in vertical reinforcement for the load on the lower edge and necessary vertical reinforcement are given:

$$S_v = qL \tag{3.93}$$

$$A_{sv} = \frac{S_v}{f_{yd}} \tag{3.94}$$

Strut and tie models for different cases are shown in the following figure:

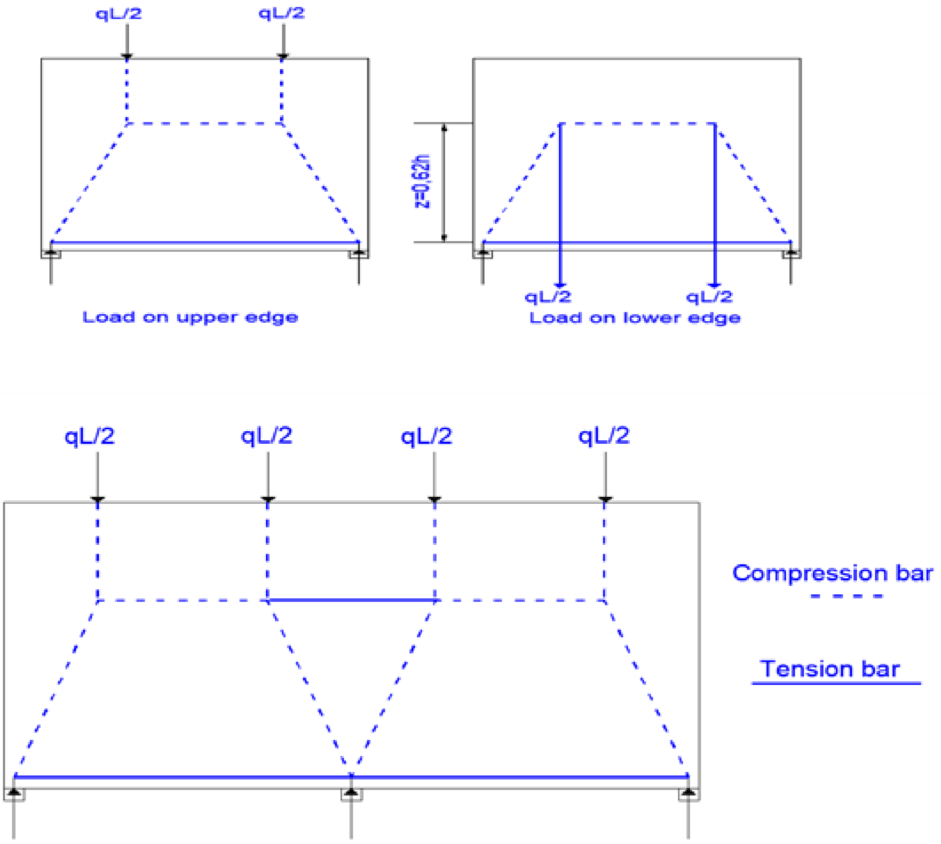


Figure 3.37: In upper picture, load on upper edge (left) and load on lower edge (right). Whereas, load on upper edge for continuous wall is illustrated in the lower picture of the figure[15]

3.1.3. Low-Carbon Concrete

Building materials generate greenhouse gas emissions in many stages; from raw material extraction, processing, transportation and construction. During the operating phase, maintenance of the materials and replacements will give discharge, and during the disposal phase demolition, sorting, processing, transport, final disposal and possible recycling will also cause emissions.

For materials such as steel and concrete, there are large emissions associated with energy use when extracting ore and from heating and melting, and further processing in many stages Transport may also require the use of fossil fuels both at sea and on land.

Reuse of materials can however result in large savings regarding greenhouse gas emissions. Recycling can, in particular, reduce emissions from transport, but also from energy consumption and process-related emissions that occur during the production of materials [37].

To reduce the carbon footprint from the material concrete, it is necessary to take a closer look at the use of low-carbon concrete. Low carbon-concrete is defined as concrete where measures have been

taken to limit greenhouse gas emissions. Greenhouse gas emissions are calculated as CO2 equivalents, where the contribution from gases other than CO2 measured in as per Global Warming Potential (GWP) [14].
There are different classes of low carbon concrete, i.e., classes A, B, and C. Class A is the strictest class, which usually requires the use of certain measures. Class A is achieved by adding a large amount of fly ash than usual and is usually challenging to achieve due to conditions related to hydration time, early strength, deformation time and so forth. Class B can usually be achieved with regular technical measures. Class C can be achieved with relatively simple technical measures[14].

Concrete's strength classes and durability classes are defined in NS-EN 1992-1-1: 2004 + NA: 2008 and NS-EN 206: 2013 + NA: 2014. The concrete composition is expected to satisfy the requirements of NS-EN 206 + NA in all low-carbon classes. The standard provides rules for concrete mix (blended concrete), and states the limit values for pozzolans (silica fume and fly ash) and hydraulic binders (slag) in the different durability classes. In the durability classes MF45 and MF40 (frost-resistant concrete) no rules have been provided for parts of the binder combinations that may be relevant for the production of low-carbon concrete in the class Low carbon A. NS-EN 206 + NA, however, allows the possibility to document frost resistance of such binder combinations.

The limit values determine the low carbon classes for greenhouse gas emissions for the selected combination of the strength classes and durability classes. The limit values are shown in the Figure 3.38. The emission values are in kg CO2-eq/m3 concrete. The values can be to convert to kg/ton by using concrete density 2400 kg/m3. The life cycle assessment covers from cradle to gate. It means from the raw material extraction to concrete production in a factory [14].

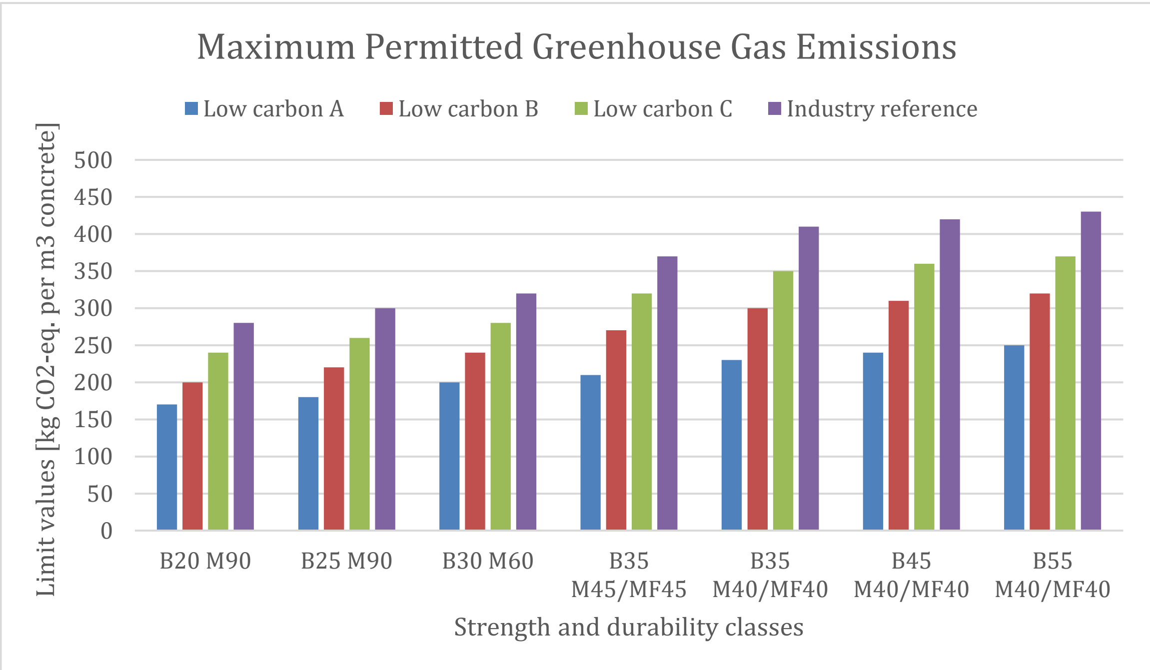


Figure 3.38: Low carbon concrete classes with limit values for greenhouse gas emissions [14]

In the low carbon class A, the limit values are set to represent what is practically possible to achieve for construction concrete with the binders that are widely available in the Norwegian market today. It will also be necessary to utilize traditional proportional techniques to keep the amount of binder down. This means that in most cases it will be necessary to use relatively high amounts of coarse aggregate as shown in Table 3.13. It has been pointed out that the classes limits should be updated regularly to meet environmental goals.

Cement contributes to more than 90% of the total greenhouse gas emissions of concrete[14]. Thus, concrete in construction accounts for most of the greenhouse gas emissions. See Figure 3.39.

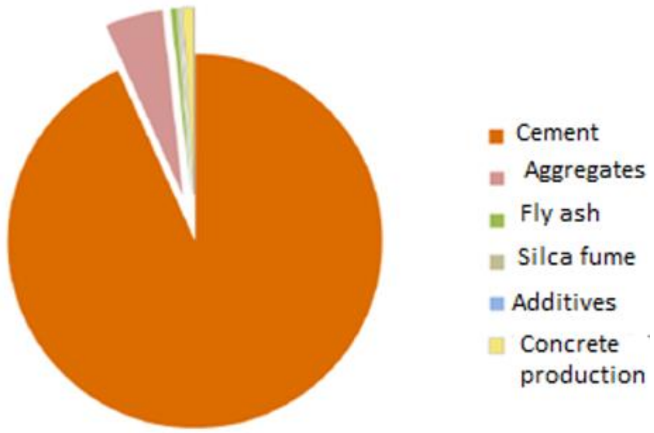


Figure 3.39: Greenhouse gas emissions for a typical concrete construction, distributed on sub-materials and concrete production. The example is for a B30M60 - concrete manufactured by Norbetong at Sjursøya in Oslo [14].

The environmental impacts from the production of Ordinary Portland Cement (OPC) are not good for the biodiversity. In a global context, (1 ton) 1000 kg CO2- equivalents per ton of OPC is released into the atmosphere. Annual, cement industries worldwide emit approximately 1600 Mt of greenhouse gases (CO2, CH4, and N2O) [38].

In Norway, Norcem Industrial Cement may have a total of approximately 800 kg CO2 emissions per ton of cement delivered from the factory. Worldwide, the production of cement stands for approximately 5% of the total human-made greenhouse gas emissions [14].

Therefore, it is natural to replace cement with environmentally friendly materials partially.
Low carbon concrete can be achieved by optimizing the concrete composition and by partial replacement of cement with supplementary cementitious materials (SCMs) such as fly ash, blast furnace slag, silica fume and so forth [14].
Low carbon concrete can be achieved by optimizing the concrete composition and by partial replacement of cement with supplementary cementitious materials (SCMs) such as fly ash, blast furnace slag, silica fume and so forth [14]. The SCMs play a significant role in the reduction of greenhouse gas emission such as CO_2 emission and energy consumption by decreasing cement production. Furthermore, the SCMs can improve the mechanical properties, durability and the service life of the concrete [39].

The use of additives (fly ash, silica, slag and limestone flour) is usually a prerequisite for being able to produce low-carbon concrete. In order to achieve the class of low carbon A, one will usually have to use binders with 25-40% of additives, either in the cement or added separately [37].

The SCM influence the workability to a certain extent, but in most cases, it is acceptable. The workability of classes B and C do not typically differ significantly from traditional concrete. In class A, however, one can expect a more significant effect. However, in most cases, it is unproblematic to achieve a good workability [14].

The consistency of the concrete may have to be changed to meet the requirements for emissions. Low carbon class A requires low consistencies (160-180 mm) for many concrete mixing plants in Norway. The amount of water has greatest impact on the consistency of concrete. The amount of cement, water-to-binder ratio and aggregate packing are all connected to the optimization of concrete mixture design. Decreasing the water-to-binder ratio greatly improves the concrete's durability and reduces the concrete's bleeding (workability).

There are however, some challenges regarding the production of the highest class, class A, of low carbon concrete. For example, in the production of prefabricated concrete elements, the use of large units of fly ash to achieve low carbon class A will generally be impossible. This is mainly due to conditions related to hydration time, early strength, deformation time and aggregate quantity with maximum grain size. Furthermore, the prescriptions are often tested and optimized over a long period of time, so that it will be a long-term process if properties and constituents must be changed to achieve low carbon class A. Today, fabrication is most often produced with a fixed number of casting operations per day. Actions on the concrete that cause these production duration to change and extend, will mean reduced production speed for the supplier and consequently increased prices. Therefore, it is not practically feasible to use the highest classes of low-carbon concrete (Class A) in prefabricated concrete elements. However, it is possible to satisfy low carbon class B or C in many areas in Norway [37].

The table below shows typical recipes with B45 MF45 Standard low carbon class A and B from a concrete manufacturer, NorBetong, in Norway. Note that from B to A, the fly ash proportion has increased, cement amount has been reduced from 325 kg/m3 to 243 kg/m3 and that sand/gravel are also adjusted. The table also shows that class A has coarser aggregates than class B

Table 3.13: Typical recipes for Low Carbon B and Low Carbon A in NorBetong AS, Norway

Material	**Law-carbon class B (kg/m3)**	**Law-carbon class A (kg/m3)**
0/8 sand	981,61	969,46
8/16 gravel	939,53	463,95
11/22 gravel	-	434,57
Standard Cement with fly ash (FA)	325,18	243,88
Silica fume	13,55	13,55
Fly ash	-	81,29

Superplasticizer (SP)	1,86	1,86
Cold water	152,88	15,88
air	0,68	0,68

NB: values are rounded to two decimal places.

From the environmental sustainability perspective, the usage of low-carbon concrete plays a very important role. In the long run, the low carbon concrete can significantly reduce the environment-degrading footprint considering current developments of greenhouse emissions.

3.1.4. Steel

Structural steel is an alloy and consists of iron and different elements such as carbon with content less than 0,25%, manganese with content less than 1,5% and chromium, aluminum, vanadium, molybdenum, niobium and copper. Iron ore can be considered one of the most essential raw materials for steel manufacturing. Another resource for steel manufacturing is scrap steel[10]. Steel as a structural material has many advantages such as:

1) Steel has high strength. This property leads to having a small weight for steel construction.
2) Uniformity: When steel is compared with reinforced concrete, properties of steel will not change significantly over time.
3) Steel's ability to bear plastic deformation before fail, gives it great reserve strength. Then, steel can resist shock loadings such as explosion and earthquake.
4) Recyclability and reusing: Many parts of used steel can be recycled and reused after dissembling.
5) Can be fastened and connected easily by welding and bolts .
6) Ability to be erected quickly.
7) It is easy to add additional parts to an existing structure [40].

Although steel has several advantages, steel also has some disadvantages

1) corrosion: Steel can be subjected to corrosion if not painted properly.
2) Fireproofing cost: Steel elements should be fireproofed sufficiently to save the strength of steel against fire and high temperature.
3) Susceptibility to buckling: Dangers of buckling increases when height and slenderness of compressive element are increased. Some additional requirement is needed to strengthen them against buckling. Additional requirements can be non-economic.

4) Fatigue and brittle fracture under certain conditions (concentration of stress and subjection to a great number of stresses) [40]. Different types of steel structures are shown in the figure below:

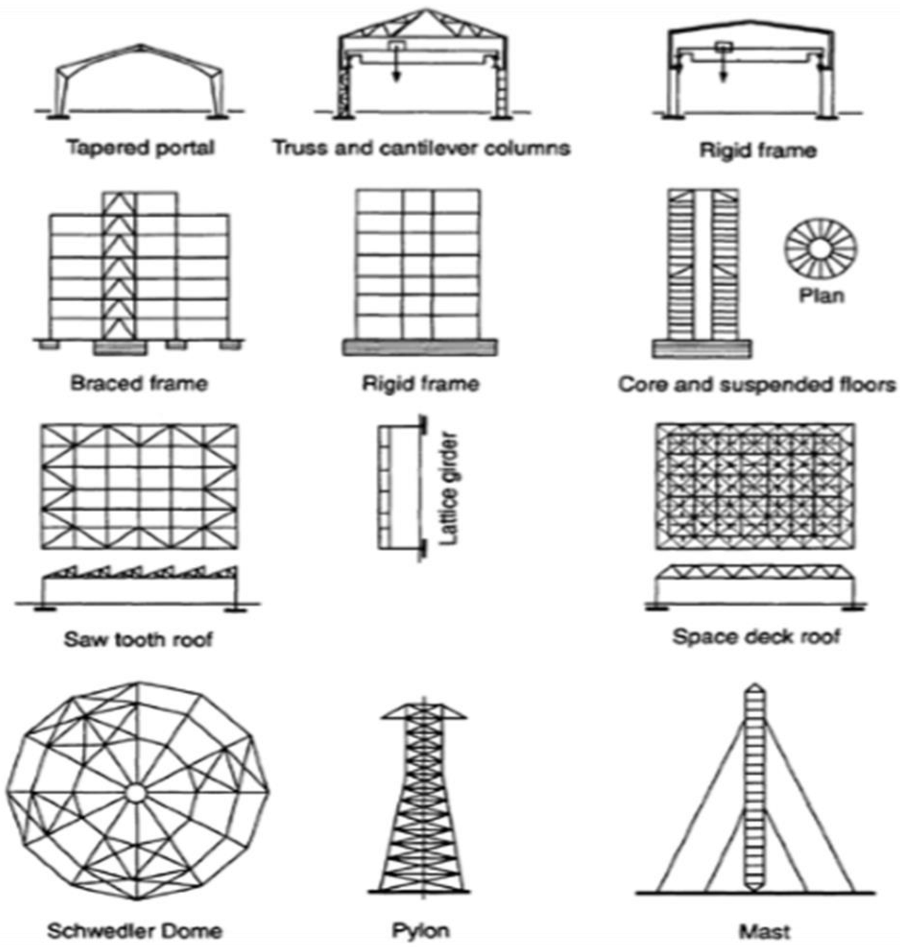


Figure 3.40: Different examples of steel-framed constructions[10]

Beams:
As said, beams are horizontal structural members that are subjected to self-weight and vertical loads and that support transverse loads[40]. Classification of the cross-section can be a crucial step in the design procedure. The classification is mentioned in EC3 as follows:
Class 1 cross-sections are those which can form a plastic hinge with the rotation capacity required from the plastic analysis without reduction of the resistance.

Class 2 cross-sections arc are those which can develop their plastic moment resistance, but have limited rotation capacity because of local buckling.

Class 3 cross-sections are those in which the stress in the extreme compression fiber of the steel member assuming an elastic distribution of stresses can reach the yield strength, but local buckling is liable to prevent development of the plastic moment resistance.

Class 4 cross-sections are those in which local buckling occurs before the attainment of yield stress in one or more parts of the cross-section [6].

If some exceptions are taken into account, IPE, HEA and RHS profiles belong to cross-section class 1 or 2[6]. Types, dimensions, and axes of these profiles are shown in the figure below:

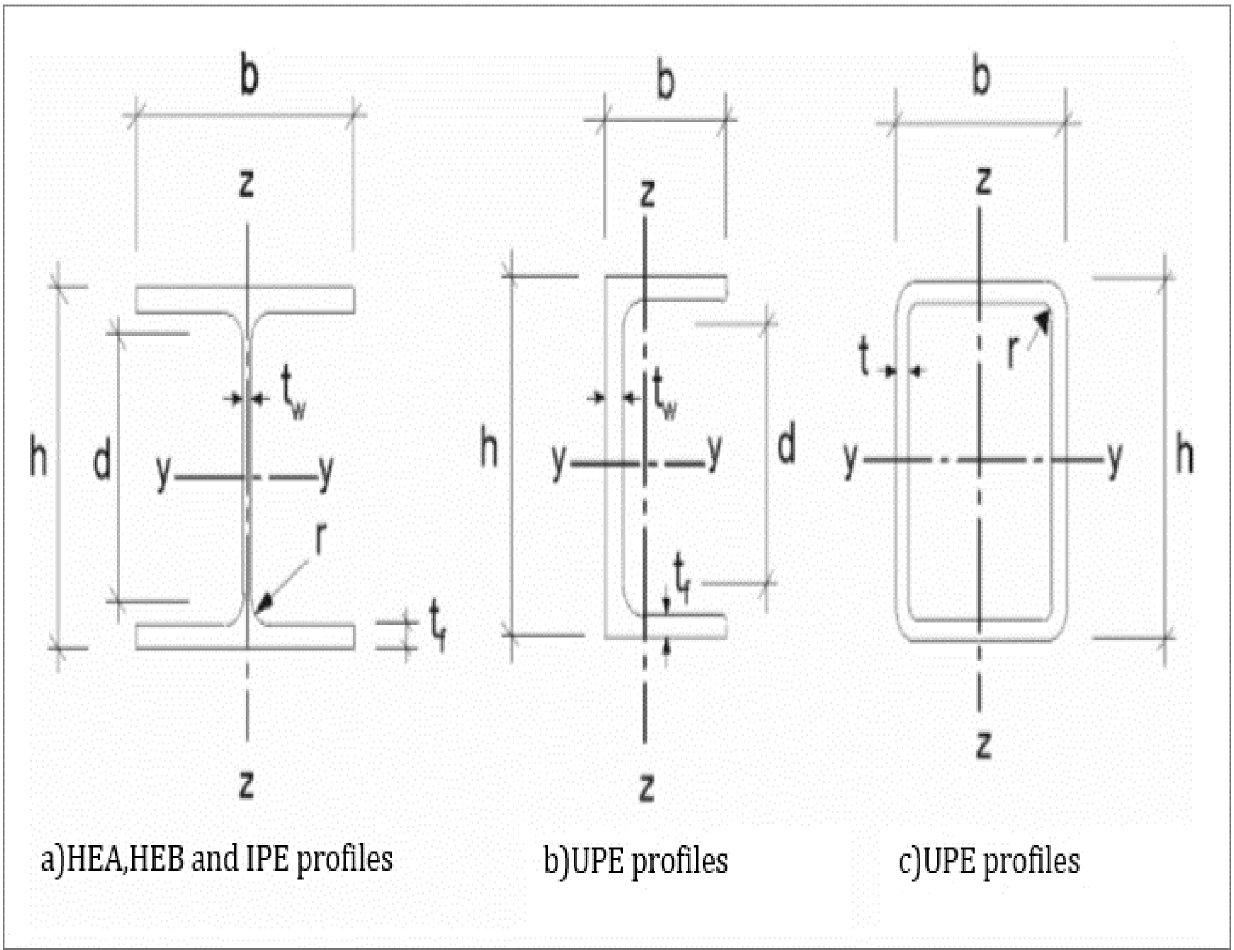


Figure 3.41: Type, strong and weak axis, dimensions of some typical steel profiles [6]

Determination of classification depends on width and thickness ratios in the pressure-affected portions of the cross-section. This ratio is given in Table 5.2 in EC3 [3, 6], see Appendix J.2 for Classification of profiles.

After the profiles are classified, the cross-sectional capacity will be detected. These capacities are bending moment, shear force and axial force [6].
For bending moments, the following requirements must be satisfied:

$$M_{Ed} \leq M_{c.Rd} \tag{3.95}$$

Where
M_{Ed} is design value of bending moment
$M_{c,Rd}$ design resistance for bending about one principal axis of a cross-section. This is given as follows based on classification of cross-section:

$$M_{c,Rd} = \begin{cases} M_{pl.Rd} = \dfrac{W_{pl}\ f_y}{\gamma_{MO}} & \text{for cross} - \text{sections of class 1 and 2} \\ M_{el.Rd} = \dfrac{W_{el}\ f_y}{\gamma_{MO}} & \text{for cross} - \text{sections of class 3} \\ \dfrac{W_{eff}\, f_y}{\gamma_{MO}} & \text{for cross} - \text{sections of class 4} \end{cases}$$

W_{pl} , W_{el} and W_{eff} are the plastic-, the elastic- and the effective sectional modulus respectively.
$\gamma_{MO} = 1{,}05$ partial factor for the resistance of the cross-sections whatever the class is[6].
f_y is yield strength
Regarding shear force, the following requirement must be satisfied:

$$V_{Ed} \leq V_{c,Rd} \tag{3.96}$$

Where
V_{Ed} is design shear force.
$V_{c,Rd}$ is the design value of shear resistance. When the design is plastic[1]c then $V_{c,Rd}$ is called design plastic shear resistance and calculated as(torsion is absent):

$$V_{c,Rd} = V_{pl,Rd} = \frac{A_v\ f_y}{\gamma_{MO}\sqrt{3}} \tag{3.97}$$

Where
A_v is the shear area and be calculated based on the following table:

Table 3.14:Area of shear force for most common steel profiles[3, 6]

Type of profile	load parallel to web	load parallel to flanges
rolled I and H sections	$A_v = A - 2bt_f + (t_w + 2r)t_f$ *but* $A_v \geq \eta h_w t_w$	$A_v = 2bt_f$
welded I, H and box sections	$A_v = \eta \sum (h_w t_w)$	$A_v = A - \sum (h_w t_w)$
RHS-profiles	$A_v = \dfrac{Ah}{b+h}$	$A_v = \dfrac{Ab}{b+h}$
CHS-profiles (Circular hollow sections)	$A_v = \dfrac{2A}{\pi}$	
U-profile	$A_v = A - 2bt_f + (t_w + r)t_f$	$-$
Where *A* is the cross-sectional area, b is the overall width, h is the overall depth, h_w is the depth of the web, *r* is the root radius, h_w is the flange thickness, t_w is the web thickness, $\eta = 1$ safe value		

In addition to the bending moment and shear force, the design value of the tension force and the compression force N_{Ed} at each cross section should satisfy[6]:

$$N_{Ed} \leq N_{t,Rd} \quad \text{tension} \tag{3.98}$$

$$N_{Ed} \leq N_{c,Rd} \quad \text{compression} \tag{3.99}$$

Where:

$$N_{t,Rd} = \min \begin{cases} N_{pl.Rd} = \dfrac{A\, f_y}{\gamma_{MO}} \\ N_{u.Rd} = \dfrac{0.9 A_{net}\, f_u}{\gamma_{M2}} \end{cases}$$

$\gamma_{M2} = 1{,}25$ is the partial factor for the resistance of the cross-sections in tension to fracture

$N_{pl.Rd}$ and $N_{u.Rd}$ are the design plastic resistance of the gross cross-section and the design ultimate resistance of the net cross-section at holes for fasteners, respectively [3].

Whereas:

$$N_{c,Rd} = \begin{cases} N_{pl.Rd} = \dfrac{A\, f_y}{\gamma_{MO}} & \text{for cross} - \text{section of 1,2 and 3} \\ N_{eff.Rd} = \dfrac{A_{eff}\, f_y}{\gamma_{M0}} & \text{for cross} - \text{section of 4} \end{cases}$$

A_{eff} is effective cross-section.

To verify the capacity of the element against the bending buckling, it is important to determine the load effects that the element is subjected to. Therefore, two cases can be determined[6].

The first case (Design of columns): a member is subjected to centric pressure load(force).Compressive member must be verified against buckling as following:

$$\frac{N_{Ed}}{N_{b,Rd}} \leq 1 \tag{3.100}$$

where

N_{Ed} is the design value of the compression force.

$N_{b,Rd}$ is the design buckling resistance of the compression member. Determination of $N_{b,Rd}$ is given in:

$$N_{b,Rd} = \frac{\chi\, A\, f_y}{\gamma_{M1}} \qquad \text{for Class I, 2 and 3 cross-sections}$$

$$N_{b,Rd} = \frac{\chi\, A_{eff}\, f_y}{\gamma_{M1}} \qquad \text{for Class 4 cross-sections}$$

Where χ is the reduction factor for the relevant buckling curve. The value of χ is calculated as:

$$\chi = \begin{cases} 1 & for\ \bar{\lambda} \leq 0.2 \\ \dfrac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} & for\ \bar{\lambda} > 0.2 \end{cases} \tag{3.101}$$

ϕ value to determine the reduction factor X is calculated as :

$$\phi = 0.5\left[1 + \alpha(\bar{\lambda} - 0.2) + \bar{\lambda}^2\right] \tag{3.102}$$

$\bar{\lambda}$ relative slenderness is given in:

$$\bar{\lambda} = \sqrt{\frac{A\ f_y}{N_{cr}}} = \frac{L_{cr}}{i}\frac{1}{\lambda_1} \quad \text{for Class I, 2 and 3 cross-sections} \tag{3.103}$$

$$\bar{\lambda} = \sqrt{\frac{A_{eff}\ f_y}{N_{cr}}} = \frac{L_{cr}}{i}\frac{\sqrt{\frac{A_{eff}}{A}}}{\lambda_1} \quad \text{for Class 4 cross-sections.} \tag{3.104}$$

L_{cr} is the buckling length in the buckling plane considered. Relevant critical buckling length is shown in the figure below:

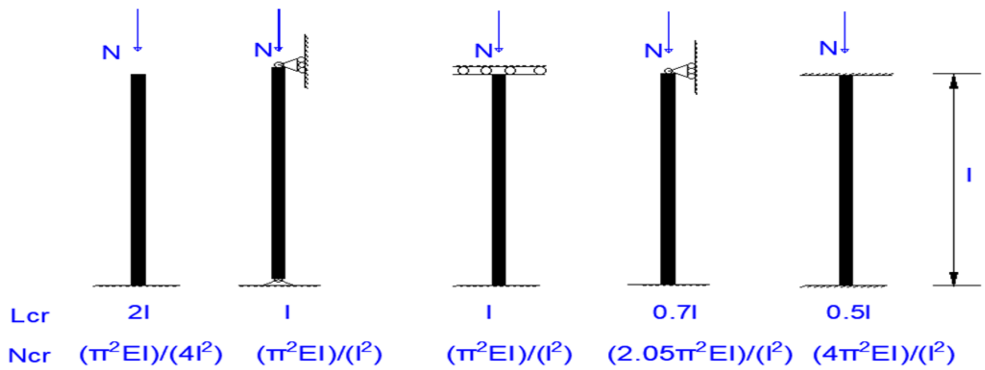


Figure 3.42:Buckling length for compressive elements

i is the radius of gyration about the relevant axis, determined using the properties of the gross cross-section.

$$\lambda_1 = \pi\sqrt{\frac{E}{f_y}} = 93{,}9\varepsilon$$

$$\varepsilon = \sqrt{\frac{235}{f_y}} \quad ; f_y\ in\ N/\text{mm}^2$$

N_{cr} is the elastic critical force for the relevant buckling mode based on the gross cross-sectional properties. (see Figure 3.42)

α is an imperfection factor and is determined by Table 3.15 according to buckling curve:

For slenderness $\bar{\lambda} \leq 0.2$ or for $\frac{N_{Ed}}{N_{cr}} \leq 0.4$ the buckling effects may be neglected and only cross-sectional checks apply[6]

Table 3.15: Imperfection factors for buckling curves[6]

Buckling curve	a_0	a	b	c	d
Imperfection factor α	0,13	0,21	0,34	0,49	0,76

Buckling curves are shown in the figure below:

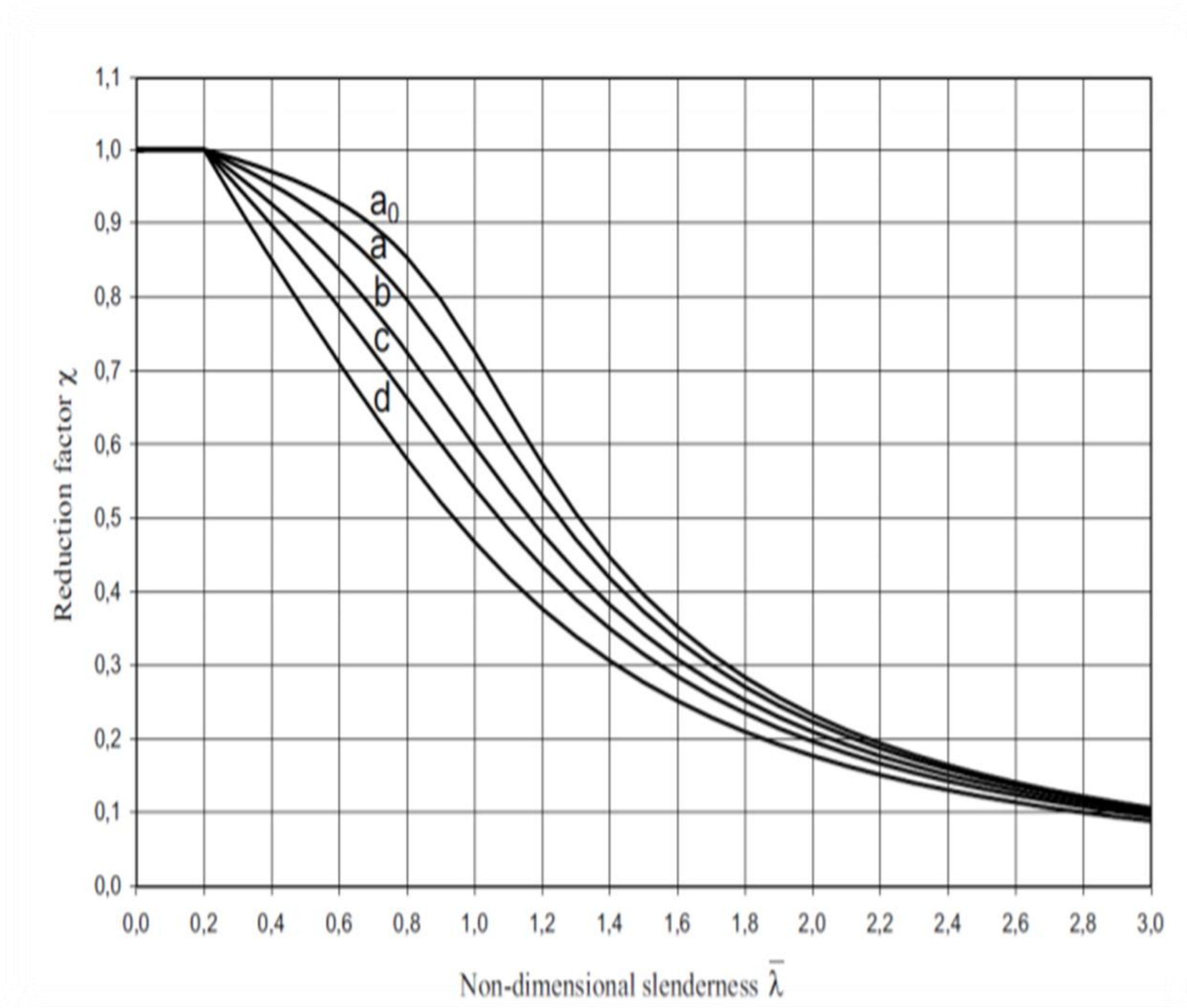
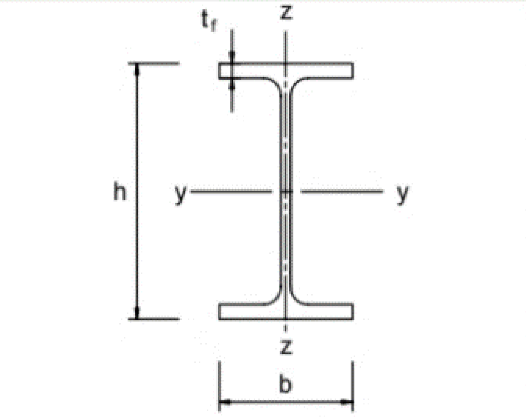
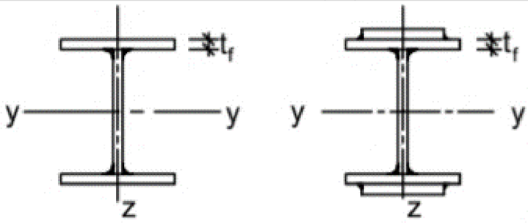
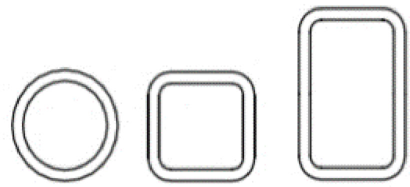


Figure 3.43: Buckling curves [6]

It is mentioned in EC3 a basis for selection buckling curves for different steel cross-sections. This basis is given in following Table can be seen in the following Table:

Table 3.16:Selection of buckling curve for a cross-section [6]

Cross section		Limits		Buckling about axis	Buckling curve: S 235, S 275, S 355, S 420	Buckling curve: S 460
Rolled sections		$h/b > 1,2$	$t_f \leq 40$ mm	y – y	a	a_0
				z – z	b	a_0
			40 mm $< t_f \leq 100$	y – y	b	a
				z – z	c	a
		$h/b \leq 1,2$	$t_f \leq 100$ mm	y – y	b	a
				z – z	c	a
			$t_f > 100$ mm	y – y	d	c
				z – z	d	c
Welded I-sections		$t_f \leq 40$ mm		y – y	b	b
				z – z	c	c
		$t_f > 40$ mm		y – y	c	c
				z – z	d	d
Hollow sections		hot finished		any	a	a_0
		cold formed		any	c	c

Nominal values of yield strength f_y and ultimate tensile strength f_u for hot rolled structural steel and design values of material coefficients are shown in the following table:

Table 3.17: Yield strength f_y , ultimate tensile strength f_u and design values of E, G, υ and α [6]

Standard and steel grade EN 10025-2	Nominal thickness of element t (mm) $t \geq 40\ mm$ f_y N/mm²	$t \geq 40\ mm$ f_u N/mm²	$t < 40 \leq 80\ mm$ f_y N/mm²	$t < 40 \leq 80\ mm$ f_u N/mm²	modulus of elasticity (E) N/mm^2	shear modulus (G) N/mm^2	Poisson's ratio in elastic stage (υ)	coefficient of linear thermal expansion *per K* (α)
S 235	235	360	215	360	210000	81000	0.3	12×10^{-6}
S 275	275	430	255	410				

S 275	355	510	355	470				
S 275	440	550	410	550				

The Second case (design of beams): In this case, the member is subjected to lateral bending (about z axis) and torsion of the cross-section. Therefore, the member (a laterally unrestrained beam) should be verified against a phenomenon that is called lateral torsional buckling:

$$\frac{M_{Ed}}{M_{b,Rd}} \leq 1 \tag{3.105}$$

M_{Ed} is the design value of the moment

$M_{b,Rd}$ is the design buckling resistance moment. This is shown in the equation below. The moment distribution between the lateral restraints of members has been taken into account

$$M_{b,Rd} = \frac{\chi_{LT,mod} W_y \ f_y}{\gamma_{M1}} \tag{3.106}$$

Where

$W_y = W_{y,pl}$ for Class I or 2 cross-sections

$W_y = W_{y,el}$ for Class 3 cross-sections

$W_y = W_{y,eff}$ for Class 4 cross-sections

$$\chi_{LT,mod} = \frac{\chi_{LT}}{f} \leq 1{,}0 \ but \begin{cases} \chi_{LT,mod} \leq 1{,}0 \\ \chi_{LT,mod} \leq \frac{1}{\bar{\lambda}_{LT}{}^2} \end{cases} \tag{3.107}$$

is modified reduction factor for lateral-torsional buckling

χ_{LT} is the reduction factor for lateral-torsional buckling. It is calculated as: '

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}{}^2 - 0{,}75\bar{\lambda}_{LT}{}^2}} \quad Where \begin{cases} \chi_{LT} \leq 1{,}0 \\ \chi_{LT} \leq \frac{1}{\bar{\lambda}_{LT}{}^2} \end{cases} \tag{3.108}$$

$\bar{\lambda}_{LT}$ is non-dimensional slenderness for lateral torsional buckling. It is given as:

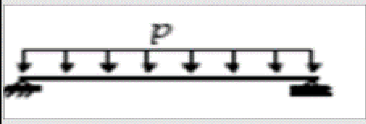
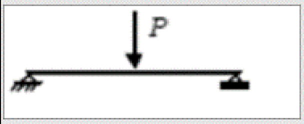
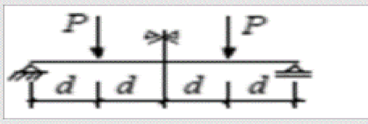
$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y \ f_y}{M_{cr}}} \tag{3.109}$$

M_{cr} is the elastic critical moment for lateral-torsional buckling. It is calculated as[3]:

$$M_{cr} = C_1 \frac{\pi^2 E \, I_z}{L_z{}^2} \left[-C_2 \, z_g + \sqrt{\frac{I_w + 0{,}039 \cdot L_z{}^2 \cdot I_t}{I_z} + C_2{}^2 \cdot z_g{}^2} \right] \tag{3.110}$$

Where:
z_g is the distance between the load application point and the beam shear center. This value is positive in compression (when the load acts stabilizing) with, for example, the downward load on the upper flange. The value is negative in tension (when the load acts destabilizing) with, for example, the downward load on the lower flange, and the value is zero when the load application point is located in the shear center of the cross section.[3]
C_1 and C_2 are coefficients that depend on the static system of beam, loading, and support condition—as seen in the table below:

Table 3.18: coefficients C_1 and C_2 [3]

Load and support condition			
C1	1.13	1,37	1,05
C2	0,46	0,55	0,43

ϕ_{LT} is value to determine the reduction factor χ_{LT} .it is calculated as:

$$\phi_{LT} = 0.5\left[1 + \alpha_{LT}\,(\bar{\lambda}_{LT} - 0{,}4) + 0{,}75\,\bar{\lambda}_{LT}{}^{2}\right] \tag{3.111}$$

α_{LT} imperfection factor and it is determined by the following table:

Table 3.19: Imperfection factors for torsional lateral buckling curves α_{LT} [6]

Buckling curve	a	b	c	d
Imperfection factor α_{LT}	0,21	0,34	0,49	0,76

Where recommended values for lateral torsional buckling curves are given in the following Table:

Table 3.20: Recommendation for the choosing of lateral torsional buckling curve for cross -section using equation 3.107[6]

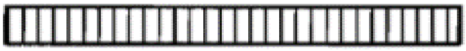
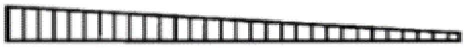
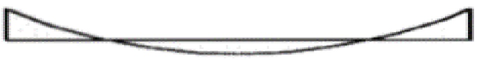
Cross-section	Limits	Buckling curve
Rolled I -sections	h/b≤ 2	b
	h/b> 2	c
Welded I-sections	h/b≤ 2	c
	h/b> 2	d

f is a modification factor for χ_{LT} .This is given as:

$f = 1 - 0{,}5(1 - k_c)\left[1 - 2\left(\bar{\lambda}_{LT} - 0{,}8\right)^2\right] \quad but \ f \leq 1{,}0$

k_c is a correction factor. As seen in the table below:

Table 3.21: Correction factors k_c [3]

Moment distribution	k_c
 $\psi = 1$	1,0
 $-1 \leq \psi \leq 1$	$\frac{1}{1{,}33 - 0{,}33\psi}$
	0,94
	0,90
	0,91
	0,86
	0,77
	0,82

lateral torsional buckling effects may be ignored and only cross-section checks when $\bar{\lambda}_{LT} \leq \bar{\lambda}_{LT,0}$ or $\frac{M_{Ed}}{M_{cr}} \leq \bar{\lambda}_{LT,0}{}^2$. Where $\bar{\lambda}_{LT,0} = 0{,}4 \ minimum \ value$.

The third case (design of beam-column): A steel element s affected by combined bending moment and axial force. Then the following equations must be satisfied:

$$\frac{N_{Ed}}{\frac{\chi_y N_{Rk}}{\gamma_{M1}}} + k_{yy}\frac{M_{y,Ed} + \Delta M_{y,Ed}}{\frac{\chi_{LT} M_{y,Rk}}{\gamma_{M1}}} + k_{yz}\frac{M_{z,Ed} + \Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1 \qquad (3.112)$$

$$\frac{N_{Ed}}{\frac{\chi_z N_{Rk}}{\gamma_{M1}}} + k_{zy}\frac{M_{y,Ed} + \Delta M_{y,Ed}}{\frac{\chi_{LT} M_{y,Rk}}{\gamma_{M1}}} + k_{zz}\frac{M_{z,Ed} + \Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1 \qquad (3.113)$$

Where

N_{Ed}, $M_{y,Ed}$, $M_{z,Ed}$ are the design values of the compression force and the maximum moments about the y-y and z-z axis along the member, respectively.

$\Delta M_{y,Ed}$, $\Delta M_{z,Ed}$ are the moments due to the shift of the centroidal axis according to EC3: 6.2.9.3 for class 4 sections, see Table below.

Table 3.22:Values for $N_{Rk} = f_y A_i$, $M_{i,Rk} = f_y W_i$ and $\Delta M_{i,Ed}$

Class	1	2	3	4
A_i	A	A	A	A_{eff}
W_y	$W_{pl,y}$	$W_{pl,y}$	$W_{el,y}$	$W_{eff,y}$
W_z	$W_{pl,z}$	$W_{pl,z}$	$W_{el,z}$	$W_{eff,z}$
$\Delta M_{y,Ed}$	0	0	0	$e_{N,y}N_{Ed}$
$\Delta M_{z,Ed}$	0	0	0	$e_{N,z}N_{Ed}$

χ_y, χ_z are the reduction factors due to flexural buckling

χ_{LT} is the reduction factor due to lateral torsional buckling

k_{yy}, k_{yz}, k_{zy}, k_{zz} are the interaction factors. Values are given in annex (see Appendix J.1 for Interaction factors and equivalent uniform factors)

$\gamma_{M1} = 1{,}05$ is partial factor for the resistance of members to instability assessed by the member checks

3.1.5. Stability

In Norway, all constructions have to be designed in accordance with the Planning and Building Act. Therefore, it is important that all regulations and requirements are followed to secure the buildings from collapsing. Along with proper design and a right structural system, stiffening is vital for the overall stability of the building. In case of horizontal forces, the stiffening elements will safeguard these efficiently and safely. A building is stable when the individual building parts are balanced and can withstand the forces applied. The term "stable" includes effects of construction shifts, 2nd order effects.

This study only focuses on horizontal loads in the form of misalignment (geometric imperfection) and wind. Unlike gravity loads, the horizontal loads can act in any direction. Selected bracing systems must be able to withstand these loads, and safely bring them down to the foundation. Proper connections between the bracing systems and other parts of the construction must be done to ensure stability.

It is crucial to stiffen correctly. So that there will not be too large shifts in the columns, as this reduces the risk of buckling. Horizontal displacements should be kept within acceptable limits.

It is important to prevent rotation in a building. To avoid this, it is important to be strategic when choosing where to place the stiffing plates. If the plates are placed in unfavorable locations, the building might, in a worst case scenario, collapse [2].

The horizontal capacity of the building is more or less secured if the wall braces satisfy the following three requirements [2, 19]:

1. The wall brace must be able to withstand horizontal forces along three different straight lines in the plane.
2. The three lines must not intersect at the same point.
3. At least two of the three lines cannot be parallel to each other.

Bracing systems

There are different types of bracing systems in buildings such as fixed columns, rigid frame systems, shear wall systems, trusses (Cross-bracing), combination systems etc. [11].

RC Shear Walls:

Shear wall systems serve to carry lateral loads applied on the structure due to wind, earthquake and so on. They provide substantial strength and stiffness to the building in the direction of their orientation. Shear walls may have openings, and this should be considered in the design as it affects the stiffness of the shear walls. When shear walls form a closed space, we usually call a core wall. In other words, core walls are a combination of shear walls. Shear core houses include services like stairs, lifts, toilets and so forth. They are usually located at the geometric center of the building to avoid rotation and torsion.

Lateral loads are transferred to stability systems through floors and roofs. Floors and roofs must be capable of carrying in-plane forces and act as in the manner of horizontal, flat beams. They can also act as deep thin beams. Stiff planes of this type are often called horizontal shear planes or diaphragms.

If horizontal shear planes are carried by, for example, pin-connected beams and column systems (frames), floors planes must be designed to serve as rigid horizontal diaphragms. They will then act as thin horizontal beam elements spanning between the bracing shear walls. Interior frames are less stiff and deflect more. Without the diaphragms, interior frames have to carry a major portion of the horizontal forces. If diaphragm is not applied in the floors, interior frames must carrying a major portion of the horizontal forces. To take the advantage of shear walls, rigid diaphragms should be applied in the floors [11] [19] [20].

Action of rigid floor diaphragms in a framed building are illustrated in Figure 3.44.

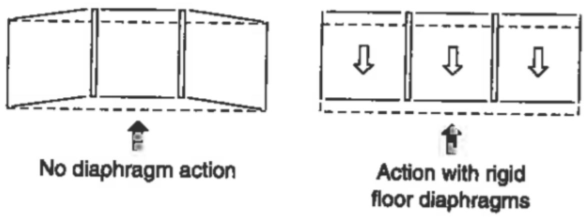


Figure 3.44: Effect of rigid floor diaphragms [19] [20]

Whereas, shear walls serve as vertical shear planes.

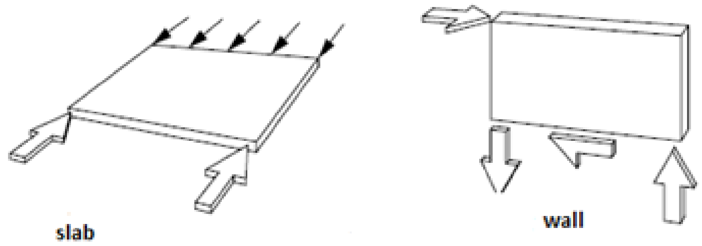


Figure 3.45: Horizontal and vertical shear planes [11]

1) Arrangement of Shear Walls

Placement of the shear walls is an integral part of stability design. To avoid the rotation of the building about the Z-axis (vertical axis) of a building, it is important to consider the location of vertical plates and the load result relative to the building's rigidity center, SS, se Figure 3.46
At the stiffness center, there will be only a moment about the axis perpendicular to the load direction and therefore no rotation of the building in the XY plane. There are methods for calculating the rigidity center (stiffness center) for buildings with a different distribution of shear walls [11] [19].

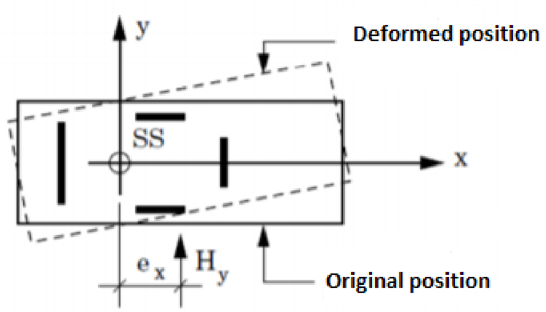


Figure 3.46: Displacement of floor [11]

2) Deformation and stiffness

In general, stiffness numbers can be expressed as follows [11]:

$$K_{bi} = (k_b \times E_i \times I_i)/l_i^3 \quad (3.114)$$

$$K_{si} = (k_s \times A_i \times E_i)/l_i^3 \quad (3.115)$$

Where:
K_{bi} = bending stiffness of wall "i", will vary according to the load situation
K_{si} = shear stiffness of wall "i", will vary according to the load situation

For a cantilevered shear wall as in the Figure 3.47 the deflection due to bending and shear is as follows:

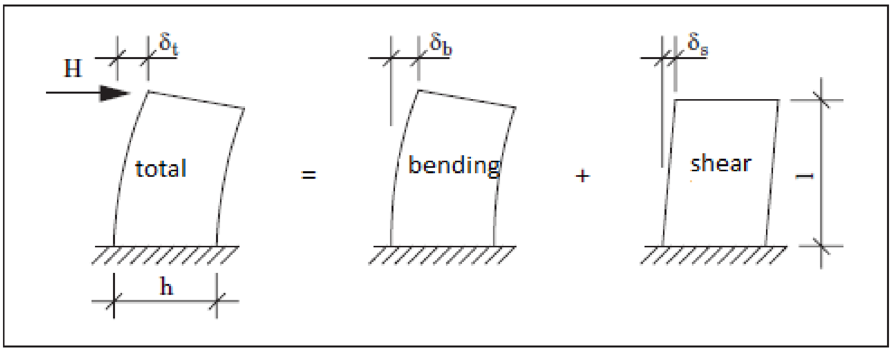


Figure 3.47: deformation of shear wall [11]

$$\delta_b = H/K_b = H/(k_b \times E \times I/l^3) = H \times l^3/(k_b \times E \times I) \quad (3.116)$$

$$\delta_s = H/K_s = H/(k_s \times E \times A/l) = H \times l/(k_s \times E \times A) \quad (3.117)$$

Where
k_b and k_s are stiffness coefficients that depend on the load situation and for the cantilevered shear wall as in the figure above the values are: k_b = 3 and k_s = 1 / 3
δ_b= deflection due to bending
δ_s = deflection due to shear
δ_t = δ_b+ δ_s = total deflection = H / K_i
H = horizontal force on the selected shear wall
K_s = shear stiffness of wall
K_b = bending stiffness of wall
K_i = stiffness of wall «i»; there 1 / Ki = 1 / K_{si} + 1 / K_{bi}
K_{xi} = rigidity of the wall in the x-direction
K_{yi} = rigidity of the wall in the y-direction
G_i = 0.4 × E_i = shear modulus of wall "i".
E_i = elastic modulus of wall "i".
A_i = area of wall "i" that resists the load, only the ladder area = h_i × t_i
I_i= moment of inertia of wall "i".
l = height of the wall segment under consideration.

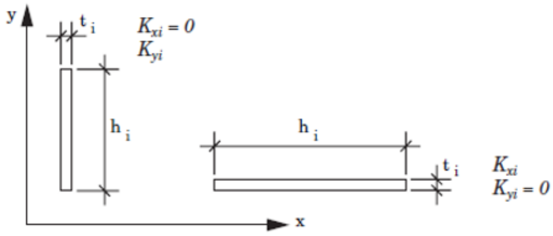


Figure 3.48: Stiffness of shear walls parallel with x-axis and y-axis

3) Distribution of force on the individual shear wall

Determination of stiffness center of individual plate:

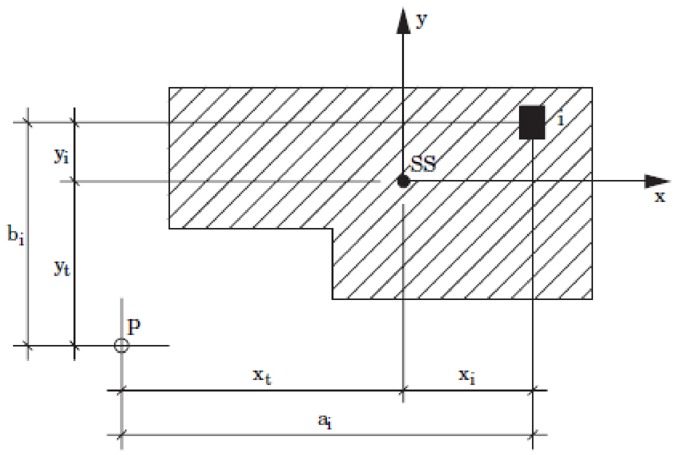


Figure 3.49 stiffness center [9]

$$x_t = \sum(a_i \times K_{yi})/K_y \tag{3.118}$$

$$y_t = \sum(a_i \times K_{xi})/K_x \tag{3.119}$$

Where

K_x and K_y are total stiffnesses due to simple displacement (translation) in x-direction and y-direction respectively.

$$K_y = \sum K_{yi} = K_{y1} + K_{y2} + K_{y3} + \ldots + K_{yi} \tag{3.120}$$

$$K_y = \sum K_{xi} = K_{y1} + K_{y2} + K_{y3} + \ldots + K_{yi} \tag{3.121}$$

And the respective deformations will be

$$\delta_x = H_{x,tot}/K_x \tag{3.122}$$

$$\delta_y = H_{y,tot}/K_y \tag{3.123}$$

Determination of rotation stiffness:

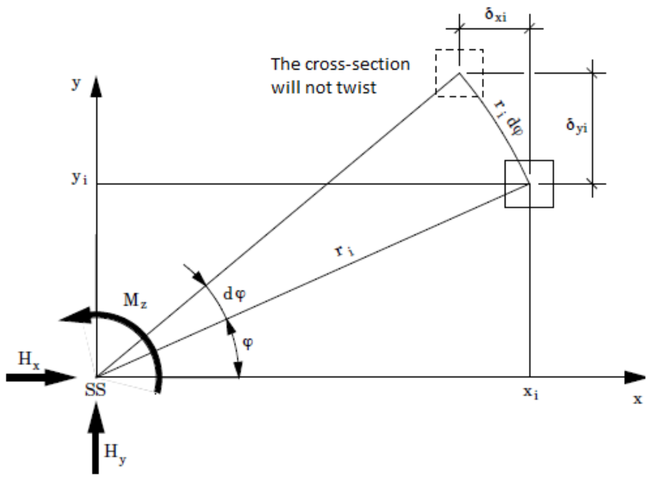


Figure 3.50: Rotation of shear wall [9]

When a shear wall "i" is located at a distance r_i from the stiffness center it will have a torque (moment-rotation) and can be expressed as follows:

$$M_{zi} = H_i \times r_i = K_i \times \delta_i \times r_i \tag{3.124}$$

Where:
$H_i = K_i \times \delta_i$ is force on the shear wall "i"
$\delta_{yi} = r_i \times \cos\varphi \times d_\varphi = x_i \times d_\varphi$ is deflection in y-direction
$\delta_{xi} = r_i \times \sin\varphi \times d_\varphi = y_i \times d_\varphi$ is deflection in x-direction

For the shear in y-direction (K_{xi} = 0) with a distance x_i and y_i from stiffness center (SS), the rotation moment M_{zi} in equation (3.46) can be rearranged as:

$$M_{zi} = K_{yi} \times \delta_{yi} \times x_i = K_{yi} \times (x_i \times d_\varphi) \times x_i = x_i^2 \times K_{yi} \times d_\varphi = I_i \times d_\varphi \tag{3.125}$$

Where I_i is the rotation stiffness of a shear wall "i"

Total rotation stiffness for all shear walls can then be calculated as:

$$I = \sum I_{xi} + \sum I_{yi} = \sum(y_i^2 \times K_{xi}) \times \sum(x_i^2 \times K_{yi}) \tag{3.126}$$

And the total rotation moment will be:

$$M_Z = \left(\sum(y_i^2 \times K_{xi}) + \sum(x_i^2 \times K_{yi})\right) \times d_\varphi = I \times d_\varphi \tag{3.127}$$

Distribution of impacts due to simple displacement (translation) and rotation on the individual shear wall in x-direction and y-direction will be [11]:

$$H = H_{translation} + H_{rotation}$$

$$H_{xi} = K_{xi} \times H_{x,tot}/K_x \pm y_i \times K_{xi} \times M_Z/I \tag{3.128}$$

$$H_{yi} = K_{yi} \times H_{y,tot}/K_y \pm x_i \times K_{yi} \times M_Z/I \quad (3.129)$$

Where

$H_{x,tot}$ and $H_{y,tot}$ is the total external load from x-direction and y-direction respectively.

4) Deformation control/ verification

According to Norwegian regulations, there are no specific requirements for limiting the horizontal deflections. Therefore, we have applied some random requirements from practical experience which have varied from l / 400 to l / 2000, where l is the cantilever length (height of the building). For the vertical constructions, the deformation calculations play a significant role in high rise buildings [11].

According to ISO standard, the permitted structural deviations for structural concrete columns and walls, can be calculated as shown in Figure 3.51. Deformation control should be done in a serviceability limit state [41].

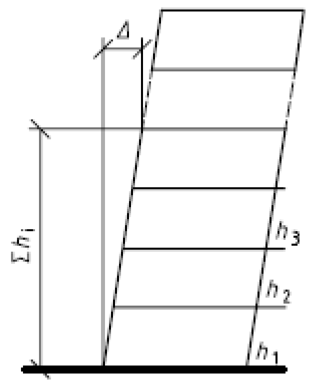
 $\sum h_i$ is the sum of height of storeys considered	Location of a column or a wall at any storey level, from a vertical line through its intended centre at base level in a multi-storey structure n is the number of storeys for $n > 1$	The smaller of 50 mm or $\sum h_i / (200 n^{1/2})$

Figure 3.51: Permitted vertical deviations for columns and walls [39]

Like RC shear walls, wood-based panels such as solid wood (CLT) can act as a shear wall [19].

Wood-based panel shear walls (cross-laminated timber)

1) Deformation and stiffness
   In the serviceability limit state, the horizontal displacement at the wall top has to be limited to at least with 1/300 of the story height. But the recommended limit is as follows [19]:

$$w_{hor} \leq \frac{h}{500} \quad (3.130)$$

Where h is storey height

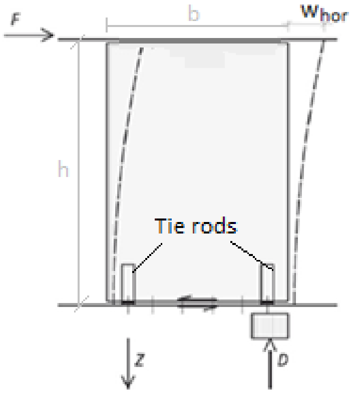


Figure 3.52: A shear wall with base connection and deformation [16]

The total horizontal deformation (w_{hor}) at the top of the shear wall is the sum of the deformation due to bending. The shear wall and the expansion of the tie rods can be calculated as follows:

$$w_{hor} = w_M + w_V + w_Z \tag{3.131}$$

Bending deformation of the shear wall:

$$w_M = \frac{F_k \cdot h^3 \cdot 10^{-4}}{3 \cdot EI} \quad \text{(mm)} \tag{3.132}$$

Shear deformation of the shear wall

$$w_v = \frac{F_k \cdot h}{GA_s} \quad \text{(mm)} \tag{3.133}$$

Expansion of the tie rods

$$w_z = \frac{F_k \cdot h^2}{b^2 c_z} \tag{3.134}$$

where

h is height of the shear wall, m
b is length of the shear wall, m
EI is Flextural stiffness, kNm2
$E = E_{0,mean}$
$I = d_{0,net} \cdot b^3/12$

$E_{0,\,mean}$ is mean modulus of elasticity in the direction of the top layers (main direction of span)
$d_{0,\,net}$ is net cross-section without the layers in the transverse direction
GAs is shear stiffness, kN
$G = 0{,}75\ G_{0,mean}$
$A = d_{gross} \cdot b$
$G_{0,\,mean}$ is mean shear modulus in the direction of the top layers (main direction of span)
d_{gross} is gross cross-section (thickness of all layers)

F_k is horizontal force at the top wall in the characteristic design situation, kN
C_z is stiffness of the fasteners for tensile anchoring, kN/mm

2) Verification:

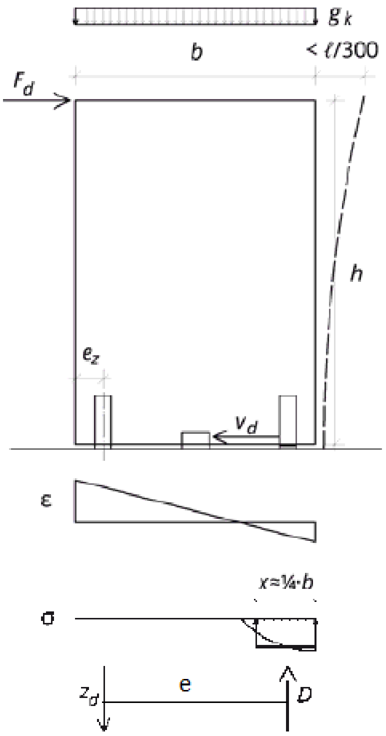


Figure 3.53: Dimensions of shear wall [16]

Tension anchoring:
Verification must be done to show that the resistance of the fasteners is higher than the tensile force Z_d:

$$Z_d \leq F_{R,1,d} \tag{3.135}$$

The tensile force can be calculated as follows:

$$Z_d = \frac{F_d \cdot h}{e} - 0{,}9 \cdot G_{Z,k} \tag{3.136}$$

Where
$F_{R,1,d}$ is tensile resistance of fasteners
e is inner lever
$G_{Z,k}$ is portion from the permanent last with a possibility relieving the effect

If we assume that there is a constant stress in the contact area, the width of the pressure zone can be calculated as follows:

$$x = {}^{1}/_{4} \cdot b$$

Thus, inner lever results as follows:

$$e = \frac{3}{4} \cdot \mathrm{b} - e_z \tag{3.137}$$

Shear anchoring:
The shear force (V_d) in the joint can be resisted by fasteners and is expressed as follows:

$$V_d \leq F_{R,2,d} \tag{3.138}$$

And the shear force can be calculated as:

$$V_d = F_d - 0{,}9 \cdot \mu \cdot G_{v,k} \tag{3.139}$$

Where
$F_{R,2,d}$ is shear resistance of fasteners
$\mu \cdot G_{v,k}$ is portion of friction from permanent force with a relieving effect.
μ = 0,2 to 0,5 ……………. sliding friction timber-timber
μ = 0,4 ……………………. sliding friction timber-concrete

In this study, the building has an elevator shaft and a stairwell at the relatively geometric center of the building. A shear wall has also been placed at each short side of the building. This placement would result in a suitable arrangement of shear walls with a small or negligible moment in XY-plane. The shear walls are placed as shown in the 3D plan view below marked with red circles.

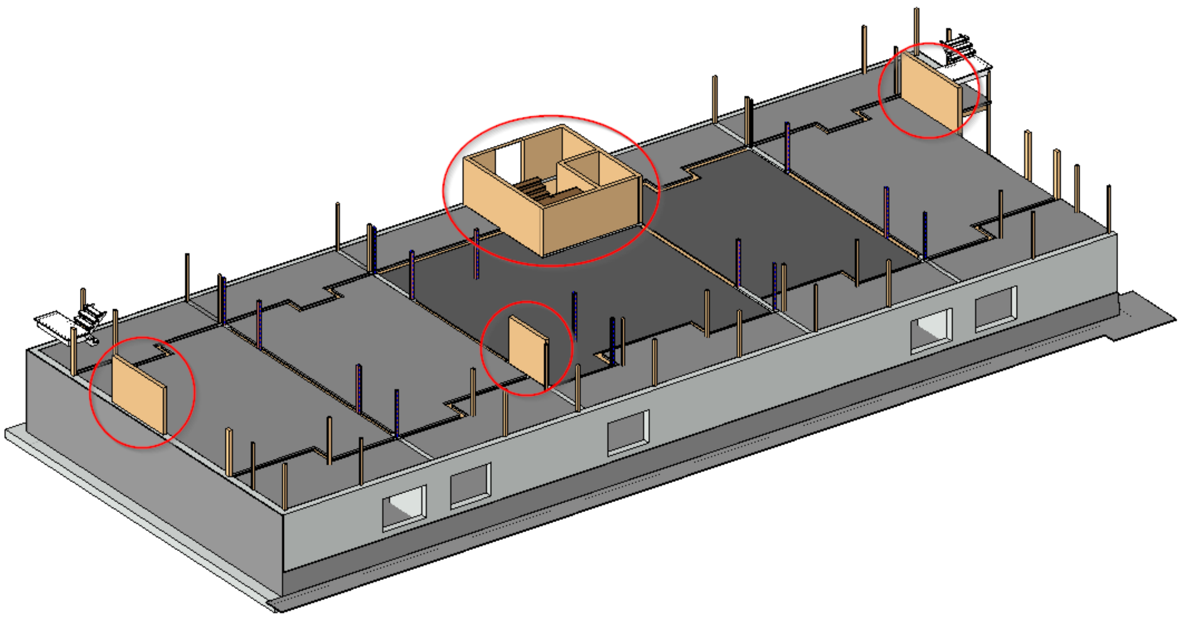


Figure 3.54: Placement of bracing systems

3.1.6. Connections

A joint is a zone in which two or more elements are attached to each other by using welded and screwed connections. A connection is defined as a joining of the base components, which gives the connection its properties for transferring load impacts. The base components can, for instance, be screws, welding and steel plates. Steel joints design is based on rules that can be applied for all structural elements of steel in bridges, buildings, offshore, and in towers [3]. The link between steel joints, connections and basic components is shown in Figure 3.55:

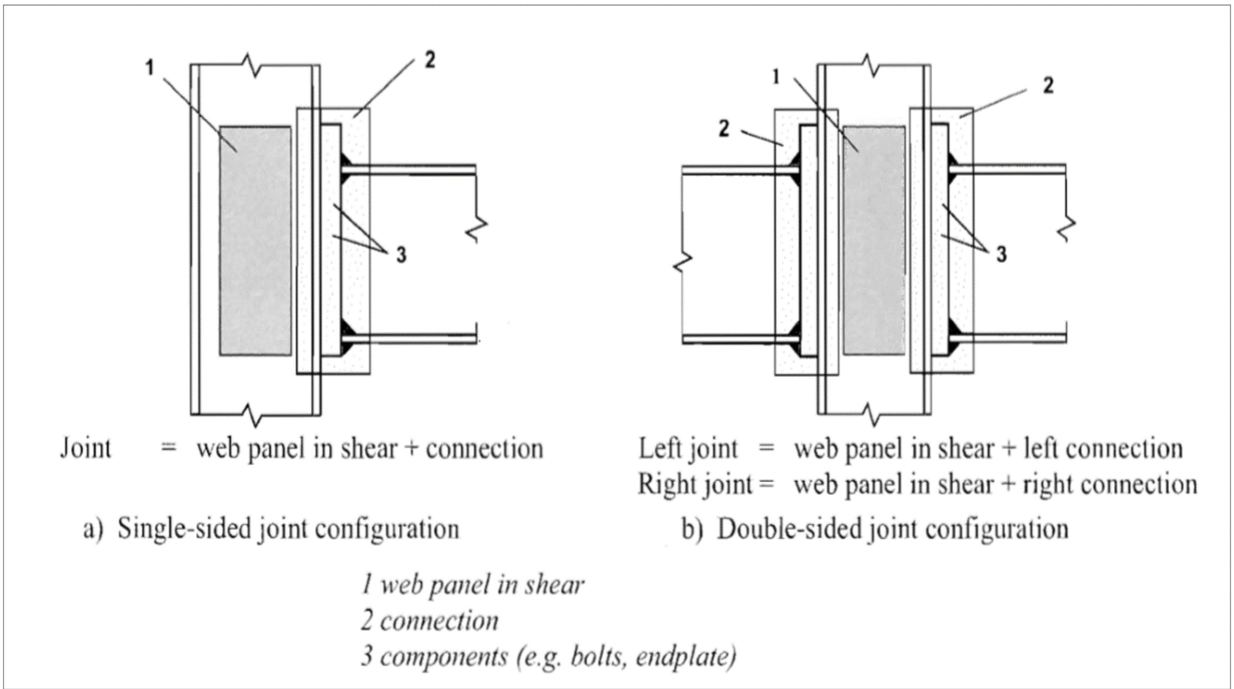


Figure 3.55: Single-sided steel joint and double-sided steel joint. [5]

The position of the joints is illustrated in Figure 3.56:

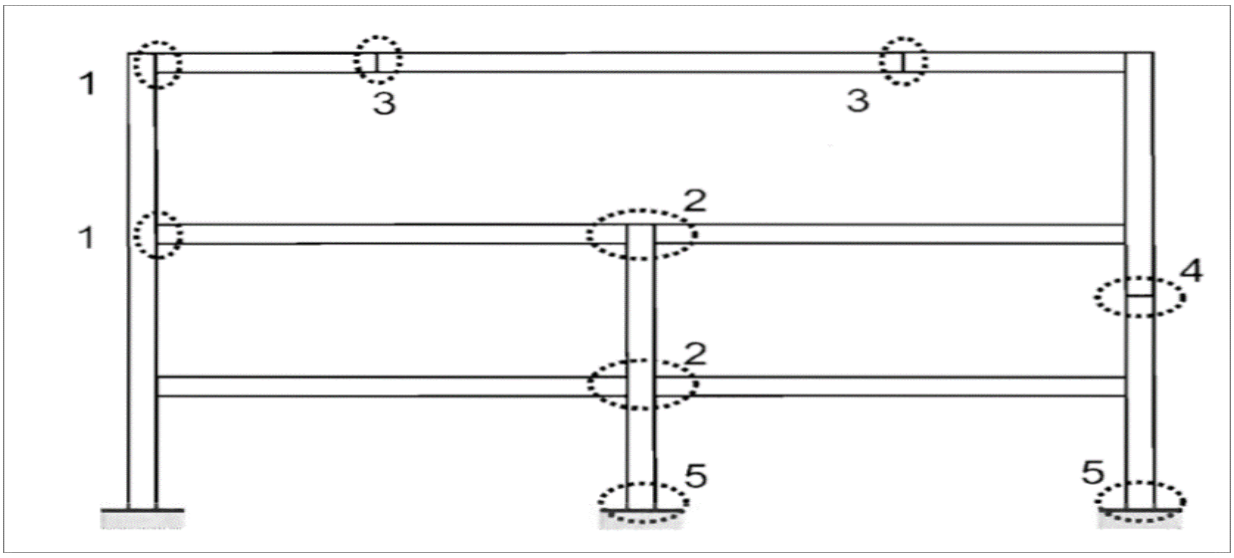


Figure 3.56: Types of joint in steel construction 1) Single-sided beam-to-column joint configuration; 2) Double-sided beam-lo-column joint configuration, 3)Beam splice; 4)Column splice, 5) column base [5]

More detailed drawings of the three types of joints are shown in Figure 3.57.

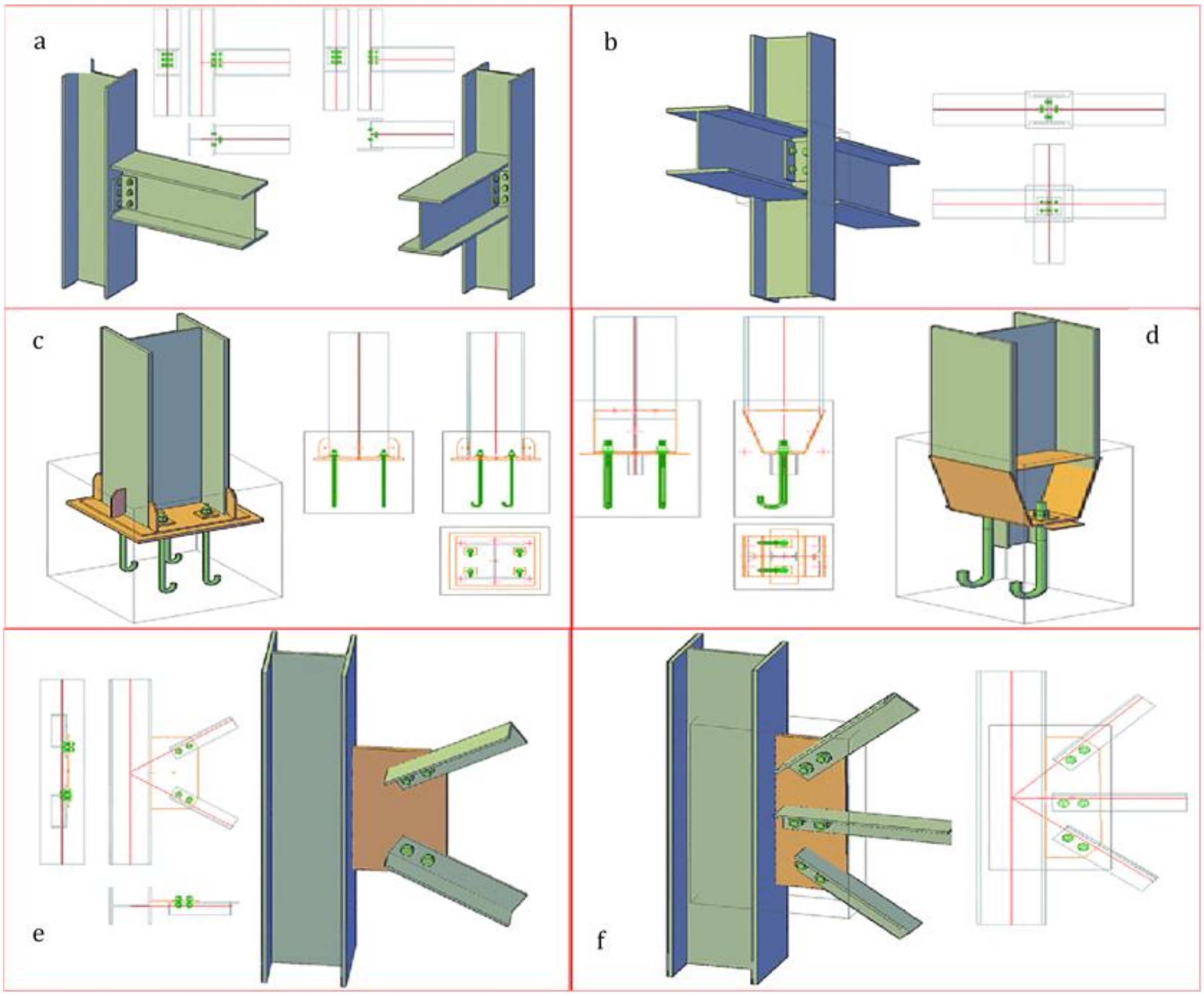


Figure 3.57: Detailing of some types of steel joints: a, b)Beam to columns - c, d)base plates -e, f)bracing

As mentioned, the connection may be welded or screwed. As a rule, a screw connection consists of two or more screws. When the connection is subjected to forces which affect perpendicularly on the screws, it is called "a shear connection". Furthermore, when forces are parallel to the longitudinal axis of the screws, the connection is called a "tension connection [3].

Regarding computing the design resistance for an individual fastener subjected to shear, the following requirement should be satisfied:

$$F_{V,Ed} \leq minimum\ of \quad \begin{cases} F_{V,Rd} \\ F_{b,Rd} \end{cases} \tag{3.140}$$

$F_{V,Rd}$ is the shear resistance per bolt
$F_{b,Rd}$ is the design bearing resistance per bolt

Design resistance for individual fasteners subjected to shear and tension is illustrated in Table below:

Table 3.23:Design resistance for individual fasteners subjected to shear and/or tension[5]

Failure mode	Bolts	Rivets
Shear resistance per shear plane	$F_{V,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}}$ where the shear plane passes through the threaded portion of the bolt (A is the tensile stress area of the bolt As): - for classes 4.6, 5.6 and 8.8: $\alpha_v = 0{,}6$ - for classes 4.8, 5.8, 6.8 and 10.9: : $\alpha_v = 0{,}5$ where the shear plane passes through the unthreaded portion of the bolt (A is the gross cross section of the bolt: α_v = 0,6	$F_{V,Rd} = \frac{0{,}6 f_{ur} A_0}{\gamma_{M2}}$
Bearing resistanc123	$F_{V,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}}$ where α_b is the smallest of(α_d ; $\frac{f_{ub}}{f_u}$ or 1,0): in the direction of load transfer: -for end bolts: $\alpha_d = \frac{e_1}{3d_0}$; for inner bolts: $\alpha_d = \frac{p_1}{3d_0} - \frac{1}{4}$ perpendicular to the direction of load transfer: -for edge bolts: k_1 is the smallest of $2{,}8\frac{e_2}{d_0}1{,}7, \quad 1{,}4\frac{p_2}{d_0} - 1{,}7, 2{,}5$ - for inner bolts: k_1 is the smallest of 1.4 $\frac{p_2}{d_0}$ -1,7 or 2,5	$F_{V,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}}$ where α_b is the smallest of α_d ; $\frac{f_{ub}}{f_u}$ or 1,0: in the direction of load transfer: -for end bolts: $\alpha_d = \frac{e_1}{3d_0}$ = ; for inner bolts: $\alpha_d = \frac{p_1}{3d_0} - \frac{1}{4}$ perpendicular to the direction of load transfer: -for edge bolts: k_1 is the smallest of $2{,}8\frac{e_2}{d_0}1{,}7, \quad 1{,}4\frac{p_2}{d_0} - 1{,}7, 2{,}5$ - for inner bolts: k_1 is the smallest of 1.4 $\frac{p_2}{d_0}$ -1,7 or 2,5

Tension resistance2	$F_{t,Rd}=\frac{k_2 f_{ub} A_s}{\gamma_{M2}}$: where $k_2=0{,}63$ for countersunk bolt, otherwise $k_2=0{,}9$.	$F_{t,Rd}=\frac{0{,}6 f_{ur} A_0}{\gamma_{M2}}$
Punching shear resistance	$B_{P,Rd}=0{,}6\pi d_m t_p f_u/\gamma_{M2}$	No check needed
Combined shear and tension	$\frac{F_{V,Ed}}{F_{V,Rd}}+\frac{F_{t,Ed}}{1{,}4F_{t,Rd}}\leq 1$	$\frac{F_{V,Ed}}{F_{V,Rd}}+\frac{F_{t,Ed}}{1{,}4F_{t,Rd}}\leq 1$

1-The bearing resistance $F_{b,Rd}$ for bolts

-in oversized holes is 0,8 times the bearing resistance for bolts in standard holes.

- in slotted holes, where the longitudinal axis of the slotted hole is perpendicular to the direction of the force transfer, is 0,6 times the bearing resistance for bolts in round, standard holes

2-For countersunk bolts:

- the bearing resistance $F_{b,Rd}$ should be based on a thickness t equal to the thickness of the connected plate minus half the depth of the countersinking.

- for the determination of the tension resistance, the angle and depth of countersinking should conform with 1.2.4 Reference Standards: Group 4. Otherwise, the tension resistance should be adjusted accordingly.

3-When the load on a bolt is not parallel to the bearing resistance may be verified separately for the bolt load components parallel and normal to the end.

Regarding bolts classes that are mentioned in table above; these classes are determined in EC3 by the following table:

Table 3.24: Classes of bolts, nominal values of the yield strength f_{yb} and the ultimate tensile strength f_{ub} for bolts[5]

Bolt class	4.6	4.8	5.6	5.8	6.8	8.8	10.9
f_{yb}(N/mm2)	240	320	300	400	480	640	900
f_{ub}(N/mm2)	400	400	500	500	600	800	1000

According to EC3, the minimum and maximum spacing, end, and edge distance are given in the following Table 3.25 and Figure 3.58.

Table 3.25: Minimum and maximum spacing, end and edge distances[5]

Distances and spacings, see Figure 3.1	Minimum	Maximum[1) 2) 3)]		
		Structures made from steels conforming to EN 10025 except steels conforming to EN 10025-5		Structures made from steels conforming to EN 10025-5
		Steel exposed to the weather or other corrosive influences	Steel not exposed to the weather or other corrosive influences	Steel used unprotected
End distance e_1	$1,2d_0$	$4t + 40$ mm		The larger of $8t$ or 125 mm
Edge distance e_2	$1,2d_0$	$4t + 40$ mm		The larger of $8t$ or 125 mm
Distance e_3 in slotted holes	$1,5d_0$ [4)]			
Distance e_4 in slotted holes	$1,5d_0$ [4)]			
Spacing p_1	$2,2d_0$	The smaller of $14t$ or 200 mm	The smaller of $14t$ or 200 mm	The smaller of $14t_{min}$ or 175 mm
Spacing $p_{1,0}$		The smaller of $14t$ or 200 mm		
Spacing $p_{1,i}$		The smaller of $28t$ or 400 mm		
Spacing p_2 [5)]	$2,4d_0$	The smaller of $14t$ or 200 mm	The smaller of $14t$ or 200 mm	The smaller of $14t_{min}$ or 175 mm

1) Maximum values for spacings, edge and end distances are unlimited, except in the following cases:
- for compression members in order to avoid local buckling and to prevent corrosion in (AC2) exposed members (the limiting values are given in the table) and; (AC2)
- for exposed tension members (AC2) to prevent corrosion (the limiting values are given in the table). (AC2)

2) The local buckling resistance of the plate in compression between the fasteners should be calculated according to EN 1993-1-1 using $0,6\ p_1$ as buckling length. Local buckling between the fasteners need not to be checked if p_1/t is smaller than $9\ \varepsilon$. The edge distance should not exceed the local buckling requirements for an outstand element in the compression members, see EN 1993-1-1. The end distance is not affected by this requirement.

3) t is the thickness of the thinner outer connected part.

4) The dimensional limits for slotted holes are given in 1.2.7 Reference Standards: Group 7.

5) For staggered rows of fasteners a minimum line spacing of $p_2 = 1,2d_0$ may be used, provided that the minimum distance, L, between any two fasteners is greater or equal than $2,4d_0$, see Figure 3.1b).

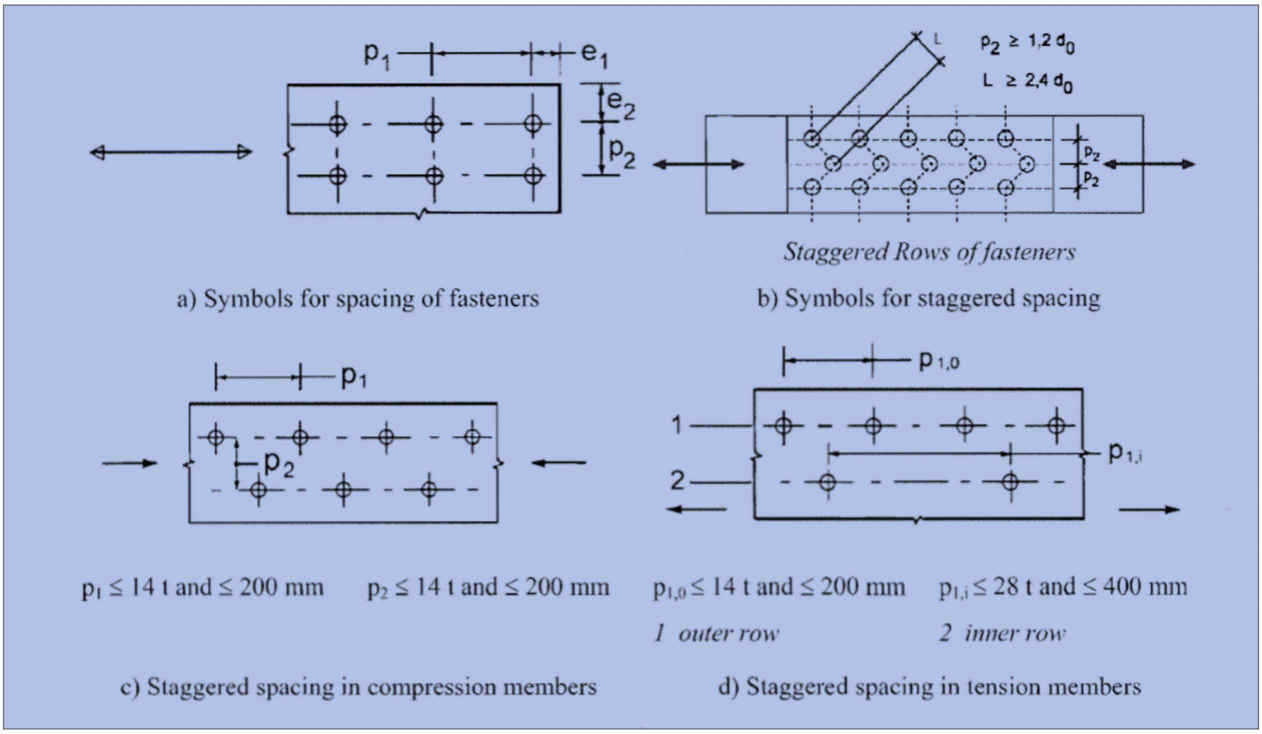


Figure 3.58: Illustration of symbols for end and edge distances and spacing of fasteners [5]

Timber Connections:

In addition to functioning as a way of connecting timber elements, timber connections play a role in making the structural elements of a timber construction work as a system. Timber joints might play a vital role in the economic contribution of timber construction as a whole because of the time saved when manufacturing these connections. The most common connections are dowel connections such as nails, screws, dowels, nail plates and punched metal plate fasteners and bolts. This connection transfers shear forces through mechanical fasteners installed at an angle to the force direction[4].
Dowel-types are illustrated in the figure below:

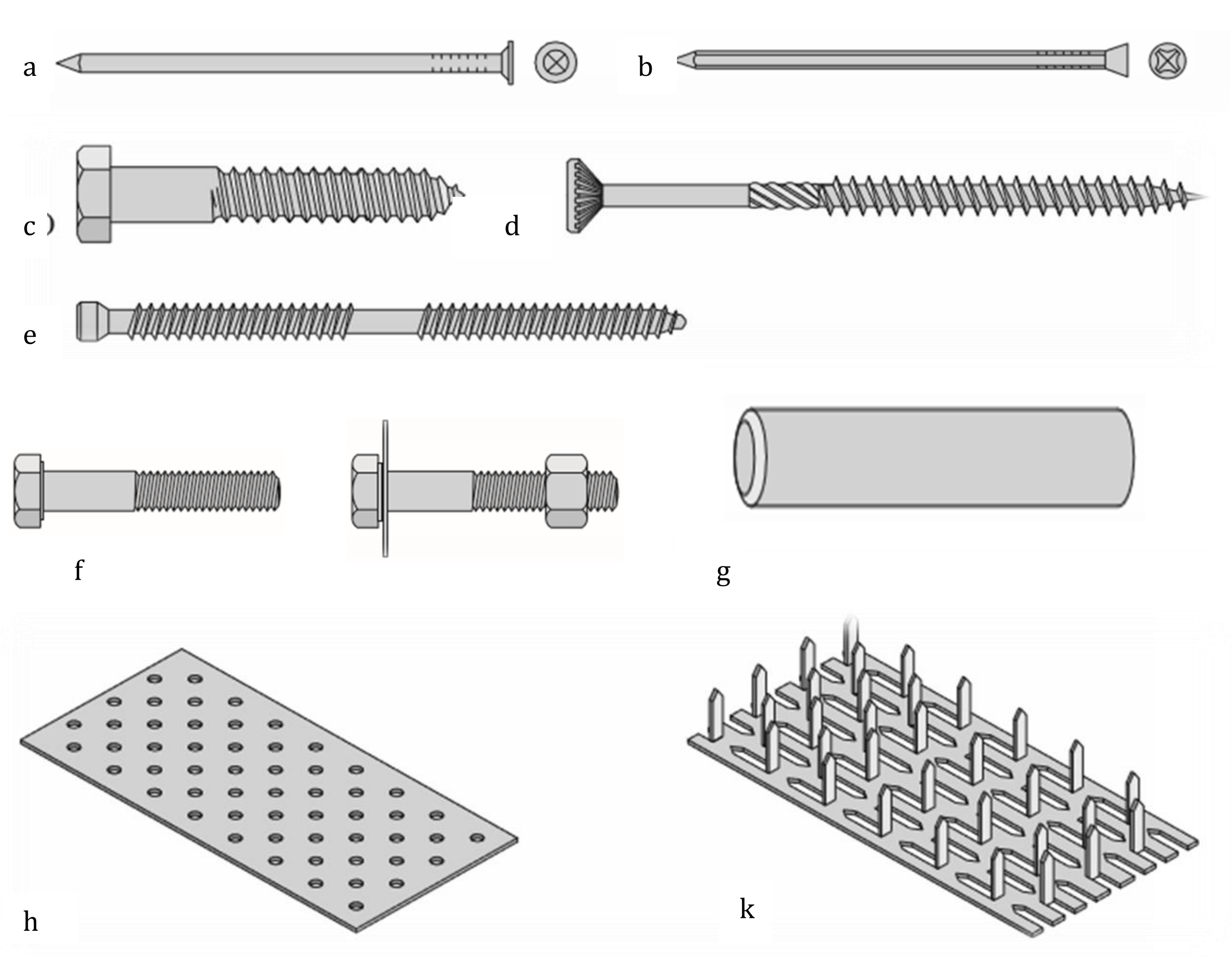


Figure 3.59: Dowelled joints: a) Round, smooth nail, b) grooved, smooth nail c) hexagon head wood screw requires pre-drilling and is however often replaced by for instance d) wood screw with countersunk head on e) double threaded wood screw f) Bolt, often to be completed with washer and nut g) dowel h) nail k) punched metal plate fastener.[4]

a) Beam-column Connection:

[2]A beam-column connection is usually designed as articulated (hinged) connections which only transfers horizontal and vertical forces. There are several types (or solutions) of this connection, including inclined screws and steel shoes. For small constructions (small loads), inclined screws can be used; for larger glulam beam-column joints, it is necessary to use specially made steel parts.[2]. Inclined screws are illustrated below:

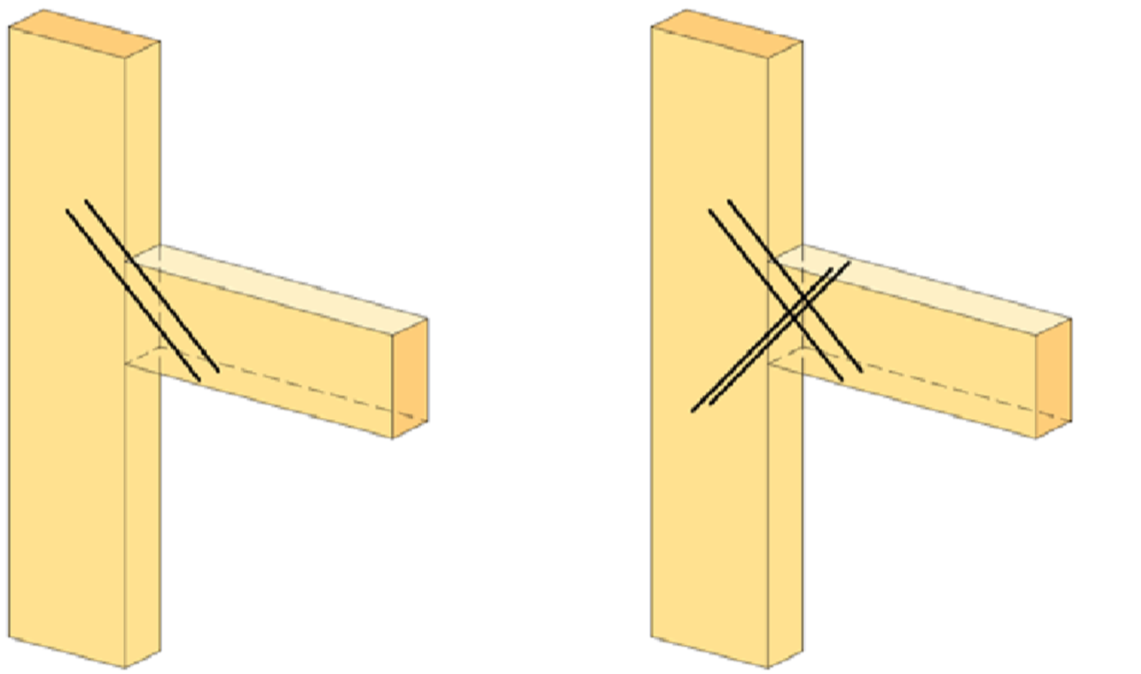


Figure 3.60: Inclined screws beam-column connection[2]

As already mentioned, welded beam shoes can be a good solution if it is necessary to transfer large forces when large forces are transferred . In the figure below, two types of welded beam shoes are shown. The major difference between the two types is the visibility of the steel part—this connection has both aesthetic and fire technical aspects. s shear load on a bar connector timber[2]

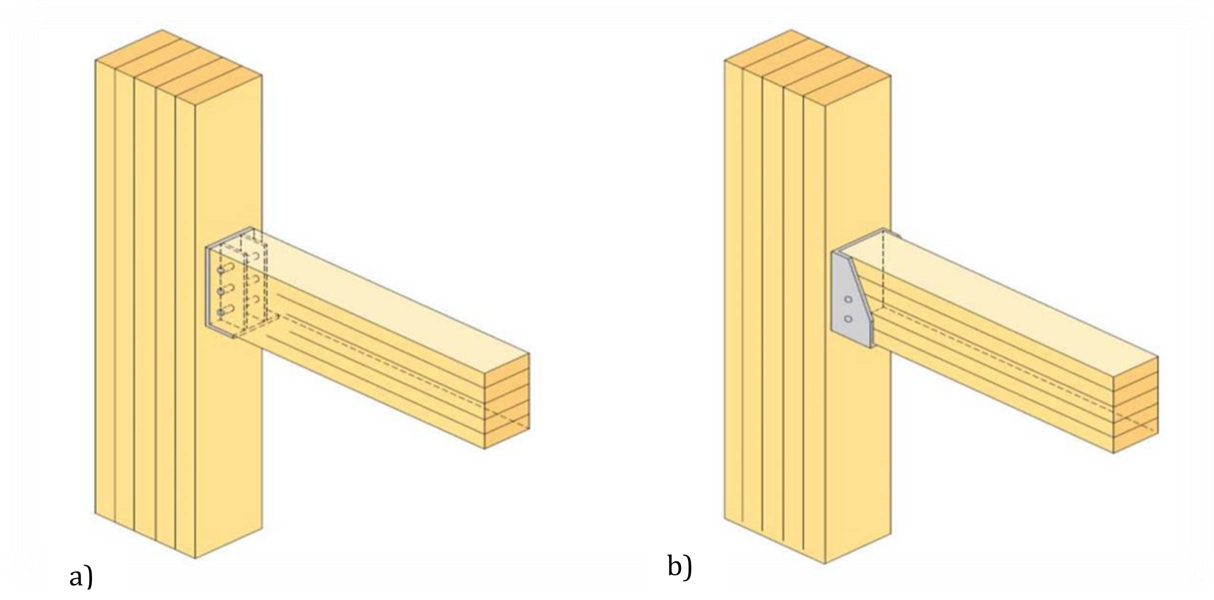


Figure 3.61: Two types of welded beam shoe connection a)Welded beam shoe with slotted-in (internal)steel plates b) welded beam shoe with external plates[2]

Regarding the first type of beam-column connection (welded beam shoe with internal plates), a tensile force in the beam is transferred to the shoe via dowels through the internal plates. The beam is attached to the column by screws in the back plate. The connection is affected by shear force $F_{E,x}$ and a normal force$F_{E,y}$ in the beam. The normal forces can be compressive or tensile, as illustrated below:

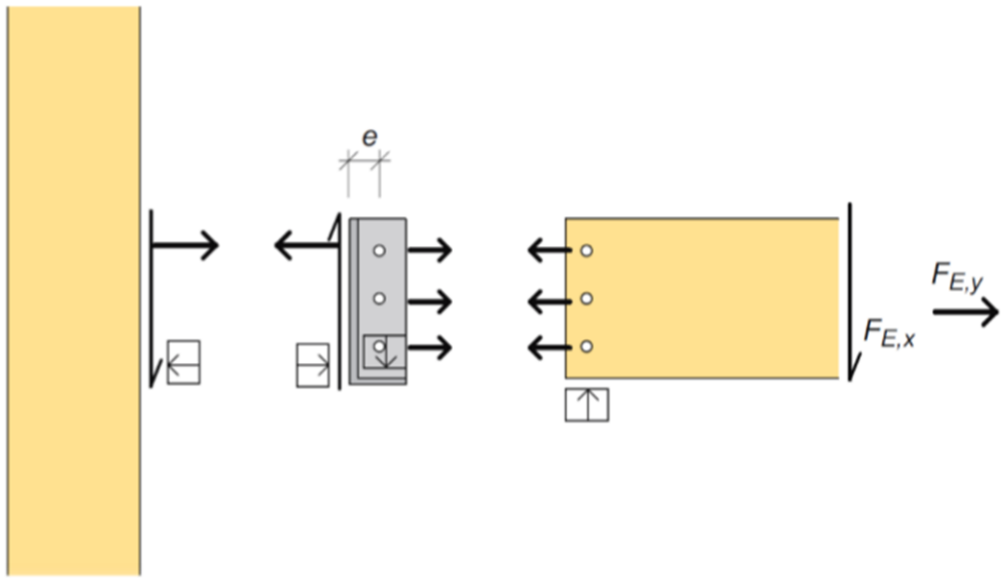


Figure 3.62: Welded beam shoe with internal plates and position of compressive and tensile forces. [2]

Assumed that the shear force is the contact pressure between the beam and the bottom plate in the connection, this pressure is then transmitted via welds to the inner plates and through new welds into the back plate. Then, from the back plate, the force is transferred to the column via shear-loaded screws. Due to the eccentricity “e”, the vertical force will cause a moment which must be taken (as a force pair against the back plate- tension in the upper screws, and as a) contact pressure in the lower part of the back plate. A pressure force in the beam is transmitted as (a) contact pressure between the beam and the back plate and further between the back plate and the column. A tensile force in the beam is transferred to the inner plates via the dowel and further to the back plate. From there it is transferred to the column via tension in the screw. Therefore, the screws in the back plate must be designed for the combination of shear and tension[2]. The following failures must be checked according to EC5 and EC3 as following steps [2]

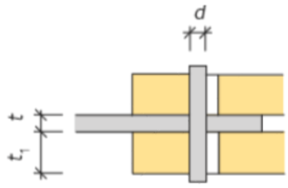
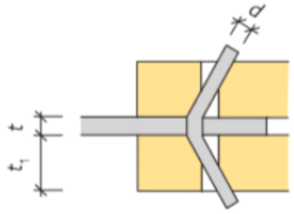
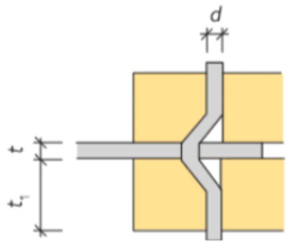
- Contact pressure between beam and base plate based on equation 3.19:

$$\sigma_{c,90,d} = \frac{F_{c,90,d}}{A_{ef}} \leq k_{c,90} f_{c,90,k}$$

This equation and relevant symbols have been illustrated in “timber part” in equation 3.19

- The shear capacity of the dowels is illustrated below:

Table 3.26: Characteristic load-carrying capacity per shear plane per fastener and failure modes for slotted in steel plates. [4]

$F_{v,Rk} = f_{h,1,k} t_1 d$	
* $F_{v,Rk} = f_{h,1,k} t_1 d \left(\sqrt{2 + \frac{4 M_{y,Rk}}{f_{h,1,k} d t_1^2}} - 1 \right) + \frac{F_{ax,Rk}}{4}$	
* $F_{v,Rk} = 2,3\sqrt{M_{y,Rk} f_{h,1,k} d} + \frac{F_{ax,Rk}}{4}$	

With taking account into that $\beta = \frac{f_{h,2,k}}{f_{h,1,k}}$

- Block and plug shear failure of the beam end (See Appendix I.4 Block shear failure and plug shear failure-timber connection)
- The withdrawal capacity of the screws in the column is given by:

$$F_{ax,\alpha,Rk} = \frac{n_{ef} \cdot f_{ax,k} \cdot d \cdot l_{ef} \cdot k_d}{1,2 \cos^2 \alpha + \sin^2 \alpha} \; [N] \tag{3.141}$$

For 6mm $\leq$d $\leq$ 12 mm and $0,6mm \leq \frac{d_1}{\mathrm{d}} \leq$ 0,75mm

Where

$$f_{ax,k} = 0,52 \cdot d^{-0,5} {l_{ef}}^{-0,1} {\rho_k}^{0,8} \tag{3.142}$$

k_d is of value min$\left\{\frac{d}{8}; 1\right\}$

$F_{ax,\alpha,Rk}$ is the characteristic withdrawal capacity of the connection at an angle *α* to the grain, in N;

d is the outer thread diameter;

d1 is the inner thread diameter

$f_{ax,k}$ is the characteristic withdrawal strength perpendicular to the grain, in N/mm2;

n_{ef} is the effective number of screws, it is clearly illustrated in EC5 8.7.2(8);

l_{ef} is the penetration length of the threaded part, in mm;

ρ_k is the characteristic density, in kg/m3;

α is the angle between the screw axis and the grain direction, with a $\geq$ 30°.

- The shear capacity of the screws are as mentioned in Table 3.26.
- Interaction between the shear and the withdraw for the screws is dependent on (see Appendix I.3 for Nailed connection).
- Contact pressure between back plate and column

$$\sigma_{c,90,d} = \frac{F_{c,90,d}}{A_{ef}} \leq k_{c,90} f_{c,90,k}$$

This equation and relevant symbols have been illustrated in "timber part" in equation 3.19

- Splitting fractures are carried out based on (see Appendix I.5 for connection forces at an angle to the grain)
- The plates and welding in the beam shoe must be checked dependent on EC3.

The difference in the calculation of welded beam shoes with external plates (Figure 3.61b,) is that bolts and screws must be used instead of dowels. Therefore, the sheer control of the connectors is not the same.[2]

b) Column-plate connection:

GLT columns are either articulated -or moment-rigidly connected to the foundation. The connection can be performed in different ways: by casting steel plates into the foundation, by welding the plate into existing steel arrangements which are already anchored in the foundation, or by using an anchor bolt. Since concrete or other moist materials directly support column ends, they should be provided with moisture hindrances such as rubber membrane or oil-hardened hardboard which is nailed or screwed to the underside. Therefore, a column-base should be designed and protected from water and other moist surfaces.

There are many types of fixing, but the most common fixing between columns and basement is external steel plates which are nailed or bolted to the column base. Standard or specially designed column shoes can be used to avoid direct contact between the column and the underlay (foundation). For aesthetic or fire-technical reasons, it is recommended to hide the connection; a glued bolt may be an alternative [2].

An articulated column base: This transmits horizontal and vertical forces, but not moments. Such connections can handle both small and large horizontal forces. There are many types of articulated column bases such as external located flat plate, glued bolt and slotted-in steel plates. All three types are illustrated below:

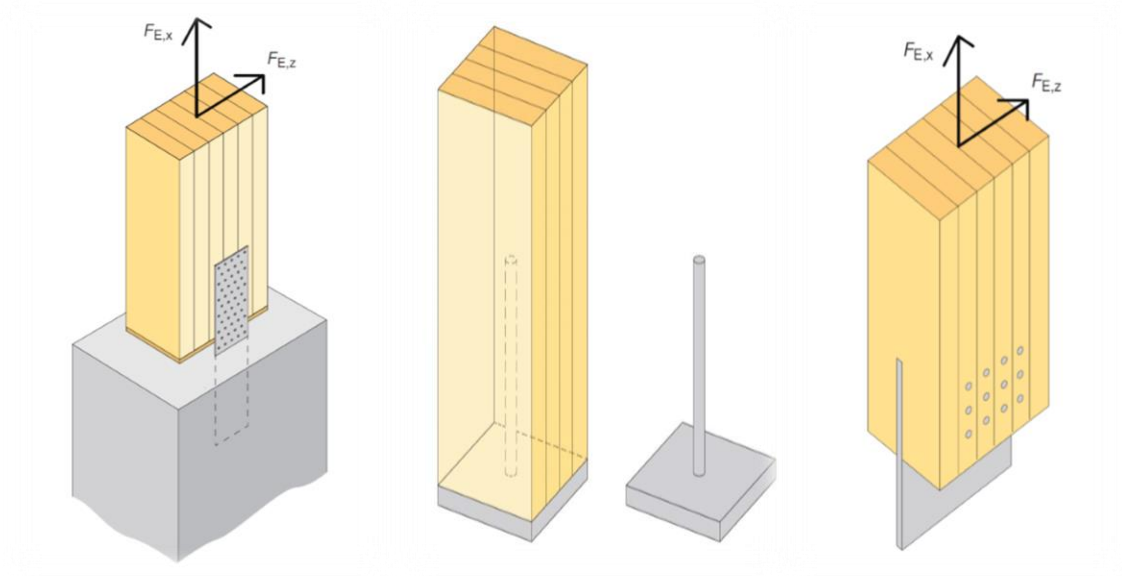


Figure 3.63: Three types of articulated column base , external located flat plate, glued in bolt and slotted in plate, from left to right ,respectively

As mentioned above, an underlay (footing) can be connected with a column by using steel plates which are slotted , combined with dowels, in the end of the column. This type of articulated column base would often consist of plates that are welded to a bottom plate which is bolted to underlay. (Figure 3.63 the last to right).

Following failures will be checked and controlled according to EC3[2]:

- Shear failure due to the load across the dowels. According to Table 3.26 that is mentioned in paragraph (beam-column connection)[2]. All failure modes and characteristic load-carrying capacity for metal dowel-type fasteners are given in (see Appendix I.1 for characteristic load-carrying capacity and failure modes)[6].
- Block and plug shear failure. This is mentioned in (see Appendix I.4 for Block shear failure and plug shear failure)[8]
- Design of the connection for axial force in the column is performed according to formula given in (see Appendix I.2 for Bolted connection and dowelled connection)[8].
- Control of steel plate is given in Table 3.27 below. Control of the steel plate, both full and net cross section, for moment, normal force and shear force.

Table 3.27: Control of slotted in steel plate[2]

Type of failure in steel plate	Equation
Tension[1]	$N_{t,Rd} = \min \begin{cases} N_{pl,Rd} = \frac{A\,f_y}{\gamma_{MO}} \\ N_{u,Rd} = \frac{0.9A_{net}\,f_u}{\gamma_{M2}} \end{cases}$
Compression [2]	$N_{c,Rd} = N_{pl,Rd} = \frac{A\,f_y}{\gamma_{MO}}$
Bending	$M_{c,Rd} = \frac{W_{pl}\ f_y}{\gamma_{MO}}$
Shear	$V_{c,Rd} = V_{pl,Rd} = \frac{A_v\ f_y}{\gamma_{MO}\sqrt{3}}$
Combination of stresses	$\left(\frac{\sigma_{x,Ed}}{\frac{f_y}{\gamma_{MO}}}\right)^2 + \left(\frac{\sigma_{z,Ed}}{\frac{f_y}{\gamma_{MO}}}\right)^2 - \left(\frac{\sigma_{z,Ed}}{\frac{f_y}{\gamma_{MO}}}\right)\left(\frac{\sigma_{z,Ed}}{\frac{f_y}{\gamma_{MO}}}\right) + 3\left(\frac{\tau_{Ed}}{\frac{f_y}{\gamma_{MO}}}\right) \leq 1$
1-Holes in tensile zone will not considered if following requirement is satisfied: $\frac{0.9A_{net}\,f_u}{\gamma_{M2}} \geq \frac{A\,f_y}{\gamma_{MO}}$. 2-it is not necessary to check the plate buckling if the distance between the connectors (a_1) satisfy following requirement: $a_1 \leq 9t \cdot \varepsilon = 9t\sqrt{\frac{235}{f_y}}$	
f_y yield strength of steel f_u ultimate strength of steel A_{net} net area of a cross section A cross-sectional area A_v shear area $\sigma_{x,Ed}$ design value of the local longitudinal stress $\sigma_{z,Ed}$ design value of the local transverse stress τ_{Ed} design value of the local shear stress $\gamma_{MO} = 1.05$ and $\gamma_{M2} = 1,25$	

3.1.7. Loads

Vertical loads:

Dead and live loads are vertical loads. Dead load is a permanent load acting on a building which consists of self-weight of the structure, finishes, plaster, partition walls etc. Dead load should be calculated accurately with a correct unit weight of the building materials.

Live load or imposed load is a load caused by the use of the building which consists of persons, furniture, movable objects etc. Live loads generally act on the floors depending on the activities. Internal floors usually have higher value than on roofs. Roofs may or may not be accessible. According to Eurocode 1, live load on building depends on the building categories. Building categories are residential, social, commercial, office, storage and industrial and so forth. Live load values on floors are given in the table below.

Generally loads are represented by uniformly distributed loads, concentrated loads and line loads.

Table 3.28: Categories of use and imposed loads on floors [42]

Category	Specific use	Example	q_k [kN/m^2] (on floors)	Q_k [kN] (on floors)
A	Areas for domestic and residential activities	Rooms in residential buildings and houses; bedrooms and wards in hospitals; bedrooms in hotels and hostels kitchens and toilets.	1,5 to 2,0	2,0 to 3,0
B	Office areas		2,0 to 3,0	1, 5 to 4,5
C	Areas where people may congregate (with the exception of areas defined under category A, B and D)	C1: Areas with tables, etc. e.g. areas in schools, cafes, restaurants, dining halls, reading rooms, receptions	2,0 to 3,0	3,0 to 4,0
		C2: Areas with fixed seats, e.g. areas in churches, theatres or cinemas, conference rooms, lecture halls, assembly halls, waiting rooms, railway waiting rooms.	3,0 to 4,0	2,5 to 7,0 (4,0)
		C3: Areas without obstacles for moving people, e.g. areas in museums, exhibition rooms, etc. and access areas in public and administration buildings, hotels, hospitals, railway station forecourts	3,0 to 5,0	4,0 to 7,0
		C4:Areas with possible physical activities, e.g. dance halls, gymnastic rooms, stages	4,5 to 5,0	3,5 to 7,0
		C5:Areas susceptible to large crowds, e.g. in buildings for public events like concert halls, sports halls including stands, terraces and access areas and railway platforms.	5,0 to 7,5	3,5 to 4,5
D	Shopping areas	D1: Areas in general retail shops	4,0 to 5,0	3,5 to 7,0 (4,0)
		D2: Areas in department stores.	4,0 to 5,0	3,5 to 7,0

Note: the recommended values by the National annex are underlined.

Movable partition walls may be accounted for by a uniformly distributed load which should be added to the live loads of floors obtained I table above. This additional load due to the movable partitions depends on the self-weight of the movable partitions and is considered as follows:
Self-weight < 1 kN/m wall length, q_k = 0,5 kN/m 2
Self-weight >1 ≤ 2,0 kN/m wall length, q_k = 0,8 kN/m 2
Self-weight >2 ≤ 3 kN/m wall length, q_k = 1,2 kN/m 2

Snow loads are variable loads acting on roofs. Snow load on roof is described in Eurocode 1 part 1-3 and in this standard snow loads on the ground are given for all municipalities in Norway. Snow load shape coefficients should be applied to snow loads on the ground to find snow loads on roofs. The snow load shape coefficients depend on the shape or angle of the roof.

Horizontal Loads:
Wind, earthquake, horizontal load due to unexpected tilt (misalignment), accident and crane load are horizontal loads on buildings. Earth and water pressure are also horizontal loads on a structure like retaining walls.
According to Eurocode 1, wind pressure depends on the terrain categories. In NS-EN 1991-1-4, reference wind speed is given for all municipalities in Norway. Wind pressure on a building can be calculated depending on the terrain category and location of the building. The wind pressure is constantly considered above the height of the building. Internal pressure/ negative pressure must be taken into account.
Wind and earthquake are variable loads which generally affect the global stability of buildings or structures.
Skew or misalignment is a horizontal load cause on the building due to geometric slenderness or geometric deviation of the building. It usually happens in ultimate limit state, but not I serviceability limit state. Geometric deviations are usually inclination deviations (skew) or unintentional eccentricity. Skew loads act on both the horizontal slabs and vertical slabs like shear walls. It is calculated from total factored vertical loads [11].

1) Wind loads
   Impact of wind load on a building is illustrated in figure below.

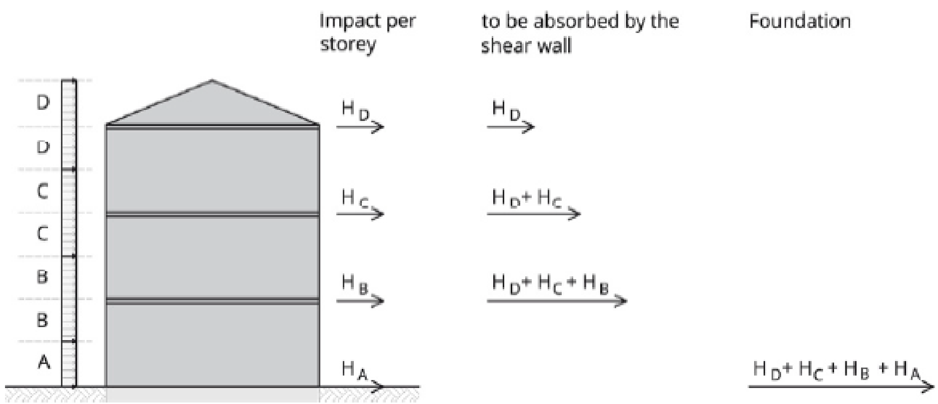


Figure 3.64: Horizontal forces per storey resulting from wind pressure [19]

2) Misalignment (imperfections)

Imperfections occur due to geometric deviations or slenderness of the structure. Imperfections shall be taken in to account only in the ultimate limit state, but not in the serviceability limit state. Imperfections can be represented by inclination θ_i and is given by (Eurocode 2) [11]. See Figure 3.65.

$$\theta_i = \theta_0 \cdot \alpha_h \cdot \alpha_m \tag{3.143}$$

Where:
θ_0 is the basic value ≈ 1/200 = 0.005
α_h is the reduction factor for length or height ≈ $2 / \sqrt{l}$; $2/3 \le \alpha_h \le 1$
α_m is the reduction factor for the number of structural members
$\alpha_m \approx \sqrt{[0{,}5 \times (1 + 1 / m)]}$
l is the length or height in meters
m is the number of vertical structural members contributing to the total effect.

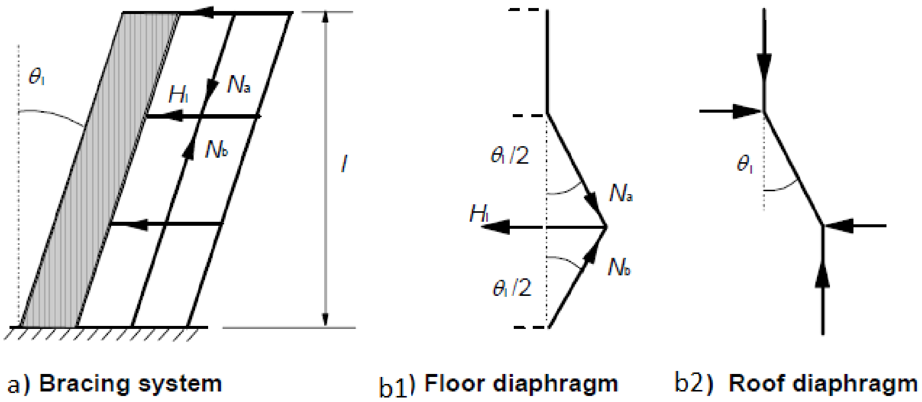


Figure 3.65: Effect of geometric imperfections [11] (Eurocode 2)

Effect of the inclination θi may be represented by horizontal forces (Hi) and is calculated as follow.
1) Effect on the bracing system:

$$H_i = \theta_i \cdot (N_b - N_a) \quad \text{in each floor} \tag{3.144}$$

Where $(N_b - N_a)$ is floor load that belongs to the current floor.

2) Effect on floor diaphragm:

$$H_i = \theta_i \cdot (N_b + N_a)/2 \tag{3.145}$$

3) Effect on roof diaphragm:

$$H_i = \theta_i \cdot N_a \tag{3.146}$$

Where Na and Nb are longitudinal forces from vertical loads contributing to H_i.
The misalignment load H_i from geometric deviations should always be included in the load combination.
For most ordinary buildings θ_i will be in the range from 0.0024 to 0.0038.

3.2. Life cycle assessment (LCA)

3.2.1. Introduction

The climate in the world has changed a lot. According to the UN's Intergovernmental Panel on Climate Change (IPCC), human activity is the main cause of the increase in temperature. Effects have been observed all over the world due to climate change. The changes in precipitation have affected both the access and the quality of water in many places around the world [43].

The Paris Agreement is an international agreement that will ensure that the world's countries manage to mitigate climate change. The countries that are obligated in the Paris Agreement are 186 countries, Norway is one of them. Thus, the countries will take action to reduce the temperature rise. One of the main points of the agreement is to limit the temperature rise to 1.5 degrees [44].

Increasing population growth will result in further densification of cities. Therefore, stricter requirements and standards that promote energy efficiency are important [45].

3.2.2. Background

In the initial phase of the work on the LCA analysis in this report, various sources of related studies were investigated. A selection of the work is presented in this chapter. Engineers and architects around the world are building very tall wood constructions. It is important to show that wood is also an alternative solution for building. It turns out that wood constructions have less CO2 emissions than steel and concrete [46].

The conclusion that the timber is a top choice building material is coming. After researching and by studying three different building materials: wood, concrete and steel, it turns out that timber is the top choice for building materials when considering reductions in Global Warming. It is important to notice that the wood structures would be a better choice if one considers carbon stored in wood products over the lifetime of the construction [47].

It was also shown in the preliminary project that building a residential block with using mostly wood material in the structure is the best choice with regard to the environment [16].

3.2.3. LCA methodology

This part of the report goes deeper into different parts of the LCA methodology. The following will be explained:
Goal and scope definition
Inventory analysis
Life cycle impact assessment
Interpretation and presentation of results

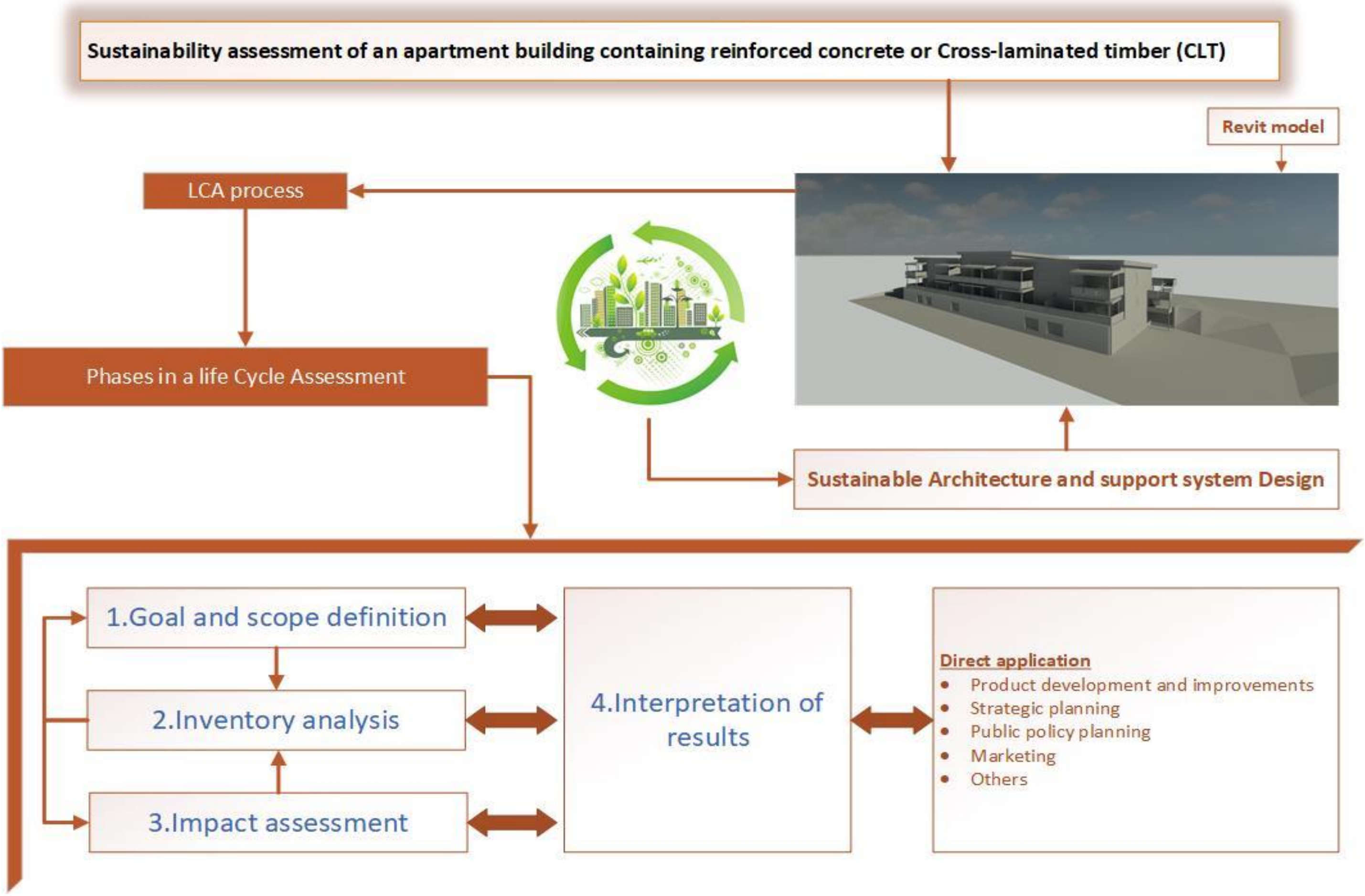


Figure 3.66: LCA methodology(Phases in a life Cycle Assessment)[1]

1. Goal and scope definition

It is important to define what is the goal of an LCA study. First, the goal and scope definition phase of an LCA study must be defined. After that, the goal must be determined. The scope and requirements for modeling an LCA study shall be specified based on the goal. This phase is crucial in LCA studies. Ideally, all choices, specifications, modeling requirements are determined in the goal and scope definition phase. Most value choices should be determined in the goal and scope definition phases. There should be no change in the subsequent LCA phases except for very few changes. It is important and advantageous to plan as many choices as possible early in an LCA study[1, 48].

<u>Goal and context of the study</u>

The goal definition is defined in the ISO standard(ISO 14041 1998) as (shall unambiguously state the intended application, the reason for carrying out the study and the intended audience). These things have to do with the conditions of the study[1].
For example:
Why doing this LCA study
How doing this LCA study

Who is going to using the result of the LCA study

There are several reasons behind the performance of an LCA. For example, explore, learn about the life cycle, support product development, strategic planning. There are different intentional audiences and it depends on the programs. The intended audience can, for example, be the authority that requires that CO2 intact be reduced. The intended can also be product developers, top management, customer or combinations between these categories.
Often at the start of an LCA study, the goal is quite vague and formulated superior. For example (LCA analysis on an apartment block). Furthermore, if this converter to more specific then it becomes, for example, (sustainability assessment of an apartment building with reinforced concrete or cross-laminated timber (CLT)). It is important that the superior goal is transformed into more specific so that one chooses the relevant methodology in subsequent modeling [1].

The purpose of the LCA study can be formulated as a question.
Example:
Where are the improvements possibilities in the life cycle of the apartment block?
Which activities or materials in the life cycle that contribute most to the environmental impact associated with the housing block?
What would the environmental consequences be when changing processes or materials in the life cycle of the apartment block?
What would the environmental consequences be when using material A,B or C?
What is the environmentally best choice between option 1, option 2 and option 3 that is used for the apartment building?

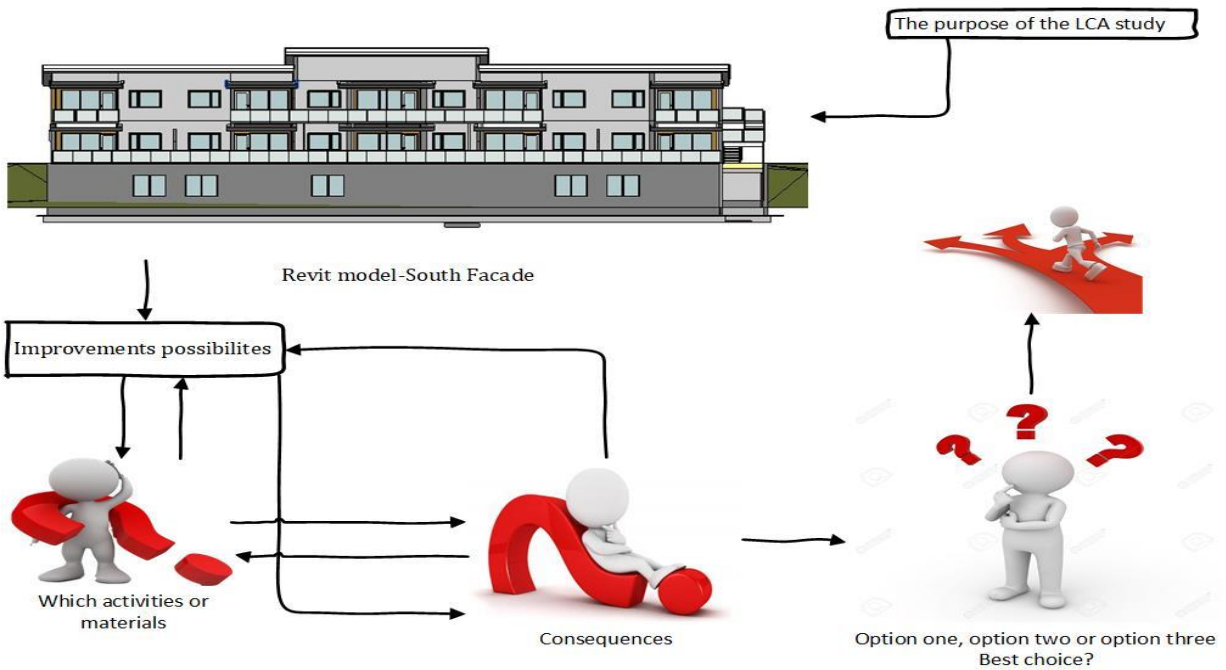


Figure 3.67: The purpose of the LCA study

Scope and modeling requirements
Necessary choices when deciding the scope of the study:

Which options to model
Determine which specific products, product design or process options are to be investigated. For example, to find the difference between option one, option tow and option three in the housing block. It is important to ensure that comparative alternatives are really technically comparable [1, 48].

Initial flowchart
At the start of a LCA study, it is useful to create a first flow chart for the entire system to be prepared and studied. The flow chart shall include all studied alternatives or products. The flow chart should be general and not detailed. Figure 3.68 shows such a flow chart for the housing block's life cycle [1, 48].

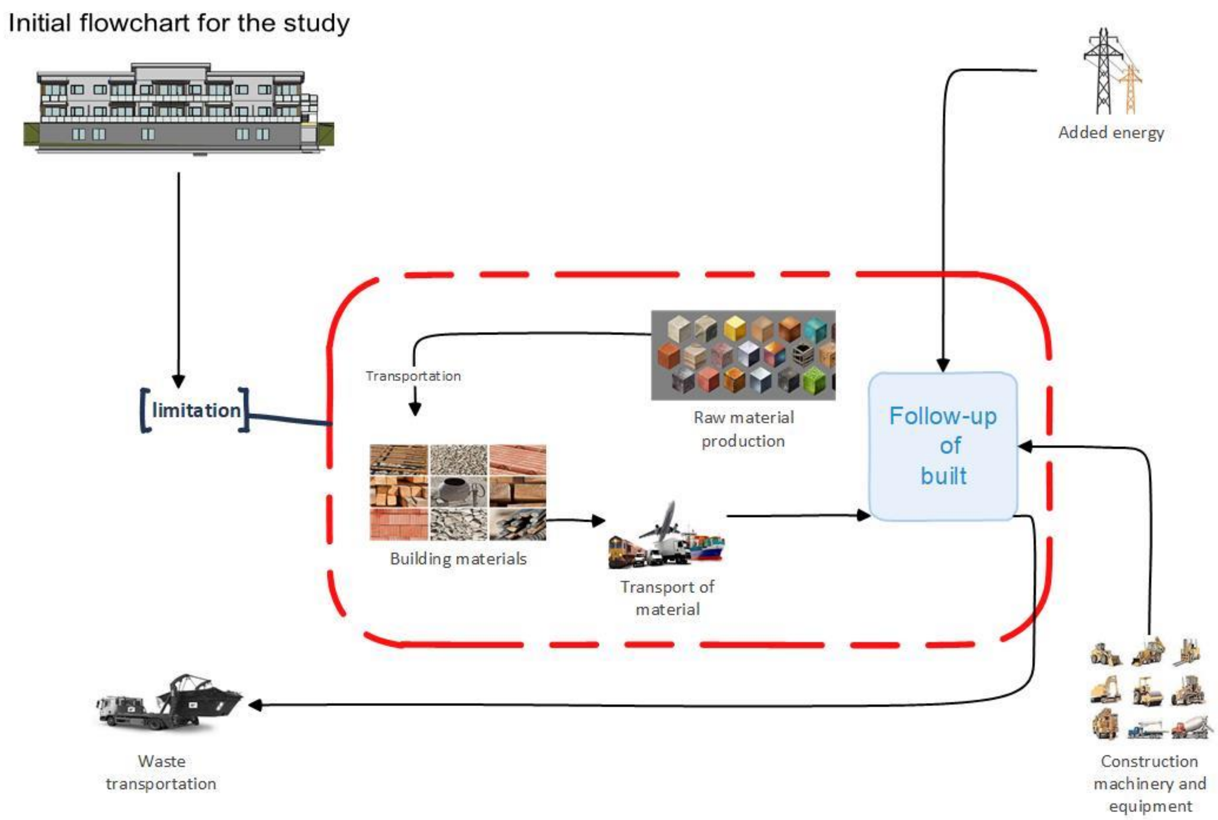


Figure 3.68: Initial flowchart for the study

Functional unit
After deciding the goal, the products and the system then functional unit should be defining. Both products or processes have more than just one function. It is often easier to define the functional unit for the LCA study of single products. It is more difficult to define the functional unit in LCA comparative studies. One reason is that the functional unit is used as the basis for comparison in an LCA comparative study. It is important that the function correlates fairly with the function of the comparative options[1, 48]. The selected function unit is Kg - this report deals with the building's

structural systems. The study is also tried to be as realistic as possible by including transport of building materials to the construction site.

Choice of impact categories and method of impact assessment
In the LCA study, the concepts of environment and environmental impact must be taken into account and assessed. In addition, it is necessary to find out which environmental impacts should be taken into account. The way to interpret the results must be decided. It is possible to interpret in inventory phase. Such a study is called a life cycle inventory analysis. Impact assessment and different ways to interpret results are presented in chapter 7.2 [1, 48].

<u>System boundaries</u>
In the analysis, processes that have significance to the result are included. There are processes that are not included because the values of these processes would be the same in all three options. If these values are included, the result will neither change nor make a noticeable difference. In the study, a truck was used during all transport of material because this is the main means of transport used for this in Norway. It is also assumed no operation since it is the support structure to be considered. The raw material used in the study is global in SimaPro program. Which mean at geographical boundaries are at global stage. See Figure 3.69.

- During the construction phase, it is included:
- Energy for production.
- Materials for building parts.
- Transport of materials to the construction site.
- Transport to raw goods production.

- It is not included during the construction phase:
- Construction machinery and equipment
- Transport of personnel to construction site
- Transport of personnel from construction site
- Transporting materials to construction site
- Transporting materials from construction site
- Maintenance and replacement of materials. It has taken a lifetime of 60 years.
- Stationary average energy consumption during the operating phase.
- Passenger transport related to the users of the building during the operational phase.
- Goods transport related to the users of the building during the operational phase.
- Transport related to the replacement of building materials is included.

<u>Allocation</u>
Usually allocation is used in systems that have multiple outputs and or multiple inputs. Allocation is used to give a fair result of LCA. An example in this report is not just show the building as a whole, but also show each material responsibility for impact. Example how much CO2 does steel material emit. Allocation procedure from ISO 14040[1].

1) Whenever possible, avoid allocation by:
    a. Increasing the level of model detail
    b. Apply system expansion

2) If allocation required, use partition(Allocation)
   Apply some form of physical relationship if possible
3) If physical relationship cannot be established, use some other relation: economy, mass, energy, or other.

2. Inventory analysis

To review an Inventory analysis means to design a flow model of a technical system. The flows within the system typically include only environmentally relevant flows. Steps of the life cycle inventory analysis (LCI) is:

1) Create a flowchart according to the system boundary. System boundaries are defined in the goal and scope definition. Look at the Figure 3.68 and Figure 3.69.
2) Data collection. Putting all the activities in the product system in a table chart. Activities followed by documentation of collected data. See Table 3.30, Table 3.31 and Table 3.32.
3) Computation of the environmental loads.

This section describes how to build an LCI model and also the method for performing the calculations. After step two is done, that is data gathered and one has got a better understanding of the studied system. Sometimes it is required and necessary to change decisions that are made in the goal and scope definition phase[1]. In practice, the line between the goal and scope definition phase and the inventory analysis phase is not as clear as the Figure 3.66.

<u>Construction of a flowchart</u>
All modeling requirements and principles for system boundaries are determined in the goal and scope definition phase. At the same time, the first general flow chart is designed. In the inventory analysis phase, the same flow chart must be prepared deeper. Thus, a detailed flow chart including all modeled activities and the flow between them will be built[1]. An example of a generic flowchart is shown in the Figure 3.68. The detailed flow chart for this project that was developed is shown in Figure 3.69.

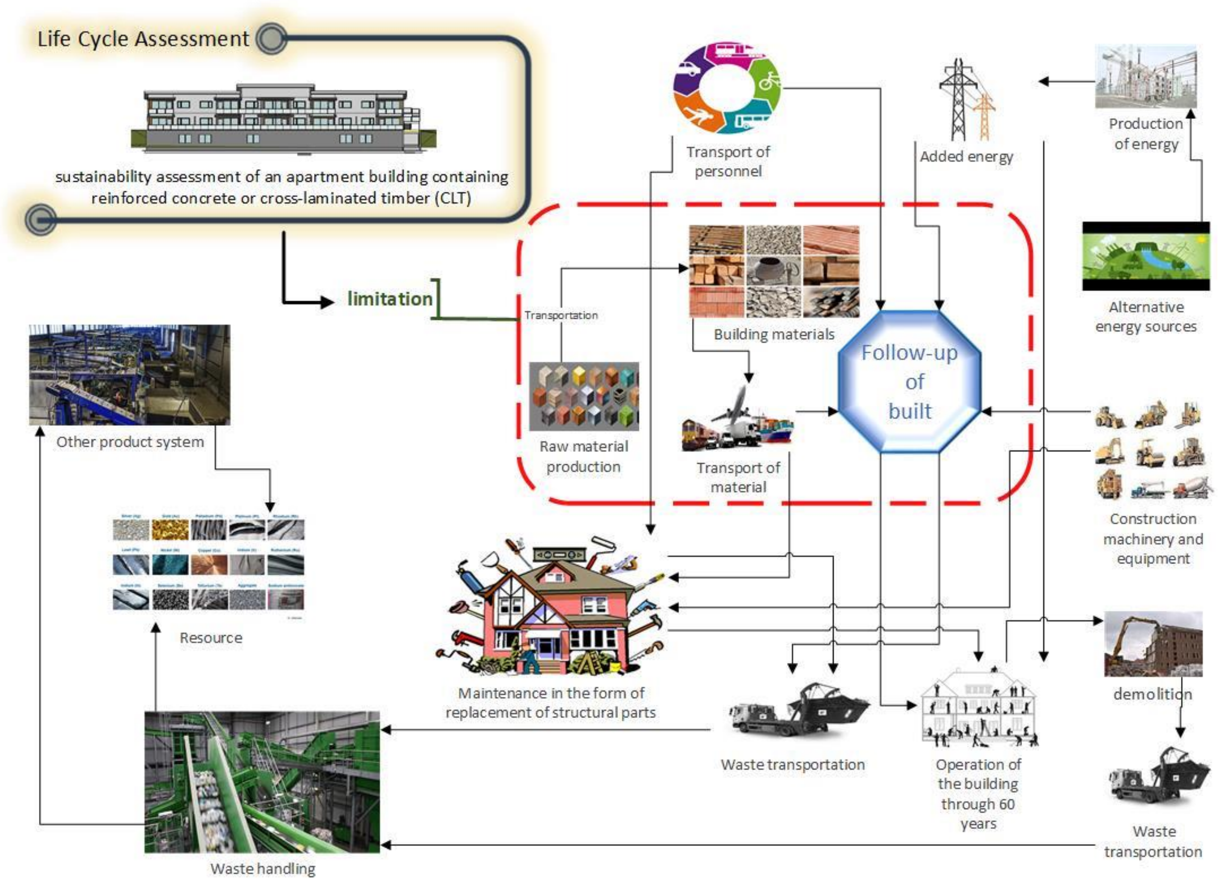


Figure 3.69: Detailed flow chart for the study

<u>Data collection</u>

It is very time-consuming to collect data. The type of data to be collected must be taken into account. In addition, how to proceed to find LCA data[1].

Which data

The data is numerical. It is necessary to Collect qualitative data. The numerical data should include both inputs and outputs to all modeled activities[1].

The following amounts and types are necessary to decide:

1) Inputs of raw materials and energy, ancillary inputs and other physical inputs (for example Land use)
2) Products
3) Emissions to air, water and land and other environmental aspects (for example noise).

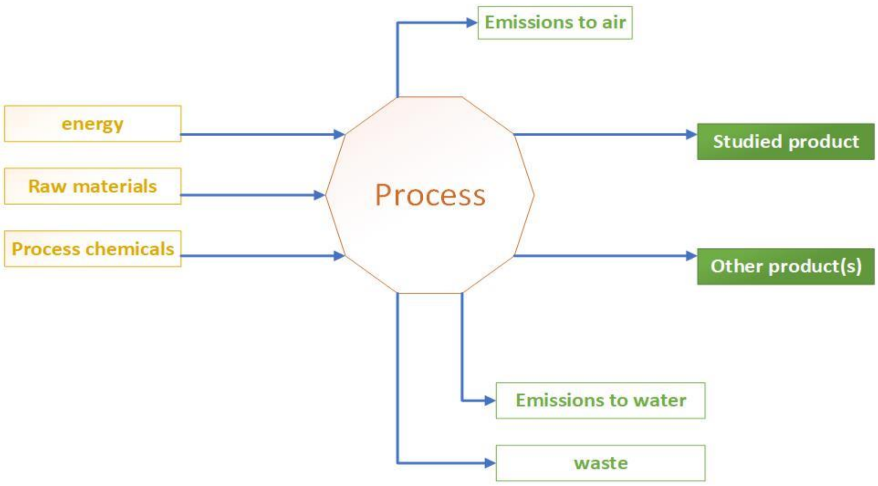


Figure 3.70: Typical necessary categories of numerical data that is needed to describe a process[1]

Distance data and route data for transportation is required. This data is used to find energy use and emissions from different modes of transport.

Data sources

An example of data collection procedures is shown in Table 3.29. This example is an LCA study on documentation systems(Paper-based documentation compared with CD-ROM-based documentation) (Baumann 1998b). This example provides guidance on a more general level about where to search for LCI data. In this project the environmental data, transport and all other data for raw materials are used from SimaPro. Environmental Product Declarations (i.e. EPD Norge) has been used as EPD data source in this project[1].

Table 3.29: Data search strategies and their success rates (From Baumann 1998b)[1]

	Successful	Dead ends	Total
Browsing(e.g, in shops)	1	1	2
Phone directory	2	1	3
Experimental(e.g., weighing)	3	1	4
Tip from the data supplier	7	1	8
Search library or www	2	No information	(2)
Tip from colleague or acquaintance	6	5	11
Unknown	1	1	2

Calculation procedure

1) Normalize data for all the activities for which data have been collected. Every data need to be recalculated to be valid, for example, 1 kg or 1 ton of product.
2) Calculate the flows linking the activities in the flowchart, using the flow representing the functional unit as a reference. This is mean to setting up relationships between inflows and outflows. In other words creating mass balances for every individual activity.
3) Calculate the flows passing the system boundary, again as related to the flow representing the functional unit.
4) Sum up the resource use and emissions to the environment for the whole system.
5) Document the calculations.

LCI data in this project is shown in Table 3.30, Table 3.31 and Table 3.32.

Table 3.30: LCI data in this project(Process A)

A				
Process (output)	Inputs		Value	Unit
Cross-laminated timber structures		100%	1	kilogram
	Sawn timber	(98,16%)	0,9816	kilogram
	Glue	(1,84%)	0,0184	kilogram
Glued-laminated timber		100%	1	kilogram
	Wood of spruce, dry weight	(88.27%)	0,8827	kilogram
	Water in wood	(10.59%)	0,1059	kilogram
	Glue, dry weight	(1.14%)	0,0114	kilogram
	Plastic for packaging	(0,34%)	0,0034	kilogram
Normal concrete		100%	1	kilogram
	Chemicals (SP)	(0,16%)	0,0016	kilogram
	Water	(6,69%)	0,0669	kilogram
	Aggregate	(78,55%)	0,7855	kilogram
	Cement	(14,16%)	0,1416	kilogram

	SCM (Silica fume)	(0,44%)	0,0044	kilogram
Low carbon concrete		100%	1	kilogram
	Cement	(11,91%)	0,1191	kilogram
	Aggregate	(77,23%)	0,7723	kilogram
	Water	(6,73%)	0,0673	kilogram
	Chemicals (SP)	(0,16%)	0,0016	kilogram
	SCM Silica fume: Flay ash:	(3,97 %) (0,567%) (3,403%)	0,0397 0,00567 0,03403	Kilogram
Reinforcement		100%	1	kilogram
	Fe – Iron	(98-99) %	0,985	kilogram
	C – Carbon	(0,05-0,02) %	0,003	kilogram
	Si- Silicon	(0,2%)	0,02	kilogram
	Mn-Manganese	(0,3-0,7) %	0,05	kilogram
Steel structures		100%	1	kilogram
	Steel	(98,6%)	0,986	kilogram
	Welding consumables	(1%)	0,01	kilogram
	Coating/finish	(0,4%)	0,004	kilogram
Fire insulation for steel		100%	1	kilogram
	Stones		0,902	kilogram
	Secondary resources mostly slag		0,251	kilogram
	Cement		0,087	kilogram
	Formaldehyde	(37%)	0,052	kilogram
	Urea	(46%)	0,021	kilogram
	Phenol		0,016	kilogram

Table 3.31: LCI data in this project(Process B)

B				
Process (output)	Inputs		Value	Unit
Reinforced normal concrete		100%	1	kilogram
	Reinforcement	(4%)	0,04	kilogram
	Normal concrete	(96%)	0,96	kilogram
Reinforced low carbon concrete		100%	1	kilogram
	Reinforcement	(4%)	0,04	kilogram
	Low carbon concrete	(96%)	0,96	kilogram
Steel		100%	1	kilogram
	Steel structures	(100%)	1	kilogram
Glulam		100%	1	kilogram
	Glued-laminated timber	(100%)	1	kilogram
Fire insulation for steel structures		100%	1	kilogram
	Fire insulation for steel	(100%)	1	kilogram
Cross-laminated timber		100%	1	kilogram
	Cross-laminated timber structures	(100%)	1	kilogram

Table 3.32: LCI data in this project (Process C)

C			
Process (output)	Inputs	Value	Unit
Option 1		1351400,89	kilogram
	Reinforced normal concrete	1077721,62	kilogram
	Glulam	5116,34	kilogram
	Cross-laminated timber (CLT)	254567,15	kilogram
	Steel	13995,78	kilogram
	Transport, freight, lorry >32 metric ton	54841,687	tkm*
	Transport, freight, lorry >32 metric ton (CLT)	38414,1829	tkm*
Option 2		1351400,89	kilogram
	Reinforced low carbon concrete	1077721,62	kilogram
	Glulam	5116,34	kilogram
	Cross-laminated timber (CLT)	254567,15	kilogram
	Steel	13995,78	kilogram
	Transport, freight, lorry >32 metric ton	54841,687	tkm*
	Transport, freight, lorry >32 metric ton (CLT)	38414,1829	tkm*
Option 3		1240186,54	kilogram
	Reinforced low carbon concrete	943214,77	kilogram
	Glulam	5116,34	kilogram
	Cross-laminated timber (CLT)	277859,65	kilogram
	Steel	13995,78	kilogram

	Transport, freight, lorry >32 metric ton	48116,3445	tkm*
	Transport, freight, lorry >32 metric ton (CLT)	41929,0212	tkm*

* tkm in construction process: transport of materials to and from construction site.

Table 3.33: Material quantities used as input to LCA

Nr.	Elements	Option 1 (kg)	Option 2 (kg)	Option 3 (kg)	Comment
1	Beams	3871,78 (Glulam) + 10515,21 (steel)	3871,78 (Glulam) + 10515,21 (steel)	3871,78 (Glulam) + 10515,21 (steel)	
2	Columns	1244,56 (glulam) + 3480,57(steel)	1244,56 (glulam) + 3480,57(steel)	1244,56 (glulam) + 3480,57(steel)	
2	Floors	168 199,84 (CLT) + 326 165,28 (normal concrete)	168 199,84 (CLT) + 326 165,28 (low carbon concrete)	168 199,84 (CLT) + 326 165,28 (low carbon concrete)	*CLT: Floors and roof* *Concrete works: Ground floor slab*
	Insulation EPS	6 058,91	6 058,91	6 058,91	*It is common for all options. Therefore, it is not considered in the analysis.*
	Insulation XPS	625,16 + 443,60	625,16 + 443,60	625,16 + 443,60	
4	Walls	522 907,04 (normal concrete)	522 907,04 (low carbon concrete)	388 400,19 (low carbon concrete) + 23 292,50 (CLT)	*Option 3: concrete walls in basement floor*
5	Roofs	86 367,31 (CLT)	86 367,31 (CLT)	86 367,31 (CLT)	
6	Foundations	228 649,30 (normal concrete)	228 649,30 (low carbon concrete)	228 649,30 (low carbon concrete)	
	Sum…	5116,34 kg (glulam) 13995,78 kg (steel) 254567,15 kg (CLT) 1077721,62 kg (normal concrete) 1351400,89(total)	5116,34 kg (glulam) 13995,78 kg (steel) 254567,15 kg (CLT) 1077721,62 kg (low carbon concrete) 1351400,89(total)	5116,34 kg (glulam) 13995,78 kg (steel) 277859,65 kg (CLT) 943214,77 kg (low carbon concrete) 1240186,54(total)	

Material quantities (Table 3.33) for the structural systems are taken from the 3D models in Revit (see Appendix H).

EPDs of the materials (process A, Table 3.30) are picked from the database of the Norwegian EPD foundation and SimaPro. See Appendix F.2 for EPD documentation.
The values for transport for the construction process are put into process C, Table 3.32. Transport distance for concrete, steel, glulam and so forth is assumed to be 50 km.
Whereas cross laminated timber (CLT) is assumed to be purchased from SPLITKON. SPLITKON is a company that produce CLT in Norway. The transport distance for CLT is 150.9 km to the construction site. See Figure 3.71 and Figure 3.72.

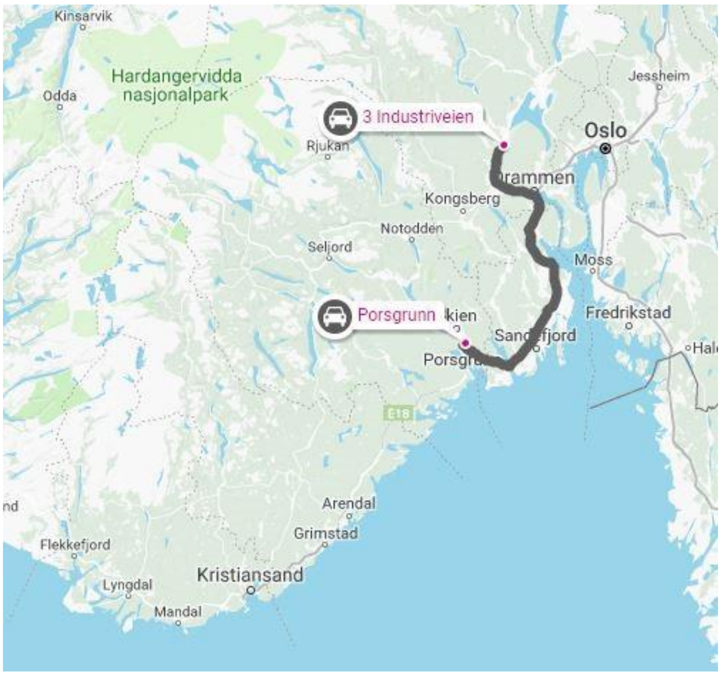


Figure 3.71: Transport CLT

Figure 3.72: Transport distance CLT

3. Life Cycle impact assessment

Phase number three in an LCA study is called Life Cycle impact assessment (LCIA). This phase aims to describe the environmental consequences of the environmental loads calculated in the inventory analysis. The impact assessment can be found by translating the environmental loads from inventory results to environmental impact. Example of environmental impact is acidification, ozone depletion, Global Warming, human toxicity, etc.
in this phase the purpose is to make the results more environmentally relevant. In addition, the results here should be understandable and easier to communicate. Another purpose is to make the results readable. Furthermore, in this phase one can make the results comparable[1, 49].

The different phases of life cycle impact assessment

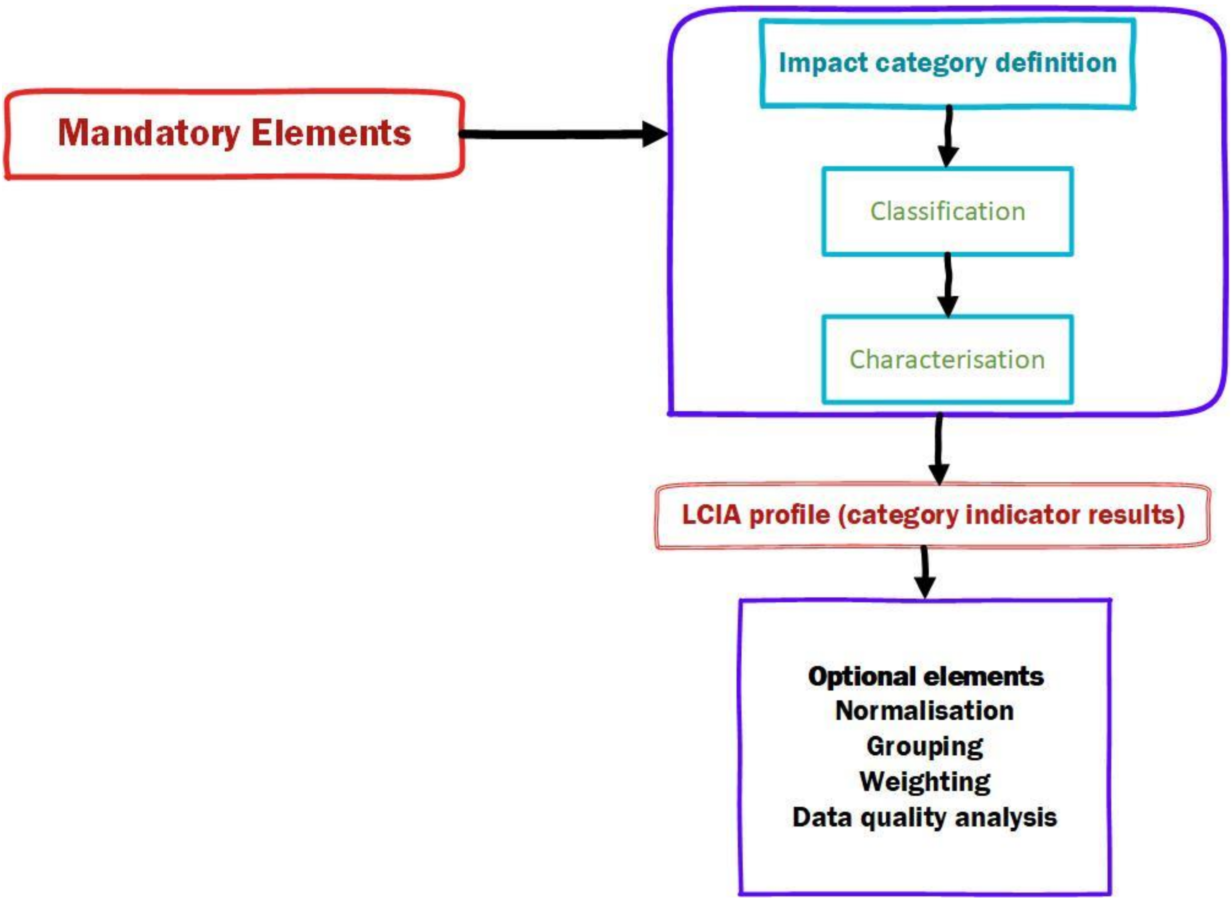


Figure 3.73: life cycle impact assessment (LCIA) according to ISO 14042(2000)[1]

Some of the phases are mandatory in LCIA. Some other Phases are optional for an LCA.
The core LCIA sub-phases consist of classification, characterisation and weighting. Typically, an LCA practitioner deals with these phases when performing an LCA study[1, 49].
Impact category definition

In this phase the set of impact categories is defined. There are several suggestions on complete sets of impact categories. One example is shown in Table 3.34.

Table 3.34: List of impact categories according to Nordic Guidelines on Life-Cycle Assessment (Nord 1995). The categories can be further divided into sub-categories as noted in the footnotes.[1]

Impact categories
1[a]. Resources- Energy and material
2. Resources- Water
3. Resources- Land (including wetlands)
4[b]. Human health – Toxicological impacts (excluding work environment)
5[b]. Human health – Non-toxicological impacts (excluding work environment)
6[b]. Human health impacts in work environment
7. Ecological consequences – Global Warming
8. Ecological consequences – Depletion of stratospheric ozone
9. Ecological consequences – Acidification
10. Ecological consequences – Eutrophication
11. Ecological consequences – Photo-oxidant formation
12. Ecological consequences – Ecotoxicological impacts
13[c]. Ecological consequences – Habitat alterations and impacts on biodiversity
14[d]. Inflows which are not traced back
15[d]. Outflows which are not followed back
a. This impact category can be divided into several sub-categories. For examples, a division can be made between energy and materials. Another division can be made between renewable and non-renewable resources. These choices can be made in relation to the choice of characterisation methods.
b. Work environment is one among other exposure situations for humans. Here, it is suggested to treat this situation separately, partly because available characterisation methods often make this distinction.
c. Several of the impact categories can cause (Habitat alterations and impacts on biological diversity) as a second order effect. This impact category, however, is related to activities and emissions that have a direct impact on habitats and biodiversity.
d. Not impact categories, but should be included.

Classification simply means sorting or assigning the LCI result parameters to the various impact categories.
Characterisation is mean calculating the extent of the environmental impact per category. Weighting means assembling of characterisation results across impact categories.
In this project it has been used CML characterization method. It focused on midpoint characterization[1]. Impact category that has been used to characterizing the three option in this project is shown in the Figure 3.75.

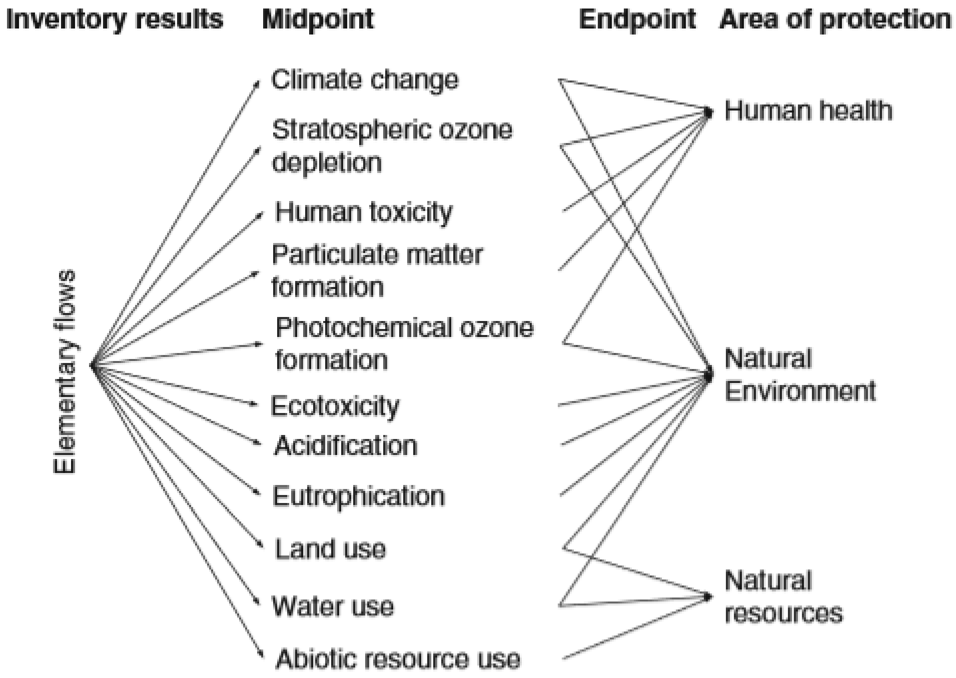


Figure 3.74: Framework and example of midpoint impact categories illustrating their relation to the areas of protection[1]

Se	Impact category	Unit
☑	Global warming	kg CO2 eq
☑	Stratospheric ozone depletion	kg CFC11 eq
☑	Ionizing radiation	kBq Co-60 eq
☑	Ozone formation, Human health	kg NOx eq
☑	Fine particulate matter formation	kg PM2.5 eq
☑	Ozone formation, Terrestrial ecosys	kg NOx eq
☑	Terrestrial acidification	kg SO2 eq
☑	Freshwater eutrophication	kg P eq
☑	Marine eutrophication	kg N eq
☑	Terrestrial ecotoxicity	kg 1,4-DCB
☑	Freshwater ecotoxicity	kg 1,4-DCB
☑	Marine ecotoxicity	kg 1,4-DCB
☑	Human carcinogenic toxicity	kg 1,4-DCB
☑	Human non-carcinogenic toxicity	kg 1,4-DCB
☑	Land use	m2a crop eq
☑	Mineral resource scarcity	kg Cu eq
☑	Fossil resource scarcity	kg oil eq
☑	Water consumption	m3

Figure 3.75: Impact category from SimaPro which is used in this project

4. Interpretation and presentation of results

The process of considering results from SimaPro in order to draw conclusion is called interpretation in LCA terminology. It is possible to bring many different diagrams from SimaPro. The use of different types of diagrams from SimaPro Is very helpful in this process. The evaluation of conclusion is also part of the interpretation phase. Furthermore it should be given recommendations and reporting in the interpretation phase. The interpretation has been detailed in chapter 7.2. Figure 3.76 illustrates the life cycle interpretation [1].

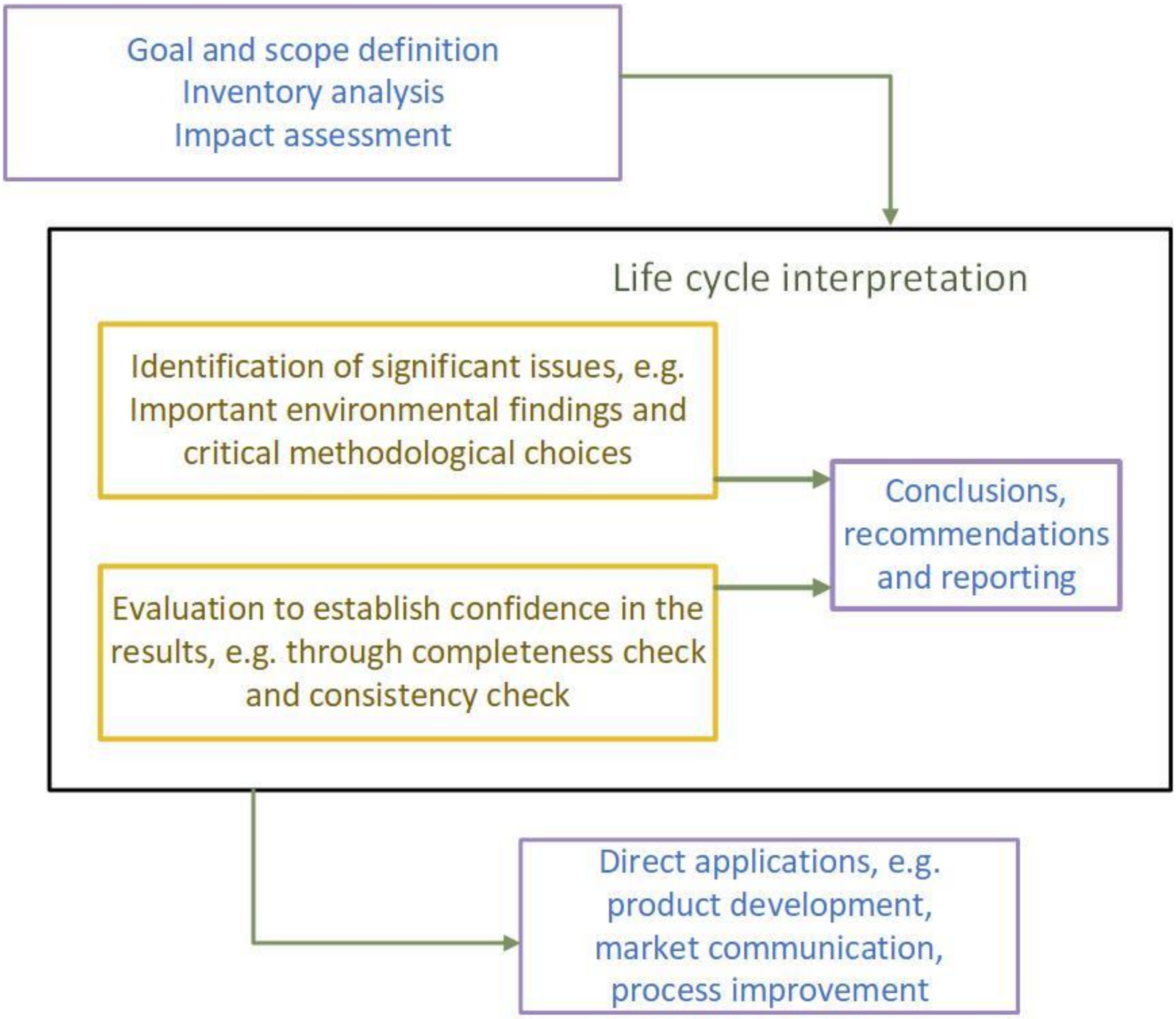


Figure 3.76: The structure of the interpretation phase in LCA (ISI 14043 2000)[1]

It has been used diagrams for showing a comparison of normalised characterisation results for the three options in this project. The information from the inventory to the characterisation level has been aggregated to the extent where all parameters can fit into one diagram, see Figure 3.77[1].

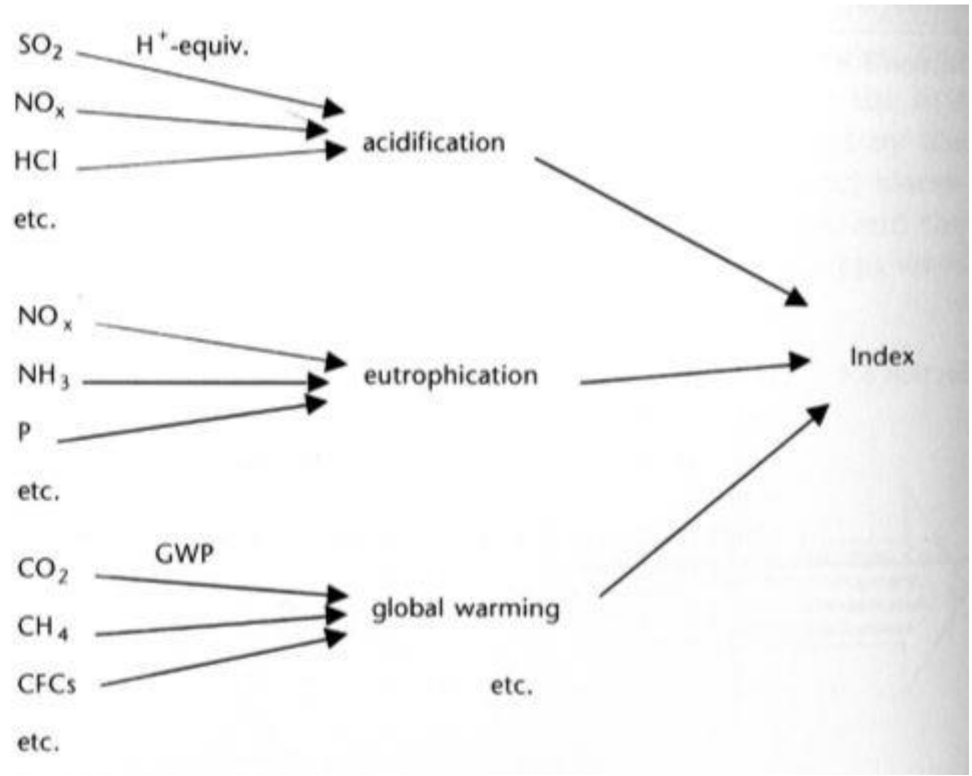


Figure 3.77: Illustration of the stepwise aggregation of information in LCA[1]

3.3. Construction Cost Estimation

Cost estimating:

Estimating a construction cost is the most practical aspect of construction management. It is part of the engineering work. The purpose of estimating is to give a reasonable idea of the cost. This will help owners to decide whether the work is feasible or not. Estimating is normally broken down into materials estimating, labour estimating, plan or equipment estimating and time estimating.
There are several types of estimating techniques and can be divided into two main categories and are:

- Approximate estimates
- Detailed estimates

An approximate estimate is a rough estimate. Whereas, a detailed estimate is calculated from exact quantities and will give a best and reliable estimate. A detailed estimate may be made in two ways and are unit quantity method and total quantity method. In unit quantity method, the work is itemized and a unit measurement is decided. This method has advantages as the quantities can easily be corrected [50].

Construction process

Quantities of various items are calculated either manually or generate from a 3D model of the construction. The accuracy of the quantities depends upon the phase of the project.
Normally a project has many phases or stages. They are:

- Concept

- Contracts and Bid Documents
- Bidding
- Construction
- Construction Payments
- Completion

The concept phase is a stage where architects start to develop planning and design. They control the overall design, specifications, finishing materials, etc. In the concept phase a rough cost estimation can be done. The estimation can be under or over the actual cost. However, it will give a good cost overview to the client.

Contracts and bid documents are the stage where the builder provide bidders with working drawing and plans, specifications etc. Here architectural plans, structural plans, Mechanical plans, electrical plans and contract specifications are prepared. In this stage, a correct estimating can be obtained.

Bidding is the third stage. In this stage, the owner determines that the project is feasible. Contractors will be invited to bid on the construction job. Contractors use standard cost manuals or building construction data to compute the bid. In Norway consultants and contractors use database like holtekalkulasjonsnøkkel, Norsk prisbok etc. to get the unit prices for construction items.

Construction (Fieldwork) is the fourth stage. The actual project is under construction. Fieldwork is broken down into building permits, subcontractors, scheduling subcontractors, shop drawings, project submissions.

The completion stage is the final phase of the construction process. Here as built plans, notice of completion etc. will be ready [51].

Norwegian standard NS 3453:2016, the standard for specification of construction costs, is a standard that can be used as an aid to structure financial routines in construction projects. It is for example used for budgeting, calculation, pricing etc.
The standard uses different summation levels. They are common cost, house cost, construction cost, basic cost, project cost and cost framework. The construction elements and summation levels are illustrated in the table below [52].

Table 3.35: elements cost and summation levels for construction project [52]

Summation levels	Cost components		
	1. Common cost	rig, operation, construction site management	**Enterprise costs** (all contractor's costs excluding VAT)
House cost ....(sum 1+2)	2. Buildings and installations		
Enterprise cost........(sum 1 to 3)	3. Outdoors		

Construction cost....(sum 1 to 4)	4. General costs	Design, administration, overhead, etc.	**Builder costs**
	5. Special costs	loose fixtures, equipment, plots, financing	
Base Cost............... (sum 1 to 6)	6. Value-added tax (VAT)		
Project cost............ (sum 1 to 7)	7. expected supplements	provision and supplements beyond the basic cost	
Cost framework...... (sum 1 to 8)	8. Uncertainty deposition	provision beyond project cost beyond project cost	

In this master's thesis the project is assumed to be in the second stage, contracts and bid documents. On this stage structural plans will be prepared including foundation plans. Here, a unit quantity method is going to be adopted. By doing so, a reliable construction cost can be calculated.

Exact quantities will be extracted from a detailed 3D model for all items. The quantities can be in m2, m3, kg, m depending on the unit price of the items. The total cost per unit quantity of each item is collected from the Norwegian construction cost database Norsk Prisbok and holte-kalkulasjonsnøkkel. Norsk Prisbok is an updated price database in book form, on the internet and on mobile phones [53]. Holte-kalkulasjonsnøkkel er Norway's most used calculator tools for building and civil engineering works [54].

Generally, the following formula is adopted based on the unit quantity method.

Total cost per item = cost per unit quantity of the item x total quantity of the item

3.4. Eurocodes and Norwegian standard

It is the Norwegian standard and the Eurocodes that show what is expected of responsible project designers for the various subjects. Common to the standards is that they are based on the principle of the partial coefficient method. The most important standards are listed below:[16]

- NS-EN 1990 Eurocode 0: Basis of Structural Design .
- NS-EN 1991 Eurocode 1: Actions on structures (load on structures)
  - NS-EN 1991-1-1 : General actions - Densities, self-weight, imposed loads for buildings
  - NS-EN 1991-1-2: General actions - Actions on structures exposed to fire
  - NS-EN 1991-1-3: General actions - Snow loads .
  - NS-EN 1991-1-4: General actions - Wind actions .

    - NS-EN 1991-1-5: General actions - Thermal actions .
    - NS-EN 1991-1-6: General actions - Actions during execution
    - NS-EN 1991-1-7: General actions - Accidental actions .
- NS-EN 1992 Eurocode 2: Design of concrete structures.
- NS-EN 1993 Eurocode 3: Design of steel structures.
- NS-EN 1994 Eurocode 4: Design of composite steel and concrete structures
- NS-EN 1995 Eurocode 5: Design of timber structures .
- NS-EN 1996 Eurocode 6: Design of masonry structures .
- NS-EN 1997 Eurocode 7: Geotechnical design
- NS-EN 1998 Eurocode 8: Design of structures for earthquake resistance .
- NS-EN 1999 Eurocode 9: Design of aluminiunl structures .[31]

3.5. Software used in the project

3.5.1. CAD-Tool – Autodesk Revit

Revit is building information modelling (BIM) software which includes features for architectural design, structural design, plumbing, electrical and mechanical work. The program is constructed based on parametric elements instead of lines. From the beginning, the program had intensions to allow architects and other building professionals to design a building by creating a parametric three-dimensional model that includes both geometry and information about the building [55].

Revit projects can be done using only the original format of the program (.rvt). Revit imports different formats, among these are CAD and images. It also links different formats like IFC models, Revit models and so on.

3.5.2. FEM-Design

FEM-Design is an advanced 3D modeling software for finite element analysis and design of steel, timber and concrete structures.

3.5.3. LCA-simulation Tool – SimaPro

SimaPro is a simulation tool for LCA. It is a professional tool to collect and analyze products and services. It can be used for different applications such as environmental product declarations, product design, sustainability reporting, carbon and water footprints among others. In this project, it was used for life cycle assessment of the project's structural systems analysis.

3.5.4. Ove Sletten-program

Ove-Sletten is a program for the design of concrete structures. We used the program to design foundations and basement walls.

3.5.5. CLT designer

CLT designer is a special program for design of solid wood elements (cross-laminated timber). In this project, it was used for design of CLT floor and roofs.

3.5.6. Other Programs

Many other programs have been used for different tasks. Microsoft Visio was used to create illustrations. Microsoft Excel was used for calculation and making tables and pie charts. Mathcad was used for design of timber connections. AutoCAD was used for illustration figures in the theory chapter. Microsoft project was used for making progress plan.

4. Research Question

This master's thesis will attempt to answer the following question:
Which structural material is sustainable considering structural stability and construction cost?

- Which material is more sustainable, reinforced concrete (normal and low carbon) or Cross-laminated timber (CLT)?
- What are the major differences, advantages and challenges between the concrete types, low-carbon concrete and normal concrete?
- What are the restrictions and limitations for reinforced concrete and Cross-laminated timber (CLT)?

5. Case/materials

5.1. Description of Project

In this master thesis, we focused on a three-story apartment building with three options that we have compared to each other. The basement is used as a parking space and the other floors as apartments. The starting point to design the project are architect's drawings that are in PDF, DWG and IFC formats. The apartment building is described as rectangular and slender, with a base area of approx. 753.35 m2. The parking basement is measured to approx. 44.0 m x 17.47 m. whereas the measurements of the apartment floors are 41.26 m x 12.30 m. Regarding the floor heights, they vary slightly and are approx. 3.0 meters. In addition, the roof has a slope of approx. 4 degrees.

As mentioned, the apartment housing is located in Heistad, Porsgrunn. The stability of the construction (bracing system) and structural system (bearing system) for this apartment housing have been designed .

An analysis of the constructions, survey of load conditions, calculation of loads and load effects, designs of load-bearing and stiffening constructions, and construction of a 3D model of the constructions are included when the design is completed. Finally, the three proposed solution options have been designed. Furthermore, these alternatives must be analyzed for two major themes: LCA and construction cost.

Basic assumptions are shown in Table 5.1, Table 5.2, Table 5.3 and Table 5.4:

Table 5.1: Construction location and use

Description	**value**
Location:	Heistad
municipality:	Porsgrunn
Province:	Telemark
Elevation of municipal center, H_u [meter above sea level (masl)]:	-
Elevation of construction site, H [masl]:	17,6
Elevation limit, H_g [masl]:	150,0
Category of use	Apartment building
Ground condition	Crushed stones, Base type A. Assumes **300 kN / m2** allowable ground pressure in ultimate limit.
Hazardous masses in the ground	No, crushed stones

Table 5.2: Climate data / frost amounts / insulation

Frost amount, F_{100} (h°C):	22 000
The annual mean temperature, Θ_m/q_m (°C):	7
Frost depth, H_o (m):	1,5
Heated or cold buildings?	Heated
Ring Wall Insulation - EPS (class 37 or better / lower)	50 mm on the outside
Mark Insulation thickness XPS (grade 37 or better / higher)	50 mm
Mark Insulating overall width (b) / corners (B) (mm)	1000/1500

Table 5.3: The scope and dimensions of the building

Number of floors:	2 + basement floor for parking
building heigh [m]:	Approximately 9,5 meter
cornice height [m]:	
roof angle [degree]:	Approximately 4

Table 5.4: Building materials and construction

Roof:	Cross-lamintaed timber
Main frames:	Glulam/steel beams and columns
Floors:	Cross-lamintaed timber
External walls:	non load bearing wooden walls
Internal walls:	non load bearing light wooden walls
Bracing system	concrete or cross-laminated shafts, shear walls

Architectural drawings: Figure 5.1, Figure 5.2, Figure 5.3, Figure 5.4 and Figure 5.5 are the basis for the project.

Figure 5.1: Basement floor plan

Figure 5.2: Floor Plan 2

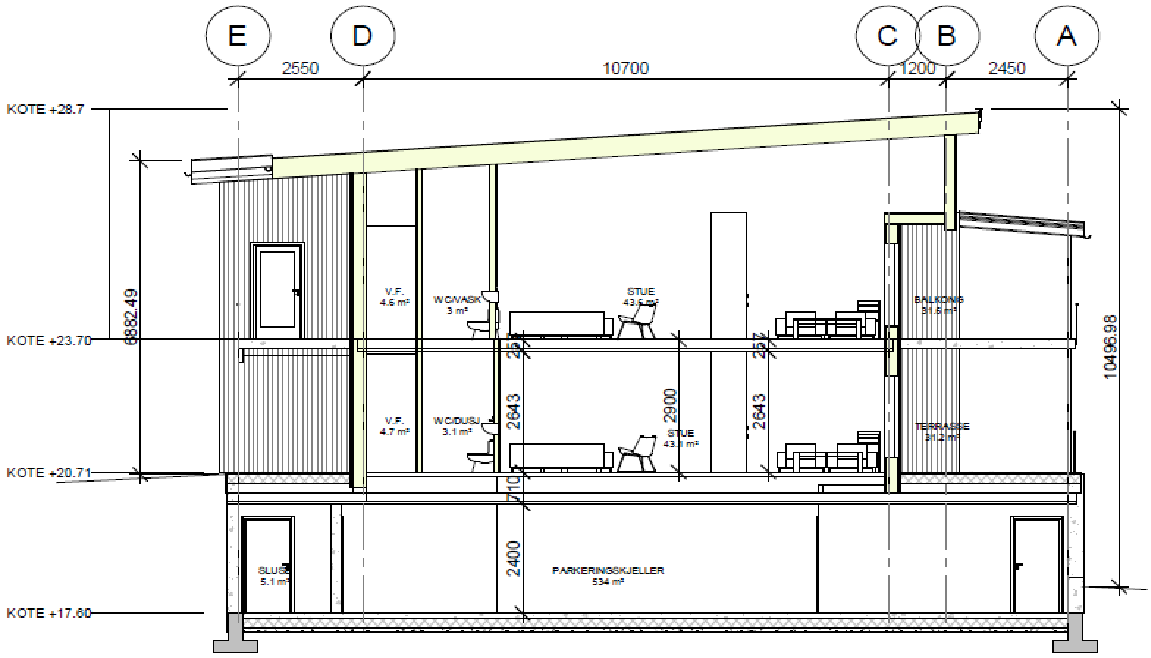


Figure 5.3: Typical Section

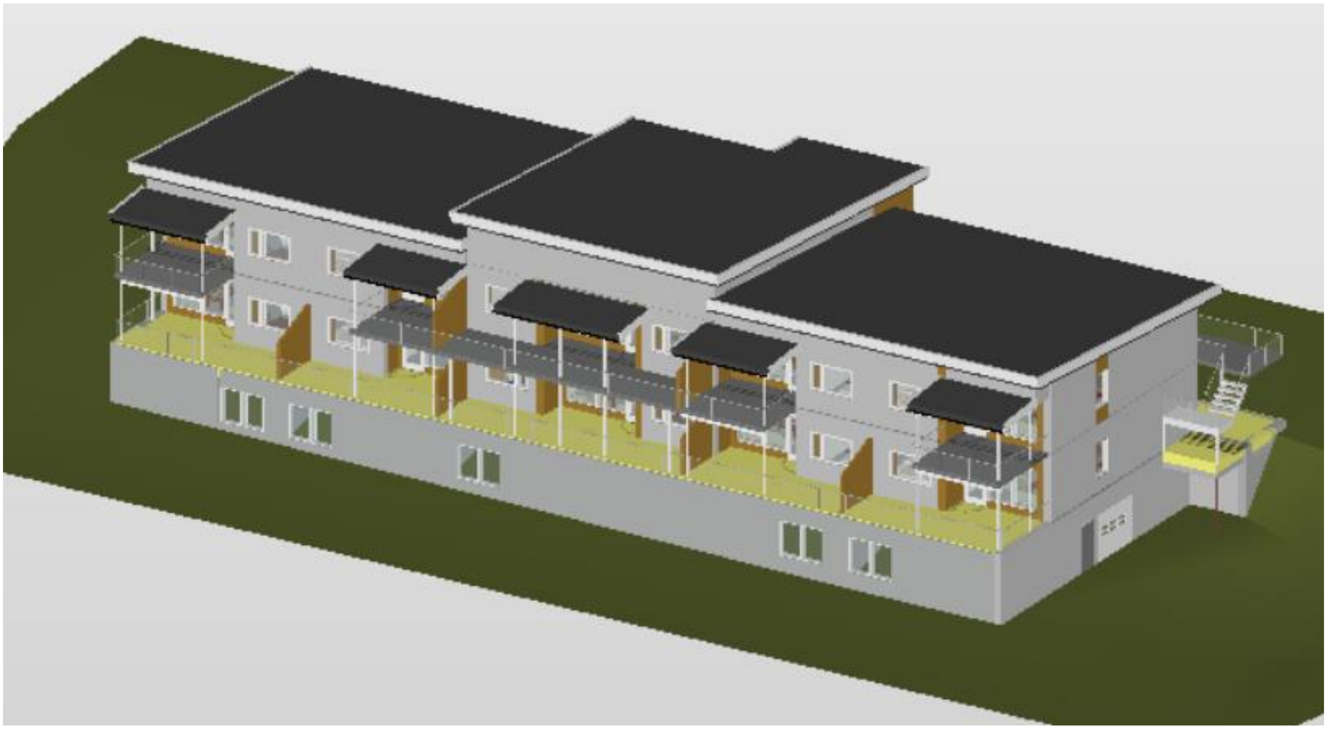


Figure 5.4: 3D Architect Model

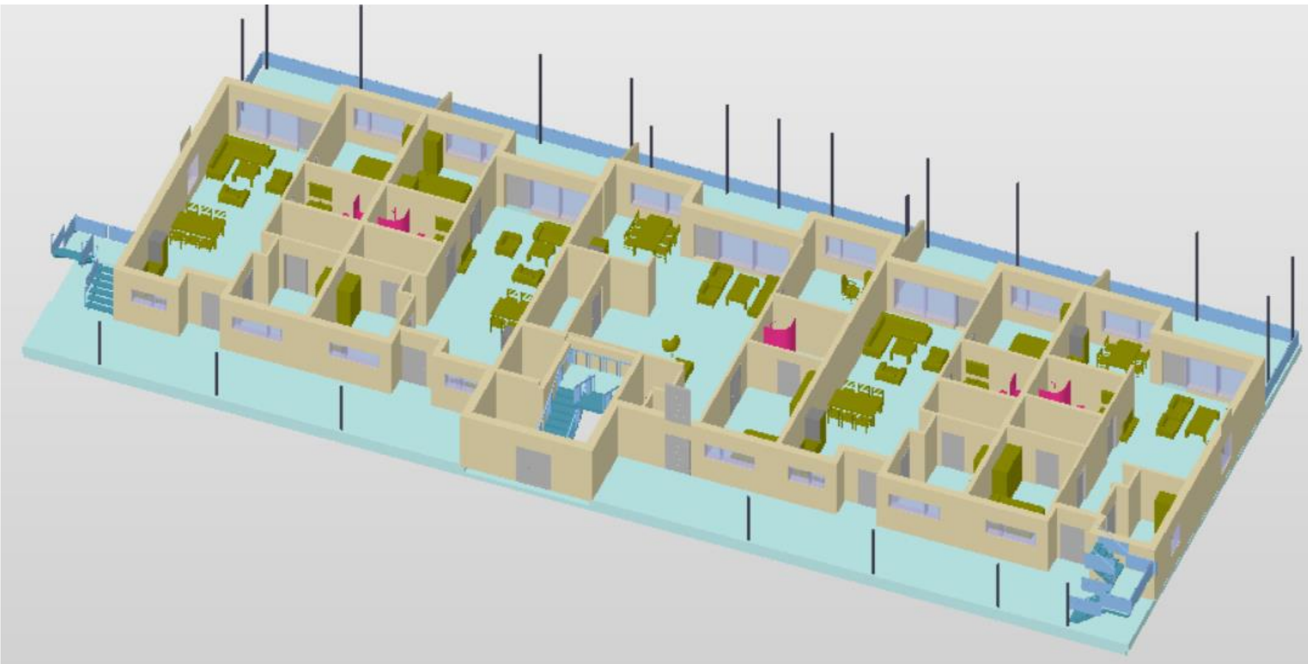


Figure 5.5: 3D Section of Apartments

5.2. Development of digital models for Structural Systems Options

A 3D digital model is done for each option in Revit.

- **Option 1: Timber structural system including walls and foundations made of normal concrete**

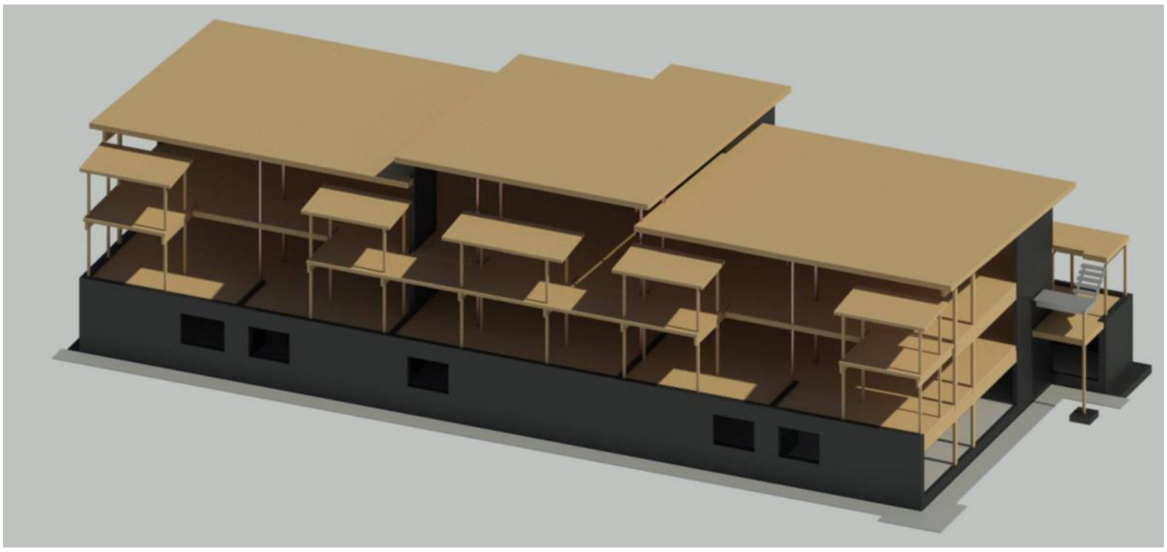


Figure 5.6: 3D Model Option 1

- **Option 2: Timber structural system including walls and foundations made of low carbon concrete.**

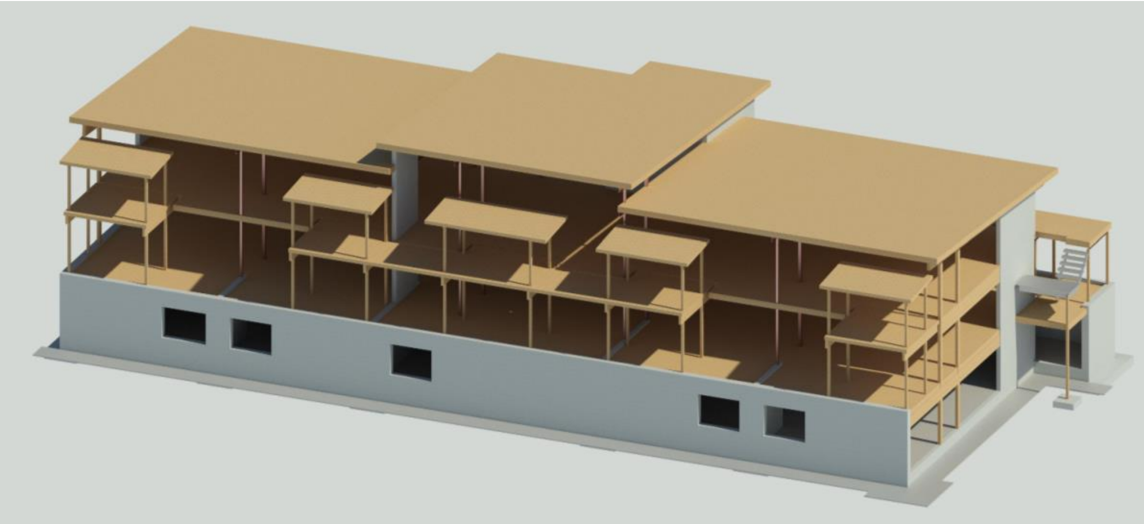


Figure 5.7: 3D Model Option 2

- **Option 3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.**

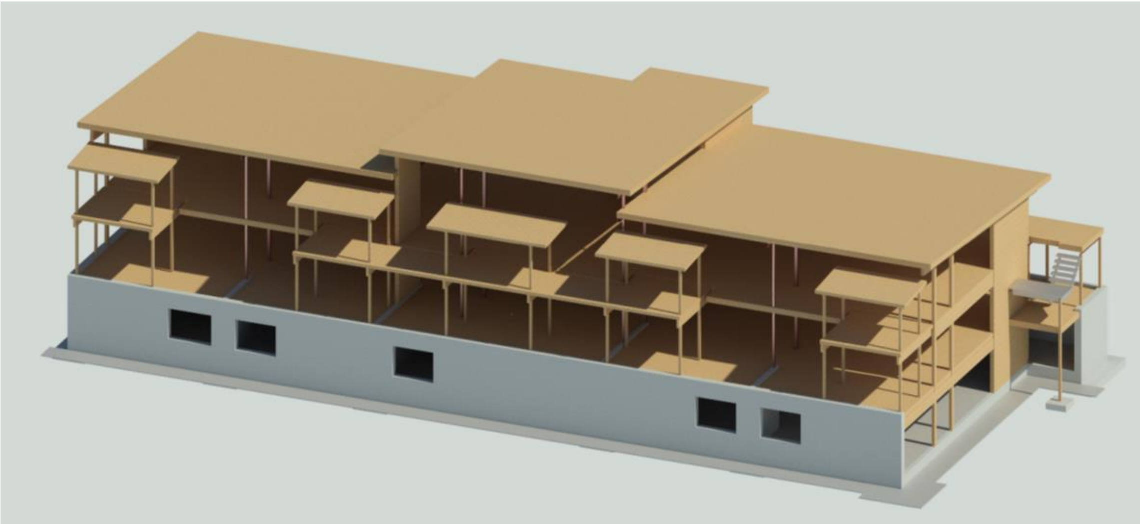


Figure 5.8: 3D Model Option 3

See Appendix H for structural drawings.

5.3. Analysis of solution alternatives

Three solution alternatives have been made for the structural system of the apartment building. Then, a methodology for determining a sustainable option was developed. The methodology was based on analysis of the following elements: 1) Design of structural system 2) LCA analysis 3) Construction cost.

6. Methods

6.1. Background

A method is a tool that says something about how one should work to obtain or verify knowledge. It is a means of solving problems and finding new knowledge. The reason for choosing a particular method is because it is believed that it will give us good data and highlight the question in a good way.

Methods can be both qualitative and quantitative. The qualitative method aims to capture opinions and experiences that cannot be quantified or measured such as people's judgments, emotions ideas, beliefs, etc. Whereas, the quantitative method aims to shape the information into measurable units and statistics for example pressures, population densities, cost indices, etc. Usually, data expressed in numbers is called quantitative data, while data expressed in words is called qualitative data [56] [57].

6.2. Choice of method

A simplified difference between quantitative and qualitative methods is related to the way data are collected and interpreted.
In this work, a quantitative approach is used. Input data's are quantitative and are analyzed using the techniques of statistics or mathematical models. During the design, we have used commonly known calculation methods, calculations are partly done by hand, but also by the following programs:

- FEM-design
- Ove Sletten beregningsprogram, Lastberegning
- Ove Sletten beregningsprogram, BTSNITT
- CLTdesigner
- SimaPro

6.3. Work flow

The work started by obtaining the basis of the design such as drawings, information about the building and the building site.

Based on this we proposed three structural systems options. The options were discussed against the use of materials, possible spans and practical solutions. Furthermore, the work on details of the various construction parts ensued.

The work has been based on collaboration and discussion, where every particular choice of building method and material alternatives as well as their challenges were discussed. We have different background knowledge, which we utilized and attempted to adapt to the work. The work has also entailed much independent work for the individual group members, but there has also been opportunity for discussion if necessary.

6.4. Modeling of 3D models

There are many 3D modeling tools for building and infrastructures among are Autodesk Revit, Archicad, Tekla Structure and so on.

We opted for the Revit program. Revit is building information modelling (BIM) software which includes features for architectural design, structural design, plumbing, electrical and mechanical work. The program is constructed based parametric elements instead of lines. New elements can be easily made by the family editor. The elements in a model will have correct geometry and properties. The model can contain all necessary information's, i.e. it will be a BIM model.

Once the model is ready in Revit, the following can be generated: floorplans, facades, sections, details, overview (3D Images), forms (example column layout), material quantities and many other desired information's.

In this project, the first thing that was done to make the 3D structural model was to import the architectural model as a Revit link, as shown in the figure below.

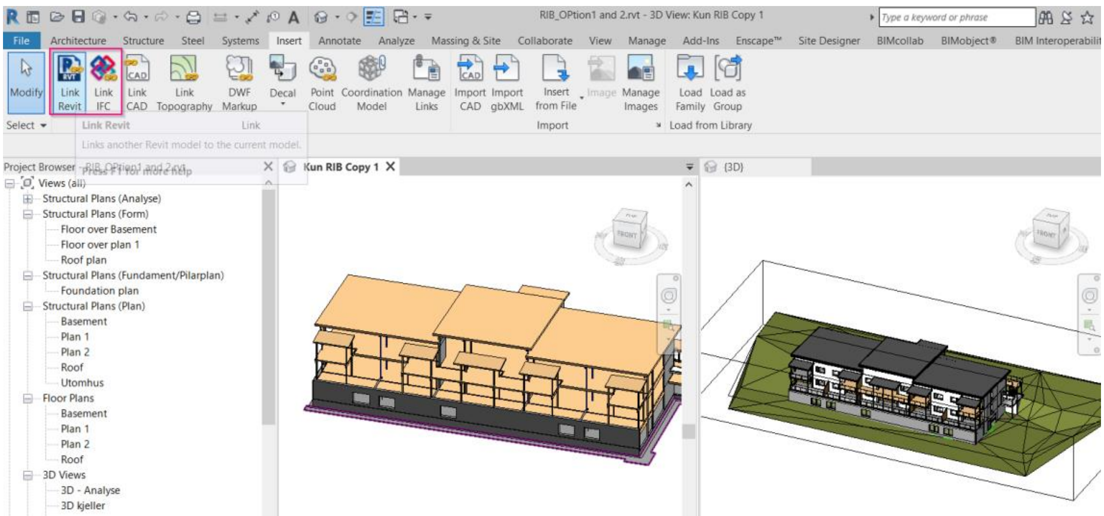
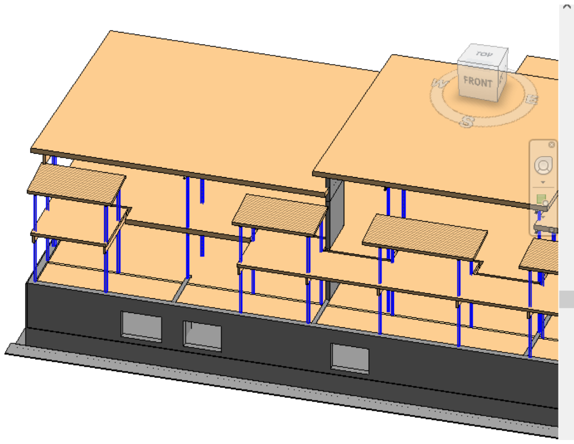


Figure 6.1: creating structural model by linking an architectural model in the same project

This means that the architectural model is used as a trace for the structural modeling. By doing so, one can easy start modeling while the architectural model is a background. This gave us good control and eliminated potential collisions that might occur when working with the two models. There is a special tool in Revit called «collaborate, copy/monitor», which helps to copy objects from a linked model. This tool has been used effectively. Walls and columns are placed without affecting the architectural design. Since architectural design was completed before hand, there were many challenges to place the vertical structural elements. Proper materials and sections were selected for all the different elements. After modelling was completed the necessary data was generated, among these are material quantities, 2d and 3d drawings as shown in the example in the figure below. Material quantities are further used in construction cost estimation as well as in LCA analysis.



<Columns>

A	B	C	D	E	F	G
Type	Antall	Length	Volume	Density	Weight	Structural Material
470.00 kg/m³						
GLT column 115x115	53	133167.49	1.76 m³	470.00 kg/m³	827.74 kg	GLT - GL30c
GLT column 140x225	4	28154.43	0.89 m³	470.00 kg/m³	416.83 kg	GLT - GL30c
		161321.91	2.65 m³		1244.56 kg	
2500.00 kg/m³						
300x300	6	3600	0.21 m³	2500.00 kg/m³	522.00 kg	Concrete, C35/45
		3600	0.21 m³		522.00 kg	
7850.00 kg/m³						
HE200A	3	8100	0.04 m³	7850.00 kg/m³	324.60 kg	Metal - Steel - S355
RHSS100x100x8	7	44883.09	0.13 m³	7850.00 kg/m³	1037.27 kg	Metal - Steel - S355
RHSS140x140x8	8	53924.77	0.23 m³	7850.00 kg/m³	1788.06 kg	Metal - Steel - S355
RHSS140x140x10	3	8100	0.04 m³	7850.00 kg/m³	330.64 kg	Metal - Steel - S355
		115007.85	0.44 m³		3480.57 kg	
		279929.77	3.3 m³		5247.13 kg	

Figure 6.2: Revit model with generated material quantity for columns

6.5. Structural design

FEM-Design is an advanced 3D modeling software for finite element analysis and design of steel, timber and concrete structures. The group chose to use Fem-Design for the structural designs of framings and walls, as well as for steel connections. The CLT floors and roof are designed in CLT designer.

Initially, the building model was exported from Revit to FEM-Design. The building is modeled with load-bearing elements, CLT floors, beams and columns made of steel and timber and walls made of concrete and CLT. Since sustainability was in focus, the group tried to use timber as far as structurally possible. Initially, all the edges between the plates and walls were rigid after export, but this was fixed in FEM design manually. The boundary conditions for structural members were done carefully. All beams are modeled free at both ends (hinged support). Cross-laminated timber floors and roofs are released at the border (edges) not to take moment so that they will only transfer transitional forces. The top walls are also released to make sure that the connection between CLT floors and walls is hinged. Stability walls (shear walls) are proposed to take horizontal forces.

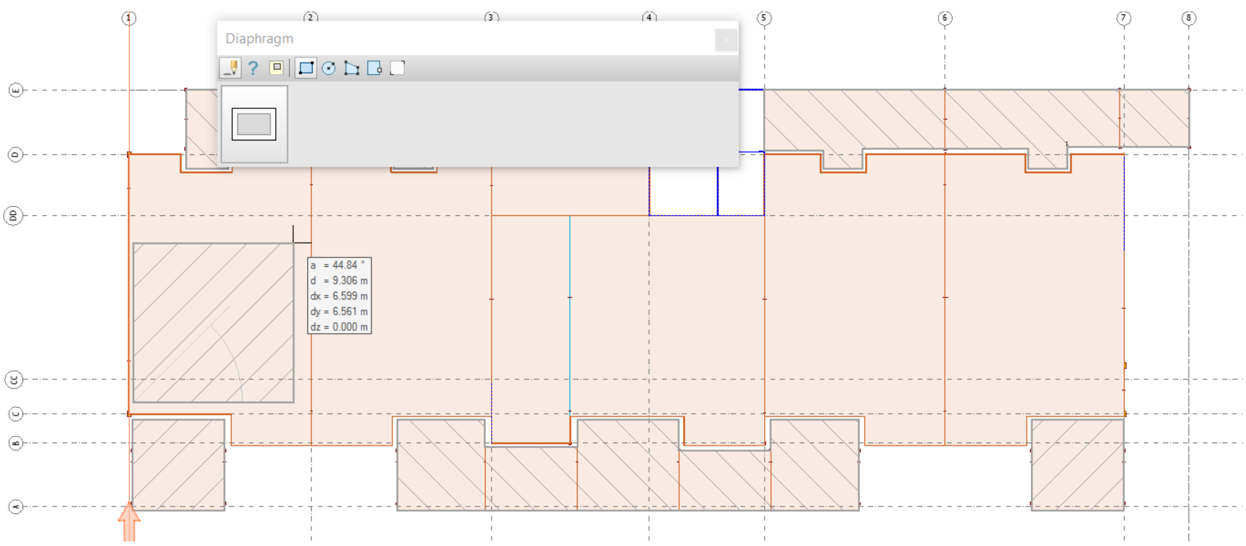


Figure 6.3: Applying diaphragm to the plates

A diaphragm, as in Figure 6.3, is also applied to all floors and roofs to get advantage of the shear walls, as it is mentioned in the theory chapter.

After modeling is completed, loads were applied to the model. Loads are entered according to the Norwegian standard. The loads applied to the models were dead load, superimposed live load, snow load, wind load and misalignment load. Furthermore, the load combinations were made according to the Norwegian standard.

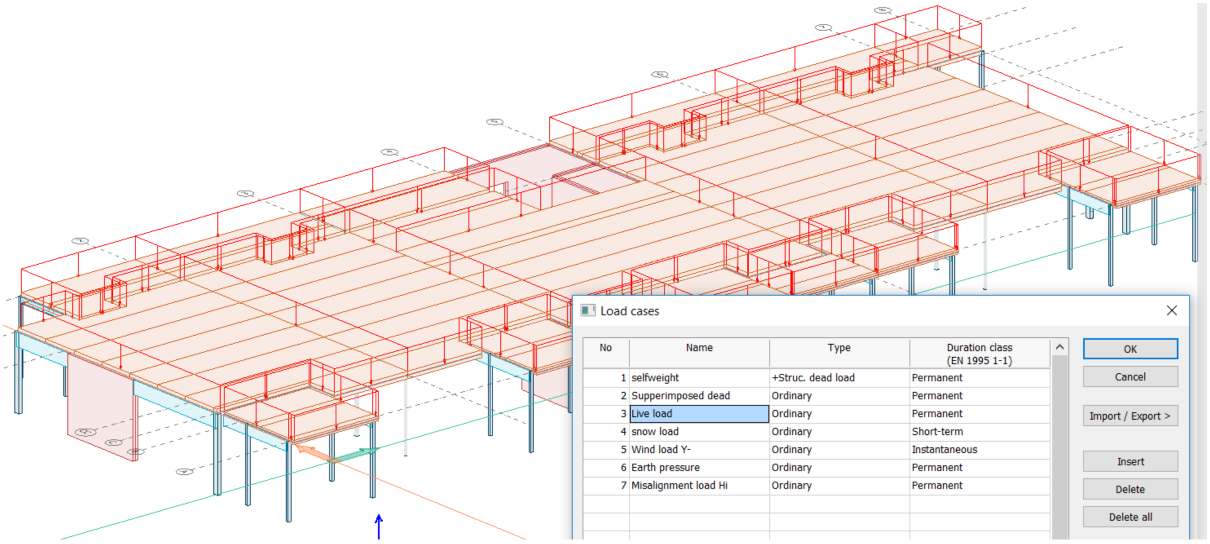


Figure 6.4: Applying loads to the model

Then, the analysis was run and the results were checked. Moment, shear, normal and deflection diagrams for all frames were generated, as well as support reactions.

Finally, RC, steel and timber design was done step by step. All structural members were checked by controlling utilization and deflection. All designs were done according the Norwegian standard. Once the design was completed, calculations were made, and the results were documented.

The timer connection was done manually in Excel and in Mathcad.

6.6. LCA analysis

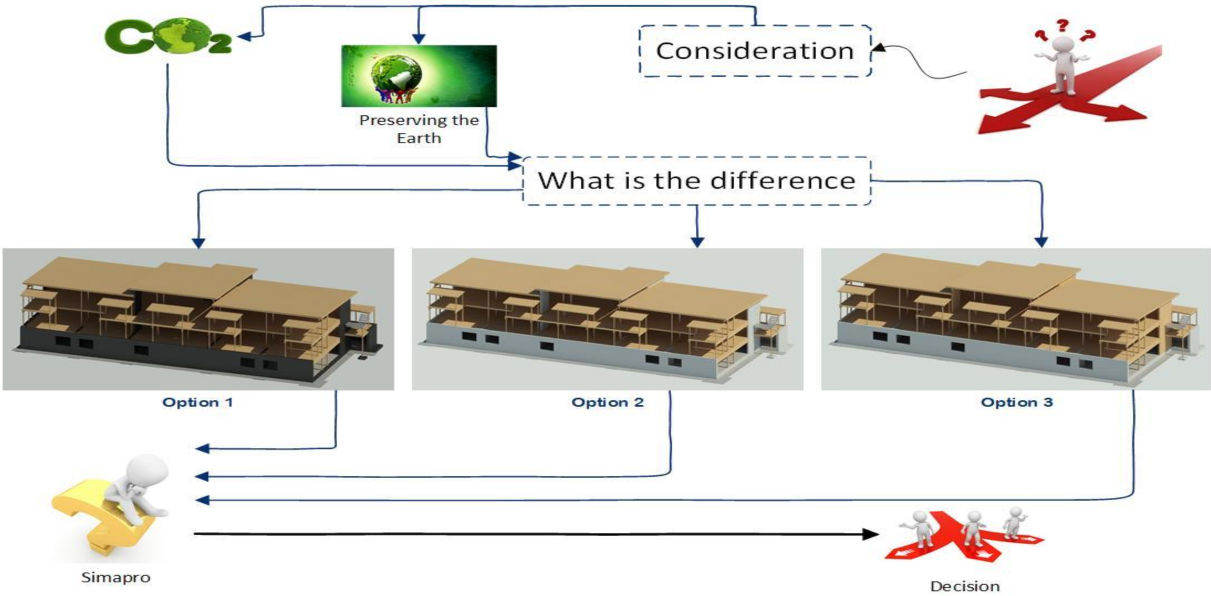


Figure 6.5 motivation of LCA analysis

For LCA analysis a simulation software called SimaPro was used. First, material quantities were collected from 3D models in Revit. After identifying the materials used in the project, EPD documents for each material was collected from epd-norge.no (EPD Norway). EPD (Environmental Product Declaration) is an independent, verifiable environmental declaration that secures the product or the material's environmental information, which is made on the basis of one LCA. Products and materials must meet certain requirements and regulations before they can be built-in [58].

6.6.1. SimaPro

Version 9 of SimaPro is used in this project. In version 9 of SimaPro ReCipe 2016 Midpoint (H) is not available in Europe. That is why global is chosen in SimaPro in methods. It is selected in SimaPro ReCipe 2016 Midpoint (H). The method focuses on the midpoint categories. LCA methodology is also described in detail in the chapter 3.2.3 theory part of LCA in this report. See Figure 6.6.

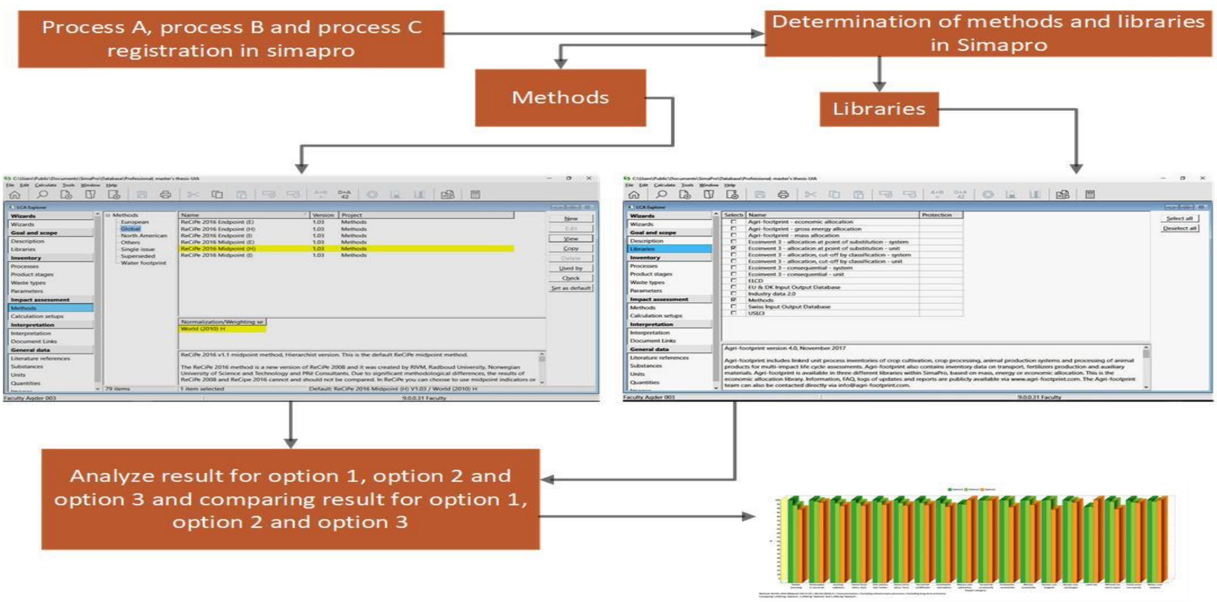


Figure 6.6 Determination of methods and libraries in SimaPro

First Table 3.30, Table 3.31 and Table 3.32 is created in the inventory phase. These tables consist of process A, process B and process C. The products for process A are from SimaPro but the values are from EPD. Process B is a combination of the process A. Process C is combination of process B. All these data are registered in SimaPro. First, a new process called comparing (option 1, option 2 and option 3) is created in inventory tab. Under the new process A, B and C are registered. Procedure of registration is shown in the figure below.

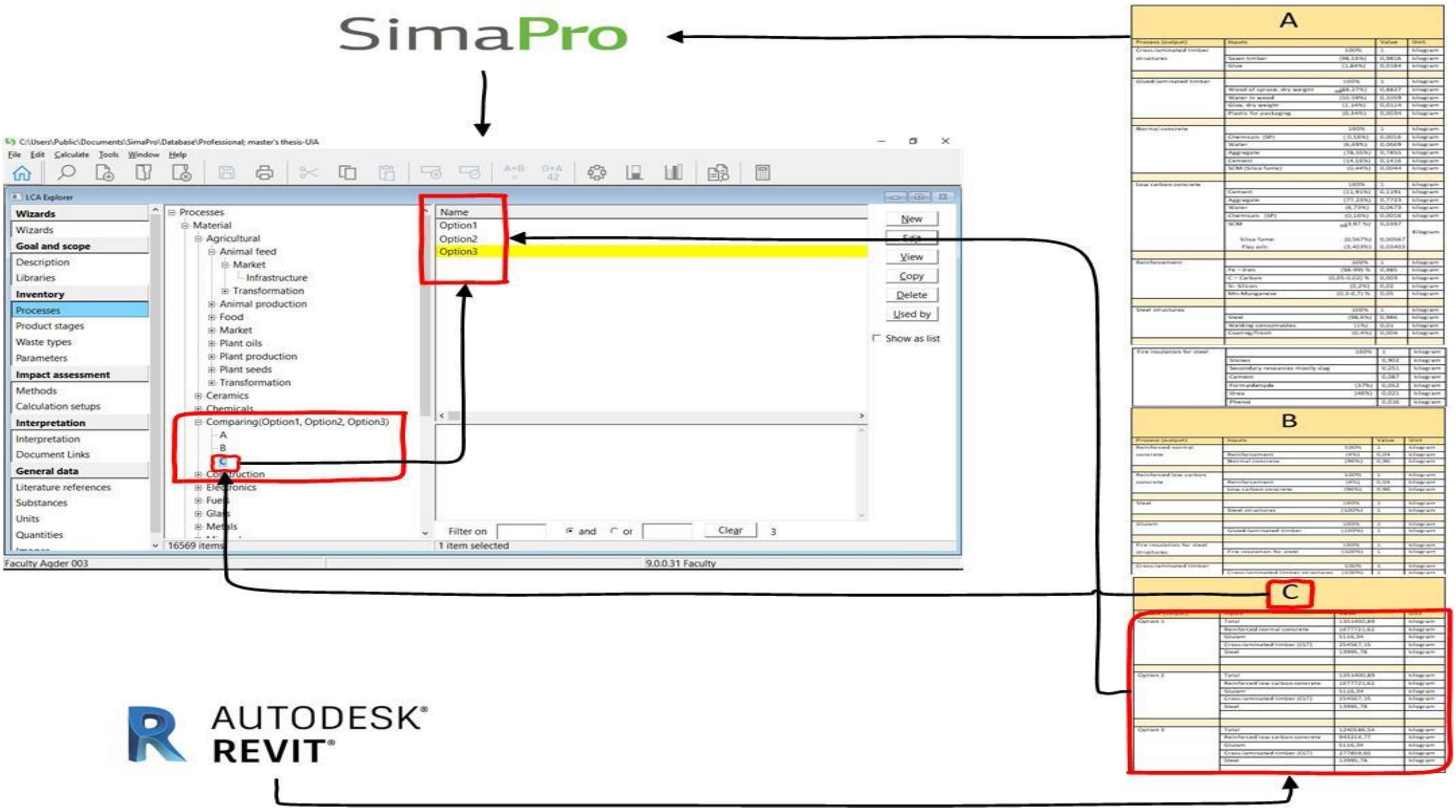


Figure 6.7 Process C registration in SimaPro

6.7. Construction cost

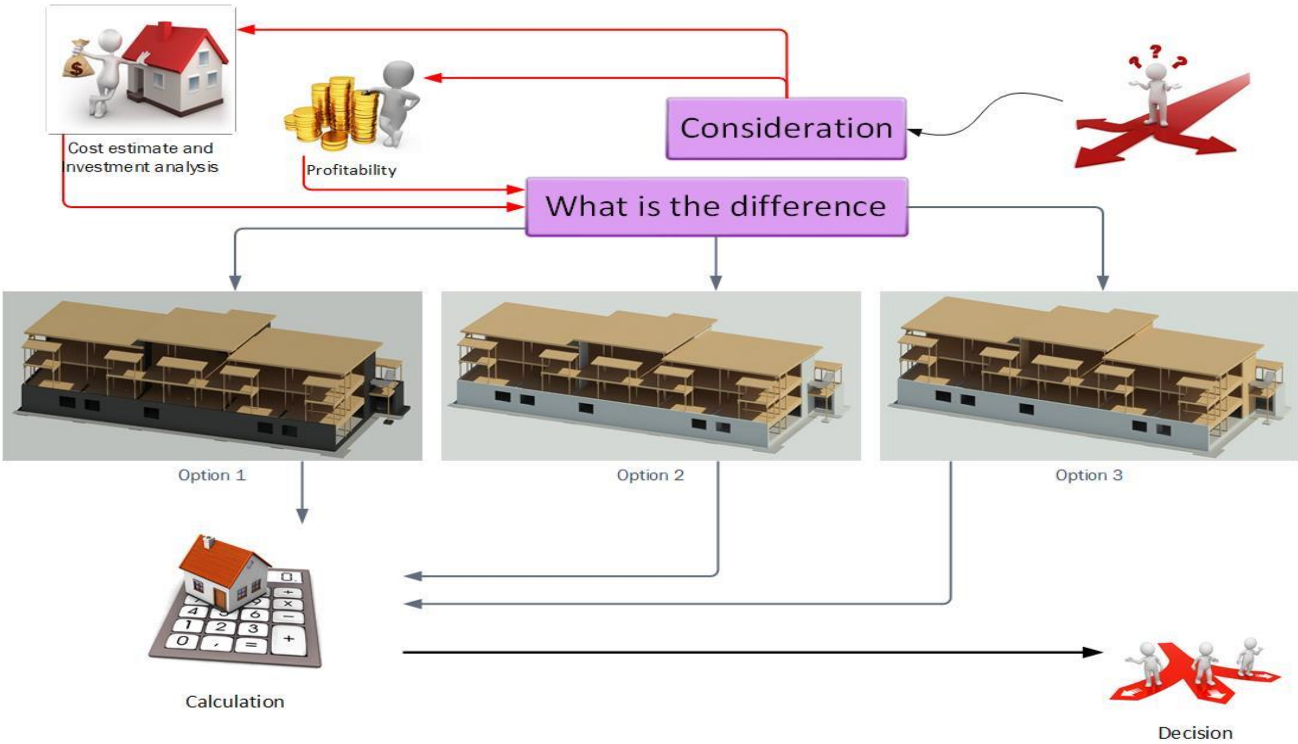


Figure 6.8 Motivation

Construction cost is done manually in Excel. The material quantities are generated from 3D models in Revit. Furthermore, the unit price for each item was collected from Norsk Prisbok and holte-kalkulasjonsnøkkel.

6.8. Progress Plan and time sheet

A progress plan is prepared at the start of the project to ensure good flow in the project assignment. The progress plan is shown in Figure 6.9. See Appendix B for time sheet, first and last version of progress plan for this project. The progress plan together with time sheet has provided a good progress throughout the master thesis. At the same time, in every formal meeting with supervisor the progress plan has been evaluated to make sure the progress flow. The group has followed the progress plan through the whole semester. Progress plan control has been carried out on skype, Microsoft Teams, telephone or meetings.

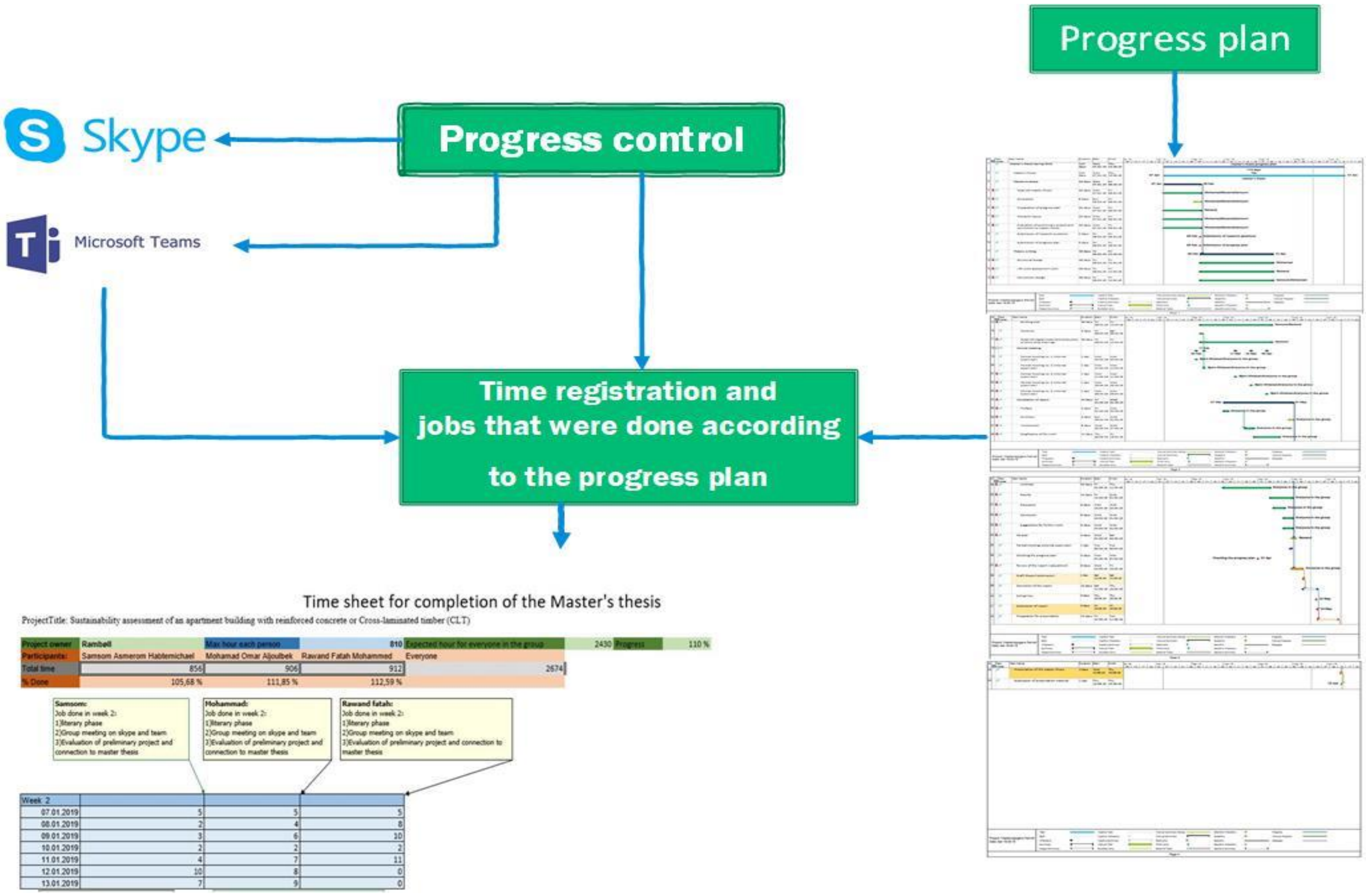


Figure 6.9 Progress Plan and time sheet

7. Results

7.1. Structural design

7.1.1. Design Assumptions

- **Basis of structural design assumptions**

Table 7.1: Basis of structural design according standard NS-EN 1990

Reliability Class	2
Consistency class (s) in general [CC]:	CC2
Reliability Class [RC]:	RC2
Design period [year]:	50
Design Control, Control Class::	Normal
Execution Control, Control Class	Normal

- **Design limit states**

Table 7.2: Design limit states according to NS-EN 1990

Ultimate limit State	**Controlled**
Service limit State	Controlled

- **Load assumptions**

The structures are designed for design situations and load combinations given in EC0 and for the loads specified in EC1-1, EC1-3 and EC1-4. During the calculations, static loads are assumed. The permanent loads are bound loads that have a fixed size, direction and location on the structure. Variable loads are considered free loads, where the most unfavorable loading location is used for sizing. In this construction, dead load and earth pressure are regarded as a permanent load. The other variable loads considered are snow load and wind load.

- **Materials**

All concrete constructions are made with concrete grade B35 with reinforcement in steel grade B500NC. Steel structures are made of steel grade S355. Timber structures are made of glue-laminated timber of grade GL30c. Solid wood plates are made of cross-laminated timber grade C24 for all layers.

See detail materials properties in the following points.

1) Cross-laminated timber according to NS-EN 1995-1-1:2004/NA:2010+A1:2013
   Strength class C24 (all layers)
   Partial safety factor (γ_M) = 1,25

The following cross-sections are used in the project:

- **Cross-laminated timber floors and roofs**

Table 7.3: Layer composition for 280 mm thick CLT (7 layer)

Layer	Thickness	Orientation	Material
# 1	40 mm	0	C24
# 2	40 mm	90	C24
# 3	40 mm	0	C24
# 4	40 mm	90	C24
# 5	40 mm	0	C24
# 6	40 mm	90	C24
# 7	40 mm	0	C24

Orientation 0 = top layer longitudinal to span; Orientation 90 = top layer perpendicular to span

Table 7.4: Layer composition for 160 mm thick CLT (5 layer)

# 1	40 mm	0	C24
# 2	20 mm	90	C24
# 3	40 mm	0	C24
# 4	20 mm	90	C24
# 5	40 mm	0	C24

Orientation 0 = top layer longitudinal to span; Orientation 90 = top layer perpendicular to span

- **Cross-laminated timber walls**

Table 7.5: Layer composition for 200 mm thick CLT (5 layer)

Layer	Thickness	Orientation	Material
# 1	40 mm	0	C24
# 2	40 mm	90	C24
# 3	40 mm	0	C24
# 4	40 mm	90	C24
# 5	40 mm	0	C24

2) Glued laminated timber (GLT) according to NS-EN 1995-1-1:2004/NA:2010+A1:2013
   Partial safety factor (γ_M) = 1,15
   Strength class: GL30c

3) Steel structure according to NS-EN 1993-1-1:2005+A1:2014+NA:2015
   Partial safety factor (γ_M) = 1,05
   Strength class: S355

4) Concrete structure: according NS - EN 1992 - 1 - 1 : 2005 + NA: 2008
   Partial safety factor (γ_M):
   Concrete = 1,50
   Reinforcement = 1,15

Table 7.6: Reinforced Concrete design assumptions

	Class			
Structural member	Strength	Durability	Exposure class	Reinforcement cover (mm)
Foundation	B 35	M 45	XC2	50 mm at Foundation bottom and 35 mm On Foundation sides
Ground floor slab	B 35	M 60	XC1	25
Walls	B 35	M 45	XC1	25

Maximum aggregate size (D_{maxs}) = 22mm

- **Deflection control**

It is assumed that the project is not reassigned to other uses that may impact structures and safety. Design life is based on EC0 and set to 50 years. The requirements for deflection control are done in accordance to EC3/ EC5 and are summarized as in table below.

Table 7.7: Deflection requirement

Beams (Steel and timber)	L/300
Columns	not relevant
Floors in CLT.....	
○ Instantaneous deformation w_{inst}	L/300
○ Final deformation w_{fin}	1/150
○ Final deformation $w_{net,fin}$	1/250

For detail design assumption, see Appendix E.1

7.1.2. Load calculations according to NS-EN 1991

Table 7.8: Characteristic Dead loads, NS-EN 1991-1-1

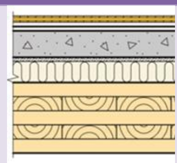
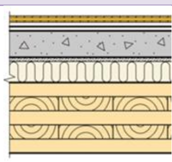
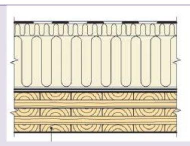
		Description	Thickness (m)	Density (kN/m3)	Load (kN/m2)	Structure
Same for all Options	1.Floor	280 mm cross-laminated timber	0,28	5	1,4	
		80 mm concrete	0,08	24	1,92	
		350 mm insulation, parquet flooring and so forth			0,3	
		Total...........			**3,62**	
	2. Floor	280 mm cross-laminated timber	0,28	5	1,4	
		60-80mm concrete	0,07	24	1,68	
		14 mm parquet, 22 mm chipboard, plasterboard 13 mm and sound plate 20 mm			0,5	
		Total...........			**3,58**	
	Roof	280 mm cross-laminated timber	0,28	5	1,4	
		200 EPS and 50 mineral wool, roofing of asphalt roofing or mechanically fastened foil mulch			0,5	
		Total...........			**1,9**	

Table 7.9: Imposed/ live loads - NS-EN 1991-1-1

Description	Value
Building in use	Category A (Apartment building)
on floors [kN/m^2]	**2,0**
On stairs [kN/m^2]	3,0
On balconies [kN/m^2]	4,0
maximum point load [kN]	2,0
Imposed load from movable partitions with a selfweight <= 1,0 kN/m [kN/m^2]	0,5
Imposed load from movable partitions with a selfweight <= 2,0 kN/m [kN/m^2]	0,8

Table 7.10: Variable load snow (S) - NS-EN 1991-1-3:2003

Description	Value
Characteristic values of snow load on ground, $s_{k,0}$ [kN/m^2]	4,0
Base value Δs_k [kN/m^2]	1,0
Snow load on ground maximum value, $s_{k,maxs}$ [kN/m^2]	-
n = (H-Hg) / 100, rounded upwards to the nearest integer (Hg is height limit = 150 m, and H is height above sea level at the construction site which is 17 m, since H is lower than Hg, snow load on ground must be equal to sk,0	-1,3
Total snow load on ground $s_k=s_{k,0}+n*\Delta_{sk}$ [kN/m^2]	4,0
Snow load shape coefficient (μ_i) for pitched and mono-pitched roofs shall be use μ_1 = 0,8 for roof angles upto 30°	0,8
Ce is the exposure coefficient which depends on topographies. For normal topography Ce is set equal to 1.0 unless other value can be documented.	1,0
C_t is the thermal coefficient which considers snow melting on the roof. It can be assumed Ct = 1	1,0
Snow loads on roof: $S = \mu_i \cdot C_e \cdot C_t \cdot s_k$ (kN/m^2)	3,2

See snow load calculation in Appendix E.9

Table 7.11: Wind load (W) - NS-EN 1991-1-4:2005

Description	Value
Height above sea level - provides the basis for level factor, c_{alt}.	Approximately 17,6 m
Return period (50 or 100 years?) 50.0	50
Reference wind speed, $v_{b,0}$ (m/s)	23,0
Roof type	Approximately flat roof with 4 degrees angle
Topography	Flat / Terrain Category II

Table 7.12: Wind load calculation summary

Description	Value	unit
Exposed facade D	0,49	kN/m2
Exposed facade E	-0,23	kN/m2
Total wind pressure……..	**0,72**	kN/m
Exposed height contributing to 2.floor plane	3,195	m
Exposed height contributing to roof	1,72	m
Wind load applied on the edge of 2.floor slab, W	**2,30**	kN/m
Wind load applied on the edge of roof slab, W	**1,24**	kN/m

See wind load calculation in Appendix E.9

Table 7.13: Inclination due to geometric imperfection

Geometric imperfection			
Height or length of the building	l	9,5	m
Number of vertical structural members	m	23	numbers
Basic value	$\theta_0 \approx 1/200$	0,005	
Reduction factor for height of the building	$\alpha_h \approx 2/\sqrt{l}; 2/3 \leq \alpha_h \leq 1$	0,67	
Reduction for number of vertical structural members	$\alpha_m \approx \sqrt{[0,5*(1+1/m)]}$	0,722315119	
Inclination	$\theta i = \theta_0 \cdot \alpha_h \cdot \alpha_m \cdot$	0,002407717	

Table 7.14: Impact of inclination on the vertical bracing system of the building

	Loads, kN/m2					Building plan, m			Hi (KN/m)			1,5 W	Total
			Only vertical loads						Load combination				1,5W+Hi
Floors	Dead load, G	Live or snow	LC1	LC2	LC3	**l**	**b**	**θi**	LC1	LC2	LC3		using LC3
Roof	1,900	3,2	5,64	7,08	1,71	40,86	14	0,00241	0,190	0,239	0,058	1,86	1,913
2nd floor	3,580	2,8	13,555	14,815	7,9613	40,86	11,9	0,00241	0,388	0,424	0,228	3,45	3,674
Shear walls	0,041												
Architectural walls	5,225												
	8,846												
1st floor	3,620	2,8	13,021	14,281	7,5609	40,86	17,25	0,00241	0,541	0,593	0,314	3,45	3,760
Shear walls	0,037												
Fixed architectural walls	4,744												
	8,401												

Load combinations used:

LC1 = 1,2G+1,05Q+1,05S+1,5 W+Hi

LC2 = 1,2G+1,5Q+1,5S+1,05 W+Hi

LC3 =0,9G+1,5W+Hi

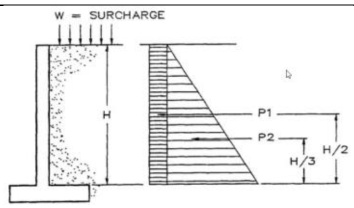
Where: W is wind load and Hi is horizontal load due to inclination (θi)

Table 7.15: Summary of Impact of inclination on the vertical bracing system of the building

Level	Hi (KN/m) fra LC3	Accumulated downwards	Hi
Roof	0,058		0,06
2nd floor	0,228	0,286	0,17
1st floor	0,314	0,600	0,44

Where Hi is horizontal load due to inclination

Table 7.16: Earth pressure on the back of basement walls

ka (coeff. Of active pressure)=	(1-SIN30)/(1+SIN30)=0,33	
ka x ρ x H = 0,33*19*3,11 =	19,68	Earth pressure at the base
ka x w = 0,33*5	1,65	due to surcharge assume w = 5 kn/m2
Total earth pressure at the base	**21,33**	
Earth pressure at the top	**1,65**	
		$K_a = \frac{1-\sin(\phi')}{1+\sin(\phi')} = \tan^2\left(45 - \frac{\phi'}{2}\right)$

7.1.3. Design Results for option 1 and option 2

Table 7.17: FEM-Design input data

Floors	Dead load excluding Selfweight of the structure	live load kN/m2	snow load kN/m2	Wind (W) (kN/m)	Misalignment Hi (kN/m)
1st floor	2,22	2			
2nd floor	2,18	2		2,30	0,23
Roof	0,5	2	3,2	1,24	0,06
Balconies	0,5	2			

- **Geometry**

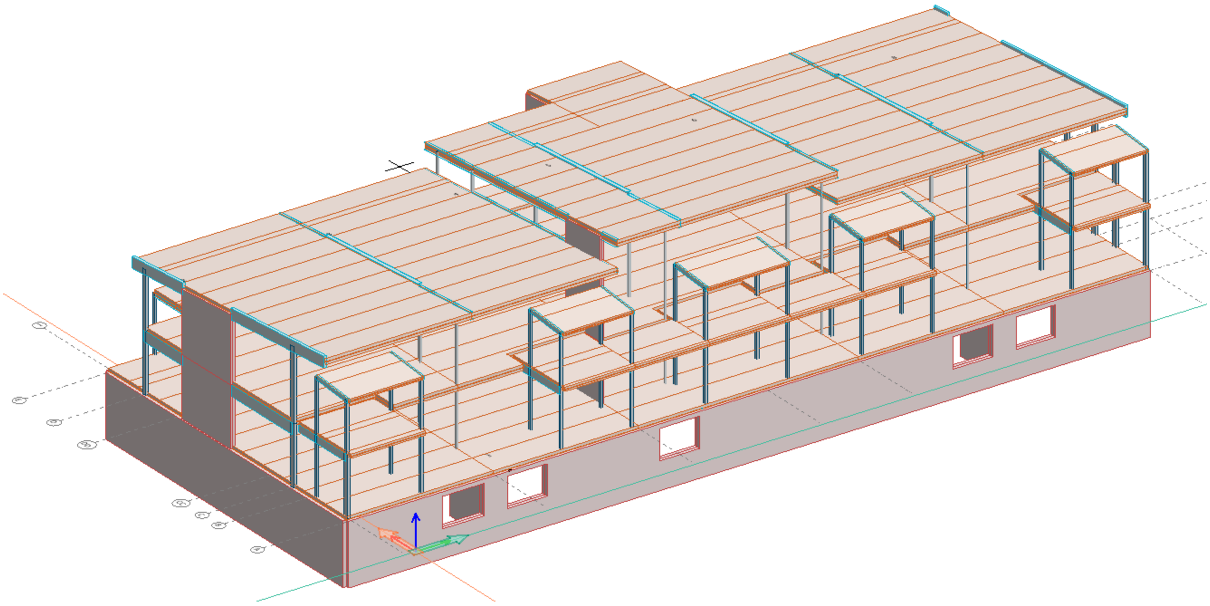


Figure 7.1: 3D model from FEM-Design

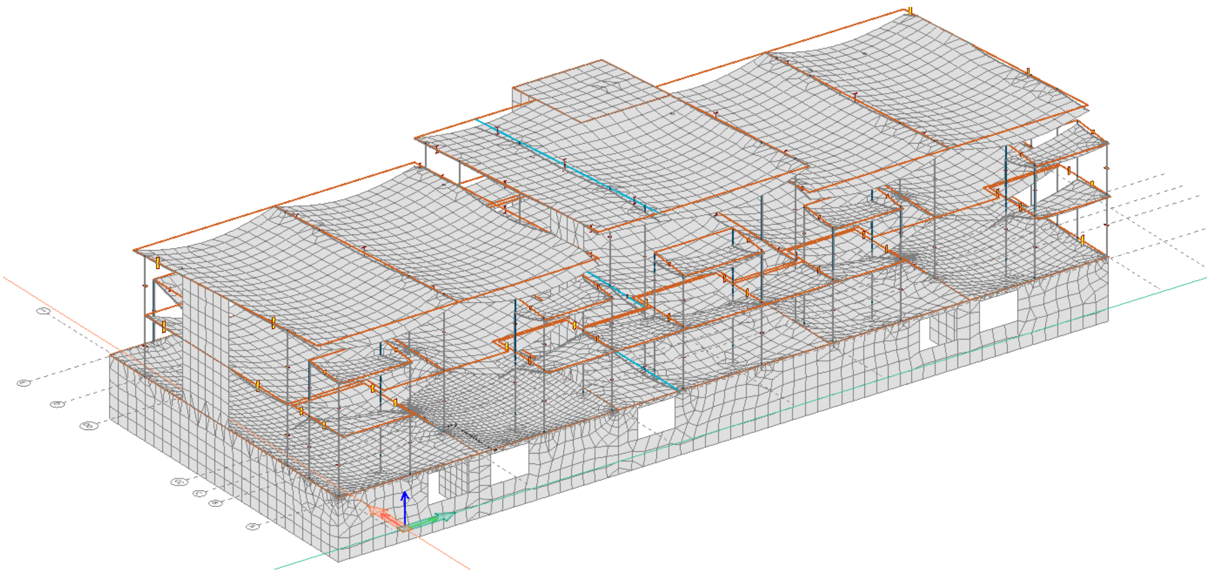


Figure 7.2: 3D deformed model from FEM-Design

- **Analysis Results**

  A typical frame analysis result is presented below.

  Frame in Axis 2:

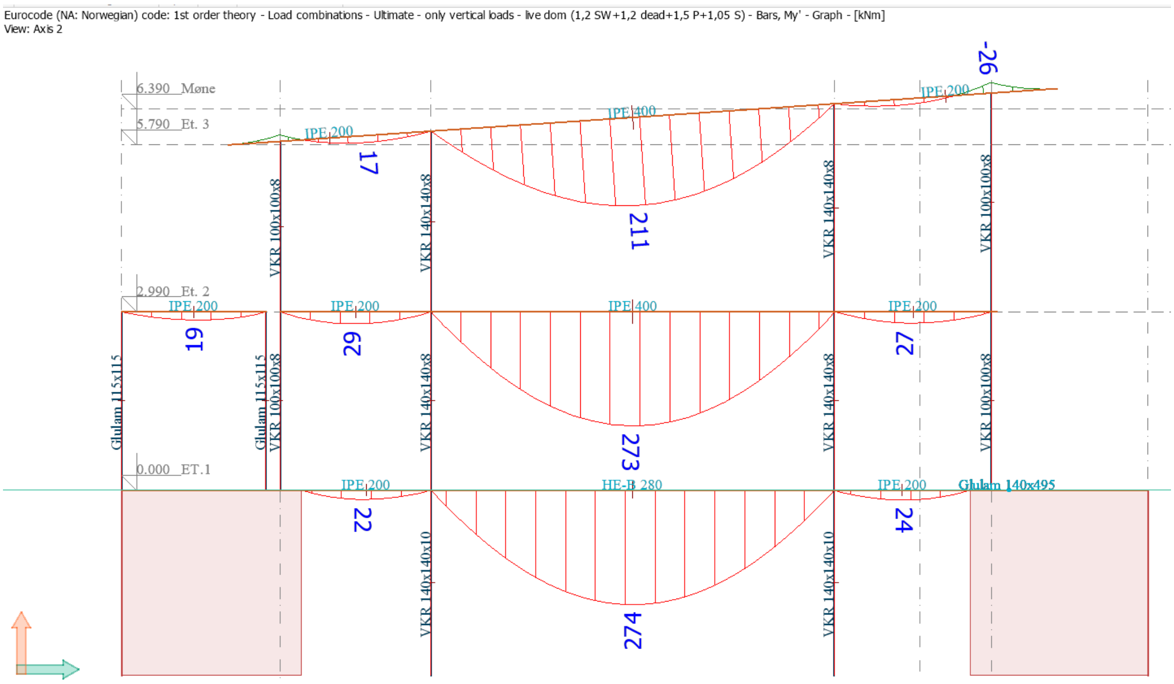


Figure 7.3: Bending Moment Diagram in Frame Axis 2

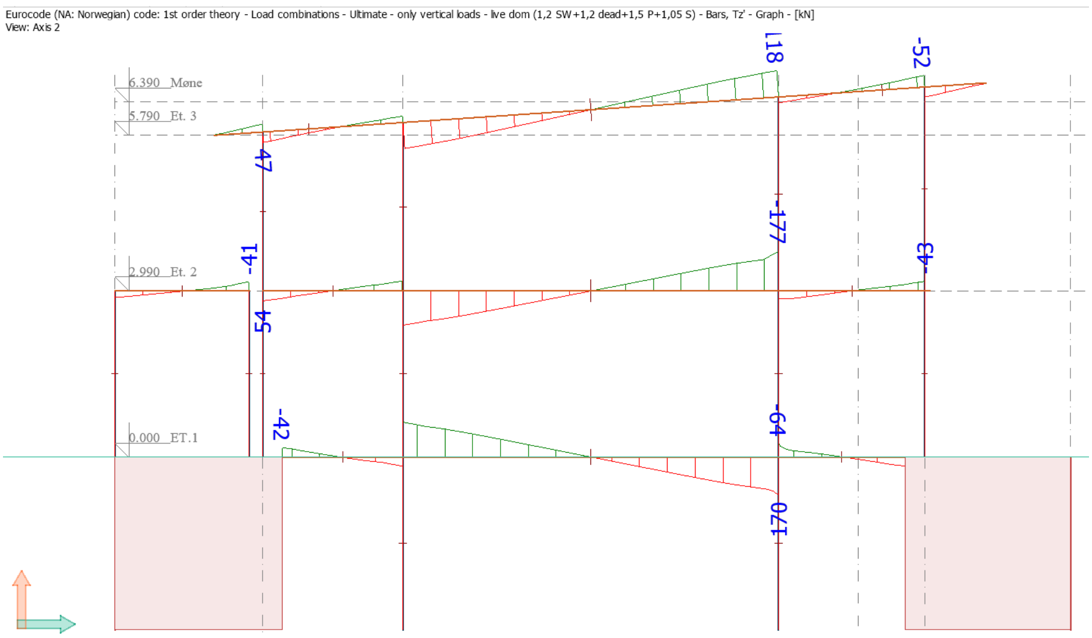


Figure 7.4: Shear Force Diagram in Frame Axis 2

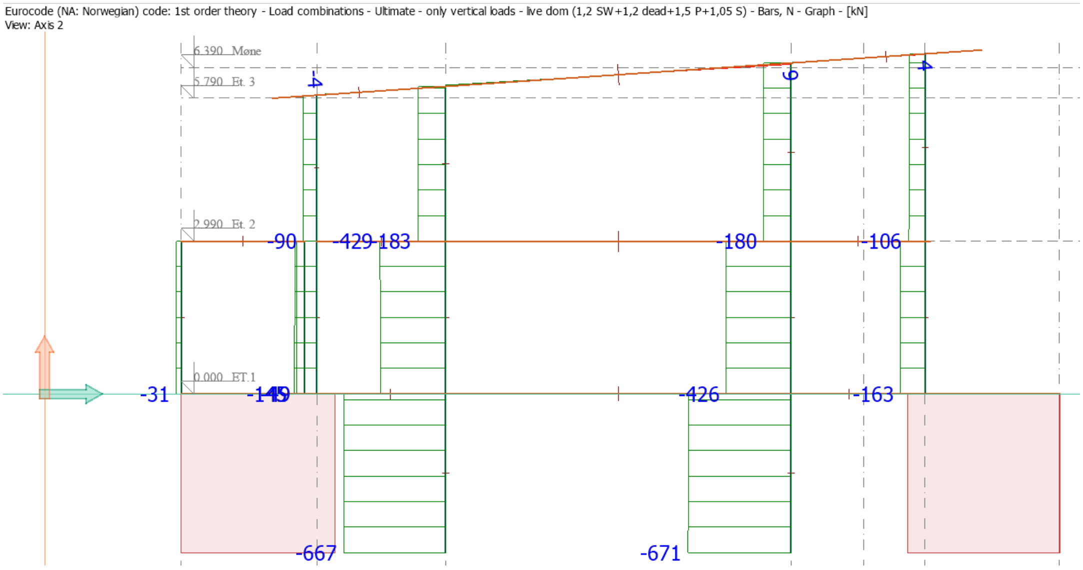


Figure 7.5: Normal Force Diagram in Frame Axis 2

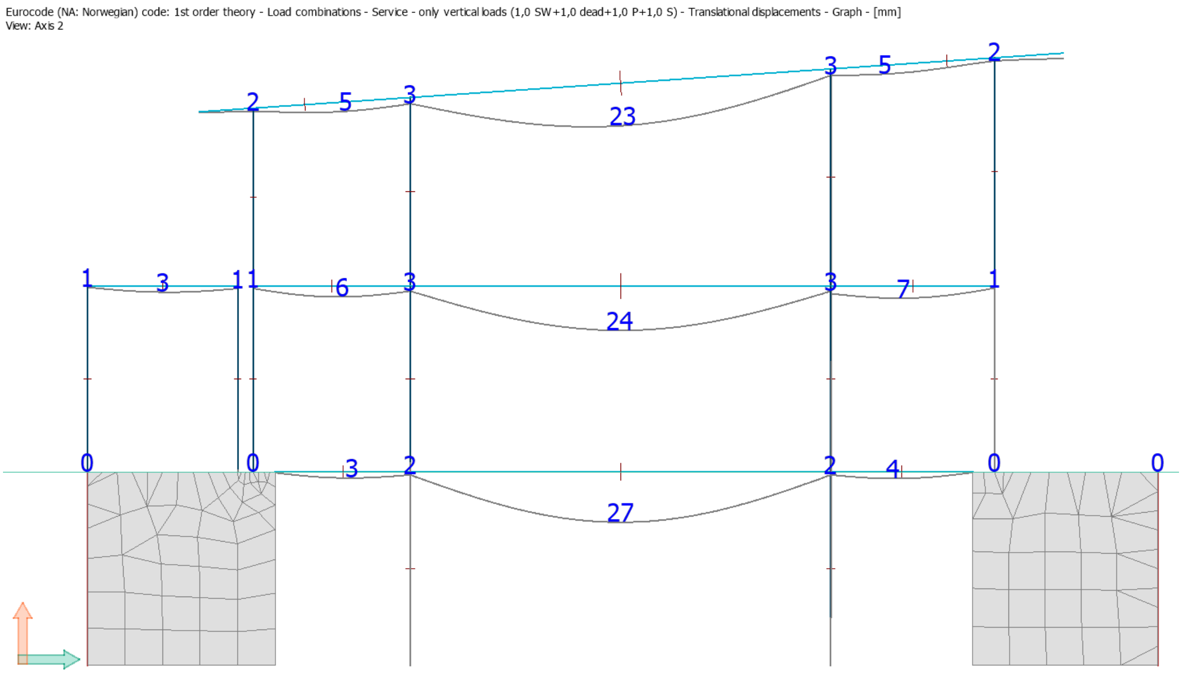


Figure 7.6: Frame Deflection Diagram in Frame Axis 2

- **Design Results**

1) RC walls

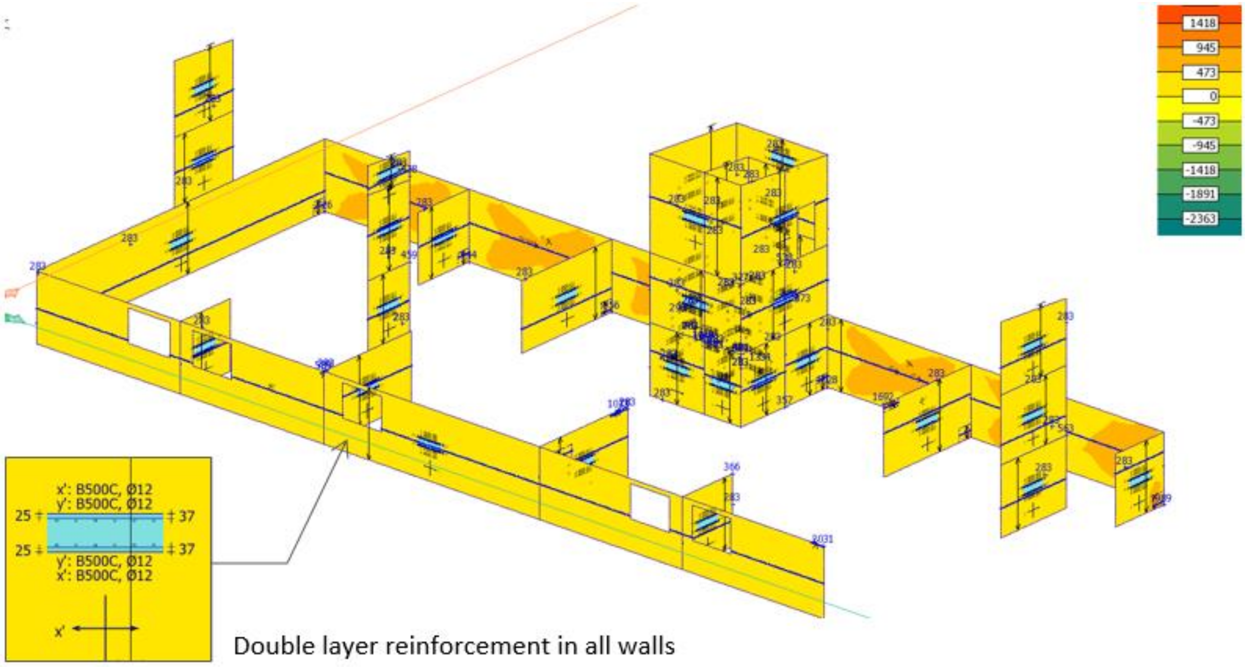


Figure 7.7: RC design - Walls Required Reinforcement

For summary of analysis and design results, see Appendix E.2

2) Steel Design - Frames

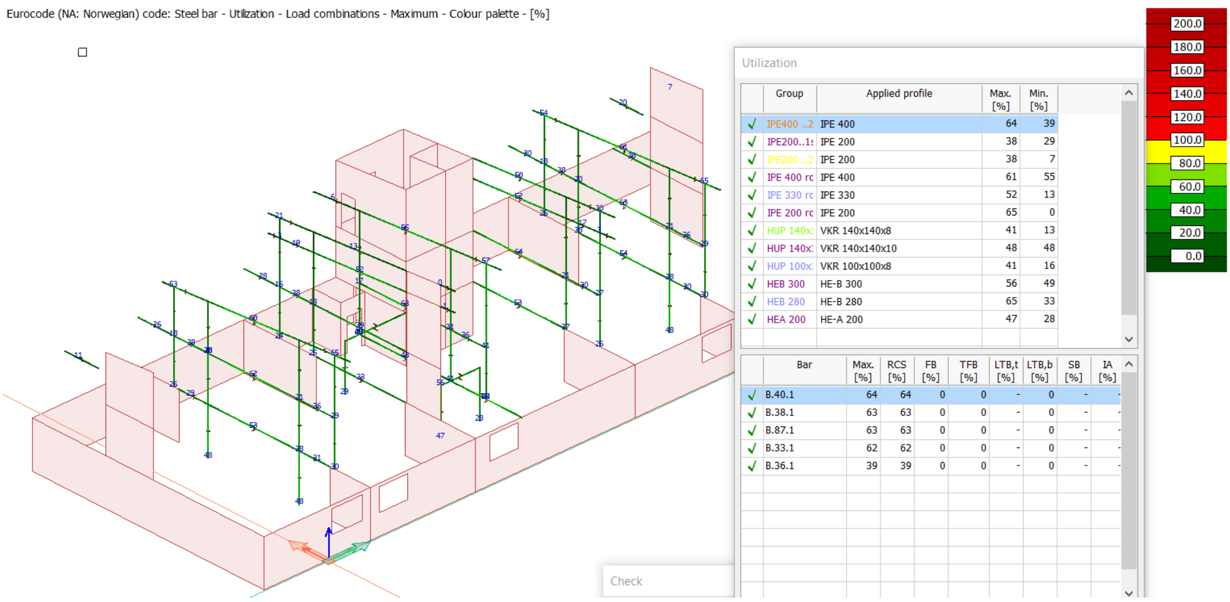


Figure 7.8: Steel utilization

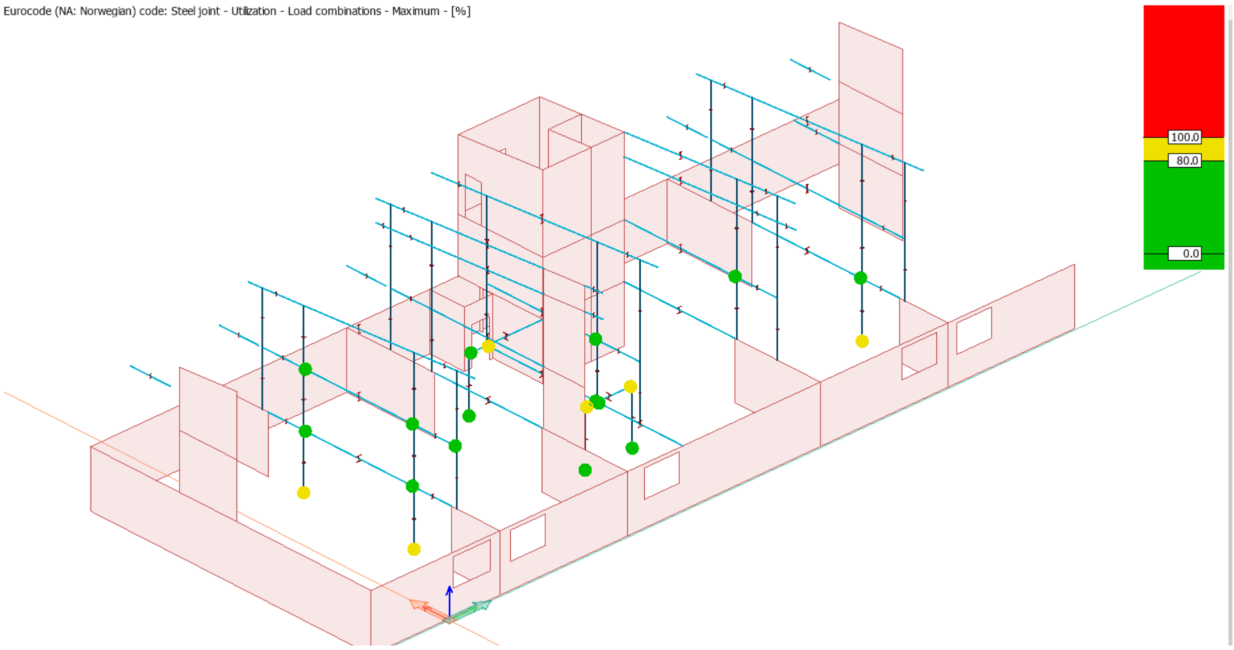


Figure 7.9: Steel Joint utilization

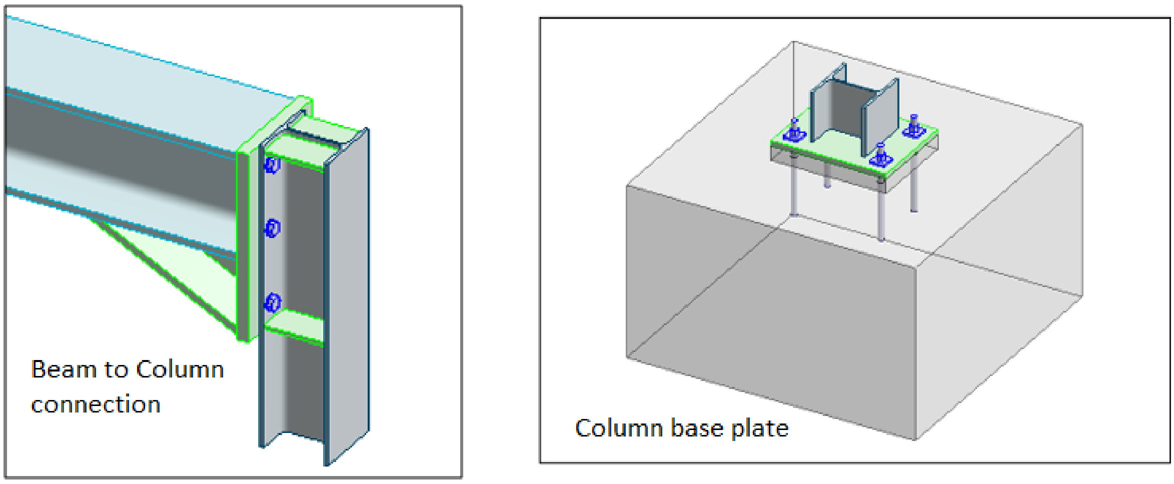


Figure 7.10: Examples of Connection types adopted

3) Timber Design

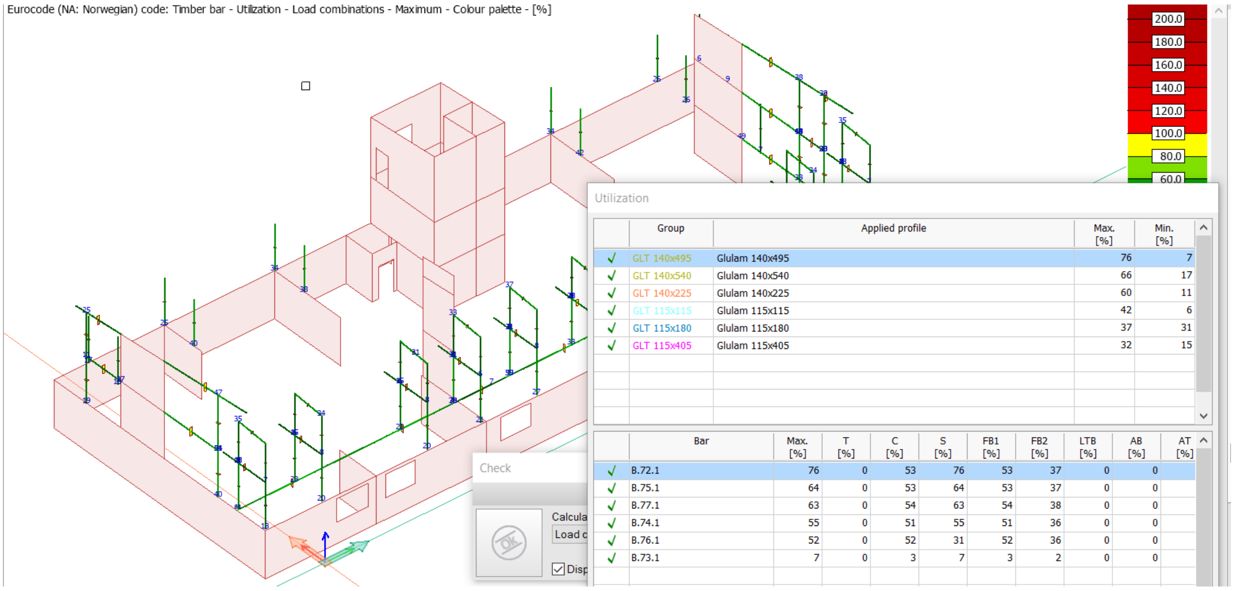


Figure 7.11: GLT (glulam) utilization

For detail analysis and design of option 1 and option 2, see Appendix E.3

7.1.4. Design results for option 3

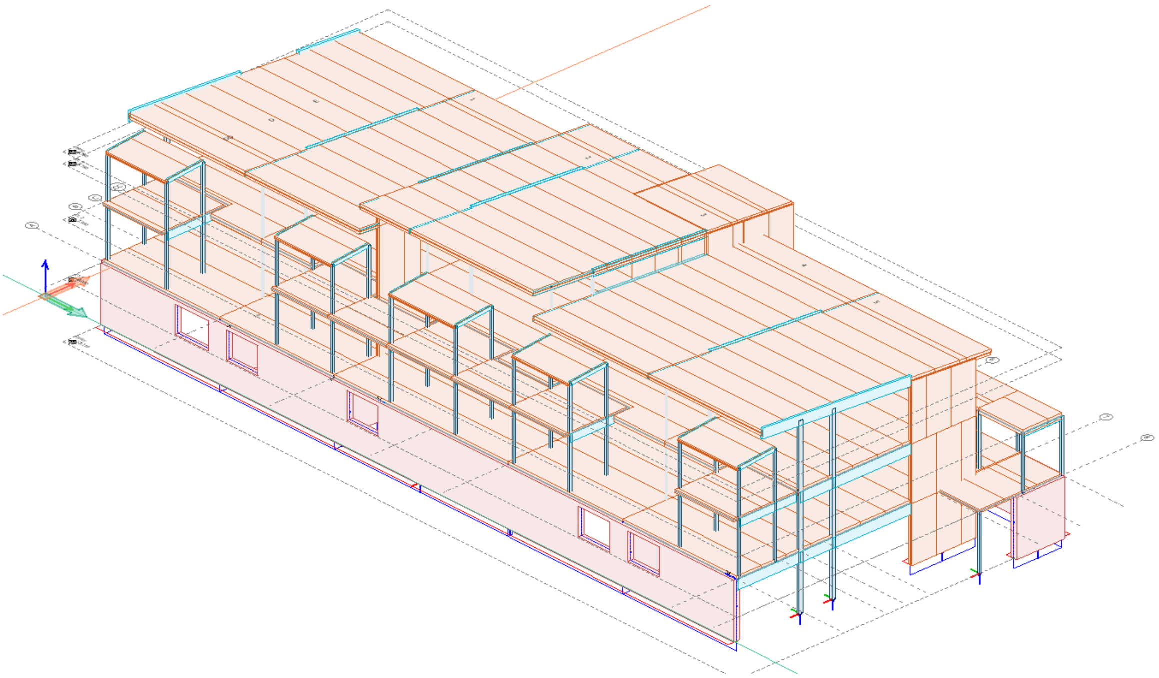


Figure 7.12: 3D model from FEM-Design

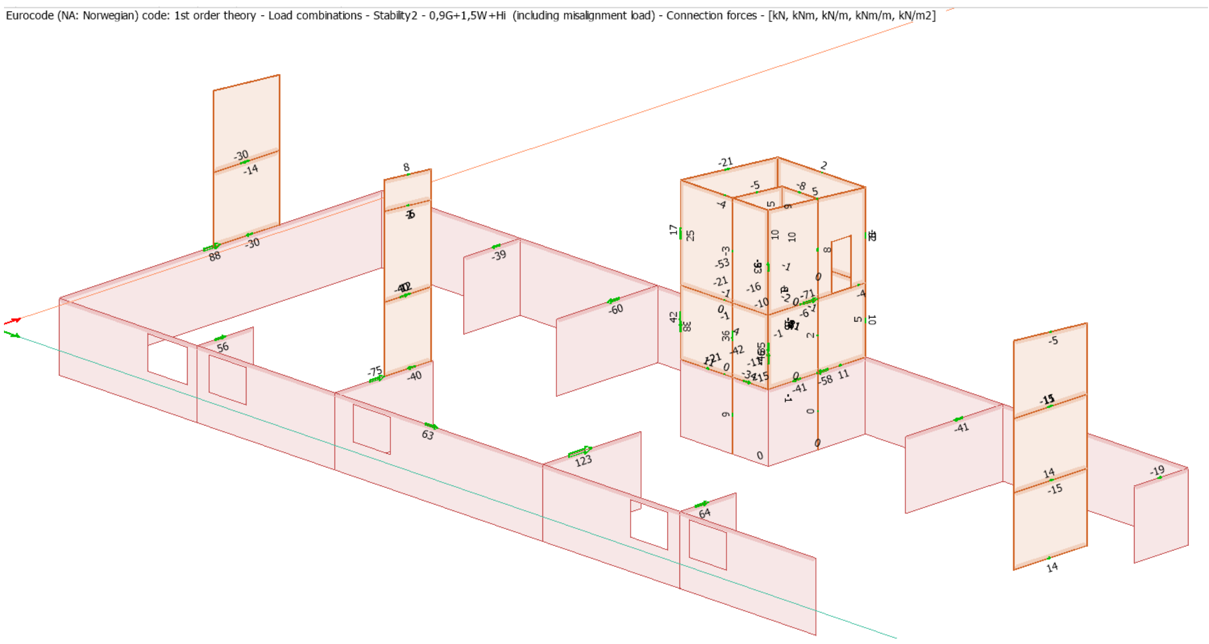


Figure 7.13: Connection Forces (Fx)

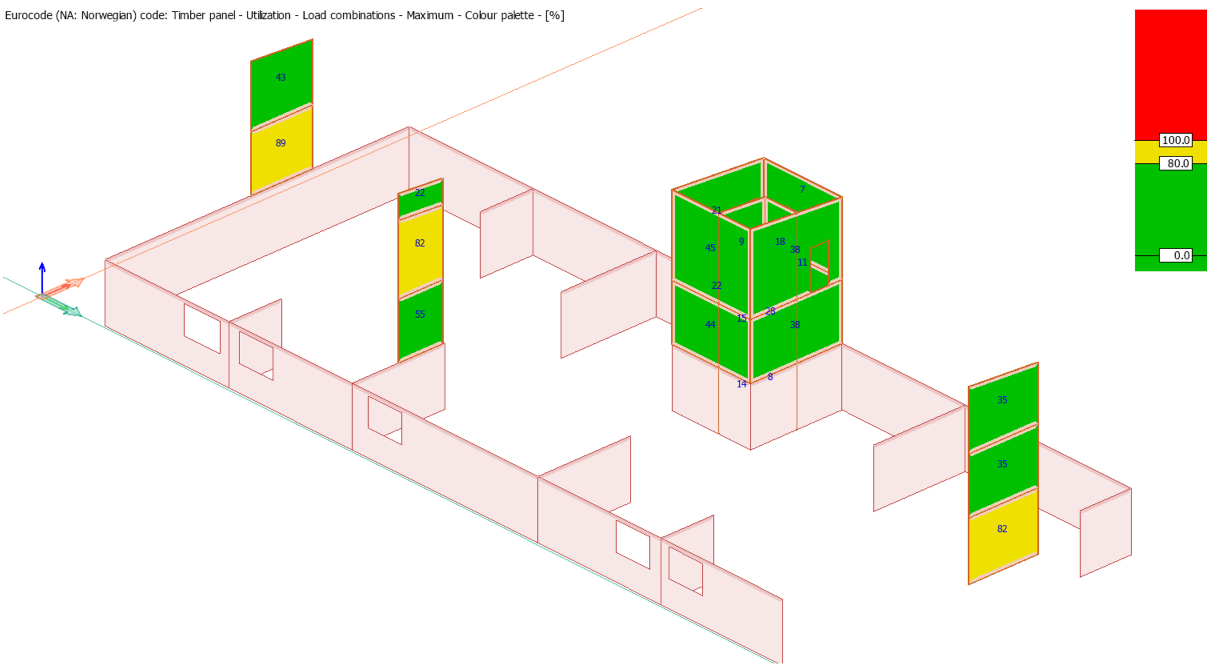


Figure 7.14: CLT Walls Utilization

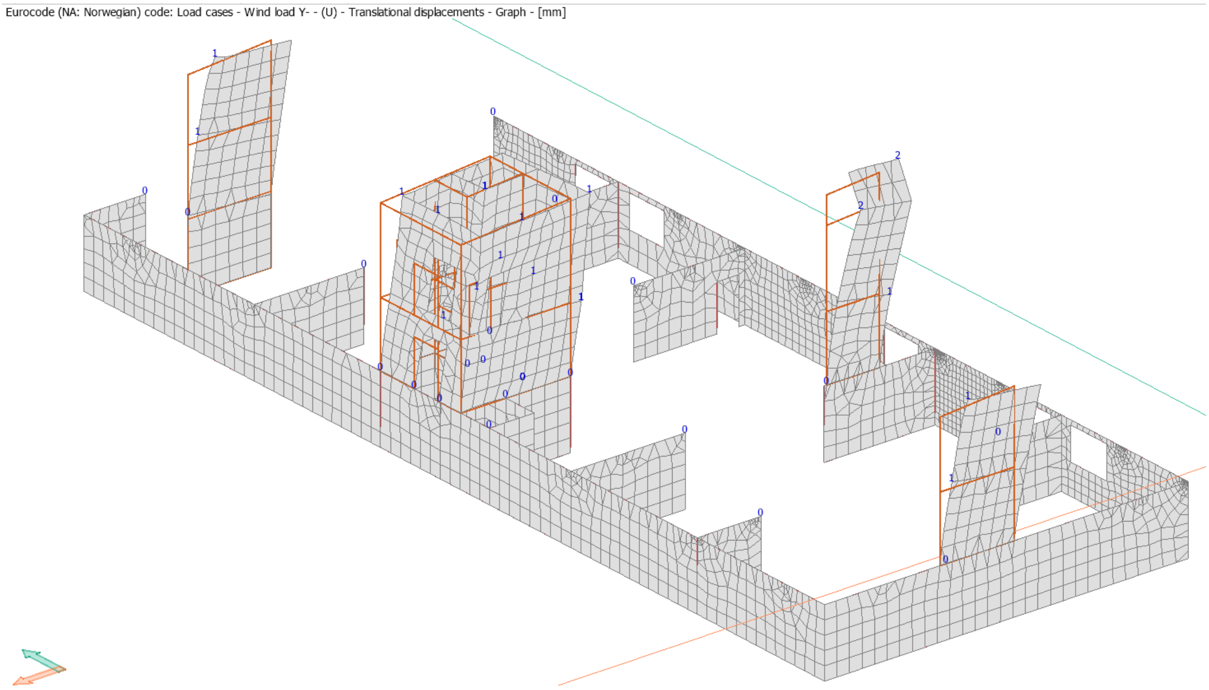


Figure 7.15: Horizontal deformation on bracing walls

NB: Frames are exactly the same in all options. Frames analysis and design results of option 1 and option 2 applies also to option 3.

For detail analysis and design of option 3, see Appendix E.4

7.1.5. Cross laminated timber floor and roof design

See Appendix E.7

7.1.6. Steel fire design

See Appendix E.5 and E.6

7.1.7. Timber Connection design

See Appendix E.8

7.1.8. Foundation design

See Appendix E.10

7.1.9. Design Summary

Table 7.18: Overview of designed materials for the structural Systems

Floor	Structural element	Option 1	Option 2	Option 3
Floors and Roof	Floor slab	CLT	CLT	CLT
	Beams	GLT and Steel	GLT and Steel	GLT and Steel
	Columns	GLT and Steel	GLT and Steel	GLT and Steel
	None bracing Walls Bracing walls	Normal Concrete Normal Concrete	Low-carbon Concrete Low-carbon Concrete	Low-carbon Concrete CLT
Sub-Structure (Ground work)	Foundation	Strip footing for walls and isolated footing for columns	Strip footing for walls and isolated footing for columns	Strip footing for walls and isolated footing for columns

For summary of analysis and design results, see Appendix E.2

7.2. Life cycle assessment (LCA) Results

7.2.1. Impact assessment comparing of option 1, option 2 and option 3

As can be seen in Figure 7.16 after analyzing all data in SimaPro, option 3 will be best in regard to low emissions. The results of the life cycle analysis for option 1, option 2 and option 3 are 234620,6 kg CO2 equivalent, 219564,5 kg CO2 equivalent and 207658,3 kg CO2 equivalent, respectively. Thus, the results of Land use for option 1, option 2 and option 3 are 443737,9 m2a crop eq, 443688,4 m2a crop eq and 483300 m2a crop eq, respectively.

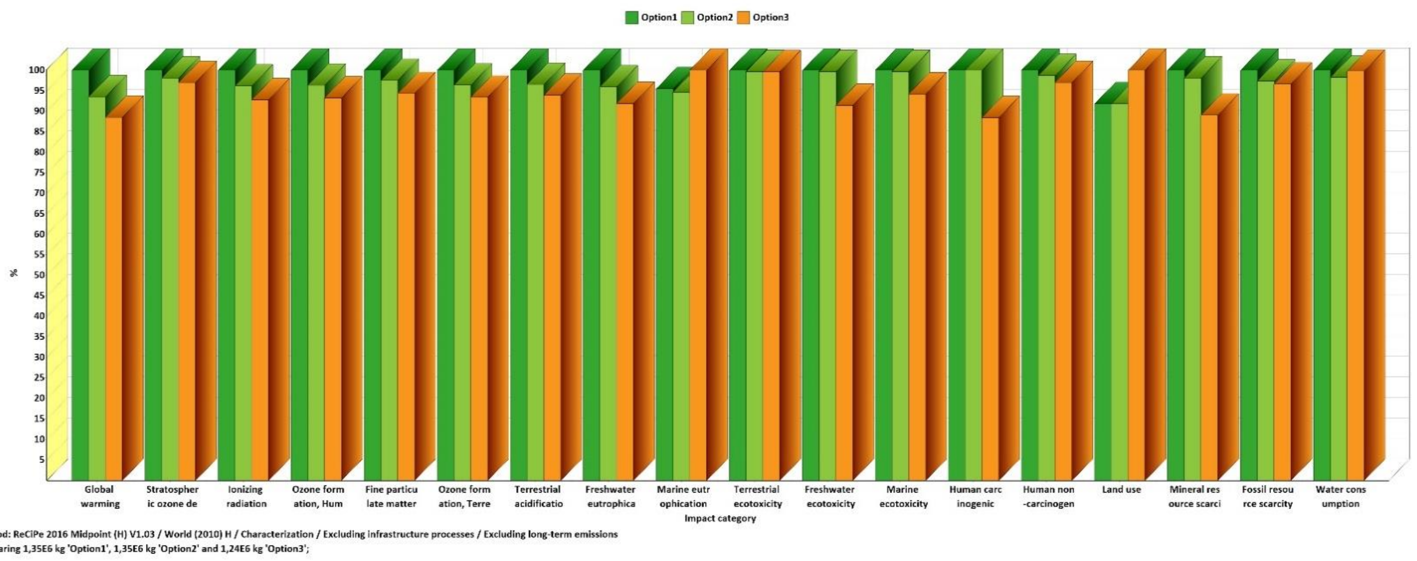


Figure 7.16 Impact assessment Comparing of option 1, option 2 and option 3

In the Figure 7.16 along the x-axis one can see the impact categories, while one can see the percentage part of the content of the various elements along the y-axis. The values for other impact categories can also be read in the Table 7.19 below. In the category "Land use", for example, option 3 has the highest value compared to option 1 and option 2, which is correct since more wood is used in option 3.

Table 7.19: Comparing option 1, option 2 and option 3

Calculation:	Compare
Results:	Impact assessment
Product 1:	1351400,89 kg Option 1 (of project master's thesis-UIA)
Product 2:	1351400,89 kg Option 2 (of project master's thesis-UIA)
Product 3:	1240186,54 kg Option 3 (of project master's thesis-UIA)
Method:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H
Indicator:	Characterization
Skip categories:	Never
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Impact category
Sort order:	Ascending

Impact category	**Unit**	**Option 1**	**Option 2**	**Option 3**
Global Warming	kg CO2 eq	234620,596	219564,5	207658,3

Stratospheric ozone depletion	kg CFC11 eq	0,05719728	0,056136	0,055472
Ionizing radiation	kBq Co-60 eq	1017,34183	978,3694	943,8868
Ozone formation, Human health	kg NOx eq	630,57924	607,6139	587,9451
Fine particulate matter formation	kg PM2.5 eq	295,015292	287,6339	278,1573
Ozone formation, Terrestrial ecosystems	kg NOx eq	644,776092	621,6096	602,1018
Terrestrial acidification	kg SO2 eq	630,56147	609,0135	592,1727
Freshwater eutrophication	kg P eq	3,83844888	3,682355	3,526426
Marine eutrophication	kg N eq	0,91129531	0,903673	0,954237
Terrestrial ecotoxicity	kg 1,4-DCB	590369,43	588424,5	588059,2
Freshwater ecotoxicity	kg 1,4-DCB	361,512109	360,562	330,4831
Marine ecotoxicity	kg 1,4-DCB	799,492162	797,2698	753,5016
Human carcinogenic toxicity	kg 1,4-DCB	20470,6831	20465,11	18108,3
Human non-carcinogenic toxicity	kg 1,4-DCB	11223,1403	11077,85	10885,06
Land use	m2a crop eq	443737,852	443688,4	483300
Mineral resource scarcity	kg Cu eq	4201,08494	4121,336	3740,552
Fossil resource scarcity	kg oil eq	41594,5759	40503,23	40199,2
Water consumption	m3	1834,12358	1801,876	1830,226

7.2.2. Inventory comparing of option 1, option 2 and option 3

The inventory result will show the chemicals that are being emitted. It has been a chosen characterization. In inventory characterization means narrowing down emissions into emissions contributing to specific emissions categories. Further, Global Warming is chosen as category. The table shows all the chemicals and their characterized amount contributing to Global Warming.
For example, ''Carbon dioxide, fossil'' released in air represents 224165,2 kg CO2-equivalents of the total 234620,6 kg CO2-equivalents emitted for the entire life cycle of option 1.
Additionally, a ''Cut-off'' of 0,1% has been chosen. A cut-off of 0,1 % means that only values greater than 0,1% and the Global Warming impact categories are included in this list. It is important to note that the rest of chemicals are summed up in the row 'Remaining substances'. The Figure 7.17, Figure 7.18 and Figure 7.19 show that ''Carbon dioxide, fossil'' released in air is the highest chemical emitted in option 1, option 2 and option 3.

Table 7.20: Inventory-Characterization (Global Warming (Cut-off 0,1%))

No	Substance	Compartment	Unit	Option 1	Option 2	Option 3
Per sub-compartment:	No					
Skip unused:	No					
Category:	Global Warming					
Cut-off:	0,1 %					
Exclude infrastructure processes:	Yes					
Exclude long-term emissions:	Yes					
Sorted on item:	Substance					
Sort order:	Ascending					
	Total of all compartments		kg CO2 eq	234620,6	219564,5	207658,3
	Remaining substances		kg CO2 eq	346,2384	337,9796	322,566
1	Carbon dioxide, fossil	Air	kg CO2 eq	224165,2	209378,7	197579,2
2	Carbon dioxide, land transformation	Air	kg CO2 eq	265,7617	263,7902	278,7233
3	Dinitrogen monoxide	Air	kg CO2 eq	1007,896	990,8982	980,0459
4	Methane, fossil	Air	kg CO2 eq	8835,473	8593,123	8497,805

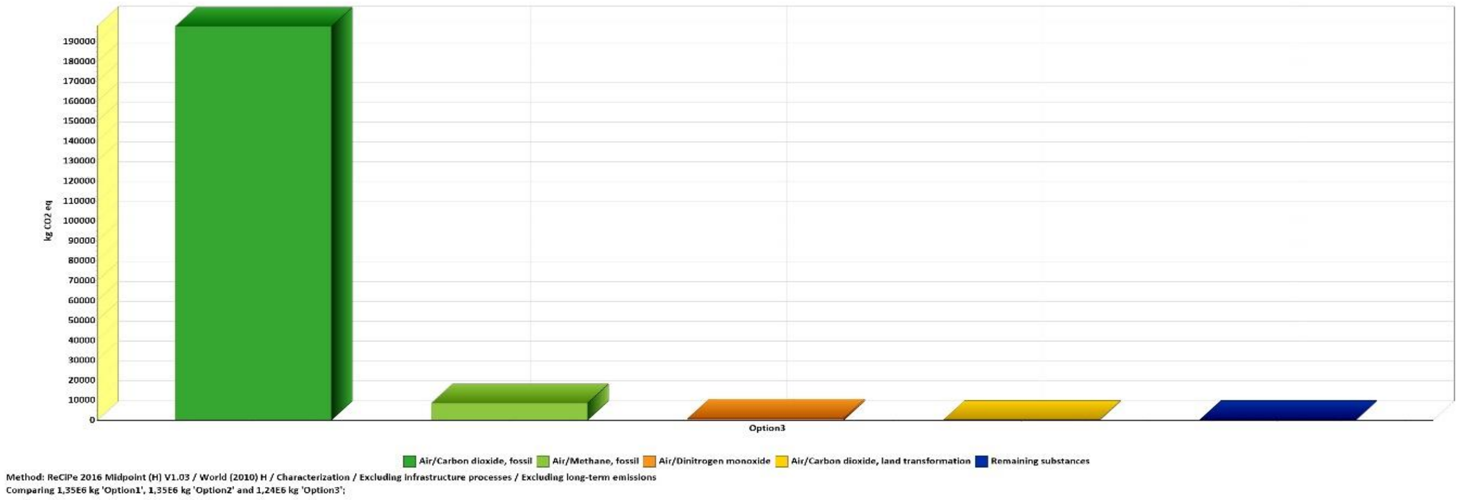


Figure 7.17 Inventory comparing of option 3-Characterization(Global Warming(Cut-off 0,1%))

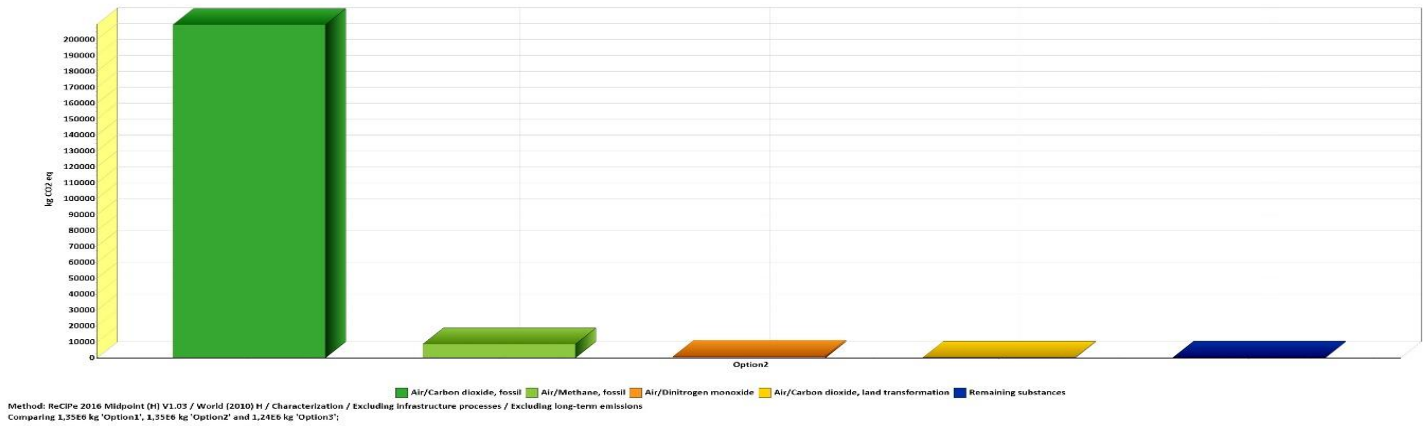


Figure 7.18 Inventory comparing of option 2-Characterization(Global Warming(Cut-off 0,1%))

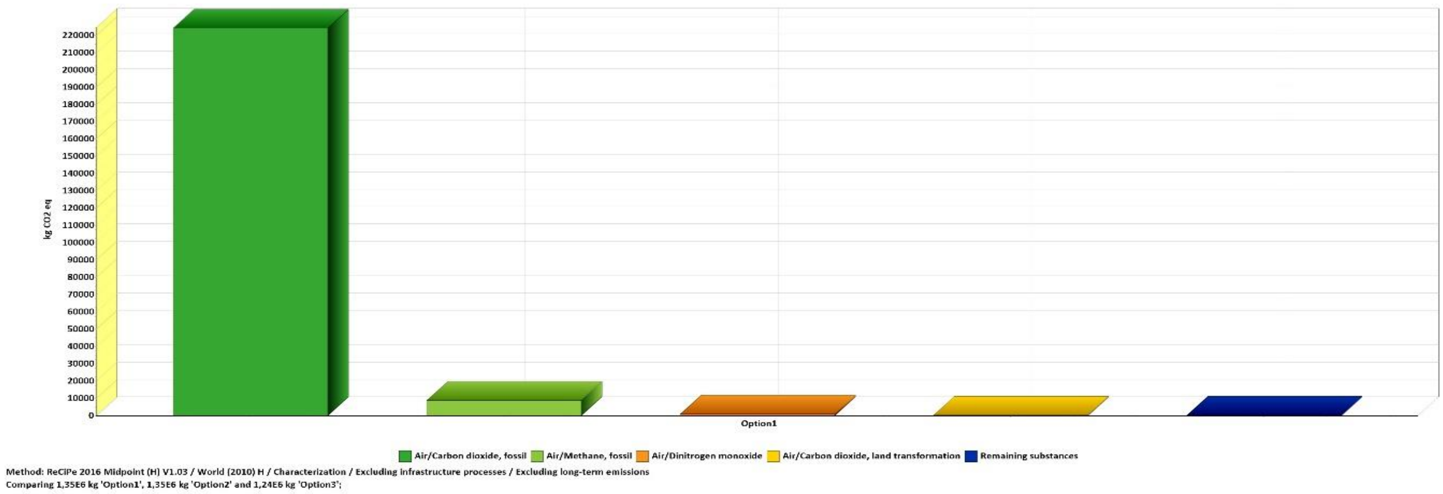


Figure 7.19 Inventory comparing of option 1-Characterization(Global Warming(Cut-off 0,1%))

7.2.3. Process contribution comparing of option 1, option 2 and option 3

The process contribution shows which input cause emissions, in this case 'Global Warming' in each process. In the Table 7.21 the rows are inputs to each process and the columns are the main process inputs. ''Remaining processes'' refers to the sum of all other processes that fall below the 1,6% cut-off that has been chosen in this project. Additionally, these results are also viewed in graphical form in Figure 7.20, Figure 7.21 and Figure 7.22. The figures show the different inputs contributing to 'Global Warming' for option 1, option 2 and option 3. The figures show that the green bar is the highest value. The green bar represents clinker production. This means that clinker production is the highest emission of all inputs. The red bar on the far right is Remaining processes which fall below the 1,6 % Cut-off.

Table 7.21: Process contribution-Global Warming(Cut-off 1,6%)

Method:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H
Indicator:	Characterization
Category:	Global Warming
Cut-off:	1,6 %
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Process
Sort order:	Ascending

No	Process	Project	Unit	Option 1	Option 2	Option 3
	Total of all processes		kg CO2 eq	234620,6	219564,5	207658,3
	Remaining processes		kg CO2 eq	88784,3	87597,5	87354,57
1	Ammonia, liquid {RoW}| ammonia production, steam reforming, liquid | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	6698,089	6697,315	7296,508
2	Clinker {Europe without Switzerland}| production | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	110989	97286,43	85146,21
3	Diesel, burned in building machine {GLO}| processing | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	3545,14	3465,847	3602,815
4	Pig iron {GLO}| production | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	9621,083	9621,069	9626,049

5	Transport, freight, light commercial vehicle {RoW}| processing | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	4785,072	4771,214	5002,354
6	Transport, freight, lorry >32 metric ton, EURO6 {RoW}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	5539,615	5539,009	5352,352
7	Transport, freight, sea, transoceanic ship {GLO}| processing | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	4658,316	4586,081	4277,469

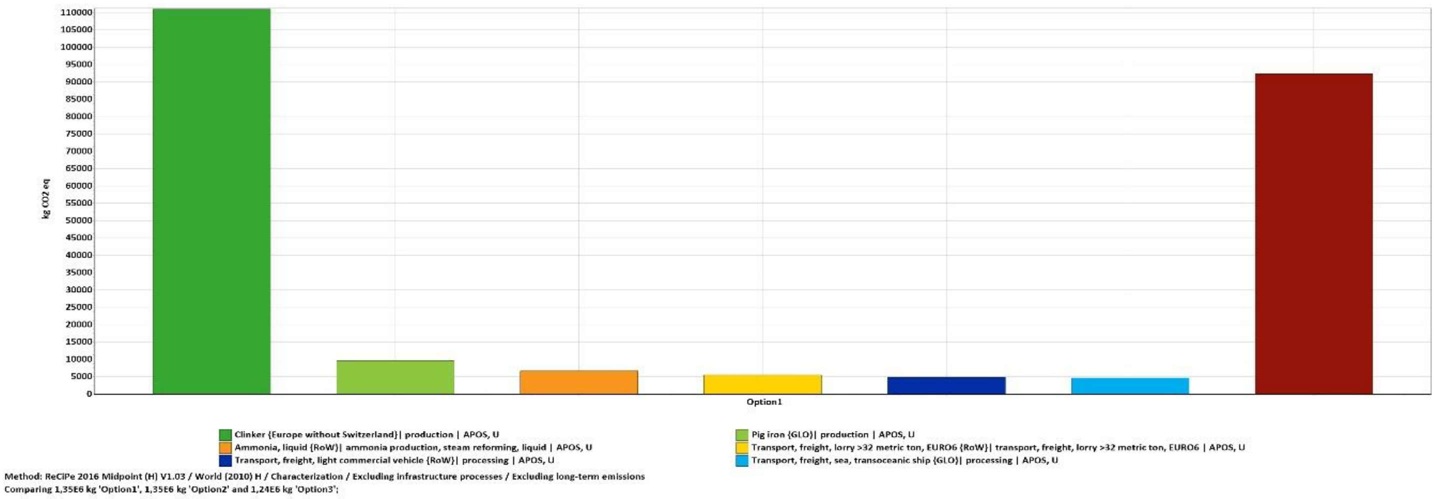


Figure 7.20: Process contribution comparing of option 1-Global Warming(Cut-off 1,6%)

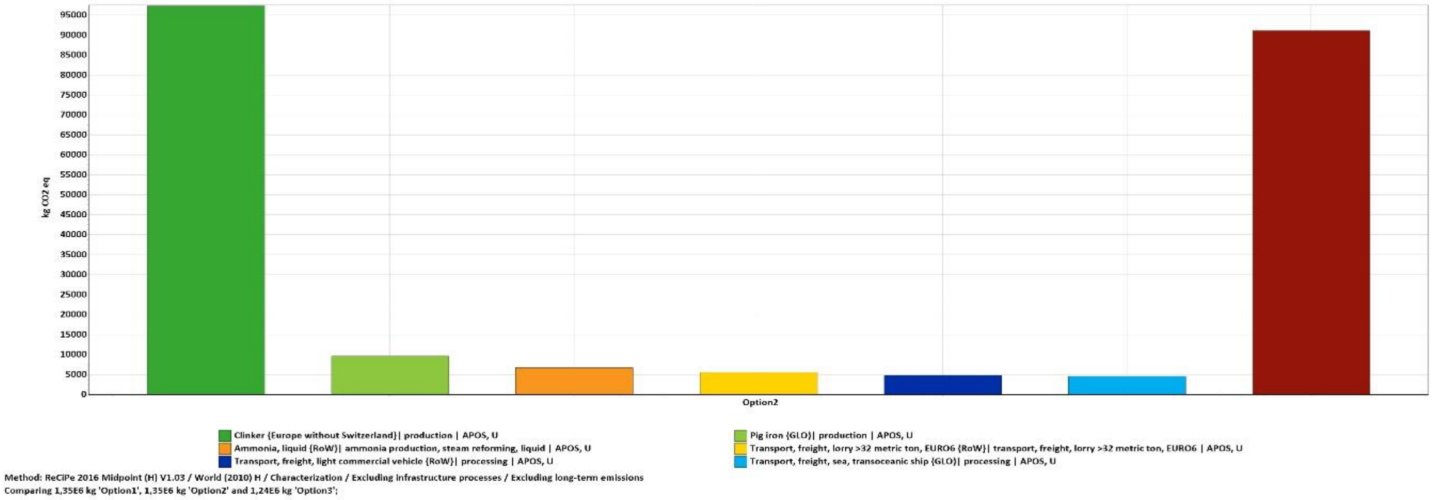


Figure 7.21: Process contribution comparing of option 3-Global Warming(Cut-off 1,6%)

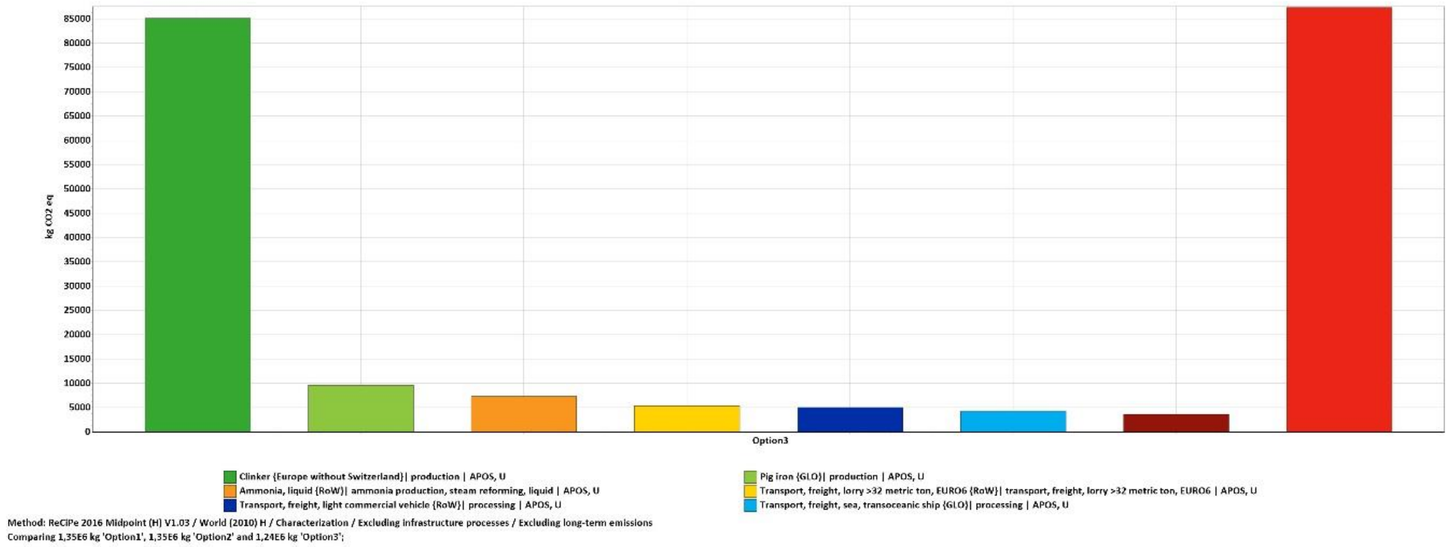


Figure 7.22: Process contribution comparing of option 2-Global Warming(Cut-off 1,6%)

7.2.4. Impact assessment analysis of option 1

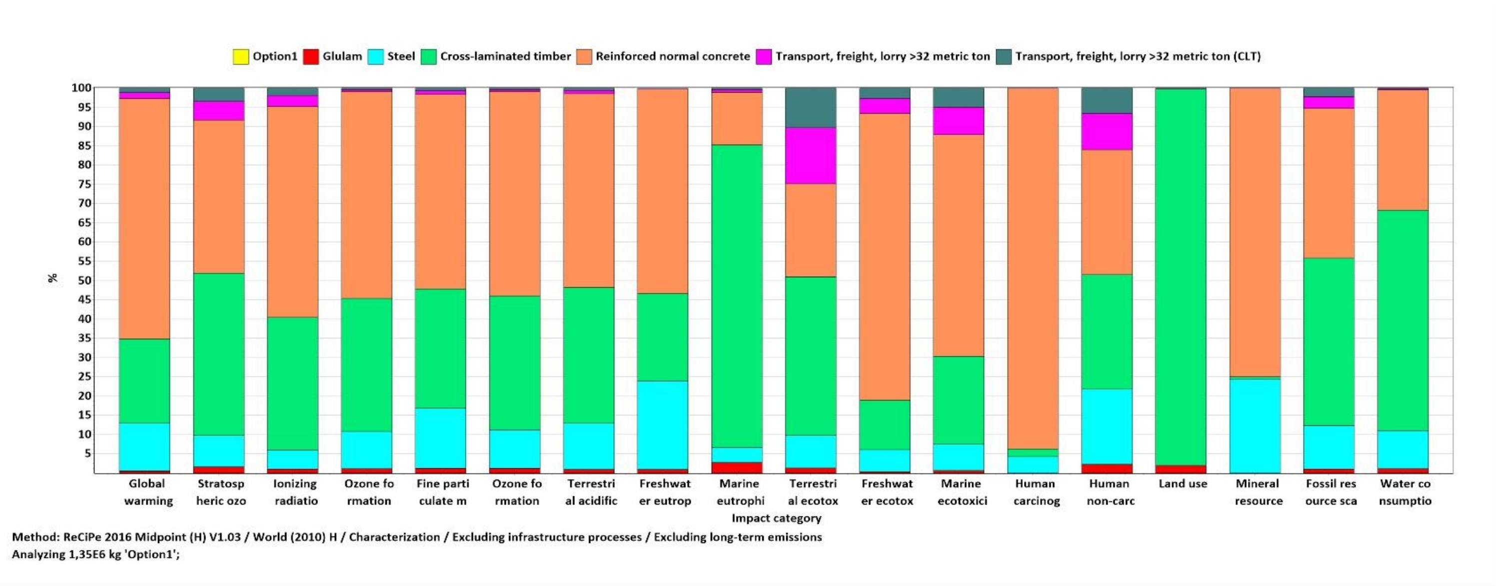


Figure 7.23: Impact assessment analyzing of Option 1

Table 7.22: Option 1 Analysis

Calculation:	Analyze
Results:	Impact assessment
Product:	1351400,89 kg Option 1 (of project master's thesis-UIA)
Method:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H
Indicator:	Characterization
Skip categories:	Never
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Impact category
Sort order:	Ascending

Impact category	Unit	Total	Option 1	Glulam	Steel	Cross-laminated timber	Reinforced normal concrete	Transport, freight, lorry >32 metric ton	Transport, freight, lorry >32 metric ton (CLT)
Global Warming	kg CO2 eq	234620,6	0	1367,669	28884,48	51544,1	146495	3722,142	2607,196
Stratospheric ozone depletion	kg CFC11 eq	0,057197	0	0,00091	0,004688	0,024097	0,022741	0,0028	0,001961
Ionizing radiation	kBq Co-60 eq	1017,342	0	11,01127	50,39374	349,5598	558,2576	28,29799	19,82149
Ozone formation, Human health	kg NOx eq	630,5792	0	7,29232	61,11493	217,9352	338,8453	3,170591	2,220859

Fine particulate matter formation	kg PM2.5 eq	295,0153	0	3,536971	46,20369	91,43655	149,0157	2,835909	1,986429
Ozone formation, Terrestrial ecosystems	kg NOx eq	644,7761	0	7,683591	64,60685	224,4224	342,4517	3,300061	2,311547
Terrestrial acidification	kg SO2 eq	630,5615	0	5,931343	75,87869	222,6275	317,2474	5,220061	3,656423
Freshwater eutrophication	kg P eq	3,838449	0	0,036698	0,884651	0,869367	2,04094	0,003995	0,002798
Marine eutrophication	kg N eq	0,911295	0	0,024863	0,035936	0,716215	0,124992	0,005462	0,003826
Terrestrial ecotoxicity	kg 1,4-DCB	590369,4	0	7703,596	49981,59	243222,8	142700,5	86306,84	60454,13
Freshwater ecotoxicity	kg 1,4-DCB	361,5121	0	1,403376	20,7312	46,33253	269,3986	13,90592	9,740487
Marine ecotoxicity	kg 1,4-DCB	799,4922	0	5,586871	54,64894	182,5093	460,0348	56,87435	39,83797
Human carcinogenic toxicity	kg 1,4-DCB	20470,68	0	3,965015	876,2772	403,6261	19184,59	1,308607	0,916621
Human non-carcinogenic toxicity	kg 1,4-DCB	11223,14	0	252,9773	2196,448	3336,204	3640,008	1057,071	740,4317
Land use	m2a crop eq	443737,9	0	8892,19	125,769	433929,1	788,2406	1,49142	1,044674
Mineral resource scarcity	kg Cu eq	4201,085	0	0,541732	1026,909	24,72679	3148,86	0,027958	0,019584
Fossil resource scarcity	kg oil eq	41594,58	0	428,3534	4704,257	18088,94	16185,33	1286,536	901,1617
Water consumption	m3	1834,124	0	20,43982	181,767	1050,123	572,3586	5,548529	3,8865

7.2.5. Inventory analysis of option 1

Table 7.23: Option 1-Inventory-characterization (Global Warming (Cut-off 0,1%))

Calculation:	Analyze
Results:	Inventory
Product:	1351400,89 kg Option 1 (of project master's thesis-UIA)
Method:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H
Indicator:	Characterization
Compartment:	All compartments
Per sub-compartment:	No
Skip unused:	No
Category:	Global Warming
Cut-off:	0,1 %
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Cross-laminated timber
Sort order:	Descending

No	Substance	Compartment	Unit	Total	Option 1	Glulam	Steel	Cross-laminated timber	Reinforced normal concrete	Transport, freight, lorry >32 metric ton	Transport, freight, lorry >32 metric ton (CLT)
	Total of all compartments		kg CO2 eq	234620,6	0	1367,669	28884,48	51544,1	146495	3722,142	2607,196
	Remaining substances		kg CO2 eq	189,8508	0	2,521244	25,96605	41,18261	119,035	0,67383	0,471988
1	Carbon dioxide, fossil	Air	kg CO2 eq	224165,2	0	1241,561	26498,7	47686,56	142593,8	3613,503	2531,1
2	Methane, fossil	Air	kg CO2 eq	8835,473	0	87,42729	2247,101	3131,751	3276,45	54,54006	38,20291
3	Dinitrogen monoxide	Air	kg CO2 eq	1007,896	0	19,39051	94,9269	417,8764	385,393	53,10854	37,20019
4	Carbon dioxide, land transformation	Air	kg CO2 eq	265,7617	0	14,23479	5,580711	209,7438	36,04647	0,091699	0,064231
5	Sulfur hexafluoride	Air	kg CO2 eq	156,3876	0	2,53448	12,20558	56,99006	84,27527	0,224792	0,157457

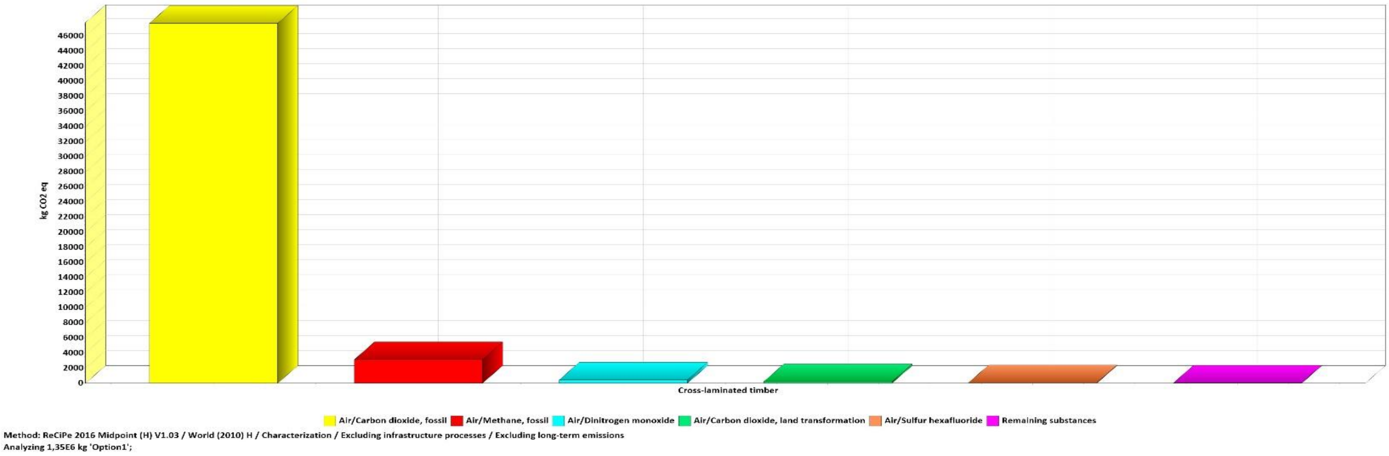


Figure 7.24: Option 1-Inventory-characterization(Global Warming(Cut-off 0,1%))Cross-laminated timber

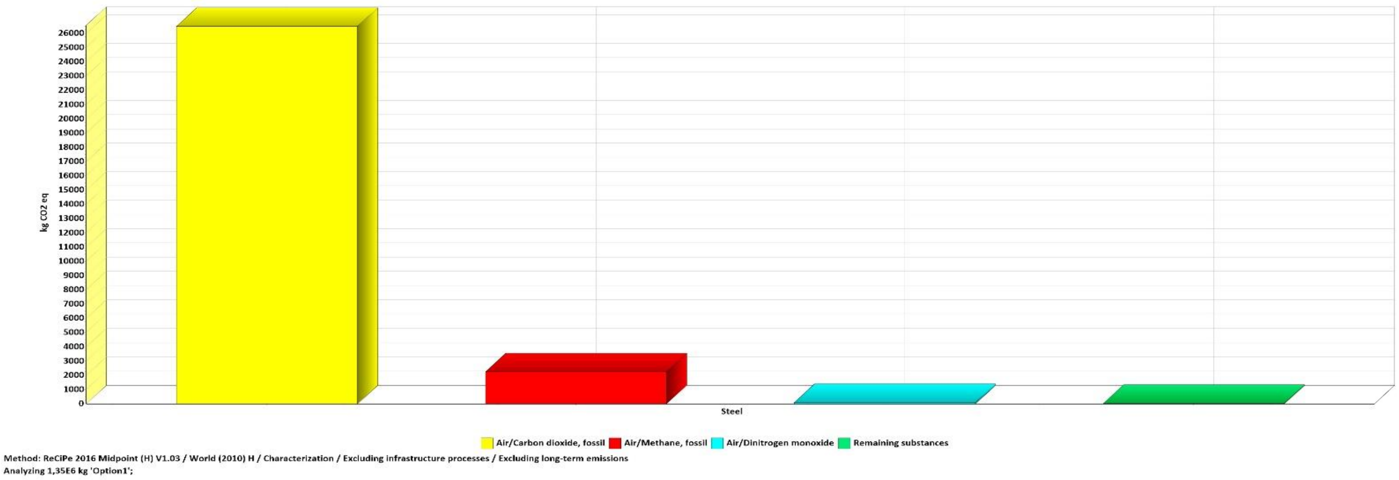


Figure 7.25: Option 1-Inventory-characterization(Global Warming(Cut-off 0,1%))Steel

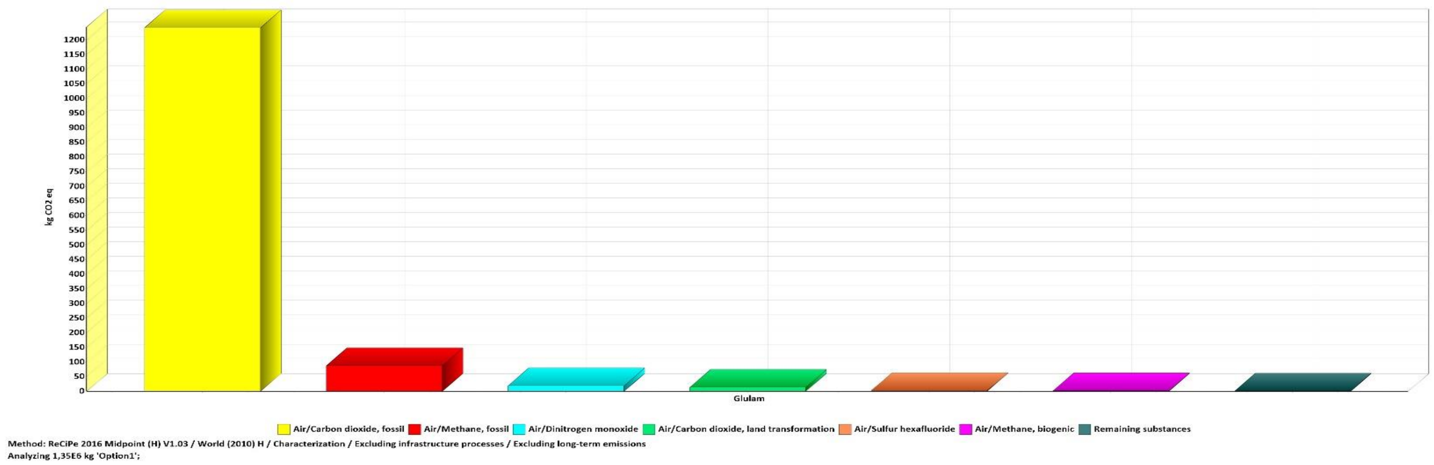


Figure 7.26: Option 1-Inventory-characterization(Global Warming(Cut-off 0,1%))Glulam

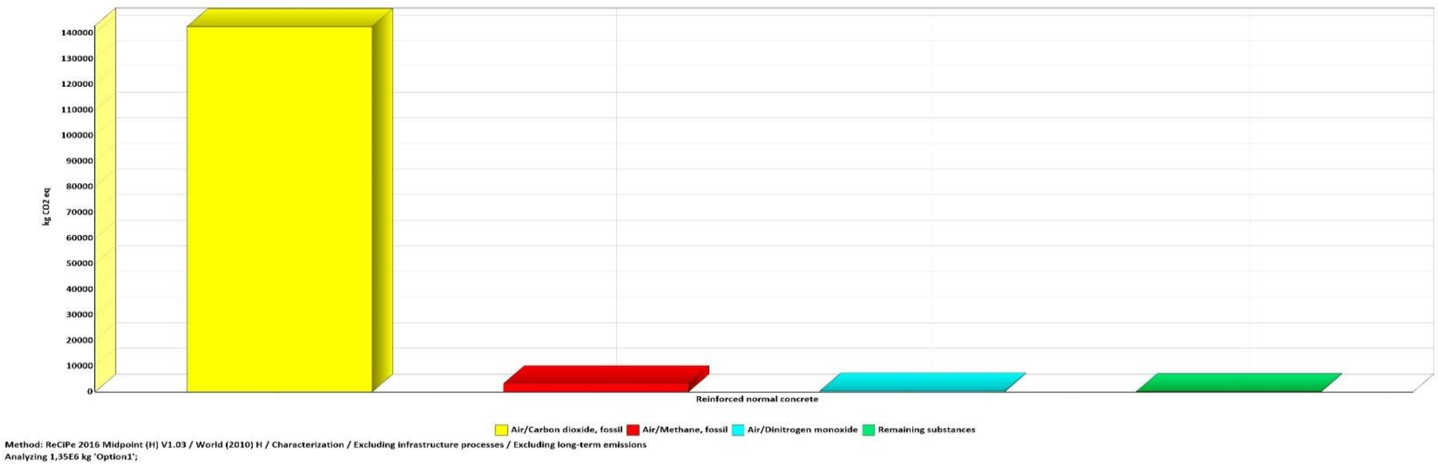


Figure 7.27: Option 1-Inventory-characterization(Global Warming(Cut-off 0,1%))Reinforced normal concrete

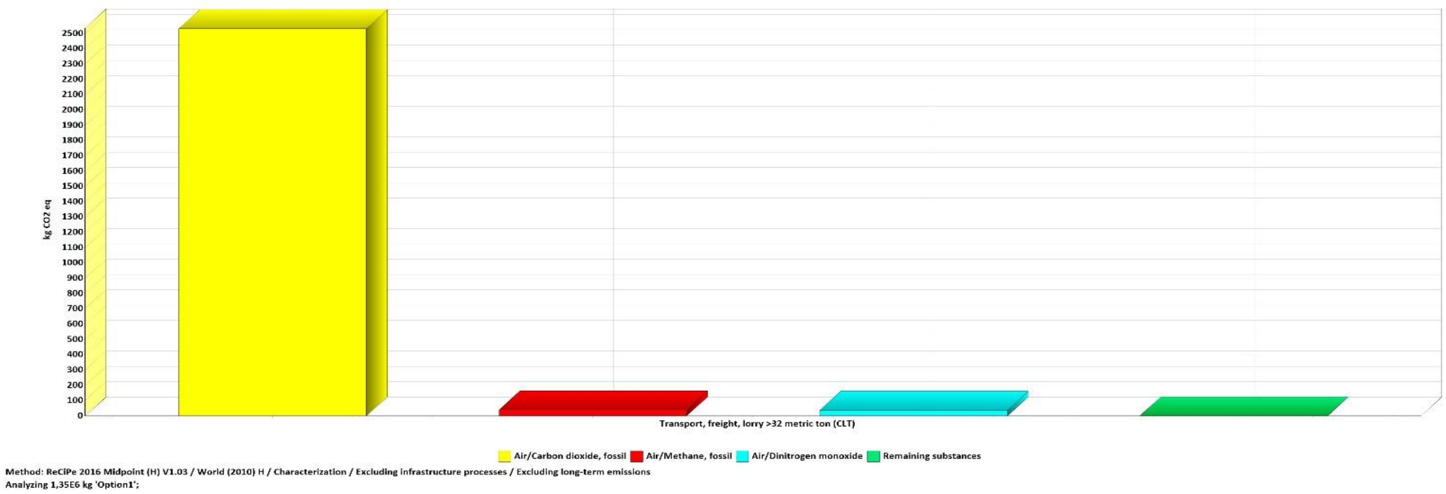


Figure 7.28: Option 1-Inventory-characterization(Global Warming(Cut-off 0,1%))Transport(CLT)

7.2.6. Process contribution analysis of option 1

Table 7.24: Option 1-Process contribution-Global Warming(Cut-off 1,6%)

Calculation:	Analyze
Results:	Process contribution
Product:	1351400,89 kg Option 1 (of project master's thesis-UIA)
Method:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H
Indicator:	Characterization
Category:	Global Warming
Cut-off:	1,6 %
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Steel
Sort order:	Descending

No	Process	Project	Unit	Total	Option 1	Glulam	Steel	Cross-laminated timber	Reinforced normal concrete	Transport, freight, lorry >32 metric ton	Transport, freight, lorry >32 metric ton (CLT)
	Total of all processes		kg CO2 eq	234620,6	0	1367,669	28884,48	51544,1	146495	3722,142	2607,196
	Remaining processes		kg CO2 eq	209923,3	0	1317,453	10043,72	49862,69	142379,9	3716,403	2603,176
1	Pig iron {GLO}| production | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	9621,083	0	1,559687	9532,965	72,94858	13,59048	0,011268	0,007893
2	Sinter, iron {GLO}| production | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	2440,53	0	0,516423	2406,113	21,12099	12,76015	0,01129	0,007908
3	Hard coal {CN}| hard coal mine operation and hard coal	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	2791,324	0	32,54539	1394,736	820,115	534,7027	5,424785	3,799822

	preparation | APOS, U										
4	Blast furnace gas {JP}| treatment of, in power plant | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	1293,346	0	0,273675	1275,107	11,19295	6,762174	0,005983	0,004191
5	Quicklime, in pieces, loose {RoW}| production | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	1642,253	0	0,356106	1174,235	13,22175	454,3396	0,059097	0,041395
6	Steel, unalloyed {RoW}| steel production, converter, unalloyed | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	888,6719	0	0,127252	882,6939	5,596529	0,252901	0,000782	0,000548
7	Transport, freight, sea, transoceanic ship {GLO}| processing | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	4658,316	0	14,54854	842,1128	724,9662	3076,341	0,204403	0,143175
8	Blast furnace gas {KR}| treatment of, in power plant | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	676,2178	0	0,143089	666,6817	5,852166	3,53556	0,003128	0,002191
9	Coke {RoW}| coking | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	685,5192	0	0,146275	666,1151	6,39941	12,82707	0,018434	0,012912

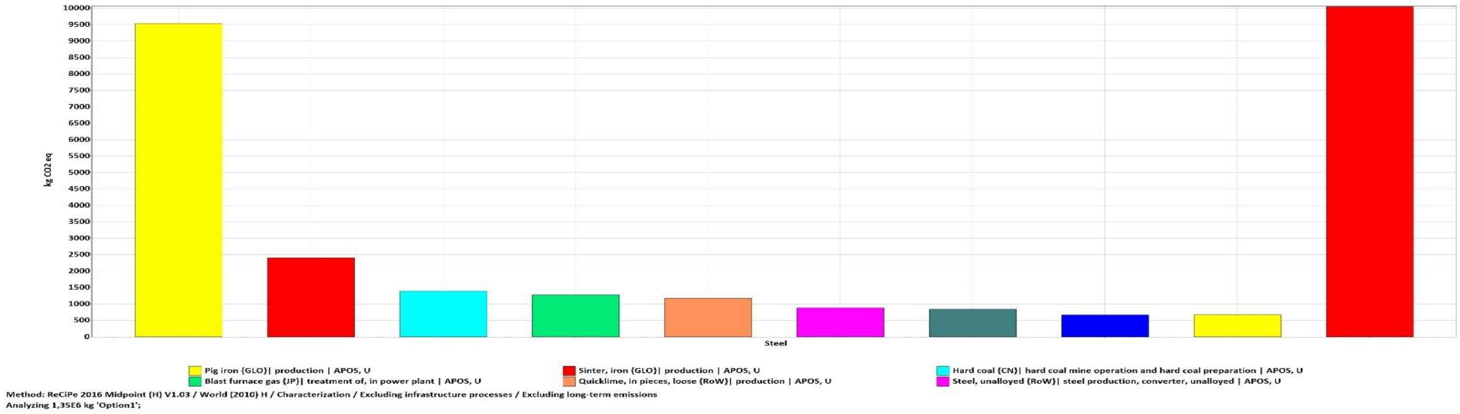


Figure 7.29: Option 1-Process contribution-Global Warming(Cut-off 1,6%) Steel

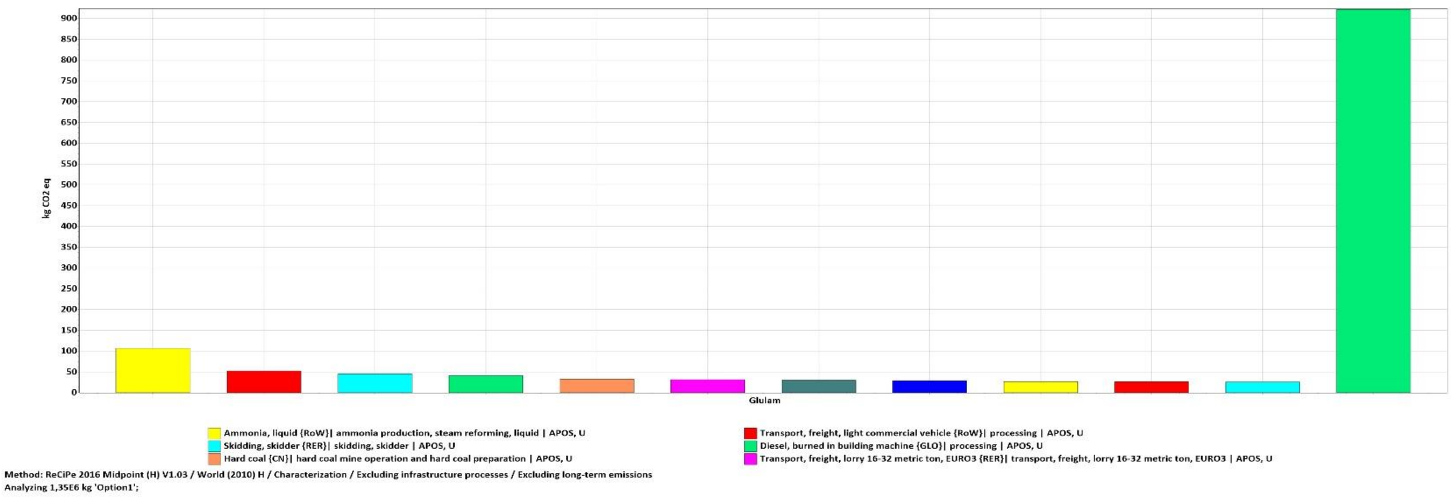


Figure 7.30: Option 1-Process contribution-Global Warming(Cut-off 1,6%) Glulam

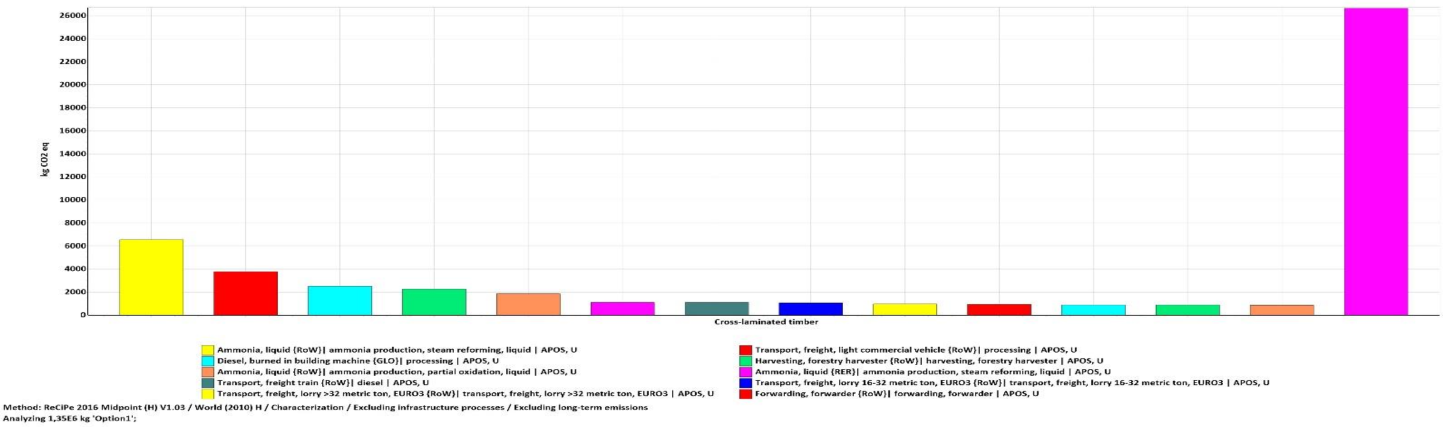


Figure 7.31: Option 1-Process contribution-Global Warming(Cut-off 1,6%) Cross-laminated timber

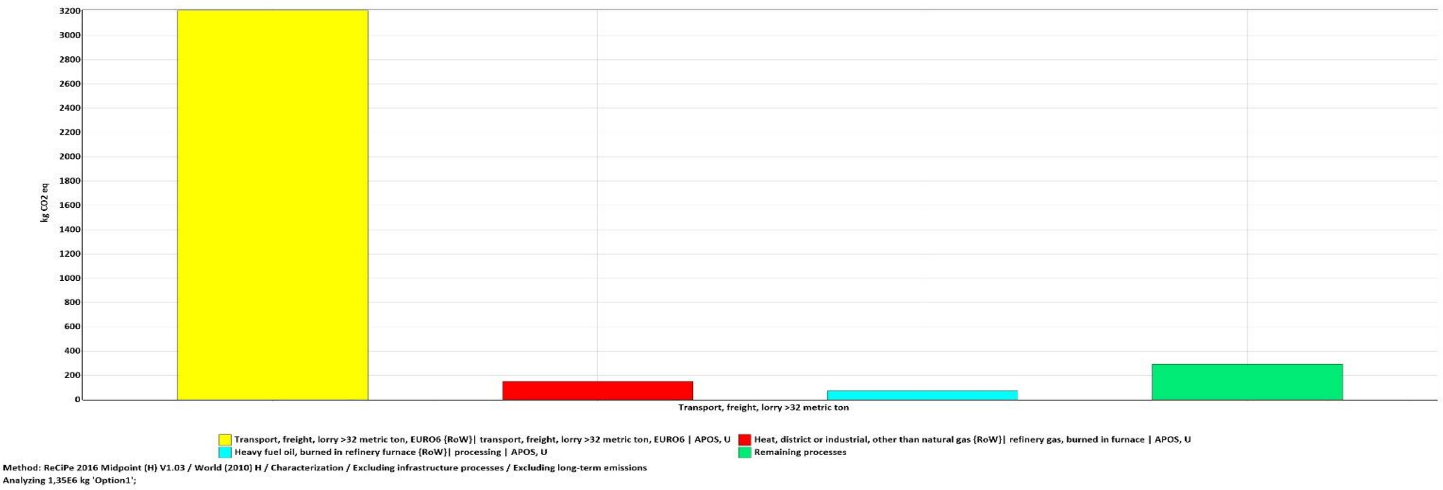


Figure 7.32: Option 1-Process contribution-Global Warming(Cut-off 1,6%) Transport for all

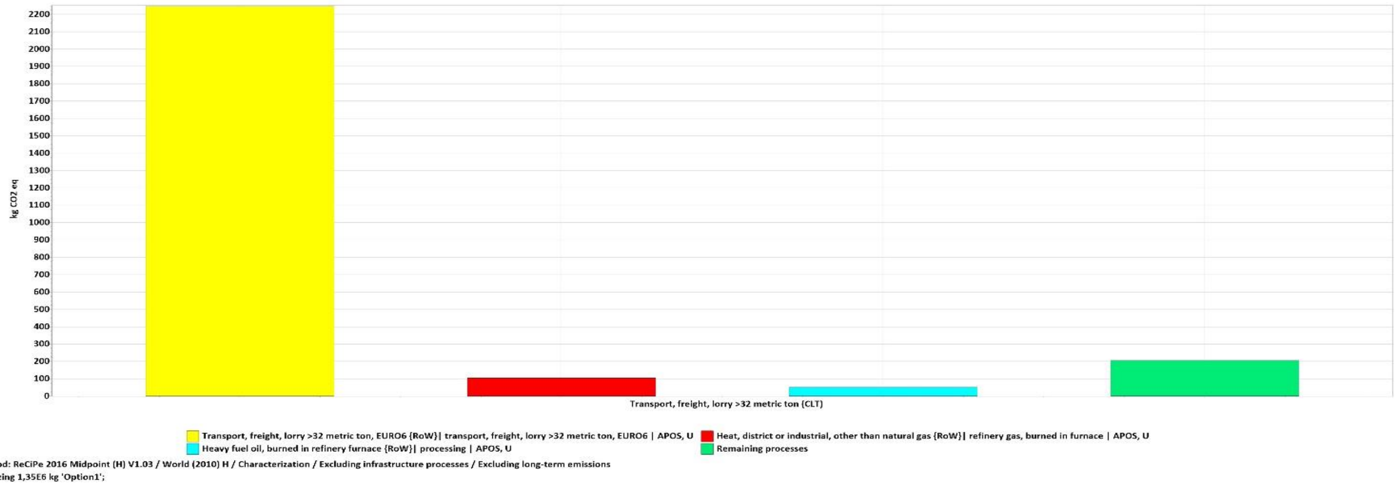


Figure 7.33: Option 1-Process contribution-Global Warming(Cut-off 1,6%) Transport for CLT

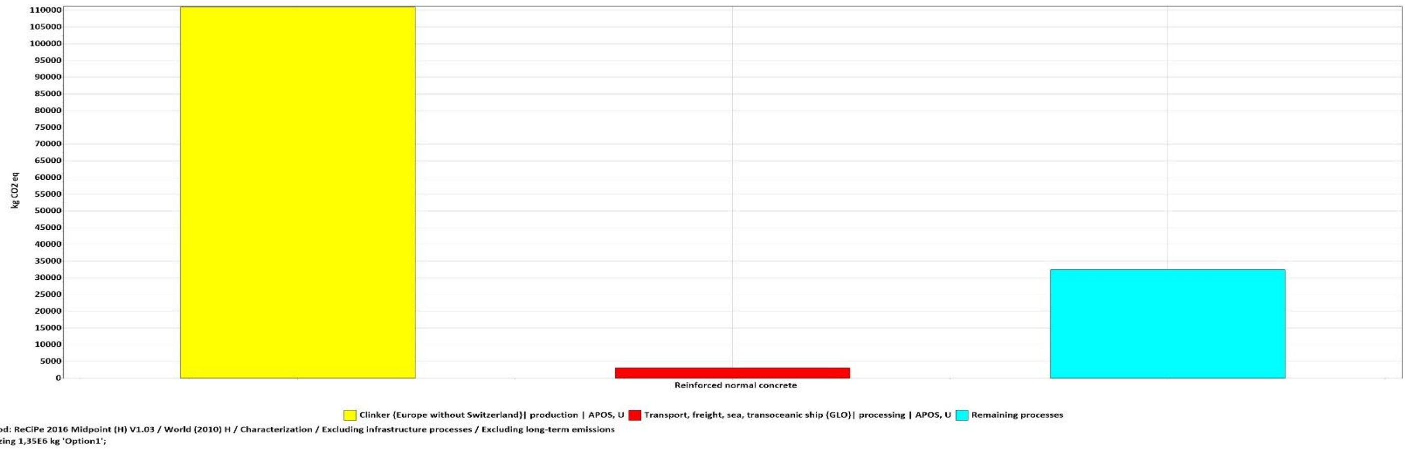


Figure 7.34: Option 1-Process contribution-Global Warming(Cut-off 1,6%) Reinforced normal concrete

7.2.7. Impact assessment analysis of option 2

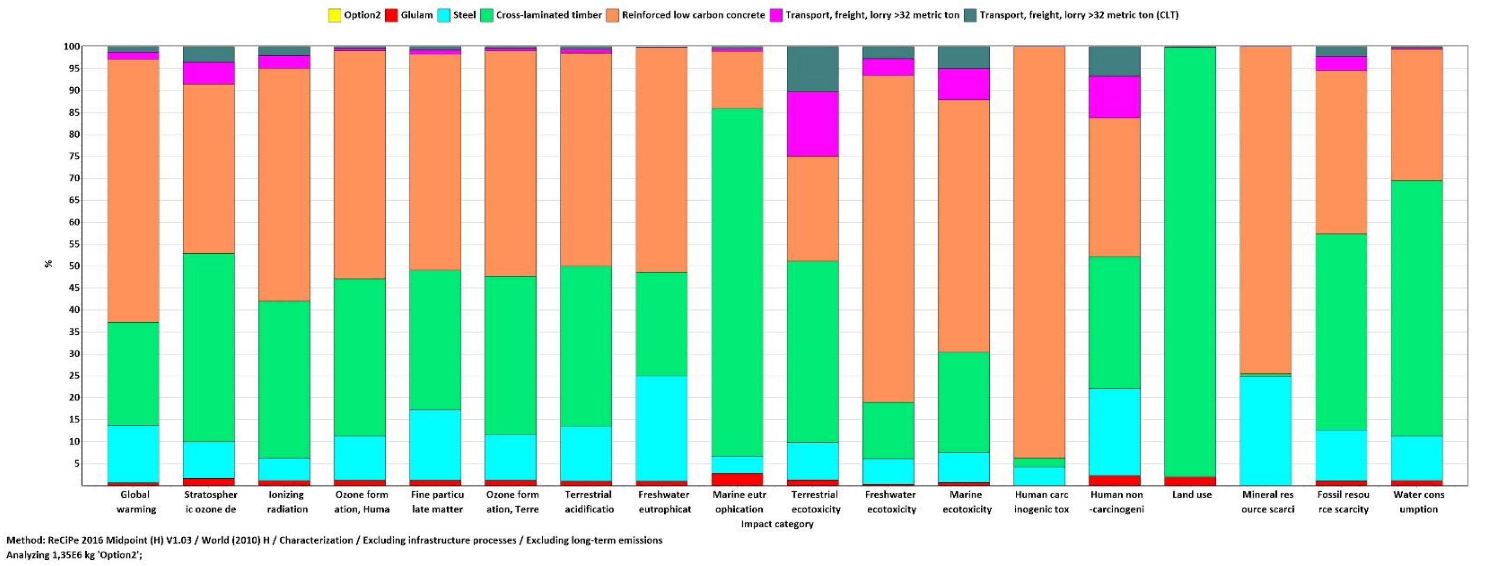


Figure 7.35: Impact assessment analyzing of option 2

Table 7.25: Option 2 Analysis

Calculation:	Analyze								
Results:	Impact assessment								
Product:	1351400,89 kg Option 2 (of project master's thesis-UIA)								
Method:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H								
Indicator:	Characterization								
Skip categories:	Never								
Exclude infrastructure processes:	Yes								
Exclude long-term emissions:	Yes								
Sorted on item:	Impact category								
Sort order:	Ascending								
Impact category	Unit	Total	Option 2	Glulam	Steel	Cross-laminated timber	Reinforced low carbon concrete	Transport, freight, lorry >32 metric ton	Transport, freight, lorry >32 metric ton (CLT)
Global Warming	kg CO2 eq	219564,5	0	1367,669	28884,48	51544,1	131438,9	3722,142	2607,196
Stratospheric ozone depletion	kg CFC11 eq	0,056136	0	0,00091	0,004688	0,024097	0,02168	0,0028	0,001961
Ionizing radiation	kBq Co-60 eq	978,3694	0	11,01127	50,39374	349,5598	519,2851	28,29799	19,82149

Ozone formation, Human health	kg NOx eq	607,6139	0	7,29232	61,11493	217,9352	315,88	3,170591	2,220859
Fine particulate matter formation	kg PM2.5 eq	287,6339	0	3,536971	46,20369	91,43655	141,6344	2,835909	1,986429
Ozone formation, Terrestrial ecosystems	kg NOx eq	621,6096	0	7,683591	64,60685	224,4224	319,2851	3,300061	2,311547
Terrestrial acidification	kg SO2 eq	609,0135	0	5,931343	75,87869	222,6275	295,6995	5,220061	3,656423
Freshwater eutrophication	kg P eq	3,682355	0	0,036698	0,884651	0,869368	1,884846	0,003995	0,002798
Marine eutrophication	kg N eq	0,903673	0	0,024863	0,035936	0,716215	0,117369	0,005462	0,003826
Terrestrial ecotoxicity	kg 1,4-DCB	588424,5	0	7703,596	49981,59	243222,8	140755,5	86306,84	60454,13
Freshwater ecotoxicity	kg 1,4-DCB	360,562	0	1,403376	20,7312	46,33253	268,4484	13,90592	9,740487
Marine ecotoxicity	kg 1,4-DCB	797,2698	0	5,586871	54,64894	182,5093	457,8124	56,87435	39,83797
Human carcinogenic toxicity	kg 1,4-DCB	20465,11	0	3,965015	876,2772	403,6261	19179,02	1,308607	0,916621
Human non-carcinogenic toxicity	kg 1,4-DCB	11077,85	0	252,9773	2196,448	3336,204	3494,713	1057,071	740,4317
Land use	m2a crop eq	443688,4	0	8892,19	125,769	433929,1	738,8275	1,49142	1,044674
Mineral resource scarcity	kg Cu eq	4121,336	0	0,541732	1026,909	24,72679	3069,111	0,027958	0,019584
Fossil resource scarcity	kg oil eq	40503,23	0	428,3534	4704,257	18088,94	15093,98	1286,536	901,1617
Water consumption	m3	1801,876	0	20,43982	181,767	1050,123	540,1108	5,548529	3,8865

7.2.8. Inventory analysis of option 2

Table 7.26: Option 2-Inventory-characterization(Global Warming(Cut-off 0,1%))

Calculation:	Analyze
Results:	Inventory
Product:	1351400,89 kg Option 2 (of project master's thesis-UIA)
Method:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H
Indicator:	Characterization
Compartment:	All compartments
Per sub-compartment:	No
Skip unused:	No
Category:	Global Warming
Cut-off:	0,1 %
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Ascending

No	Substance	Compartment	Unit	Total	Option 2	Glulam	Steel	Cross-laminated timber	Reinforced low carbon concrete	Transport, freight, lorry >32 metric ton	Transport, freight, lorry >32 metric ton (CLT)
	Total of all compartments		kg CO2 eq	219564,5	0	1367,669	28884,48	51544,1	131438,9	3722,142	2607,196
	Remaining substances		kg CO2 eq	337,9796	0	5,055724	38,17163	98,17267	195,0516	0,898622	0,629445
1	Carbon dioxide, fossil	Air	kg CO2 eq	209378,7	0	1241,561	26498,7	47686,56	127807,3	3613,503	2531,1
2	Carbon dioxide, land transformation	Air	kg CO2 eq	263,7902	0	14,23479	5,580711	209,7438	34,07494	0,091699	0,064231
3	Dinitrogen monoxide	Air	kg CO2 eq	990,8982	0	19,39051	94,9269	417,8764	368,3956	53,10854	37,20019
4	Methane, fossil	Air	kg CO2 eq	8593,123	0	87,42729	2247,101	3131,751	3034,1	54,54006	38,20291

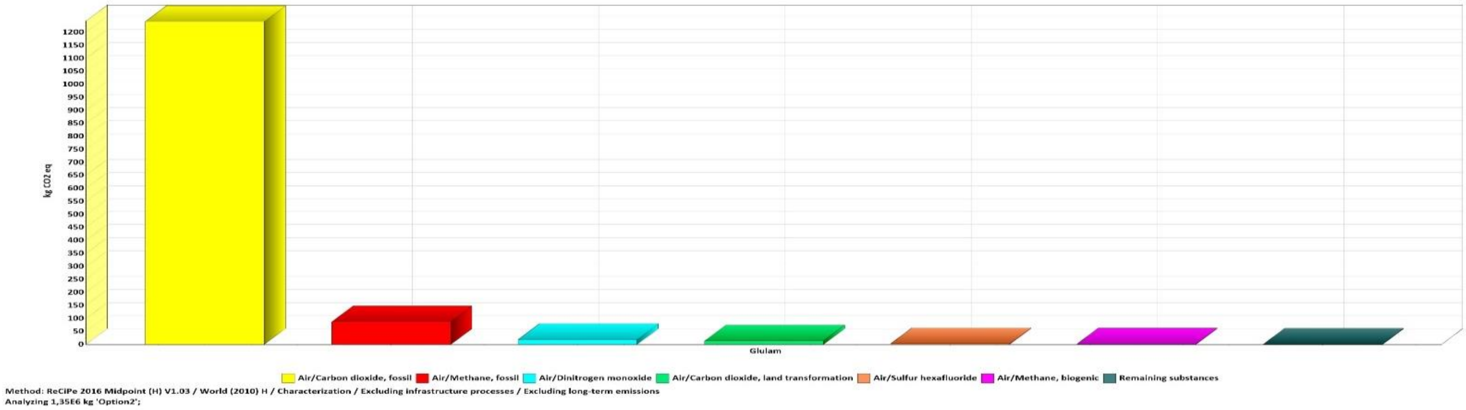


Figure 7.36: Option 2-Inventory-characterization(Global Warming(Cut-off 0,1%))Glulam

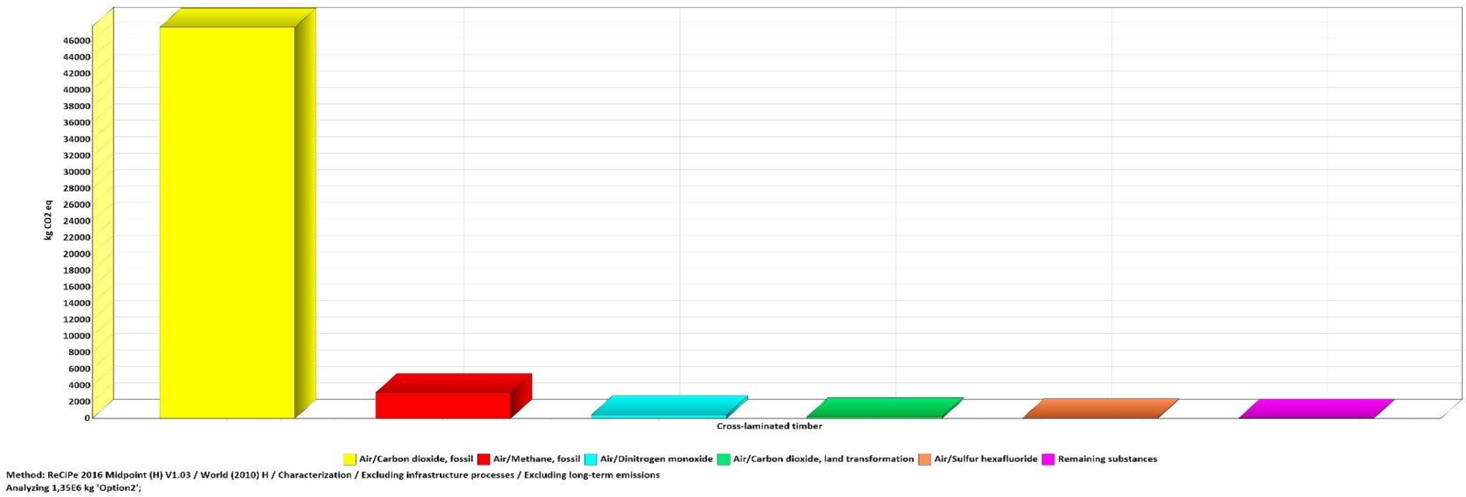


Figure 7.37: Option 2-Inventory-characterization(Global Warming(Cut-off 0,1%))Cross-Laminated timber

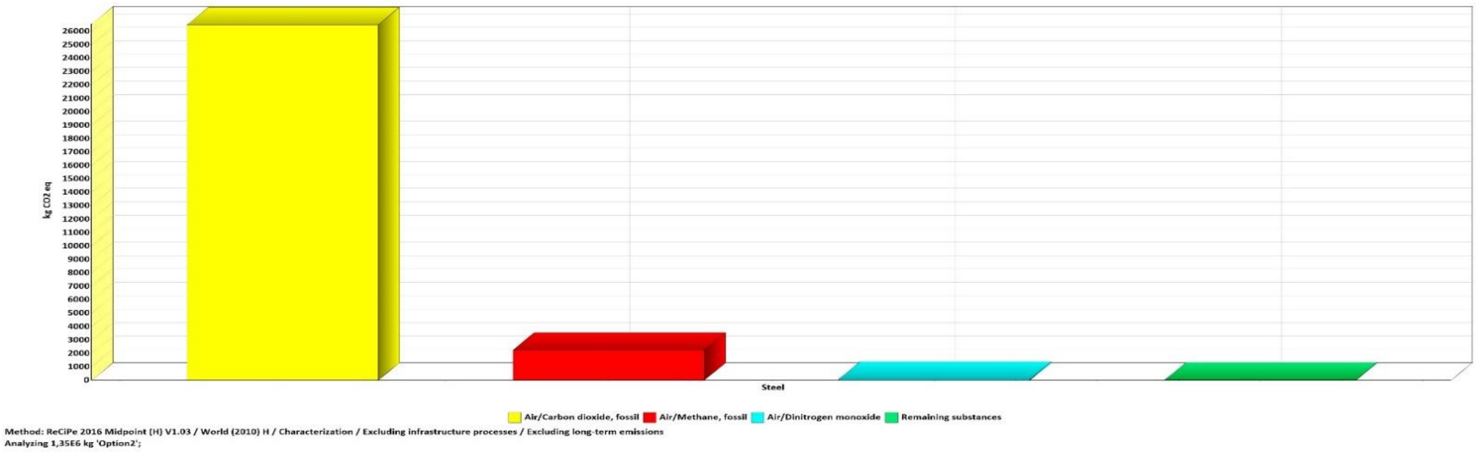


Figure 7.38: Option 2-Inventory-characterization(Global Warming(Cut-off 0,1%))Steel

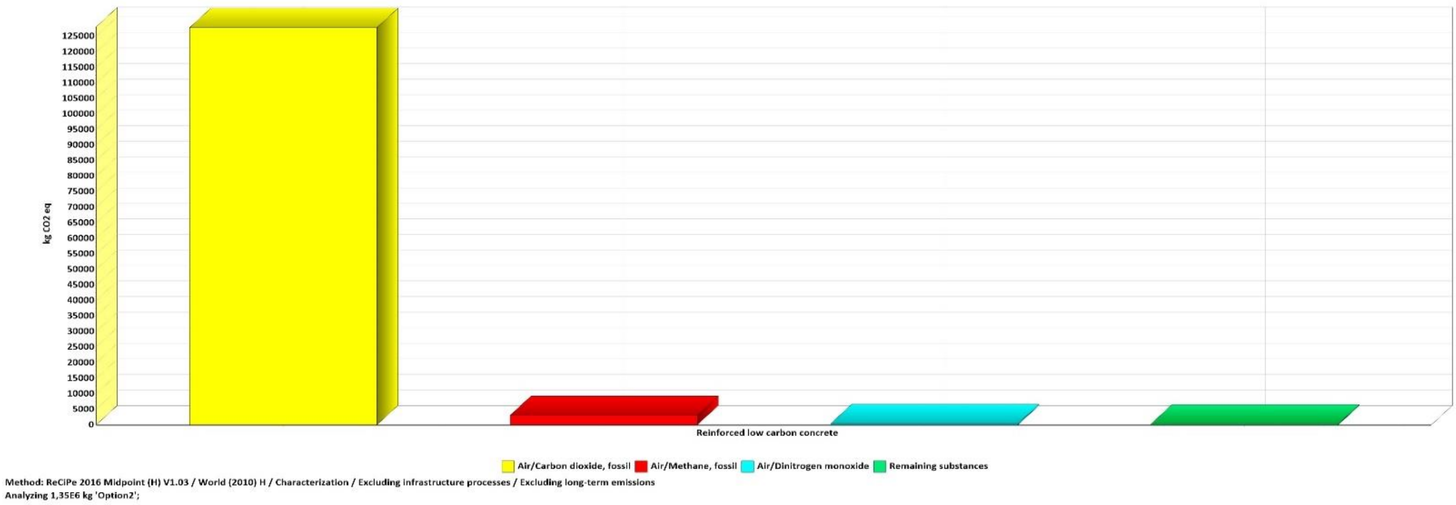


Figure 7.39: Option 2-Inventory-characterization(Global Warming(Cut-off 0,1%))Reinforced low carbon concrete

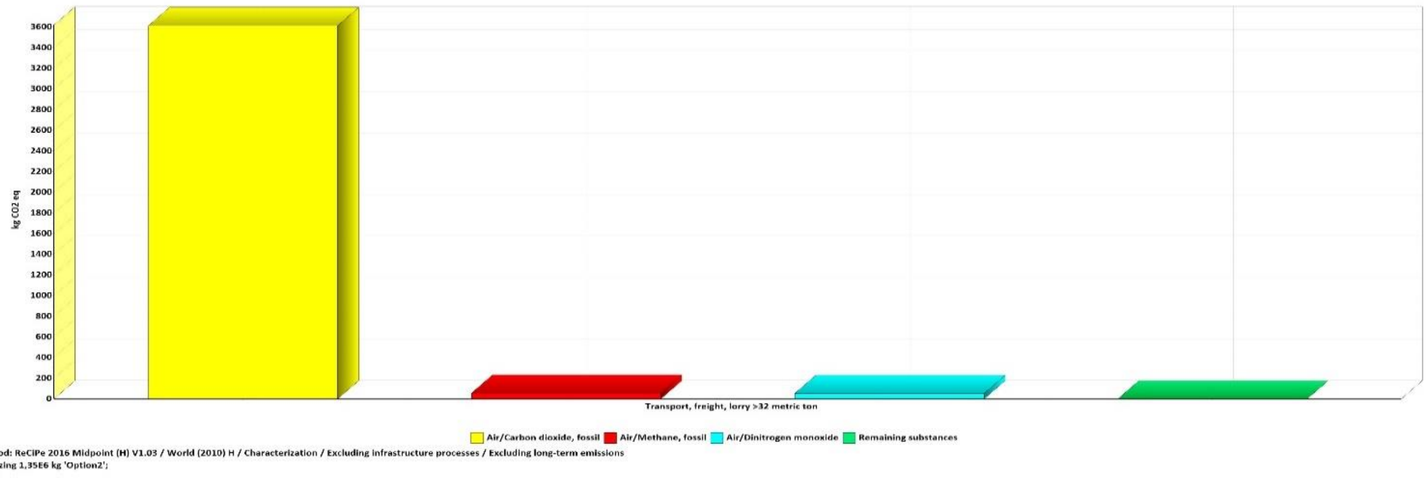


Figure 7.40: Option 2-Inventory-characterization(Global Warming(Cut-off 0,1%))Transport for all

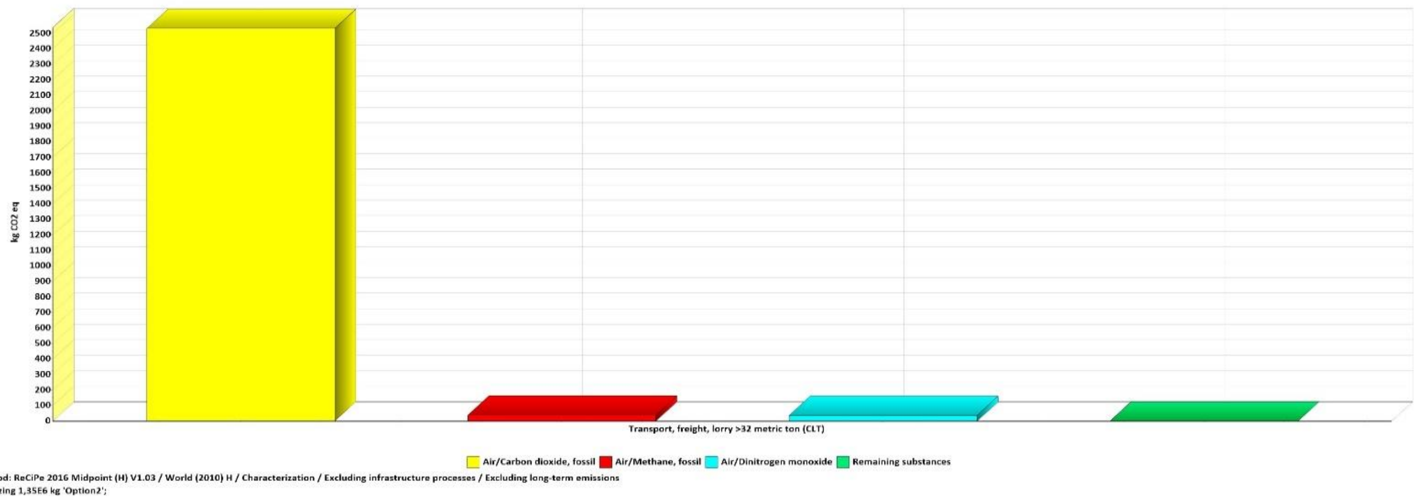


Figure 7.41: Option 2-Inventory-characterization(Global Warming(Cut-off 0,1%))Transport CLT

7.2.9. Process contribution analysis of option 2

Table 7.27: Option 2-Process contribution-Global Warming(Cut-off 1,6%)

No	Process	Project	Unit	Total	Option 2	Glulam	Steel	Cross-laminated timber	Reinforced low carbon concrete	Transport, freight, lorry >32 metric ton	Transport, freight, lorry >32 metric ton (CLT)
	Total of all processes		kg CO2 eq	219564,5	0	1367,669	28884,48	51544,1	131438,9	3722,142	2607,196
	Remaining processes		kg CO2 eq	91063,35	0	1191,993	18473	40342,11	30184,14	512,8663	359,2402
1	Ammonia, liquid {RoW}| ammonia production, steam reforming, liquid | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	6697,315	0	106,3765	5,071818	6570,079	15,66106	0,0743	0,052044
2	Clinker {Europe without Switzerland}| production | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	97286,43	0	0,023456	13,00814	0,6757	97272,72	0,003102	0,002173
3	Pig iron {GLO}| production | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	9621,069	0	1,559687	9532,965	72,94858	13,57679	0,011268	0,007893
4	Transport, freight, light commercial vehicle {RoW}| processing | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	4771,214	0	52,18393	13,16864	3782,062	919,5562	2,495855	1,748237

5	Transport, freight, lorry >32 metric ton, EURO6 {RoW}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	5539,009	0	0,984041	5,148071	51,26084	29,12663	3206,487	2246,003
6	Transport, freight, sea, transoceanic ship {GLO}| processing | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	4586,081	0	14,54854	842,1128	724,9662	3004,105	0,204403	0,143175

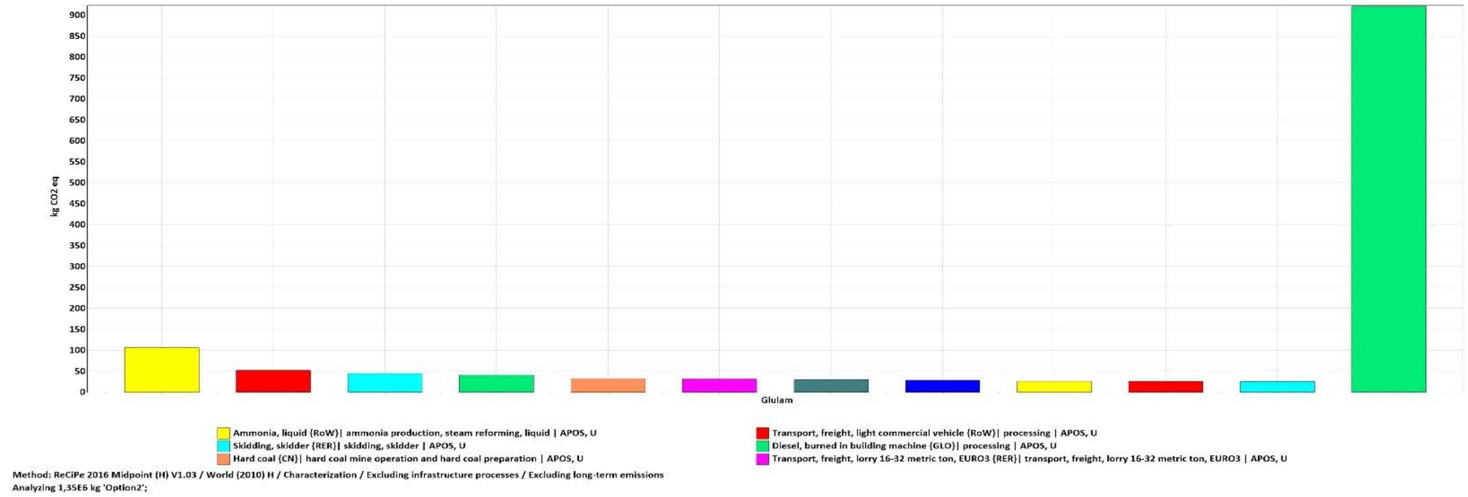


Figure 7.42: Option 2-Process contribution-Global Warming(Cut-off 1,6%) Glulam

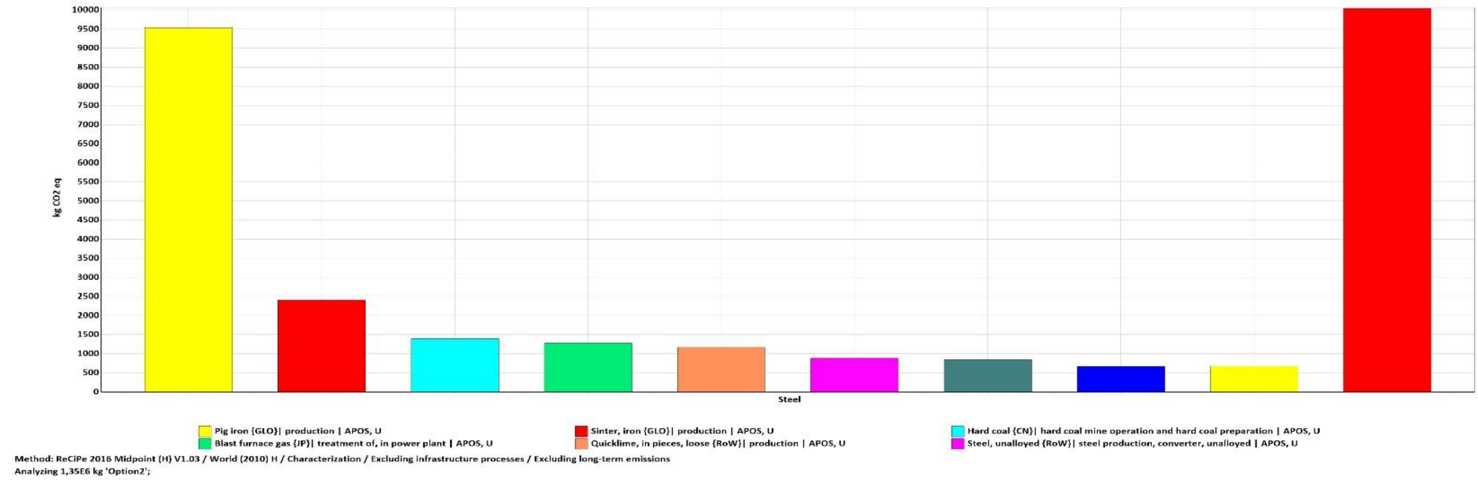


Figure 7.43: Option 2-Process contribution-Global Warming(Cut-off 1,6%) Steel

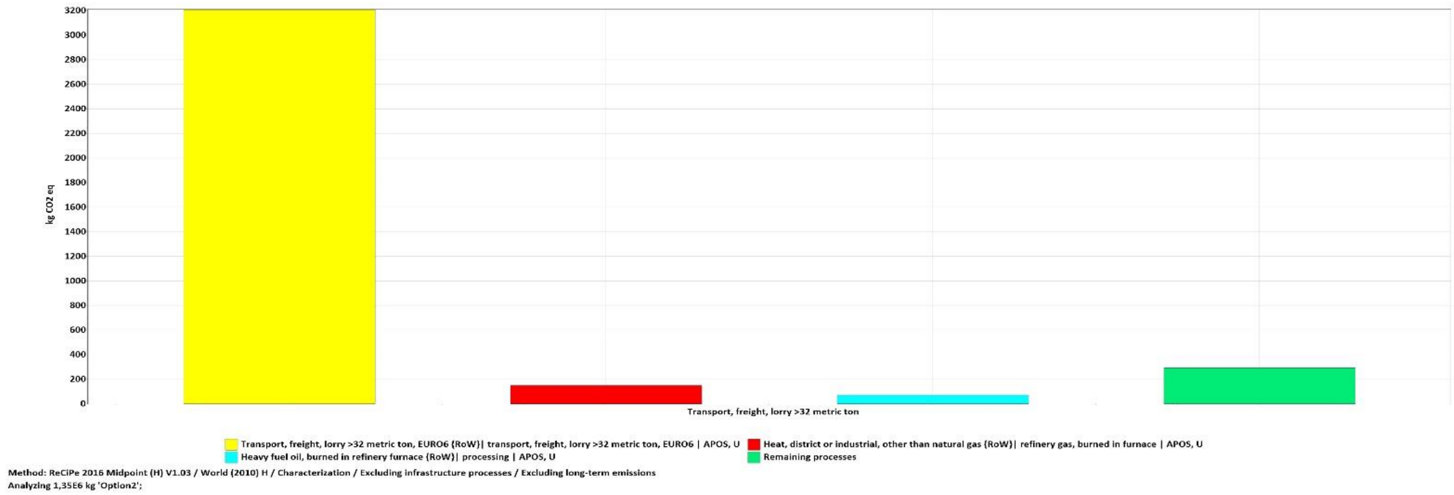


Figure 7.44: Option 2-Process contribution-Global Warming(Cut-off 1,6%) Transport

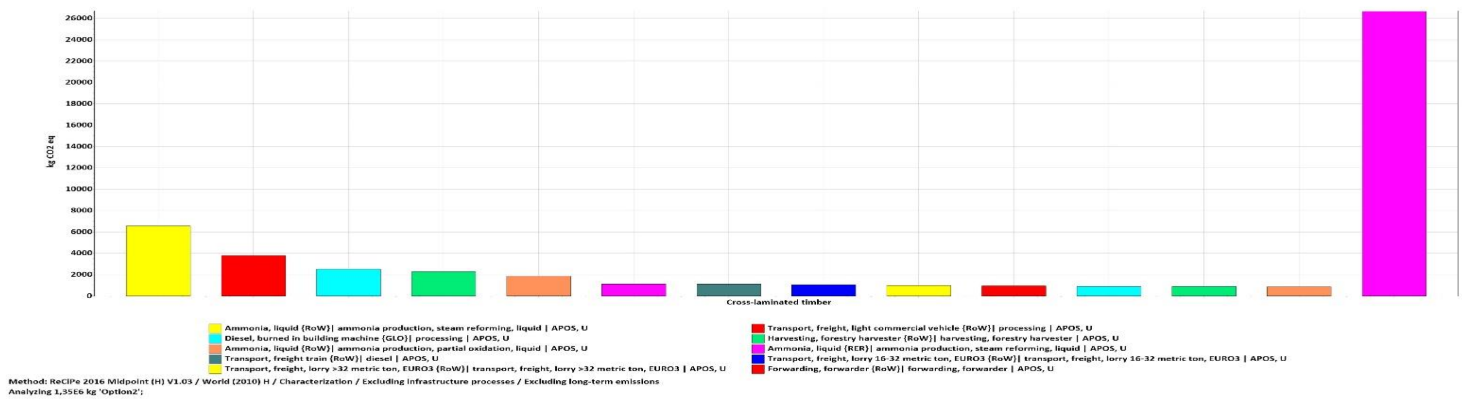


Figure 7.45: Option 2-Process contribution-Global Warming(Cut-off 1,6%) Cross-Laminated timber

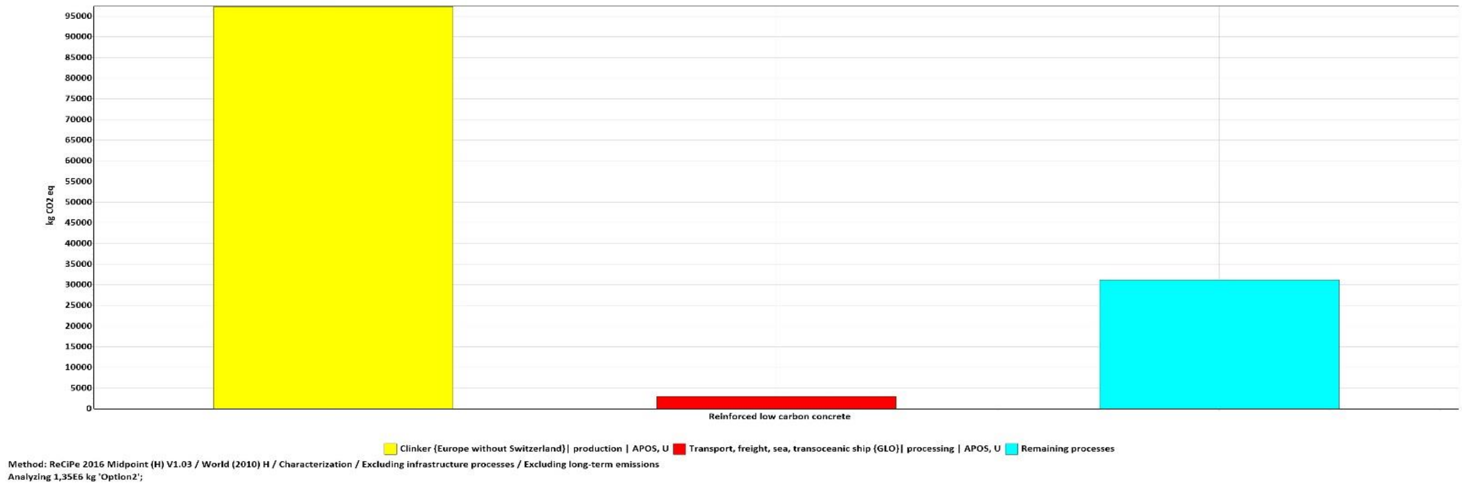


Figure 7.46: Option 2-Process contribution-Global Warming(Cut-off 1,6%) Reinforced low carbon concrete

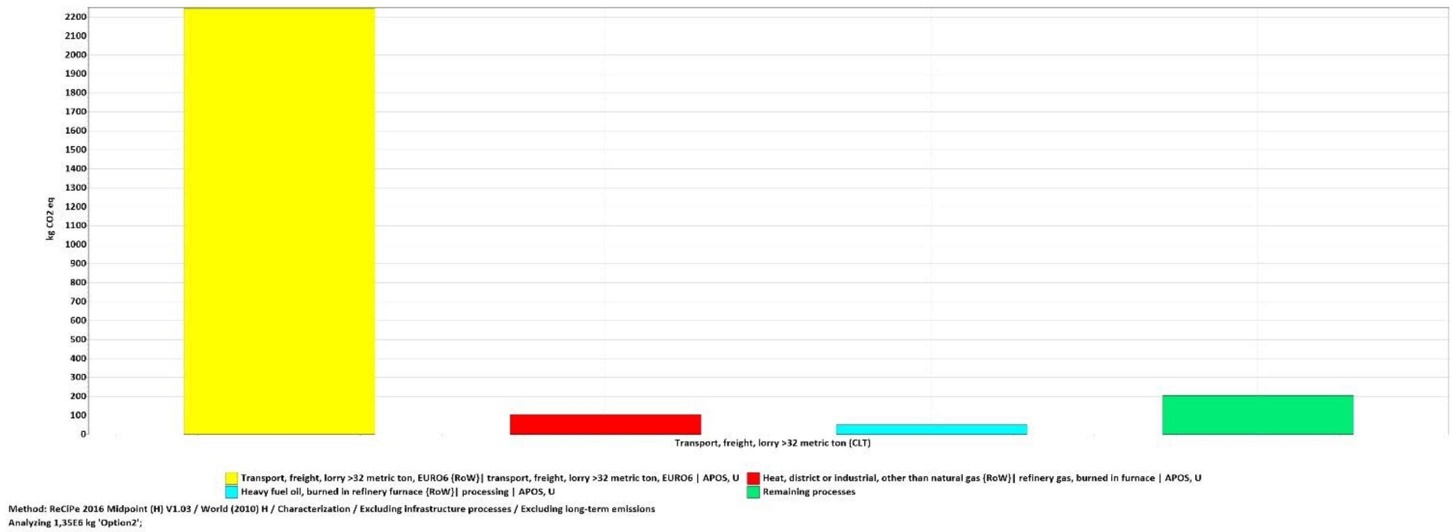


Figure 7.47: Option 2-Process contribution-Global Warming(Cut-off 1,6%) Transport CLT

7.2.10. Impact assessment analysis of option 3

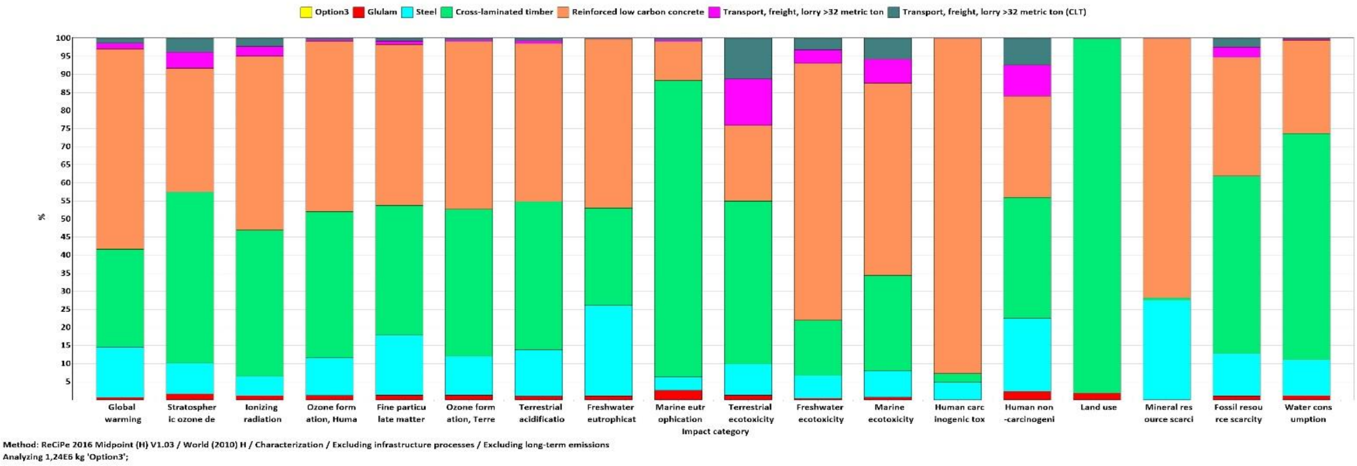


Figure 7.48: Impact assessment analyzing of option 3

Table 7.28: Option 3 Analysis

Calculation:	Analyze
Results:	Impact assessment
Product:	1240186,54 kg Option 3 (of project master's thesis-UIA)
Method:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H
Indicator:	Characterization
Skip categories:	Never
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Impact category
Sort order:	Ascending

Impact category	Unit	Total	Option 3	Glulam	Steel	Cross-laminated timber	Reinforced low carbon concrete	Transport, freight, lorry >32 metric ton	Transport, freight, lorry >32 metric ton (CLT)
Global Warming	kg CO2 eq	207658,3	0	1367,669	28884,48	56260,31	115034,4	3265,689	2845,751
Stratospheric ozone depletion	kg CFC11 eq	0,055472	0	0,00091	0,004688	0,026302	0,018974	0,002457	0,002141
Ionizing radiation	kBq Co-60 eq	943,8868	0	11,01127	50,39374	381,544	454,4749	24,82775	21,63513

Ozone formation, Human health	kg NOx eq	587,9451	0	7,29232	61,11493	237,876	276,4561	2,781775	2,424064
Fine particulate matter formation	kg PM2.5 eq	278,1573	0	3,536971	46,20369	99,80286	123,9575	2,488136	2,168185
Ozone formation, Terrestrial ecosystems	kg NOx eq	602,1018	0	7,683591	64,60685	244,9567	279,4362	2,895368	2,52305
Terrestrial acidification	kg SO2 eq	592,1727	0	5,931343	75,87869	242,9976	258,7942	4,579915	3,99098
Freshwater eutrophication	kg P eq	3,526426	0	0,036698	0,884651	0,948913	1,649604	0,003505	0,003054
Marine eutrophication	kg N eq	0,954237	0	0,024863	0,035936	0,781748	0,102721	0,004793	0,004176
Terrestrial ecotoxicity	kg 1,4-DCB	588059,2	0	7703,596	49981,59	265477,3	123188,3	75722,86	65985,59
Freshwater ecotoxicity	kg 1,4-DCB	330,4831	0	1,403376	20,7312	50,57188	234,9443	12,20061	10,63173
Marine ecotoxicity	kg 1,4-DCB	753,5015	0	5,586871	54,64894	199,2086	400,6743	49,89974	43,48308
Human carcinogenic toxicity	kg 1,4-DCB	18108,3	0	3,965015	876,2772	440,5573	16785,35	1,14813	1,000491
Human non-carcinogenic toxicity	kg 1,4-DCB	10885,06	0	252,9773	2196,448	3641,462	3058,55	927,4405	808,1801
Land use	m2a crop eq	483300	0	8892,19	125,769	473633	646,6169	1,308524	1,14026
Mineral resource scarcity	kg Cu eq	3740,552	0	0,541732	1026,909	26,98925	2686,065	0,02453	0,021375
Fossil resource scarcity	kg oil eq	40199,2	0	428,3534	4704,257	19744,05	13210,15	1128,766	983,6166
Water consumption	m3	1830,226	0	20,43982	181,767	1146,208	472,7014	4,868102	4,242108

7.2.11. Inventory analysis of option 3

Table 7.29: Option 3-Inventory-characterization(Global Warming(Cut-off 0,1%))

Calculation:	Analyze
Results:	Inventory
Product:	1240186,54 kg Option 3 (of project master's thesis-UIA)
Method:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H
Indicator:	Characterization
Compartment:	All compartments
Per sub-compartment:	No
Skip unused:	No
Category:	Global Warming
Cut-off:	0,1 %
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Ascending

No	Substance	Compartment	Unit	Total	Option 3	Glulam	Steel	Cross-laminated timber	Reinforced low carbon concrete	Transport, freight, lorry >32 metric ton	Transport, freight, lorry >32 metric ton (CLT)
	Total of all compartments		kg CO2 eq	207658,3	0	1367,669	28884,48	56260,31	115034,4	3265,689	2845,751
	Remaining substances		kg CO2 eq	322,566	0	5,055724	38,17163	107,1553	170,7078	0,788422	0,687038
1	Carbon dioxide, fossil	Air	kg CO2 eq	197579,2	0	1241,561	26498,7	52049,8	111856,1	3170,372	2762,691
2	Carbon dioxide, land transformation	Air	kg CO2 eq	278,7233	0	14,23479	5,580711	228,935	29,82216	0,080454	0,070108
3	Dinitrogen monoxide	Air	kg CO2 eq	980,0459	0	19,39051	94,9269	456,1114	322,4174	46,59574	40,60395
4	Methane, fossil	Air	kg CO2 eq	8497,805	0	87,42729	2247,101	3418,302	2655,424	47,85171	41,69841

Option 3-Inventory-characterization(Global Warming(Cut-off 0,1%))

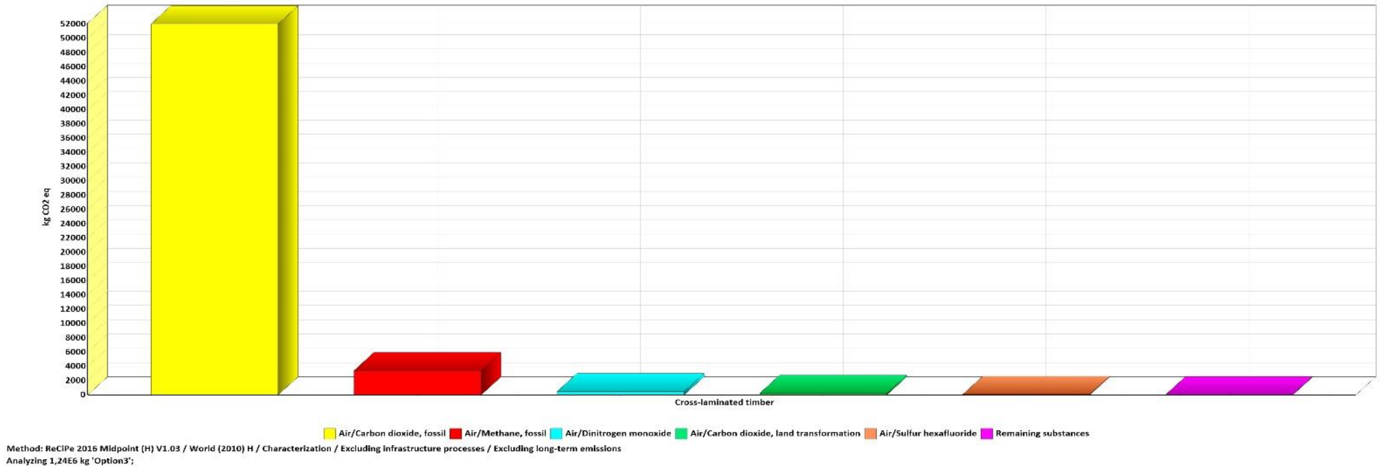


Figure 7.49: Option 3-Inventory-characterization(Global Warming(Cut-off 0,1%))Cross-laminated timber

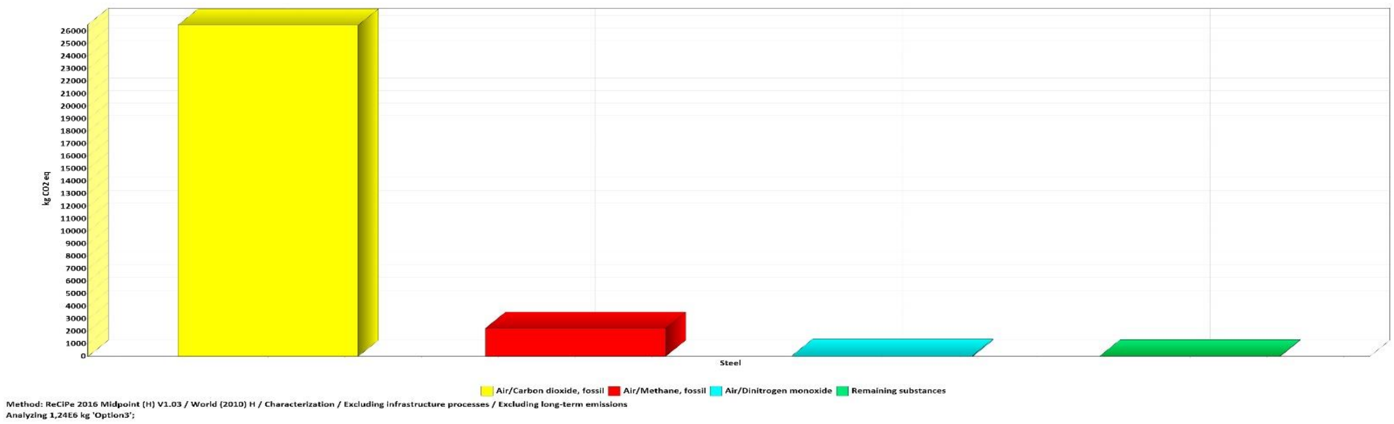


Figure 7.50: Option 3-Inventory-characterization(Global Warming(Cut-off 0,1%))Steel

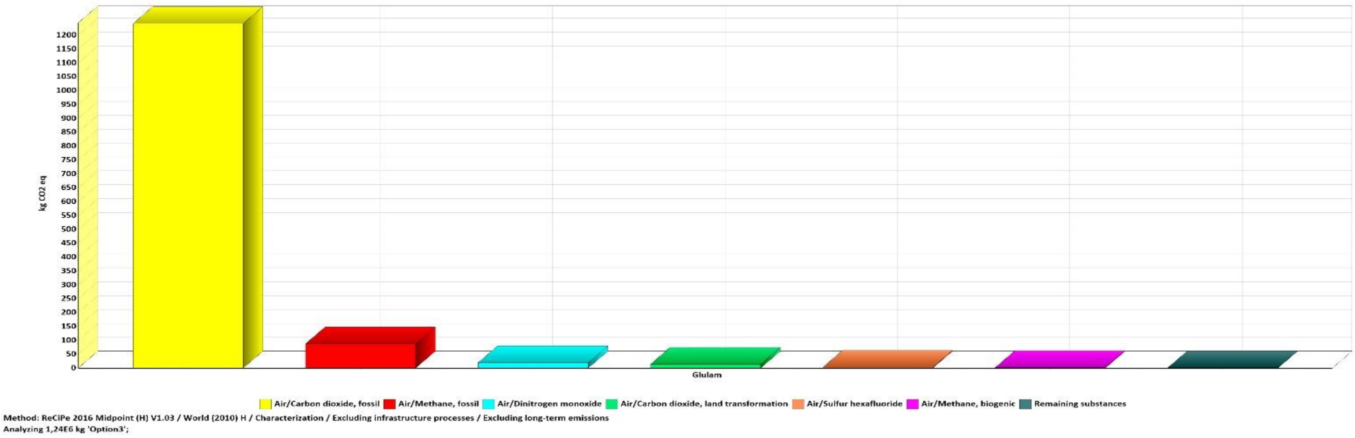


Figure 7.51: Option 3-Inventory-characterization(Global Warming(Cut-off 0,1%))Glulam

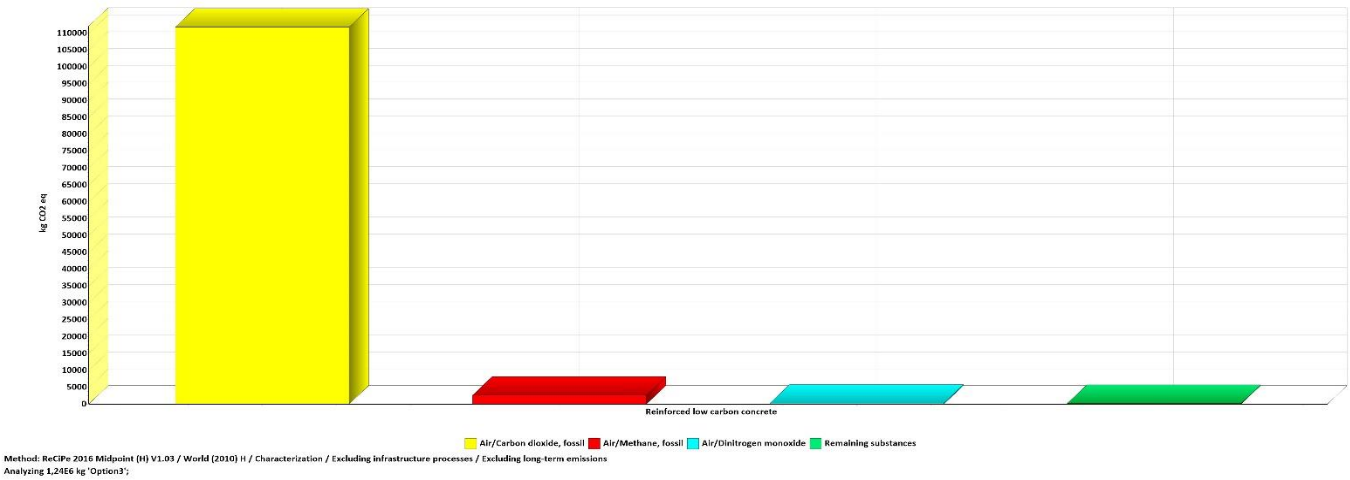


Figure 7.52: Option 3-Inventory-characterization(Global Warming(Cut-off 0,1%))Reinforced low carbon concrete

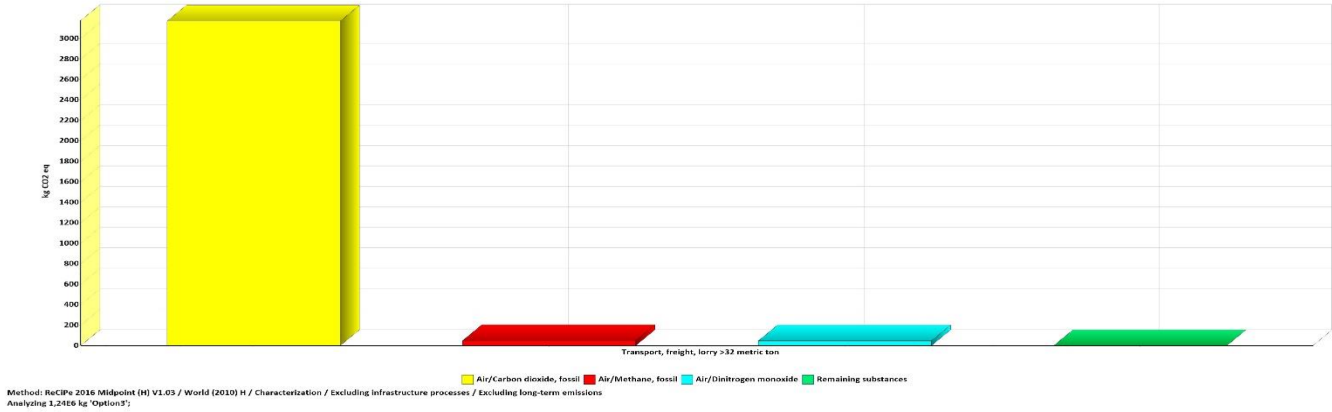


Figure 7.53: Option 3-Inventory-characterization(Global Warming(Cut-off 0,1%))Transport

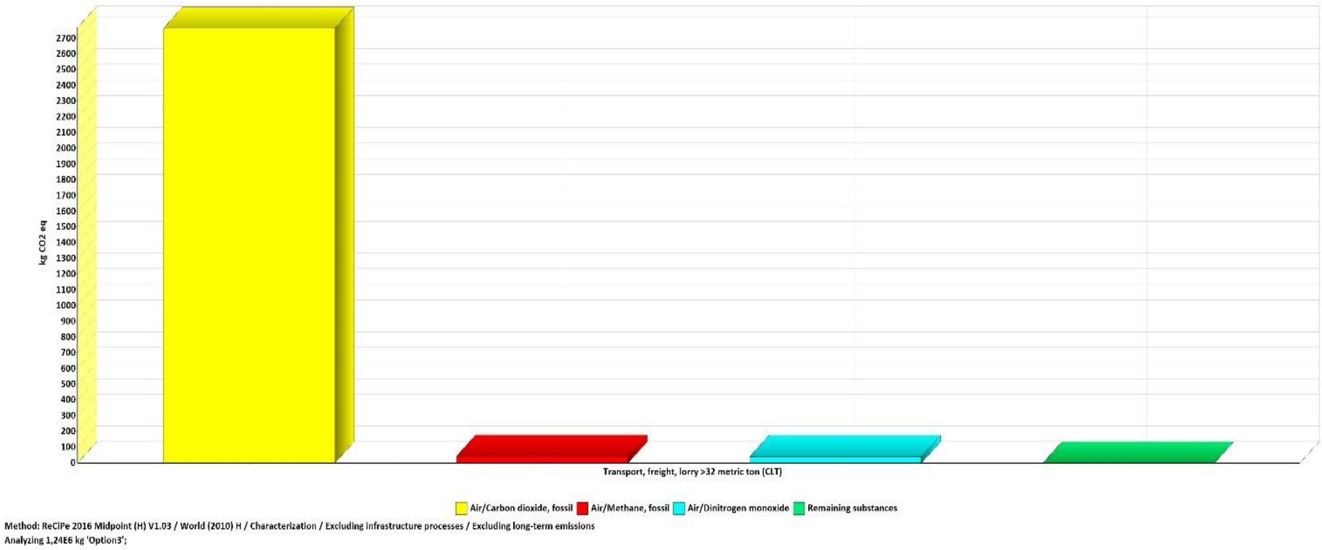


Figure 7.54: Option 3-Inventory-characterization(Global Warming(Cut-off 0,1%))Transport CLT

7.2.12. Process contribution analysis of option 3

Table 7.30: Option 3-Process contribution-Global Warming(Cut-off 1,6%)

Calculation:	Analyze
Results:	Process contribution
Product:	1240186,54 kg Option 3 (of project master's thesis-UIA)
Method:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H
Indicator:	Characterization
Category:	Global Warming
Cut-off:	1,6 %
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Process
Sort order:	Ascending

No	Process	Project	Unit	Total	Option 3	Glulam	Steel	Cross-laminated timber	Reinforced low carbon concrete	Transport, freight, lorry >32 metric ton	Transport, freight, lorry >32 metric ton (CLT)
	Total of all processes		kg CO2 eq	207658,3	0	1367,669	28884,48	56260,31	115034,4	3265,689	2845,751
	Remaining processes		kg CO2 eq	87354,57	0	1151,105	18319,6	41281,87	25760,04	449,9031	392,0496
1	Ammonia, liquid {RoW}| ammonia production, steam reforming, liquid | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	7296,508	0	106,3765	5,071818	7171,231	13,70645	0,065188	0,056806
2	Clinker {Europe without Switzerland}| production | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	85146,21	0	0,023456	13,00814	0,737526	85132,43	0,002722	0,002372
3	Diesel, burned in building machine {GLO}| processing | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	3602,815	0	40,88783	153,4054	2751,479	656,9131	0,069479	0,060545

4	Pig iron {GLO}| production | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	9626,048	0	1,559687	9532,965	79,62327	11,88232	0,009886	0,008615
5	Transport, freight, light commercial vehicle {RoW}| processing | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	5002,354	0	52,18393	13,16864	4128,114	804,7894	2,189784	1,908198
6	Transport, freight, lorry >32 metric ton, EURO6 {RoW}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	5352,352	0	0,984041	5,148071	55,95112	25,49143	2813,269	2451,508
7	Transport, freight, sea, transoceanic ship {GLO}| processing | APOS, U	Ecoinvent 3 - allocation at point of substitution - unit	kg CO2 eq	4277,469	0	14,54854	842,1128	791,2995	2629,173	0,179337	0,156276

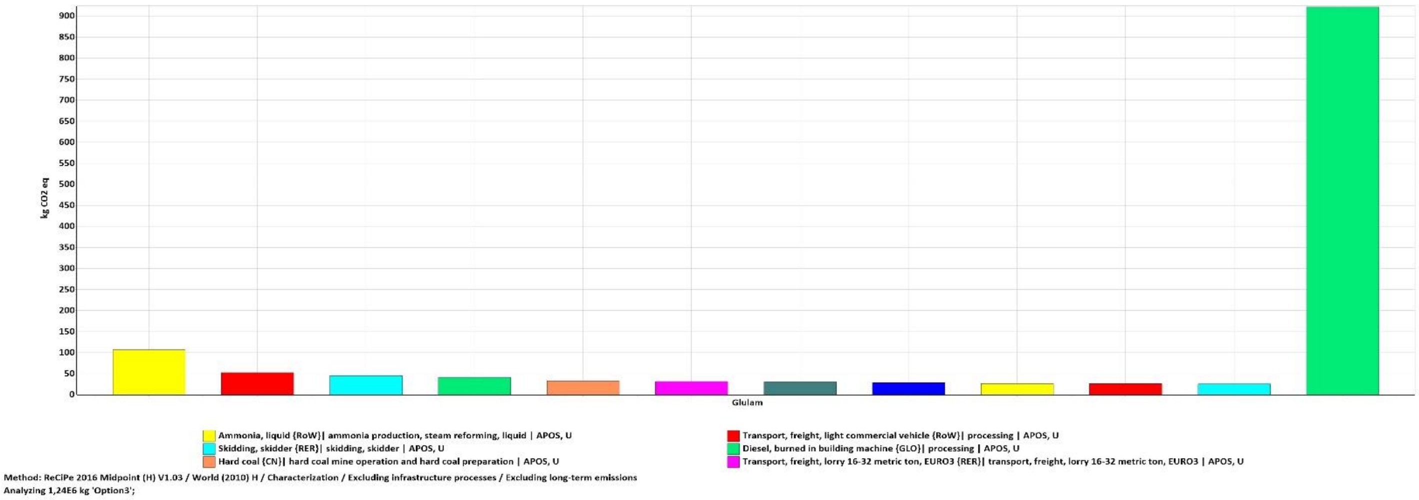


Figure 7.55: Option 3-Process contribution-Global Warming(Cut-off 1,6%)Glulam

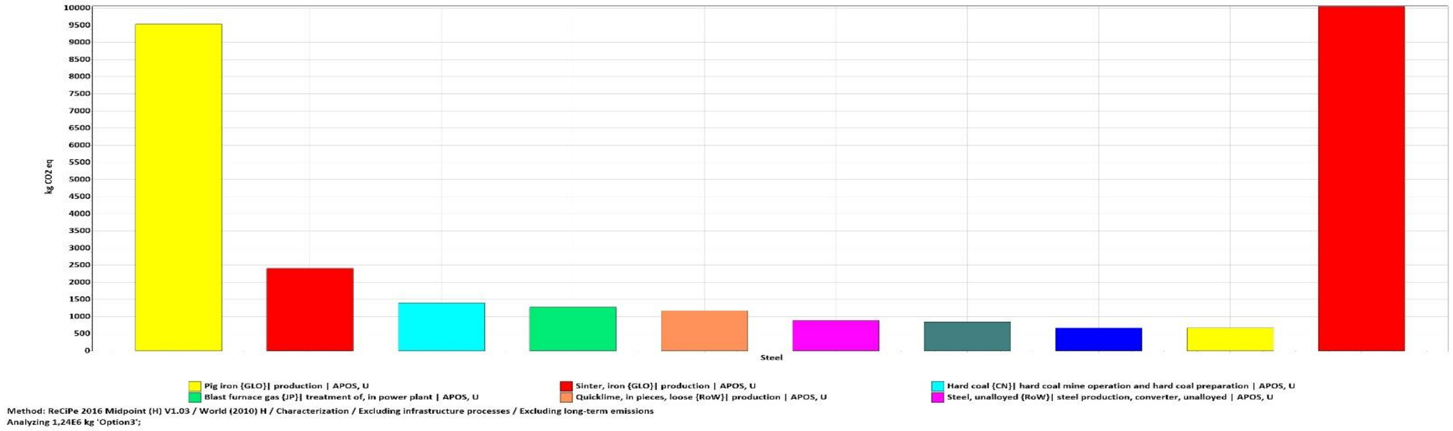


Figure 7.56: Option 3-Process contribution-Global Warming(Cut-off 1,6%)Steel

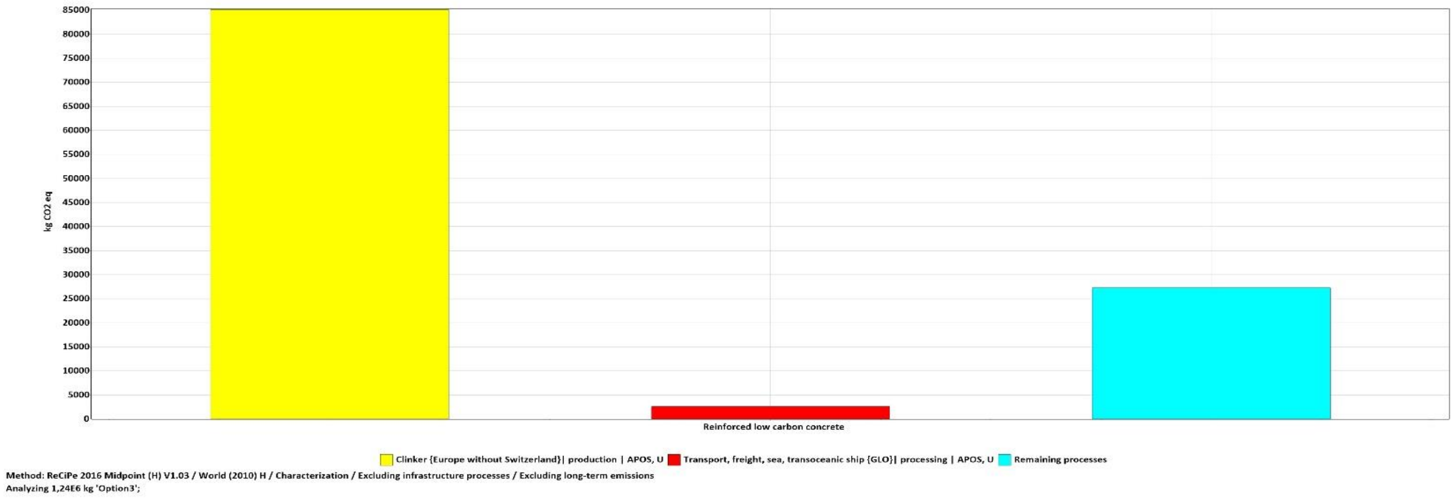


Figure 7.57: Process contribution-Global Warming(Cut-off 1,6%)Reinforced low carbon concrete

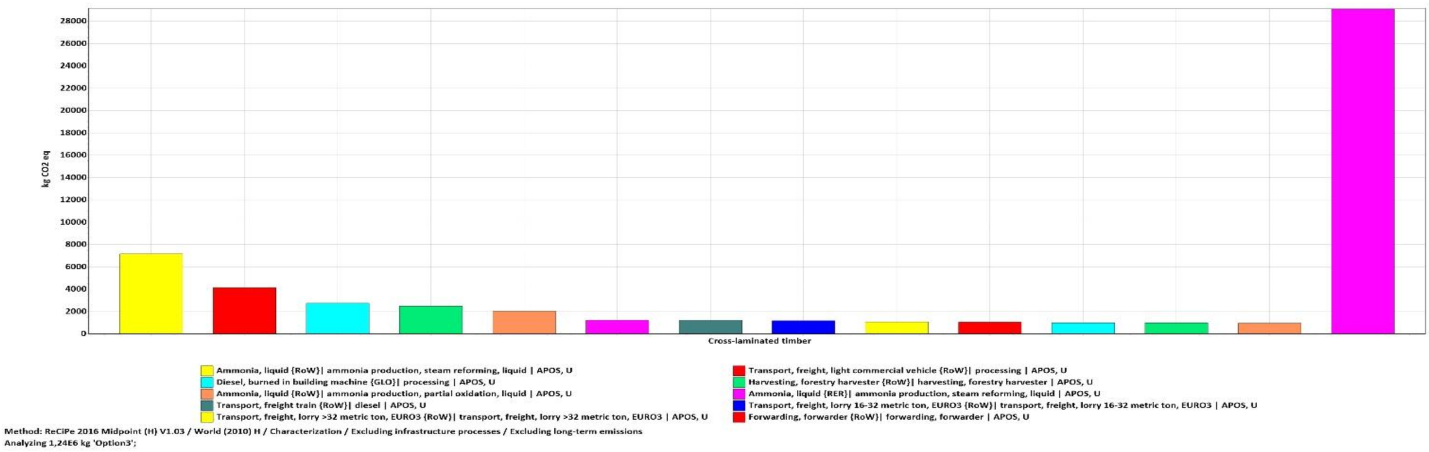


Figure 7.58: Option 3-Process contribution-Global Warming(Cut-off 1,6%)Cross-laminated timber

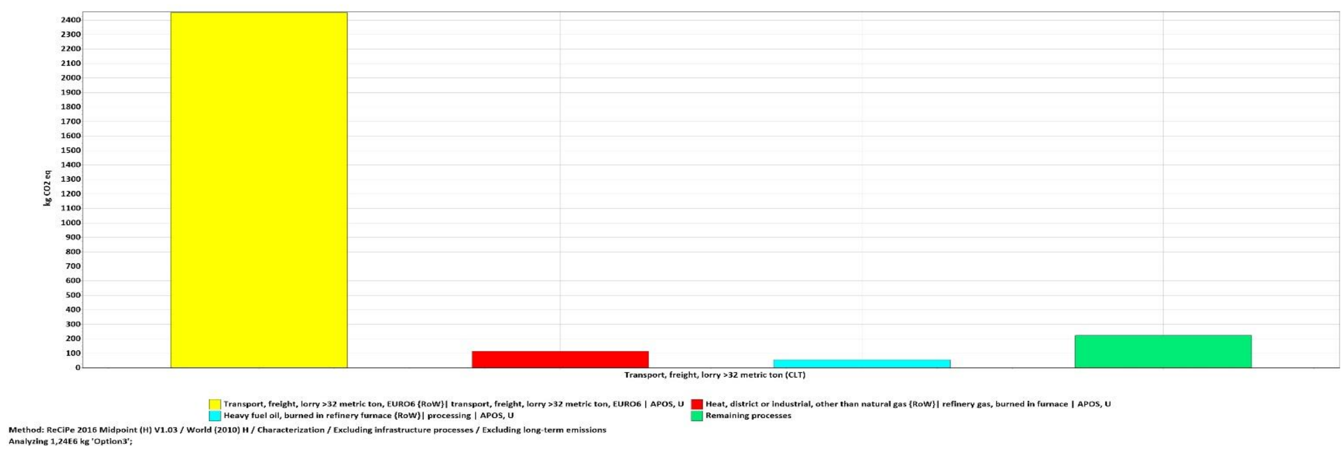


Figure 7.59: Option 3-Process contribution-Global Warming(Cut-off 1,6%)Transport CLT

Figure 7.60: Option 3-Process contribution-Global Warming(Cut-off 1,6%)Transport

7.2.13. Networks for option 1, option 2 and option 3

Another interesting tab in SimaPro is the 'Network' tab. The network tab makes characterization visually displayed by the inputs which contribute to the emission. This has been done by first choosing ''Characterization'' then ''Global Warming'' to view the flows of CO2-equivalent emissions. A cut-off value of 5,5 % has been chosen in SimaPro. The values on the top of each box are the amount of each input described and the values on the bottom are the amount of emissions from this input. Emissions are given in both CO2-equivalents and in percent. (For further details on networks, see Appendix F.1, F.2 and F.3)

For documentation of Environmental Product Declaration (EPD) of materials used in the LCA analysis, see Appendix F.4.

7.3. Construction Cost

Table 7.31: Estimation

Assumption for calculation		Calculation include:			Cost in Kroner		
Project for Master Thesis		Structural systems of an Apartment building			Structural systems options		
Drawing program (CAD): Revit		Gross area... m2		1 748	Option 1	Option 2	Option 3
Unit prices are picked from:				**SUM....**	**8 156 436**	**8 259 650**	**8 155 757**
Holte Kalkulasjonsnøkkel og Norsk Prisbok				**M2-PRICE**	**4 666**	**4725**	**4 666**
Note	*Construction member*	*Unit*	*Quantity*	*Unit price*	*Cost*		
	Concrete work:						
	Option 1: *Concrete B35 (C35/45) Ordinary concrete*						
	Option 2 and Option 3*: Concrete B35 (C35/45) Low carbon concrete Class A = 3% more expensive than ordinary concrete according to a concrete supplier NORBETONG, Norway.*						
	FOUNDATION						
	Wall (strip) foundation:						
Common For All options	1000x300mm	lm	59,64	1800	107352	110573	110573
	1200x400mm	lm	15,00	2760	41400	42642	42642
	16000x400mm	lm	64,33	3552	228500	235355	235355
	1700x400mm	lm	36,79	3750	137963	142101	142101
			175,76				
	Isolated footing:						
Common For All	1700x1700x400mm	no.	4	9604	38415	39568	39568
	1300x1300x350mm	no.	2	4914	9828	10123	10123
	100x1000x300mm	no.	1	2492	2492	2567	2567
			7				
	Structural systems						
	RCC walls						
Option 1 and option 2	200 mm shear walls	m2	34,9	1620	56538	58234	
	220 mm basement walls + shear walls	m2	367,71	1655	608560	626817	
	250 mm basement walls + shear walls	m2	182,1	1710	311391	320733	
	350 mm basement walls	m2	210,78	1886	397531	409457	
	200 mm ring wall	m2	10	1620	16200	16686	

	200 mm shear walls	m2	-				
	220 mm basement walls + shear walls	m2	154,81	1655			263897
	250 mm basement walls + shear walls	m2	182,1	1710			320733
	350 mm basement walls	m2	210,78	1886			409457
	200 mm ring wall	m2	10	1620			16686
	Cross-laminated wall						
Option 3	200 mm	m2	247,86	1280			317261
Common	50 mm XPS on outside of external walls	m2	295,73	190	56189	56189	56189
	Beams:						
Common For All	Glulam , GL30c						
	GLT 115x180	lm	23,66	527	12459	12459	12459
	GLT 115x405	lm	37,49	1262	47312	47312	47312
	GLT 140x495	lm	40,72	1549	63064	63064	63064
	GLT 140x540	lm	42,16	1690	71229	71229	71229
	Steel, S355						
Common For All	HE300B	kg	744,66	30	22340	22340	22340
	HE280B	kg	3744,94	30	112348	112348	112348
	IPE 200	kg	1396,59	30	41898	41898	41898
	IPE 330	kg	1258,89	30	37767	37767	37767
	IPE 400	kg	3377,68	30	101330	101330	101330
	Columns:						
Common For All	Concrete B35, Foundation column						
	300x300 mm	lm	3,6	1821	6556	6752	6752
	Steel, S 355						
Common For All Options	HE200A	kg	324,6	30	9738	9738	9738
	HUP 100X100X8	kg	1037,27	30	31118	31118	31118
	HUP 140X140X8	kg	1788,06	30	53642	53642	53642
	HUP 140X140X10	kg	330,64	30	9919	9919	9919
	Glulam , GL30c						
common	GLT column 115x115	lm	133,17	760	101209	101209	101209
	GLT column 140x225	lm	28,15	1779	50079	50079	50079

	Floors:						
	Ground floor slab 120mm concrete + 200mm XPS	m2	689	1810	1247090	1284503	1284503
	50 mm XPS insulation on the ground	m2	67	190	12730	12730	12730
	Cross-laminated floors						
	CLT 280, Et. 01 and Et.02	m2	1224,86	1750	2143505	2143505	2143505
	CLT 160 in balcony, Et.02	m2	93,18	1043	97173	97173	97173
	60 - 80 mm over CLT 280 for sound requirement, Et. 02 apartments	m2	424	263	111512	114857	114857
	300 mm EPS insulation below CLT plan 1	m2	479,83	640	307091	307091	307091
	50 mm EPS insulation over CLT plan 1	m2	423,57	137	58029	58029	58029
	80 mm cast in situ concrete, over CLT plan 1	m2	424	281	119144	122718	122718
	80 mm XPS insulation under Precast concrete elements in balconies	m2	218,83	350	76591	76591	76591
Common For All Options	50 mm Precast concrete element in balconies	m2	218,83	220	48143	48143	48143
	Roof:						
	CLT 280 main roof	m2	621,9	1750	1088325	1088325	1088325
Common	CLT 160 roof balconies	m2	60,15	1043	62736	62736	62736
			Total .... Kr		**8156436**	**8259650**	**8155757**

See Appendix H for quantities from Revit which are used in tables above.

Table 7.32: Summary of Estimation for Table 7.31

Structural Systems Options: Option 1: Timber structural system including walls and foundations made of normal concrete Option 2: Timber structural system including walls and foundations made of low carbon concrete. Low-carbon concrete foundations.						
				Building type:	Apartment building	
		COST SUMMARY		Gross Area............m^2 =		**1 748**
				Structural systems Options		
		Summation levels		Option 1	Option 2	Option 3
		Common cost	5 %	407 822	412 983	407 788
	1	**House Cost**		**8 564 258**	**8 672 633**	**8 563 545**
		General Costs	10 %	856 426	867 263	856 354
	2	**Construction Cost**		**9 420 684**	**9 539 896**	**9 419 899**
		Special costs	2 %	188 414	190 798	188 398
		Value Added Tax (VAT)	25 %	2 402 274	2 432 674	2 402 074
	4	**Project Cost**		**12 011 372**	**12 163 368**	**12 010 372**
		Safety margin/ Contingency	5 %	600 569	608 168	600 519
		Price inflation	3 %	360 341	364 901	360 311
	5	**Cost Framework**		**12 972 282**	**13 136 437**	**12 971 202**
		M2-price Construction Cost (post 2)		5 389	5 458	5 389
		M2-prisce Project Cost (post 4)		6 871	6 958	6 871

Table 7.32 presents cost summary at different levels and is performed according to Table 3.35.

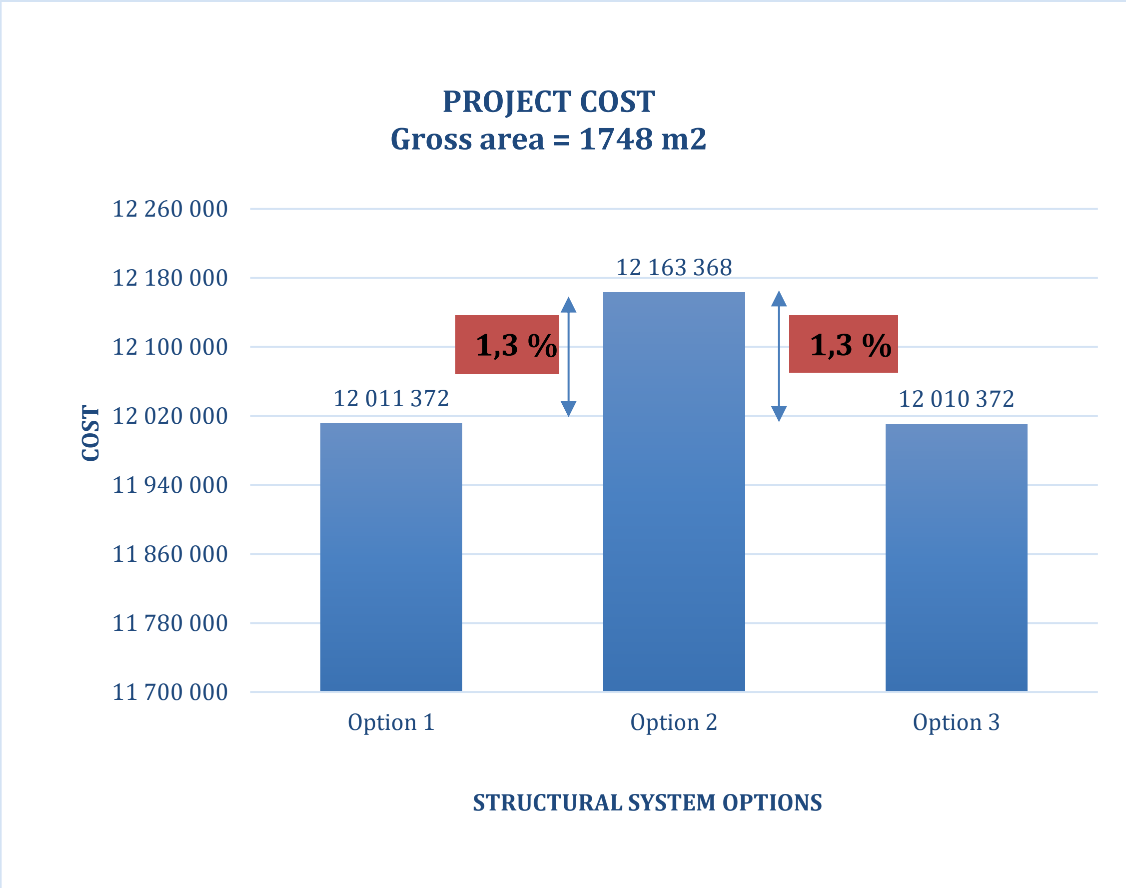


Figure 7.61: Comparison of Project Cost between the options

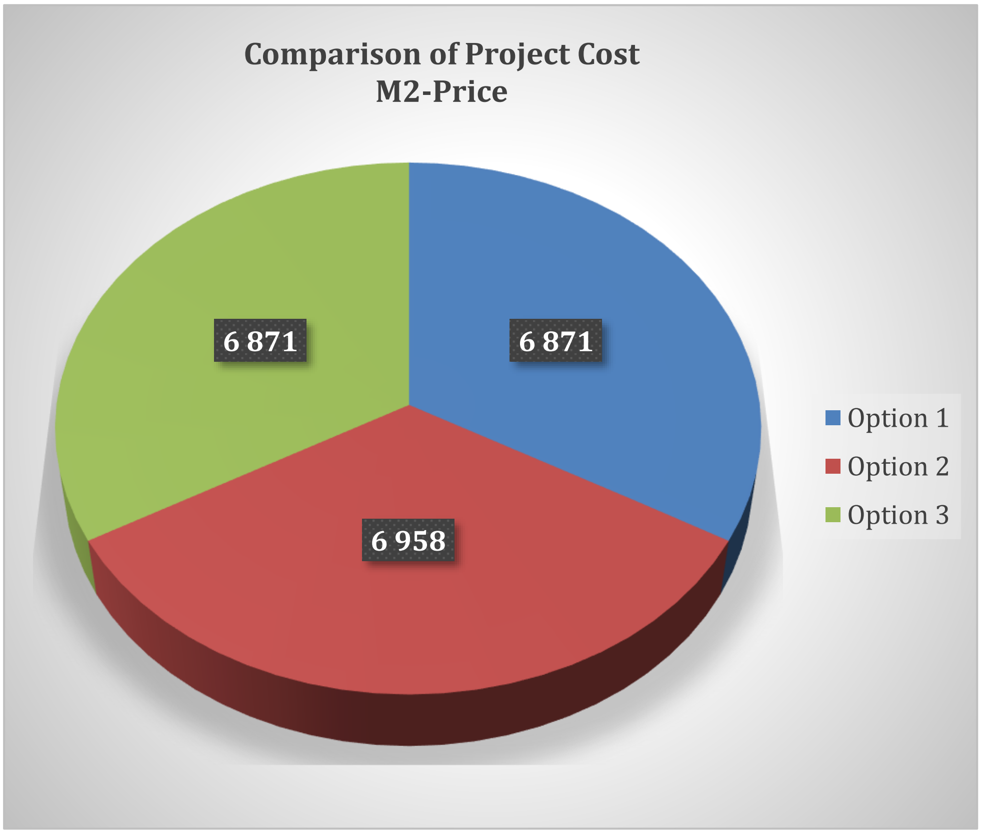


Figure 7.62: Comparison of Project cost in M2-Prise (Meter-square Price) between options

See Appendix G for detail calculation of construction estimation.

8. Discussion

8.1. Structural Design

8.1.1 Modelling of the Structure

When the rough design began to take shape, it was drawn into Revit with the ARK model linked up in background so that the support and bracing systems could be placed without collisions. This meant that new issues and new challenges had to be solved. To use the architectural model as a background for the structural model assisted in the live collaboration between the models through the modelling process. Structural supporting and bracing systems should be placed as much as possible within the planned architectural walls deployed by an architect. This posed some challenges in regards to the spans and loading areas of the support system.

A lot of time was spent finding a concept for the structural system. The architectural drawing was completed and could not be changed in this work, which created quite big challenges in regards to adding the support construction parts. The columns in the apartment's first floor had to be placed on exchange beams over the basement floor to transfer the loads down to the columns in the basement floor. Figure 8.1 is an illustration of the columns over the exchange beams. At the same time, it became challenging when it came to the beams above the parking basement. The beam heights had to be limited to maintain a full floor height in the parking basement. HEB beams with low beam height were therefore utilized. This will make it possible to park vehicles in the basement without problems or structural compromises.

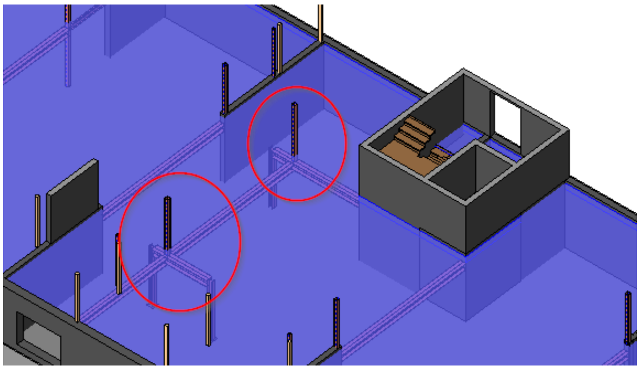


Figure 8.1: Illustration of columns over exchange beams

8.1.2 Design Process in FEM-Design:

When load widths, load area and loads were mapped, different types of software were used for design and analysis, among these were FEM-Design, CLT designer and the Ove Sletten program. The designs were done in the ultimate, service and fire limit states.

Design work flow in FEM-Design usually goes from the modelling to the design phase. After a structural model was done in Revit, a 3D analytical model was created in Revit using a StruSoft plugin for FEM-Design. Here, materials were mapped from Revit to FEM Design. Connection points (nodes) between elements were controlled. After the model was verified, it was exported into the FEM-Design software for analysis and design. Once more, in FEM-design, the model was properly controlled among are nodes, material properties, end or edge reassess and so forth. Some first assumptions for material properties and cross-sections were provided. The structural members chosen from the beginning did not have the right dimensions. They had to be re-designed and changed as needed, as we figured out loads and everything that worked on the different parts of the building. It was a concern for us that the design should be safe as well as economical.

After the model was verified, load cases were created and applied to the model. Then, load combinations were generated according to the Norwegian standard. Some additional load combinations were also added manually. When the analysis ran, analysis results were controlled one by one to make sure that results were as expected. Some unexpected results were found at the first run-through. Then, necessary controls and improvements were done in the models to get reliable and acceptable results. Bar forces, reaction forces, deflection and so forth were controlled and generated.

In the analysis phase a diaphragm is applied. The diagrams were meant to distribute the horizontal forces effectively to the bracing systems. As it is explained in the theory chapter, diaphragm will increase the efficiency of bracing walls. That means that the impact of horizontal loads on bracing systems will increase by applying the diaphragms. By doing so, the columns will deflect less whereas bracing systems will deflect more.

Initially all the columns and beams were in timber. Because of capacity problems however, some beams and columns were changed to steel. The reason for choosing steel instead of GLT was that steel has significantly higher capacity than timber. Elastic Modulus of steel S355 is 210000 N/mm2 whereas Elastic Modulus of GLT GL30c is 13000 N/mm2. This means that the strength capacity of the steel is almost 16 times more than timber. Timber sections will usually be much bigger than steel sections to withstand the same stress and will take up much more space. Steel beams and columns must of course be fire insulated to withstand the stresses and meet the requirements set for such buildings.

When designing the bracing systems, the stairwell in the center of the building was a good start, but there was some uncertainty related to the capacity of the entire system alone. Therefore, in addition, a shear wall was added at each end of the building. To handle stress from horizontal forces we have chosen to use the stairwell. The stairwell and shear walls are constructed in concrete in option 1 and option 2 and in CLT in option 3, and are consistently similar throughout the floors when it comes to thickness and reinforcement. We have also dimensioned bracing systems for misalignment load and wind load. The horizontal loops were transferred through each floor/ceiling before being absorbed by the stairwell, which must bring the forces down into the foundation. These calculations were performed in FEM-Design. The results show that concrete walls end up with a wall thickness of 220 mm and 200 mm and a reinforcement corresponding to Ø12 c / c 150 and CLT walls 200 mm.

8.1.3 CLT floor and Roof design

CLT floors and roof were designed using a dimensioning program (CLTdesigner). CLT floor design was very challenging. Compared to concrete and steel, CLT has restrictions in span limits. The maximum span was kept 7.44 m as a single span and 8.01 m as continuous span. As logically would be expected, the deflection for CLT floors are significantly greater than for those with concrete and steel materials. Usually, deflection controls for design of CLT. The thickness of solid wood (CLT) had to be increased to 280 mm to achieve both strength and deflection requirements. Despite the strength limits of CLT, all floors are designed to be solid wood (CLT). The results are shown in Appendix E.7.

8.1.4 Foundation Design

The next step was to find out which loads could challenge the foundations. Using permitted carrying capacity and identified loads, point foundation and strip foundation were performed in the calculation program Ove-Sletten.

In addition to the calculation programs that have been used, we also had to do some calculations by hand. What was done by hand were controls and some manual designs for example timer connection design.

8.1.5 Design Summary

Table 8.1 is an overview of the analysis and design of the project. Floor and roof materials, foundation types, LCA results, cost of construction are summarized as shown in table below.

Table 8.1: Over view of design results

Tema	Option 1	Option 2	Option 3	Comment
Floor/ Roof	280 mm CLT	280 mm CLT	280 mm CLT	The same material in all options
Fundament • Strip footing • Isolated Footing	1700x400 mm 1700 x1700x400	1700x400 mm 1700 x1700x400	1700x400 mm 1700 x1700x400	Foundation size is the same in all options.
LCA • Global Warming [kg CO2 eq] • Land use [m2a crop eq] • Ozone formation, Human health [kg NOx eq] • Terrestrial acidification [kg SO2 eq]	234620,6 443737,85 630,58 630,56147	219564,5 443688,4 607,61 609,0135	207658,3 483300 587,95 592,1727	
House Cost: M2 – price [kr/m2]	4 666	4 725	4 666	Option 2 is slightly expensive

Since all the options had the same floor type, CLT, the total load at the foundation was almost equal in all options. Therefore, the size of the foundations (table 8.1 above) is the same for all options.

8.2. Life Cycle Assessment (LCA) discussion

8.1.6 Life Cycle Assessment of Option 1

Option 1 consists of glulam, steel, cross-laminated timber, reinforced normal concrete and transport that contribute to CO2 emission. Reinforced normal concrete has the highest value in most categories. Cross-laminated timber has the highest value at Land use category and glulam is the next highest. This is because option 1 includes 51544,1 kilograms cross-laminated timber (CLT) and 1367,7 kilograms glulam. To reduce CO2 emissions in this option, one must use materials other than concrete that have less impact on the climate. The results of the life cycle analysis for glulam, steel, cross-laminated timber, reinforced normal concrete, transport and transport for CLT are respectively 1367,7 kg CO2 eq, 28884,5 kg CO2 eq, 51544,1 kg CO2 eq, 146495 kg CO2 eq, 3722,1 kg CO2 eq, 2607,2 kg CO2 eq. The results from SimaPro are shown in Figure 8.2:

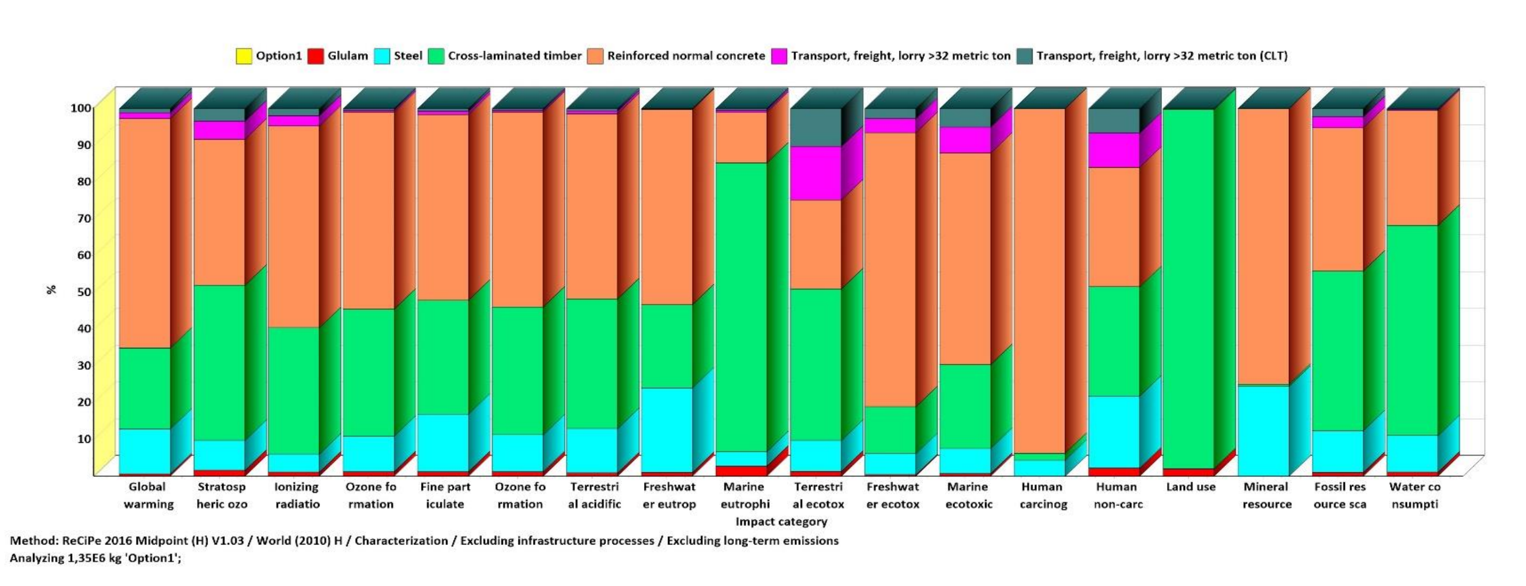


Figure 8.2: Impact assessment analyzing of option 1

Transport for CLT alone causes 1 percent of Global Warming while transport for all other material in option 1 causes 2 percent of Global Warming. It is because CLT is transported from 150,9 km distance to the building site while all other material is assumed to be transported in 50 km distance to the building site. Thus, the shorter distance will give less CO2 emission.

The pie chart in Figure 8.3 shows the percentage of materials and transport up to total Global Warming (CO2 equivalent). The diagram is based on Table 7.22.

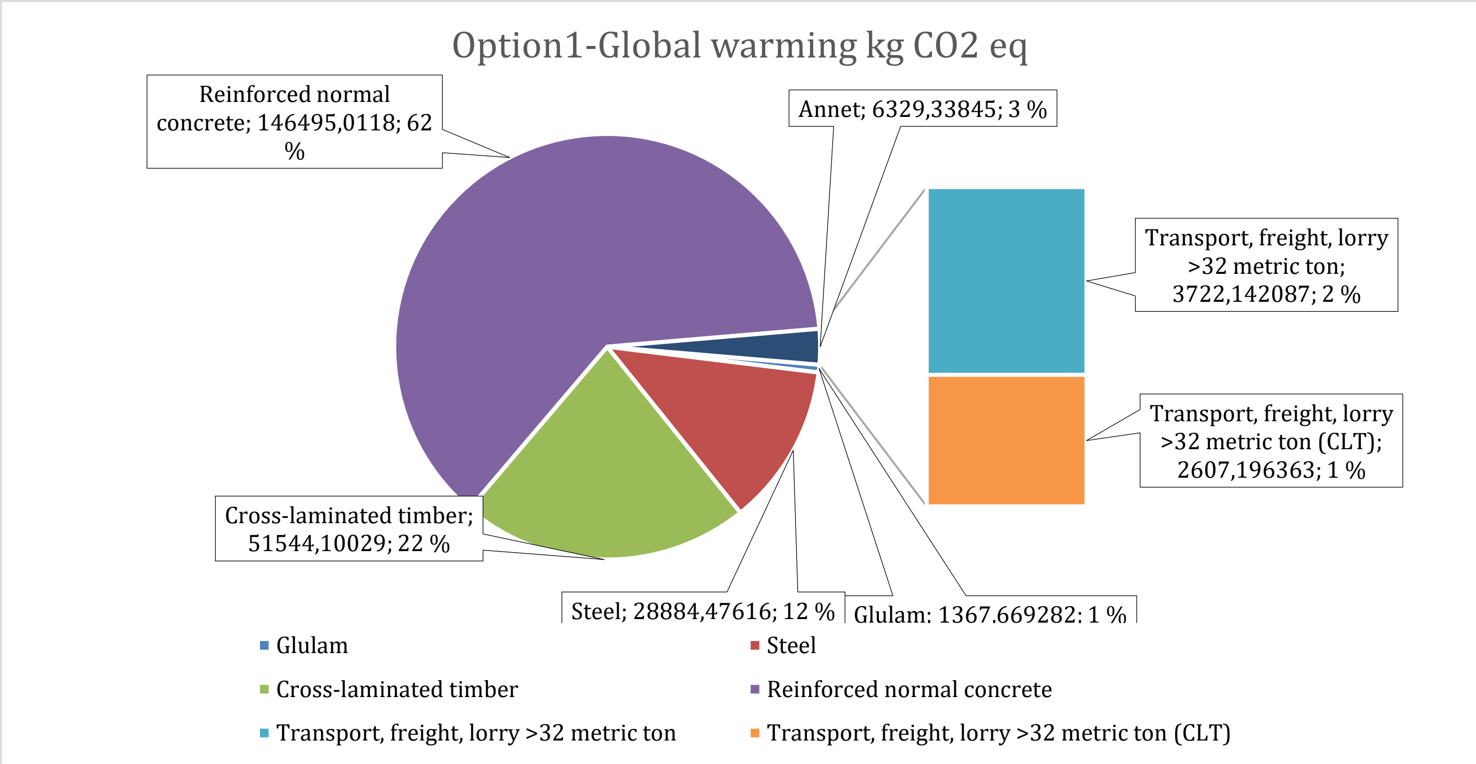


Figure 8.3: Global Warming analyzing of option 1

Figure 8.4 shows the chemicals that are being emitted in option 1. ''Carbon dioxide, fossil'' released in air represents 224165,2 kg CO2-equivalents of the total 234620,6 kg CO2-equivalents emitted for the entire life cycle of the option 1. It means that 96 % of the emitted chemical in option 1 is ''Carbon dioxide, fossil''. ''Methane, fossil'' emitted from option 1 is 4%. As the figure shows there are other chemicals emitted in option 1. The other chemicals have small values which give almost 0 %. The value which is less than 0,1 % is included in remaining substance. Remaining substance has only 189,85 kg CO2 eq.

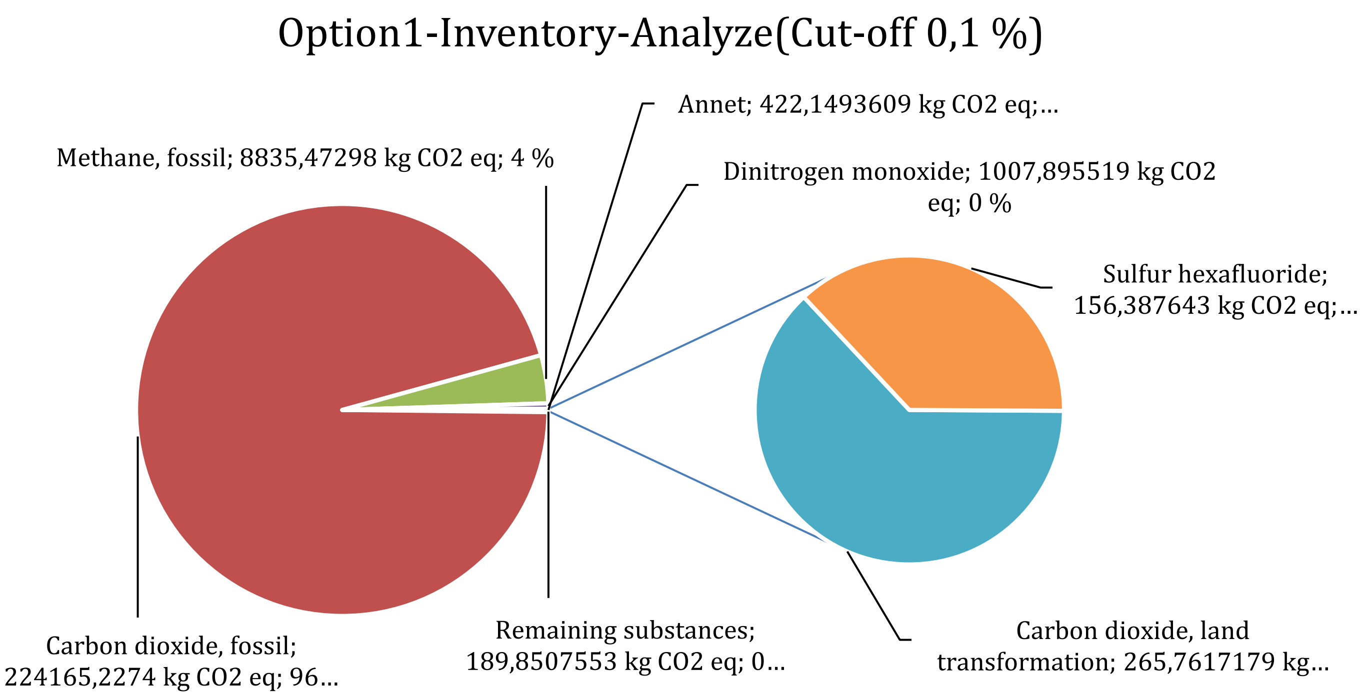


Figure 8.4: Option 1-Inventory-characterization(Global Warming(Cut-off 0,1%))Total

Figure 8.5 shows which input causes emissions. It is important to note that ''Remaining processes'' refers to the sum of all other processes that fall below the 1,6 % cut-off. Production of clinker causes 47% of the total CO2 emission in option 1. There are three types of transport that together cause 6 % of the total CO2 emission in option 1.

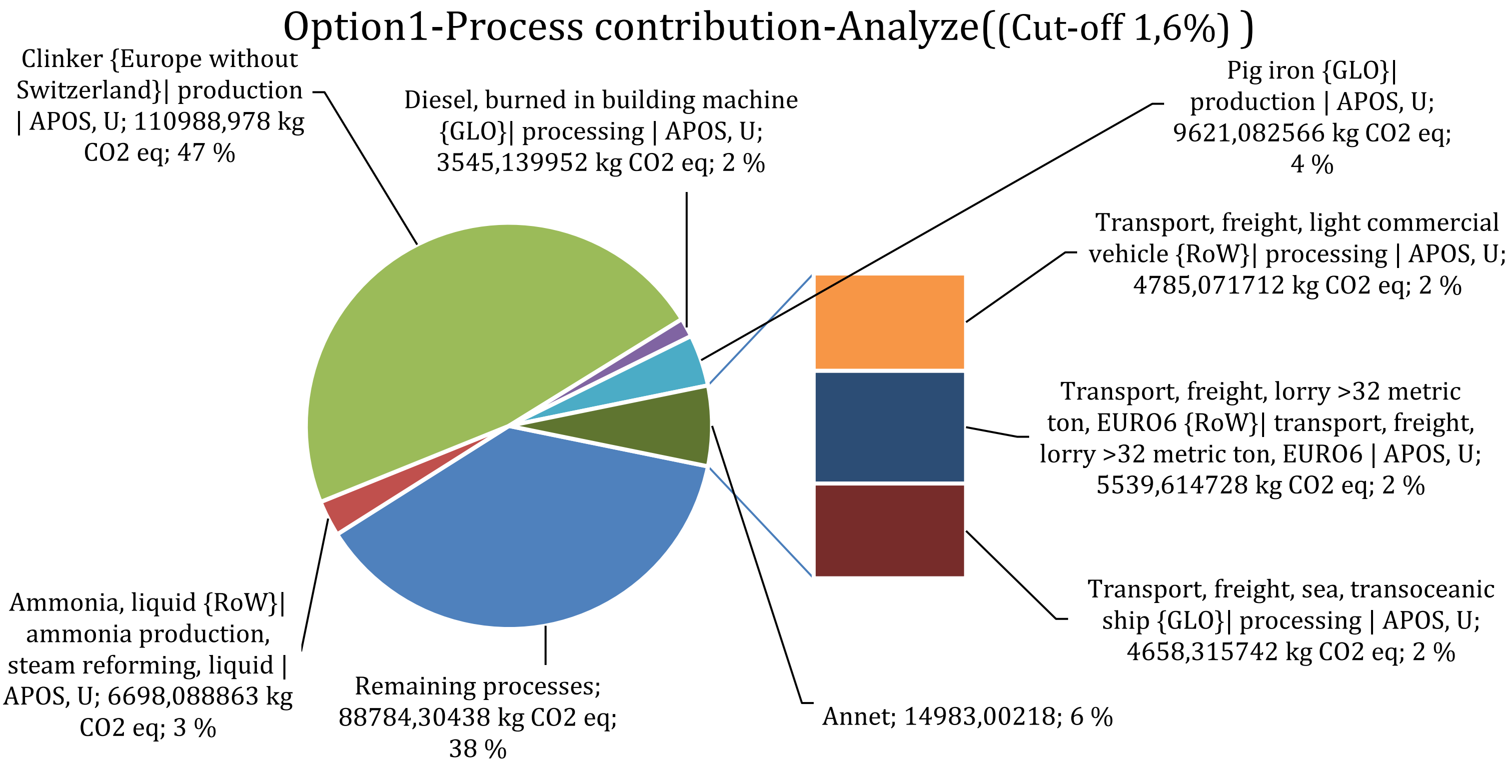


Figure 8.5: Option 1-Process contribution-Global Warming(Cut-off 1,6%) Total

8.1.7 Life Cycle Assessment of Option 2

Option 2 consists of glulam, steel, cross-laminated timber, reinforced low carbon concrete and transport that contribute to CO2 emission. Reinforced low carbon concrete has the highest value at most categories. It is important to notice the emission from concrete changes from 62% in option1 to 60% in option 2 because of the change from normal concrete to low carbon concrete. Cross-laminated timber has the highest value at Land use category and glulam is the next highest. This is because option 2 includes 5116,34 kilograms of cross-laminated timber (CLT) and 1367,669 kilogram glulam. It has been used much more cross-laminated timber compared glulam. To reduce CO2 emissions in this option, one must use materials other than low carbon concrete or steel that have less impact on the climate. The results of the life cycle analysis for glulam, steel, cross-laminated timber, reinforced low carbon concrete, transport and transport for CLT are respectively 1367,7 kg CO2 eq, 28884,5 kg CO2 eq, 51544,1 kg CO2 eq, 131438,9 kg CO2 eq, 3722,1 kg CO2 eq, 2607,2 kg CO2 eq. The results from SimaPro are shown in Figure 8.6.

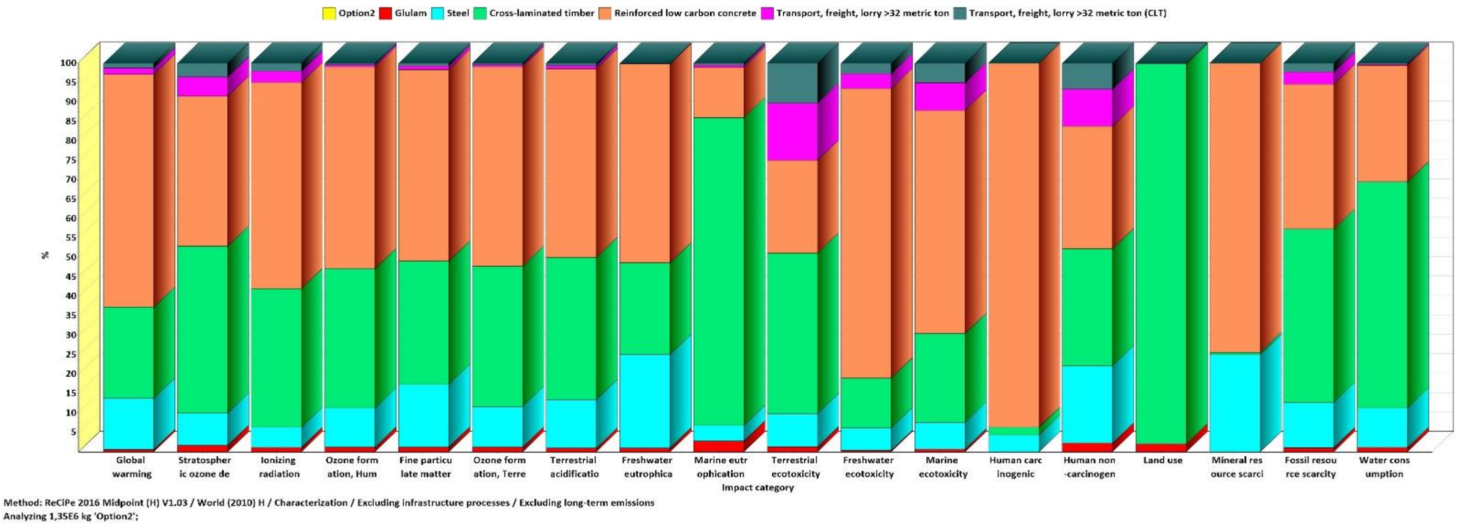


Figure 8.6: Impact assessment analyzing of option 2

Equivalent to option 1, transport for CLT alone causes 1 percent of Global Warming, while transport for all the other materials in option 2 causes 2 percent of Global Warming. This is because CLT is transported 150,9 km to the building site, while all other materials are assumed to be transported in 50 km distance to the building site. Thus, as it has been shown before, the shorter the distance will give less CO2 emission. Using low carbon concrete has an impact of decreasing the CO2 emission. The pie chart in Figure 8.7 shows the percentage of materials and transport up to total Global Warming (CO2 equivalent). The diagram is based on Table 7.25.

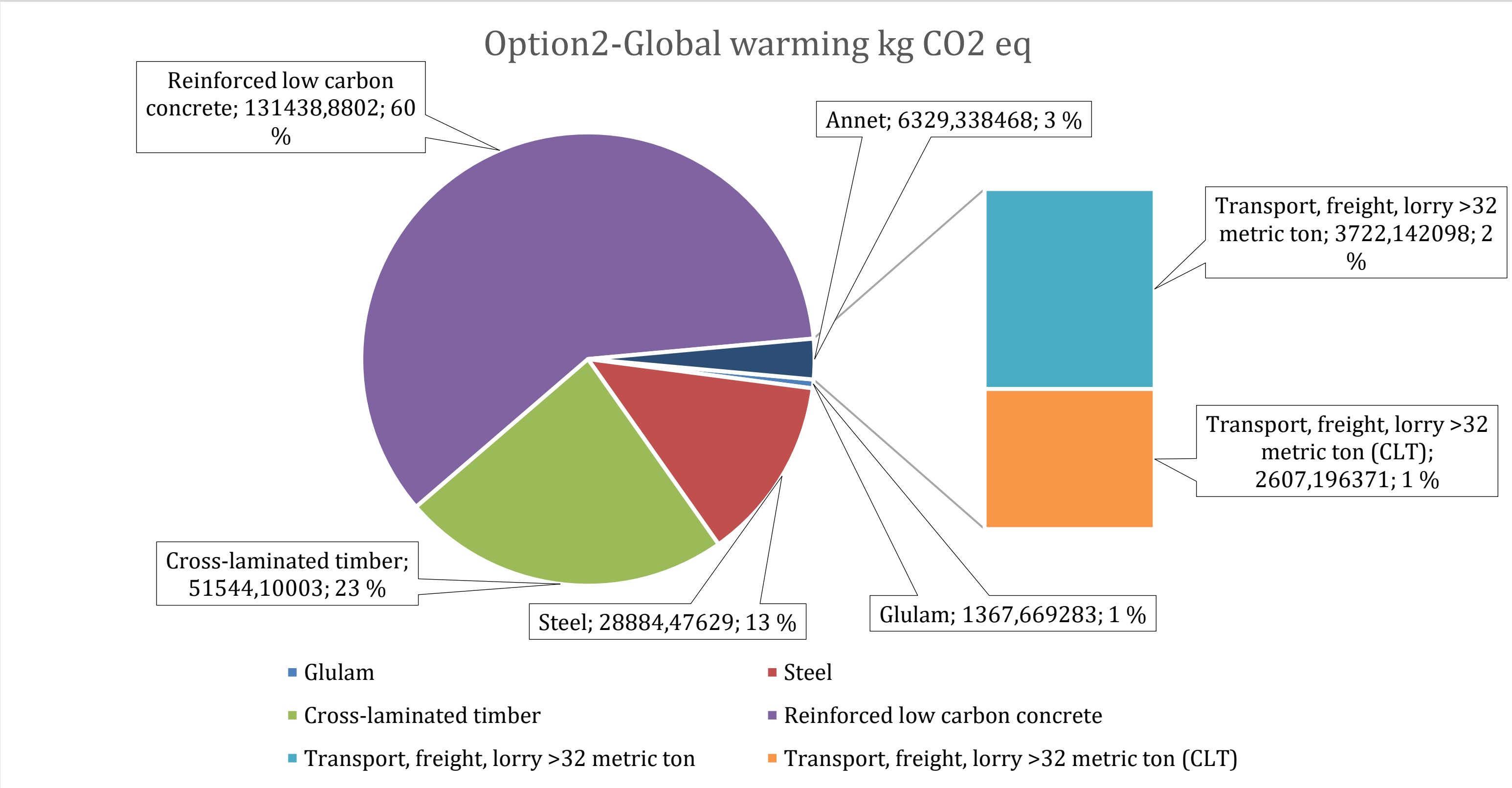


Figure 8.7: Global Warming analyzing of option 2

Figure 8.8 shows the chemicals that are being emitted in option 2. ''Carbon dioxide, fossil'' released into the air represents 209378,67 kg CO2-equivalents of the total 219564,5 kg CO2-equivalents emitted for the entire life cycle of the option 2. This means that 95 % of the emitted chemical in option 2 is ''Carbon dioxide, fossil''. ''Methane, fossil'' emitted from option 2 is the same as in option 1, which is 4%. As the Figure 8.8 shows there are other chemicals emitted in option 2. Some of the other chemical have small values which give almost 0 %. The values which are less than 0,1 % are included in remaining substances. Remaining substances has only 337,97 kg CO2 eq.

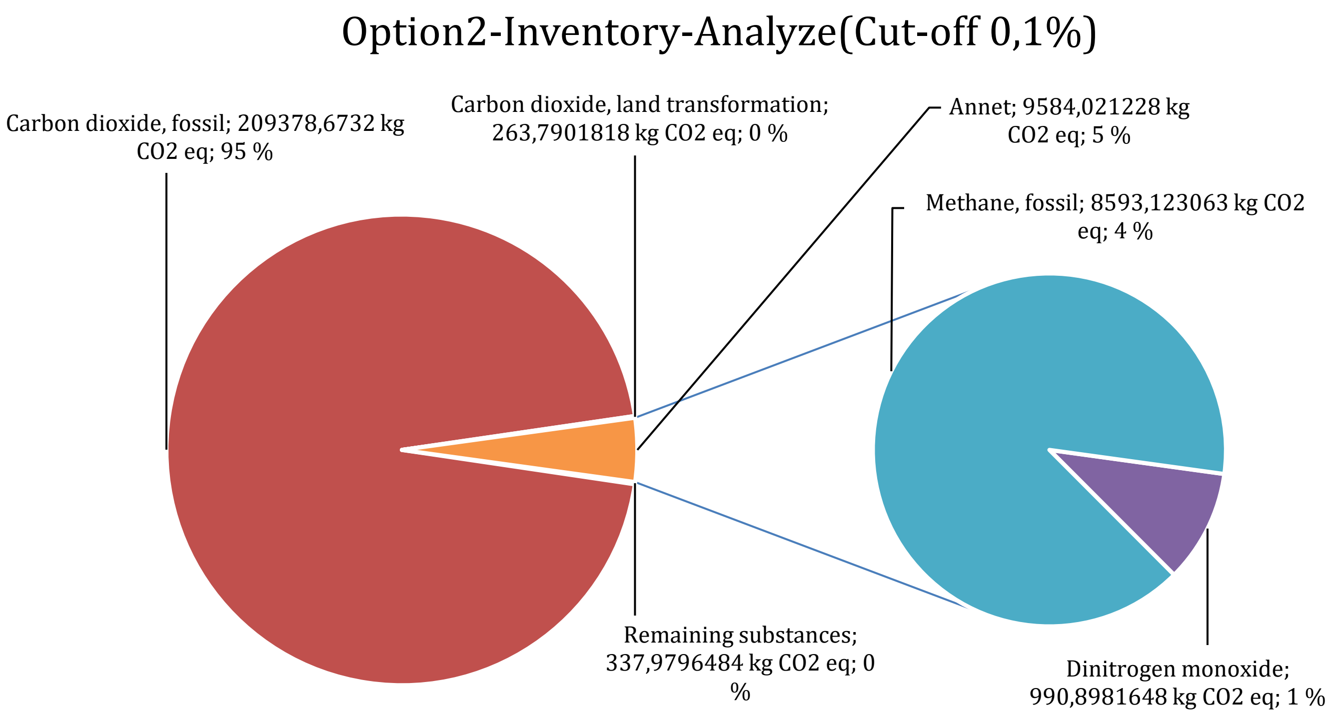


Figure 8.8: Option 2-Inventory-characterization (Global Warming(Cut-off 0,1%))Total

Figure 8.9 shows which inputs causes emissions. It is important to note that ''Remaining processes'', also here, refers to the sum of all other processes that fall below the 1,6 % cut-off. Normal concrete in option1 is changed to low carbon concrete in option2. The result of changing type of concrete caused 3% reducing of clinker production. Production of clinker causes 44% of the total CO2 emission in option 2. There are three types of transport that together cause 7 % of the total CO2 emission in option 2.

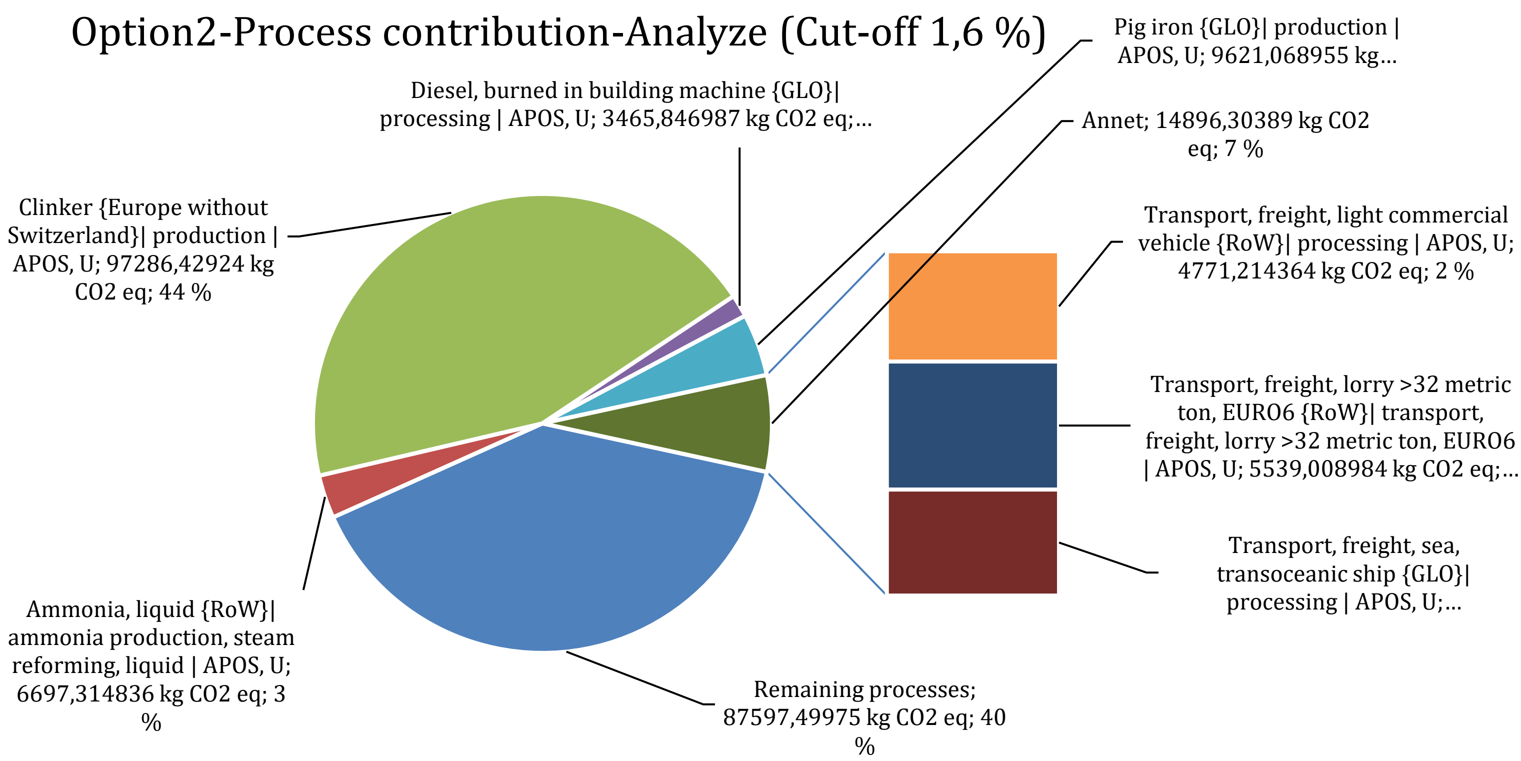


Figure 8.9: Option 2-Process contribution-Global Warming(Cut-off 1,6%) Total

8.1.8 Life Cycle Assessment of Option 3

Option 3 consists of glulam, steel, cross-laminated timber, reinforced low carbon concrete and transport that contribute to CO2 emission. Reinforced low carbon concrete have still the highest value at most categories. It is important to notice the emission from concrete changes from 60% in option 2 to 55 % in option 3 because the use of less low carbon concrete and utilization of cross-laminated timber instead. Cross-laminated timber has the highest value at Land use category and glulam is the next highest. This is because option 3 includes 56260,3 kilograms cross-laminated timber (CLT) and 1367,7 kilograms glulam. Similarly, in option 3 there has been used much more cross-laminated timber compared to glulam. To reduce CO2 emissions in this option, one must use materials other than low carbon concrete or steel that have less impact on the climate. The results of the life cycle analysis for glulam, steel, cross-laminated timber, reinforced low carbon concrete, transport and transport for CLT are respectively 1367,7 kg CO2 eq, 28884,5 kg CO2 eq, 56260,3kg CO2 eq, 115034,4kg CO2 eq, 3265,7 kg CO2 eq, 2845,8 kg CO2 eq. The results from SimaPro are shown in Figure 8.10.

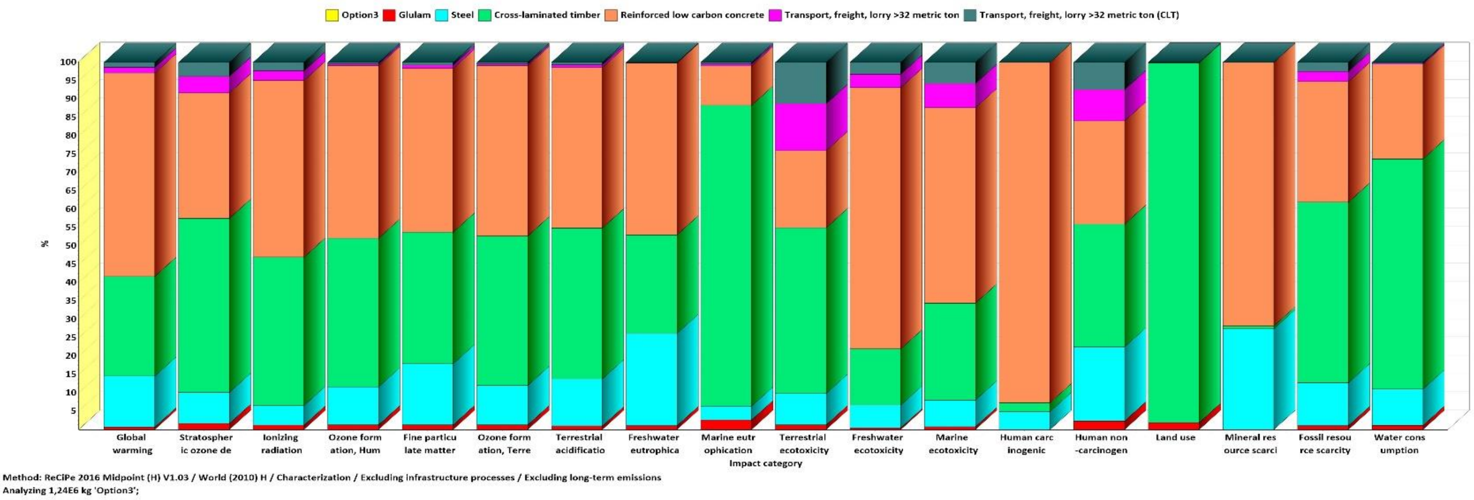


Figure 8.10: Impact assessment analyzing of option 3

Equivalent to option 1 and option 2, transport for CLT alone causes 1 percent of Global Warming while transport for all other material in option 3 causes 2 percent of Global Warming. This is because CLT is transported from 150,9 km distance to the building site while all other material is assumed to be transported in 50 km distance to the building site. Thus, the shorter the distance the less CO2 emission. Using low carbon concrete have impact of decreasing the CO2 emission. It is important to notice that in option 3 there has been used less reinforced low carbon concrete than option 2. Instead more cross-laminated timber is used. These changes of material quantity cause reduction in CO2 emission from 60% in option 2 to 55% in option3.

The pie chart in Figure 8.11 shows the percentage of materials and transport up to total Global Warming (CO2 equivalent). The diagram is based on Table 7.28.

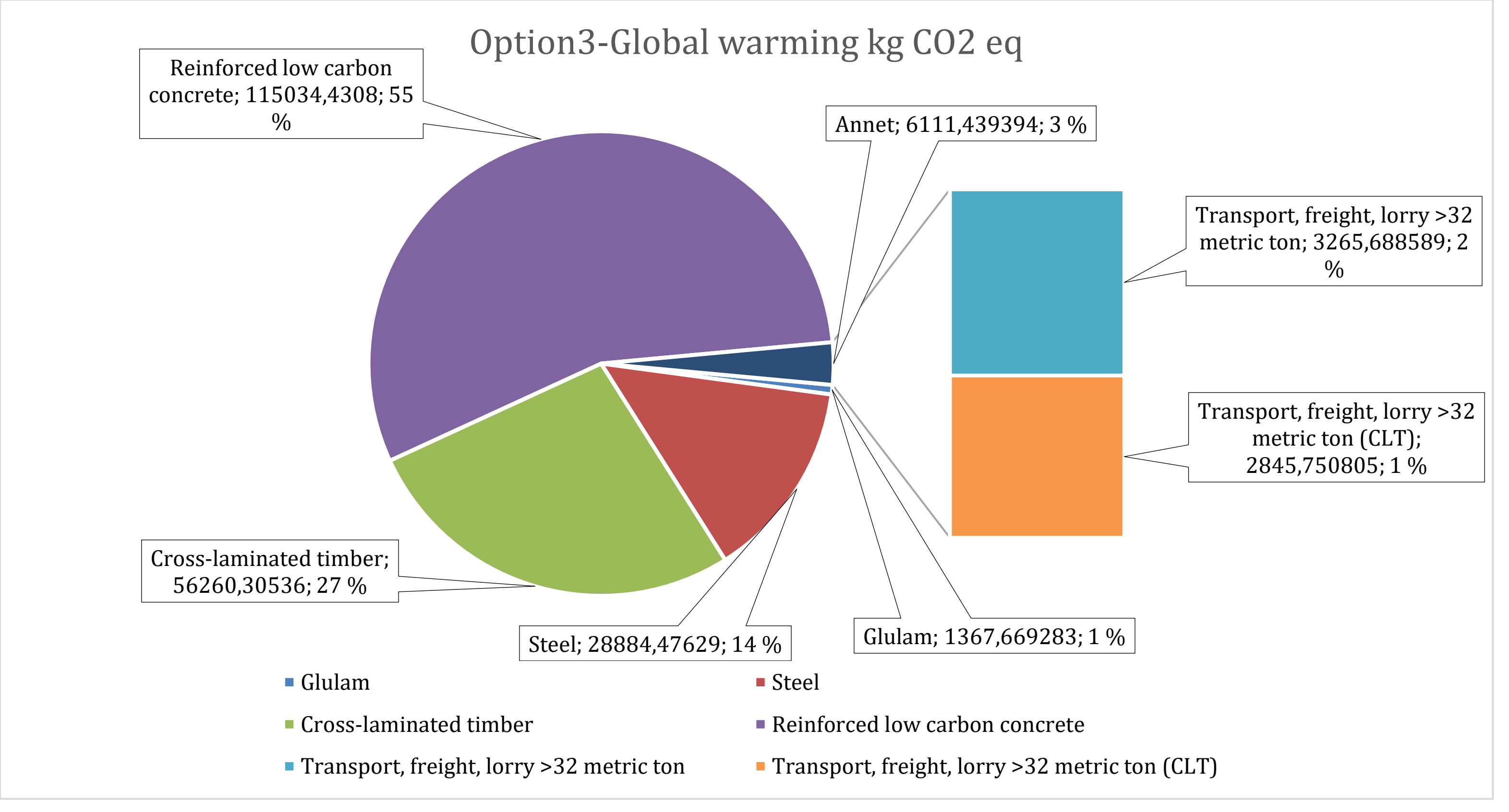


Figure 8.11: Global Warming analyzing of option 3

Figure 8.12 shows the chemicals that are being emitted in option3. ''Carbon dioxide, fossil'' released in air represents 197579,2kg CO2-equivalents of the total 207658,3 kg CO2-equivalents emitted for the entire life cycle of the option 3. This means that 95 % of the emitted chemical in option 3 is ''Carbon dioxide, fossil''. ''Methane, fossil'' emitted from option 3 is also the same as option 1 and option 2 which is 4%. As the Figure 8.12 shows there are other chemicals emitted in option 3. Some of the other chemicals have small values which give almost 0 %. The values that are less than 0,1 % is included in "remaining substances". Remaining substances has only 322,6 kg CO2 eq.

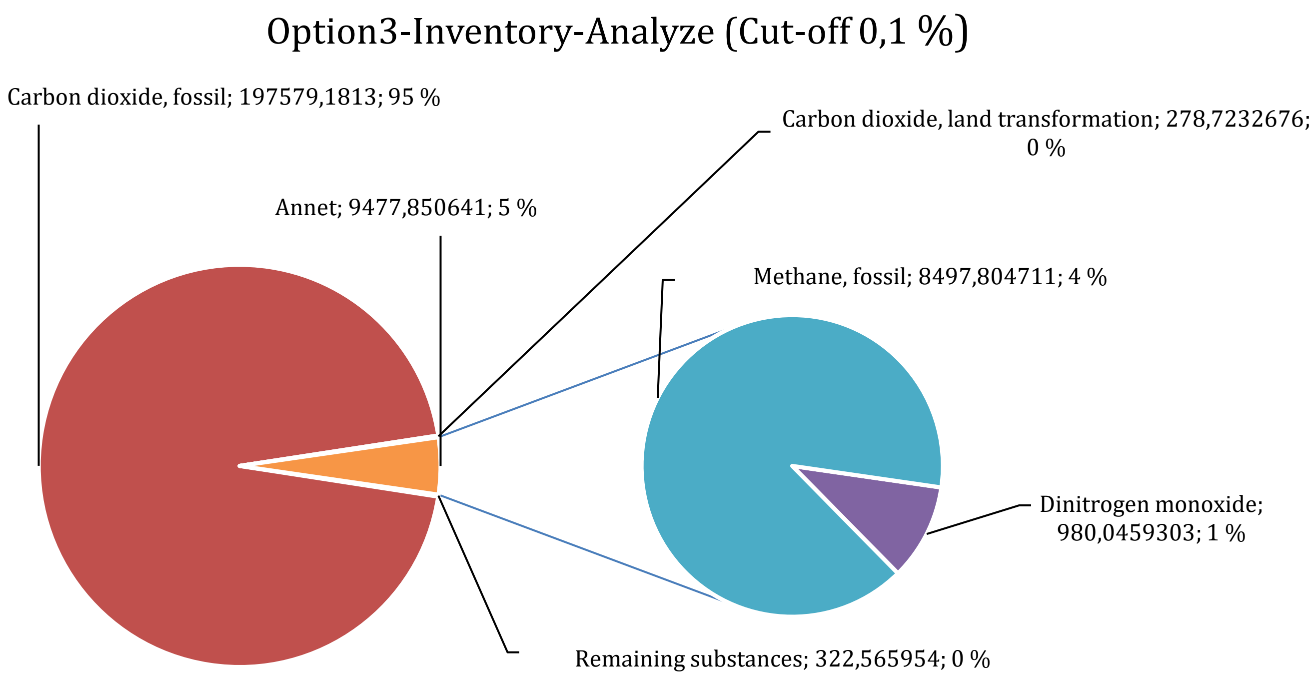


Figure 8.12: Option 3-Inventory-characterization(Global Warming(Cut-off 0,1%))Total

Figure 8.13 shows which inputs causes emissions. It is important to note that ''Remaining processes'' refers to the sum of all other processes that fall below the 1,6 % cut-off. Using less low carbon concrete in option 3 caused 3% reduction of clinker production compared to option 2. Production of clinker causes 41% of the total CO2 emission in option 3. There are three types of transport that together cause 7 % of the total CO2 emission in option 3.

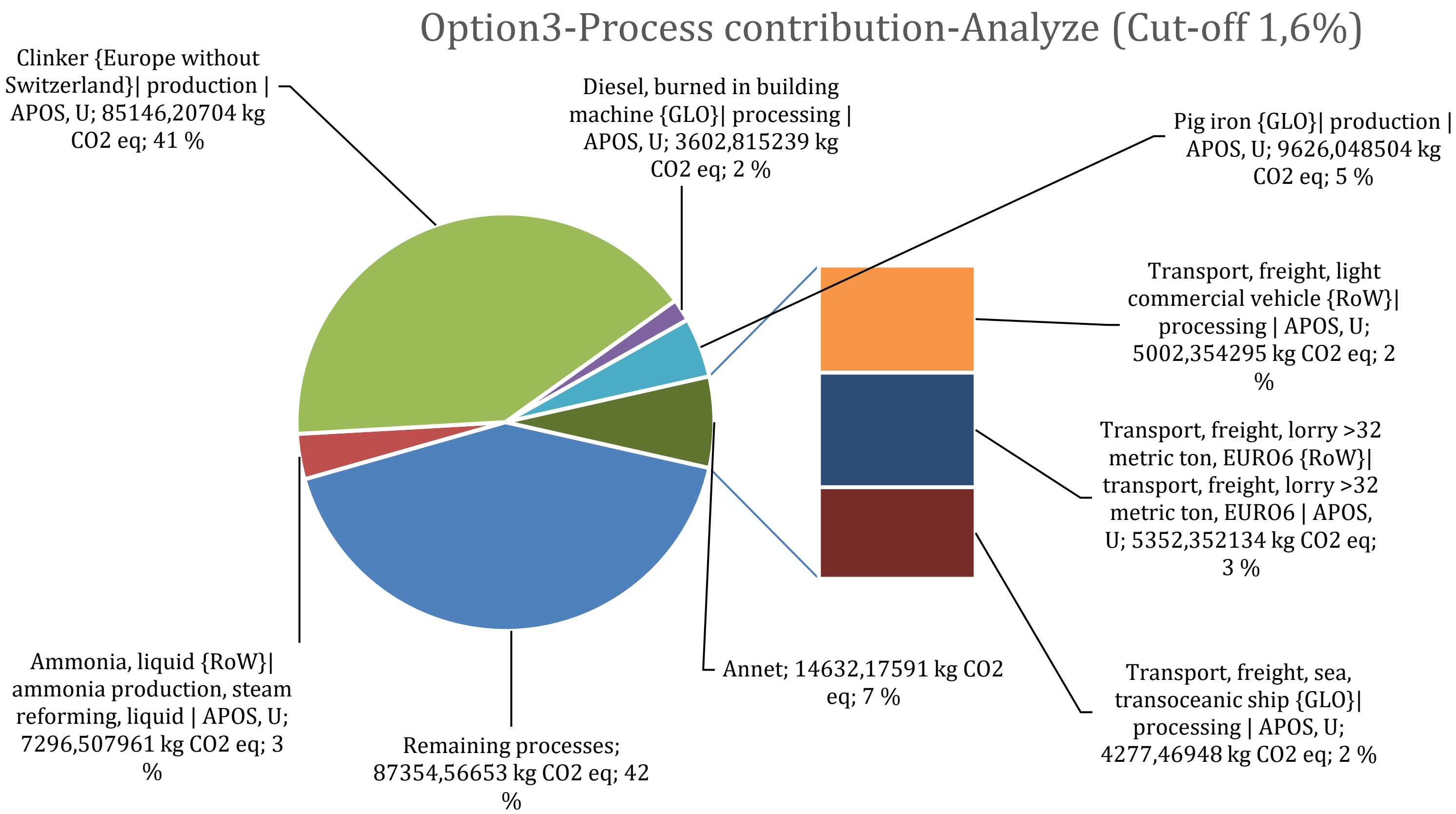
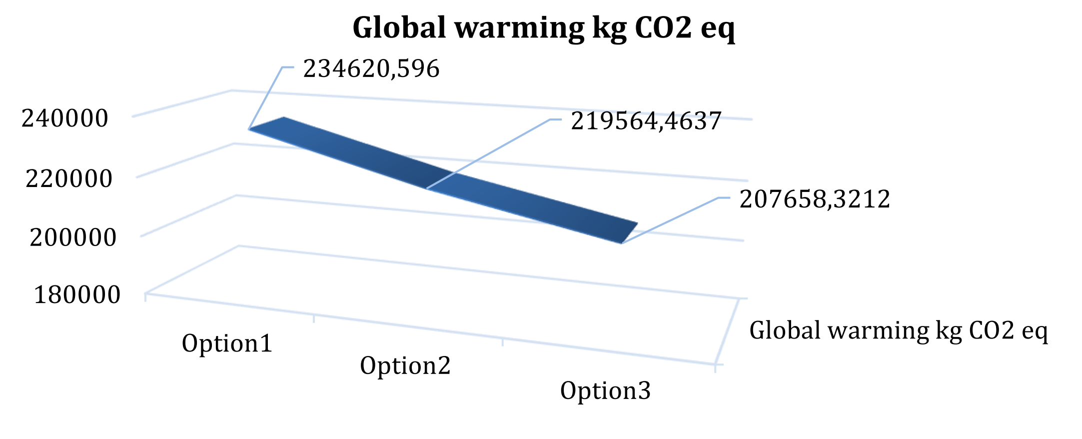


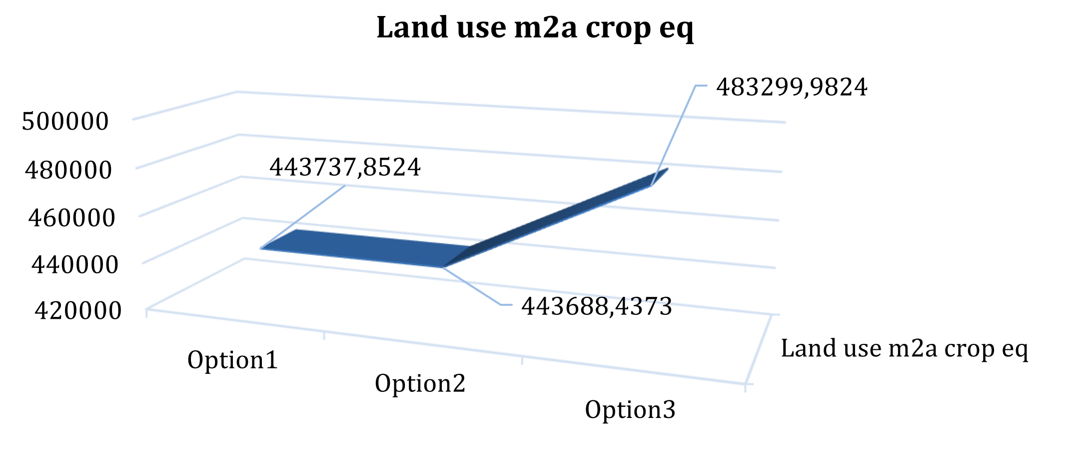
Figure 8.13: Option 3-Process contribution-Global Warming(Cut-off 1,6%)Total

- **LCA discussion summary of option 1, option 2 and option 3**



	Option1	Option2	Option3
Global warming kg CO2 eq	234620,596	219564,4637	207658,3212

Figure 8.14: 3D line chart for Global Warming comparison of option 1, option 2 and option 3



	Option1	Option2	Option3
Land use m2a crop eq	443737,8524	443688,4373	483299,9824

Figure 8.15: 3D line chart for Land use comparison of option 1, option 2 and option 3

The Global Warming Potential (GWP) of option 3 appears to be much lower, compared to the other two options, followed by option 2 and option 1. However, Land use in option 3 is found to be 9% higher than the option 1 and option 2. The GWP of option 3 was at 11% and 5% lower than option 1 and option 2 respectively. See Figure 8.14 and Figure 8.15.
It is important to note that replacing normal concrete with low carbon concrete in option 2 has reduced the GWP by 6 %. Furthermore, in option 3, replacing some of the low carbon concrete walls with CLT has reduced the GWP by 5%. Based on these LCA results, option 3 would give the lowest environmental impact. The reason is that in option 3 more timber materials and lower low carbon concrete is used compared to option 2.

8.3. Discussion on the cost of construction

Cost calculations were done manually in this project. Material quantities were generated from Revit models. Unit price for each material is picked from Norsk Prisbok and Holte-kalkulasjonsnøkkelen. After that, the cost calculation was done in Excel.

Cost calculation (Table 7.31) and pie chart (Figure 7.62 and Figure 8.16) are intended to illustrate a compilation of the calculated building costs. The results show that option 2 is slightly more expensive than the other two options.

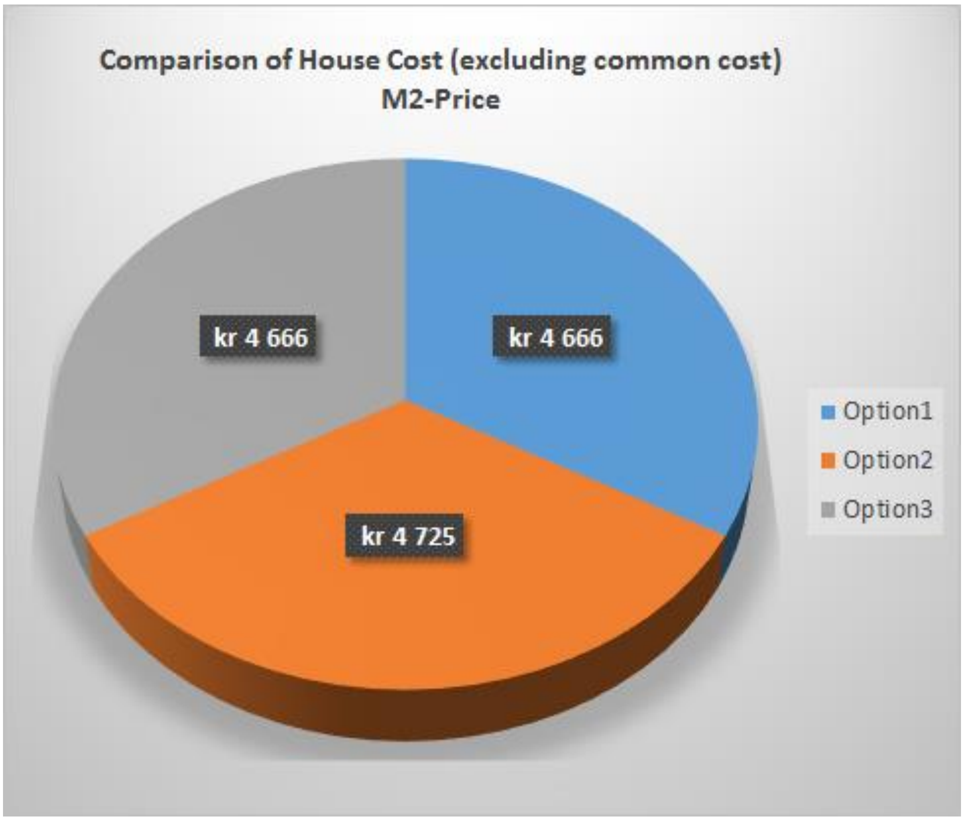


Figure 8.16: Comparison of House Cost in M2-Prise (Meter-square price) between options

As it can be seen from Figure 8.17, option 2 is 1.3% more expensive than Option 1 and Option 3.

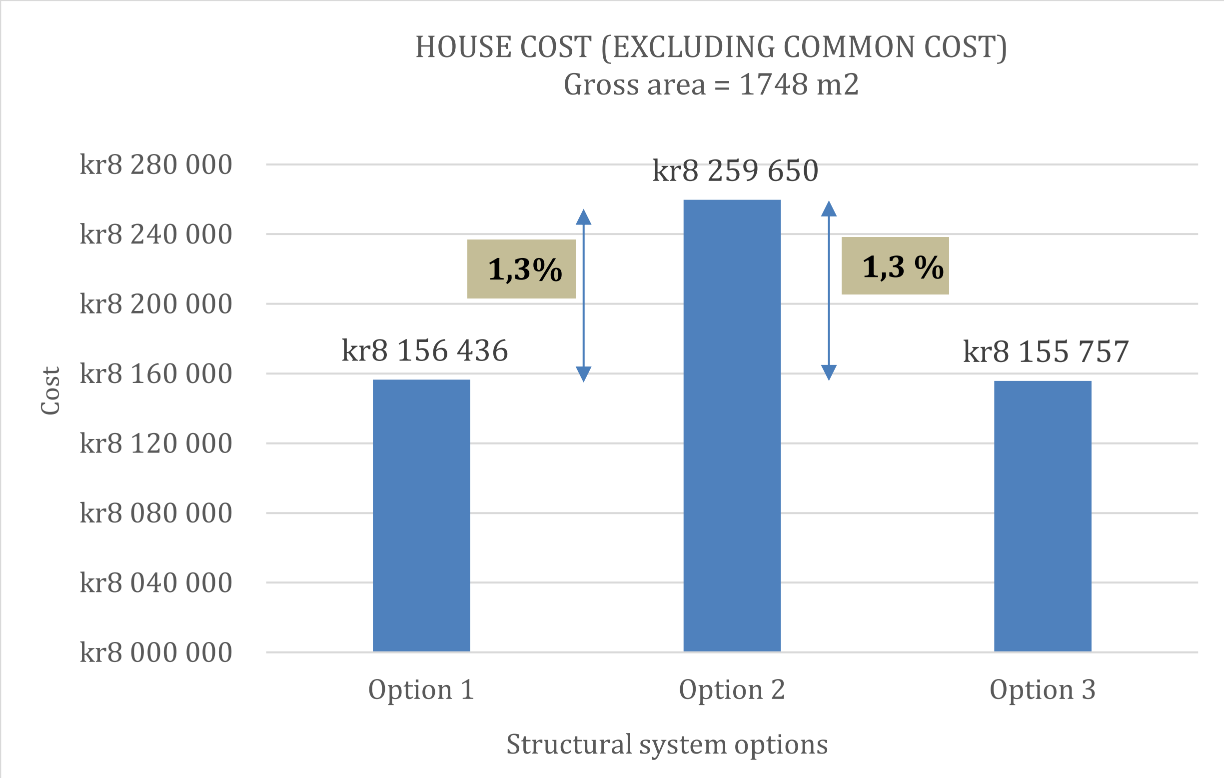


Figure 8.17: Graphical Comparison of House Cost among Options

Moreover, the cost summary (Table 7.32) shows an overview of all summation levels and a comparison of costs between the alternatives. The calculations are performed in accordance with Table 3.35.

8.4. Summary of the preliminary and master's thesis project

Preliminary project: (Studied in Autumn 2018) [16]

Option 1P: Concrete structural systems (normal cast in situ concrete)
Option 2P: Steel frames with hollow core slabs (precast slabs) including walls and foundations made of normal concrete
Option 3P: Timber structural system including walls and foundations made of normal concrete

Master's thesis project

Option 1: Timber structural system including walls and foundations made of normal concrete
Option 2: Timber structural system including walls and foundations made of low carbon concrete.
Option 3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.

- **Construction Cost Summary**

Summary of the six options studied for the project is presented below. The first three options were done in the preliminary project and the second three options were done in final or main project for the master's thesis.

Table 8.2: Construction Cost Summary of the Preliminary and master's project

Preliminary Project: (Studied in Autumn 2018)			Master's thesis Project (Studied in Spring 2019)			
Preliminary Project for Master's thesis			Master's thesis project			
Option 1P (Preliminary Project)	Option 2P (Preliminary Project)	Option 3P (Preliminary Project)	Option 1 (Master's Project)	Option 2 (Master's Project)	Option 3 (Master's Project)	
7 799 640	**6 628 389**	**8 161 548**	**8 156 436**	**8 259 650**	**8 155 757**	**Total (kroner)**
4 462	**3 792**	**4 669**	**4 666**	**4 725**	**4 666**	**M2-price**

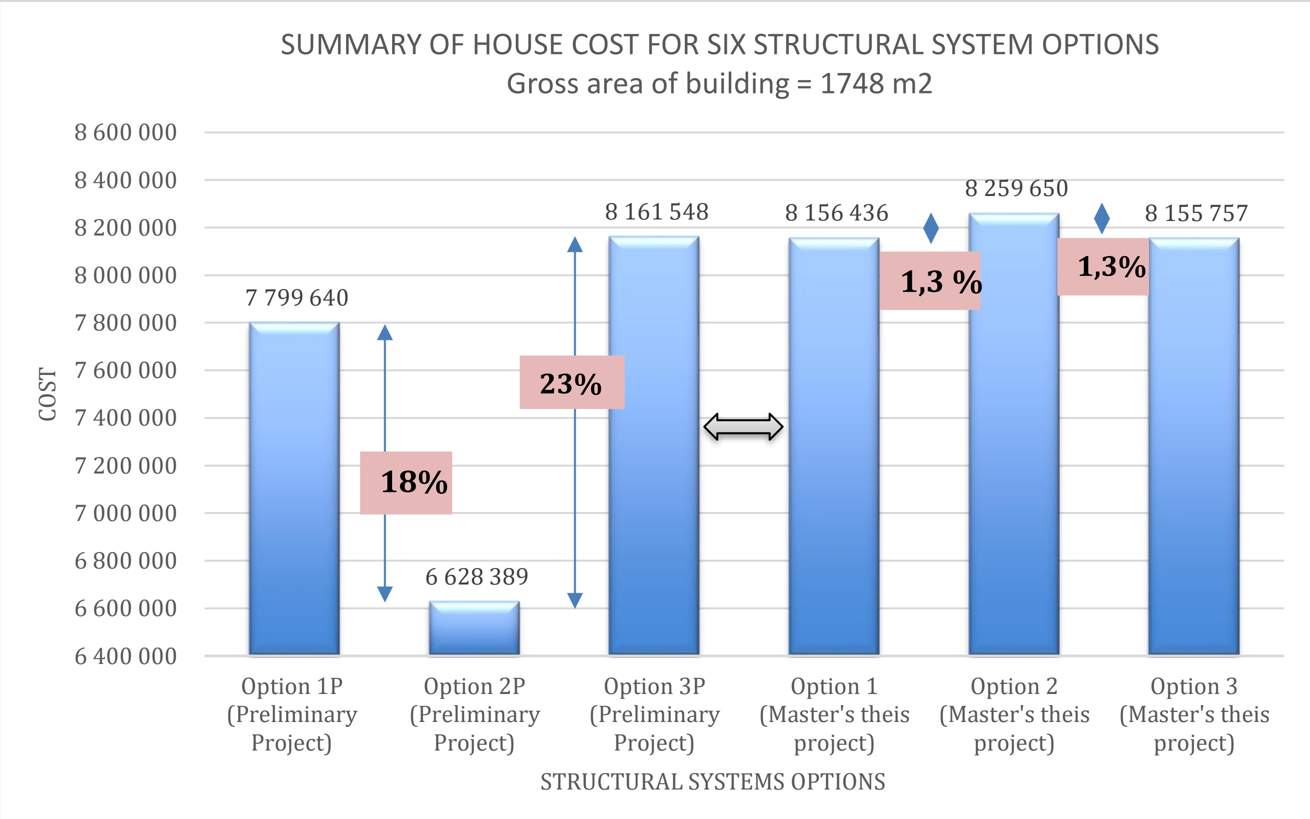


Figure 8.18: Summary of preliminary and main project of Master's Thesis. The three options to the left are picked from the preliminary project for this Master's Thesis[16].

From the Figure 8.18, option 2P (preliminary project) came out cheapest. It is 18% and 23% cheaper than option 1P (preliminary project) and option 3P (preliminary project), respectively. The cost of option 3P (preliminary project), option 1 and option 3 (main project) are very similar. Option 2 (master's thesis project) is 24,3% more expensive than option 2P (preliminary project).

Based on the results found in the cost calculation, option 2P (preliminary project) appears to be better compared to the other options. This means that from an economic perspective, we can conclude that option 2P (preliminary project) is the most favourable when it comes to economic costs.
(For construction cost estimation of preliminary project, see Appendix L)

- **Life Cycle Assessment Summary**

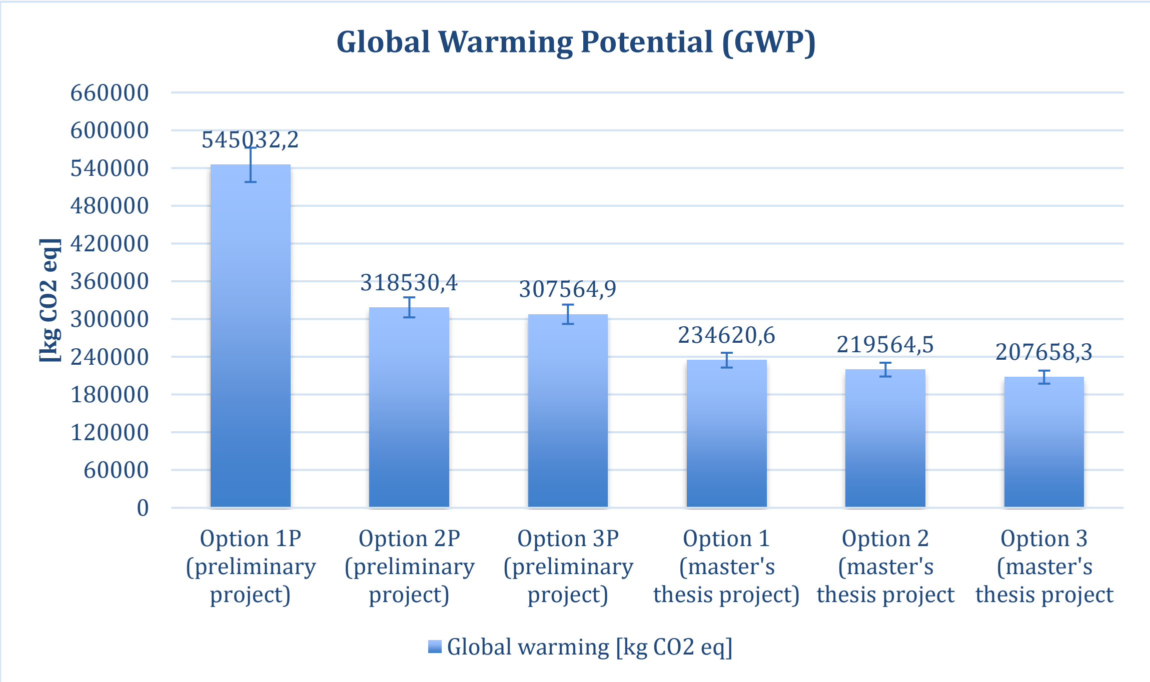


Figure 8.19: Graphical comparison of GWP for preliminary [16] and master's thesis project

Figure 8.19 shows an overview of GWP of the six structural systems options which are studied in this master's thesis and the preliminary project prior to the master's thesis. As it can be seen from the figure above, option 1P (preliminary project) has the highest CO2 emission. Whereas, option 3 (master's thesis project) has the lowest CO2 emission. GWP of option 3 (master's thesis project) is found to be approximately 62%, 35%, 32%, 11% and 5% lower than option 1P (preliminary project), option 2P (preliminary project), option 3P (preliminary project), option 1 (master's thesis project) and option 2 (master's thesis project), respectively.

The reason for the dramatic reduction of GWP from option 1P (preliminary project) to option 3 (master's thesis project) is due to the fact, that the sustainability of materials increase from left to right as shown in Figure 8.19. For example option 1P (preliminary project) is a structural system made of only normal cast in-situ concrete. In this option, normal concrete proved to have the highest GWP. Option 3 (master's thesis project) is a timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations. This option proved to be the best to the environment. Therefore, timber structural system including low carbon concrete would give the best alternative solution for a sustainable construction. From the environmental perspective, the best option would be option 3 (master's thesis project).
(For LCA results of preliminary project, see Appendix K)

9. Conclusion

This master's thesis has explored different alternative solutions for the structural system of an apartment building, with focus on environmental issues. Three alternatives were compared. The comparison has included structural system, life cycle assessment (LCA) and economy. The main focus has been to find out which of the three alternatives is most sustainable based on an overall assessment of the structural system, LCA and construction cost.

Usually, timber structures have limitations in terms of spans, as deflection often will be critical for glulam beams and cross laminated timber (CLT) floors. For spans of more than about 6 meters, it is difficult to satisfy the requirements for both strength and against deformation. In addition, the thickness of CLT elements and glulam beam cross section will be large, which in turn will be driving for the floor height up. This has negative economic consequences. In this project, all options gave certain challenges in terms of spans, which was resolved by replacing glulam beams with steel beams to improve capacity. However, steel structural system has limitations with regard to fire safety and will in practice have to be fire-insulated.

For comparison, reinforced concrete structures have better strength, and are therefore better suited to large spans. In other words, there are fewer challenges associated with spans, compared to the alternative with wood. However, reinforced concrete often provides large massive cross-sections. This leads to high self-loading, which in turn means that the foundations become correspondingly larger compared to structures with timber.
Another limitation is fire properties. Wood has good fire properties, but it is flammable. Concrete has good fire properties because it is non-flammable and largely maintains its load bearing capacity under fire.

When it comes to restrictions, reinforced structures have almost no restrictions with regard the area of use. They are suited to any weather conditions they are even an alternative in undersea structures. Concrete is durable and has good moisture resistance. However, reinforced concrete (RC) structures should be designed in accordance to durability and exposure class, for example proper reinforcement covers that are required to withstand different weather conditions.

CLT elements have certain restrictions with regard to area of use. CLT elements must be prevented from being exposed to high humidity for long periods. It needs protective measures, which protects the wood materials from direct water, stress and moisture. Such constructive protection forms of a building are: Good roof protrusions, sufficient distance from wood to terrain, proper connections and details, and aerated and drained exterior cladding. In addition, external parts of the building should be designed with good solutions that avoid problems and damages. Examples of such solutions are: avoid details which can lead to water traps, rainwater must be led down and away without dampening the elements, cover elements used in hallways or balconies with waterproof coating, adequately shield and protect against fire, pressure impregnate exposed wood in the elements for improving the resistance to rot fungi when the elements are used outdoor.

In this project, because of the above CLT restrictions, all walls against the terrain are made of concrete in all options.

The concrete types have some essential differences. The difference between the low carbon concrete and normal concrete is the limit values for CO2 emission. According to Figure 3.38, the limit values of CO2 increases from the highest class (class A) to lowest class (class C) and then to industrial reference. Considering durability class M40/MF40 and strength class B35, class A has approximately 23% and 40 % lower CO2 emission compared to class B and industrial reference respectively. Therefore, to reduce the carbon footprint from the concrete, it is necessary to take a closer look at the use of low-carbon concrete.

However, there are some challenges of using low carbon concrete. According to Table 3.13, Typical recipes for low carbon class B and low carbon class A in NorBetong AS, Norway, low carbon class A has coarser aggregates than class B. Resource materials for low carbon concrete may require long transportation in relation to their location. Thus, greenhouse gas emissions from transportation may be increased. Low carbon class A requires low consistencies (160-180 mm) for many concrete mixing plants in Norway. Decreasing the water-to-binder ratio has great impacts regarding the reduction of concrete bleeding (workability).

There are, however, also challenges in the production of pre-fabricated concrete elements. It is mainly due to conditions related to hydration time, early strength, deformation time and aggregate quantity with maximum grain size. Fabrication is most often produced with a fixed number of casting operations per day. However, tests of low carbon class A are assessed and optimized over longer periods of time, so it will be a long-term process if properties and constituents must be changed to achieve low carbon class A requirements. Production speed must be reduced to achieve class A. But, reducing production speed, will have a negative consequence on the economic costs.

Generally, wood is the most sustainable material compared to steel and concrete. Some of the reasons are: It is a renewable natural resource. Wood and wood products can be reused and recycled and have good durability. It will have a much shorter construction time than many other materials, which leads to a good economic cost. When using wood inside the building, we ensure a good indoor environment. In addition to this, wood contributes to nice aesthetic and psychosocial conditions and has the ability to regulate humidity and indoor temperature.

Normal concrete has more environmental impact than wood. Production of cement demands high energy, which results in high CO2 emissions. Cement contributes to more than 90% of the total greenhouse gas emissions of concrete. Thus, concrete in construction accounts for most of the greenhouse gas emissions. Measures have been taken to reduce the CO2 emission in ordinary concrete. A concrete type called low-carbon is developed to replace the normal concrete. Low carbon concrete, Class A, has much less CO2 emission than ordinary concrete. Despite all the measures taken to reduce CO2 footprint in concrete, wood is still the most sustainable material according the LCA assessment done in this study.

To find the most sustainable option, an overall assessment based on LCA results was done in this study. Environmental impacts of the structural systems, option 1 (timber structural system including walls and foundations made of normal concrete), option 2 (timber structural system including walls and foundations made of low carbon concrete), and option 3 (timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations), were compared using the impact categories of ReCiPe 2016 Midpoint (H) method. The pollutant emissions are calculated for each impact category for all alternatives.

LCA results show that option 3 has lower environmental impact in most of the impact categories including Global Warming Potential (GWP), stratospheric ozone depletion, ionizing radiation, ozone formation and so on. However, Land use and marine eutrophication of option 3 appeared to be higher compared to the other two options, followed by option 2 and option 1. GWP of option 3 appears to be 11% and 5% lower than option 1 and option 2, respectively. The Land use of option 3 is 9% higher than the other two options.

It can clearly be seen that replacing normal concrete with low carbon concrete in option 2 has reduced the GWP by 6 %. Apparently, in option 3, replacing some of the low carbon concrete walls with CLT has reduced the GWP by 5%. Based on these LCA results, it can be concluded that structural systems containing low carbon concrete and CLT would give lowest environmental impact. When it comes to construction costs, option 2 was 1.3% more expensive than the other two options.

Based on an overall assessment, option 3 (timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations) is preferable; it has more positive properties in most of the impact categories than the other alternatives with regard to the environment and construction cost. Moreover, as in option 3, it can be concluded that a structural system containing floors made of cross laminated timber and foundation made of low carbon concrete would be the best alternative materials.

It is important to note that the results of this study are not generalizable for all types of buildings.

10. Suggestions for further work

In the preliminary and the main project of this master thesis we have examined six different structural systems options. The study was done with focus on environmental issues. All the six options were analyzed for structural system, life cycle assessment (LCA) and construction cost. In addition to this, in the preliminary project, energy performance of the building was analyzed.

The main purpose of the project was to find the most suitable alternative solution for the structural system of the building studied. In the study, materials like normal concrete, low carbon concrete, cross laminated timber elements, prefabricated concrete elements (hollow core slab), steel, glulam have been explored. Results show that structural systems containing floors made of cross laminated timber and foundation made of low carbon concrete gave the lowest environmental impact. It is also important to note that all walls above ground can be replaced by CLT. However, it is not recommended to use CLT elements below the ground floor because of damages and problems due to moisture variation, temperature variation, precipitation and so on.

Sound and fire are considered roughly in the study. These could be important topics for further work.

The study has examined a way towards sustainable assessment of structural systems of a building. The method applied in this study would give designers and clients a good idea on how to reduce the environmental impact of materials.

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12. Appendices

APPENDIX A

Group agreement

This group agreement concerns to the group consisting of (Samsom Asmerom Habtemichael, Rawand Fatah Mohammad, Mohamad Omar Aljoulbek), master's thesis in spring semester 2019.

Project Duration

07.01.2019 – 13.06.2019

Requirements for project participants

1. All meetings at the agreed time and agreed place.
2. Everyone should ensure a fair division of work.
3. Deadlines must be kept according to the progress plan.
4. Absence must be justified, and must be reported at least before one day.
5. All documentation and work must be saved on One Drive.
6. Problems with following the progress of the project must be reported as soon as possible.
7. Respect each other and hold an open dialogue.
8. Disagreements are determined by democratic vote.
9. Decisions are taken in fellowship.

Grimstad 04.02.2019

I accept the contents of this collaboration agreement.

Samsom Asmerom Habtemichael

Mohamad Omar Aljoulbek

Rawand Fatah Mohammad

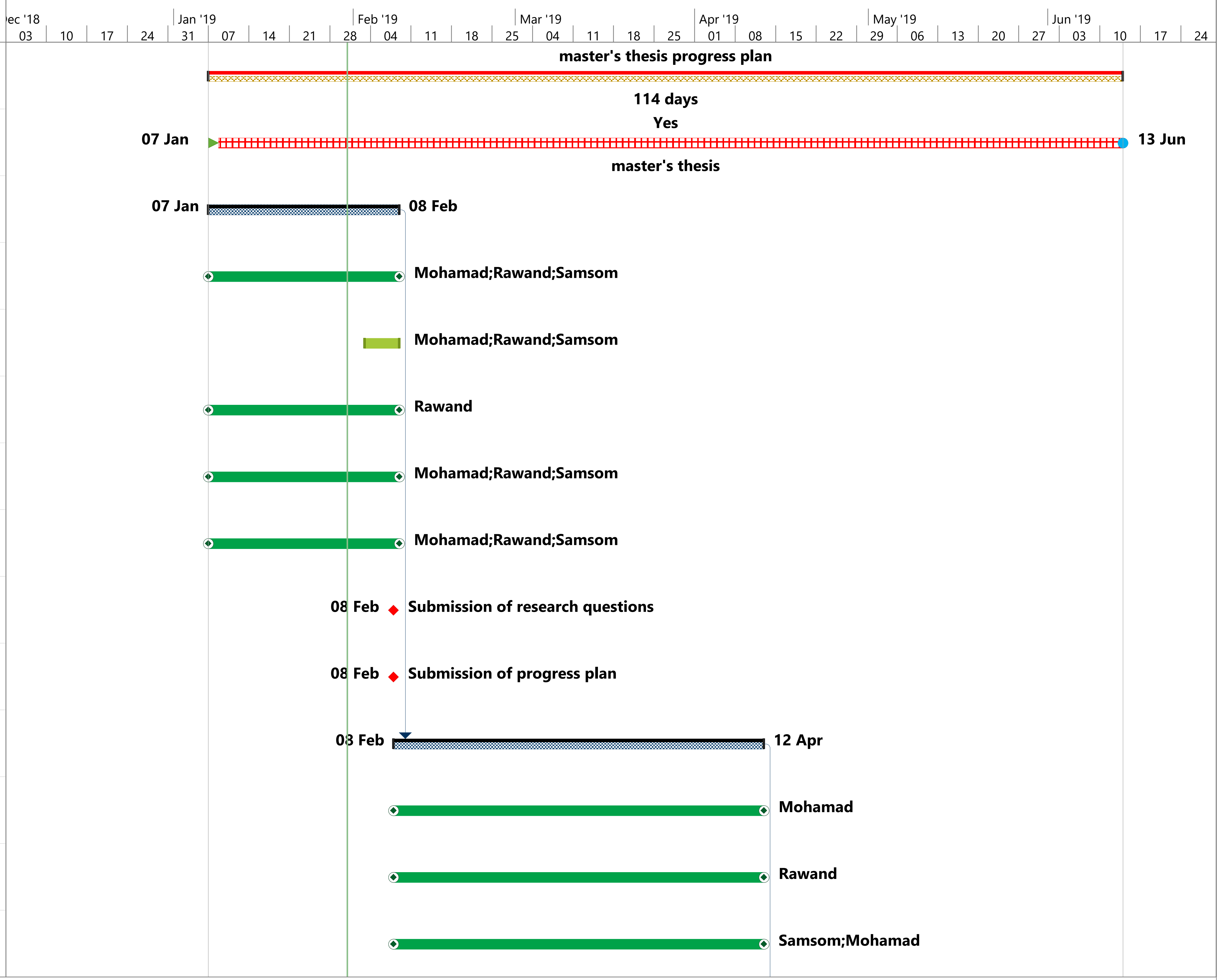
APPENDIX B

master's thesis progress plan first version

master's thesis progress plan last version

Time sheet

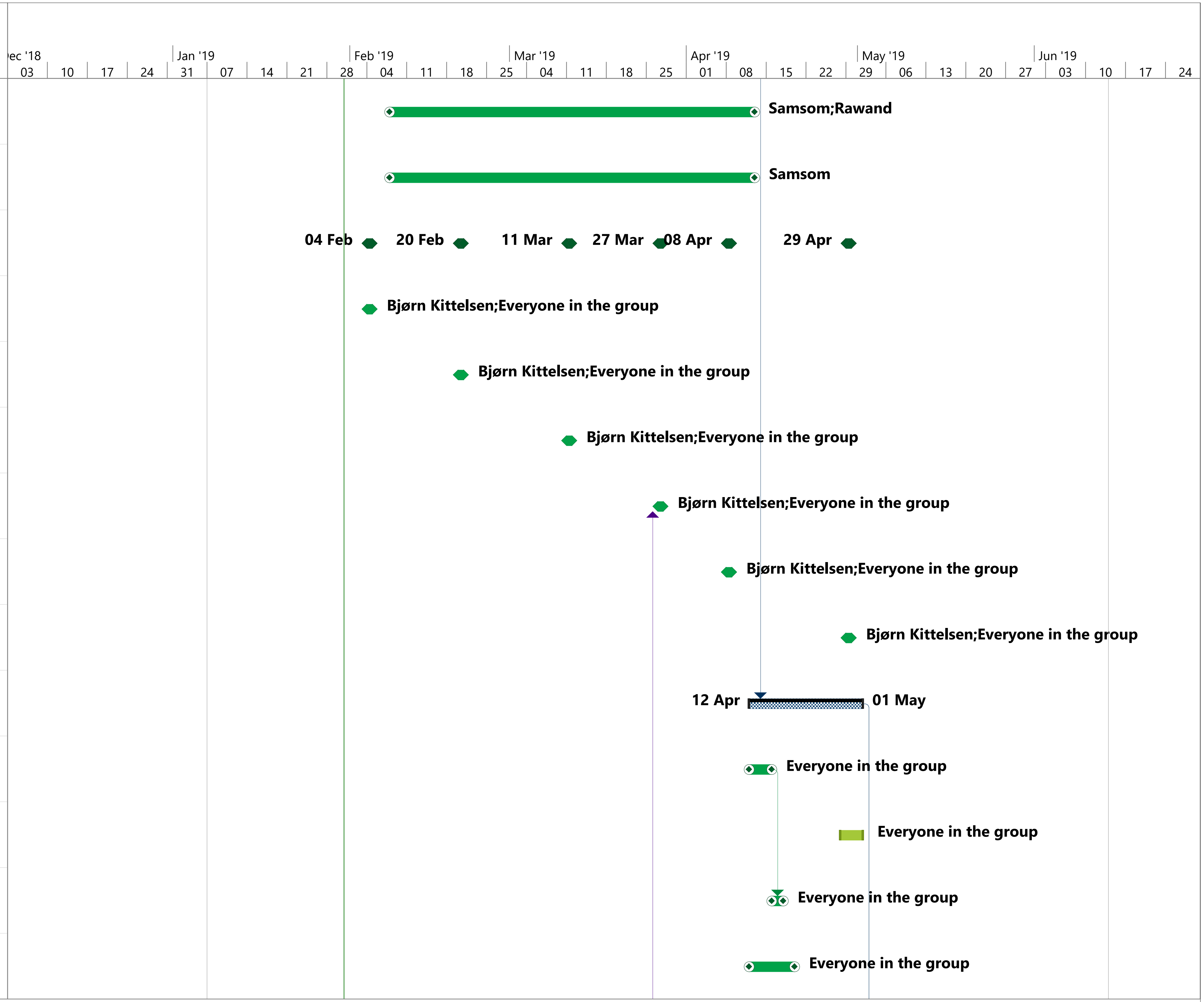
ID	Task Mode	Task Name	Duration	Start	Finish
1		**Master's thesis-Spring 2019**	**114 days**	**Mon 07.01.19**	**Thu 13.06.19**
2		master's thesis	114 days	Mon 07.01.19	Thu 13.06.19
3		**literature phase**	**25 days**	**Mon 07.01.19**	**Fri 08.02.19**
4		Read old master thesis	25 days	Mon 07.01.19	Fri 08.02.19
5		Eurocodes	6 days	Sun 03.02.19	Fri 08.02.19
6		Preparation of progress plan	25 days	Mon 07.01.19	Fri 08.02.19
7		Research topics	25 days	Mon 07.01.19	Fri 08.02.19
8		Evaluation of preliminary project and connection to master thesis	25 days	Mon 07.01.19	Fri 08.02.19
9		Submission of research questions	0 days	Fri 08.02.19	Fri 08.02.19
10		Submission of progress plan	0 days	Fri 08.02.19	Fri 08.02.19
11		**Theory writing**	**46 days**	**Fri 08.02.19**	**Fri 12.04.19**
12		Structural design	46 days	Fri 08.02.19	Fri 12.04.19
13		Life cycle assessment (LCA)	46 days	Fri 08.02.19	Fri 12.04.19
14		Connection design	46 days	Fri 08.02.19	Fri 12.04.19



Project: Masteroppgave fremdr
Date: Thu 31.01.19

Task	Inactive Task	Manual Summary Rollup	External Milestone	Progress
Split	Inactive Milestone	Manual Summary	Deadline	Manual Progress
Milestone	Inactive Summary	Start-only	Baseline	Slippage
Summary	Manual Task	Finish-only	Baseline Milestone	
Project Summary	Duration-only	External Tasks	Baseline Summary	

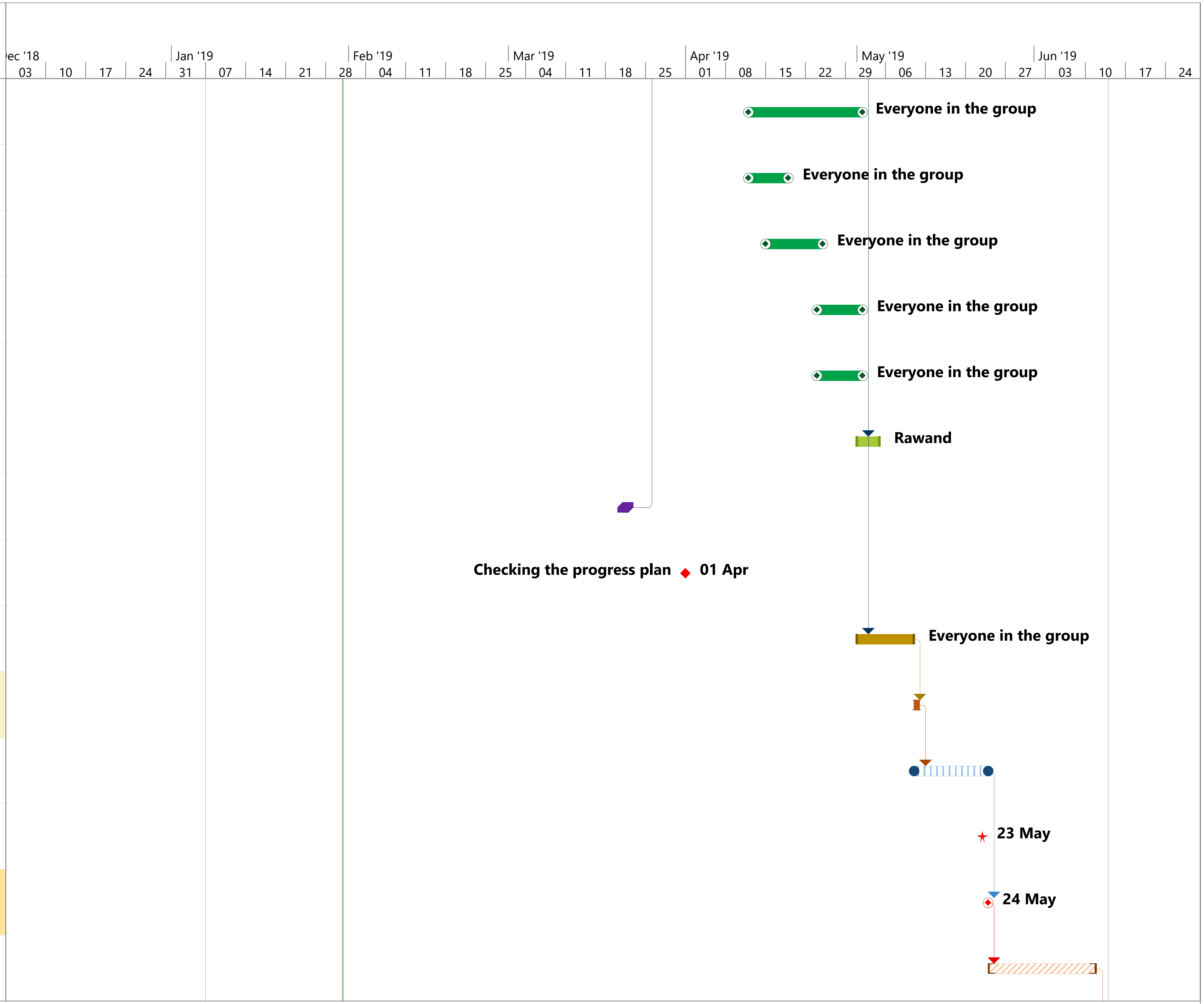
ID	Ta Mc	Task Name	Duration	Start	Finish
15		Building cost	46 days	Fri 08.02.19	Fri 12.04.19
16		Detail 3D digital model and production of some shop drawings	46 days	Fri 08.02.19	Fri 12.04.19
17		**Formal meeting**			
18		Formal meeting no. 1 (internal supervisor)	1 day	Mon 04.02.19	Mon 04.02.19
19		Formal meeting no. 2 (internal supervisor)	1 day	Wed 20.02.19	Wed 20.02.19
20		Formal meeting no. 3 (internal supervisor)	1 day	Mon 11.03.19	Mon 11.03.19
21		Formal meeting no. 4 (internal supervisor)	1 day	Wed 27.03.19	Wed 27.03.19
22		Formal meeting no. 5 (internal supervisor)	1 day	Mon 08.04.19	Mon 08.04.19
23		Formal meeting no. 6 (internal supervisor)	1 day	Mon 29.04.19	Mon 29.04.19
24		**Completion of report**	**14 days**	**Fri 12.04.19**	**Wed 01.05.19**
25		Preface	2 days	Fri 12.04.19	Mon 15.04.19
26		Summary	4 days	Sun 28.04.19	Wed 01.05.19
27		Introduction	2 days	Tue 16.04.19	Wed 17.04.19
28		Singificance of the work	6 days	Fri 12.04.19	Fri 19.04.19



Project: Masteroppgave fremdr
Date: Thu 31.01.19

Task		Inactive Task		Manual Summary Rollup		External Milestone		Progress	
Split		Inactive Milestone		Manual Summary		Deadline		Manual Progress	
Milestone		Inactive Summary		Start-only		Baseline		Slippage	
Summary		Manual Task		Finish-only		Baseline Milestone			
Project Summary		Duration-only		External Tasks		Baseline Summary			

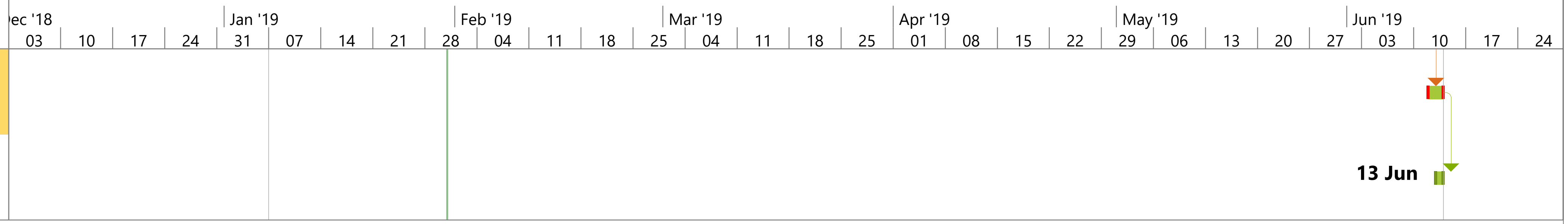
ID	Task Mode	Task Name	Duration	Start	Finish
29		Methods	14 days	Fri 12.04.19	Wed 01.05.19
30		Results	5 days	Fri 12.04.19	Thu 18.04.19
31		Discussion	8 days	Mon 15.04.19	Wed 24.04.19
32		Conclusion	6 days	Wed 24.04.19	Wed 01.05.19
33		Suggestions for further work	6 days	Wed 24.04.19	Wed 01.05.19
34		A3 post	4 days	Wed 01.05.19	Sat 04.05.19
35		Formal meeting (external supervisor)	1 day	Thu 21.03.19	Thu 21.03.19
36		Checking the progress plan	0 days	Mon 01.04.19	Mon 01.04.19
37		Review of the report + adjustment	8 days	Wed 01.05.19	Fri 10.05.19
38		Draft (Report Submission)	1 day	Sat 11.05.19	Sat 11.05.19
39		Correction of the report	10 days	Sat 11.05.19	Thu 23.05.19
40		Critical line	0 days	Thu 23.05.19	Thu 23.05.19
41		Submission of report	0 days	Fri 24.05.19	Fri 24.05.19
42		Preparation for presentation	13 days	Fri 24.05.19	Tue 11.06.19



Project: Masteroppgave fremdr
Date: Thu 31.01.19

Task		Inactive Task		Manual Summary Rollup		External Milestone		Progress	
Split		Inactive Milestone		Manual Summary		Deadline		Manual Progress	
Milestone		Inactive Summary		Start-only		Baseline		Slippage	
Summary		Manual Task		Finish-only		Baseline Milestone			
Project Summary		Duration-only		External Tasks		Baseline Summary			

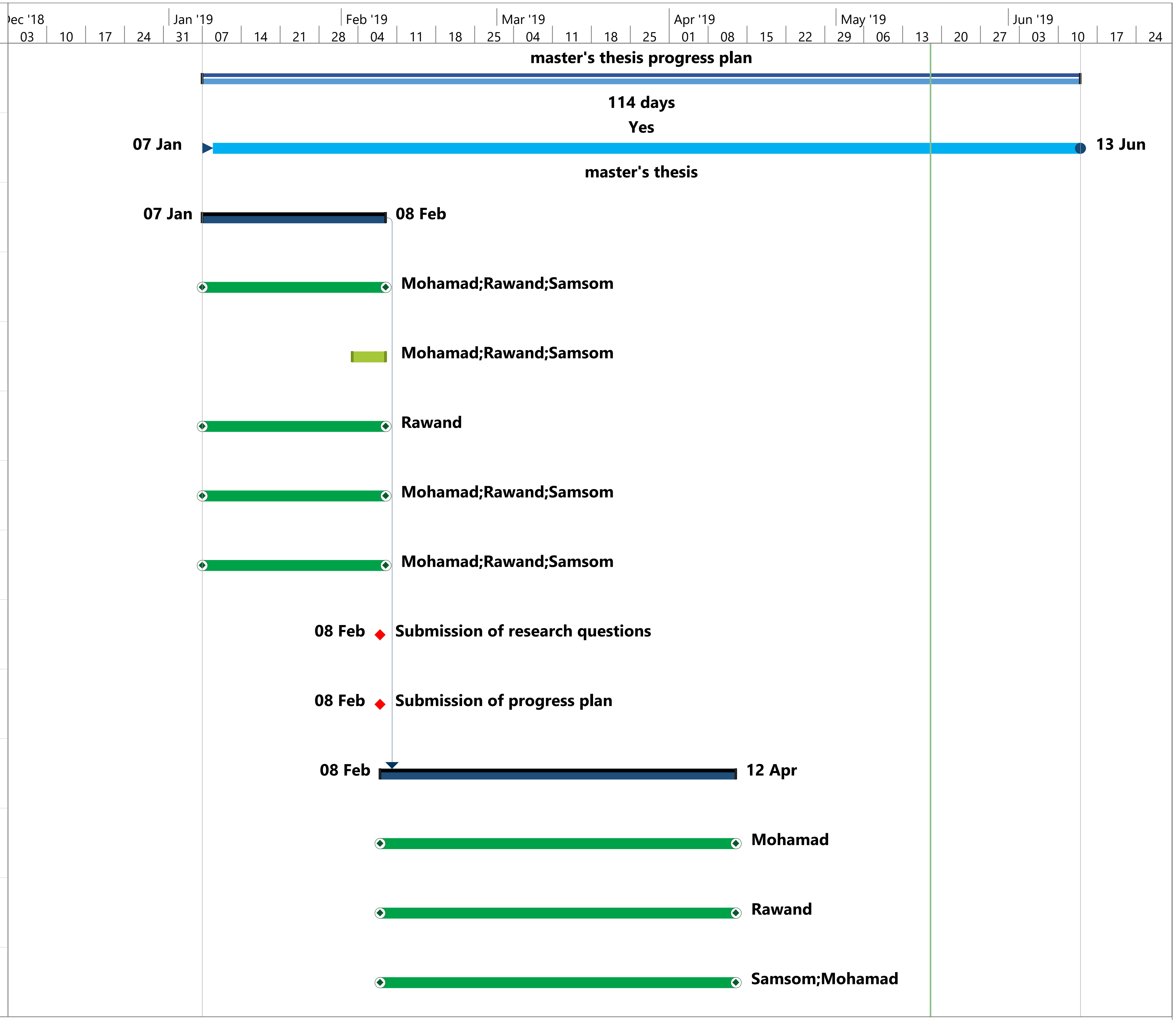
ID	Ta Mc	Task Name	Duration	Start	Finish
43		Presentation of the master thesis	2 days	Wed 12.06.19	Thu 13.06.19
44		Submission of presentation material	1 day	Thu 13.06.19	Thu 13.06.19



Project: Masteroppgave fremdr
Date: Thu 31.01.19

Task		Inactive Task		Manual Summary Rollup		External Milestone		Progress	
Split		Inactive Milestone		Manual Summary		Deadline		Manual Progress	
Milestone		Inactive Summary		Start-only		Baseline		Slippage	
Summary		Manual Task		Finish-only		Baseline Milestone			
Project Summary		Duration-only		External Tasks		Baseline Summary			

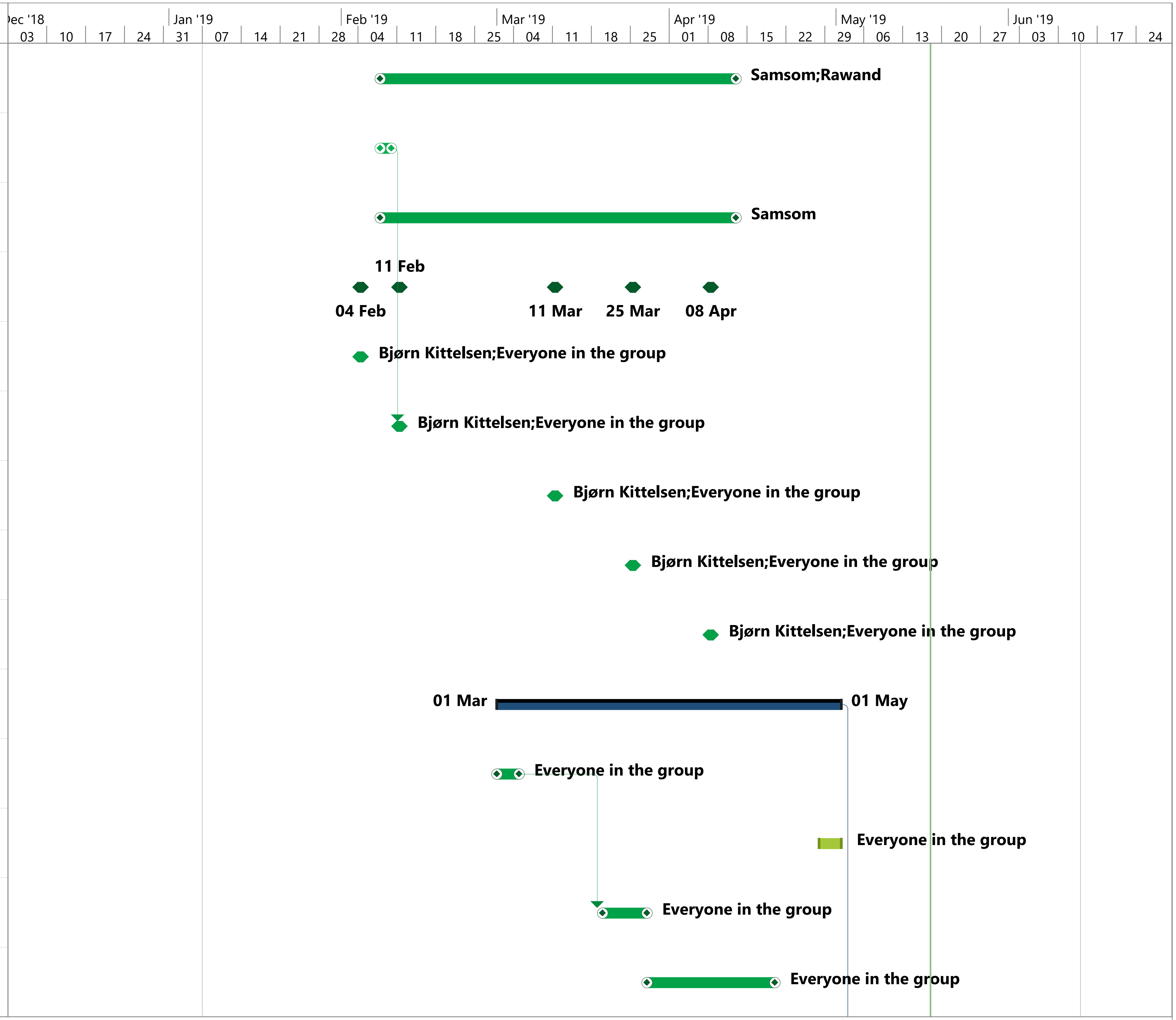
ID	Task Mode	Task Name	Duration	Start	Finish
1		**Master's thesis-Spring 2019**	**114 days**	**Mon 07.01.19**	**Thu 13.06.19**
2		master's thesis	114 days	Mon 07.01.19	Thu 13.06.19
3		**literature phase**	**25 days**	**Mon 07.01.19**	**Fri 08.02.19**
4		Read old master thesis	25 days	Mon 07.01.19	Fri 08.02.19
5		Eurocodes	6 days	Sun 03.02.19	Fri 08.02.19
6		Preparation of progress plan	25 days	Mon 07.01.19	Fri 08.02.19
7		Research topics	25 days	Mon 07.01.19	Fri 08.02.19
8		Evaluation of preliminary project and connection to master thesis	25 days	Mon 07.01.19	Fri 08.02.19
9		Submission of research questions	0 days	Fri 08.02.19	Fri 08.02.19
10		Submission of progress plan	0 days	Fri 08.02.19	Fri 08.02.19
11		**Theory writing**	**46 days**	**Fri 08.02.19**	**Fri 12.04.19**
12		Structural design	46 days	Fri 08.02.19	Fri 12.04.19
13		Life cycle assessment (LCA)	46 days	Fri 08.02.19	Fri 12.04.19
14		Connection design	46 days	Fri 08.02.19	Fri 12.04.19



Project: Masteroppgave fremdr
Date: Sat 18.05.19

Task	Inactive Task	Manual Summary Rollup	External Milestone	Progress
Split	Inactive Milestone	Manual Summary	Deadline	Manual Progress
Milestone	Inactive Summary	Start-only	Baseline	Slippage
Summary	Manual Task	Finish-only	Baseline Milestone	
Project Summary	Duration-only	External Tasks	Baseline Summary	

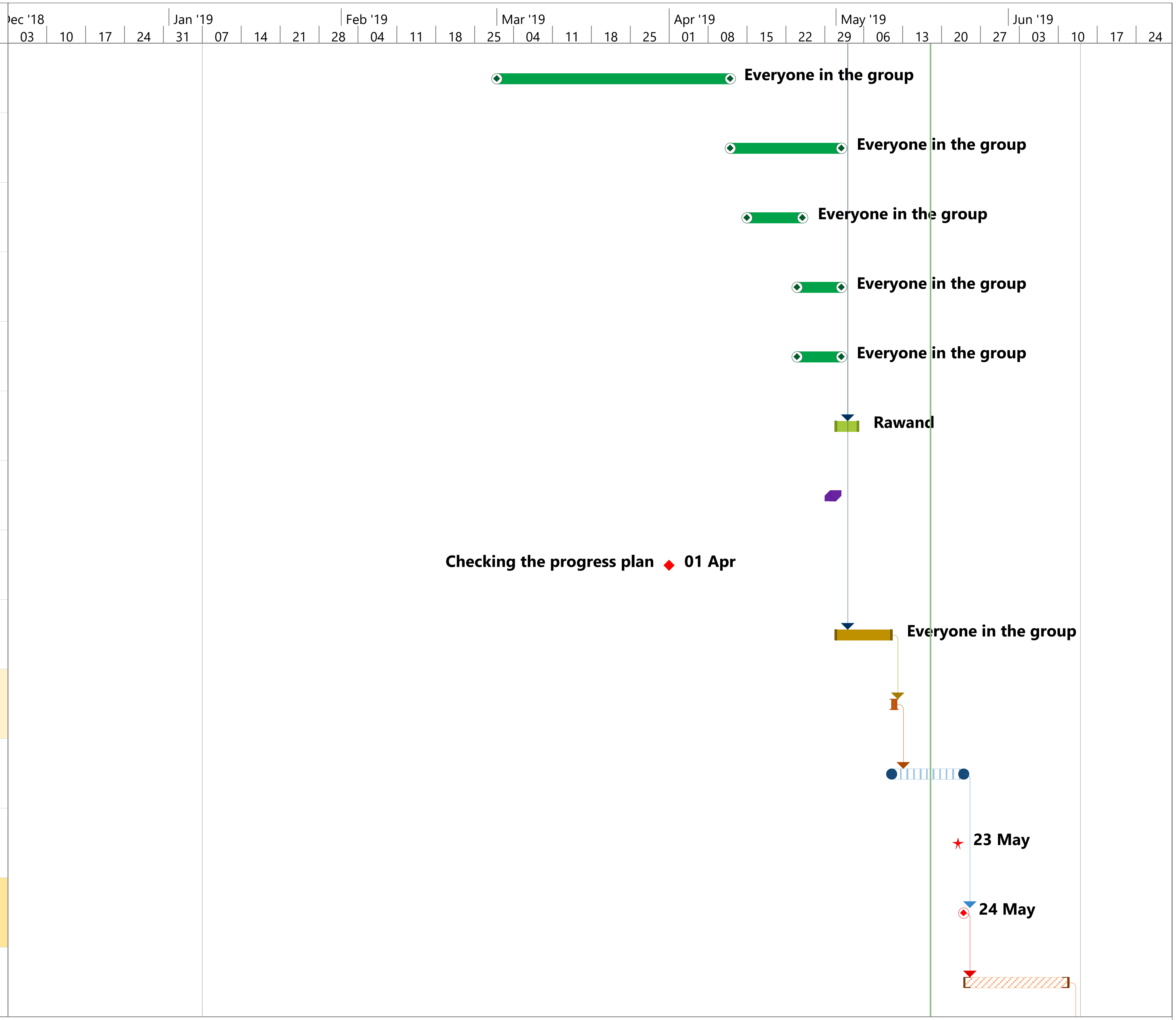
ID	Task Mode	Task Name	Duration	Start	Finish
15		Building cost	46 days	Fri 08.02.19	Fri 12.04.19
16		Contents	2 days	Fri 08.02.19	Sat 09.02.19
17		Detail 3D digital model and production of some shop drawings	46 days	Fri 08.02.19	Fri 12.04.19
18		**Formal meeting**			
19		Formal meeting no. 1 (internal supervisor)	1 day	Mon 04.02.19	Mon 04.02.19
20		Formal meeting no. 2 (internal supervisor)	1 day	Mon 11.02.19	Mon 11.02.19
21		Formal meeting no. 3 (internal supervisor)	1 day	Mon 11.03.19	Mon 11.03.19
22		Formal meeting no. 4 (internal supervisor)	1 day	Mon 25.03.19	Mon 25.03.19
23		Formal meeting no. 5 (internal supervisor)	1 day	Mon 08.04.19	Mon 08.04.19
24		**Completion of report**	**44 days**	**Fri 01.03.19**	**Wed 01.05.19**
25		Preface	2 days	Fri 01.03.19	Mon 04.03.19
26		Summary	4 days	Sun 28.04.19	Wed 01.05.19
27		Introduction	6 days	Wed 20.03.19	Wed 27.03.19
28		Singificance of the work	17 days	Thu 28.03.19	Fri 19.04.19



Project: Masteroppgave fremdr
Date: Sat 18.05.19

Task	Inactive Task	Manual Summary Rollup	External Milestone	Progress
Split	Inactive Milestone	Manual Summary	Deadline	Manual Progress
Milestone	Inactive Summary	Start-only	Baseline	Slippage
Summary	Manual Task	Finish-only	Baseline Milestone	
Project Summary	Duration-only	External Tasks	Baseline Summary	

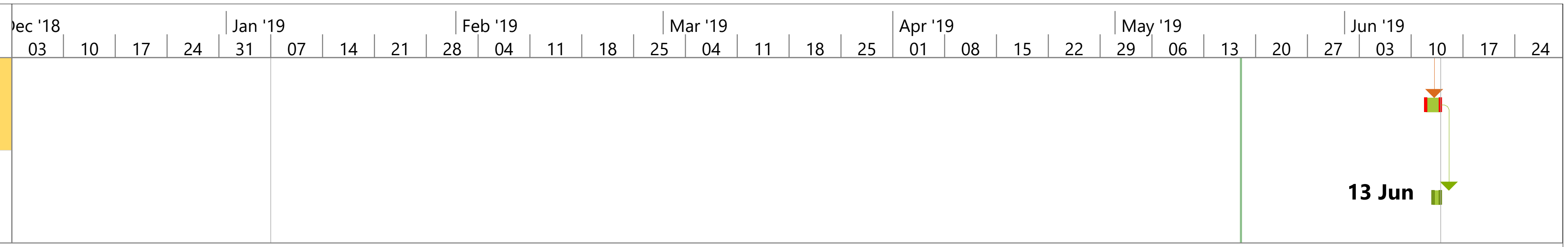
ID	Task Mode	Task Name	Duration	Start	Finish
29		Methods	30 days	Fri 01.03.19	Thu 11.04.19
30		Results	14 days	Fri 12.04.19	Wed 01.05.19
31		Discussion	8 days	Mon 15.04.19	Wed 24.04.19
32		Conclusion	6 days	Wed 24.04.19	Wed 01.05.19
33		Suggestions for further work	6 days	Wed 24.04.19	Wed 01.05.19
34		A3 post	4 days	Wed 01.05.19	Sat 04.05.19
35		Formal meeting (external supervisor)	1 day	Tue 30.04.19	Tue 30.04.19
36		Checking the progress plan	0 days	Mon 01.04.19	Mon 01.04.19
37		Review of the report + adjustment	8 days	Wed 01.05.19	Fri 10.05.19
38		Draft (Report Submission)	1 day	Sat 11.05.19	Sat 11.05.19
39		Correction of the report	10 days	Sat 11.05.19	Thu 23.05.19
40		Critical line	0 days	Thu 23.05.19	Thu 23.05.19
41		Submission of report	0 days	Fri 24.05.19	Fri 24.05.19
42		Preparation for presentation	13 days	Fri 24.05.19	Tue 11.06.19



Project: Masteroppgave fremdr
Date: Sat 18.05.19

Task		Inactive Task		Manual Summary Rollup		External Milestone		Progress	
Split		Inactive Milestone		Manual Summary		Deadline		Manual Progress	
Milestone	◆	Inactive Summary		Start-only		Baseline		Slippage	
Summary		Manual Task		Finish-only		Baseline Milestone			
Project Summary		Duration-only		External Tasks		Baseline Summary			

ID	Task Mode	Task Name	Duration	Start	Finish
43		Presentation of the master thesis	2 days	Wed 12.06.19	Thu 13.06.19
44		Submission of presentation material	1 day	Thu 13.06.19	Thu 13.06.19



Project: Masteroppgave fremdr
Date: Sat 18.05.19

Task		Inactive Task		Manual Summary Rollup		External Milestone		Progress	
Split		Inactive Milestone		Manual Summary		Deadline		Manual Progress	
Milestone		Inactive Summary		Start-only		Baseline		Slippage	
Summary		Manual Task		Finish-only		Baseline Milestone			
Project Summary		Duration-only		External Tasks		Baseline Summary			

Time sheet for completion of the Master's thesis

ProjectTitle: Sustainability assessment of an apartment building with reinforced concrete or Cross-laminated timber (CLT)

Project owner	Rambøll	Max hour each person	810	Expected hour for everyone in the group	2430	Progress	110 %
Participants:	Samsom Asmerom Habtemichael	Mohamad Omar Aljoulbek	Rawand Fatah Mohammed	Everyone			
Total time	828	920	913	2661			
% Done	102,22 %	113,58 %	112,72 %				

Samsom:
Job done in week 2:
1)literary phase
2)Group meeting on skype and team
3)Evaluation of preliminary project and connection to master thesis

Mohammad:
Job done in week 2:
1)literary phase
2)Group meeting on skype and team
3)Evaluation of preliminary project and connection to master thesis

Rawand fatah:
Job done in week 2:
1)literary phase
2)Group meeting on skype and team
3)Evaluation of preliminary project and connection to master thesis

Week 2			
07.01.2019	5	5	5
08.01.2019	2	4	8
09.01.2019	3	6	10
10.01.2019	2	2	2
11.01.2019	4	7	11
12.01.2019	10	8	0
13.01.2019	7	9	0

Samsom:
Job done in week 3:
1)Group meeting on skype and team
2)literary phase
3)Evaluation of preliminary project and connection to master thesis

Mohamad:
Job done in week 3:
1)Group meeting on skype and team
2)literary phase
3)Evaluation of preliminary project and connection to master thesis

Rawand fatah:
Job done in week 3:
1)Creating progress plan
2) literary phase
3)Group meeting on skype and team
4)Evaluation of preliminary project and connection to master thesis

Week 3			
14.01.2019	2	7	11
15.01.2019	3	8	8
16.01.2019	4	6	6
17.01.2019	2	8	9
18.01.2019	4	7	0
19.01.2019	8	6	6
20.01.2019	9	6	2

Samsom:
Job done in week 4:
1)Group meeting on skype and team
2)literary phase
3)Problem statement
4)Evaluation of preliminary project and connection to master thesis

Mohamad:
Job done in week 4:
1)Group meeting on skype and team
2)literary phase
3)Evaluation of preliminary project and connection to master thesis
4)

Rawand fatah:
Job done in week 4
1)creating meeting call template
2)creating meeting minutes template
3)Group meeting on skype and team
4)literary phase
5)Evaluation of preliminary project and connection to master thesis

Week 4			
21.01.2019	2	5	9
22.01.2019	3	8	8
23.01.2019	8	6	8
24.01.2019	6	7	2
25.01.2019	4	8	7
26.01.2019	5	4	2
27.01.2019	10	8	0

Samsom:
Job done in week 5:
1)Problem statement
2)Theory writing
3)Skype meeting
4)Evaluation of preliminary project and connection to master thesis

Mohamad:
Job done in week 5:
1)Research topics
2)Evaluation of preliminary project and connection to master thesis
3)Skype meeting

Rawand fatah:
Job done in week 5:
1)creating meeting call template
2)creating meeting minutes template
3)Skype meeting
4)Evaluation of preliminary project and connection to master thesis

Week 5			
28.01.2019	2	6	10
29.01.2019	7	11	4
30.01.2019	5	5	3
31.01.2019	4	4	6
01.02.2019	5	8	8
02.02.2019	9	10	1
03.02.2019	5	5	0

Samsom:
Job done in week 6:
1)Theory writing, construction cost, low carbon
2)Skype meeting,formall meeting and minutes of meeting
3)

Mohamad:
Job done in week 6:
1)have worked on theory and wrote about timber
2)Skype meeting,formall meeting and minutes of meeting

Rawand fatah:
Job done in week 6:
1)
2)Skype meeting,formall meeting and minutes of meeting
3)Life cycle assessment (LCA) theory

Week 6			
04.02.2019	3	9	4
05.02.2019	5	8	9
06.02.2019	8	8	8
07.02.2019	4	9	9
08.02.2019	6	9	9
09.02.2019	7	6	0
10.02.2019	8	4	4

Samsom:
Job done in week 7:
1)Theory writing.. Low carbon, Introduction, method
2)formall meeting and minutes of meeting
4)

Mohamad:
Job done in week 7:
1)have worked on theory and wrote about timber
2)formall meeting and minutes of meeting
3)

Rawand fatah:
Job done in week 7:
1)Life cycle assessment (LCA) theory
2)formall meeting and minutes of meeting

Week 7			
11.02.2019	5	10	3
12.02.2019	3	9	8
13.02.2019	8	8	7
14.02.2019	5	8	7
15.02.2019	4	9	4
16.02.2019	6	5	8
17.02.2019	4	4	6

Samsom:
Job done in week 8:
1) Thory writing .. Stability,
2)Skype meeting
3)
4)

Mohamad::
Job done in week 8:
1)have worked on theory and wrote about timber
2)Skype meeting

Samsom:
Job done in week 8:
1) Thory writing .. Stability,
2)Skype meeting
3)
4)

Mohamad::
Job done in week 8:
1)have worked on theory and wrote about timber
2)Skype meeting

Rawand fatah:
Job done in week 8:
1)Life cycle assessment (LCA) theory
2)Skype meeting
3)
4)

Week 8			
18.02.2019	3	9	2
19.02.2019	8	9	5
20.02.2019	5	9	6
21.02.2019	4	9	9
22.02.2019	5	8	8
23.02.2019	9	5	8
24.02.2019	4	5	3

Samsom:
Job done in week 9:
1)Theory wring... Stability, loads
2)Skype meeting
3)
4)

Mohamad::
Job done in week 9:
1)have worked on theory and wrote about timber
2)List of Abbreviations
3)Skype meeting

Rawand fatah:
Job done in week 9:
1)Life cycle assessment (LCA) theory
2)Completion of report
3)Skype meeting
4)

Week 9			
25.02.2019	4	8	10
26.02.2019	3	9	9
27.02.2019	3	9	8
28.02.2019	4	7	8
01.03.2019	5	8	8
02.03.2019	5	5	2
03.03.2019	6	4	4

Samsom:
Job done in week 10:
1)Calcualtion..loads, basic assumptions, modeling
2)Skype meeting
3)Completion of report

Mohamad::
Job done in week 10:
1)have worked on theory and wrote about concrete (foundation)
2)Skype meeting
3)Completion of report

Rawand fatah:
Job done in week 10:
1)Completion of report
2)Skype meeting
3)Life cycle assessment (LCA) theory
4)

Week 10			
04.03.2019	5	7	3
05.03.2019	4	6	10
06.03.2019	9	8	8
07.03.2019	4	9	6
08.03.2019	5	5	9
09.03.2019	6	3	2
10.03.2019	4	3	6

Rawand fatah:
Job done in week 11:
1)load calculations
2)Structural design in FEM-desing,formall meeting and minutes of meeting
3)3D modell in Revit
4)Completion of report

Mohamad::
Job done in week 11:
1)have worked on theory and wrote about concrete(walls)
2)formall meeting and minutes of meeting
3) List of Abbreviations
4)Completion of report

Rawand fatah:
Job done in week 11:
1) Life cycle assessment (LCA) theory
2)formall meeting and minutes of meeting
3)Completion of report
4)

Week 11			
11.03.2019	5	8	3
12.03.2019	6	7	8
13.03.2019	7	5	8
14.03.2019	3	5	9
15.03.2019	5	6	10
16.03.2019	4	4	3
17.03.2019	7	3	0

Samsom Asmerom Habtemichael:
Job done in week 12:
1)Structural design in FEM-desing
2)Skype meeting
3) 3D modell in Revit
4)Completion of report

Mohamad::
Job done in week 12:
1)have worked on theory and wrote about (foundation,walls)
2)Skype meeting
3)Completion of report

Rawand fatah:
Job done in week 12:
1)Life cycle assessment (LCA) theory
2)Skype meeting
3)Completion of report

Week 12			
18.03.2019	3	7	9
19.03.2019	9	6	2
20.03.2019	4	7	6
21.03.2019	2	8	0
22.03.2019	8	5	9
23.03.2019	4	4	9
24.03.2019	5	3	8

Rawand fatah:
Job done in week 13:
1)have worked on theory
2)formall meeting and minutes of meeting
3)Completion of report

Mohamad::
Job done in week 13:
1)have worked on theory and wrote about (steel)
2)formall meeting and minutes of meeting
3)Completion of report

Rawand fatah:
Job done in week 13:
1)have worked on theory.
2)formall meeting and minutes of meeting
3)Completion of report
4)Life cycle assessment (LCA) theory

Week 13			
25.03.2019	1	7	10
26.03.2019	6	6	5
27.03.2019	3	4	8
28.03.2019	8	8	4
29.03.2019	9	4	9
30.03.2019	8	3	2
31.03.2019	8	3	6

Rawand fatah:
Job done in week 14:
1)have worked on theory
2)Skype meeting
3)Completion of report
4)

Mohamad::
Job done in week 14:
1)have worked on theory and wrote about steel
2)Skype meeting
3)Completion of report

Rawand fatah:
Job done in week 14:
1)have worked on theory
2)Skype meeting
3)Completion of report
4)Life cycle assessment (LCA) theory

Week 14			
01.04.2019	2	3	6
02.04.2019	5	3	6
03.04.2019	9	4	3
04.04.2019	8	6	8
05.04.2019	10	7	9
06.04.2019	7	4	8
07.04.2019	5	4	0

Rawand fatah:
Job done in week 15:
1)have worked on theory
2)formall meeting and minutes of meeting
3)Completion of report
4)

Mohamad::
Job done in week 15:
1)have worked on theory and wrote about connections
2)formall meeting and minutes of meeting
3)introduction
4)Completion of report

Rawand fatah:
Job done in week 15:
1)have worked on theoriy
2)formall meeting and minutes of meeting
3)Completion of report
4)Life cycle assessment (LCA) theory

Rawand fatah:
Job done in week 15:
1)have worked on theoriy
2)formall meeting and minutes of meeting
3)Completion of report
4)Life cycle assessment (LCA) theory

Week 15			
08.04.2019	4	9	10
09.04.2019	9	7	8
10.04.2019	9	8	8
11.04.2019	6	4	9
12.04.2019	4	7	7
13.04.2019	5	5	5
14.04.2019	8	3	0

Rawand fatah:
Job done in week 16:
1)have worked on results.
2)Skype meeting
3)Completion of report
4)

Mohamad:
Job done in week 16:
1)have worked on theory and wrote about connections
2)Skype meeting
3) List of Abbreviations
4)Completion of report

Rawand fatah:
Job done in week 16:
1)have worked on theory
2)Skype meeting
3)Start with LCA result
4)Start with discussion
5)Completion of report

Week 16			
15.04.2019	1	5	9
16.04.2019	6	8	11
17.04.2019	8	4	8
18.04.2019	5	9	9
19.04.2019	4	7	9
20.04.2019	9	5	0
21.04.2019	6	5	0

Rawand fatah:
Job done in week 17:
1)have worked on results
2)Completion of report
3)
4)

Mohamad::
Job done in week 17:
1)have worked on theory and wrote about case and material
2)have worked on Autocad and drawn illustartions
3)Completion of report

Rawand fatah:
Job done in week 17:
1)have worked on theory
2)Completion of report
3)LCA result
4)Discussion

Week 17			
22.04.2019	3	5	6
23.04.2019	7	4	6
24.04.2019	9	4	4
25.04.2019	2	5	6
26.04.2019	6	6	7
27.04.2019	8	4	4
28.04.2019	9	4	1
	3		1

Rawand fatah:
Job done in week 18:
1)have worked on discussion
2)formall meeting and minutes of meeting
3)Skype meeting
4)Suggestions for further work

Mohamad:
Job done in week 18:
1)have worked on Autocad and drawn illustations
2)formall meeting and minutes of meeting
3)Skype meeting
4)Preface
5)results

Rawand fatah:
Job done in week 18:
1)have worked on theory
2)formall meeting and minutes of meeting
3)Skype meeting
4)Writing minutes from the meeting
5)Finishing result from LCA

Week 18			
29.04.2019	5	3	10
30.04.2019	4	5	1
01.05.2019	3	6	3
02.05.2019	8	4	8
03.05.2019	6	4	8
04.05.2019	7	3	7
05.05.2019	8	4	9

Rawand fatah:
Job done in week 19:
1)have worked on discussion
2)Review of the report + adjustment
3)
4)

Mohamad:
Job done in week 19:
1)have worked on Autocad and drawn illustations
2)have re-corrected the text
3)discussion
4) List of Abbreviations

Rawand fatah:
Job done in week 19:
1)have worked on theory
2)Correction of the report
3)Review of the report + adjustment
4)Working on LCA result
5)Working on discussion

Week 19			
06.05.2019	4	6	10
07.05.2019	8	5	6
08.05.2019	0	7	2
09.05.2019	8	8	8
10.05.2019	4	8	7
11.05.2019	2	3	8
12.05.2019	9	3	12

Rawand fatah:
Job done in week 20:
1)have worked on discussion
2)Correction of the report
3)
4)Skype meeting

Mohamad:
Job done in week 20:
1)have re-corrected the text
2)conclusion
3)Checking overall
4)Skype meeting
5)Correction of the report

Rawand fatah:
Job done in week 20:
1)have worked on theory
2)Correction of the report
4)Skype meeting
5)Finishing discussion
6)Finishing LCA result

Week 20			
13.05.2019	0	7	11
14.05.2019	9	8	7
15.05.2019	2	8	9
16.05.2019	6	7	9
17.05.2019	3	8	7
18.05.2019	7	5	2
19.05.2019	2	6	3

Rawand fatah:
Job done in week 21:
1)have worked on conclusion
2)Checking overall
3)
4)

Mohamad:
Job done in week 21:
1)have worked on theory
2)Checking overall
3)delivery
4)

Rawand fatah:
Job done in week 21:
1)have worked on theory
2)Create A3 post
3)Finishing attachment
4)Checking overall
5)writing method part in the report

Week 21			
20.05.2019	7	8	7
21.05.2019	10	9	8
22.05.2019	8	5	5
23.05.2019	5	7	4
24.05.2019	2	1	2
25.05.2019	2	2	0
26.05.2019	3	0	5

From 24.05, the time assumed for the preparation of presentation

Rawand fatah:
Job done in week 22:
1)have worked on theory
2)Planning to create presentation.
3)Review the report.
4)Discuss with the group the entire report. Ensure that everyone in the group has a good understanding of the entire report.

Mohamad:
Job done in week 22:
1)have worked on theory
2)Planning to create presentation.
3)Review the report.
4)Discuss with the group the entire report. Ensure that everyone in the group has a good understanding of the entire report.

Rawand fatah:
Job done in week 22:
1)have worked on theory
2)Review the report.
3)Planning to create presentation.
4)Discuss with the group the entire report. Ensure that everyone in the group has a good understanding of the entire report.

Rawand fatah:
Job done in week 22:
1)have worked on theory
2)Planning to create presentation.
3)Review the report.
4)Discuss with the group the entire report. Ensure that everyone in the group has a good understanding of the entire report.

Mohamad:
Job done in week 22:
1)have worked on theory
2)Planning to create presentation.
3)Review the report.
4)Discuss with the group the entire report. Ensure that everyone in the group has a good understanding of the entire report.

Week 22			
27.05.2019	3	3	3
28.05.2019	4	4	4
29.05.2019	0	0	0
30.05.2019	0	0	0
31.05.2019	3	3	3
01.06.2019	3	3	3
02.06.2019	2	2	2

Rawand fatah:
Job done in week 22:
1)have worked on theory
2)Review the report.
3)Planning to create presentation.
4)Discuss with the group the entire report. Ensure that everyone in the group has a good understanding of the entire report.

Rawand fatah:
Job done in week 23:
1)have worked on theory
2)Production of presentation. Utilization of 3d software plus powerpoint for a clear presentation.
3)own exercise for presentation.
4)Discuss with the group the entire report. Ensure that everyone in the group has a good understanding of the entire report.

Mohamad:
Job done in week 23:
1)have worked on theory
2)Production of presentation. Utilization of 3d software plus powerpoint for a clear presentation.
3)own exercise for presentation.
4)Discuss with the group the entire report. Ensure that everyone in the group has a good understanding of the entire report.

Week 23			
03.06.2019	4	4	4
04.06.2019	4	4	4
05.06.2019	10	10	10
06.06.2019	6	6	6
07.06.2019	5	5	5
08.06.2019	5	5	5
09.06.2019	4	4	4

Rawand fatah:
Job done in week 23:
1)have worked on theory
2)Production of presentation. Utilization of 3d software plus powerpoint for a clear presentation.
3)own exercise for presentation.
4)Discuss with the group the entire report. Ensure that everyone in the group has a good understanding of the entire report.

Rawand fatah:
Job done in week 24:
1)have worked on theori.
2)own exercise for presentation.
3)group meeting and practice of the presentation before official and final presentation.
4)Discuss with the group the entire report. Ensure that everyone in the group has a good understanding of the entire report.

Mohamad:
Job done in week 24:
1)have worked on theori.
2)own exercise for presentation.
3)group meeting and practice of the presentation before official and final presentation.
4)Discuss with the group the entire report. Ensure that everyone in the group has a good understanding of the entire report.

Week 24			
10.06.2019	12	12	12
11.06.2019	6	6	6
12.06.2019	2	2	2
13.06.2019	0	0	0

Rawand fatah:
Job done in week 24:
1)have worked on theori.
2)own exercise for presentation.
3)group meeting and practice of the presentation before official and final presentation.
4)Discuss with the group the entire report. Ensure that everyone in the group has a good understanding of the entire report.

APPENDIX C

INVITATION TO PROJECT MEETING NO 1

INVITATION TO PROJECT MEETING NO 2

INVITATION TO PROJECT MEETING NO 3

INVITATION TO PROJECT MEETING NO 4

INVITATION TO PROJECT MEETING NO 5

MINUTES OF MEETING NO 1

MINUTES OF MEETING NO 2

MINUTES OF MEETING NO 3

MINUTES OF MEETING NO 4

MINUTES OF MEETING NO 5

MINUTES OF MEETING NO 1 (external supervisor)

UNIVERSITY OF AGDER
Faculty of Technology
Master's thesis

Title: Development of a methodology for a specific sustainable solution for an apartment block.

Grimstad, 04.02.19

To: Bjørn Kittelsen, Mohamad Omar Aljoulbek, Samsom Asmerom Habtemichael og Rawand Fatah Mohammed

MEETING INVITATION NO 1

Place: D3100 (Jon Lilletunsvei 9, Grimstad)
Time and duration: 04.02.2019 kl. 09.00-10.00

Meeting referent: *Samsom Asmerom Habtemichael*

Case 1/2019 Introduction cases

1. Election of chairman of the meeting and referent.
2. Approval of meeting invitation.
3. Approval of agenda.
4. Report status.
5. Possible cases.

Case 2/2019 Status / information cases

1. Progress plan.
2. Project title.
3. Problem statement.
4. Research question.
5. Group agreement.
6. Questions.

Case 3/2019 Decision case 1 – Progress plan
Revision of progress plan

Case 4/2019 Decision case 2 - Project title
Evaluation of project title

Case 5/2019 Decision case 3- Problem statement
Evaluation of problem statement

Case 6/2019 Decision case 4- Research question
Evaluation of research question

Case 7/2019 Decision case 5 – Group agreement
Evaluation of group agreement

Case 8/2019 Election of chairman of the meeting and referent to the next meeting
Suggestion: Mohamad Omar Aljoulbek as chairman and Rawand Fatah Mohammed as referent.

Case 9/2019 Questions
Skype meeting

Case 10/2019 Possible cases

Rawand Fatah Mohammad
The Chairman

Attachments:
1. Progress plan
2. Contents contain (Problem statement, Research question, Project title)
3. Group Agreement

NB: Each attachment must be clearly marked with the attachment number, date and signature.

UNIVERSITY OF AGDER
Faculty of Technology
Master's thesis

Title: Sustainability assessment of an apartment building with reinforced concrete or Cross-laminated timber (CLT)

Grimstad, 11.02.19

To: Bjørn Kittelsen, Mohamad Omar Aljoulbek, Samsom Asmerom Habtemichael og Rawand Fatah Mohammed

MEETING INVITATION NO 2

Place: D3100 (Jon Lilletunsvei 9, Grimstad)
Time and duration: 11.02.2019 kl. 09.00-10.00

Meeting referent: *Rawand Fatah Mohammed*

Case 11/2019 Introduction cases

1. Election of chairman of the meeting and referent.
2. Approval of meeting invitation.
3. Approval of agenda.
4. Report status.
5. Approval of minutes of the previous meeting.
6. Possible cases.

Case 12/2019 Status / information cases

1. Progress plan.
2. Project title.
3. Problem statement.
4. Research question.
5. Review of theory.
6. Contents.
7. Questions.

Case 13/2019 Decision case 1 – Progress plan
Revision of progress plan

Case 14/2019 Decision case 2 - Project title
Evaluation of project title
Suggestion is (Sustainability assessment of an apartment building with reinforced concrete or Cross-laminated timber (CLT))

Case 15/2019 Decision case 3- Problem statement
Evaluation of problem statement

Case 16/2019 Decision case 4- Research question
Evaluation of research question

Case 17/2019 Review of theory
Introduction of timber

Case 18/2019 Contents
Evaluation of contents

Case 19/2019 Election of chairman of the meeting and referent to the next meeting
Suggestion: Samsom Asmerom Habtemichael as chairman and Mohamad Omar Aljoulbek as referent.

Case 20/2019 Questions
Evaluation of timber books
Evaluation of time sheet

Case 21/2019 Possible cases

Mohamad Omar Aljoulbek
The Chairman

Attachments:
1. Progress plan
2. Project template contains (Theory, Project title)
3. Problem statement, Research question
4. Minutes of the previous meeting
5. Time sheet

NB: Each attachment must be clearly marked with the attachment number, date and signature.

UNIVERSITY OF AGDER
Faculty of Technology
Master's thesis

Title: Sustainability assessment of an apartment building containing reinforced concrete or cross-laminated timber (CLT)

Grimstad, 11.03.19

To: Bjørn Kittelsen, Mohamad Omar Aljoulbek, Samsom Asmerom Habtemichael og Rawand Fatah Mohammed

MEETING INVITATION NO 3

Place: D3100 (Jon Lilletunsvei 9, Grimstad)
Time and duration: 11.03.2019 kl. 09.00-10.00

Meeting referent: *Mohamad Omar Aljoulbek*

Case 22/2019 Introduction cases

1. Election of chairman of the meeting and referent.
2. Approval of meeting invitation.
3. Approval of agenda.
4. Report status.
5. Approval of minutes of the previous meeting.
6. Possible cases.

Case 23/2019 Status / information cases

1. Progress plan.
2. Project title.
3. Problem statement.
4. Research question.
5. Review of theory.
6. Contents.
7. Questions.

Case 24/2019 Decision case 1 – Progress plan
Revision of progress plan

Case 25/2019 Decision case 2 - Project title
Evaluation of project title
Suggestion is (Sustainability assessment of an apartment building containing reinforced concrete or cross-laminated timber (CLT))

Case 26/2019 Decision case 3- Problem statement
Evaluation of problem statement

Case 27/2019 Decision case 4- Research question
Evaluation of research question

Case 28/2019 Review of theory
Design of glued laminated timber and cross-laminated timber
Low carbon concrete
Stability
Construction cost and LCA
Loads

Case 29/2019 Contents
Evaluation of contents

Case 30/2019 Election of chairman of the meeting and referent to the next meeting
Suggestion: Rawand Fatah Mohammed as chairman and Samsom Asmerom Habtemichael as referent.

Case 31/2019 Questions
Evaluation of connection of theory to the project

Case 32/2019 Possible cases

Samsom Asmerom Habtemichael
The Chairman

Attachments:

1. Progress plan
2. Project template contains (Theory, Project title)
3. Minutes of the previous meeting

NB: Each attachment must be clearly marked with the attachment number, date and signature.

UNIVERSITY OF AGDER
Faculty of Technology
Master's thesis

Title: Sustainability assessment of an apartment building containing reinforced concrete or cross-laminated timber (CLT)

Grimstad, 25.03.19

To: Bjørn Kittelsen, Mohamad Omar Aljoulbek, Samsom Asmerom Habtemichael og Rawand Fatah Mohammed

MEETING INVITATION NO 4

Place: D3100 (Jon Lilletunsvei 9, Grimstad)
Time and duration: 25.03.2019 kl. 09.00-10.00

Meeting referent: *Samsom Asmerom Habtemichael*

Case 33/2019 Introduction cases

1. Election of chairman of the meeting and referent.
2. Approval of meeting invitation.
3. Approval of agenda.
4. Report status.
5. Approval of minutes of the previous meeting.
6. Possible cases.

Case 34/2019 Status / information cases

1. Progress plan.
2. Review of theory.
3. Questions.

Case 35/2019 Decision case 1 – Progress plan
Revision of progress plan

Case 36/2019 Review of theory
Design of glued laminated timber and cross-laminated timber
Low carbon concrete
Foundation
Stability
Construction cost and LCA
Loads

Case 37/2019 Election of chairman of the meeting and referent to the next meeting
Suggestion: Mohamad Omar Aljoulbek as chairman and Rawand Fatah Mohammed as referent.

Case 38/2019 Questions
Can we use source from another country like USA?
Is it popular to use raft foundation in Norway?

Case 39/2019 Possible cases

Rawand Fatah Mohammed
The Chairman

Attachments:
1. Progress plan
2. Project template contains (Theory, Project title)
3. Minutes of the previous meeting

NB: Each attachment must be clearly marked with the attachment number, date and signature.

UNIVERSITY OF AGDER
Faculty of Technology
Master's thesis

Title: Sustainability assessment of an apartment building containing reinforced concrete or cross-laminated timber (CLT)

Grimstad, 08.04.19

To: Bjørn Kittelsen, Mohamad Omar Aljoulbek, Samsom Asmerom Habtemichael og Rawand Fatah Mohammed

MEETING INVITATION NO 5

Place: D3100 (Jon Lilletunsvei 9, Grimstad)
Time and duration: 08.04.2019 kl. 09.00-10.00

Meeting referent: *Rawand Fatah Mohammed*

Case 40/2019 Introduction cases
1. Election of chairman of the meeting and referent.
2. Approval of meeting invitation.
3. Approval of agenda.
4. Report status.
5. Approval of minutes of the previous meeting.
6. Possible cases.

Case 41/2019 Status / information cases
1. Progress plan.
2. Autocad
3. Review of theory.
4. Introduction
5. Methods
6. Questions.

Case 42/2019 Decision case 1 – Progress plan
Revision of progress plan

Case 43/2019 Autocad
Use of Autocad for illustration. For example, drawing of foundation theory illustration, wall theory illustration and so on.

Case 44/2019 Review of theory
Design of glued laminated timber and cross-laminated timber
Low carbon concrete
Foundation
Wall
Steel
Stability

Construction cost and LCA
Loads

Case 45/2019 Introduction
Assessment of the introduction.

Case 46/2019 Methods
Assessment of the methods

Case 47/2019 Election of chairman of the meeting and referent to the next meeting
Suggestion: Samsom Asmerom Habtemichael as chairman and Mohamad Omar Aljoulbek as referent.

Case 48/2019 Questions
Any suggestion to the report?

Case 49/2019 Possible cases

Mohamad Omar Aljoulbek
The Chairman

Attachments:
1. Progress plan
2. Project template contains (Theory, Project title)
3. Minutes of the previous meeting

NB: Each attachment must be clearly marked with the attachment number, date and signature.

UNIVERSITY OF AGDER
Faculty of Technology
Master's thesis

Title: Development of a methodology for a specific sustainable solution for an apartment block.

Grimstad, 04.02.19

To: Bjørn Kittelsen, Mohamad Omar Aljoulbek, Samsom Asmerom Habtemichael og Rawand Fatah Mohammed

MINUTES OF MEETING NO 1

Place: D3100 (Jon Lilletunsvei 9, Grimstad)
Time and duration: 04.02.2019 kl. 09.00-10.00

<u>**Meeting referent:** *Samsom Asmerom Habtemichael*</u>

Case 1/2019 Introduction cases

1. Election of chairman of the meeting and referent.
   OK
2. Approval of meeting invitation.
   OK
3. Approval of agenda.
   OK
4. Report status.
   OK
5. Possible cases.
   OK

Case 2/2019 Status / information cases

1. Progress plan.
2. Project title.
3. Problem statement.
4. Research question.
5. Group agreement.
6. Questions.

Case 3/2019 Decision case 1 – Progress plan

Revision of progress plan
Small adjustments have been done. Meeting dates are changed from 20.02.2019 to 11.02.2019 and 08.04.2019 to 10.02.2019.
Contents is listed as a new task in the progress plan. Then progress plan has been approved.

Case 4/2019 Decision case 2 - Project title

Evaluation of project title

It has been discussed about the project title and some comments have been mentioned. The building name, apartment block, mentioned in the project title is commented to be revised. In addition, the group has proposed three options to the project title and suggestion is given by supervisor. Evaluation of project title will be continued until next meeting.

Case 5/2019 Decision case 3- Problem statement

Evaluation of problem statement
Problem statement is approved with small comments. Connection design should be listed under structural design. Problem statement is ready for submission.

Case 6/2019 Decision case 4- Research question

Evaluation of research question
Comments are given by the supervisor. The research questions should be more specific, it should not be more general. For example, the question, what are the advantages and disadvantages of low carbon concrete? should be more specific for the project.

Case 7/2019 Decision case 5 – Group agreement

Evaluation of group agreement
Group agreement is approved.

Case 8/2019 Election of chairman and referent to the next meeting
Suggestion: Mohamad Omar Aljoulbek as chairman and Rawand Fatah Mohammed as referent.
Approved.

Case 9/2019 Questions

Skype meeting
It has been discussed about possibilities on Skype meeting with supervisor and some of the meetings are approved to be on Skype.

Case 10/2019 Possible cases

OK

UNIVERSITY OF AGDER
Faculty of Technology
Master's thesis

Title: Sustainability assessment of an apartment building with reinforced concrete or Cross-laminated timber (CLT)

Grimstad, 11.02.19

To: Bjørn Kittelsen, Mohamad Omar Aljoulbek, Samsom Asmerom Habtemichael og Rawand Fatah Mohammed

MINUTES OF MEETING NO 2

Place: D3100 (Jon Lilletunsvei 9, Grimstad)
Time and duration: 11.02.2019 kl. 09.00-10.00

Meeting referent: *Rawand Fatah Mohammed*

Case 11/2019 Introduction cases

1. Election of chairman of the meeting and referent.
   OK
2. Approval of meeting invitation.
   OK
3. Approval of agenda.
   OK
4. Report status.
   OK
5. Approval of minutes of the previous meeting.
   OK
6. Possible cases.
   OK

Case 12/2019 Status / information cases

1. Progress plan.
2. Project title.
3. Problem statement.
4. Research question.
5. Review of theory.
6. Contents.
7. Questions.

Case 13/2019 Decision case 1 – Progress plan
Revision of progress plan
Approved.

Case 14/2019 Decision case 2 - Project title
Evaluation of project title
Suggestion:

1. Sustainability assessment of an apartment building with reinforced concrete or Cross-laminated timber (CLT)
2. Sustainability assessment of an apartment building containing reinforced concrete or Cross-laminated timber (CLT)

The group has discussed and been agree for choosing number two. Evaluation of the title will still continue, and the group will try to improve the project title.

Case 15/2019 Decision case 3- Problem statement
Evaluation of problem statement
Suggestion from internal supervisor:
The group and supervisor reviewed Problem statement and discussed. Problem statement should be more focused on master's thesis.

Case 16/2019 Decision case 4- Research question
Evaluation of research question
Suggestion:
Research question should be more related to the project. Further Research question should not be general.

Case 17/2019 Review of theory
Introduction of timber
Recommendation:
Should use formula with text to explain a subject. The group and the supervisor reviewed a theory example on paper to explain shear force, displacement and deflection. One example is given by Supervisor about combined glulam beam. It is also explained some examples about load combination factors.

Case 18/2019 Contents
Evaluation of contents
Suggestion:
Overview three should be divided into two parts, the building materials should have own overview. Contents will still be modified.

Case 19/2019 Election of chairman of the meeting and referent to the next meeting
Suggestion: Samsom Asmerom Habtemichael as chairman and Mohamad Omar Aljoulbek as referent.
Approved.

Case 20/2019 Questions
Evaluation of timber books
Evaluation of time sheet
The books which have already been used by the group are mentioned at the meeting and discussed. For example (Dimensjonering av trekonstruksjoner,design of timber structures,NS-EN 1990 Eurocode 0).
The group will use time sheet for own progress through the semester.

Case 21/2019 Possible cases
OK.

UNIVERSITY OF AGDER
Faculty of Technology
Master's thesis

Title: Sustainability assessment of an apartment building containing reinforced concrete or cross-laminated timber (CLT)

Grimstad, 11.03.19

To: Bjørn Kittelsen, Mohamad Omar Aljoulbek, Samsom Asmerom Habtemichael og Rawand Fatah Mohammed

MINUTES OF MEETING NO 3

Place: D3100 (Jon Lilletunsvei 9, Grimstad)
Time and duration: 11.03.2019 kl. 09.00-10.00

Meeting referent: *Mohamad Omar Aljoulbek*

Case 22/2019 Introduction cases

1. Election of chairman of the meeting and referent.
   OK
2. Approval of meeting invitation.
   OK
3. Approval of agenda.
   OK
4. Report status.
   OK
5. Approval of minutes of the previous meeting.
   OK
6. Possible cases.
   OK

Case 23/2019 Status / information cases

1. Progress plan.
2. Project title.
3. Problem statement.
4. Research question.
5. Review of theory.
6. Contents.
7. Questions.

Case 24/2019 Decision case 1 – Progress plan
Revision of progress plan
Progress plan is been discussed and approved.

Case 25/2019 Decision case 2 - Project title
Evaluation of project title

Suggestion is:

Sustainability assessment of an apartment building containing reinforced concrete or cross-laminated timber (CLT)

Approved.

Case 26/2019 Decision case 3- Problem statement

Evaluation of problem statement

Approved.

Case 27/2019 Decision case 4- Research question

Evaluation of research question

Approved.

Case 28/2019 Review of theory

Design of glued laminated timber and cross-laminated timber

It has been discussed about cross-laminated timber. It generally looks good. Some formulas were discussed in detail and will be fixed afterwards. Moreover, it is mentioned that own produced figures are recommended to use in the report.

Low carbon concrete

It is also been discussed about low carbon concrete. It is discussed about CO2 emission values for different classes of low carbon. There were some questions about these classes and what consequences the different classes have.

Stability

It is also discussed about the maximum span of cross-laminated timber with regard to the project. It has been seen that there are some challenges in the project. The Revit model which is converted two (FEM Structural Analysis Software) is been viewed. Different type of load has been viewed like snow, wind and also much more.

Construction cost and LCA

Reviewed and discussed.

Loads

Reviewed and discussed.

Case 29/2019 Contents

Evaluation of contents

Approved.

Case 30/2019 Election of chairman of the meeting and referent to the next meeting

Suggestion: Rawand Fatah Mohammed as chairman and Samsom Asmerom Habtemichael as referent.

Approved.

Case 31/2019 Questions

Evaluation of connection of theory to the project

There should be a lot of focus on linking the theory to the project. At the same time it is important that sometimes the connection can take place through illustrations.

Case 32/2019 Possible cases

Formula in the following book **(Cross-Laminated Timber Structural Design (Basic design and engineering principles according to Eurocode))** is been discussed:
Formula (5.3)
Formula (5.4)
Formula (5.5)
Formula (5.6)
Formula (5.13)
These formulas were discussed so that the group could have a better understanding of the topic.

UNIVERSITY OF AGDER
Faculty of Technology
Master's thesis

Title: Sustainability assessment of an apartment building containing reinforced concrete or cross-laminated timber (CLT)

Grimstad, 25.03.19

To: Bjørn Kittelsen, Mohamad Omar Aljoulbek, Samsom Asmerom Habtemichael og Rawand Fatah Mohammed

MINUTES OF MEETING NO 4

Place: D3100 (Jon Lilletunsvei 9, Grimstad)
Time and duration: 25.03.2019 kl. 09.00-10.00

Meeting referent: *Samsom Asmerom Habtemichael*

Case 33/2019 Introduction cases

1. Election of chairman of the meeting and referent.
   OK
2. Approval of meeting invitation.
   OK
3. Approval of agenda.
   OK
4. Report status.
   OK
5. Approval of minutes of the previous meeting.
   OK
6. Possible cases.
   OK

Case 34/2019 Status / information cases

1. Progress plan.
2. Review of theory.
3. Questions.

Case 35/2019 Decision case 1 – Progress plan
Revision of progress plan
Progress plan is been discussed and approved.

Case 36/2019 Review of theory
Design of glued laminated timber and cross-laminated timber
Reviewed and discussed.

Low carbon concrete
Reviewed and discussed.

Foundation

Table 3.12 must be checked. Find out if it is (KN / mm) or (KN / m).
Values that should be explained and elaborated more (G_K,Q_K,W, P_b)
Theory of foundation must be deepened.

When you create the foundation it is the challenge to get equal tension throughout the building. It is then not guaranteed due to variances in the loads such as (snow, wind, ...) etcetera. Nevertheless, one must aim for equal tension throughout the building.

Questions that should be prioritized
What is the limitation on the foundation of projects?
How much should it focus on the foundation?

Stability

Reviewed and discussed.

Construction cost and LCA

Reviewed and discussed.

Loads

Reviewed and discussed.

Case 37/2019 Election of chairman of the meeting and referent to the next meeting
Suggestion: Mohamad Omar Aljoulbek as chairman and Rawand Fatah Mohammed as referent.
Approved.

Case 38/2019 Questions
Can we use source from another country like USA?
It is advisable to use multiple sources.

Is it popular to use raft foundation in Norway?
Raft foundation is used if the basement is below groundwater level as generally.
Water pressure must also be taken into account when designing the foundation.

Case 39/2019 Possible cases

Continues from the previous meeting!

Formula in the following book (Cross-Laminated Timber Structural Design (Basic design and engineering principles according to Eurocode)) is been discussed:
Formula (5.3)
Formula (5.4)
Formula (5.5)

Formula (5.6)
Formula (5.13)
These formulas were discussed so that the group could have a better understanding of the topic.

UNIVERSITY OF AGDER
Faculty of Technology
Master's thesis

Title: Sustainability assessment of an apartment building containing reinforced concrete or cross-laminated timber (CLT)

Grimstad, 08.04.19

To: Bjørn Kittelsen, Mohamad Omar Aljoulbek, Samsom Asmerom Habtemichael og Rawand Fatah Mohammed

MINUTES OF MEETING NO 5

Place: D3100 (Jon Lilletunsvei 9, Grimstad)
Time and duration: 08.04.2019 kl. 09.00-10.00

Meeting referent: *Rawand Fatah Mohammed*

Case 40/2019 Introduction cases

1. Election of chairman of the meeting and referent.
   OK
2. Approval of meeting invitation.
   OK
3. Approval of agenda.
   OK
4. Report status.
   OK
5. Approval of minutes of the previous meeting.
   OK
6. Possible cases.
   OK

Case 41/2019 Status / information cases

1. Progress plan.
2. Autocad
3. Review of theory.
4. Introduction
5. Methods
6. Questions.

Case 42/2019 Decision case 1 – Progress plan
Revision of progress plan
Progress plan has been discussed and approved.

Case 43/2019 Autocad

Use of Autocad for illustration. For example, drawing of foundation theory illustration, wall theory illustration and so on.

The illustrations should be more clear when is drawn in Autocad. Line thickness and text placement should be suited for the overall illustrations.

Case 44/2019 Review of theory

Design of glued laminated timber and cross-laminated timber

Reviewed and discussed.

Low carbon concrete

Reviewed and discussed.

Foundation

Reviewed and discussed.

Should pay more attention to the language. In addition, the use of symbols in the right form and the right place is important. Be sure to avoid extra spaces between words.

Wall

Reviewed and discussed.

Should pay more attention to the language. In addition, the use of symbols in the right form and the right place is important. Be sure to avoid extra spaces between words.

Steel

Reviewed and discussed.

Should pay more attention to the language. In addition, the use of symbols in the right form and the right place is important. Be sure to avoid extra spaces between words.

Stability

Reviewed and discussed.

Construction cost and LCA

Reviewed and discussed.

Loads

Reviewed and discussed.

Case 45/2019 Introduction

Assessment of the introduction.

Since the master’s thesis has been decided to be written in English, Norwegian language must be avoided in the report as generally in both text and figure. The figure shown on the introduction is Norwegian and must be exchanged to English. The figure should have a common area for the three circles. So that the figure reflects over the text.

Case 46/2019 Methods

Assessment of the methods

Reviewed and discussed.

Case 47/2019 Election of chairman of the meeting and referent to the next meeting

Suggestion: Samsom Asmerom Habtemichael as chairman and Mohamad Omar Aljoulbek as referent.

Approved.

Case 48/2019 Questions

Any suggestion to the report?

The theory that is written must be related to the whole of the report. Must ensure that the whole theory is used in the report. This means that one must make sure that the whole theory is used in the result capital in the report.

After the group finishes the result section, it is important to go through the theory thoroughly. Further find out if there are parts in the theory that are not used in the result section.

The group and the supervisor must go through both theory and the result fundamentally in meeting number six. The focus comes in the form of reviewing theory and results and all other parts of the report. Furthermore, find out if there is a need for more theory or the opposite. In addition, find out if it needs cutting out part of the report. It should focus on the whole of the report. It is important that the report is printed for the next meeting !!

Case 49/2019 Possible cases

Page 60 in the report (equation 3.110)
the equation is not in the Norwegian standard. The equation is found in Steel Hand Book Part Three.

Is the equation number (3.110) enough for our report or one must also use linear equation?

It is important to give reasons why the equation should not be included. Must check if both equations were used in the calculation or just the one in the report.

UNIVERSITY OF AGDER
Faculty of Technology
Master's thesis

Title: Sustainability assessment of an apartment building containing reinforced concrete or cross-laminated timber (CLT)

Grimstad, 30.04.19

To: Simon Hugo Haugen, Mohamad Omar Aljoulbek, Samsom Asmerom Habtemichael og Rawand Fatah Mohammed

MINUTES OF MEETING NO 1 (External supervisor**)**

Place: Skype
Time and duration: 30.04.2019 kl. 10.00-10.45

Participant in the meeting	***Places in the meeting time***
Simon Hugo Haugen	Rambøll Norge AS avd Skien
Mohamad Omar Aljoulbek	Bergen
Samsom Asmerom Habtemichael	Gjøvik
Rawand Fatah Mohammed	Grimstad

Meeting referent: *Rawand Fatah Mohammed*

Case 01/2019 Introduction cases

1. Approval of meeting invitation.
   OK
2. Approval of agenda.
   OK
3. Report status.
   OK
4. Possible cases.
   OK

Case 02/2019 General discussion of the report

The problem statement was discussed in detail.

Comment from the supervisor:
The report is very good and a great work has been done.
Use of the preliminary project as a source in the master's thesis was discussed.

Those who read master's thesis should know that there is a foundation report. The master's thesis should be connected or referred to preliminary project. It will give an overview of the work which has been done in one year in the same project. It can be discussed with the internal supervisor about using the preliminary project as a source.

There should be more discussion and conclusion comparing with the previous semester project.
It should be clear which alternative is better. The difference should be shown with percentage and diagrams.
Supervisor means the report is alive and has a good illustration that gives a good impression.

It should be mentioned in suggestions for further work:
What could be considered more which is not done in the report?
Example (the progress plan to build the project, fire, sound, also on) which can be suggested in further work.
Some of the terms can also be explained in short.

Introduction and summary should suitable to different type of readers. Such that readers at different levels can understand and take advantage of reading the report even if readers are not experts.

Production of shop drawing was discussed. Now days digital models are more important than on paper. It was recommended to have a digital model.

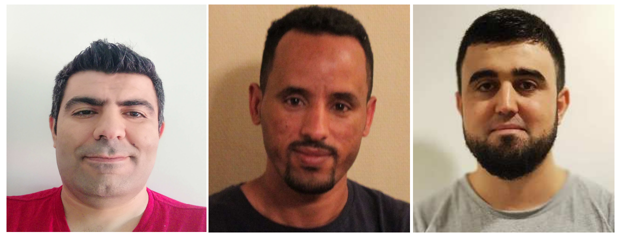
It is important to show 3d models in presentation time because it will give a good overview.

Case 03/2019 Possible cases

OK

BYG508-G Master's Thesis

Candidate:
Mohamad Omar Aljoulbek
Samsom Asmerom Habtemichael
Rawand Fatah Mohammad



Title:

Sustainability assessment of an apartment building containing reinforced concrete or cross-laminated timber (CLT)

Supervisor:
Bjørn Kittelssen , UiA

Introduction

In this study, a methodology for determining a sustainable solution for a structural system of an apartment building has been investigated**.** The study has proposed and compared three structural systems options with more focus on the environmental issue. The options are:

Option 1: Timber structural system including walls and foundations made of normal concrete

Option 2: Timber structural system including walls and foundations made of low carbon concrete.

Option 3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.

The above options are assessed based on: structural design; Life cycle assessment (LCA) and construction cost. The building is located at Heistad in the municipality of Porsgrunn in Norway.

Figure 1: 3D Architect model

This master's thesis will attempt to answer the following question:

Which structural material is sustainable considering structural stability and construction cost?

1. Which material is more sustainable, reinforced concrete (normal and low carbon) or Cross-laminated timber (CLT)?
2. What are the major differences, advantages and challenges between the concrete types, low-carbon concrete and normal concrete?
3. What are the restrictions and limitations for reinforced concrete and Cross-laminated timber (CLT)?

The software Revit was used to design all three options.

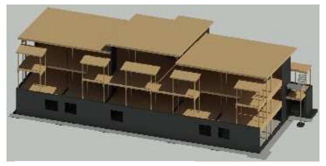


Figure 2: Option 1

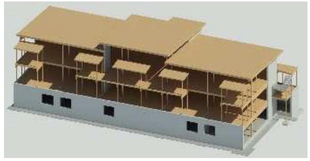
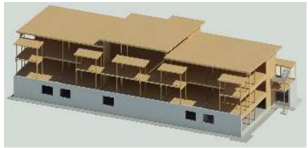


Figure 3: Option 2



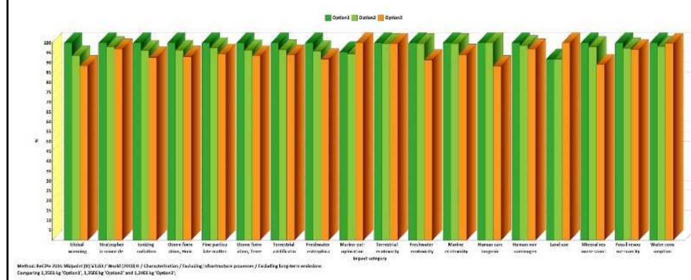
Figur 4: Option 3

The results of the studies conducted show the following:

1) Generally, wood is the most sustainable material compared to steel and concrete. Wood is a renewable natural resource. Normal concrete has more environmental impact than wood. A concrete type called low-carbon is developed to replace the normal concrete in order to reduce CO2 emission. Based on the LCA results of this study, however, wood is still the most sustainable material compared to reinforced concrete. LCA results show that option 3 has lower Global Warming Potential (GWP). However, land use of option 3 appeared to be higher, compared to the other two options.

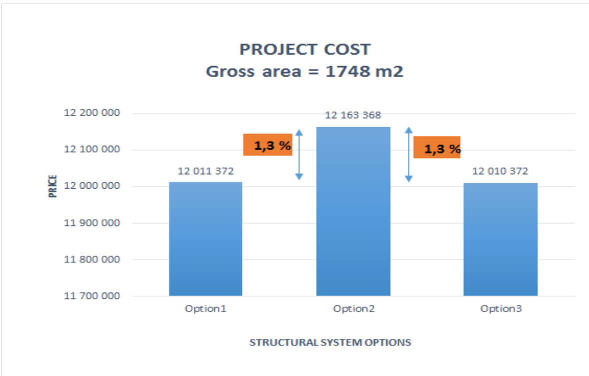
2) The difference between the low carbon concrete and normal concrete is the limit values for CO2 emission. The limit values of CO2 emission of low carbon is much lower, compared to normal concrete. However, there are some challenges of using low carbon concrete. Some of the challenges are: low carbon has coarser aggregates than normal concrete; transport distance of resource materials can be long. Moreover, low carbon class A requires low consistencies (160-180 mm) which also can affect the concrete workability.

- **LCA result**



Impact assessment Comparing of option1, option 2 and option 3

- **Economy result**



Comparison of Project Cost between the options

3) CLT floors have limitations in terms of spans. For spans of more than about 6 meters, it is difficult to satisfy the requirements for both strength and deformation. In addition, thickness of CLT will be large and this will have negative economic consequences. For comparison, reinforced concrete structures have better strength, and are therefore better suited to large spans. When it comes to restrictions, reinforced structures have almost no restrictions with regard the area of use. They can suit to any weather conditions. However, CLT elements must be prevented from being exposed to high humidity.

Summary and Conclusion

This master's thesis has explored three alternative solutions for the structural system of an apartment building, with focus on environmental issues. The comparison has included design, LCA and economy. The main focus has been to find out which of the three alternatives is most sustainable based on an overall assessment of the structural system, LCA and construction cost.

Results of LCA show GWP of option 3 appears to be 11% and 5% lower than option 1 and option 2, respectively. However, land use of option 3 is 9% higher than the other two options. When it comes to construction costs, option 2 was 1.3% more expensive than the other two options.

Based on an overall assessment, option 3 is preferred in regard to environmental concerns.

Grimstad May 2019

APPENDIX E

Appendix E.1

Appendix E.2

Appendix E.3

Appendix E.4

Appendix E.5

Appendix E.6

Appendix E.7

Appendix E.8

Appendix E.9

Appendix E.10

Design Assumptions

1) Concrete structure: according NS - EN 1992 - 1 - 1 : 2005 + NA: 2008

		Class			
Structural member		Strength	Durability	Exposure class	reinforcement cover (mm)
Foundation		B 35	M 45	XC2	50 and 35 on the sides
Ground floor slab		B 35	M 60	XC1	25
Walls		B 35	M 45	XC1	25

Aggregate size D_{maks} = 22mm

Minimum cover for reinforcement:

		Example
Cast against and permanently in conctact with the ground	50mm +/- 10mm	**Foundation bottom**
Exposed to weather or in contact with the ground	25mm +/- 10mm	**Foundation sides**
Not exposed to weather or in conctact with the ground	15mm +/- 10mm	Columns, beams, slabs, **walls**

	Concrete	fck	B35	35	N/mm2
		fctm		3,21	N/mm2
	Reinforcement	fyk	B500C	500	N/mm2
Partial safety factor (γ_M):	Concrete	1,5			
	Reinforcement	1,15			

Maximum and minimum reinforcement area

	cross-section		Rein. cover	effective depth	requirement for area of rein.		Area of reinforcement			
	B	H	C	d	$A_{s,min}$	$A_{s,max}$	$A_{s,min}$	12mm C/C	$A_{s,max}$	NB
Foundations	1000	300	35	259	0.26(fctm/fyk)bd ≥ 0.0013bd	0,04BH	432	262	12000	
Beams	300	600	35	547	0.26(fctm/fyk)bd ≥ 0.0013bd	0,04BH	432		7200	
Columns	300	300	25	257	0,01Ac	0,04BH	900		3600	
Walls:			25							
Vertical rein.	1000	220	25	189	0,002BH	0,04BH	440	257	8800	half
Horizontal rein.	1000	220	25	190	0,001BH	0,04BH	220	514	8800	on
Vertical rein.	1000	350	35	315	0,002BH	0,04BH	700	162	14000	each
Horizontal rein.	1000	350	35	310	0,001BH	0,04BH	350	323	14000	side

Plater/vegger		DIA.
Dia main reinforcement		12
Dia of distibution reinf.		10

Beams/slabs, As,min..biggest of	
0.26(fctm/fyk) bd	432,3177416
0.0013bd	336,7

column		Min dia. = 10mm
fcd	19,83	Stirrups 1. 15xdia.
fyd	434,78	2. Column min. width
As,min..biggest of		3. 400mm
0,01Ac	900	
$0,2A_cf_{cd}/f_{yd}$	821,1	

Beam/column	
Lengdearmering	16
Bøyler	10

2) Cross-laminated timber according to NS-EN 1995-1-1:2004/NA:2010+A1:2013

Strength class C24 (all layers)

Partial safety factor (γ_M) = 1,25

γ_M = 1,25

The following crossections are used in the project:

Cross-laminated timber floors and roofs:

For 280 mm thick CLT (7 layer) is shown in table below:

# 1	40 mm	0	C24
# 2	40 mm	90	C24
# 3	40 mm	0	C24
# 4	40 mm	90	C24
# 5	40 mm	0	C24
# 6	40 mm	90	C24
# 7	40 mm	0	C24

Orientation 0 = top layer longitudinal to span; Orientation 90 = top layer perpendicular to span

For 160 mm thick CLT (5 layer) is shown in table below:

# 1	40 mm	0	C24
# 2	20 mm	90	C24
# 3	40 mm	0	C24
# 4	20 mm	90	C24
# 5	40 mm	0	C24

Orientation 0 = top layer longitudinal to span; Orientation 90 = top layer perpendicular to span

Cross-laminated timber walls:

200 mm thick (5 layer) as shown in table below:

Layer	Thickness	Orientation	Material
# 1	40 mm	0	C24
# 2	40 mm	90	C24
# 3	40 mm	0	C24
# 4	40 mm	90	C24
# 5	40 mm	0	C24

3) Glued laminated timber (GLT) according to NS-EN 1995-1-1:2004/NA:2010+A1:2013

γ_M = 1,15

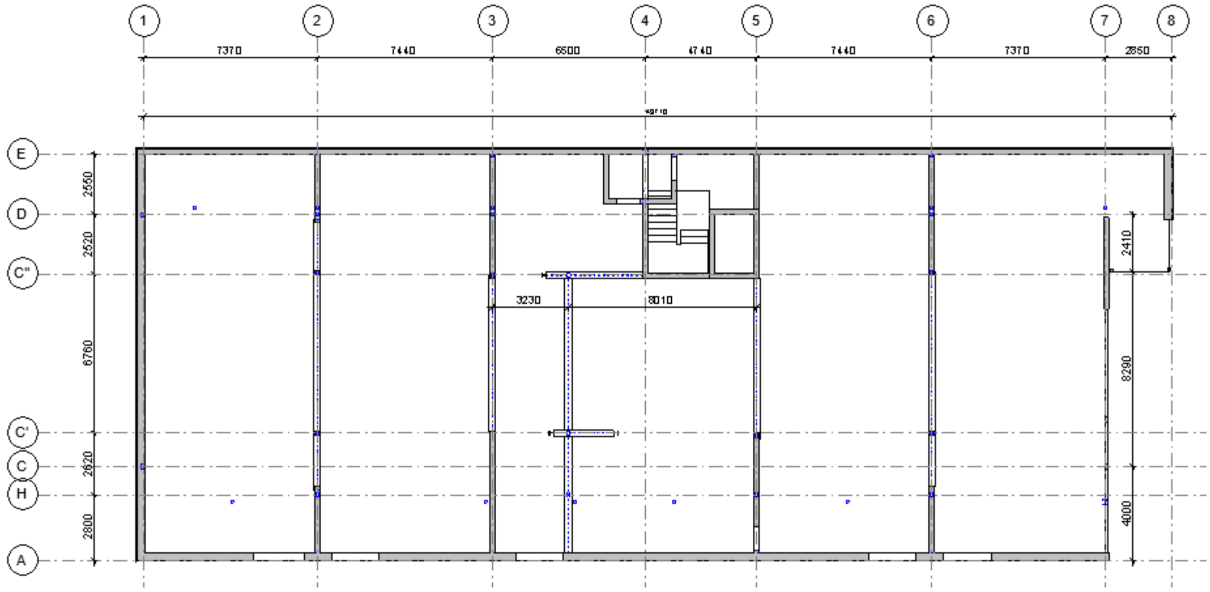
Strength class: GL30c

4) Steel structure according to NS-EN 1993-1-1:2005+A1:2014+NA:2015

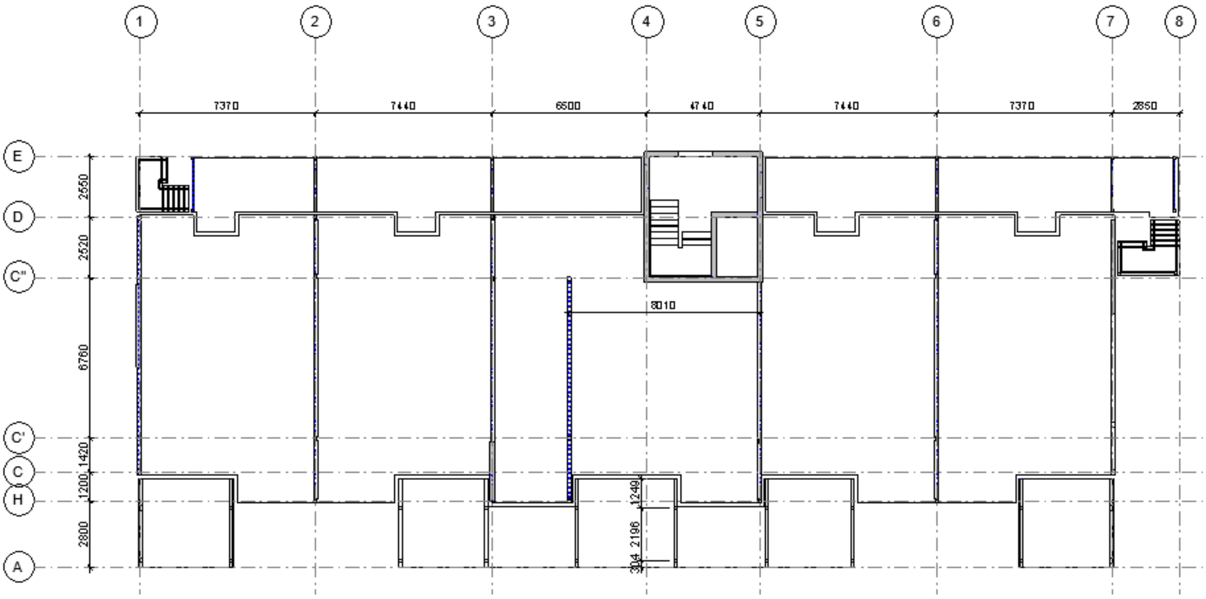
Strength class: S355

γ_M = 1,05

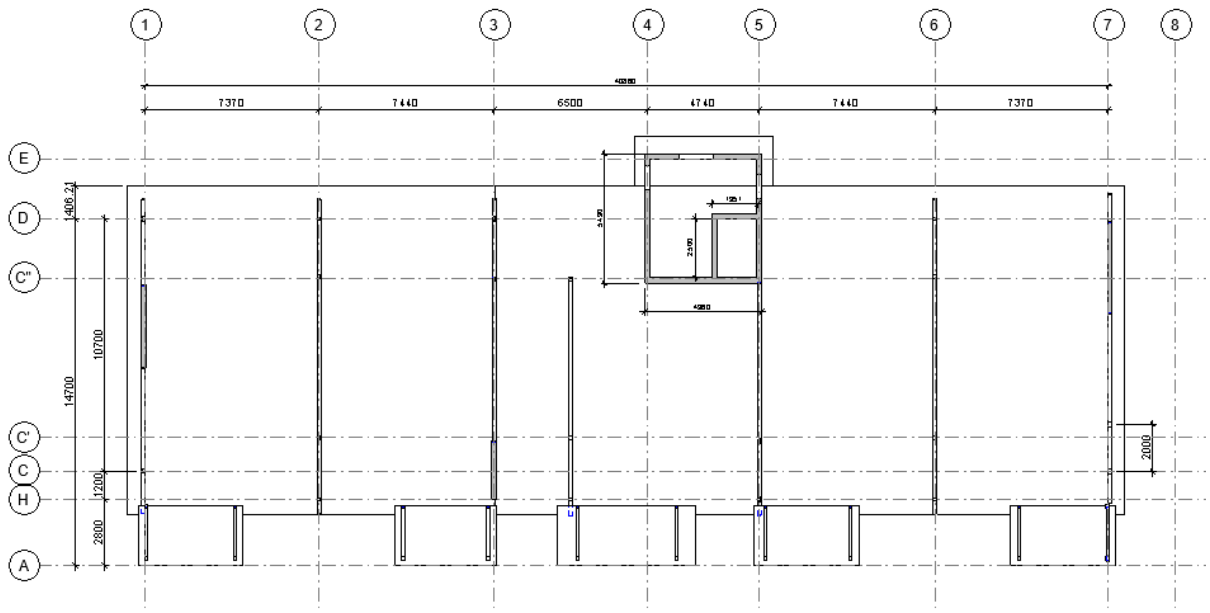
1. Structural plans



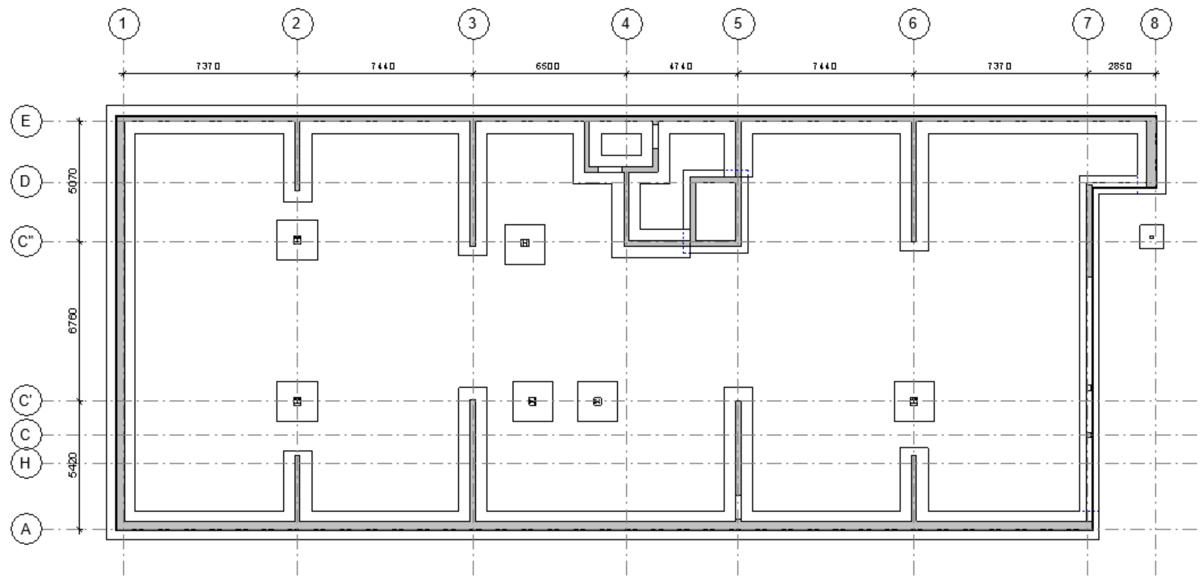
Floor over Basement



Floor over plan 1



Roof slab

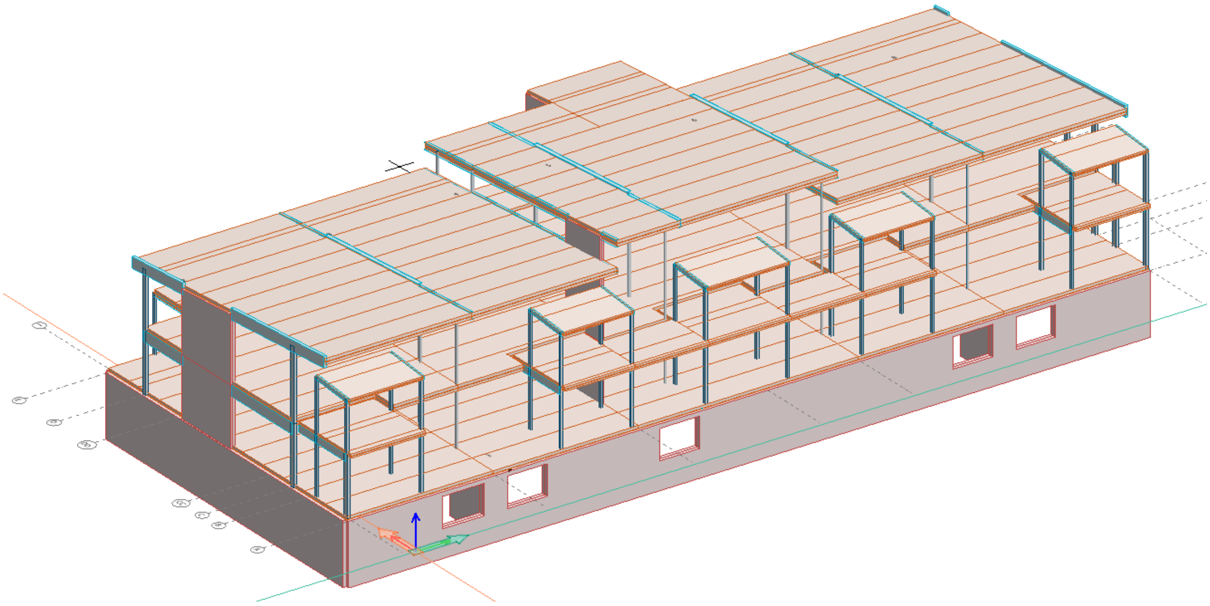


Foundation plan

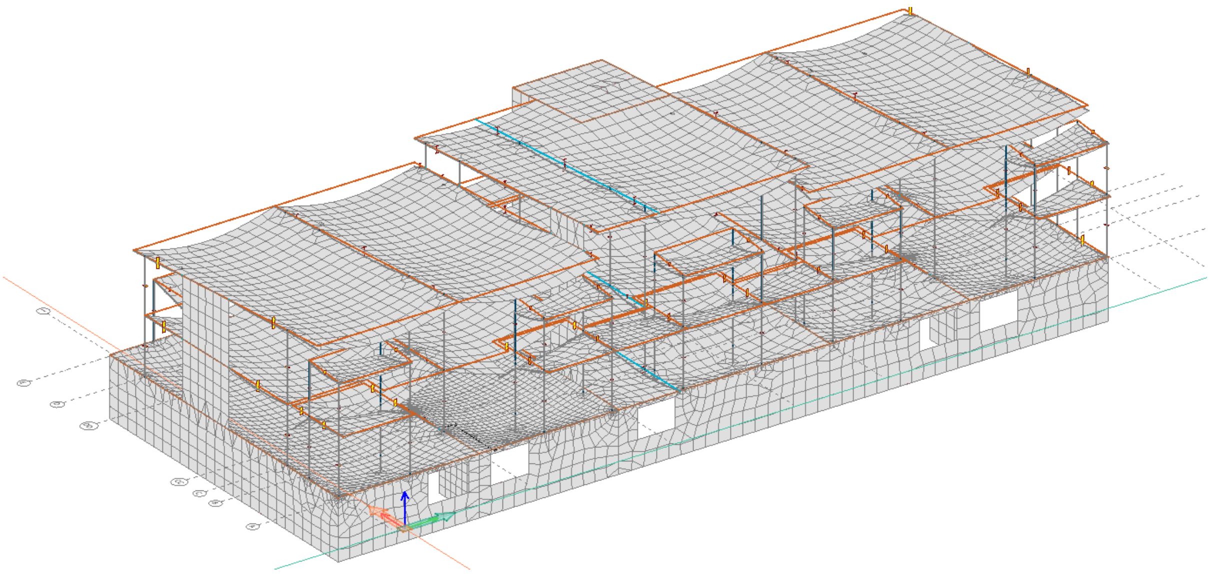
Table of Contents

2. Results from Fem-design for option1 and option2

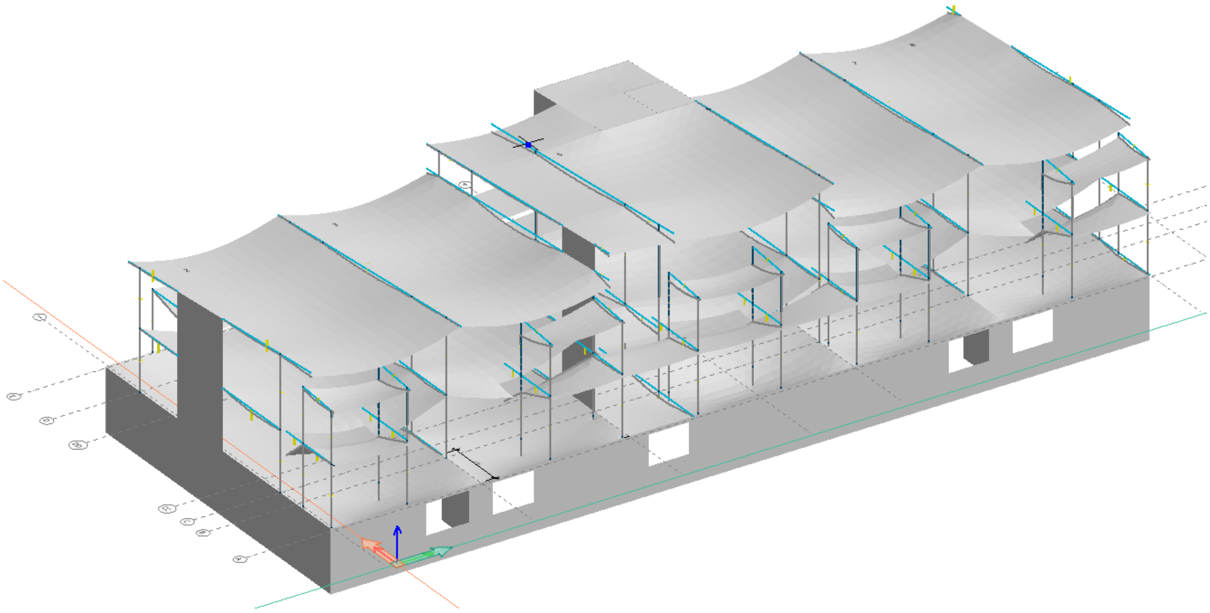
2.1. Geometry



Undeformed model



Deformed model

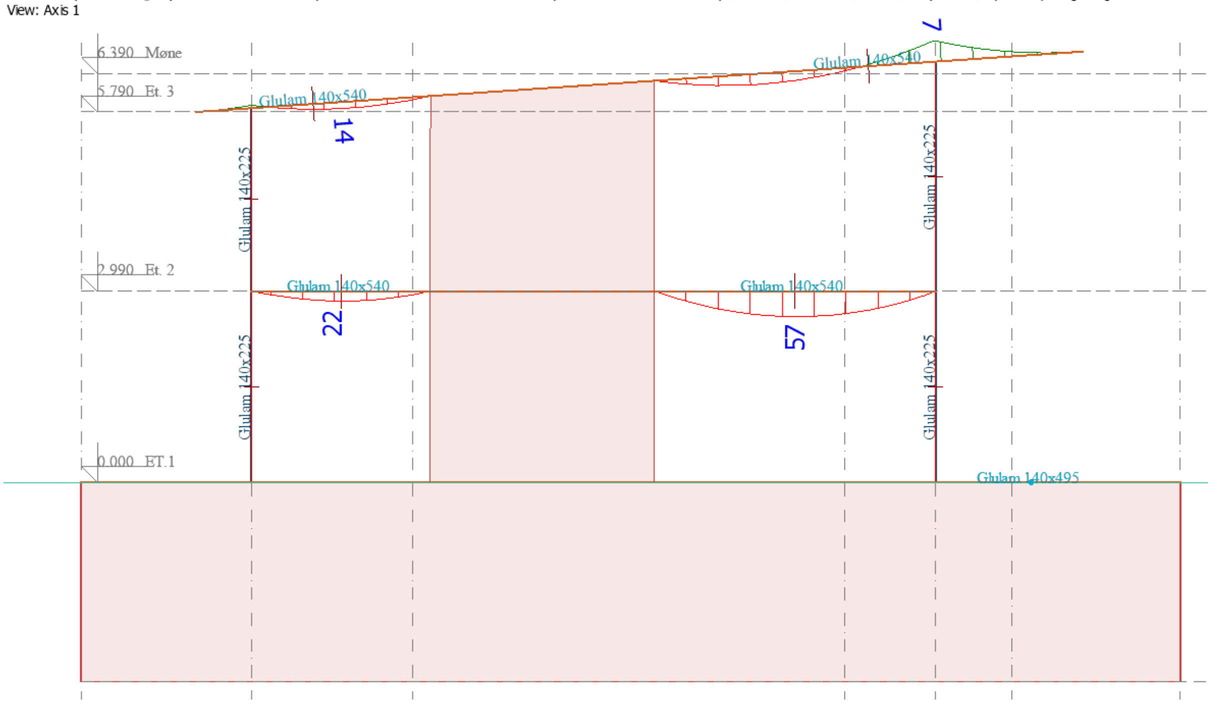


Deformed model

2.2. Analysis results:

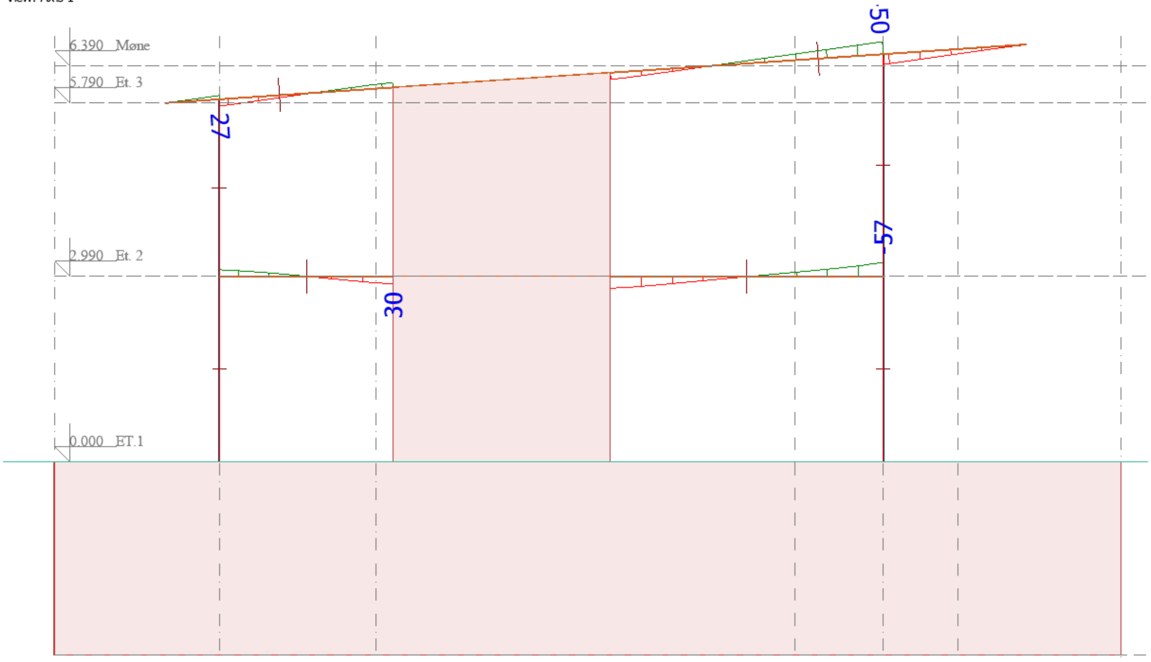
- Axis 1
  - Bending moment

Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S) - Bars, My' - Graph - [kNm]
View: Axis 1



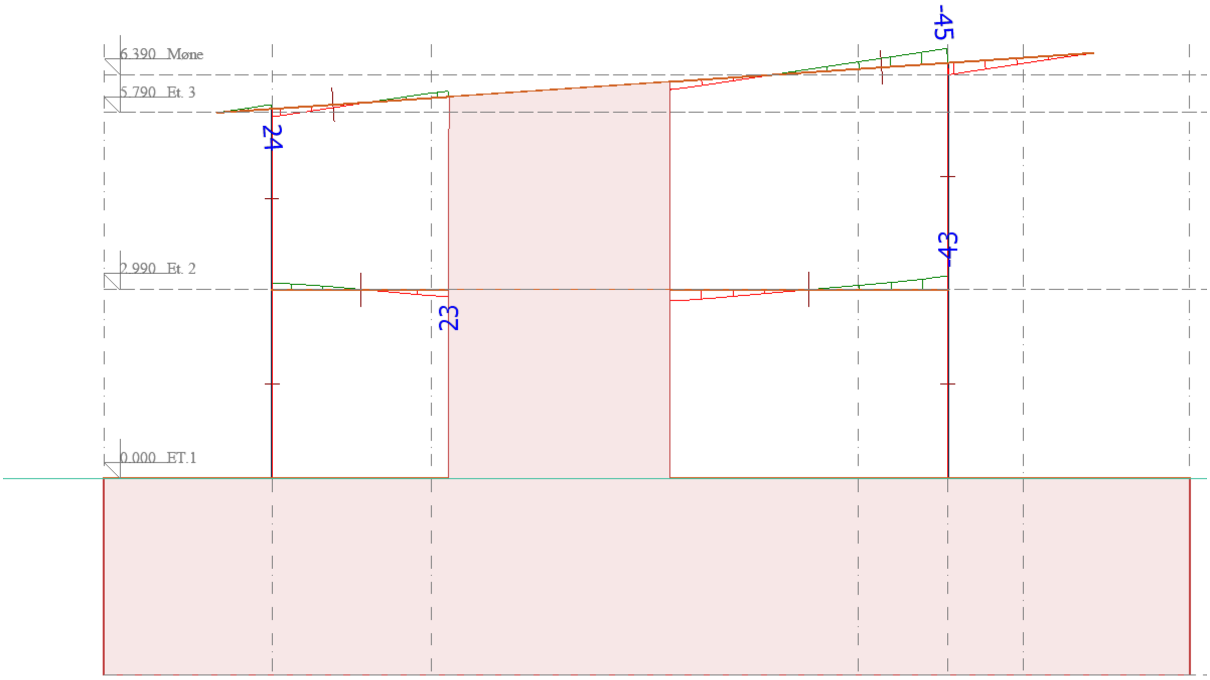
  - Shear force

Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S) - Bars, Tz' - Graph - [kN]
View: Axis 1



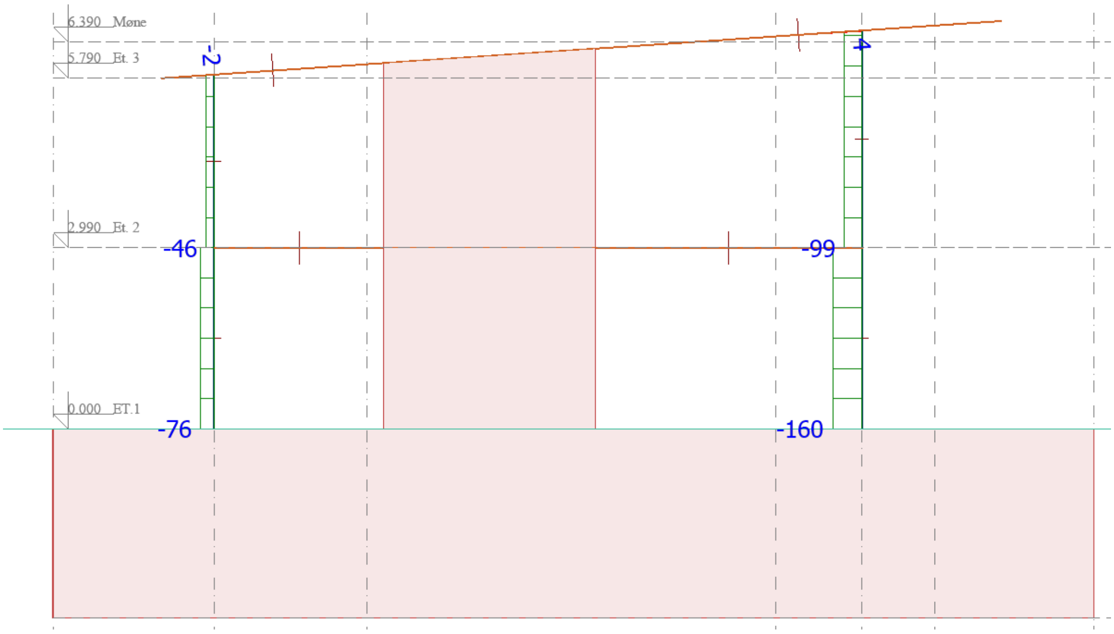
- Shear force diagram at service state

Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Service - only vertical loads (1,0 SW+1,0 dead+1,0 P+1,0 S) - Bars, Tz' - Graph - [kN]
View: Axis 1



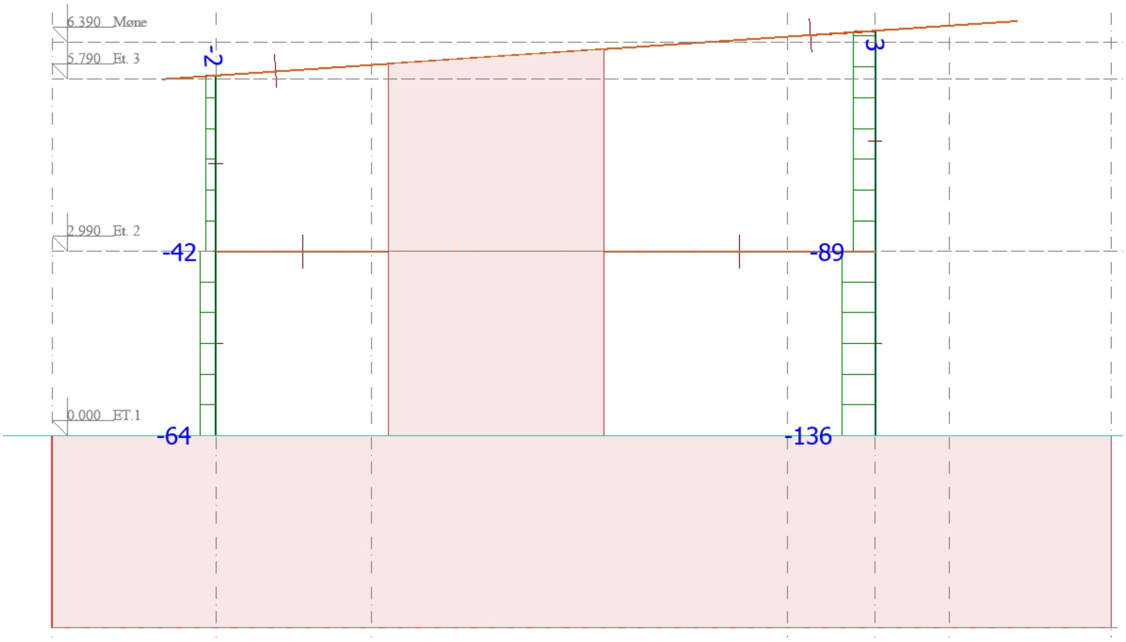
- Normal force diagram

Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S) - Bars, N - Graph - [kN]
View: Axis 1

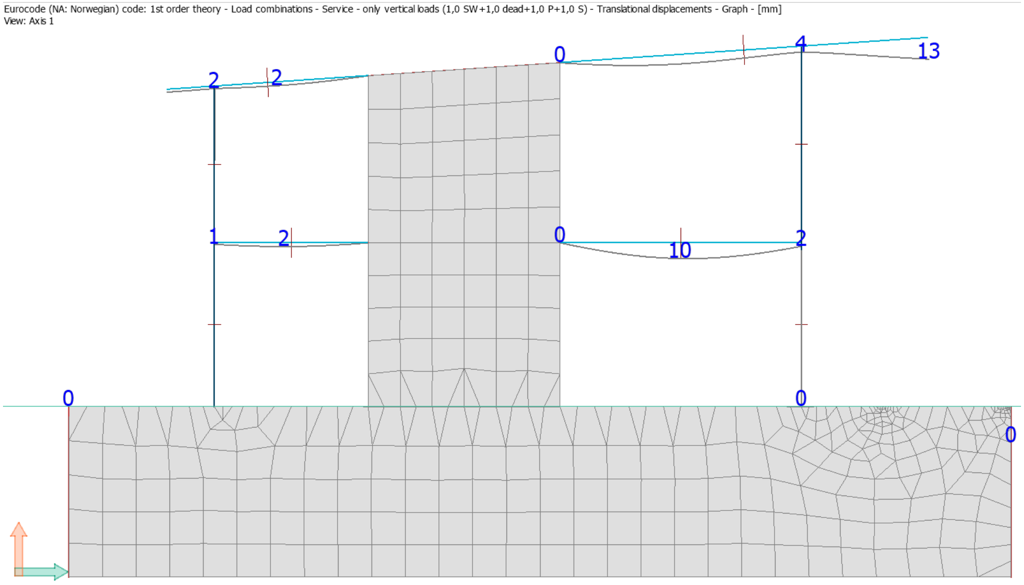


- Normal force diagram at service state:

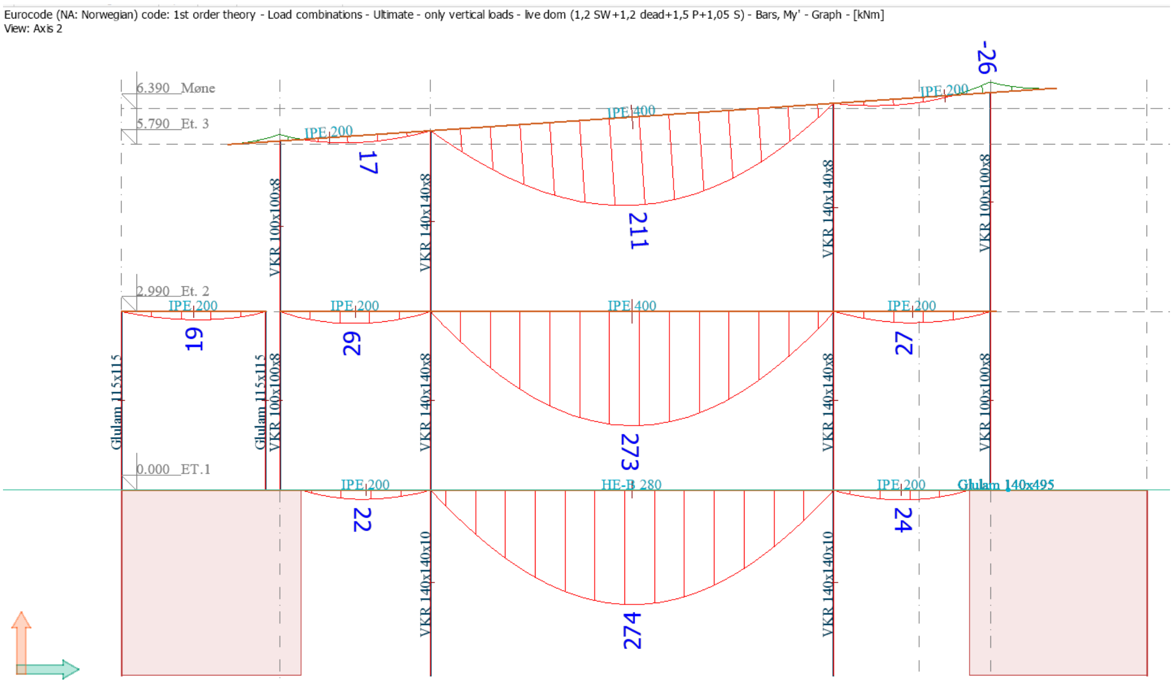
Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Service - only vertical loads (1,0 SW+1,0 dead+1,0 P+1,0 S) - Bars, N - Graph - [kN]
View: Axis 1



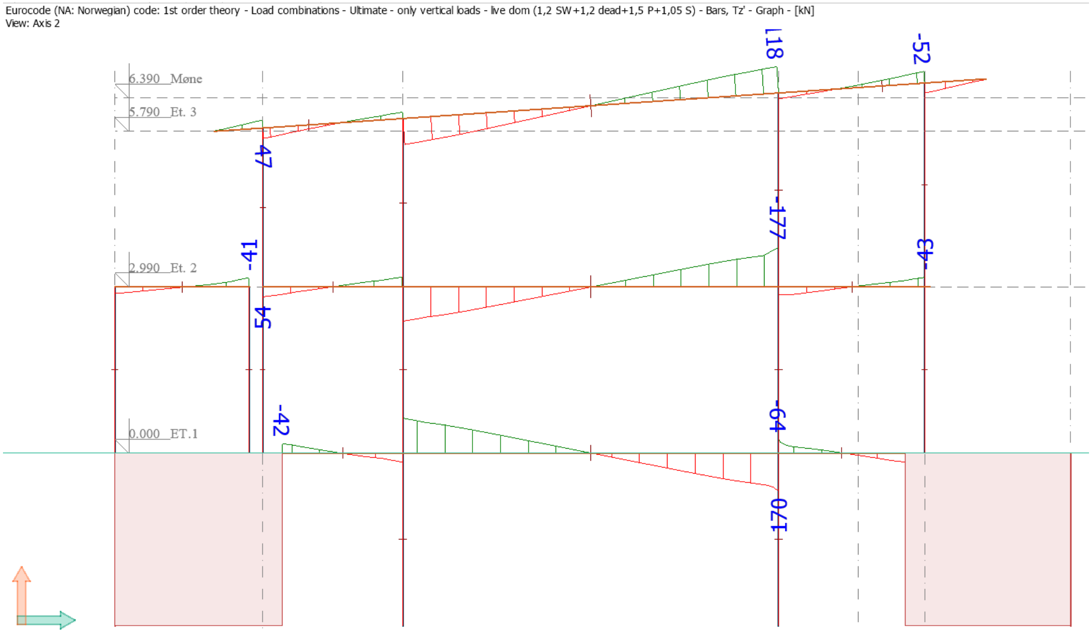
- Deformation



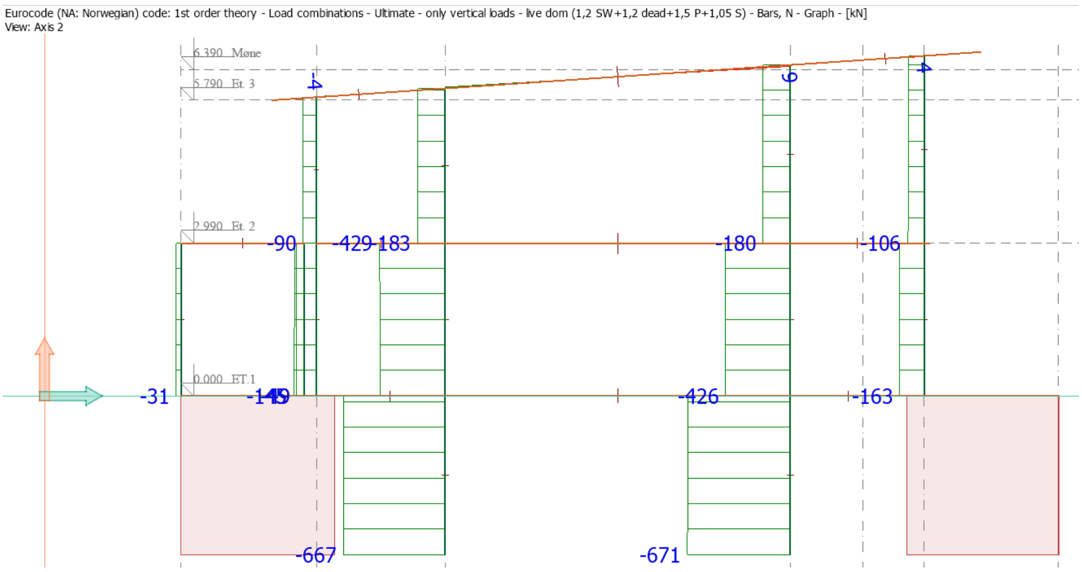
- Axis 2
  - Bending moment



  - Shear force

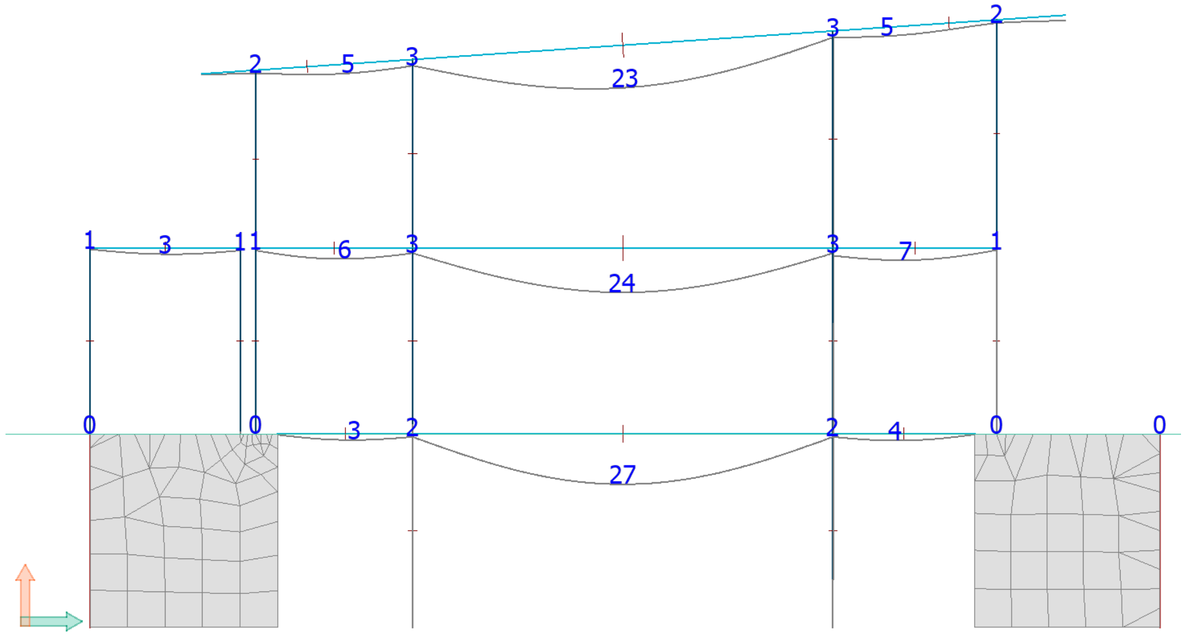


- Axial forces



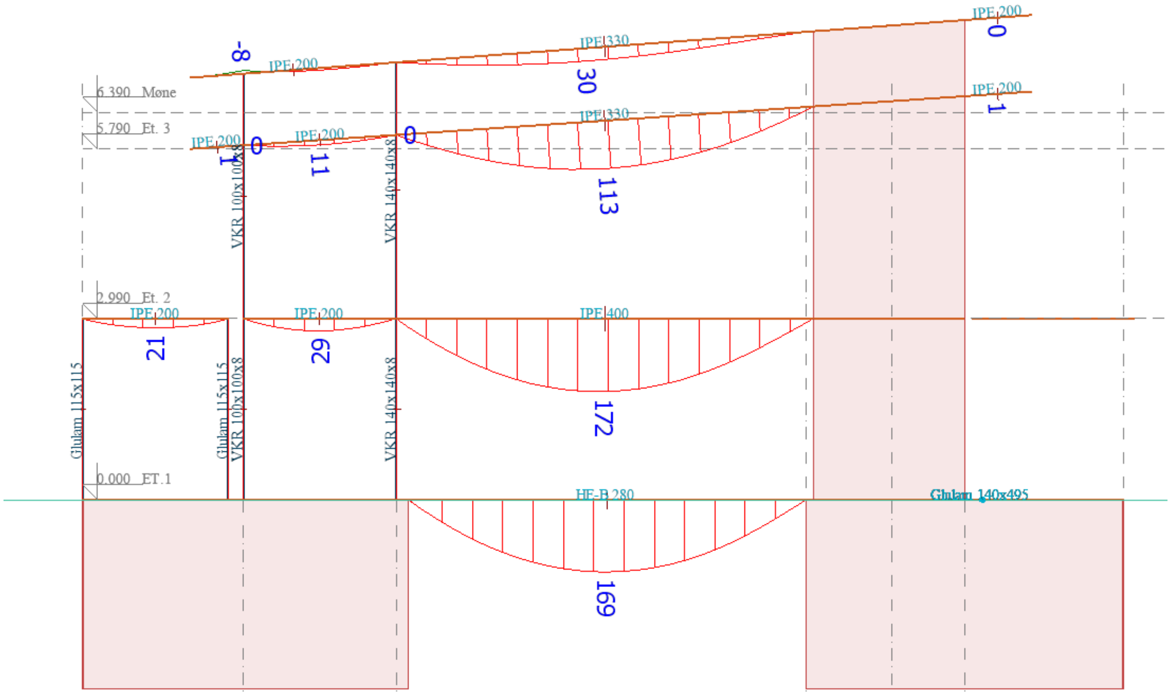
- Deformation

Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Service - only vertical loads (1,0 SW+1,0 dead+1,0 P+1,0 S) - Translational displacements - Graph - [mm]
View: Axis 2



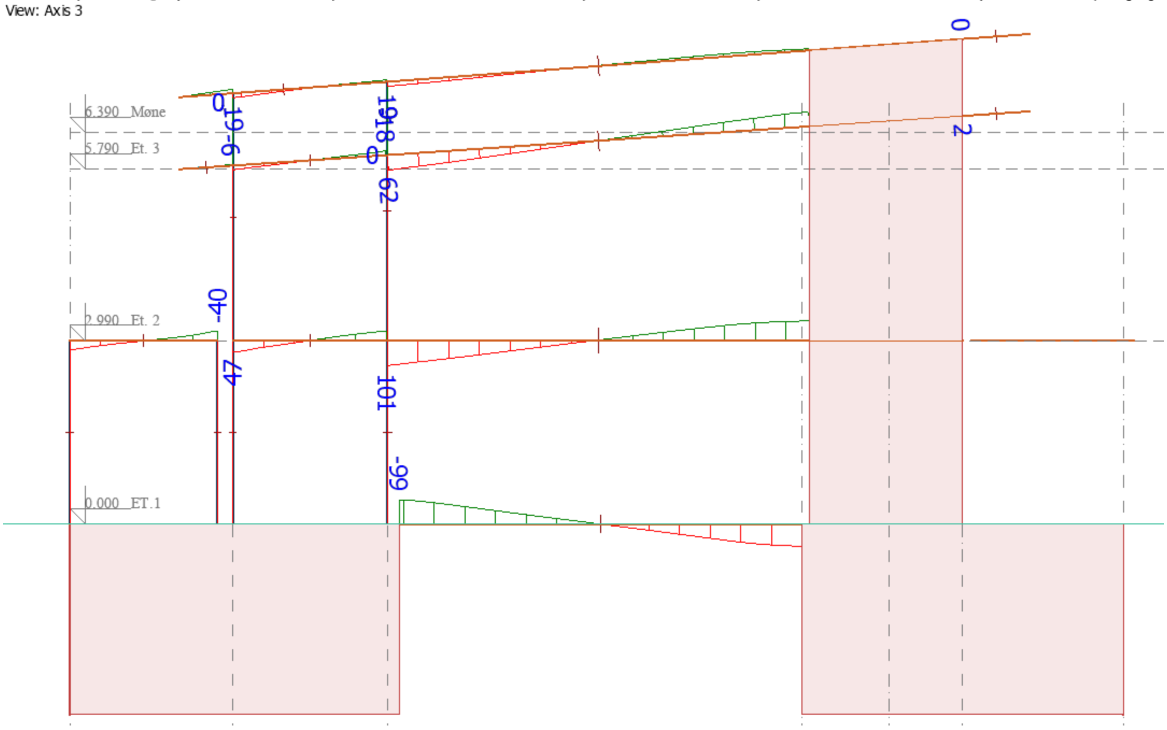
- Axis 3
  - Bending moment

Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S) - Bars, My' - Graph - [kNm]
View: Axis 3



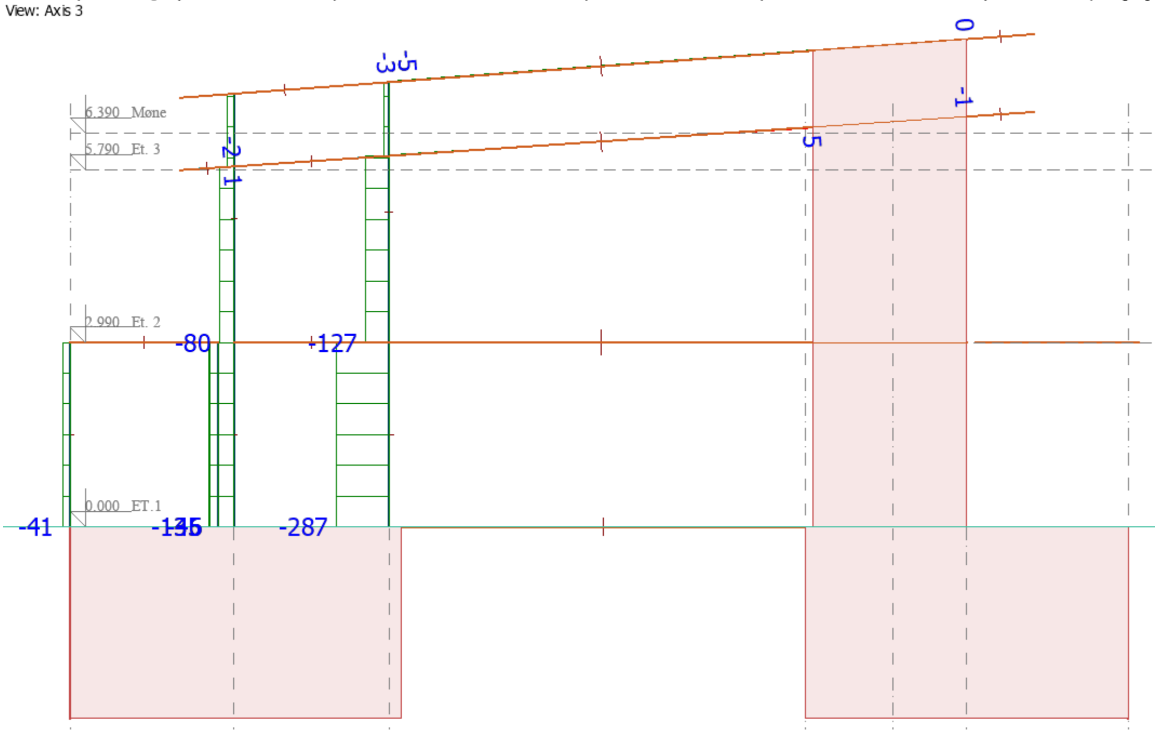
  - Shear force

Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S) - Bars, Tz' - Graph - [kN]
View: Axis 3

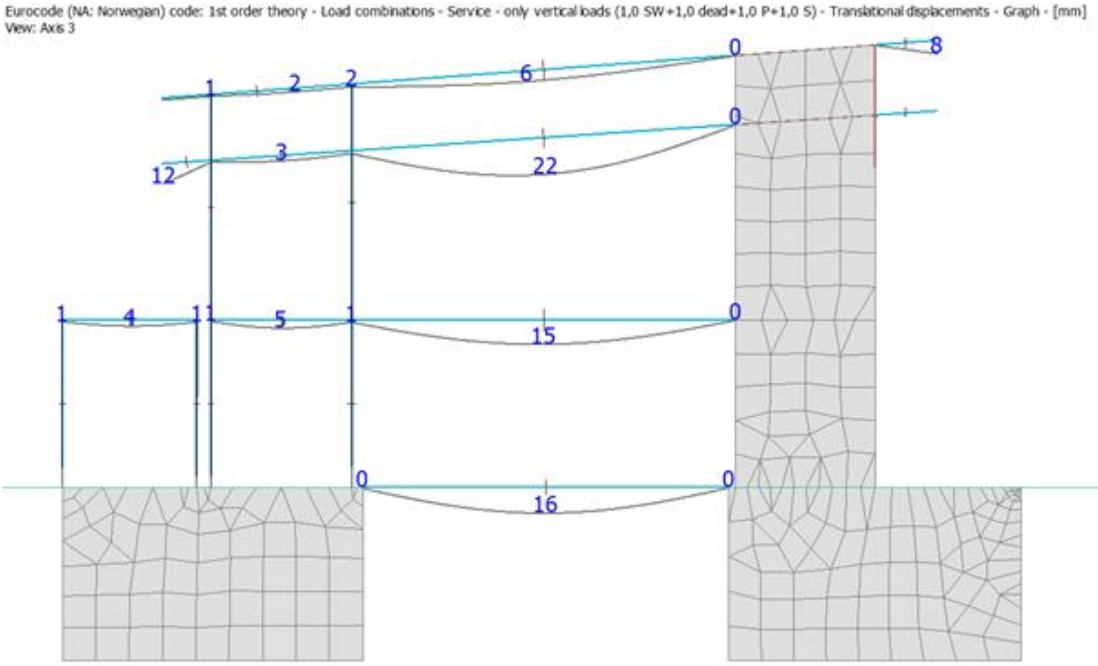


- Axial forces

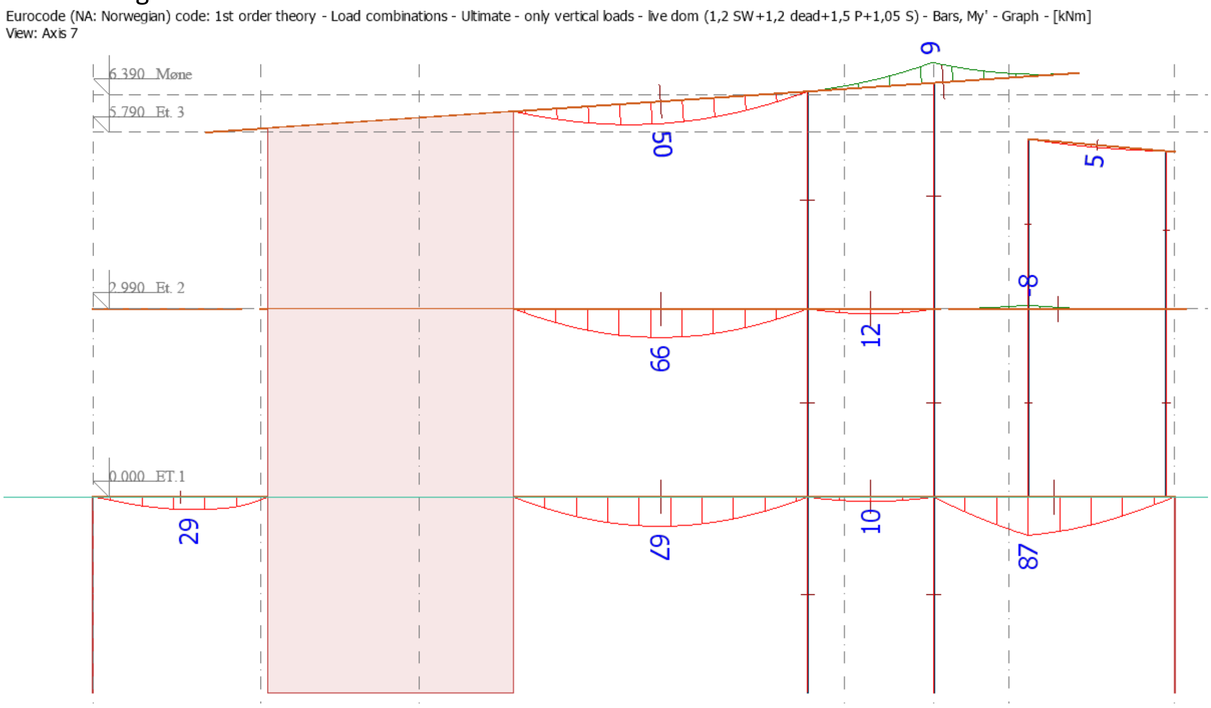
Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S) - Bars, N - Graph - [kN]
View: Axis 3



- Deformation

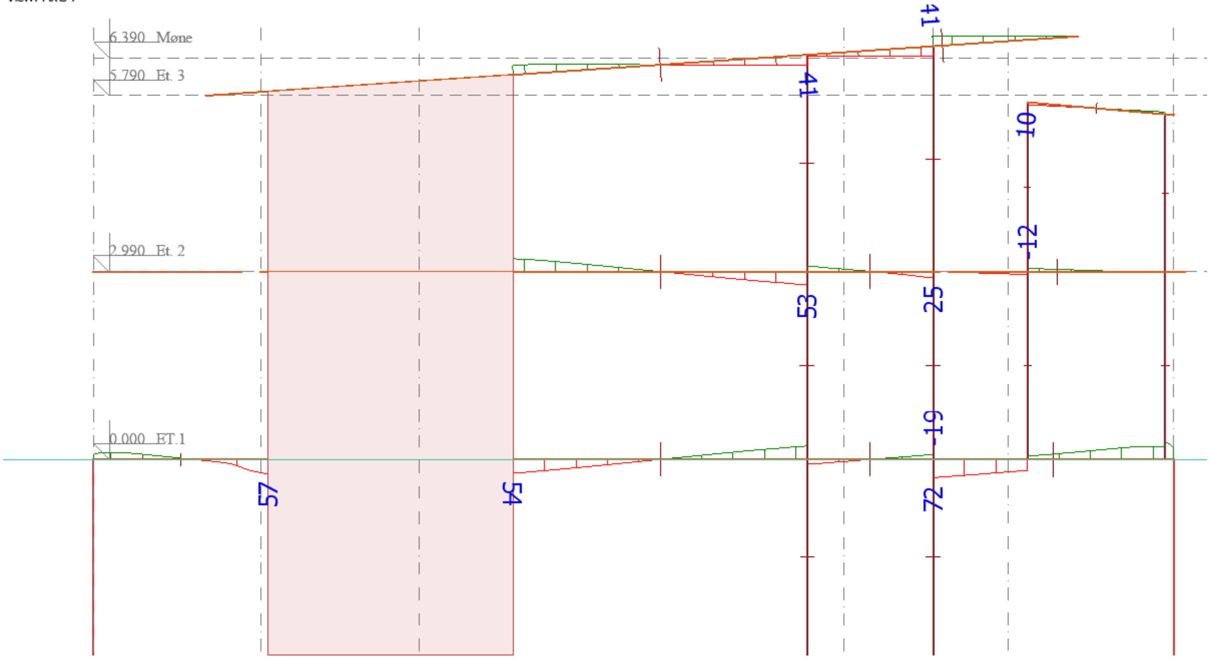


- Axis 7
  - Bending moment



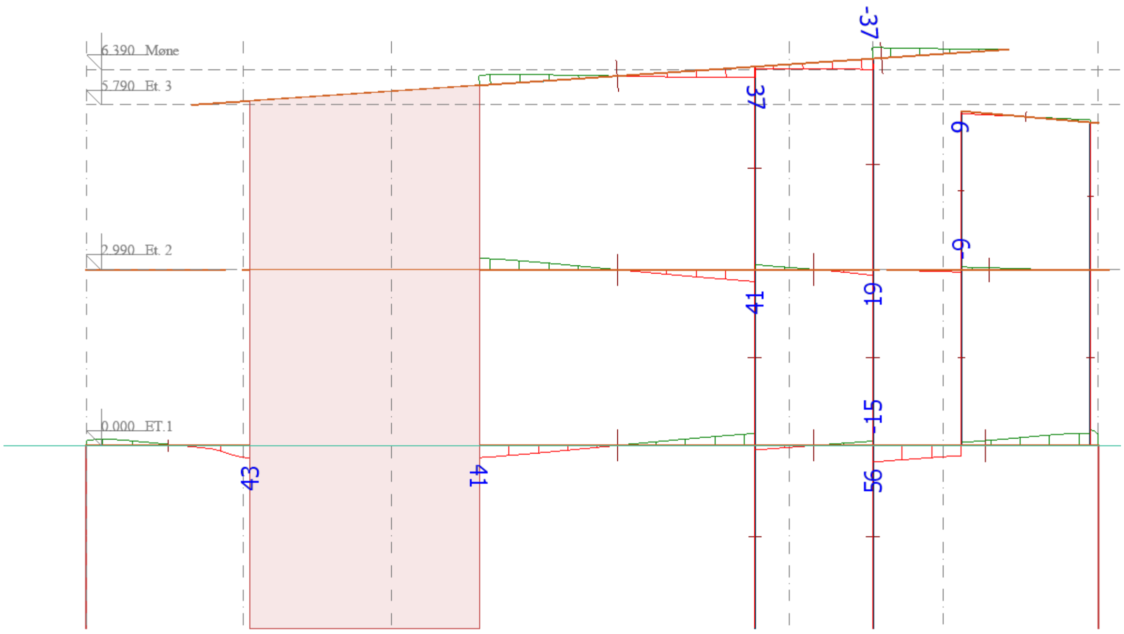
  - Shear force diagram

Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S) - Bars, Tz' - Graph - [kN]
View: Axis 7



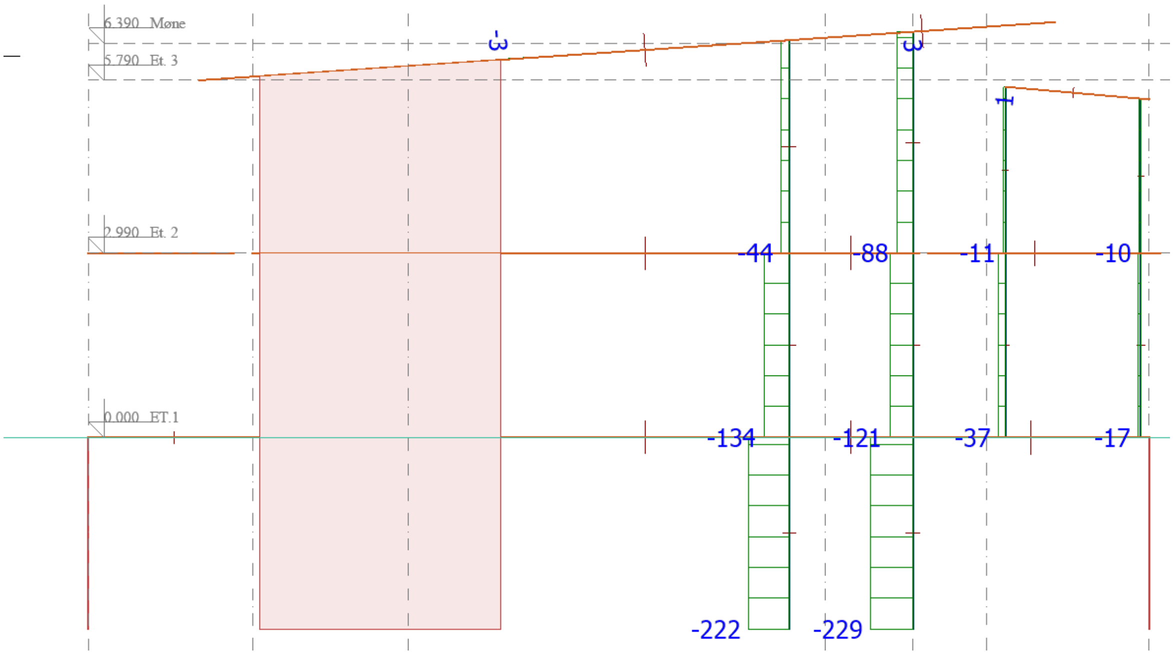
- Shear force diagram at service state

Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Service - only vertical loads (1,0 SW+1,0 dead+1,0 P+1,0 S) - Bars, Tz' - Graph - [kN]
View: Axis 7



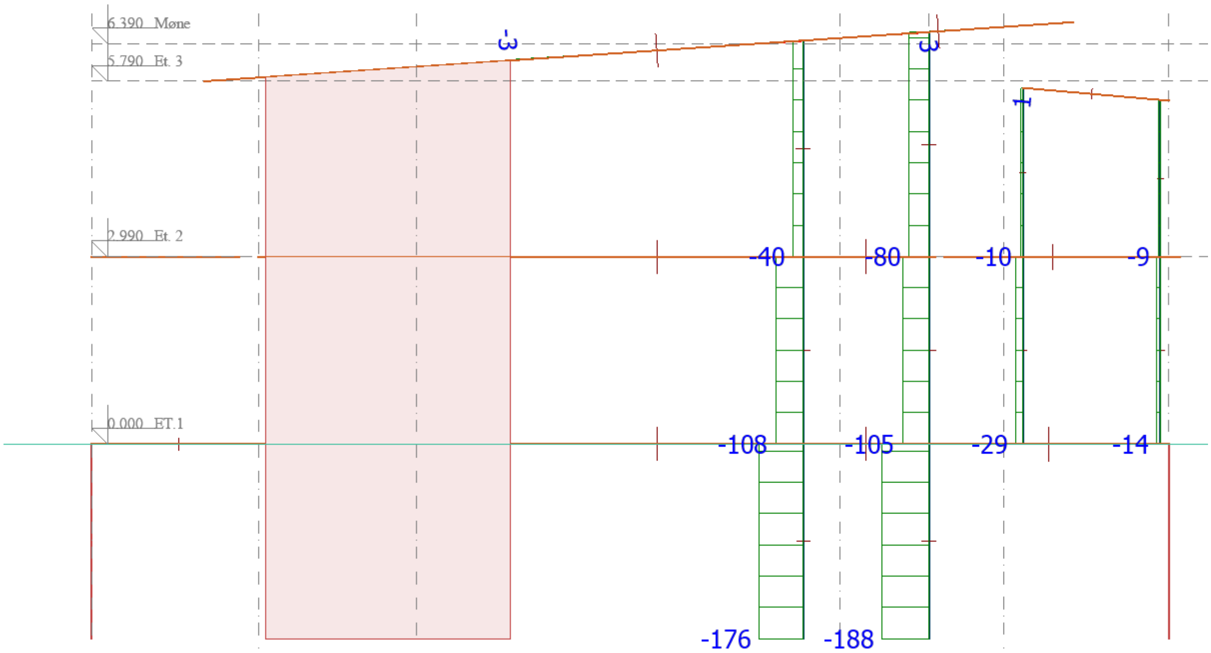
- Normal force diagram

Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S) - Bars, N - Graph - [kN]
View: Axis 7

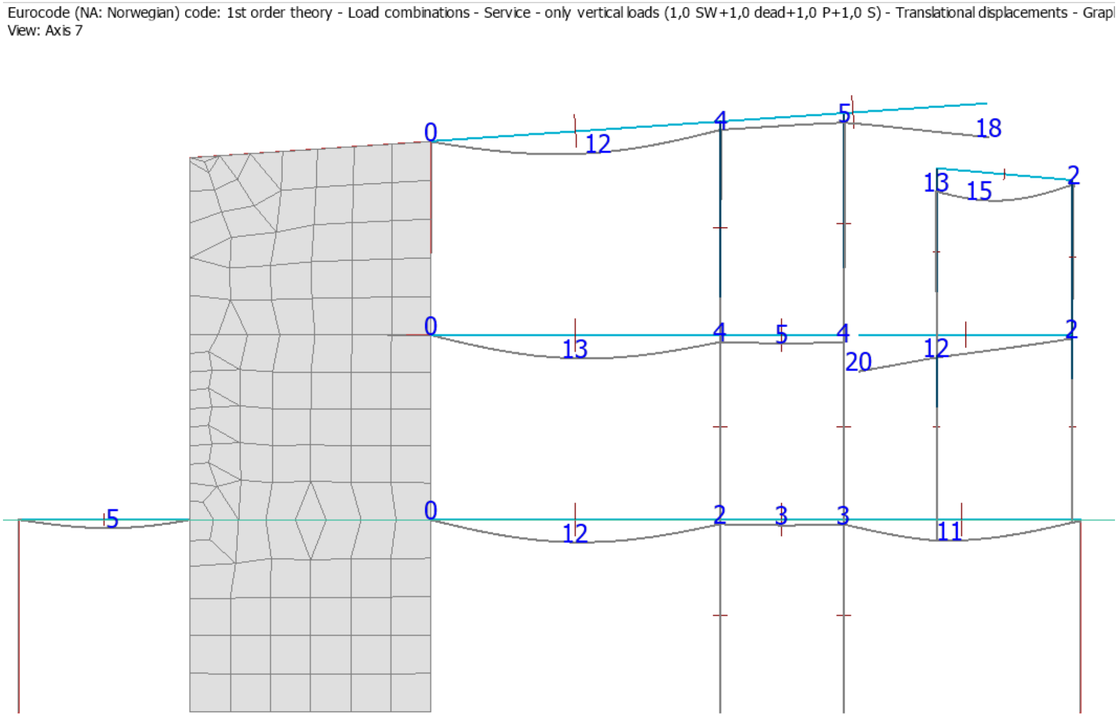


- Normal force diagram at service state

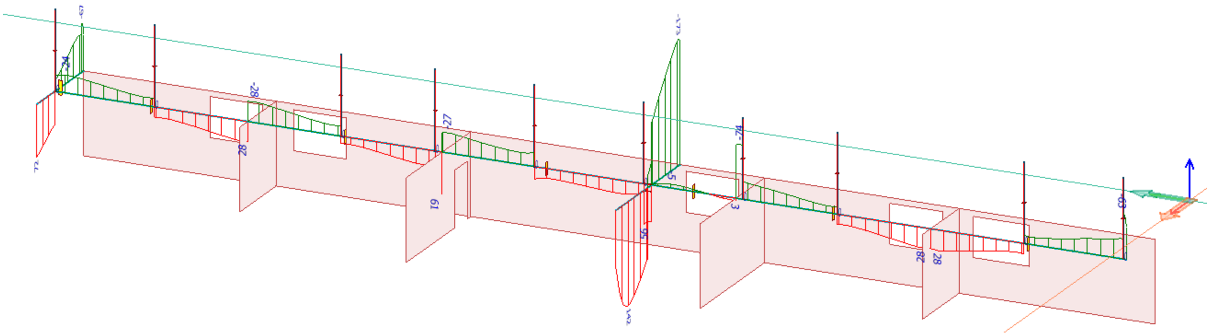
Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Service - only vertical loads (1,0 SW+1,0 dead+1,0 P+1,0 S) - Bars, N - Graph - [kN]
View: Axis 7



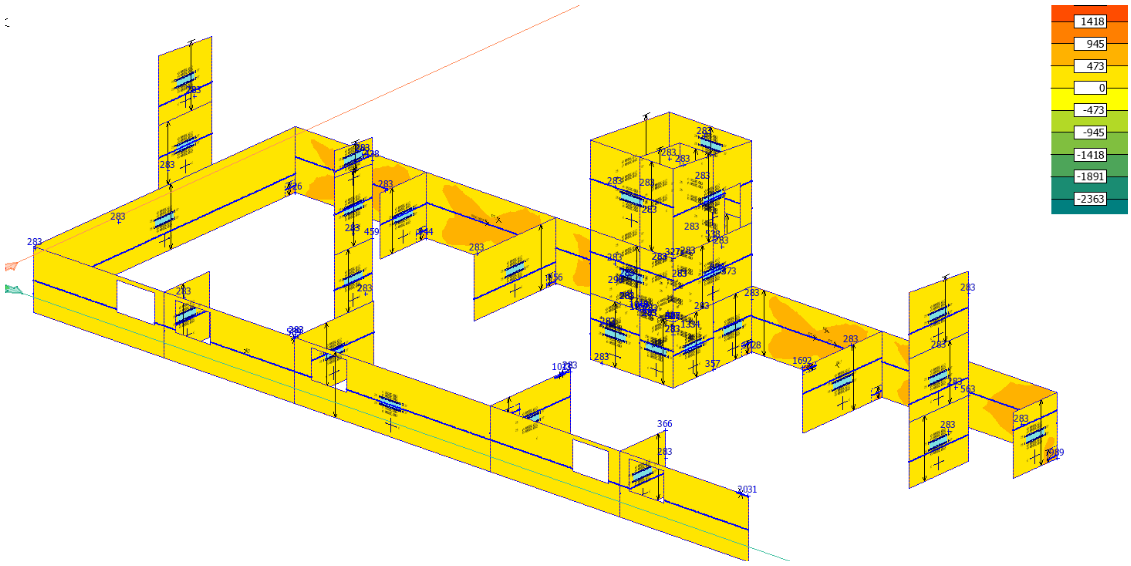
- Deflection

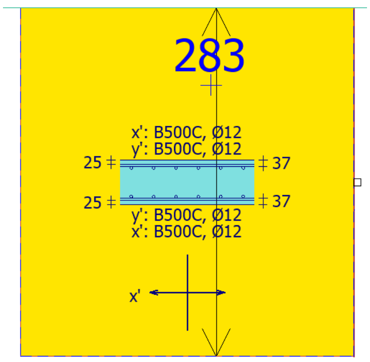


Beams which carry point loads from columns at the balcong:



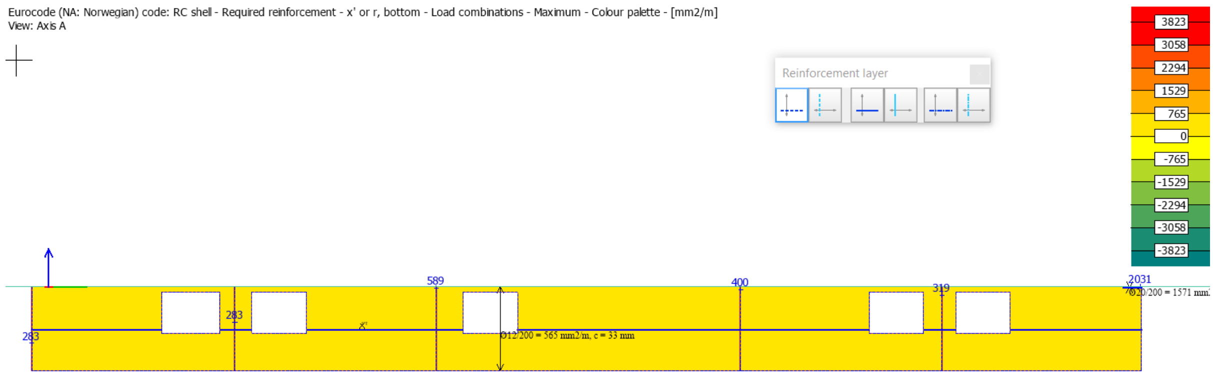
2.3. RCC design



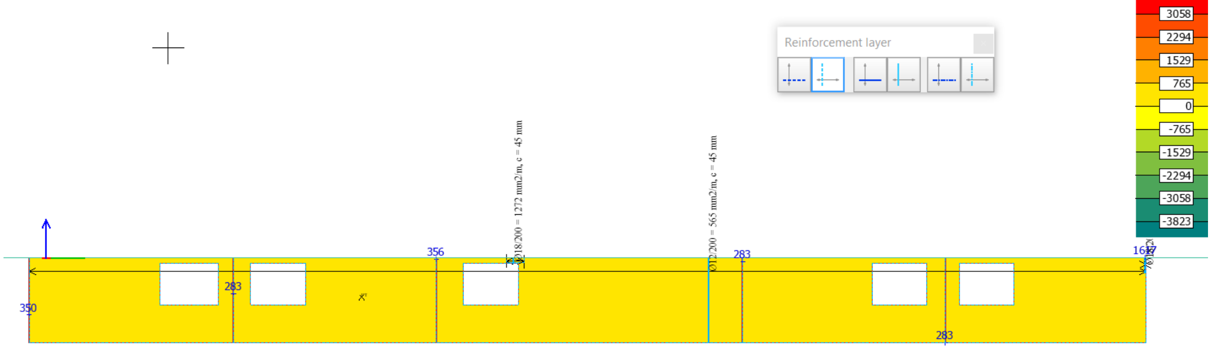


Double layer reinforcement on all walls

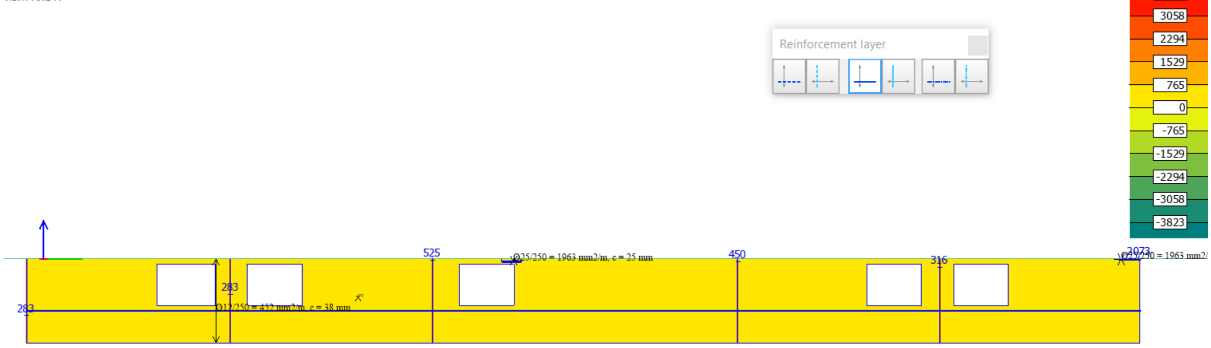
- Axis A



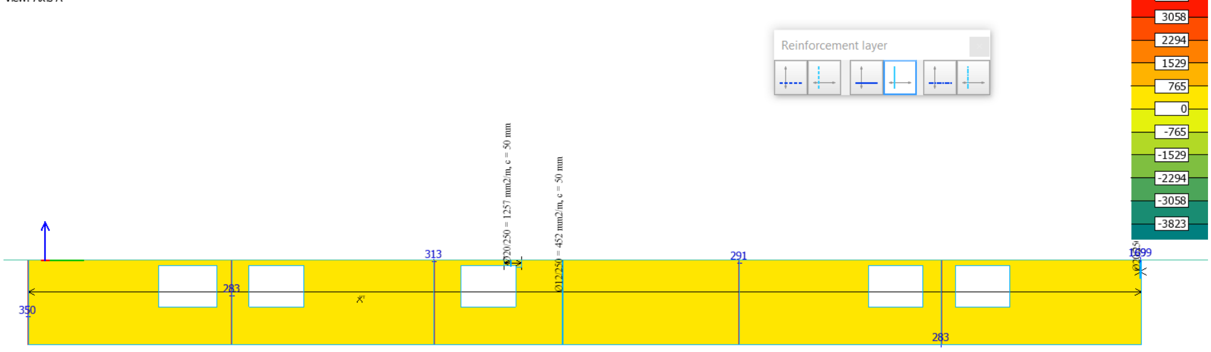
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, bottom - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis A



Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, top - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis A

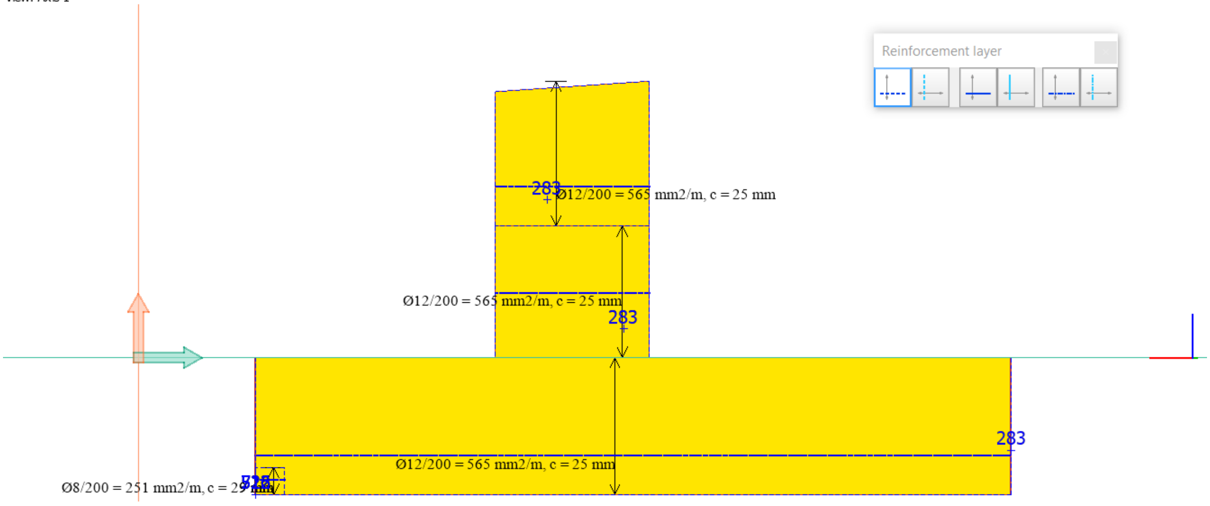


Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, top - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis A

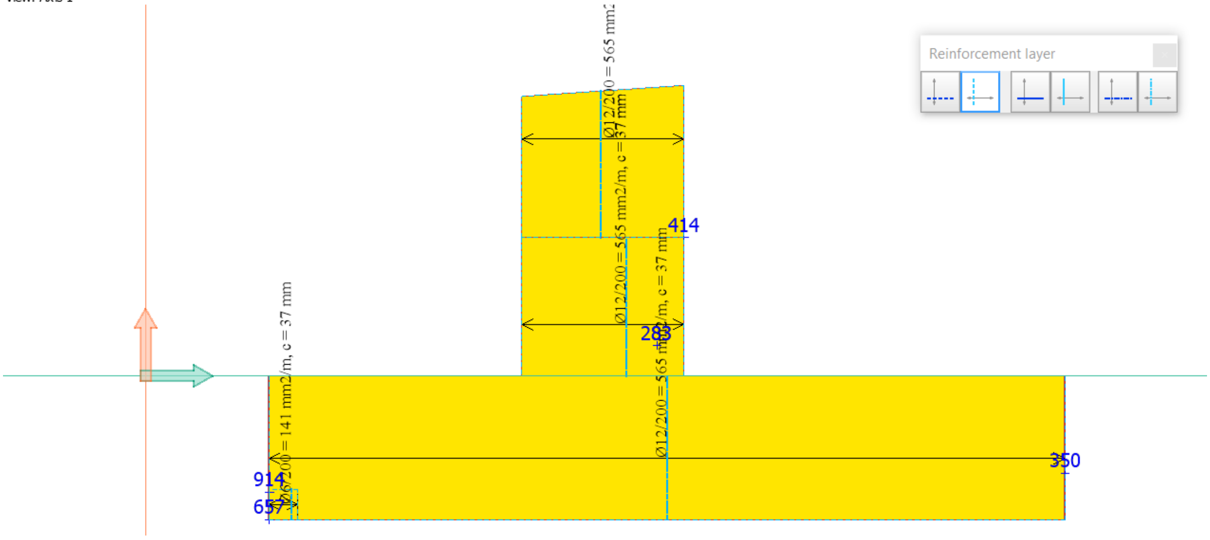


- ### Axis 1 and (axis 8 has similar reinforcement in basement floor)

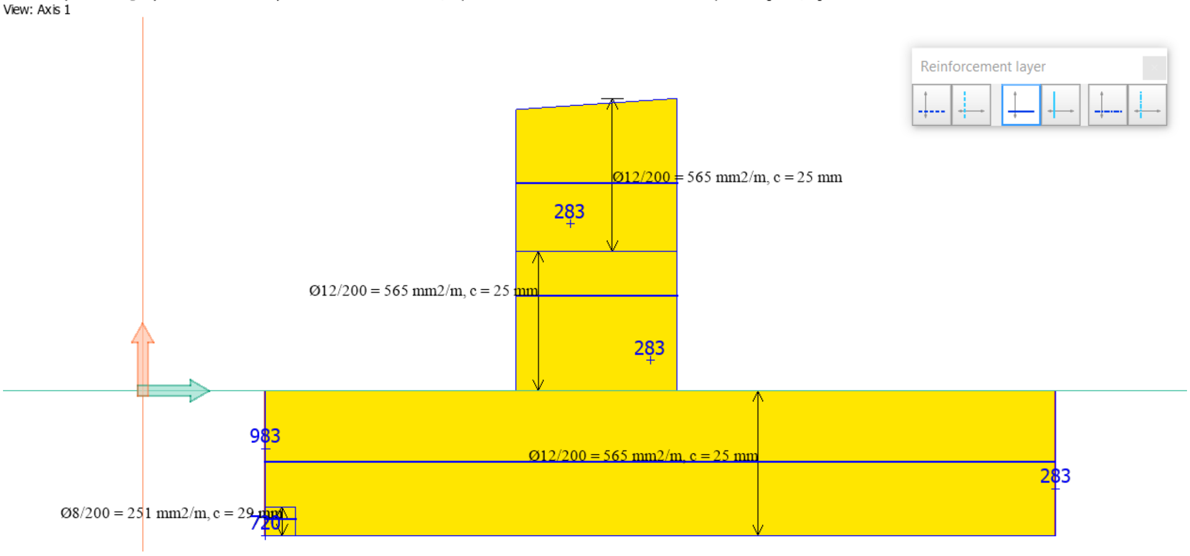
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, bottom - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 1



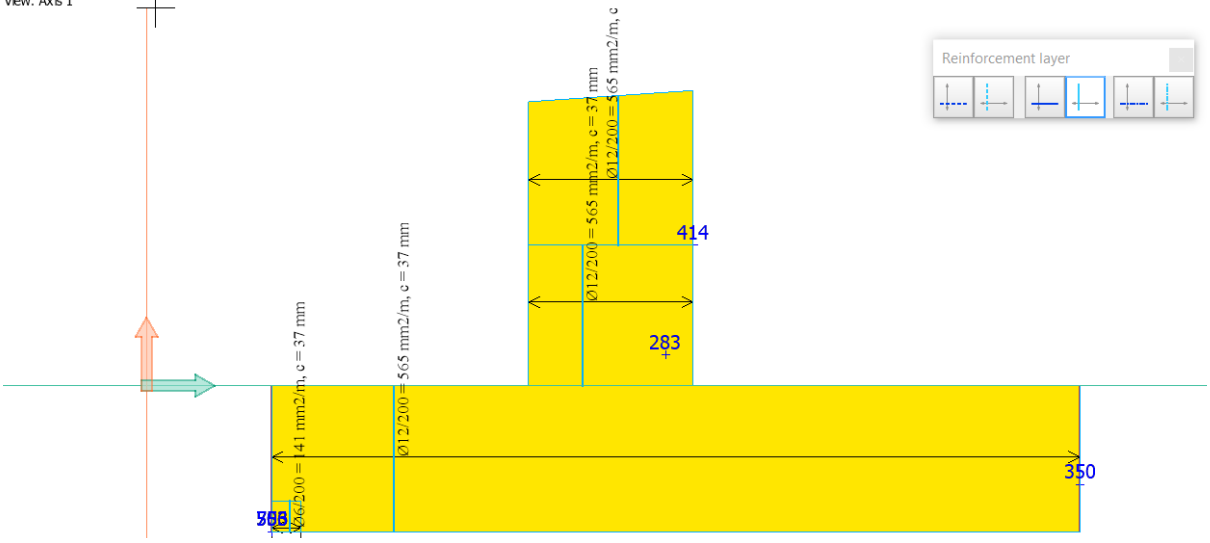
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, bottom - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 1



Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, top - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 1

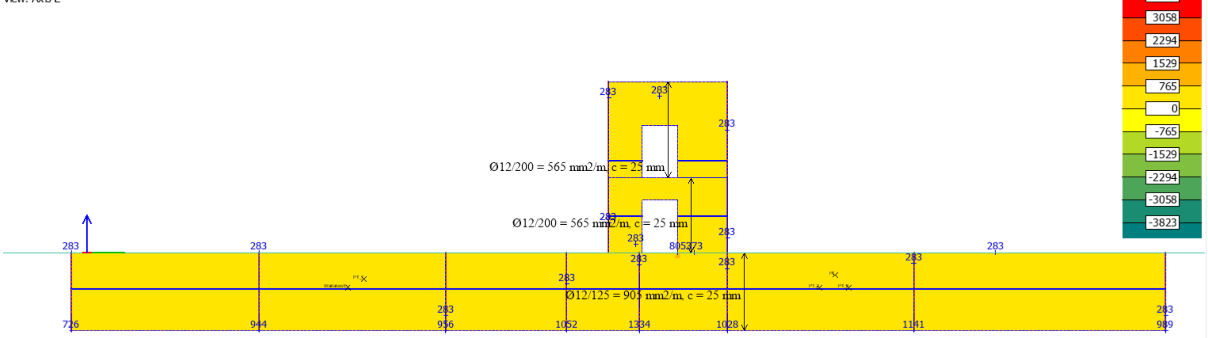


Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, top - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 1

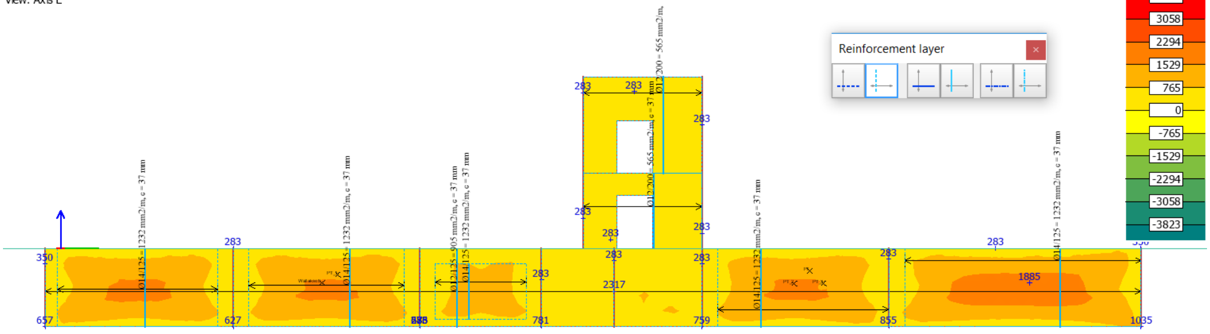


- Axis E

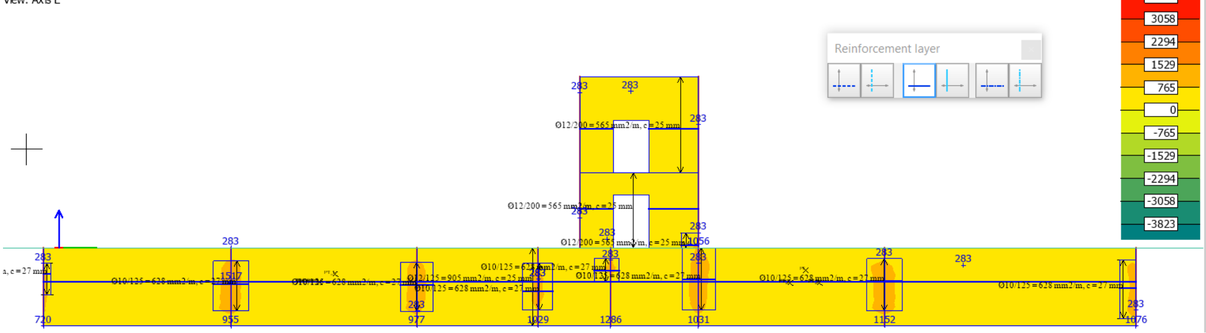
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, bottom - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis E



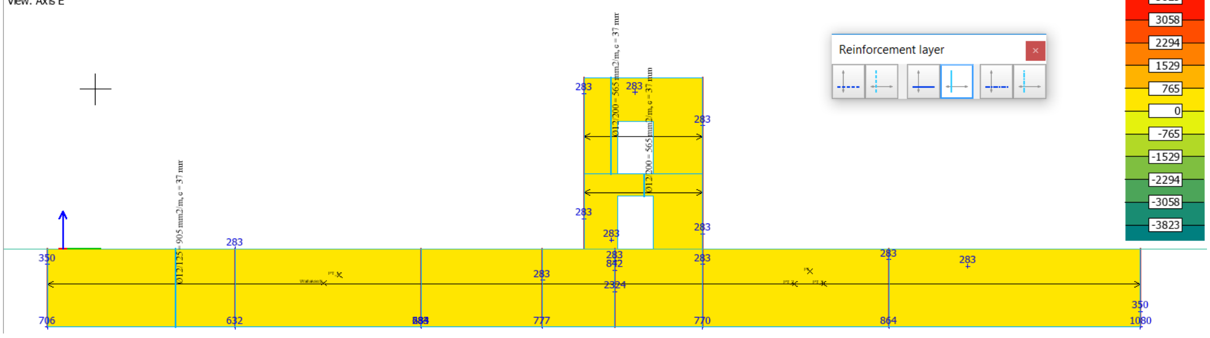
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, bottom - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis E



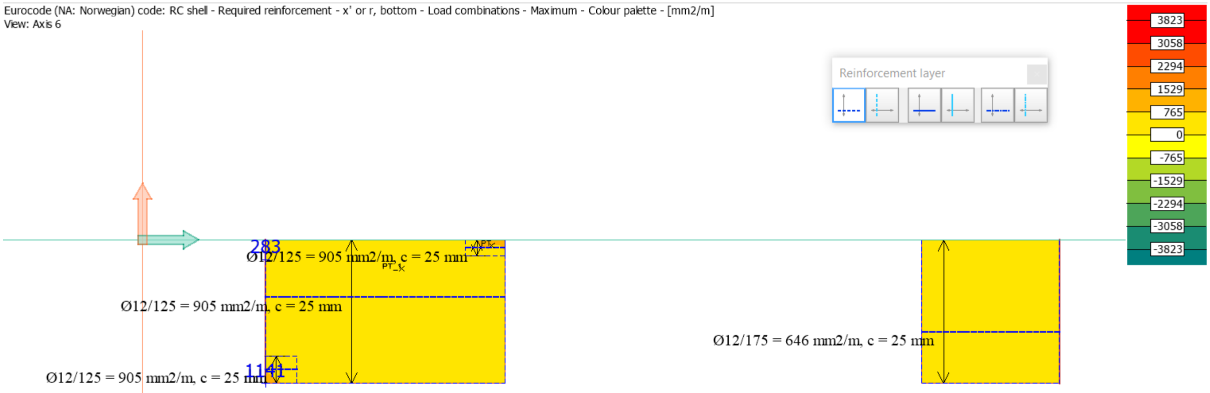
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, top - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis E

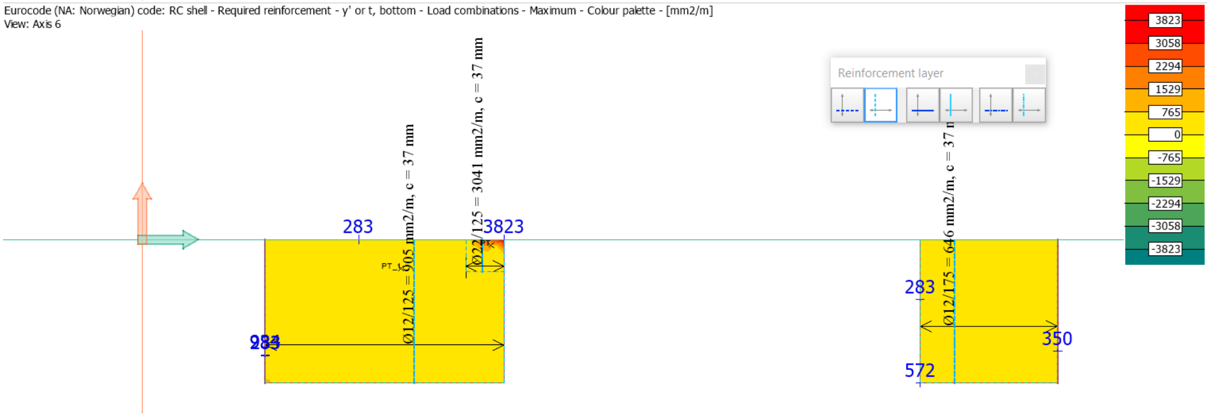


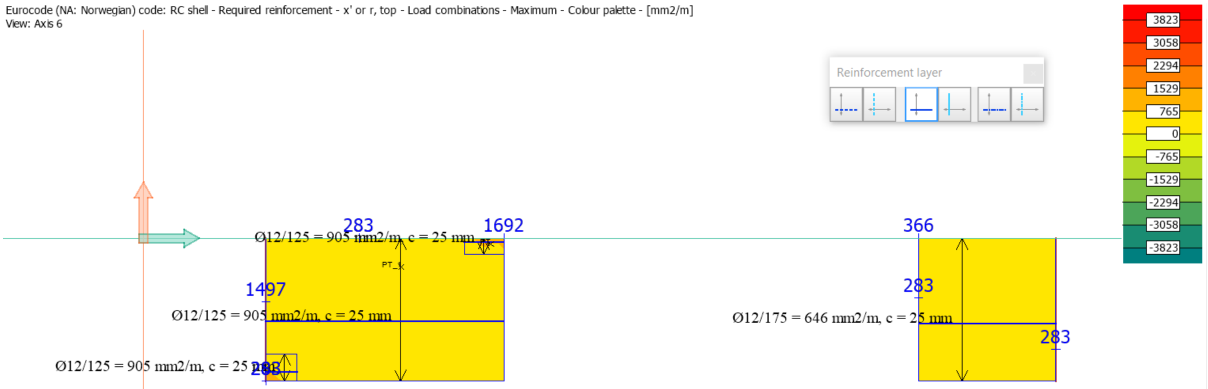
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, top - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis E

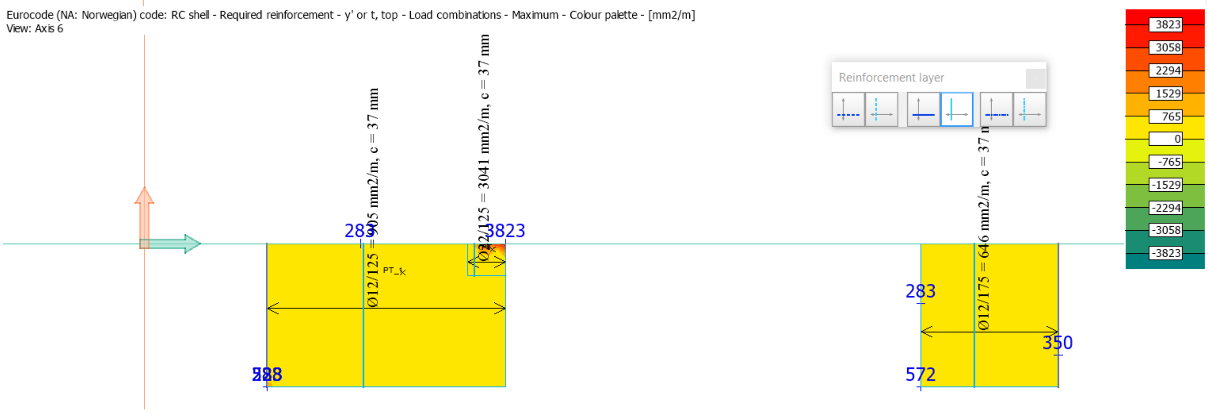


- Axis 6 and (axis 2 has similar reinforcement distribution)



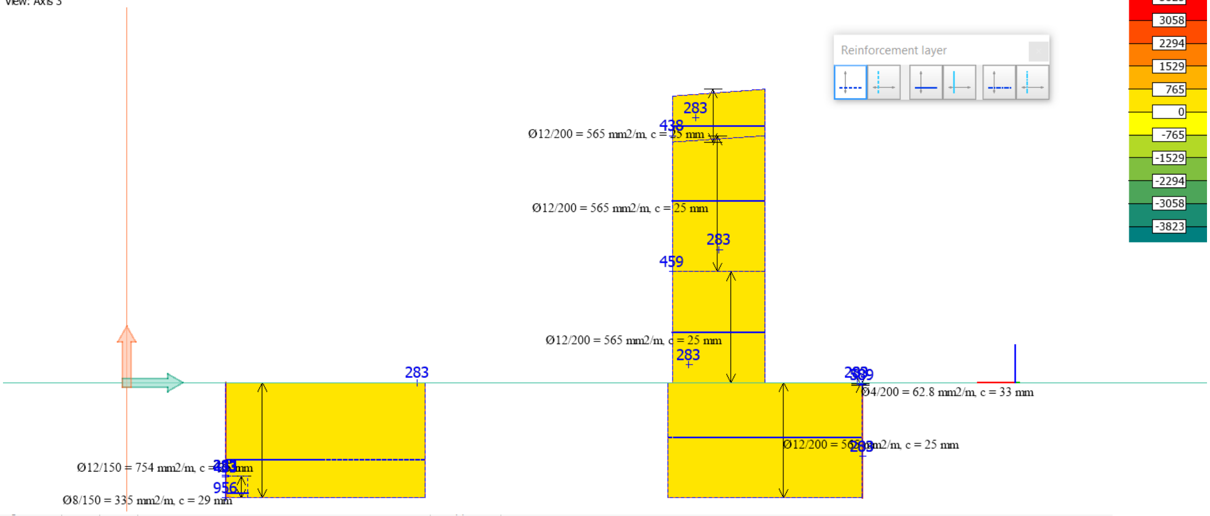




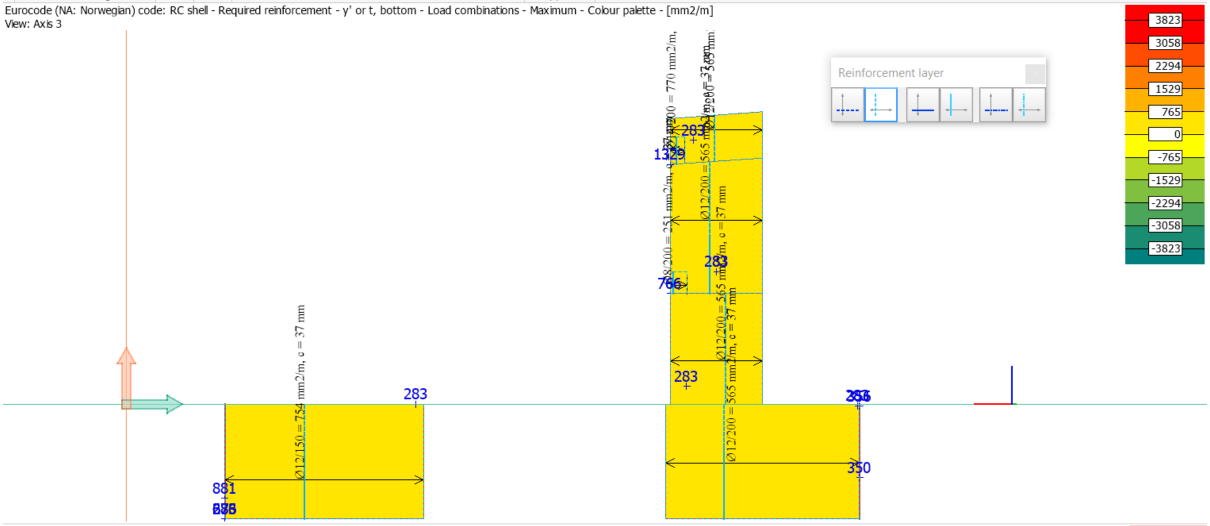


- Axis 3

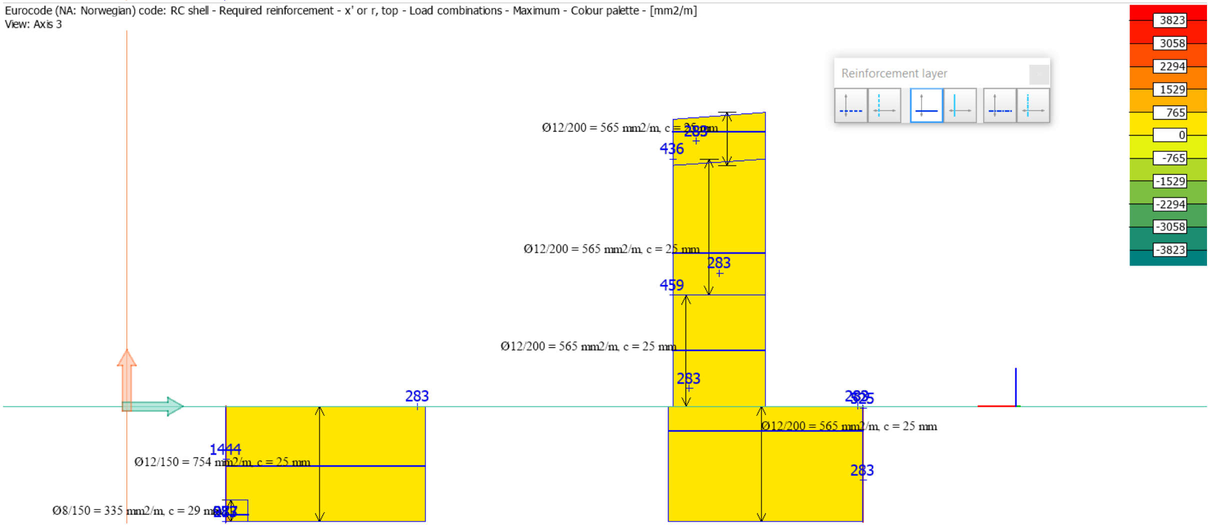
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, bottom - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 3

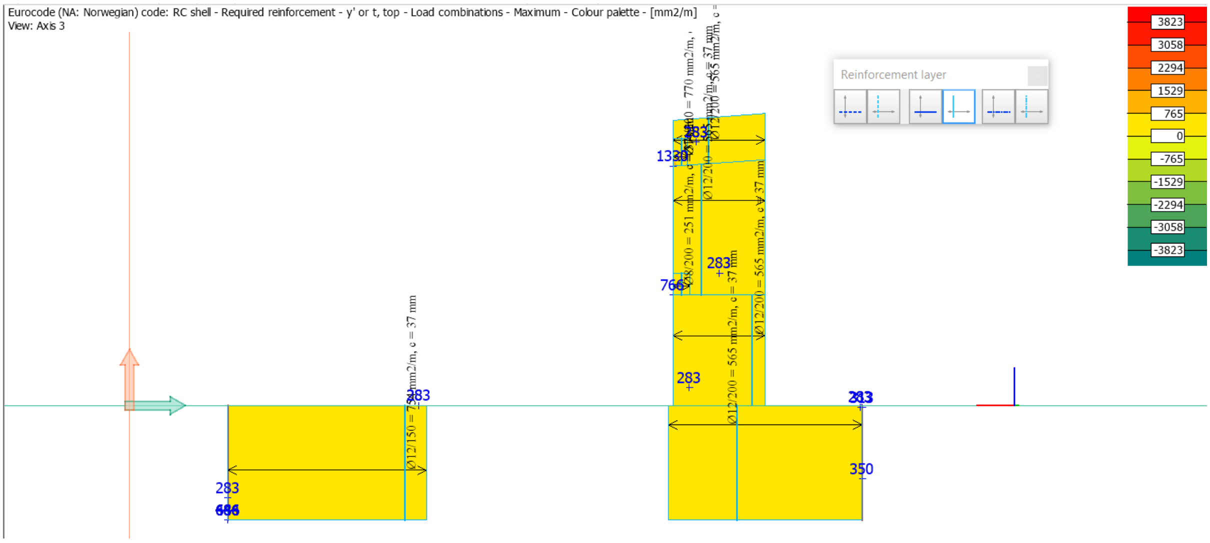


Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, bottom - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 3



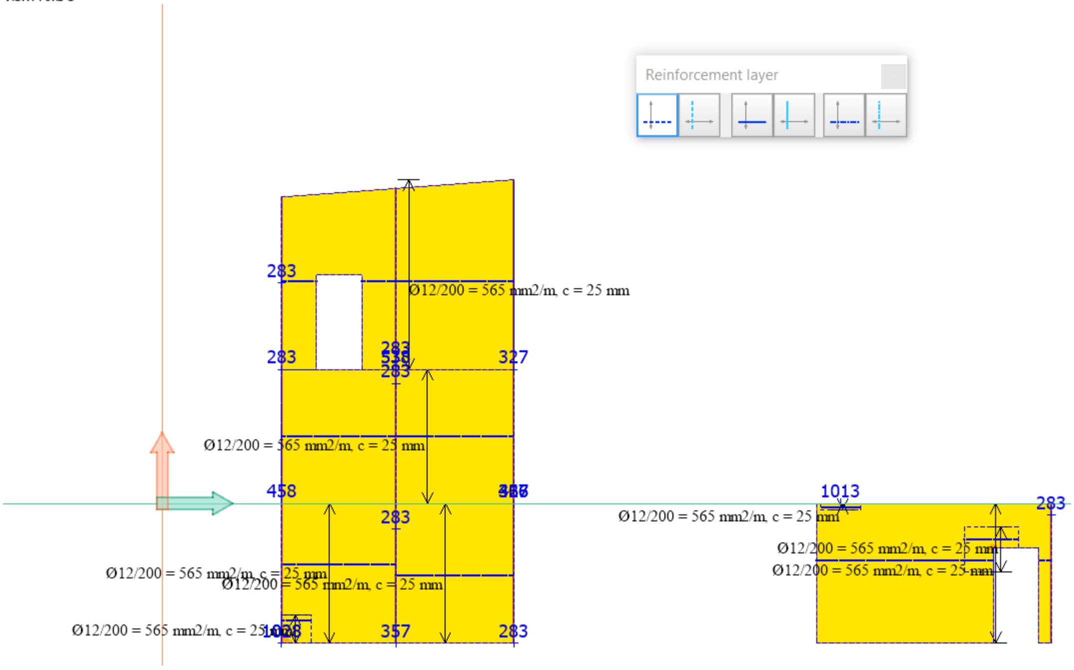
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, top - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 3



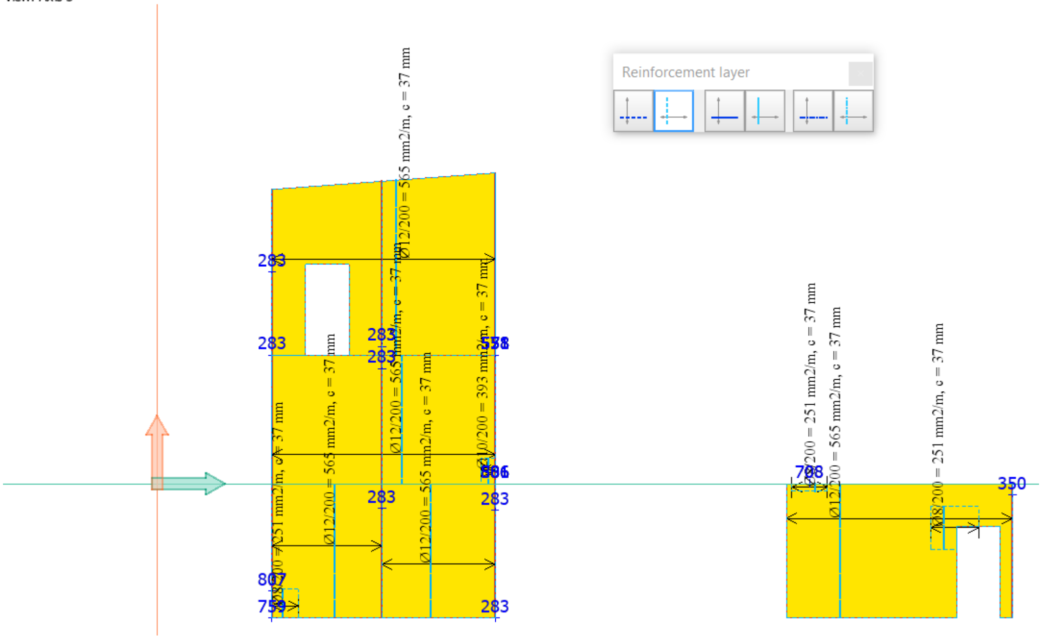


Axis 5

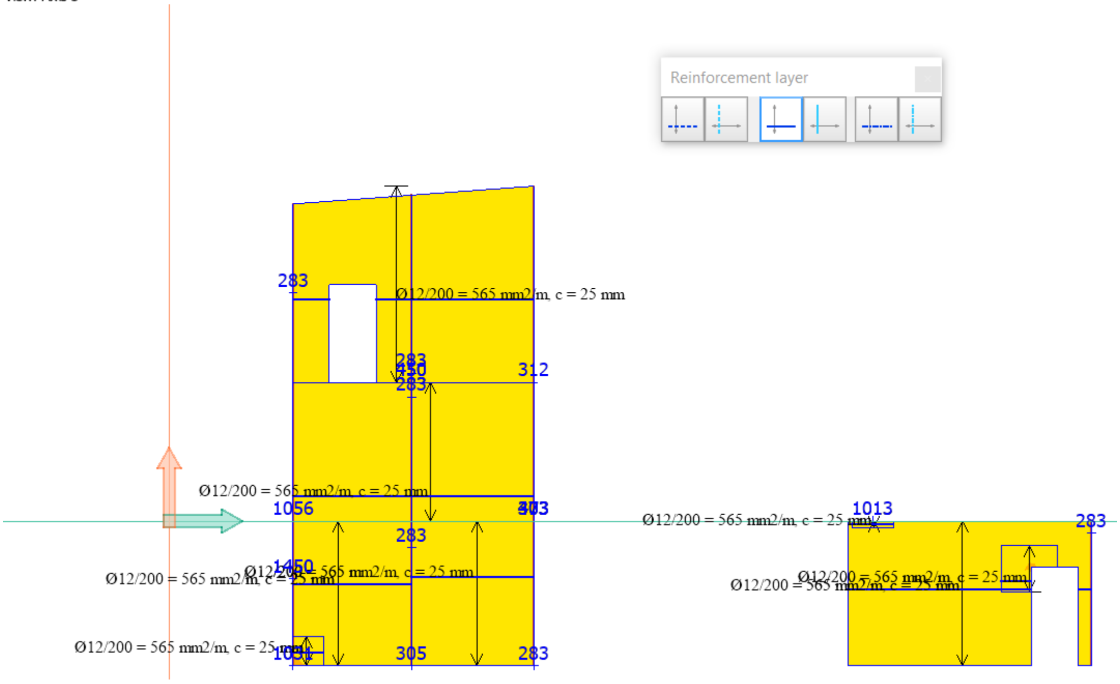
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, bottom - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 5



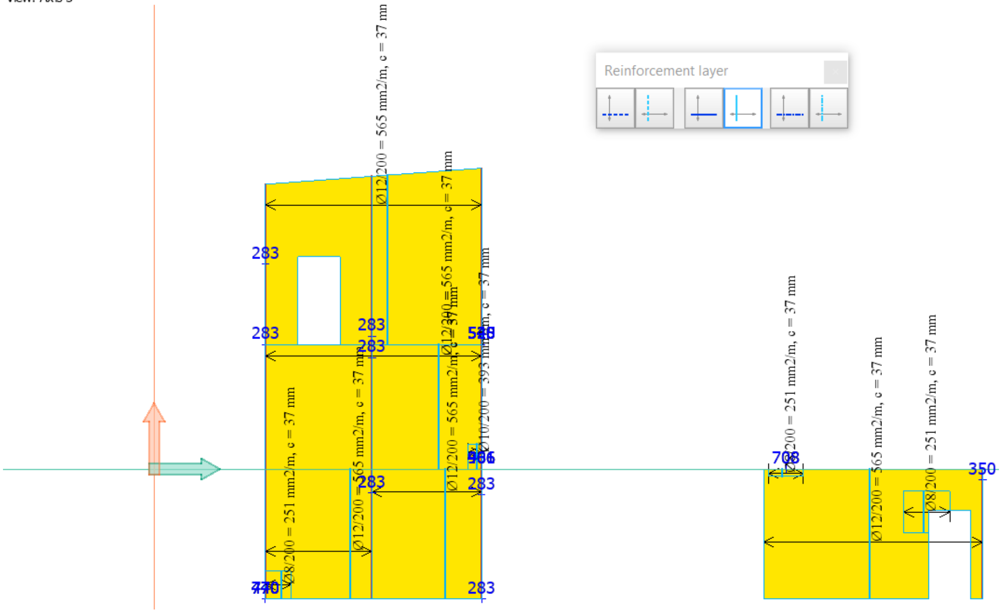
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, bottom - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 5



Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, top - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 5

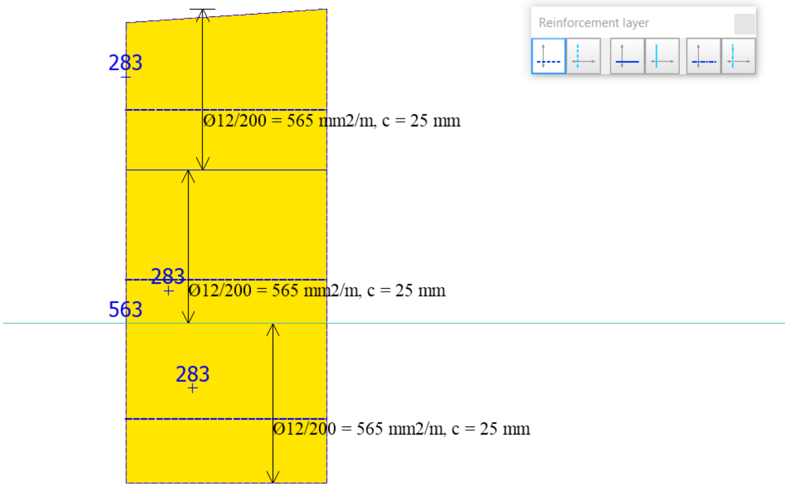


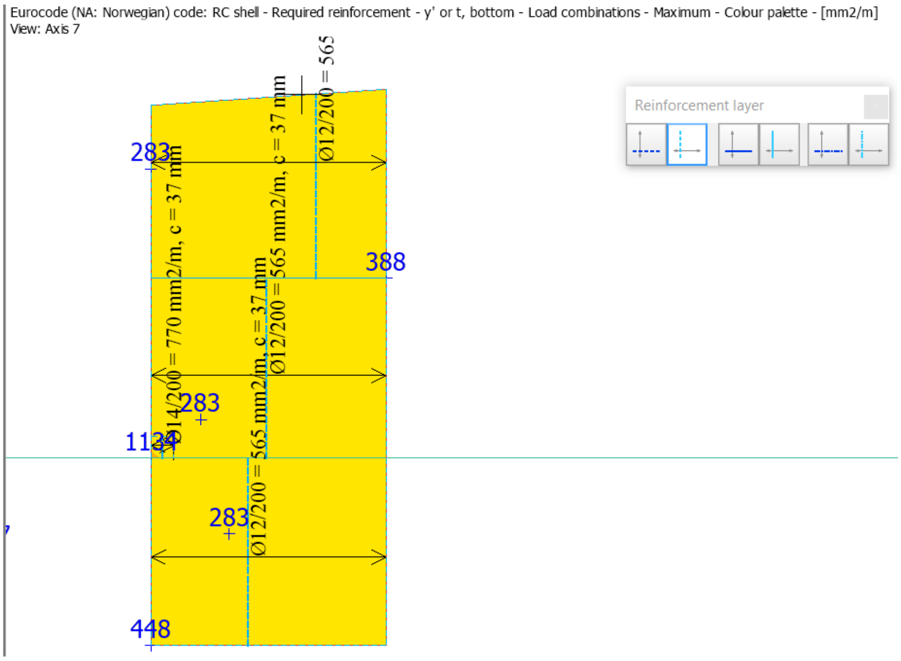
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, top - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 5

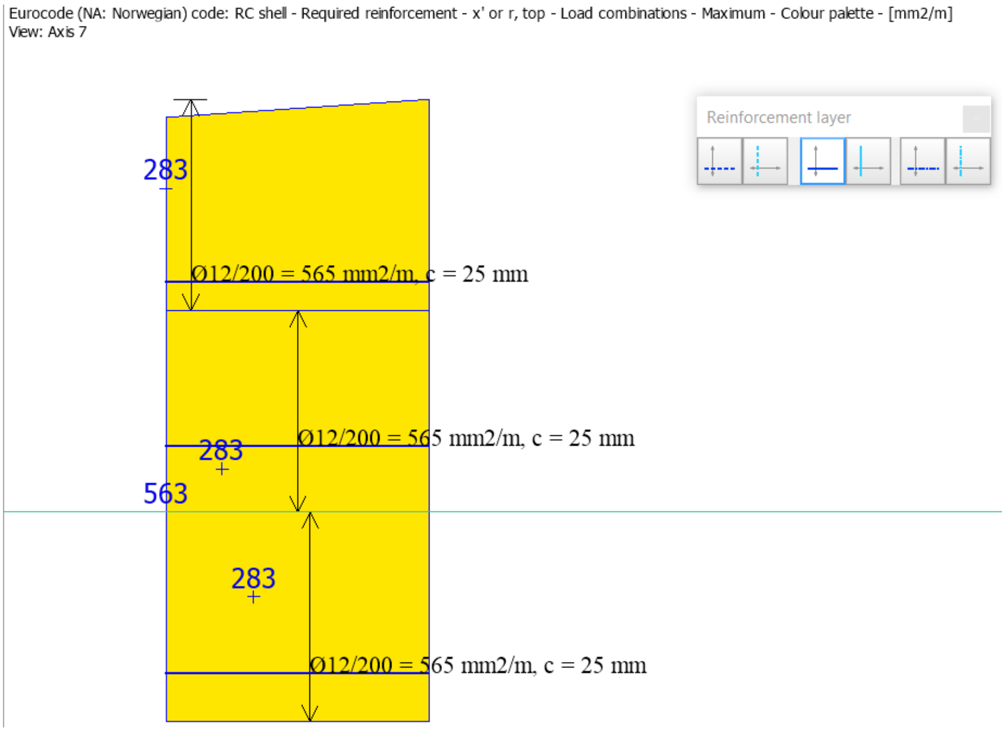


Axis 7

Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, bottom - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 7




Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, bottom - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 7
Reinforcement layer
Ø12/200 = 565
Ø14/200 = 770 mm2/m, c = 37 mm
Ø12/200 = 565 mm2/m, c = 37 mm
Ø12/200 = 565 mm2/m, c = 37 mm
Ø12/200 = 565
283
388
283
1134
283
448

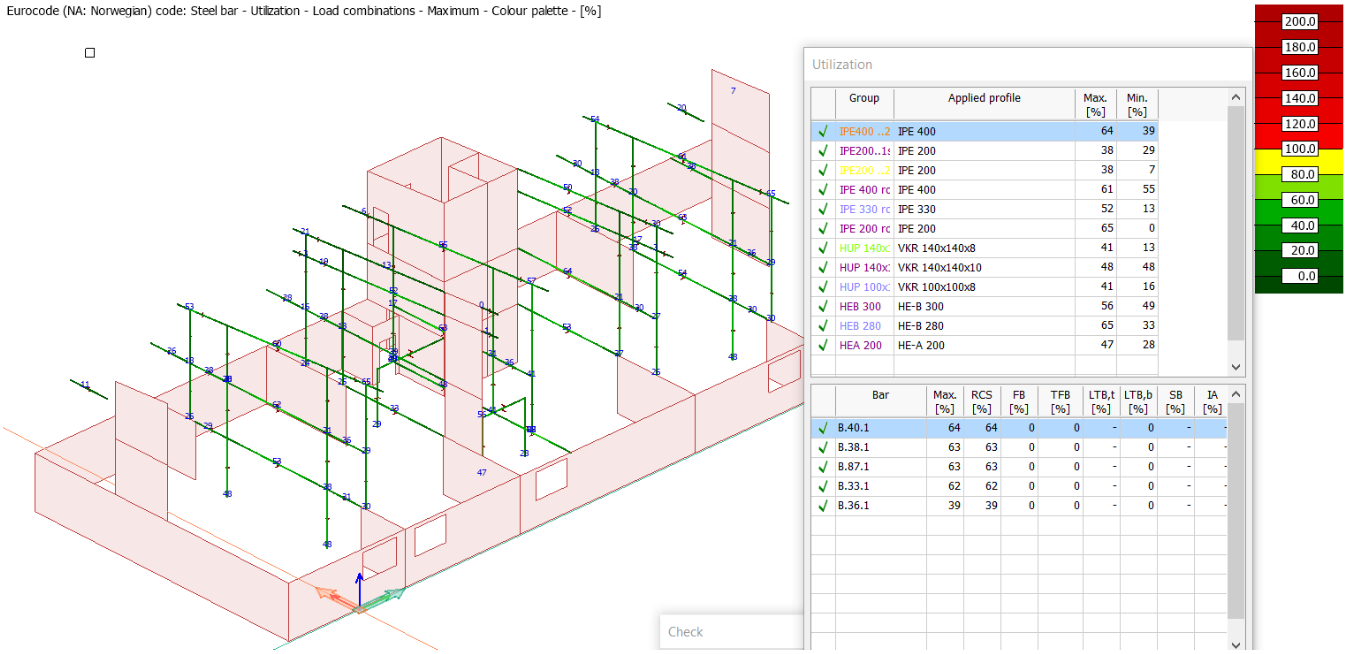

Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, top - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 7
Reinforcement layer
283
Ø12/200 = 565 mm2/m, c = 25 mm
Ø12/200 = 565 mm2/m, c = 25 mm
283
563
283
Ø12/200 = 565 mm2/m, c = 25 mm

Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, top - Load combinations - Maximum - Colour palette - [mm2/m]
View: Axis 7

2.4. Steel design

3.1.1. Steel utilization:

Eurocode (NA: Norwegian) code: Steel bar - Utilization - Load combinations - Maximum - Colour palette - [%]

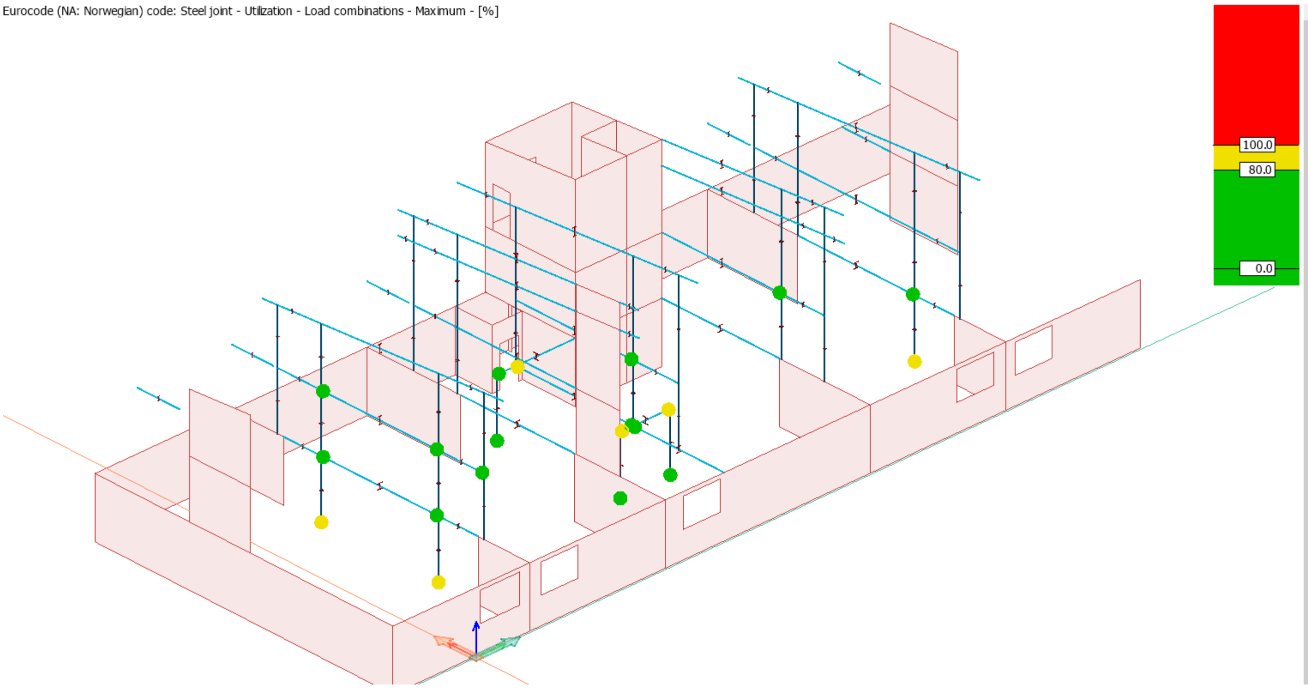


	Group	Applied profile	Max. [%]	Min. [%]
✓	IPE400 ..2	IPE 400	64	39
✓	IPE200..1	IPE 200	38	29
✓	IPE200 ..2	IPE 200	38	7
✓	IPE 400 rc	IPE 400	61	55
✓	IPE 330 rc	IPE 330	52	13
✓	IPE 200 rc	IPE 200	65	0
✓	HUP 140x	VKR 140x140x8	41	13
✓	HUP 140x	VKR 140x140x10	48	48
✓	HUP 100x	VKR 100x100x8	41	16
✓	HEB 300	HE-B 300	56	49
✓	HEB 280	HE-B 280	65	33
✓	HEA 200	HE-A 200	47	28

	Bar	Max. [%]	RCS [%]	FB [%]	TFB [%]	LTB,t [%]	LTB,b [%]	SB [%]	IA [%]
✓	B.40.1	64	64	0	0	-	0	-	-
✓	B.38.1	63	63	0	0	-	0	-	-
✓	B.87.1	63	63	0	0	-	0	-	-
✓	B.33.1	62	62	0	0	-	0	-	-
✓	B.36.1	39	39	0	0	-	0	-	-

3.1.2. Steel Joint utilization

Eurocode (NA: Norwegian) code: Steel joint - Utilization - Load combinations - Maximum - [%]



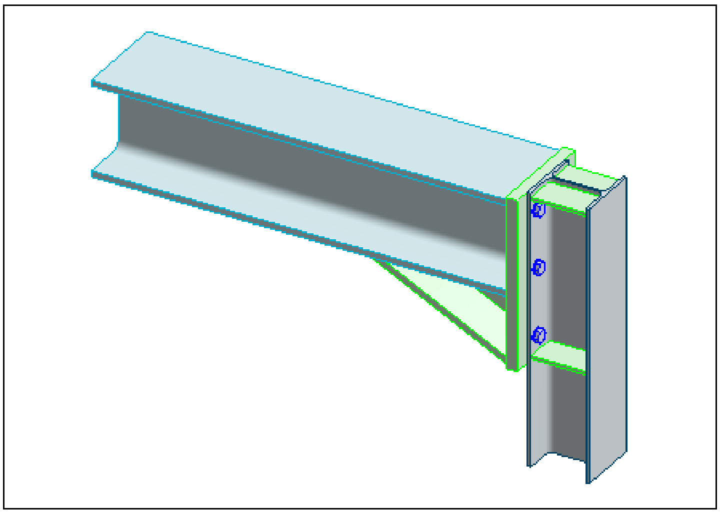
Examples from the detail results:

Max. of load combinations, Joint, Utilization

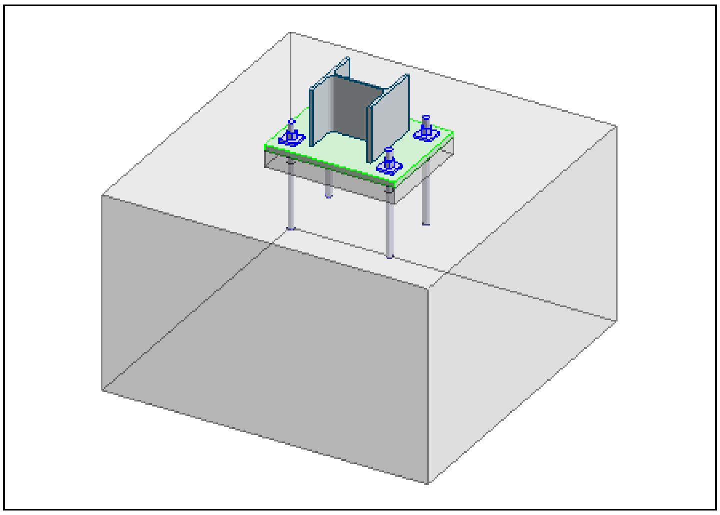
ID	Solution	Utilization	Comb
[-]	[-]	[%]	[-]
SJ.1	BC1	93	0.89*1.35*SW...
SJ.2	BC1	59	0.89*1.35*SW ...
SJ.3	BC5A	88	0.89*1.35*SW ...
SJ.4	CB1	71	0.89*1.35*SW ...
SJ.5	CB1	43	0.89*1.35*SW ...
SJ.6	CB1	44	0.89*1.35*SW ...
SJ.7	BC3	40	0.89*1.35*SW ...
SJ.8	BC3	42	0.89*1.35*SW ...
SJ.9	BC3	24	0.89*1.35*SW ...
SJ.10	BB3	37	Ultimate - only ...

ID	Solution	Utilization	Comb
[-]	[-]	[%]	[-]
SJ.11	BB3	68	0.89*1.35*SW...
SJ.12	BB3	99	0.89*1.35*SW ...
SJ.13	CB2	84	0.89*1.35*SW ...
SJ.14	CB2	84	0.89*1.35*SW ...
SJ.15	CB2	84	0.89*1.35*SW ...
SJ.16	BC3	33	0.89*1.35*SW ...
SJ.17	BC3	32	0.89*1.35*SW ...
SJ.18	BC3	34	0.89*1.35*SW ...
SJ.19	BC3	31	0.89*1.35*SW ...
SJ.20	BC3	34	0.89*1.35*SW ...

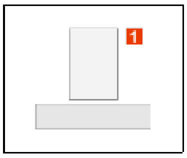
SJ.3.1
Maximum of load combinations

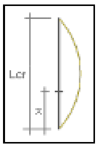


SJ.6.1
Maximum of load combinations



Member data

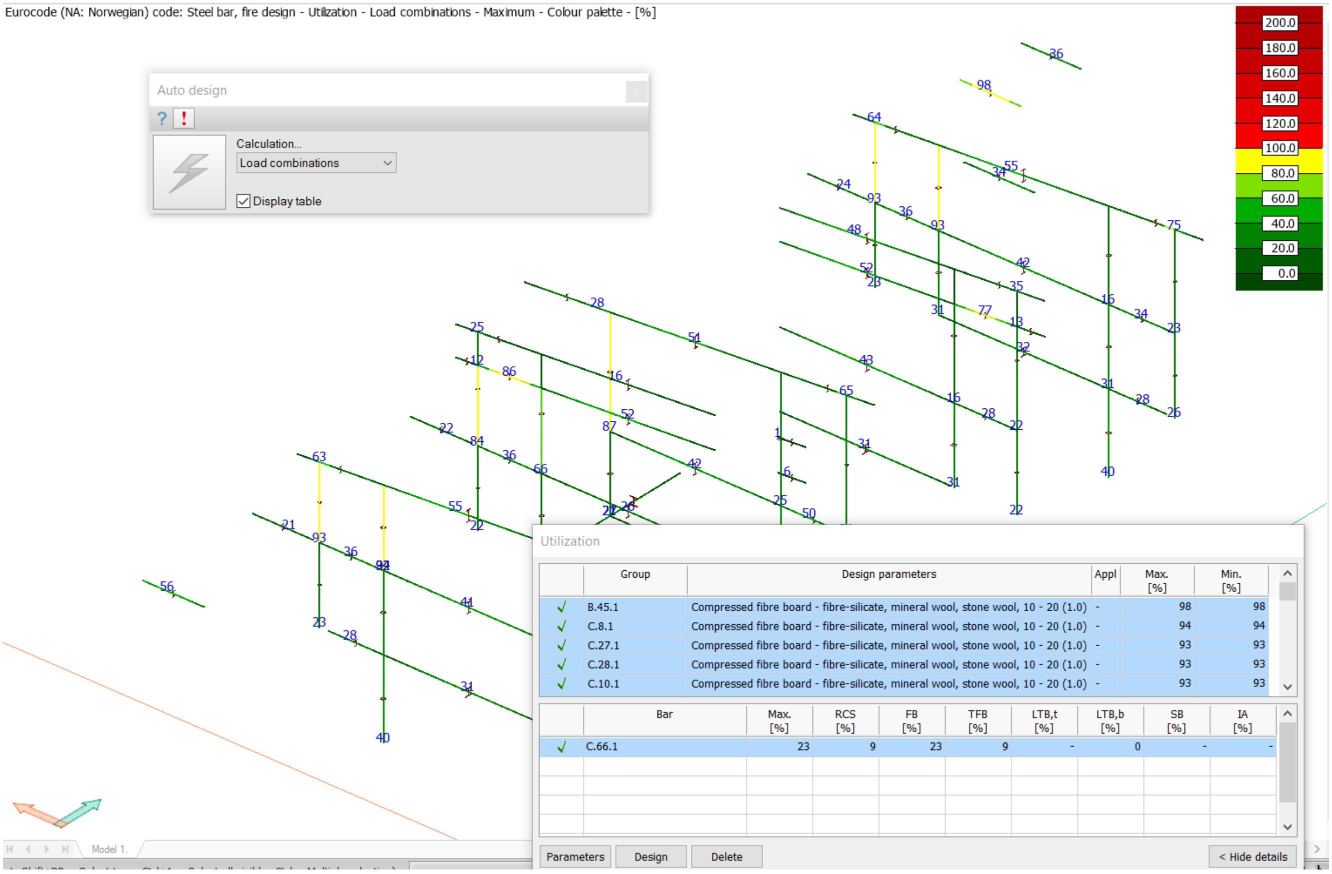




	Member 1
Cross-section	HE-A 200
Material	S 355
γ_{M0}	1.05
γ_{M1}	1.05
γ_{M2}	1.25
γ_{M5}	1.00
Lcr, y [m]	6.00
Lcr, z [m]	6.00

3.1.3. Steel – Fire design

Rockwool Conlit 150 fire protection is assumed to be used. 20 mm of Conlit 150 is used as insulation for fire and the maximum steel temperature is found to be below 350 ^{0}C. Design calculations are shown in figure below.



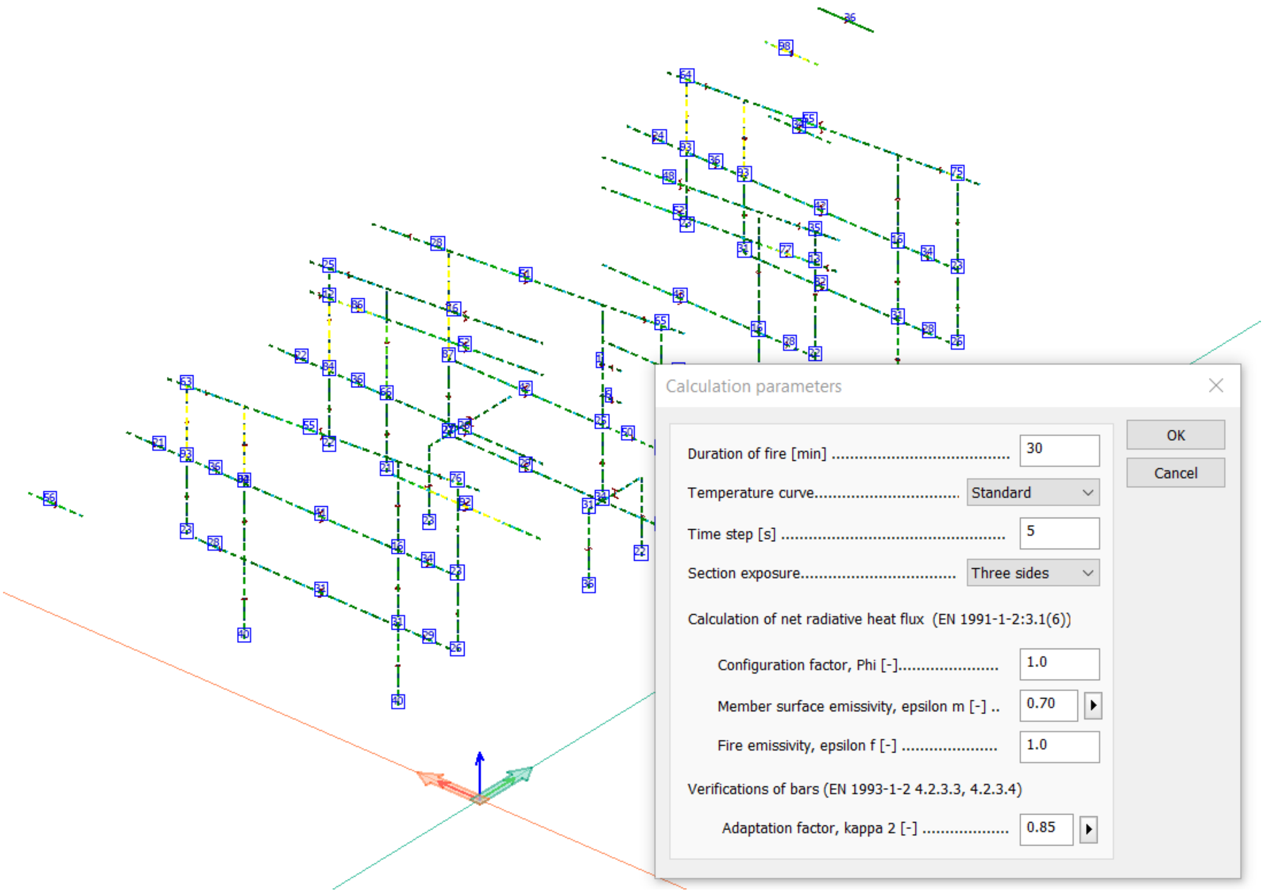


Figure above shows Calculation parameters

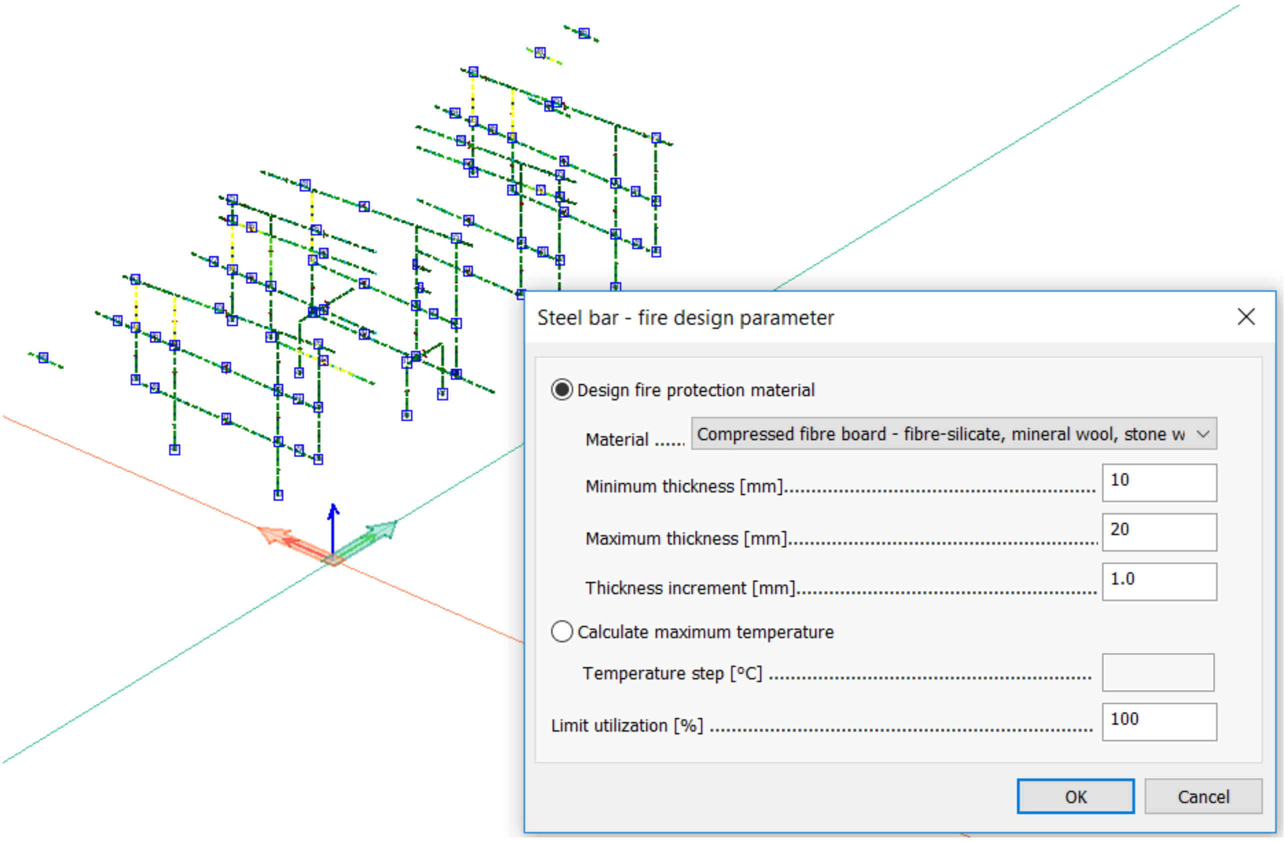
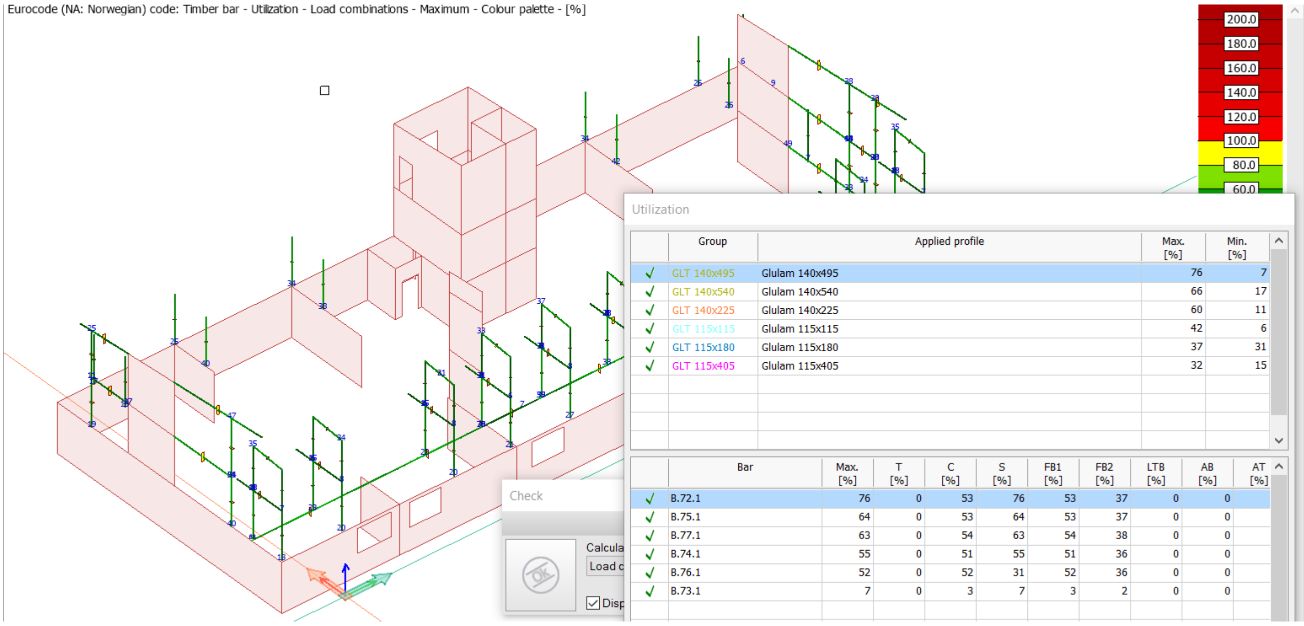


Figure above shows Insulation material used

2.5. Timber design:

Timber utilization:

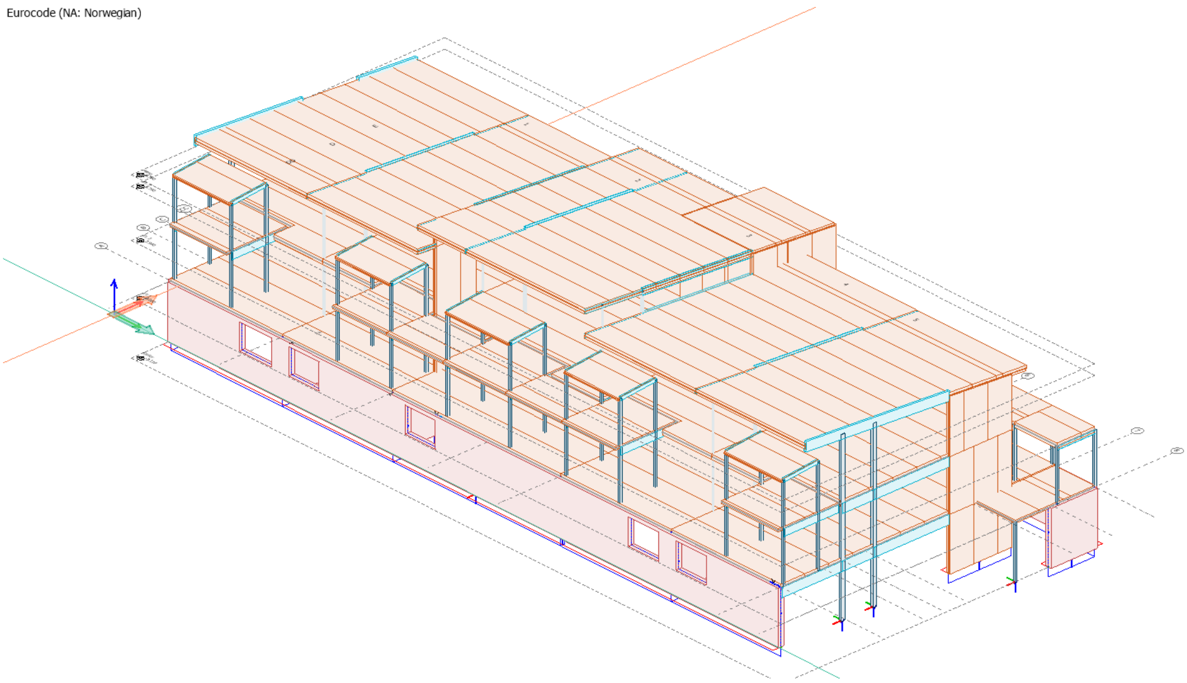


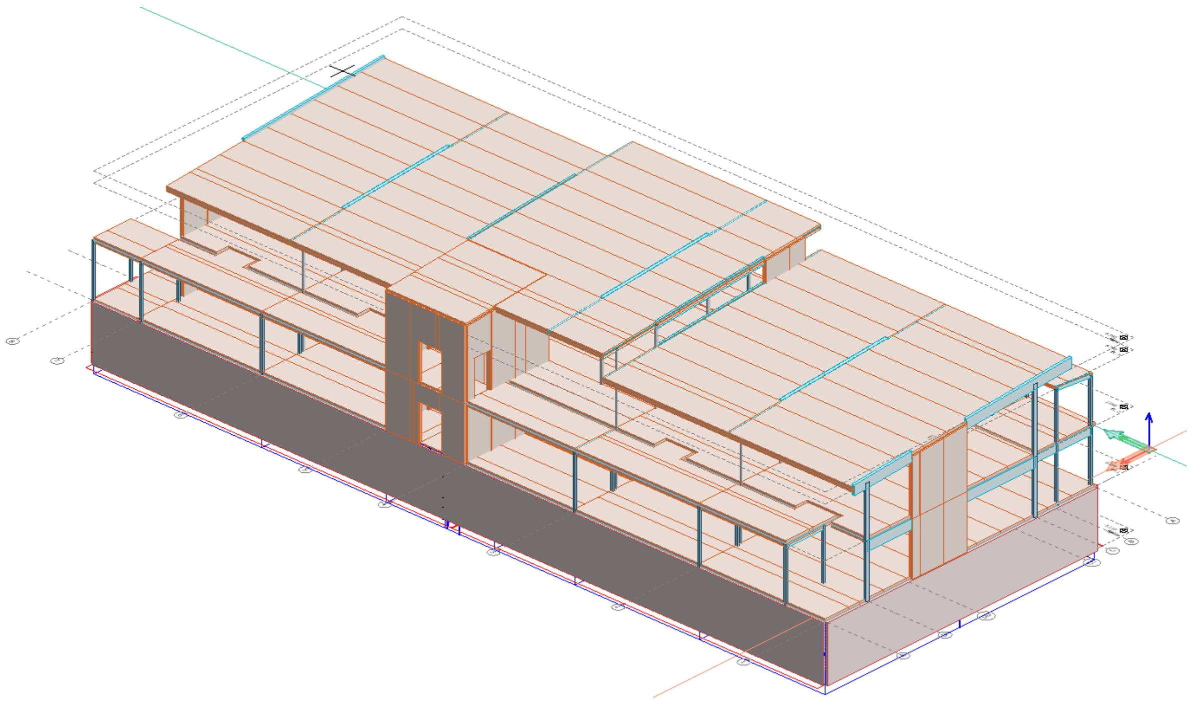
	Group	Applied profile	Max. [%]	Min. [%]
✓	GLT 140x495	Glulam 140x495	76	7
✓	GLT 140x540	Glulam 140x540	66	17
✓	GLT 140x225	Glulam 140x225	60	11
✓	GLT 115x115	Glulam 115x115	42	6
✓	GLT 115x180	Glulam 115x180	37	31
✓	GLT 115x405	Glulam 115x405	32	15

	Bar	Max. [%]	T [%]	C [%]	S [%]	FB1 [%]	FB2 [%]	LTB [%]	AB [%]	AT [%]
✓	B.72.1	76	0	53	76	53	37	0	0	
✓	B.75.1	64	0	53	64	53	37	0	0	
✓	B.77.1	63	0	54	63	54	38	0	0	
✓	B.74.1	55	0	51	55	51	36	0	0	
✓	B.76.1	52	0	52	31	52	36	0	0	
✓	B.73.1	7	0	3	7	3	2	0	0	

3. Results from Fem-design for option3

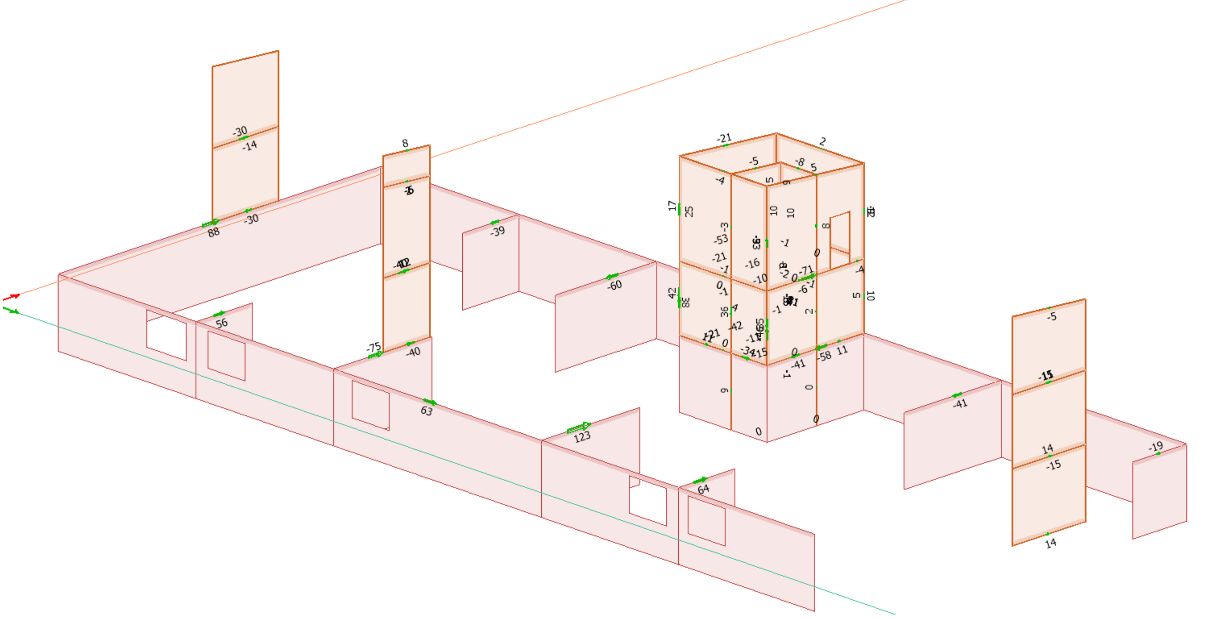
3.2. Model



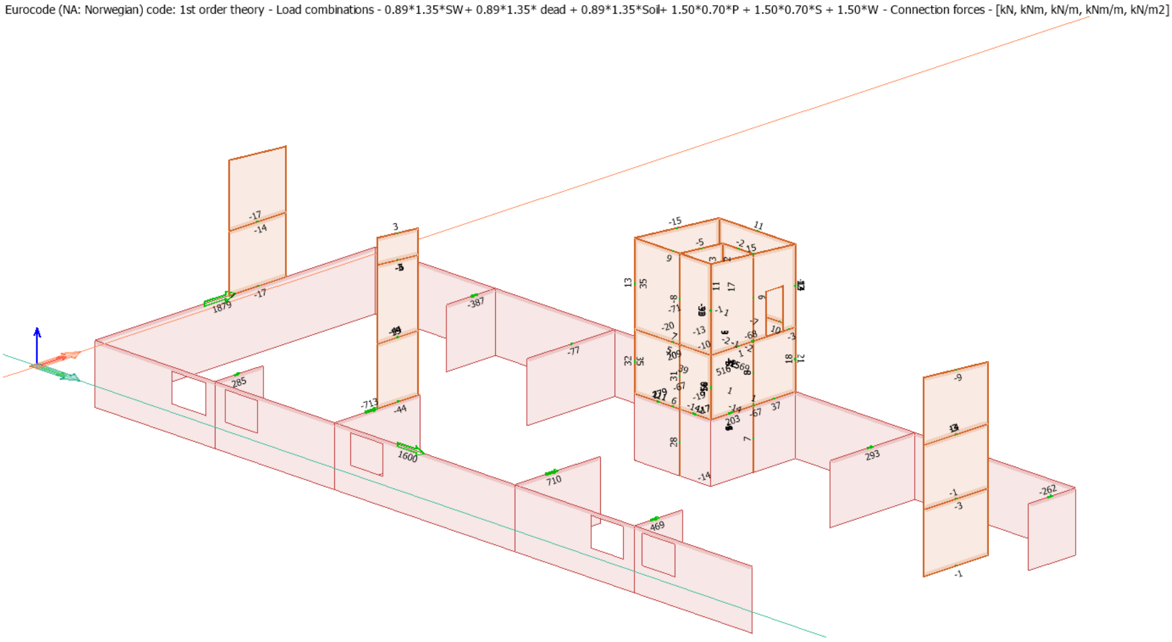


3.3. Connection forces

Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Stability2 - 0,9G+1,5W+Hi (including misalignment load) - Connection forces - [kN, kNm, kN/m, kNm/m, kN/m2]



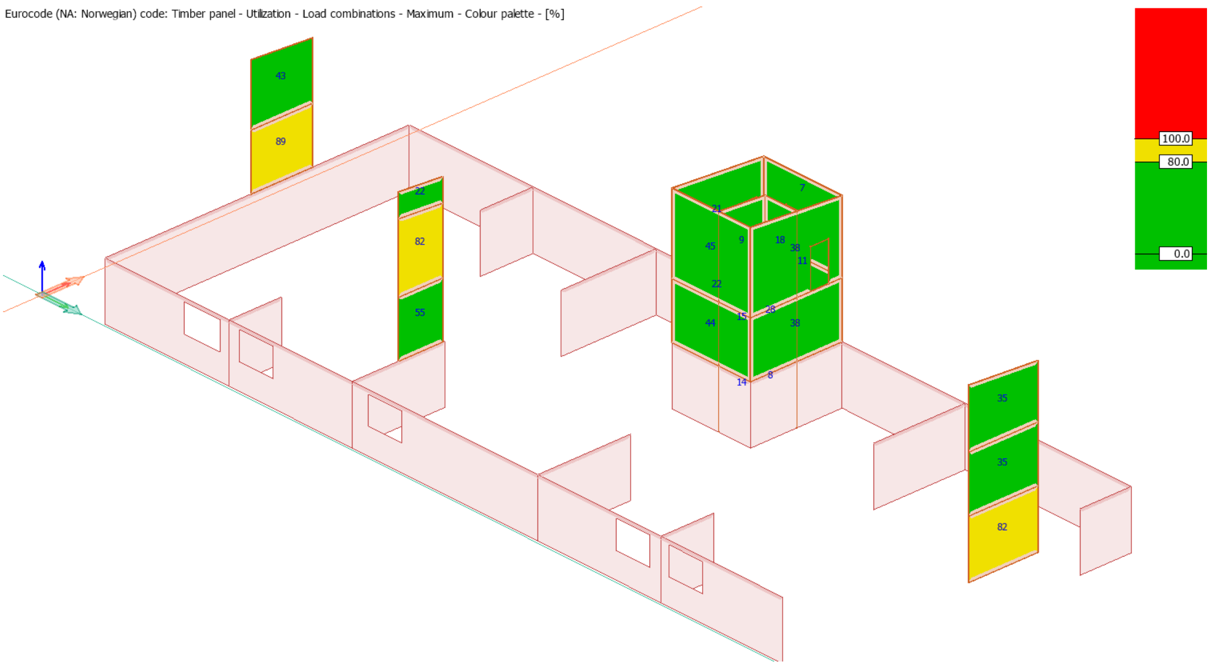
LC1: Connection force Fx with load combination= 0,9 G+1,5 W+1,0 Hi (misalignment load)



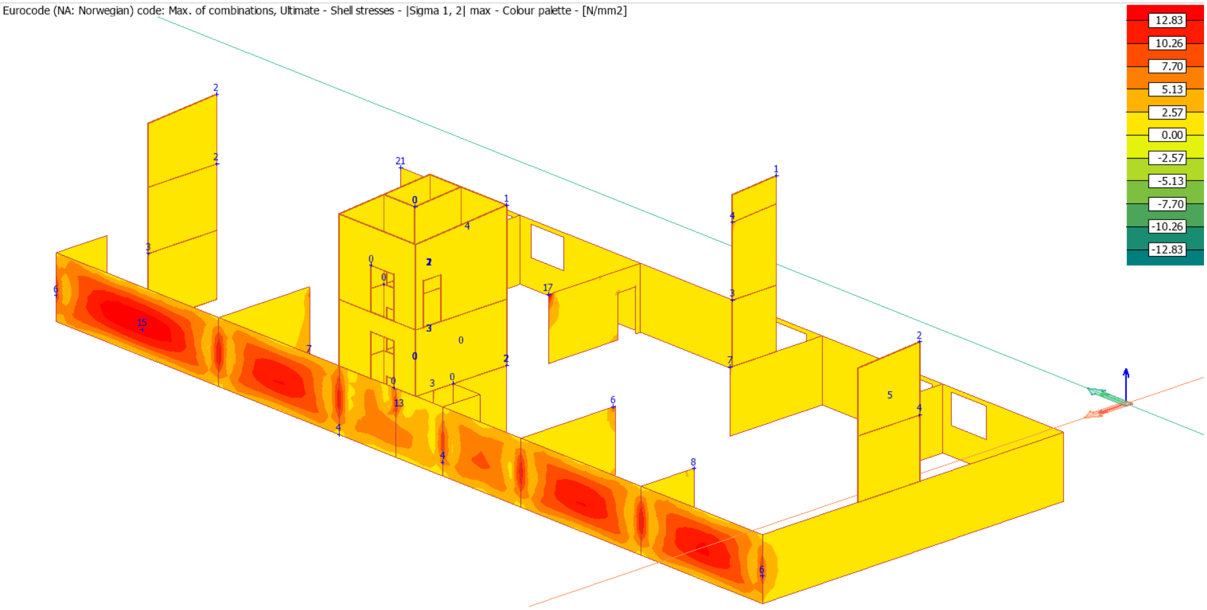
LC2

3.4. CLT wall design

3.4.1. CLT wall utilization

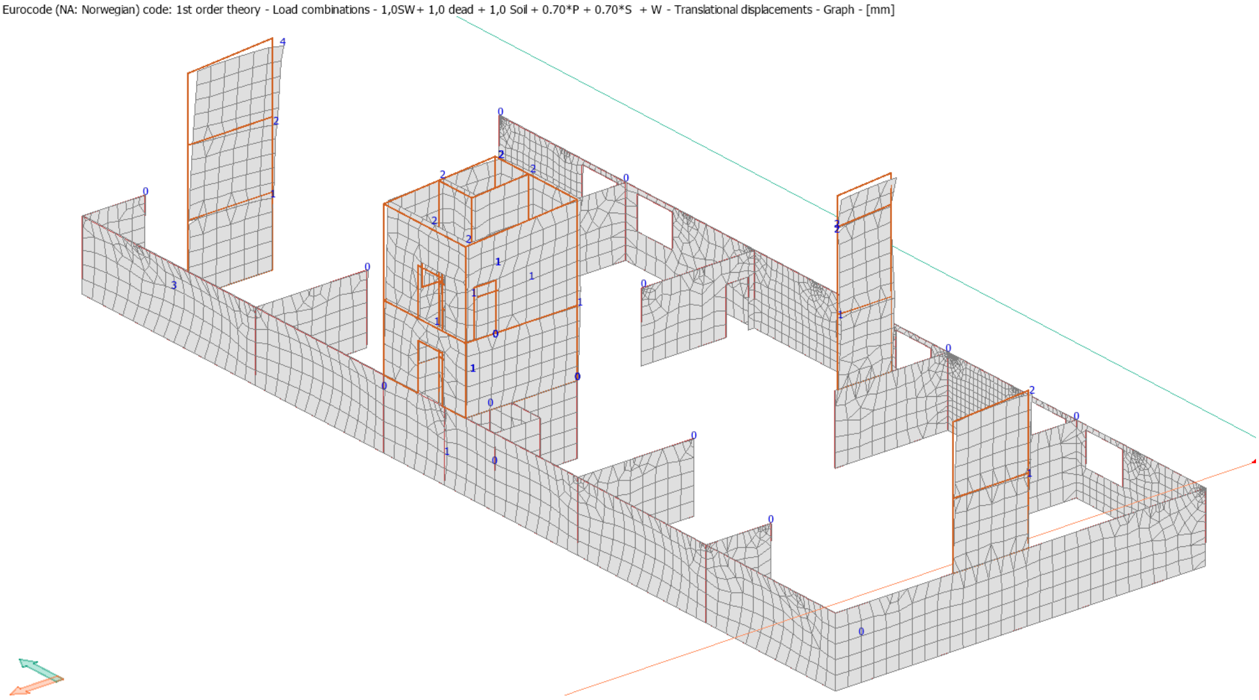


Eurocode (NA: Norwegian) code: Max. of combinations, Ultimate - Shell stresses - |Sigma 1, 2| max - Colour palette - [N/mm2]

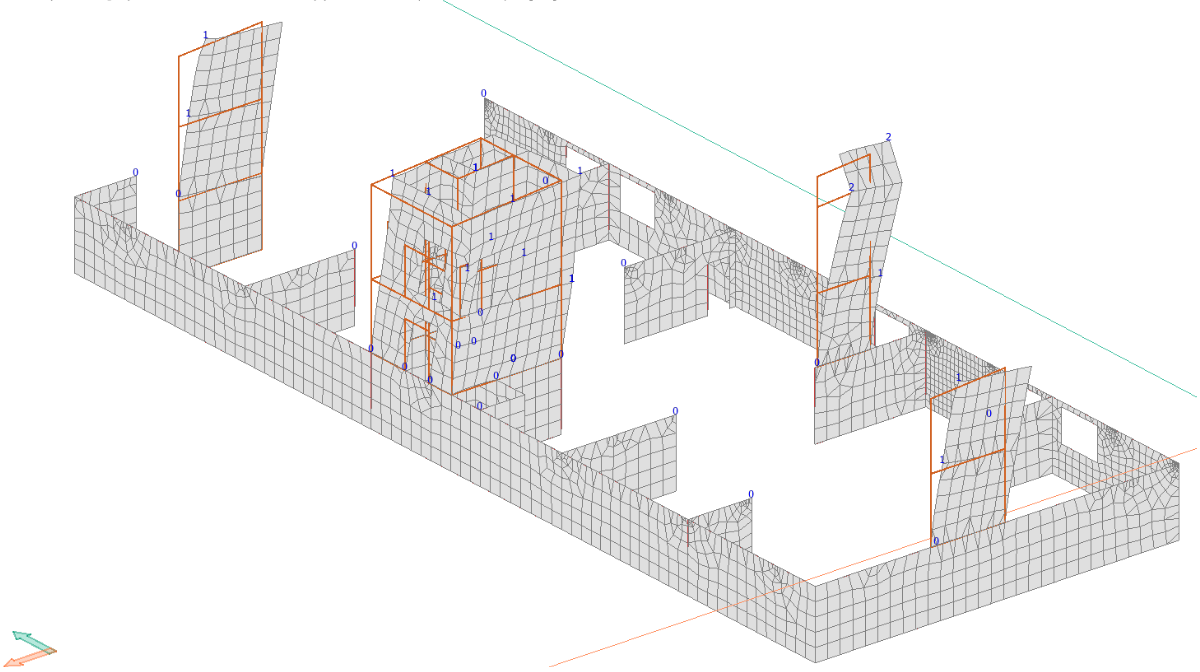


3.4.2. CLT walls horizontal deformation

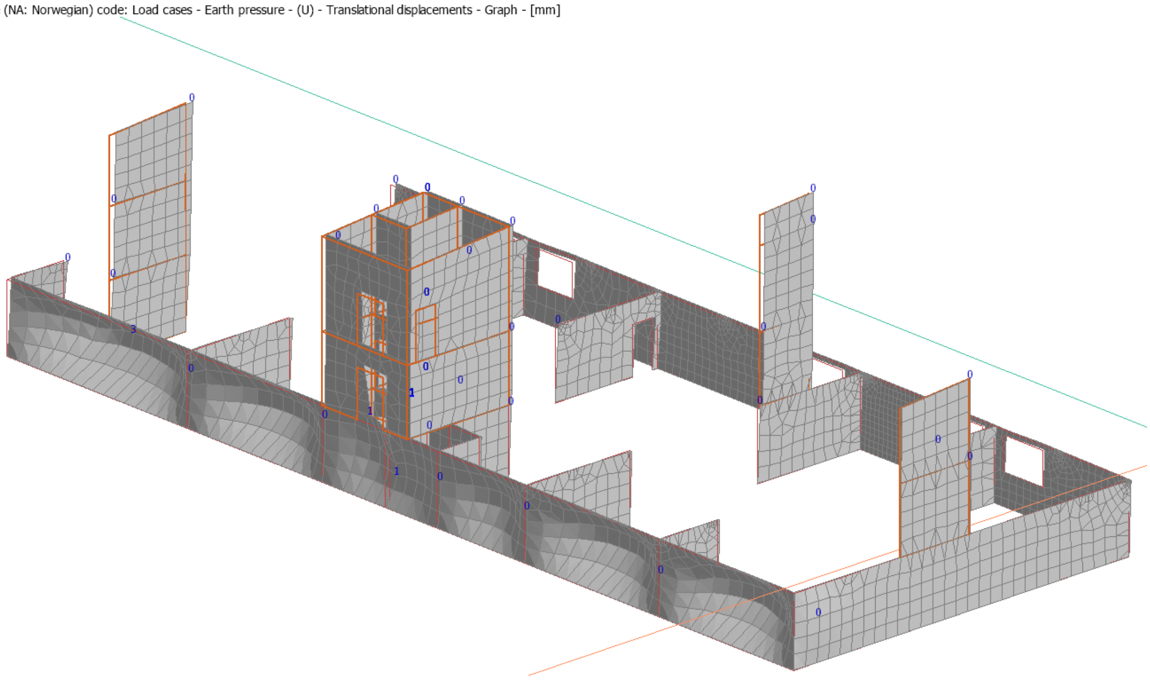
Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - 1,0SW+ 1,0 dead + 1,0 Soil + 0.70*P + 0.70*S + W - Translational displacements - Graph - [mm]

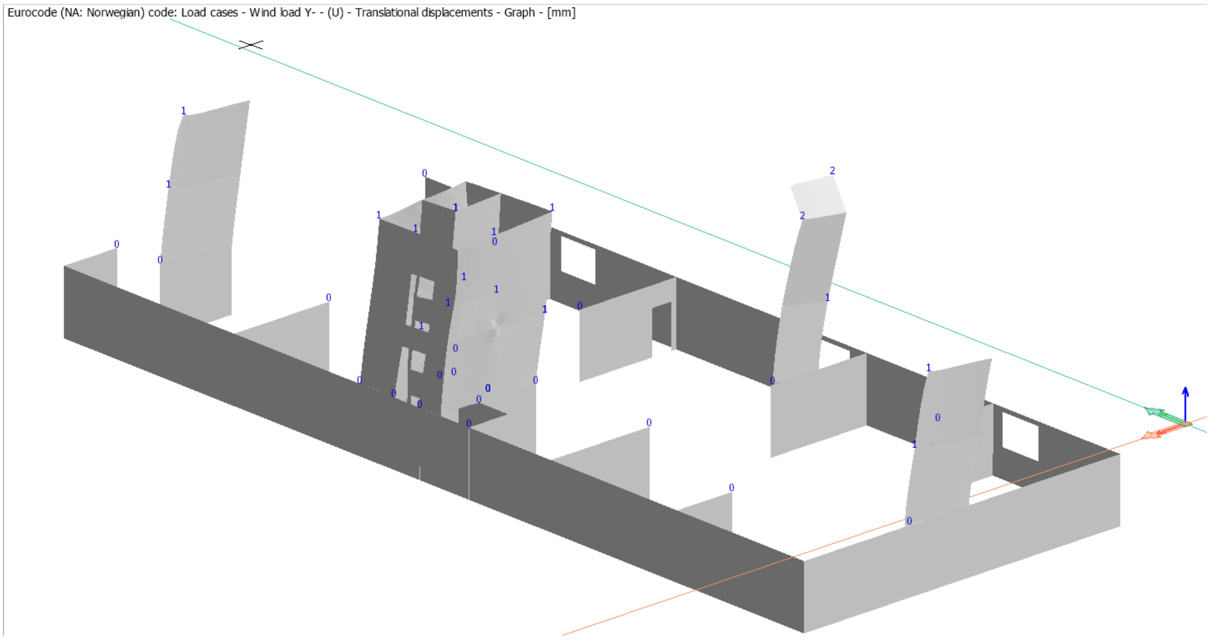


Eurocode (NA: Norwegian) code: Load cases - Wind load Y- - (U) - Translational displacements - Graph - [mm]

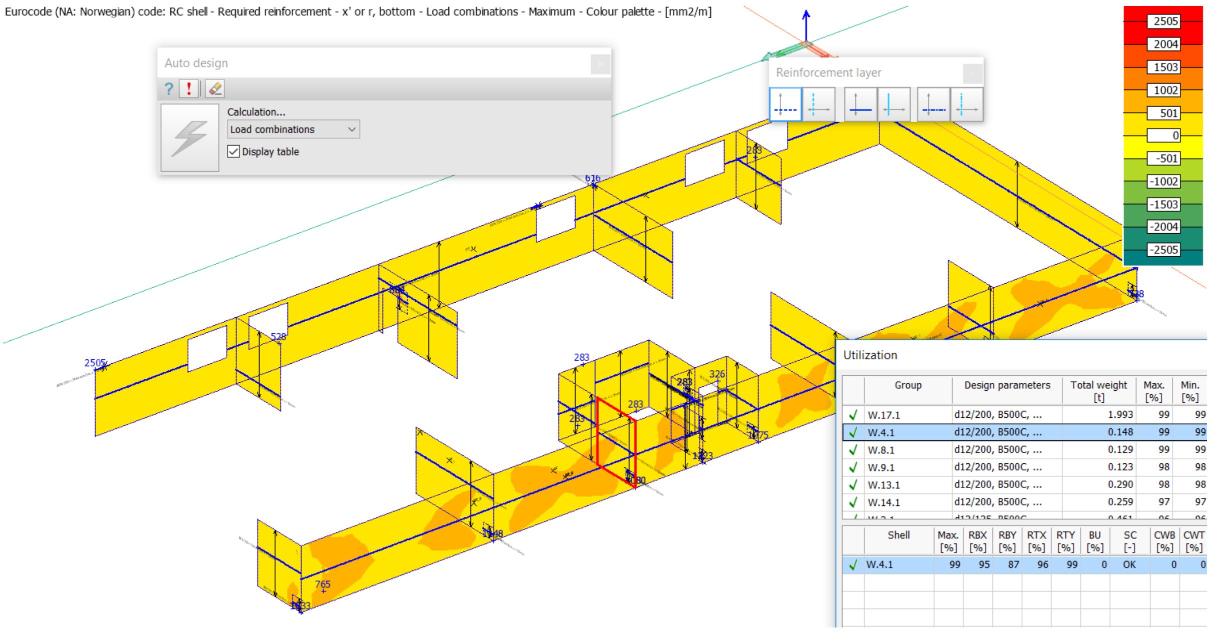


Eurocode (NA: Norwegian) code: Load cases - Earth pressure - (U) - Translational displacements - Graph - [mm]

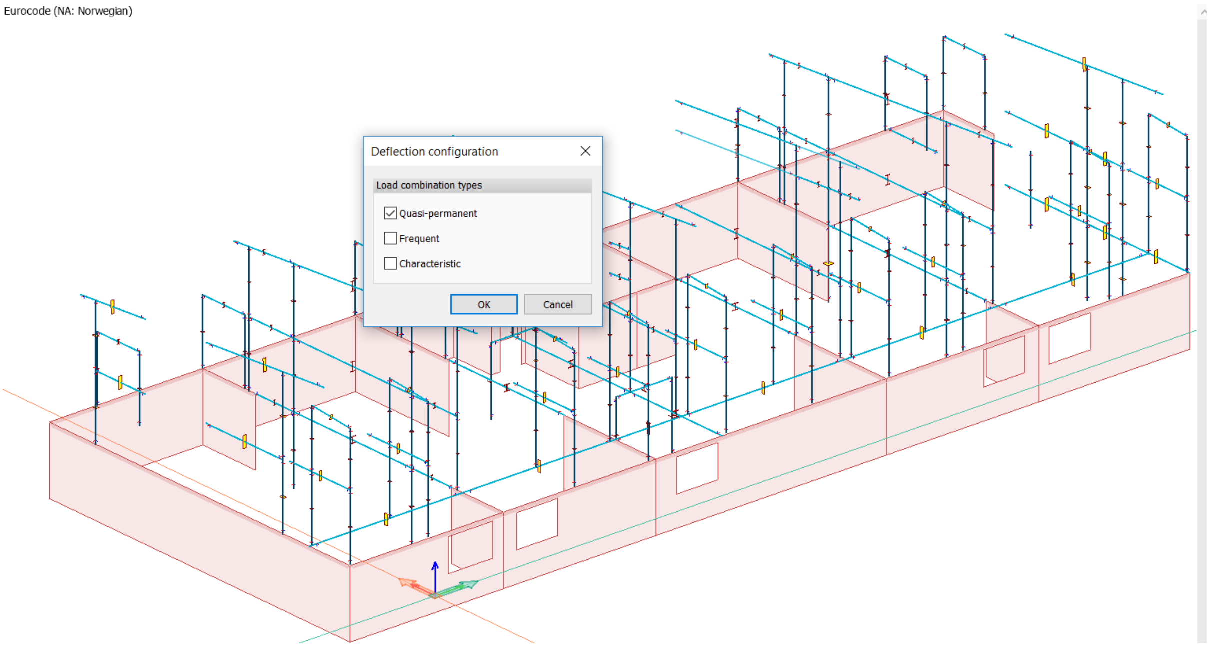


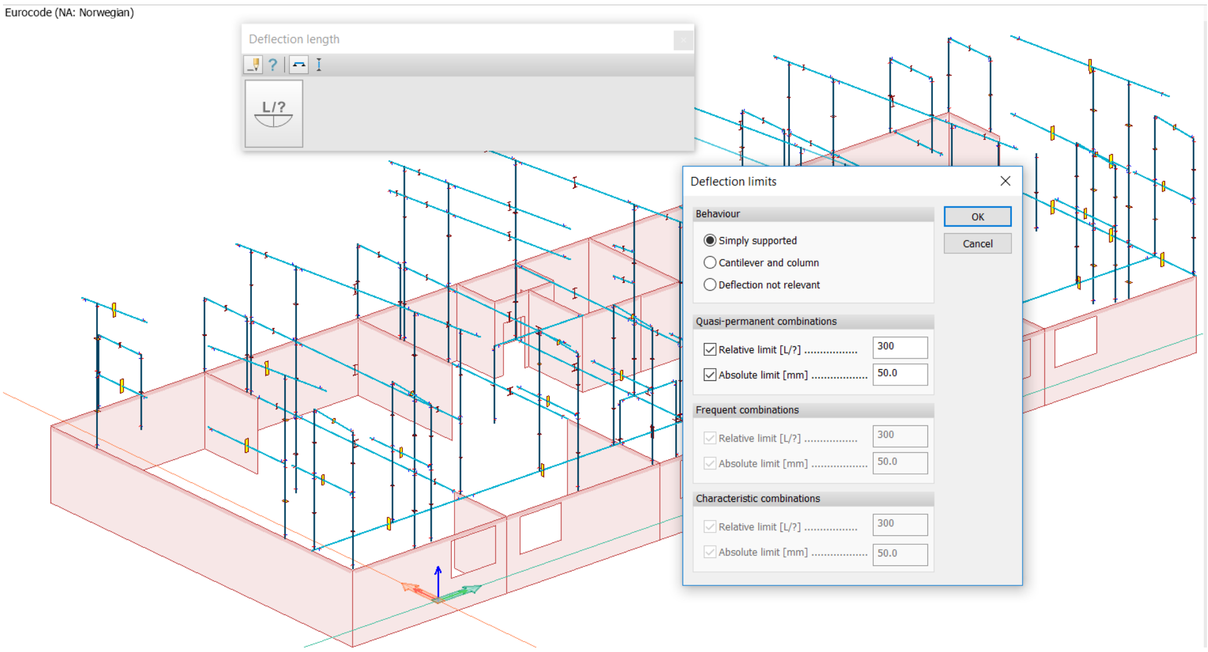


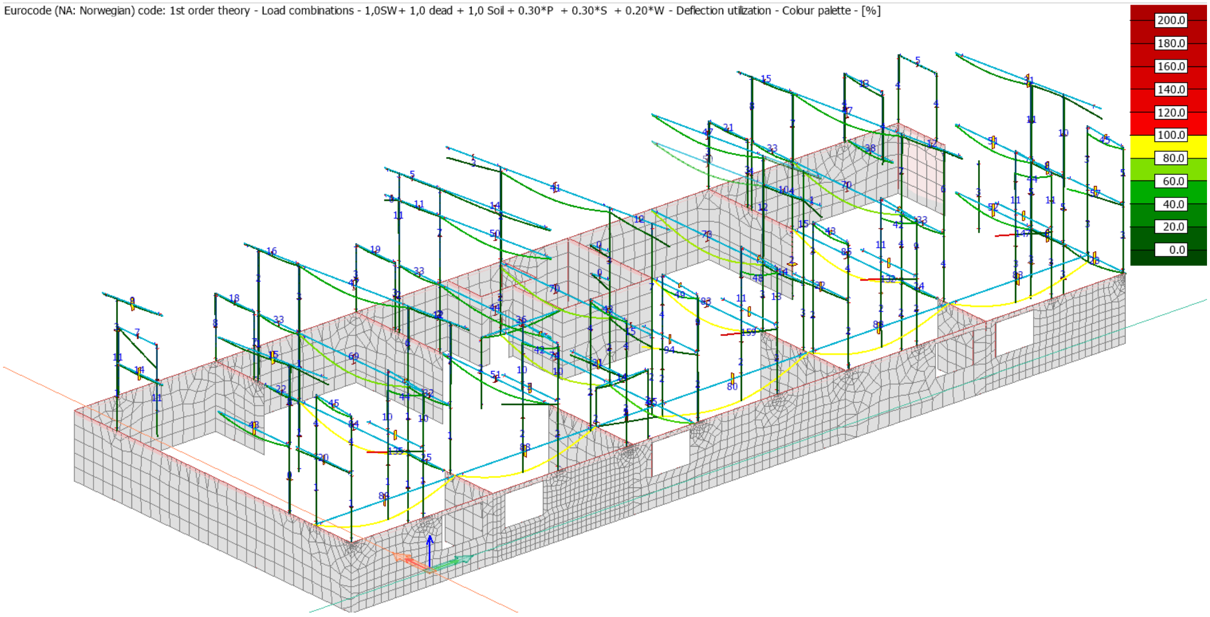
3.5. RCC wall design



3.6. Frames deformation check

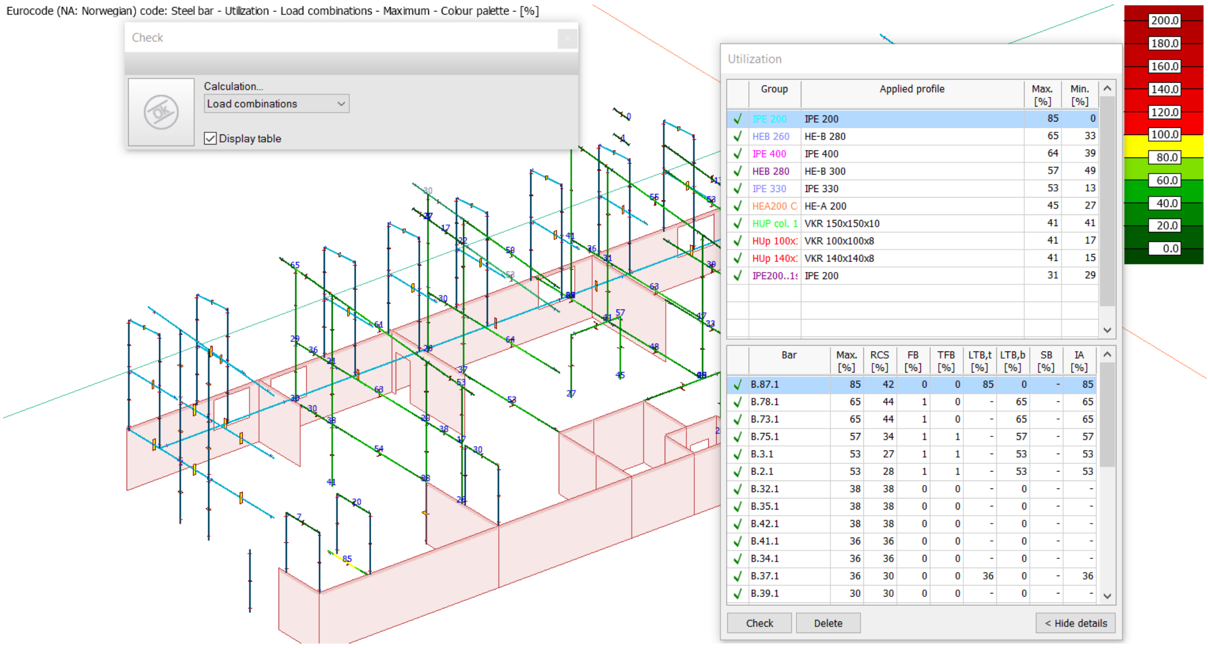

Eurocode (NA: Norwegian)
Deflection configuration
Load combination types
Quasi-permanent
Frequent
Characteristic
OK
Cancel

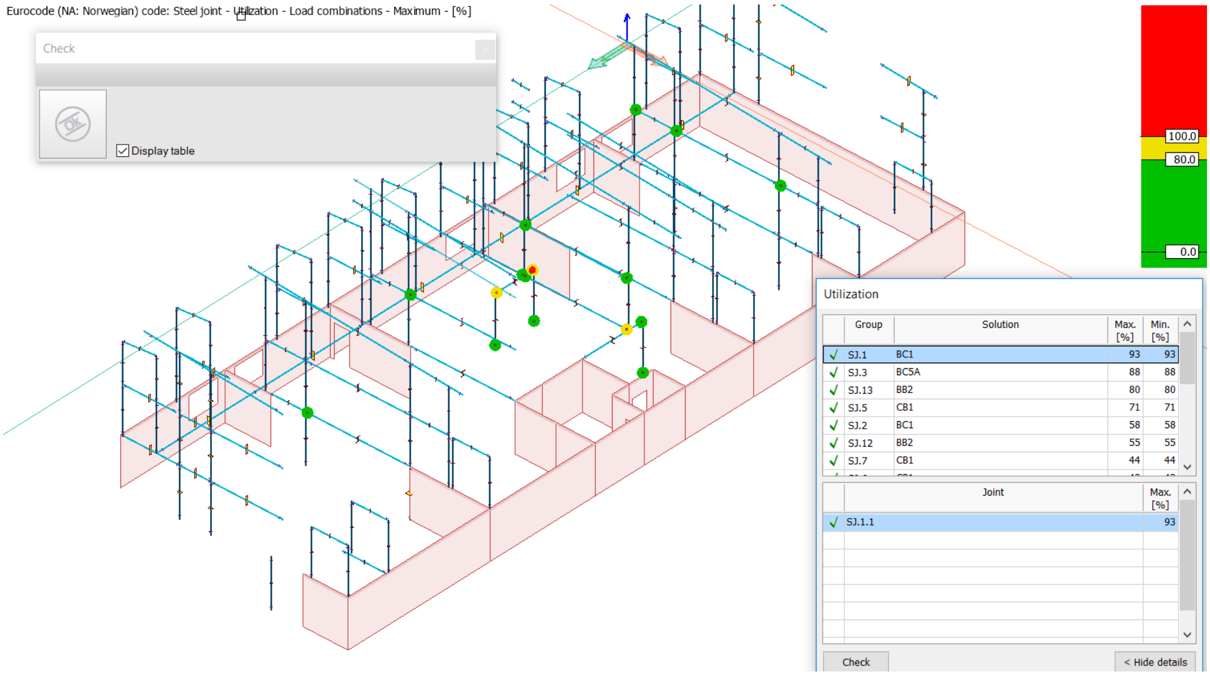

Eurocode (NA: Norwegian)
Deflection length
L/?
Deflection limits
Behaviour
Simply supported
Cantilever and column
Deflection not relevant
Quasi-permanent combinations
Relative limit [L/?]
300
Absolute limit [mm]
50.0
Frequent combinations
Relative limit [L/?]
300
Absolute limit [mm]
50.0
Characteristic combinations
Relative limit [L/?]
300
Absolute limit [mm]
50.0
OK
Cancel



3.7. Steel design

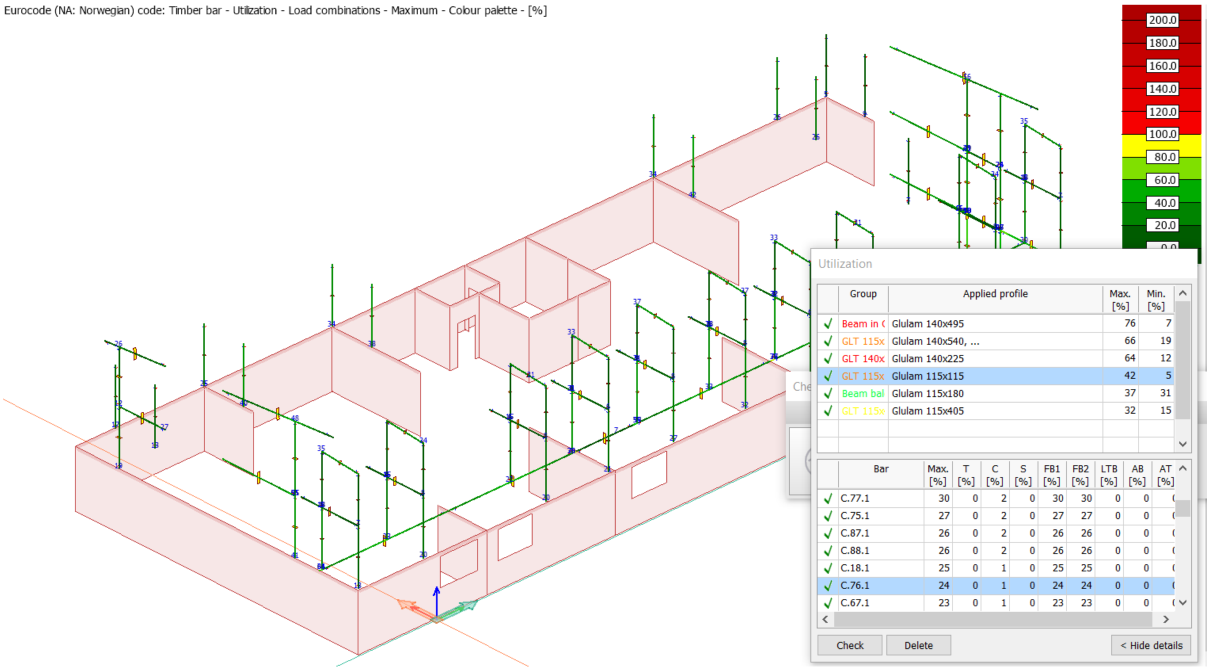
Steel utilization





Steel joint utilization

3.8. GLT (glulam) design

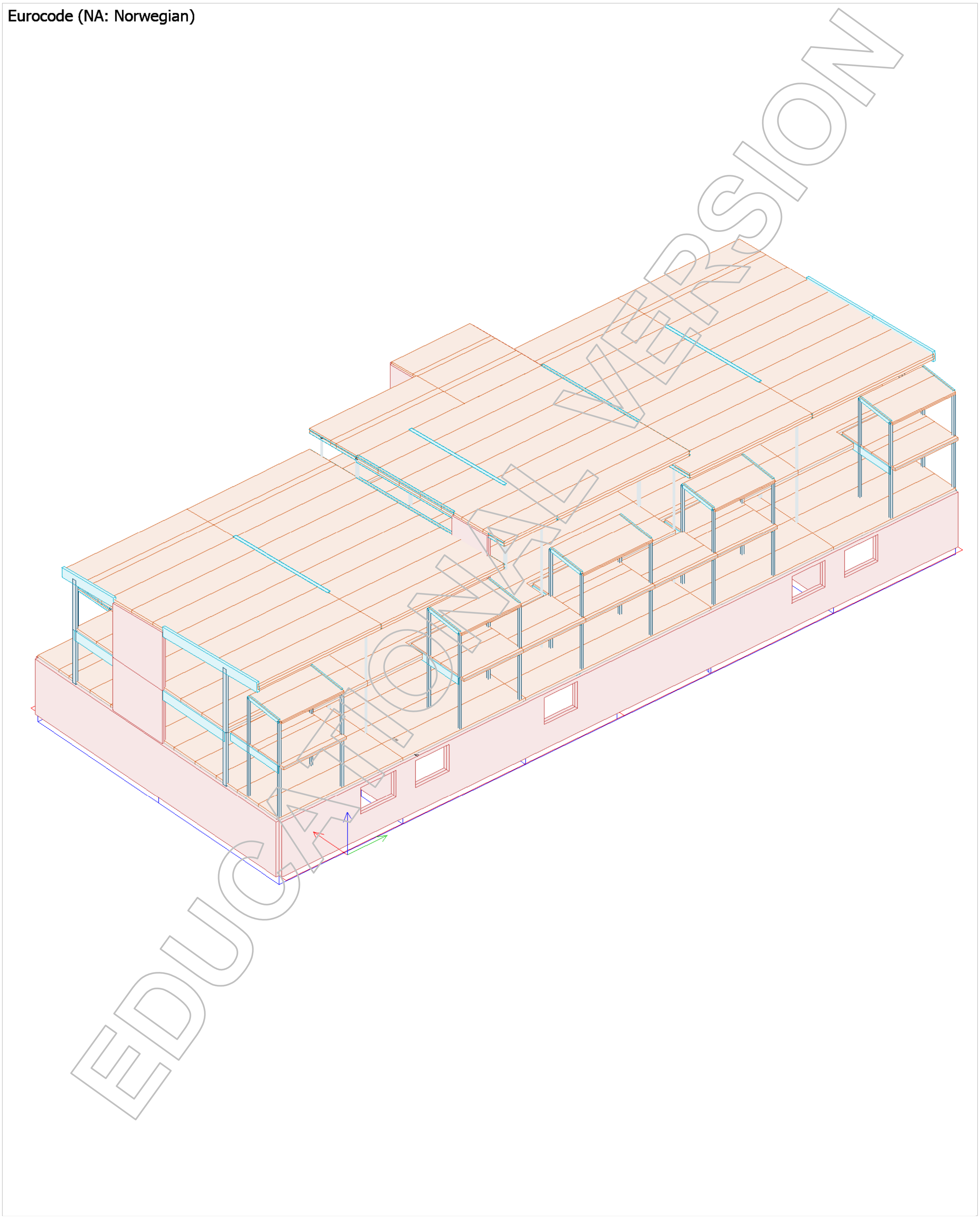


Documentation of the structural design in FEM-Design

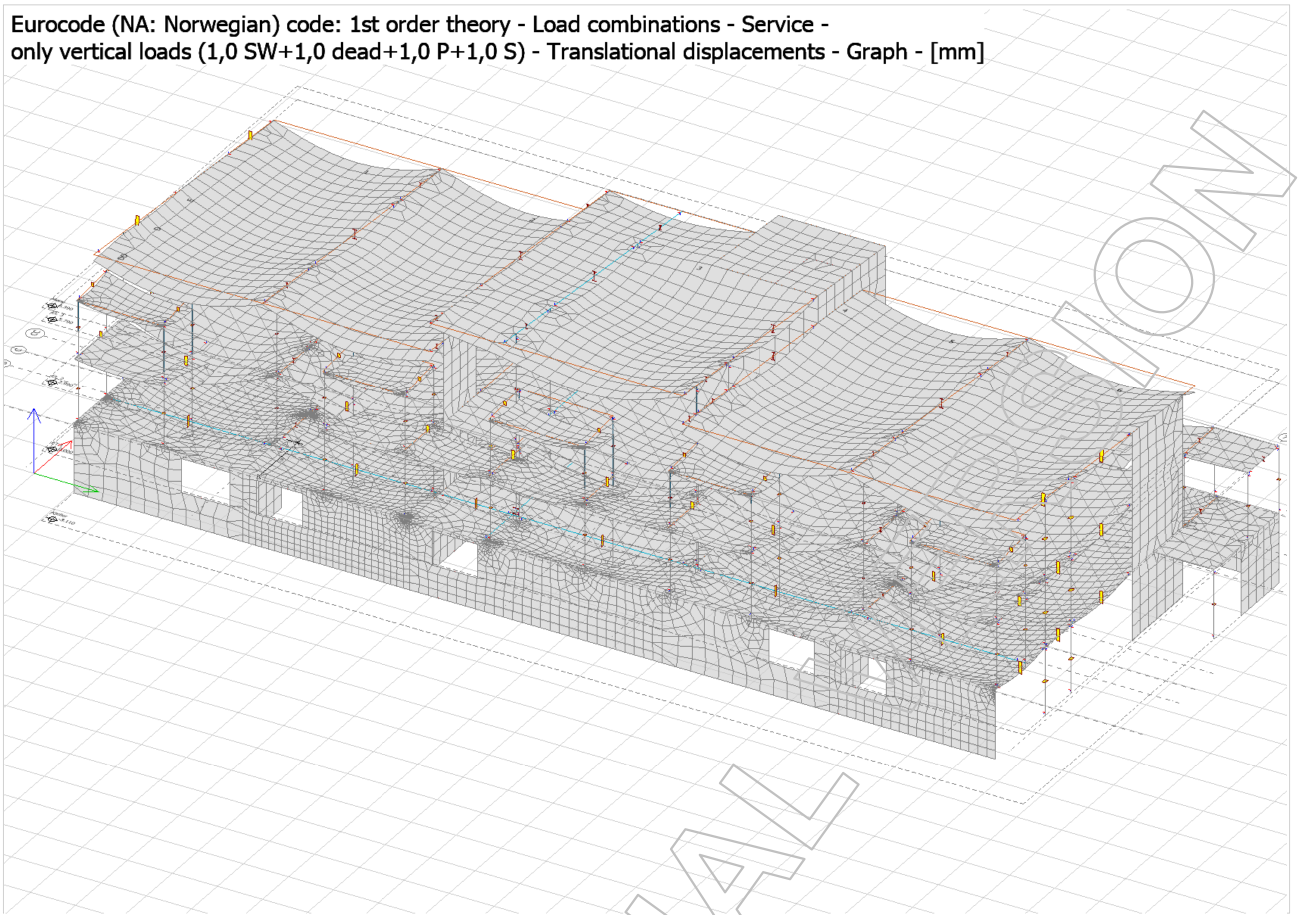
Contents

1 Geometry

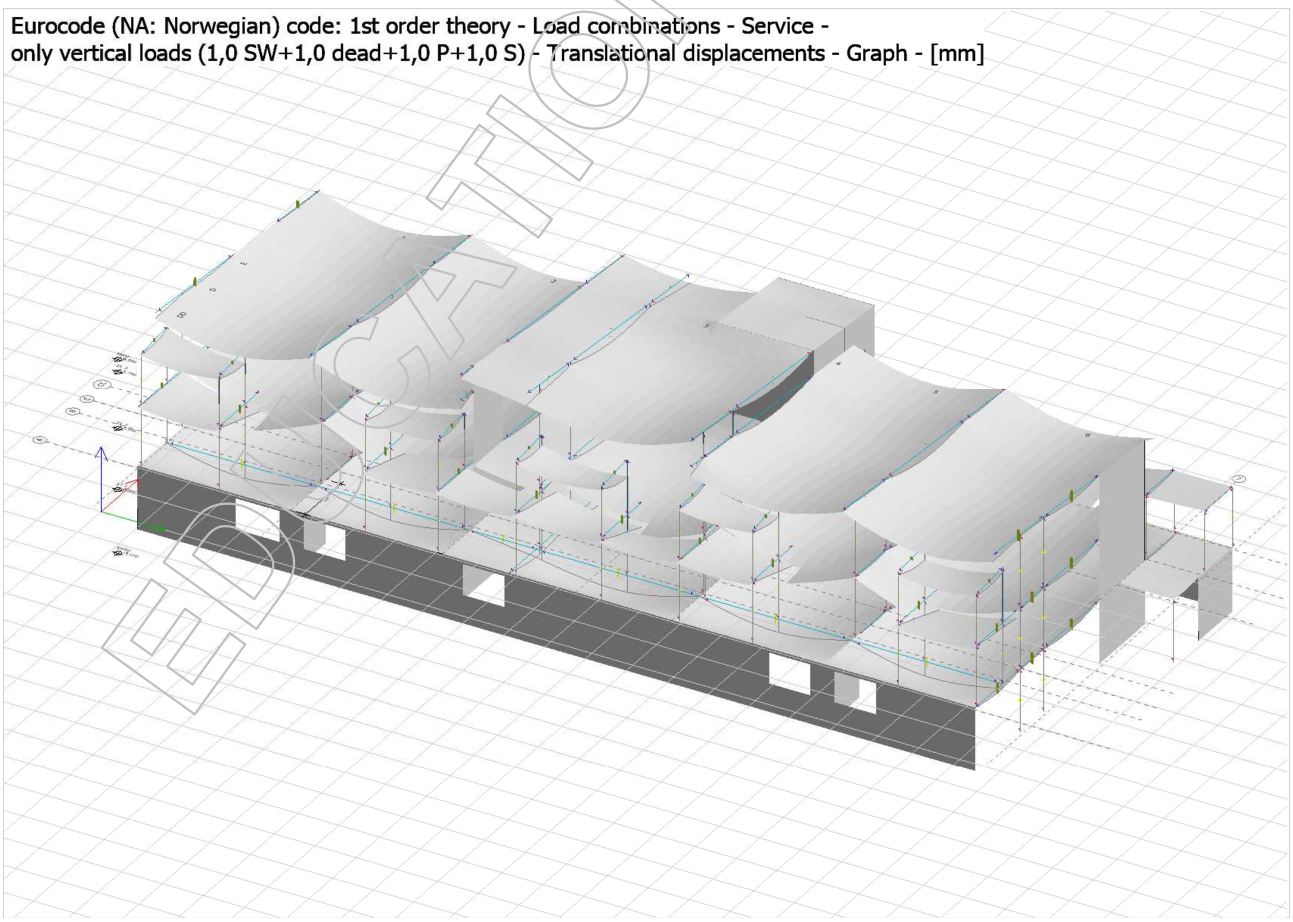
1.1 3D Modell



Deformed 3D model

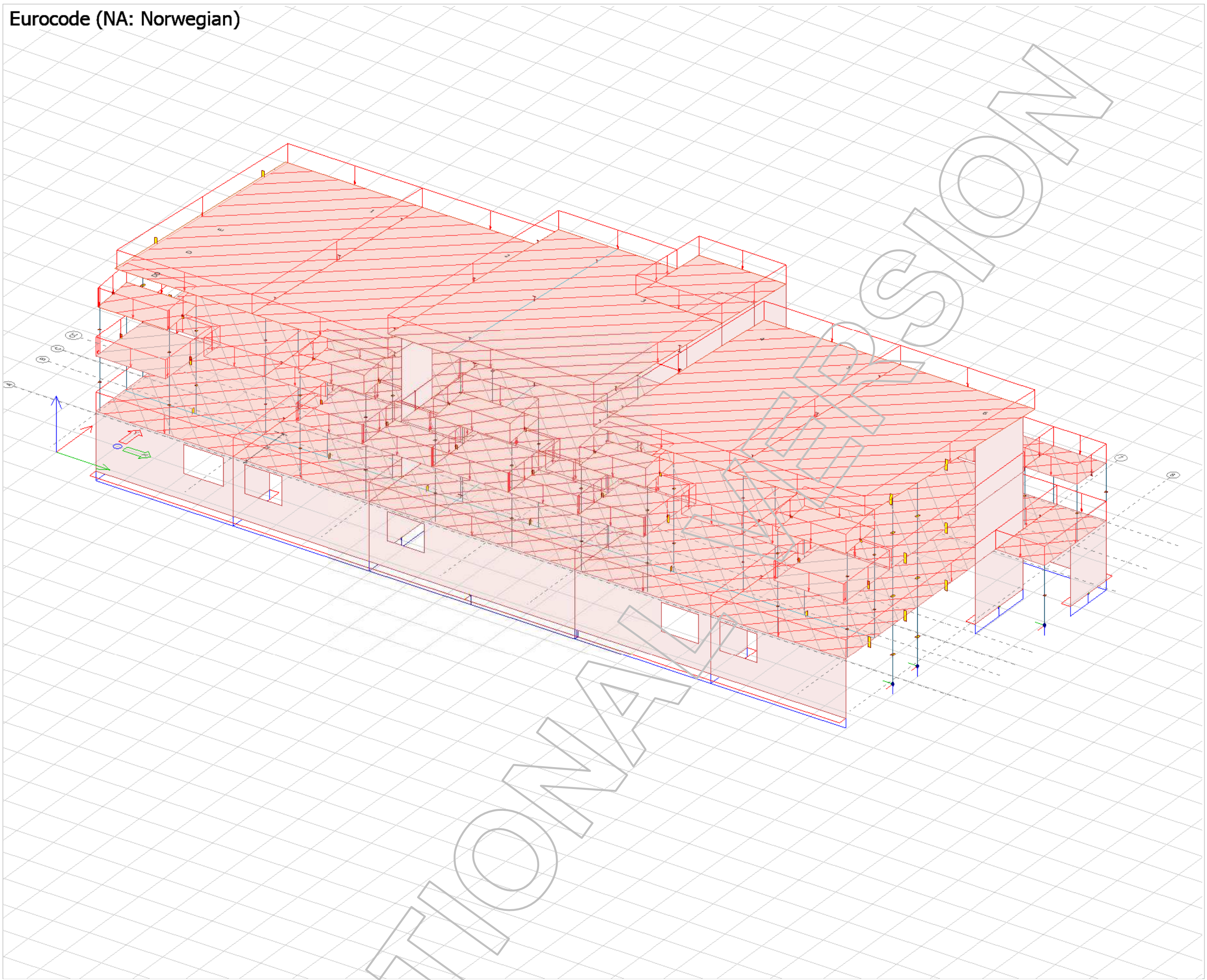


Deformed 3D model 2

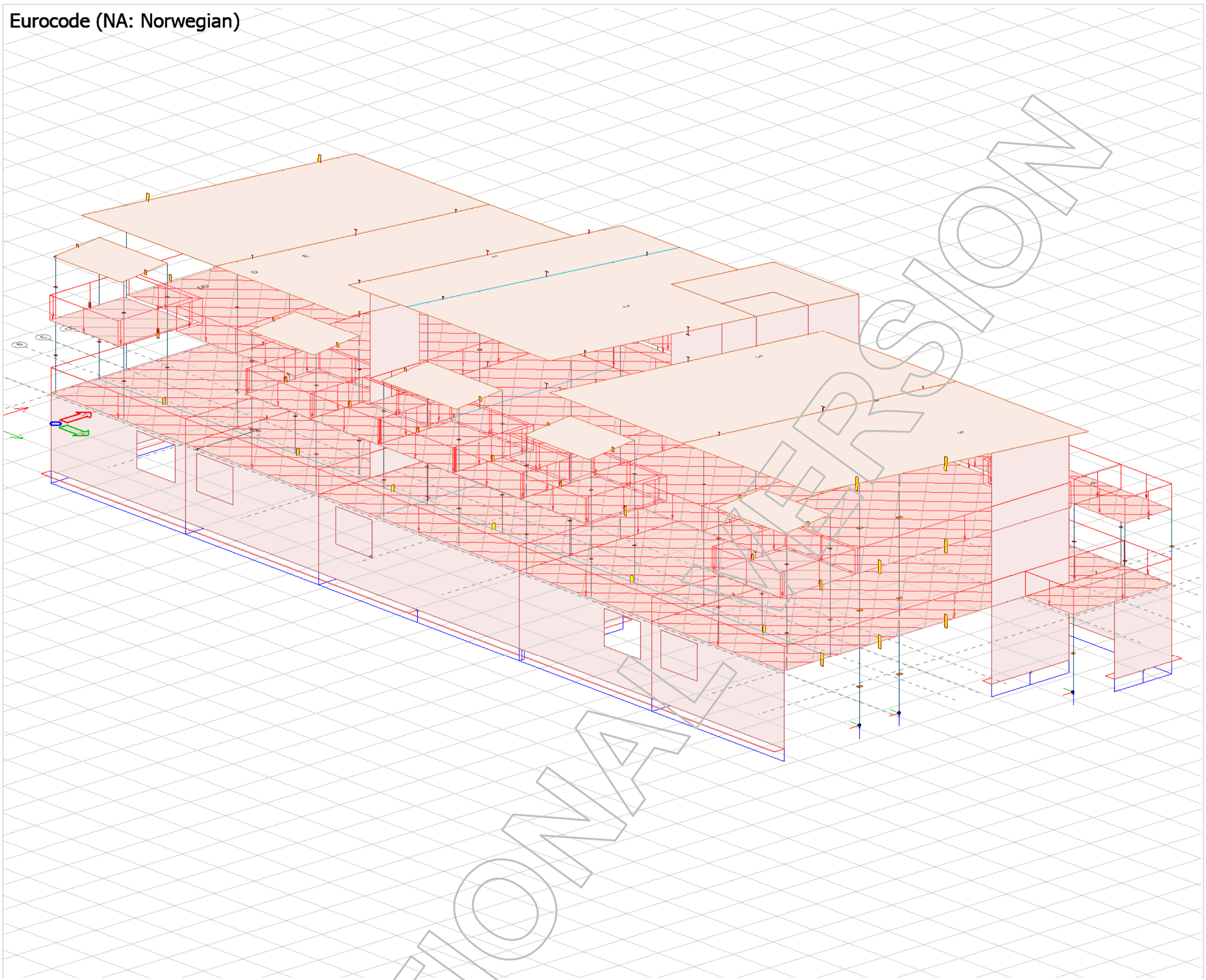


1.2 Loads applied on the model

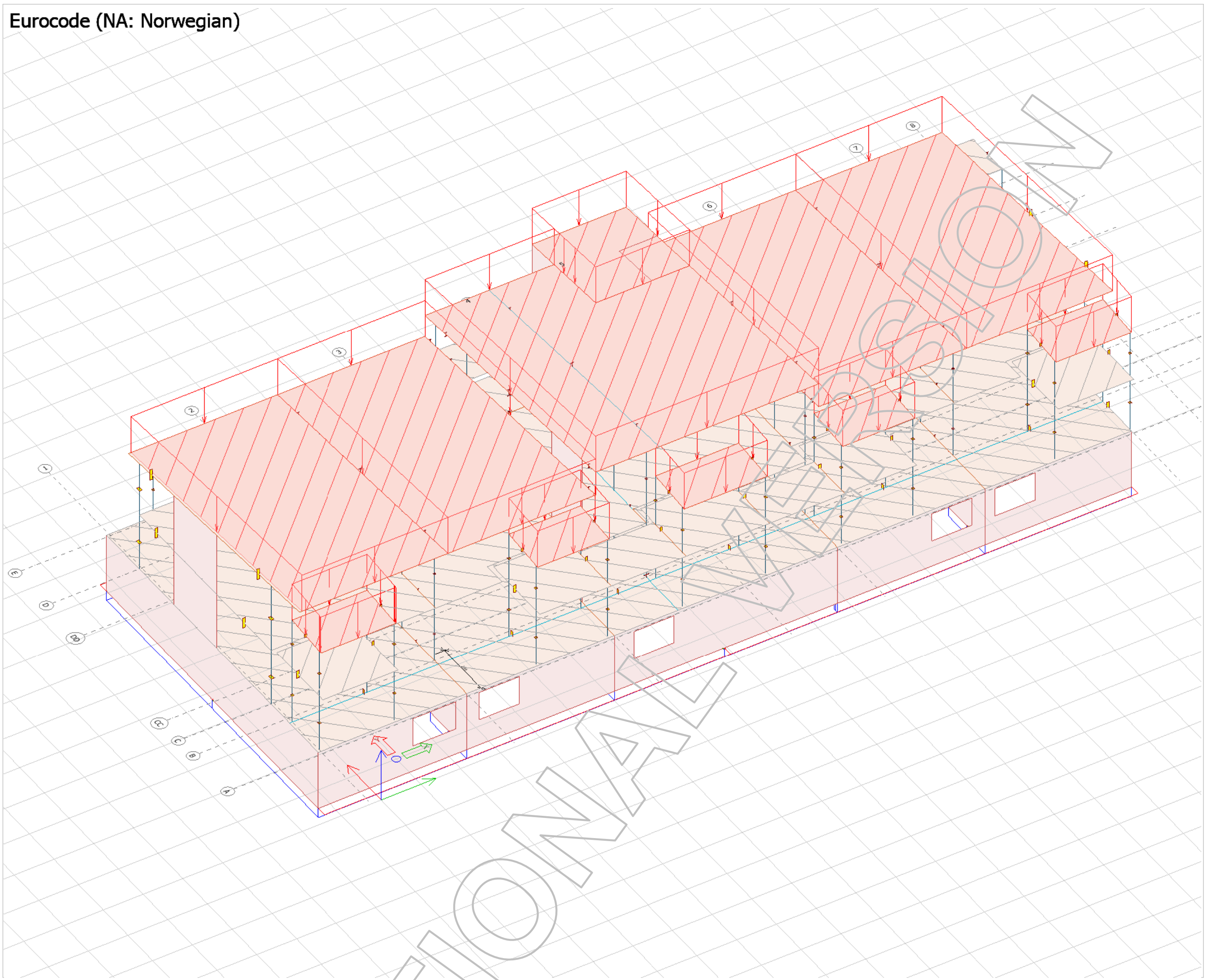
Supperimposed dead



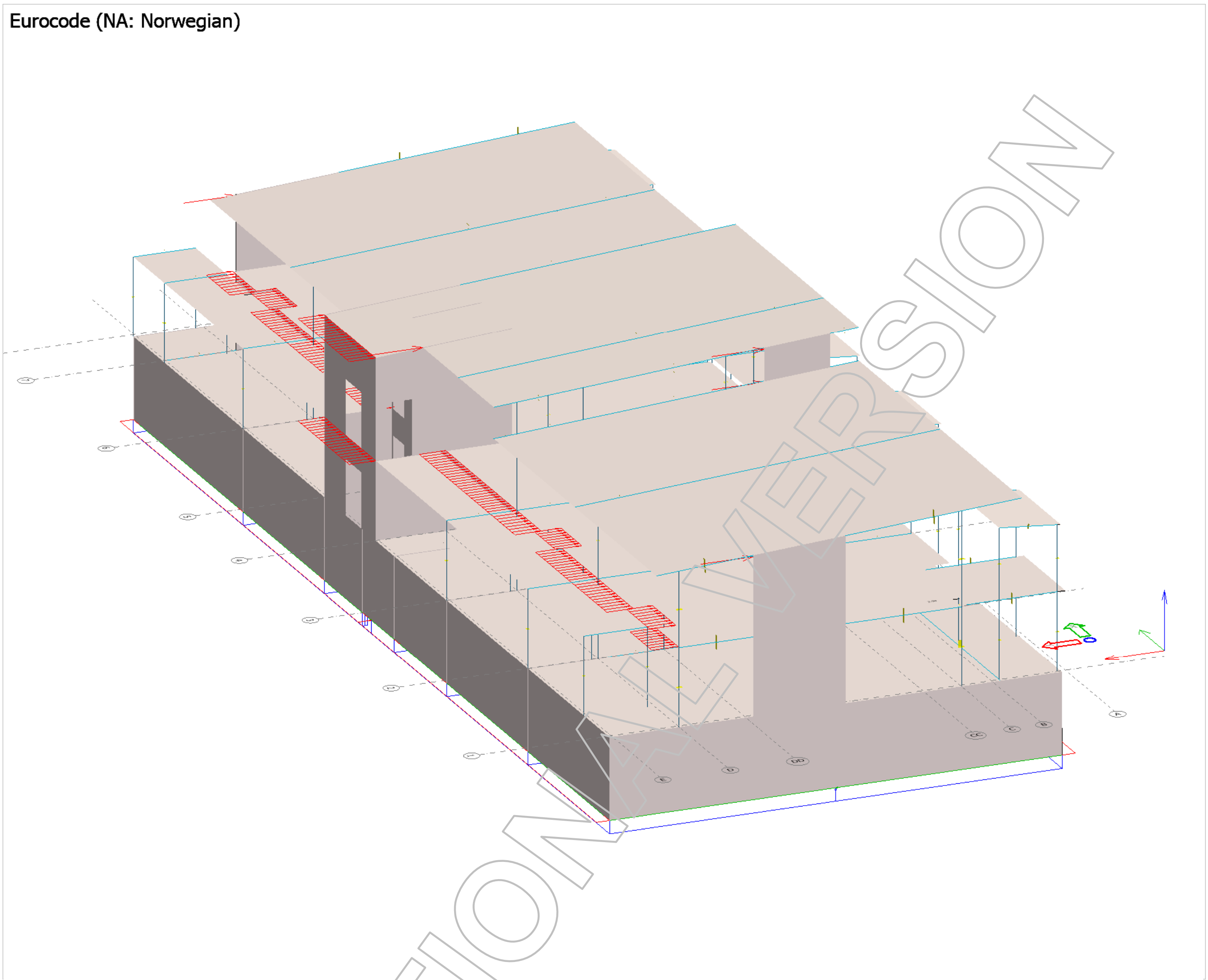
Live load



snow load

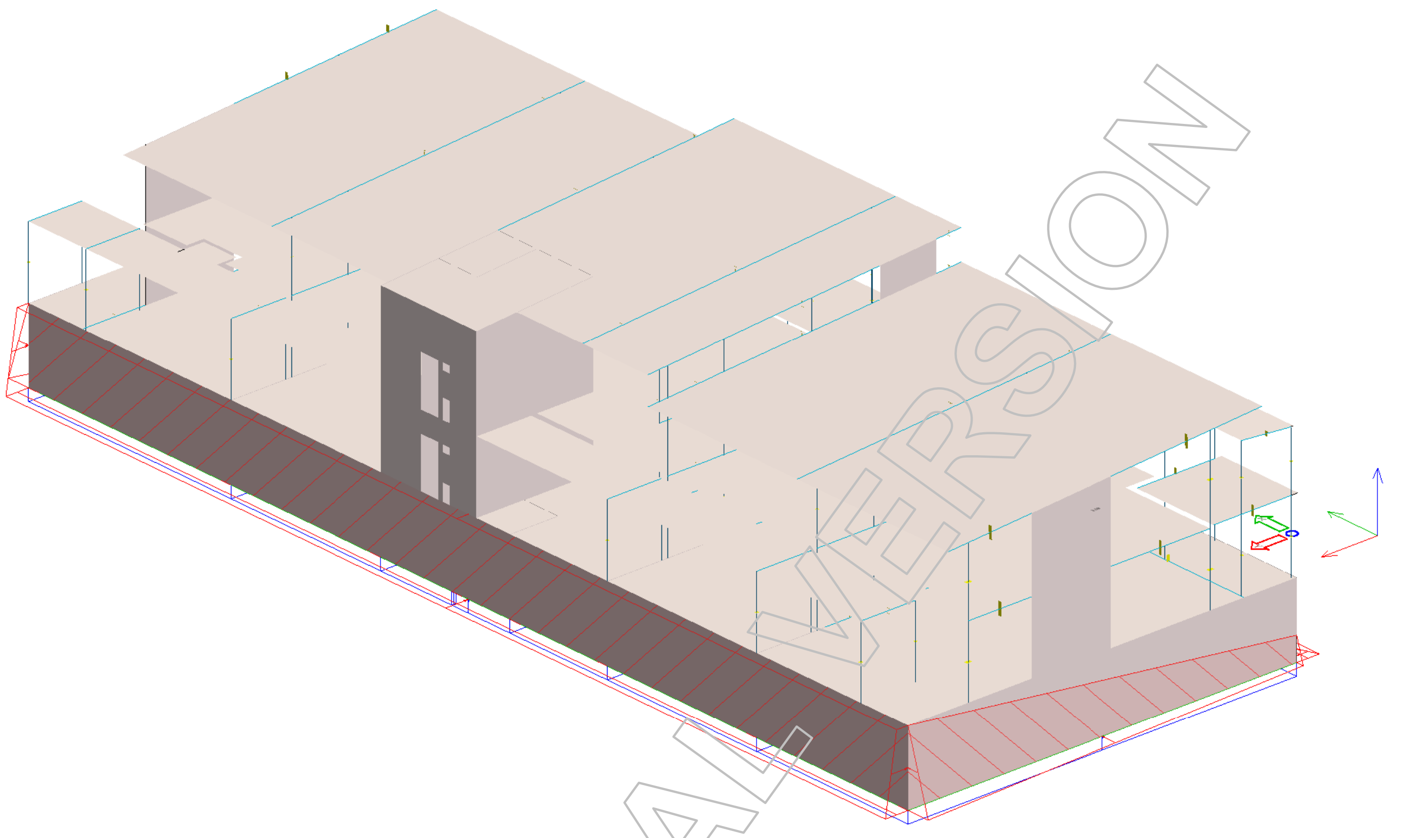


Wind load Y-



Earth pressure

Eurocode (NA: Norwegian)



Surface loads (Ordinary)

No.	q1	q2	q3	Load case	Comment	Applied on Ecc	Assigned	Intensity
[-]	[kN/m2]	[kN/m2]	[kN/m2]	[-]	[-]	[-]	[-]	[-]
1	2.220	2.220	2.220	Supperimposed dead		No	-	Action
2	2.220	2.220	2.220	Supperimposed dead		No	-	Action
3	2.220	2.220	2.220	Supperimposed dead		No	-	Action
4	2.200	2.200	2.200	Supperimposed dead		No	-	Action
5	2.200	2.200	2.200	Supperimposed dead		No	-	Action
6	2.200	2.200	2.200	Supperimposed dead		No	-	Action
7	2.200	2.200	2.200	Supperimposed dead		No	-	Action
8	0.500	0.500	0.500	Supperimposed dead		No	-	Action
9	0.500	0.500	0.500	Supperimposed dead		No	-	Action
10	0.500	0.500	0.500	Supperimposed dead		No	-	Action
11	0.500	0.500	0.500	Supperimposed dead		No	-	Action
12	0.500	0.500	0.500	Supperimposed dead		No	-	Action
13	0.500	0.500	0.500	Supperimposed dead		No	-	Action
14	0.500	0.500	0.500	Supperimposed dead		No	-	Action
15	0.500	0.500	0.500	Supperimposed dead		No	-	Action
16	0.500	0.500	0.500	Supperimposed dead		No	-	Action
17	0.500	0.500	0.500	Supperimposed dead		No	-	Action
18	0.500	0.500	0.500	Supperimposed dead		No	-	Action
19	0.500	0.500	0.500	Supperimposed dead		No	-	Action
20	0.500	0.500	0.500	Supperimposed dead		No	-	Action
21	0.500	0.500	0.500	Supperimposed dead		No	-	Action
22	0.500	0.500	0.500	Supperimposed dead		No	-	Action

No.	q1	q2	q3	Load case	Comment	Applied on Ecc	Assigned	Intensity
[-]	[kN/m2]	[kN/m2]	[kN/m2]	[-]	[-]	[-]	[-]	[-]
23	0.500	0.500	0.500	Supperimposed dead		No	-	Action
24	0.500	0.500	0.500	Supperimposed dead		No	-	Action
25	0.500	0.500	0.500	Supperimposed dead		No	-	Action
26	0.500	0.500	0.500	Supperimposed dead		No	-	Action
27	0.500	0.500	0.500	Supperimposed dead		No	-	Action
28	0.500	0.500	0.500	Supperimposed dead		No	-	Action
29	0.500	0.500	0.500	Supperimposed dead		No	-	Action
30	0.500	0.500	0.500	Supperimposed dead		No	-	Action
31	0.500	0.500	0.500	Supperimposed dead		No	-	Action
32	2.000	2.000	2.000	Live load		No	-	Action
33	2.000	2.000	2.000	Live load		No	-	Action
34	2.000	2.000	2.000	Live load		No	-	Action
35	2.000	2.000	2.000	Live load		No	-	Action
36	2.000	2.000	2.000	Live load		No	-	Action
37	2.000	2.000	2.000	Live load		No	-	Action
38	2.000	2.000	2.000	Live load		No	-	Action
39	2.000	2.000	2.000	Live load		No	-	Action
40	2.000	2.000	2.000	Live load		No	-	Action
41	2.000	2.000	2.000	Live load		No	-	Action
42	2.000	2.000	2.000	Live load		No	-	Action
43	2.000	2.000	2.000	Live load		No	-	Action
44	2.000	2.000	2.000	Live load		No	-	Action
45	2.000	2.000	2.000	Live load		No	-	Action
46	2.000	2.000	2.000	Live load		No	-	Action
47	2.000	2.000	2.000	Live load		No	-	Action
48	2.000	2.000	2.000	Live load		No	-	Action
49	2.000	2.000	2.000	Live load		No	-	Action
50	2.000	2.000	2.000	Live load		No	-	Action
51	2.000	2.000	2.000	Live load		No	-	Action
52	3.200	3.200	3.200	snow load		No	-	Action
53	3.200	3.200	3.200	snow load		No	-	Action
54	3.200	3.200	3.200	snow load		No	-	Action
55	3.200	3.200	3.200	snow load		No	-	Action
56	3.200	3.200	3.200	snow load		No	-	Action
57	3.200	3.200	3.200	snow load		No	-	Action
58	3.200	3.200	3.200	snow load		No	-	Action
59	3.200	3.200	3.200	snow load		No	-	Action
60	3.200	3.200	3.200	snow load		No	-	Action
61	3.200	3.200	3.200	snow load		No	-	Action
62	3.200	3.200	3.200	snow load		No	-	Action
63	2.220	2.220	2.220	Supperimposed dead		No	-	Action
64	2.220	2.220	2.220	Supperimposed dead		No	-	Action
65	2.000	2.000	2.000	Live load		No	-	Action
66	2.000	2.000	2.000	Live load		No	-	Action
67	2.220	2.220	2.220	Supperimposed dead		No	-	Action
68	2.220	2.220	2.220	Supperimposed dead		No	-	Action
69	2.000	2.000	2.000	Live load		No	-	Action
70	2.000	2.000	2.000	Live load		No	-	Action
71	2.000	2.000	2.000	Live load		No	-	Action
72	2.000	2.000	2.000	Live load		No	-	Action
73	2.000	2.000	2.000	Live load		No	-	Action
74	2.220	2.220	2.220	Supperimposed dead		No	-	Action

No.	q1	q2	q3	Load case	Comment	Applied on Ecc	Assigned	Intensity
[-]	[kN/m2]	[kN/m2]	[kN/m2]	[-]	[-]	[-]	[-]	[-]
75	2.220	2.220	2.220	Supperimposed dead		No	-	Action
76	2.000	2.000	2.000	Live load		No	-	Action
77	2.000	2.000	2.000	Live load		No	-	Action
78	2.000	2.000	2.000	Live load		No	-	Action
79	2.220	2.220	2.220	Supperimposed dead		No	-	Action
80	0.000	19.680	6.330	Earth pressure		No	-	Action
81	0.000	0.000	3.160	Earth pressure		No	-	Action
82	0.000	19.680	3.160	Earth pressure		No	-	Action

Surface loads (Soil/Hydrostatic pressure)

No.	z0	q0	qh	qbottom	qtop	Load case	Comment	Applied on Ecc	Assigned	Intensity
[-]	[m]	[kN/m2]	[kN/m2/m]	[kN/m2]	[kN/m2]	[-]	[-]	[-]	[-]	[-]
1	3.100	1.650	21.300	133.923	67.680	Earth pr...		No	-	Action

Load cases

No.	Name	Type	Duration class
1	selfweight	+Struc. dead load	Permanent
2	Supperimposed dead	Ordinary	Permanent
3	Live load	Ordinary	Permanent
4	snow load	Ordinary	Short-term
5	Wind load Y-	Ordinary	Instantaneous
6	Earth pressure	Ordinary	Permanent
7	Misalignement load Hi	Ordinary	Permanent

Load combinations

No.	Name	Type	Factor	Load cases
1	Stability1: wind y- dom....	Ultimate	0.900	selfweight (+Struc. dead load)
			0.900	Earth pressure
			0.900	Supperimposed dead
			1.500	Wind load Y-
2	Staility2: 0,9G+1,5W+Hi...	Ultimate	0.900	selfweight (+Struc. dead load)
			0.900	Supperimposed dead
			1.500	Wind load Y-
			1.000	Misalignement load Hi
3	Service - only vertical lo...	Characteristic	1.000	selfweight (+Struc. dead load)
			1.000	Supperimposed dead
			1.000	Live load
			1.000	snow load
4	Ultimate - only vertical l...	Ultimate	1.200	selfweight (+Struc. dead load)
			1.200	Supperimposed dead
			1.500	Live load
			1.050	snow load
5	1.35*SW + 1.35*dead ...	Ultimate	1.350	selfweight (+Struc. dead load)
			1.350	Supperimposed dead
			1.350	Earth pressure
			1.050	Live load
			1.050	snow load
			1.050	Wind load Y-
6	0.89*1.35*SW + 0.89*1...	Ultimate	1.202	selfweight (+Struc. dead load)
			1.202	Supperimposed dead

No.	Name	Type	Factor	Load cases
			1.202	Earth pressure
			1.500	Live load
			1.050	snow load
			1.050	Wind load Y-
7	0.89*1.35*SW+ 0.89*1....	Ultimate	1.202	selfweight (+Struc. dead load)
			1.202	Supperimposed dead
			1.202	Earth pressure
			1.050	Live load
			1.500	snow load
			1.050	Wind load Y-
8	0.89*1.35*SW+ 0.89*1....	Ultimate	1.202	selfweight (+Struc. dead load)
			1.202	Supperimposed dead
			1.202	Earth pressure
			1.050	Live load
			1.050	snow load
			1.500	Wind load Y-
9	SW + dead + Soil + P(li...	Characteristic	1.000	selfweight (+Struc. dead load)
			1.000	Supperimposed dead
			1.000	Earth pressure
			1.000	Live load
			0.700	snow load
			0.700	Wind load Y-
10	SW + dead + Soil + 0.7...	Characteristic	1.000	selfweight (+Struc. dead load)
			1.000	Supperimposed dead
			1.000	Earth pressure
			0.700	Live load
			1.000	snow load
			0.700	Wind load Y-
11	SW + dead + Soil + 0.7...	Characteristic	1.000	selfweight (+Struc. dead load)
			1.000	Supperimposed dead
			1.000	Earth pressure
			0.700	Live load
			0.700	snow load
			1.000	Wind load Y-
12	SW + dead + Soil + 0.3...	Quasi-perman...	1.000	selfweight (+Struc. dead load)
			1.000	Supperimposed dead
			1.000	Earth pressure
			0.300	Live load
			0.300	snow load
			0.200	Wind load Y-
13	SW + dead + Soiid + 0....	Frequent	1.000	selfweight (+Struc. dead load)
			1.000	Supperimposed dead
			1.000	Earth pressure
			0.500	Live load
			0.300	snow load
			0.200	Wind load Y-
14	SW + dead + Soil+ 0.3...	Frequent	1.000	selfweight (+Struc. dead load)
			1.000	Supperimposed dead
			1.000	Earth pressure
			0.300	Live load
			0.500	snow load
			0.200	Wind load Y-
15	SW + dead + Soil + 0.3...	Frequent	1.000	selfweight (+Struc. dead load)

No.	Name	Type	Factor	Load cases
			1.000	Supperimposed dead
			1.000	Earth pressure
			0.300	Live load
			0.300	snow load
			0.500	Wind load Y-

1.3 Material properties

Concrete materials

No.	Name	Fck	Fck,cube	Fctm	Fctk	Ecm	Yield strain
[-]	[-]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[-]
1	C30/37	30.000	37.000	2.900	2.000	33000.000	0.00175
2	C35/45	35.000	45.000	3.200	2.200	34000.000	0.00175

Ultimate strain	Gamma c	Gamma c, Acc	Gamma cE	Gamma s	Gamma s, Acc	Alfa cc	Alfa ct
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.00350	1.50	1.20	1.20	1.15	1.00	1.00	1.00
0.00350	1.50	1.20	1.20	1.15	1.15	1.00	1.00

Density	Therm. coeff.	Poisson's ratio	Creep coefficient, SLS	Creep coefficient, ULS	Shrinkage
[t/m3]	[1/°C]	[-]	[-]	[-]	[-]
2.548	0.000010	0.200	0.000	0.000	0.000
2.548	0.000010	0.200	0.000	0.000	0.000

Dyna r.	Stab r.
[-]	[-]
1.000	1.000
1.000	1.000

Steel materials

No.	Name	fyk(t<16)	fyk(16<=t<=40)	fyk(40<t<=63)	fyk(63<t<=80)
[-]	[-]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]
1	S 355	355.000	355.000	335.000	335.000
2	S 355_1	355.000	355.000	335.000	335.000

fyk(80<t<=100)	fyk(100<t<=150)	fyk(150<t<=200)	fyk(200<t<=250)	fyk(250<t<=400)	fuk(t<3)
[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]
335.000	335.000	335.000	335.000	335.000	510.000
335.000	335.000	335.000	335.000	335.000	510.000

fuk(3<=t<=40)	fuk(40<t<=100)	fuk(100<t<=150)	fuk(150<t<=250)	fuk(250<t<=400)	Gamma M0
[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[-]
510.000	470.000	470.000	470.000	470.000	1.000
510.000	470.000	470.000	470.000	470.000	1.050

Gamma M0, Acc	Gamma M1	Gamma M1, Acc	Gamma M2	Gamma M2, Acc	Gamma M5	Gamma M5, Acc	Gamma Mfi	Ek
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[N/mm2]
1.000	1.000	1.000	1.250	1.250	1.000	1.000	1.000	210000.000
1.000	1.050	1.000	1.250	1.000	1.000	1.000	1.000	210000.000

Poisson's ratio	G	Therm. coeff.	Density
[-]	[N/mm2]	[1/°C]	[t/m3]
0.300	80769.000	1.2000e-05	7.850000
0.300	80769.000	1.2000e-05	7.850000

Timber materials

No.	Name	Type	Gamma M	Gamma M, Acc	Service class	System factor	k cr factor	f m,0,k
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[N/mm2]
1	GL 30c	Glued lamin...	1.150	1.000	2	1.000	0.800	30.000

f m,90,k	f t,0,k	f t,90,k	f c,0,k	f c,90,k	f v,k	E 0,mean	E 90,mean	E 0,05
[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]
30.000	19.500	0.500	24.500	2.500	3.500	13000.000	300.000	10800.000

G mean	G 0,05	Rho k	Rho mean	Thermal coefficient x'	Thermal coefficient y'
[N/mm2]	[N/mm2]	[kg/m3]	[kg/m3]	[-]	[-]
650.000	540.000	390.000	430.000	0.000	0.000

Thermal coefficient z'
[-]
0.000

Timber panels - for selected objects

ID	Panel type	Alignment	Eccentricity	Gamma M, Ult	Gamma M, Acc./seis	Service class	System factor	Creep factor
[-]	[-]	[-]	[m]	[-]	[-]	[-]	[-]	
TP.1	L(T)280-7S	Center	0.000	1.300	1.000	2	1.000	0.670
TP.2	L(T)280-7S	Center	0.000	1.300	1.000	2	1.000	0.670
TP.3	L(T)160-5S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.4	L(T)160-5S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.5	L(T)160-5S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.6	L(T)160-5S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.7	L(T)160-5S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.8	L(T)160-5S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.9	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.10	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.11	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.12	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.13	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.14	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.15	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.16	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.17	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.18	L(T)160-5S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.19	L(T)160-5S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.20	L(T)160-5S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.21	L(T)160-5S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.22	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.23	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.24	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.25	L(T)200-5S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.26	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.27	L(T)160-5S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.28	L(T)160-5S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.29	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670
TP.30	L(T)280-7S	Center	0.000	1.250	1.000	2	1.000	0.670

Sections - for selected objects

Section	Composite	Height	Width	A	P	A/P	Yg	Zg
[-]	[-]	[mm]	[mm]	[mm2]	[mm]	[mm]	[mm]	[mm]
Timber sections Glulam 115x115	No	115	115	13225	460	28.8	0.000	0.000
Timber sections Glulam 140x540	No	540	140	75600	1360	55.6	0.000	0.000
Timber sections Glulam 140x225	No	225	140	31500	730	43.2	0.000	0.000
Timber sections Glulam 115x180	No	180	115	20700	590	35.1	0.000	0.000
Timber sections Glulam 115x405	No	405	115	46575	1040	44.8	0.000	0.000

Ys	Zs	Iy	Wy	ez max	ez min	iy	Sy	Iz	Wz
[mm]	[mm]	[mm4]	[mm3]	[mm]	[mm]	[mm]	[mm3]	[mm4]	[mm3]
0.000	0.000	14575052	253479	58	58	33.2	190211	14575052	253479
0.000	0.000	1837080000	6804000	270	270	155.9	5103000	123480000	1764000
0.000	0.000	132890625	1181250	113	113	65.0	885938	51450000	735000
0.000	0.000	55890000	621000	90	90	52.0	465913	22813125	396750
0.000	0.000	636622031	3143813	203	202	116.9	2357859	51329531	892688

ey max	ey min	iz	Sz	It	Wt	Iw	Iyz	z omega	alpha1
[mm]	[mm]	[mm]	[mm3]	[mm4]	[mm3]	[mm6]	[mm4]	[-]	[rad]
58	58	33.2	190211	24587037	317265	310863346	0	0	0.000
70	70	40.4	1325527	413216239	2962760	2271920959002	0	0	0.000
70	70	40.4	551250	126119022	1034366	44971813327	0	0	0.000
58	57	33.2	297562	55040470	555676	11662481645	0	0	0.000
58	58	33.2	670794	168576009	1475343	503625514448	0	0	0.000

I1	W1 min	W1 max	e2 max	e2 min	i1	S1	S01	c1	Rho 1	z2
[mm4]	[mm3]	[mm3]	[mm]	[mm]	[mm]	[mm3]	[mm3]	[-]	[-]	[mm]
14575052	253479	253479	58	58	33.2	190211	190189	1.501	0.833	0
1837080000	6804000	6804000	270	270	155.9	5103000	5102793	1.500	0.833	0
132890625	1181250	1181250	113	113	65.0	885938	885882	1.500	0.833	0
55890000	621000	621000	90	90	52.0	465913	465913	1.501	0.833	0
636622031	3143813	3143813	203	202	116.9	2357859	2357751	1.500	0.833	0

alpha2	I2	W2 min	W2 max	e1 max	e1 min	i2	S2	S02	c2	Rho 2
[rad]	[mm4]	[mm3]	[mm3]	[mm]	[mm]	[mm]	[mm3]	[mm3]	[-]	[-]
1.571	14575052	253479	253479	58	58	33.2	190211	190189	1.501	0.833
1.571	123480000	1764000	1764000	70	70	40.4	1325527	1325249	1.503	0.833
1.571	51450000	735000	735000	70	70	40.4	551250	551196	1.500	0.833
1.571	22813125	396750	396750	58	58	33.2	297562	297563	1.500	0.833
1.571	51329531	892688	892688	58	58	33.2	670794	670794	1.503	0.833

z1	Other
[mm]	[-]
0	-
0	-
0	-
0	-
0	-

Section	Composite	Height	Width	A	P	A/P	Yg	Zg
[-]	[-]	[mm]	[mm]	[mm2]	[mm]	[mm]	[mm]	[mm]
Steel sections HE-B 280	No	280	280	13136	1618	8.1	0.000	0.000
Steel sections HE-B 300	No	300	300	14908	1732	8.6	0.000	0.000
Steel sections IPE 400	No	400	180	8446	1467	5.8	0.000	0.000
Steel sections IPE 200	No	200	100	2848	768	3.7	0.000	0.000
Steel sections IPE 330	No	330	160	6261	1254	5.0	0.000	0.000

Ys	Zs	Iy	Wy	ez max	ez min	iy	Sy	Iz	Wz
[mm]	[mm]	[mm4]	[mm3]	[mm]	[mm]	[mm]	[mm3]	[mm4]	[mm3]
0.000	0.000	192702776	1376448	140	140	121.1	767217	65945220	471037
0.000	0.000	251656844	1677712	150	150	129.9	934337	85628301	570855
0.000	0.000	231283781	1156419	200	200	165.5	653575	13178239	146425
0.000	0.000	19431689	194317	100	100	82.6	110319	1423683	28474
0.000	0.000	117669093	713146	165	165	137.1	402166	7881421	98518

ey max	ey min	iz	Sz	It	Wt	Iw	Iyz	z omega	alpha1
[mm]	[mm]	[mm]	[mm3]	[mm4]	[mm3]	[mm6]	[mm4]	[-]	[rad]
140	140	70.9	358838	1452618	50857	1107204564844	-0	0	0.000
150	150	75.8	435132	1873995	61489	1651023599417	-0	0	0.000
90	90	39.5	114568	504116	22398	482886186833	0	0	0.000
50	50	22.4	22320	68464	4924	12746157814	0	0	0.000
80	80	35.5	76882	275905	13973	196088467329	-0	0	0.000

I1	W1 min	W1 max	e2 max	e2 min	i1	S1	S01	c1	Rho 1	z2
[mm4]	[mm3]	[mm3]	[mm]	[mm]	[mm]	[mm3]	[mm3]	[-]	[-]	[mm]
192702776	1376448	1376448	140	140	121.1	767217	767217	1.115	0.688	0
251656844	1677712	1677712	150	150	129.9	934337	934337	1.114	0.689	0
231283781	1156419	1156419	200	200	165.5	653575	653575	1.130	0.536	0
19431689	194317	194317	100	100	82.6	110319	110319	1.135	0.557	0
117669093	713146	713146	165	165	137.1	402166	402165	1.128	0.546	0

alpha2	I2	W2 min	W2 max	e1 max	e1 min	i2	S2	S02	c2	Rho 2
[rad]	[mm4]	[mm3]	[mm3]	[mm]	[mm]	[mm]	[mm3]	[mm3]	[-]	[-]
1.571	65945220	471037	471037	140	140	70.9	358838	358838	1.524	0.217
1.571	85628301	570855	570855	150	150	75.8	435132	435130	1.524	0.216
1.571	13178239	146425	146425	90	90	39.5	114568	114568	1.565	0.400
1.571	1423683	28474	28474	50	50	22.4	22320	22320	1.568	0.385
1.571	7881421	98518	98518	80	80	35.5	76882	76882	1.561	0.388

z1	Other
[mm]	[-]
0	tw=10.5mm; hw=244mm;...
0	tw=11.0mm; hw=262mm;...
0	tw=8.6mm; hw=373mm; t...
0	tw=5.6mm; hw=183mm; t...
0	tw=7.5mm; hw=307mm; t...

Section	Composite	Height	Width	A	P	A/P	Yg	Zg
[-]	[-]	[mm]	[mm]	[mm2]	[mm]	[mm]	[mm]	[mm]
Steel sections HE-A 200	No	190	200	5383	1136	4.7	0.000	0.000
Steel sections VKR 140x140x8	No	140	140	4155	1022	4.1	0.000	0.000
Steel sections VKR 140x140x10	No	140	140	5093	997	5.1	0.000	0.000
Steel sections VKR 100x100x8	No	100	100	2875	702	4.1	0.000	0.000

Ys	Zs	Iy	Wy	ez max	ez min	iy	Sy	Iz	Wz
[mm]	[mm]	[mm4]	[mm3]	[mm]	[mm]	[mm]	[mm3]	[mm4]	[mm3]
0.000	0.000	36921561	388648	95	95	82.8	214742	13355094	133551
-0.000	0.001	11950231	170715	70	70	53.6	102168	11950231	170717
0.000	0.001	14160776	202295	70	70	52.7	123045	14160776	202296
0.000	0.000	3995961	79919	50	50	37.3	49092	3995961	79919

ey max	ey min	iz	Sz	It	Wt	Iw	Iyz	z omega	alpha1
[mm]	[mm]	[mm]	[mm3]	[mm4]	[mm3]	[mm6]	[mm4]	[-]	[rad]
100	100	49.8	101924	204312	11561	105578311699	-0	0	0.000
70	70	53.6	102167	19281071	237949	73465032	0	-0	0.000
70	70	52.7	123045	23261188	294428	121981645	0	-0	0.000
50	50	37.3	49092	6634322	116067	20549602	0	0	0.000

I1	W1 min	W1 max	e2 max	e2 min	i1	S1	S01	c1	Rho 1	z2
[mm4]	[mm3]	[mm3]	[mm]	[mm]	[mm]	[mm3]	[mm3]	[-]	[-]	[mm]
36921561	388648	388648	95	95	82.8	214742	214742	1.105	0.678	-0
11950231	170715	170718	70	70	53.6	102168	102168	1.197	0.442	0
14160776	202295	202297	70	70	52.7	123045	123045	1.216	0.449	0
3995961	79919	79919	50	50	37.3	49092	49092	1.229	0.454	0

alpha2	I2	W2 min	W2 max	e1 max	e1 min	i2	S2	S02	c2	Rho 2
[rad]	[mm4]	[mm3]	[mm3]	[mm]	[mm]	[mm]	[mm3]	[mm3]	[-]	[-]
1.571	13355094	133551	133551	100	100	49.8	101924	101924	1.526	0.224
1.571	11950231	170717	170719	70	70	53.6	102167	102167	1.197	0.442
1.571	14160776	202296	202298	70	70	52.7	123045	123045	1.216	0.449
1.571	3995961	79919	79919	50	50	37.3	49092	49092	1.229	0.454

z1	Other
[mm]	[-]
0	tw=6.5mm; hw=170mm; t...
-0	t=8.0mm; r=8.00mm
-0	t=10.0mm; r=10.00mm
0	t=8.0mm; r=8.00mm

Beams - for selected objects

ID	Material	Section, start	Section, end	Ecc. mode.	Ecc. crack.	Sp. cond.	Ep. cond.
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
B.1.1	GL 30c	Glulam 140x540	Glulam 140x540	Release at END	No	FFFF--	FFFF--
B.2.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.3.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.4.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.5.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--

ID	Material	Section, start	Section, end	Ecc. mode.	Ecc. crack.	Sp. cond.	Ep. cond.
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
B.6.1	S 355_1	IPE 330	IPE 330	Release at END	No	FFFF--	FFFF--
B.7.1	GL 30c	Glulam 115x180	Glulam 115x180	Release at END	No	FFFF--	FFFF--
B.8.1	GL 30c	Glulam 115x180	Glulam 115x180	Release at END	No	FFFF--	FFFF--
B.9.1	GL 30c	Glulam 115x180	Glulam 115x180	Release at END	No	FFFF--	FFFF--
B.10.1	GL 30c	Glulam 115x180	Glulam 115x180	Release at END	No	FFFF--	FFFF--
B.11.1	GL 30c	Glulam 115x180	Glulam 115x180	Release at END	No	FFFF--	FFFF--
B.12.1	GL 30c	Glulam 115x180	Glulam 115x180	Release at END	No	FFFF--	FFFF--
B.13.1	GL 30c	Glulam 115x180	Glulam 115x180	Release at END	No	FFFF--	FFFF--
B.14.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.15.1	GL 30c	Glulam 140x540	Glulam 140x540	Release at END	No	FFFF--	FFFF--
B.16.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.17.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.18.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.19.1	S 355_1	HE-B 280	HE-B 280	Release at END	No	FFFF--	FFFF--
B.20.1	S 355_1	HE-B 280	HE-B 280	Release at END	No	FFFF--	FFFF--
B.21.1	S 355_1	HE-B 300	HE-B 300	Release at END	No	FFFF--	FFFF--
B.22.1	S 355_1	HE-B 280	HE-B 280	Release at END	No	FFFF--	FFFF--
B.23.1	S 355_1	HE-B 300	HE-B 300	Release at END	No	FFFF--	FFFF--
B.24.1	S 355_1	HE-B 280	HE-B 280	Release at END	No	FFFF--	FFFF--
B.25.1	S 355_1	HE-B 280	HE-B 280	Release at END	No	FFFF--	FFFF--
B.26.1	GL 30c	Glulam 140x540	Glulam 140x540	Release at END	No	FFFF--	FFFF--
B.27.1	GL 30c	Glulam 140x540	Glulam 140x540	Release at END	No	FFFF--	FFFF--
B.28.1	GL 30c	Glulam 140x540	Glulam 140x540	Release at END	No	FFFF--	FFFF--
B.29.1	S 355_1	HE-B 280	HE-B 280	Release at END	No	FFFF--	FFFF--
B.30.1	GL 30c	Glulam 140x540	Glulam 140x540	Release at END	No	FFFF--	FFFF--
B.31.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.32.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.33.1	S 355_1	IPE 400	IPE 400	Release at END	No	FFFF--	FFFF--
B.34.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.35.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.36.1	S 355_1	IPE 400	IPE 400	Release at END	No	FFFF--	FFFF--
B.37.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.38.1	S 355_1	IPE 400	IPE 400	Release at END	No	FFFF--	FFFF--
B.39.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.40.1	S 355_1	IPE 400	IPE 400	Release at END	No	FFFF--	FFFF--
B.41.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.42.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.43.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.44.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.45.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.46.1	GL 30c	Glulam 140x540	Glulam 140x540	Release at END	No	FFFF--	FFFF--
B.47.1	GL 30c	Glulam 140x540	Glulam 140x540	Release at END	No	FFFF--	FFFF--
B.48.1	GL 30c	Glulam 140x540	Glulam 140x540	Release at END	No	FFFF--	FFFF--
B.49.1	GL 30c	Glulam 115x180	Glulam 115x180	Release at END	No	FFFF--	FFFF--
B.50.1	GL 30c	Glulam 115x180	Glulam 115x180	Release at END	No	FFFF--	FFFF--
B.51.1	GL 30c	Glulam 115x180	Glulam 115x180	Release at END	No	FFFF--	FFFF--
B.52.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.53.1	GL 30c	Glulam 140x540	Glulam 140x540	Release at END	No	FFFF--	FFFF--
B.54.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.55.1	S 355_1	IPE 330	IPE 330	Release at END	No	FFFF--	FFFF--
B.56.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.57.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--

ID	Material	Section, start	Section, end	Ecc. mode.	Ecc. crack.	Sp. cond.	Ep. cond.
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
B.58.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.59.1	S 355_1	IPE 330	IPE 330	Release at END	No	FFFF--	FFFF--
B.60.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.61.1	GL 30c	Glulam 115x405	Glulam 115x405	Release at END	No	FFFF--	FFFF--
B.62.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.63.1	S 355_1	IPE 400	IPE 400	Release at END	No	FFFF--	FFFF--
B.64.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.65.1	S 355_1	IPE 400	IPE 400	Release at END	No	FFFF--	FFFF--
B.66.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.67.1	S 355_1	IPE 330	IPE 330	Release at END	No	FFFF--	FFFF--
B.68.1	S 355_1	IPE 400	IPE 400	Release at END	No	FFFF--	FFFF--
B.69.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--
B.70.1	S 355_1	IPE 200	IPE 200	Release at END	No	FFFF--	FFFF--

Columns - for selected objects

ID	Material	Section, start	Section, end	Ecc. mode.	Ecc. crack.	Sp. cond.	Ep. cond.
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
C.1.1	S 355_1	VKR 140x140x10	VKR 140x140x10	Release at END	No	FFFF--	FFFF--
C.2.1	S 355_1	VKR 140x140x10	VKR 140x140x10	Release at END	No	FFFF--	FFFF--
C.3.1	S 355_1	VKR 140x140x10	VKR 140x140x10	Release at END	No	FFFF--	FFFF--
C.4.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.5.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.6.1	S 355_1	HE-A 200	HE-A 200	Release at END	No	FFFF--	FFFF--
C.7.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.8.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.9.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.10.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.11.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.12.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.13.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.14.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.15.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.16.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.17.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.18.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.19.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.20.1	GL 30c	Glulam 140x225	Glulam 140x225	Release at END	No	FFFF--	FFFF--
C.21.1	GL 30c	Glulam 140x225	Glulam 140x225	Release at END	No	FFFF--	FFFF--
C.22.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.23.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.24.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.25.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.26.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.27.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.28.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.29.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.30.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.31.1	GL 30c	Glulam 140x225	Glulam 140x225	Release at END	No	FFFF--	FFFF--
C.32.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.33.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.34.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--

ID	Material	Section, start	Section, end	Ecc. mode.	Ecc. crack.	Sp. cond.	Ep. cond.
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
C.35.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.36.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.37.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.38.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.39.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.40.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.41.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.42.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.43.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.44.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.45.1	GL 30c	Glulam 140x225	Glulam 140x225	Release at END	No	FFFF--	FFFF--
C.46.1	S 355_1	HE-A 200	HE-A 200	Release at END	No	FFFF--	FFFF--
C.47.1	S 355_1	HE-A 200	HE-A 200	Release at END	No	FFFF--	FFFF--
C.48.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.49.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.50.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.51.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.52.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.53.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.54.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.55.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.56.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.57.1	S 355_1	VKR 140x140x8	VKR 140x140x8	Release at END	No	FFFF--	FFFF--
C.58.1	GL 30c	Glulam 140x225	Glulam 140x225	Release at END	No	FFFF--	FFFF--
C.59.1	GL 30c	Glulam 140x225	Glulam 140x225	Release at END	No	FFFF--	FFFF--
C.60.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.61.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.62.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.63.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.64.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.65.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.66.1	S 355_1	VKR 100x100x8	VKR 100x100x8	Release at END	No	FFFF--	FFFF--
C.67.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.68.1	GL 30c	Glulam 140x225	Glulam 140x225	Release at END	No	FFFF--	FFFF--
C.69.1	GL 30c	Glulam 140x225	Glulam 140x225	Release at END	No	FFFF--	FFFF--
C.70.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.71.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.72.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.73.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.74.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.75.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.76.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.77.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.78.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.79.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.80.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.81.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.82.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.83.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.84.1	GL 30c	Glulam 140x225	Glulam 140x225	Release at END	No	FFFF--	FFFF--
C.85.1	GL 30c	Glulam 140x225	Glulam 140x225	Release at END	No	FFFF--	FFFF--
C.86.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--

ID	Material	Section, start	Section, end	Ecc. mode.	Ecc. crack.	Sp. cond.	Ep. cond.
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
C.87.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.88.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.89.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.90.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.91.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.92.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.93.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.94.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.95.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.96.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.97.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.98.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--
C.99.1	GL 30c	Glulam 115x115	Glulam 115x115	Release at END	No	FFFF--	FFFF--

Walls - for selected objects

ID	Material	t1	t2	t3	E2 / E1	Alpha	Ecc.	Ecc. calc.	Ecc. crack.	Length	Height
[-]	[-]	[m]	[m]	[m]	[-]	[rad]	[m]	[-]	[-]	[m]	[m]
W.1.1	C35/45	0.250	0.250	-	1.000	0.000	0.000	No	No	43.660	3.110
W.2.1	C35/45	0.350	0.350	-	1.000	0.000	0.000	No	No	2.902	3.110
W.3.1	C35/45	0.250	0.250	-	1.000	0.000	0.000	No	No	5.180	3.110
W.4.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	2.550	3.110
W.5.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	2.820	3.110
W.6.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	2.630	3.110
W.7.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	1.920	3.110
W.8.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	3.060	3.110
W.9.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	2.900	3.110
W.10.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	2.120	3.110
W.11.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	2.120	3.110
W.12.1	C35/45	0.350	0.350	-	1.000	0.000	0.000	No	No	17.185	3.110
W.13.1	C35/45	0.250	0.250	-	1.000	0.000	0.000	No	No	2.975	3.110
W.14.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	2.975	3.110
W.15.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	5.245	3.110
W.16.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	5.245	3.110
W.17.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	5.380	3.110
W.18.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	3.010	3.110
W.19.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	5.180	2.990
W.20.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	4.740	2.990
W.21.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	2.630	2.990
W.22.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	1.920	2.990
W.23.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	5.180	2.990
W.24.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	4.740	3.842
W.25.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	4.740	4.227
W.26.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	5.180	4.227
W.27.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	4.740	2.990
W.28.1	C35/45	0.350	0.350	-	1.000	0.000	0.000	No	No	40.985	3.110
W.29.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	1.920	3.110
W.30.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	2.630	3.110
W.31.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	5.180	4.227
W.32.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	3.500	3.288
W.33.1	C35/45	0.200	0.200	-	1.000	0.000	0.000	No	No	3.900	3.132
W.34.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	2.630	4.227

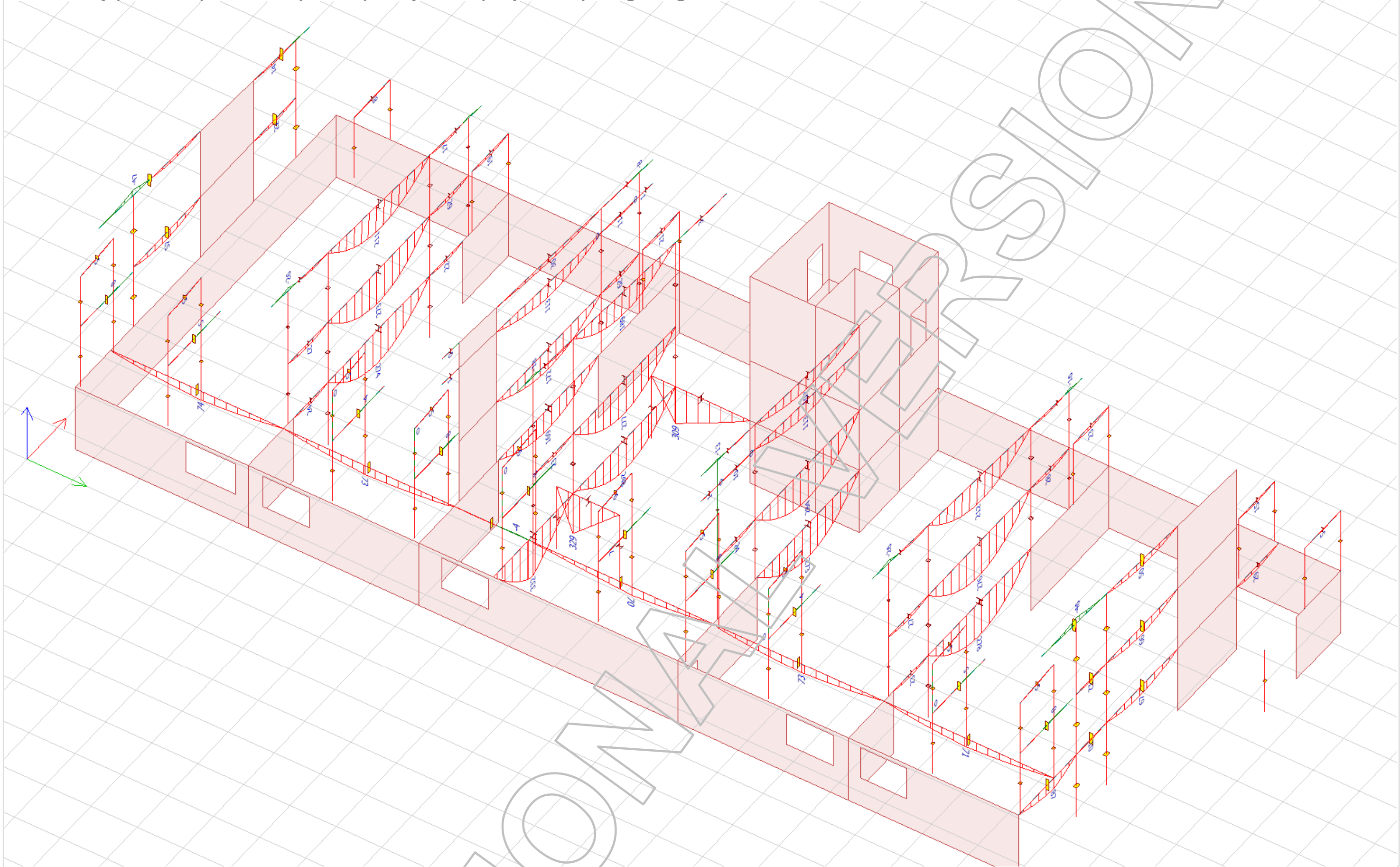
ID	Material	t1	t2	t3	E2 / E1	Alpha	Ecc.	Ecc. calc.	Ecc. crack.	Length	Height
[-]	[-]	[m]	[m]	[m]	[-]	[rad]	[m]	[-]	[-]	[m]	[m]
W.35.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	1.920	4.031
W.36.1	C35/45	0.200	0.200	-	1.000	0.000	0.000	No	No	3.900	3.110
W.37.1	C35/45	0.200	0.200	-	1.000	0.000	0.000	No	No	3.900	2.990
W.38.1	C35/45	0.220	0.220	-	1.000	0.000	0.000	No	No	3.500	2.990
W.39.1	C35/45	0.200	0.200	-	1.000	0.000	0.000	No	No	2.495	2.990
W.40.1	C35/45	0.200	0.200	-	1.000	0.000	0.000	No	No	2.495	3.669
W.41.1	C35/45	0.200	0.200	-	1.000	0.000	0.000	No	No	2.495	1.425

2 Analysis results

2.1 Frame analysis results

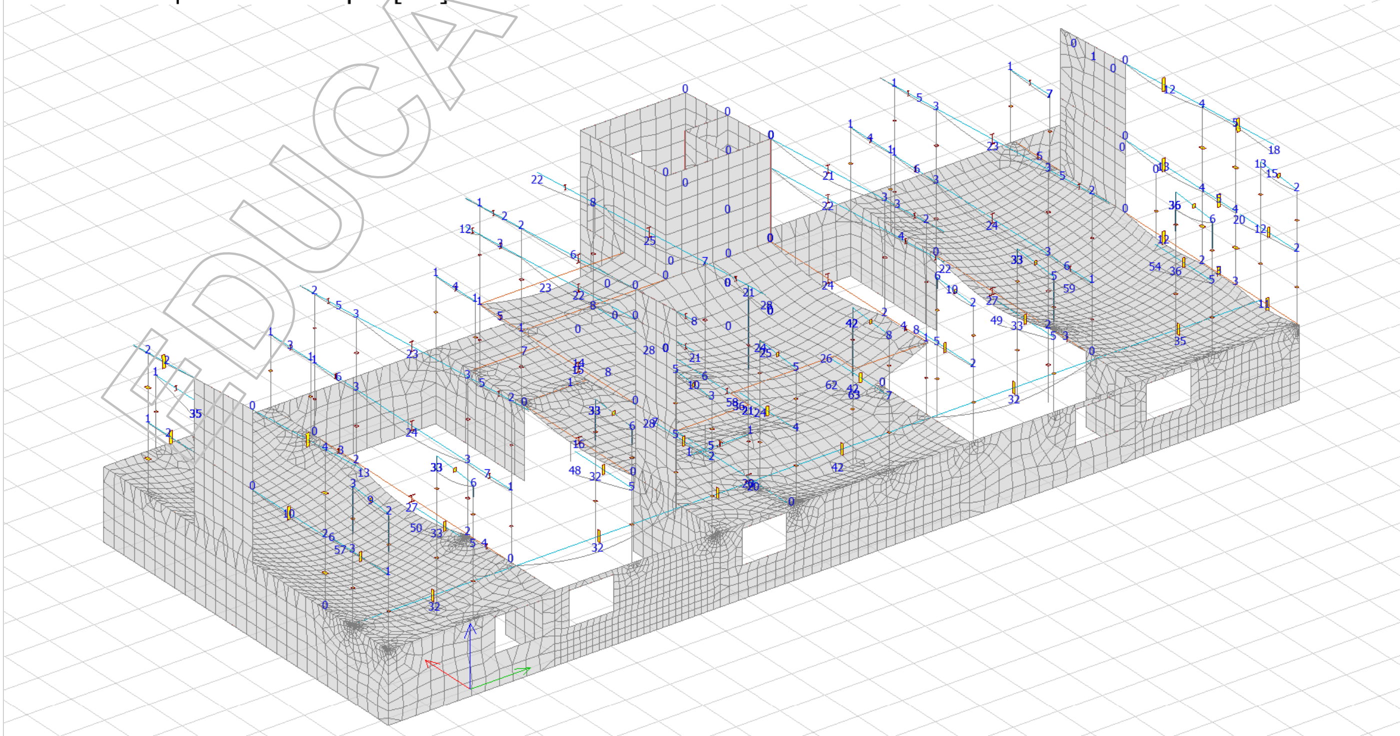
Bending moment diagram

Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S) - Bars, My' - Graph - [kNm]

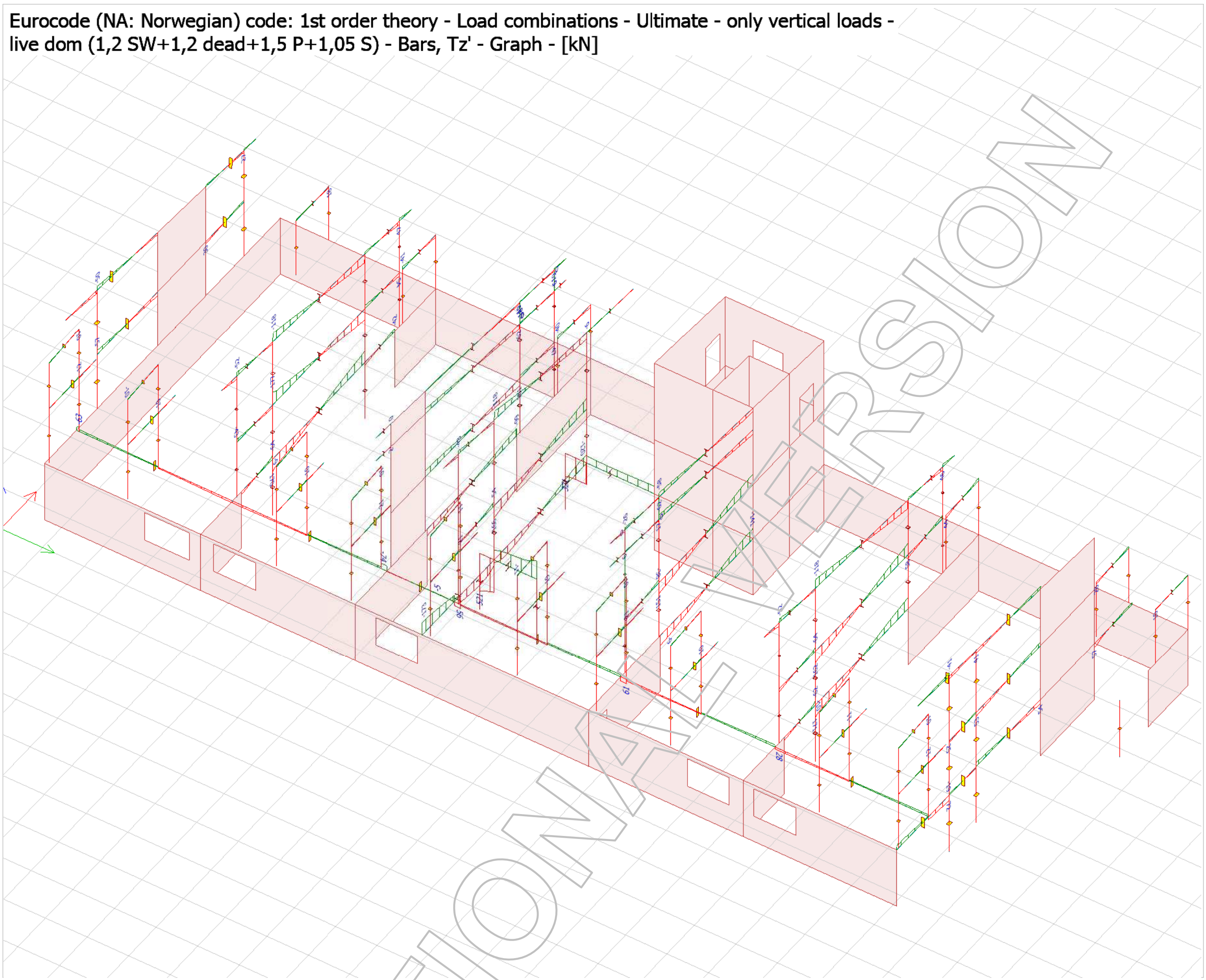


Deflection frames

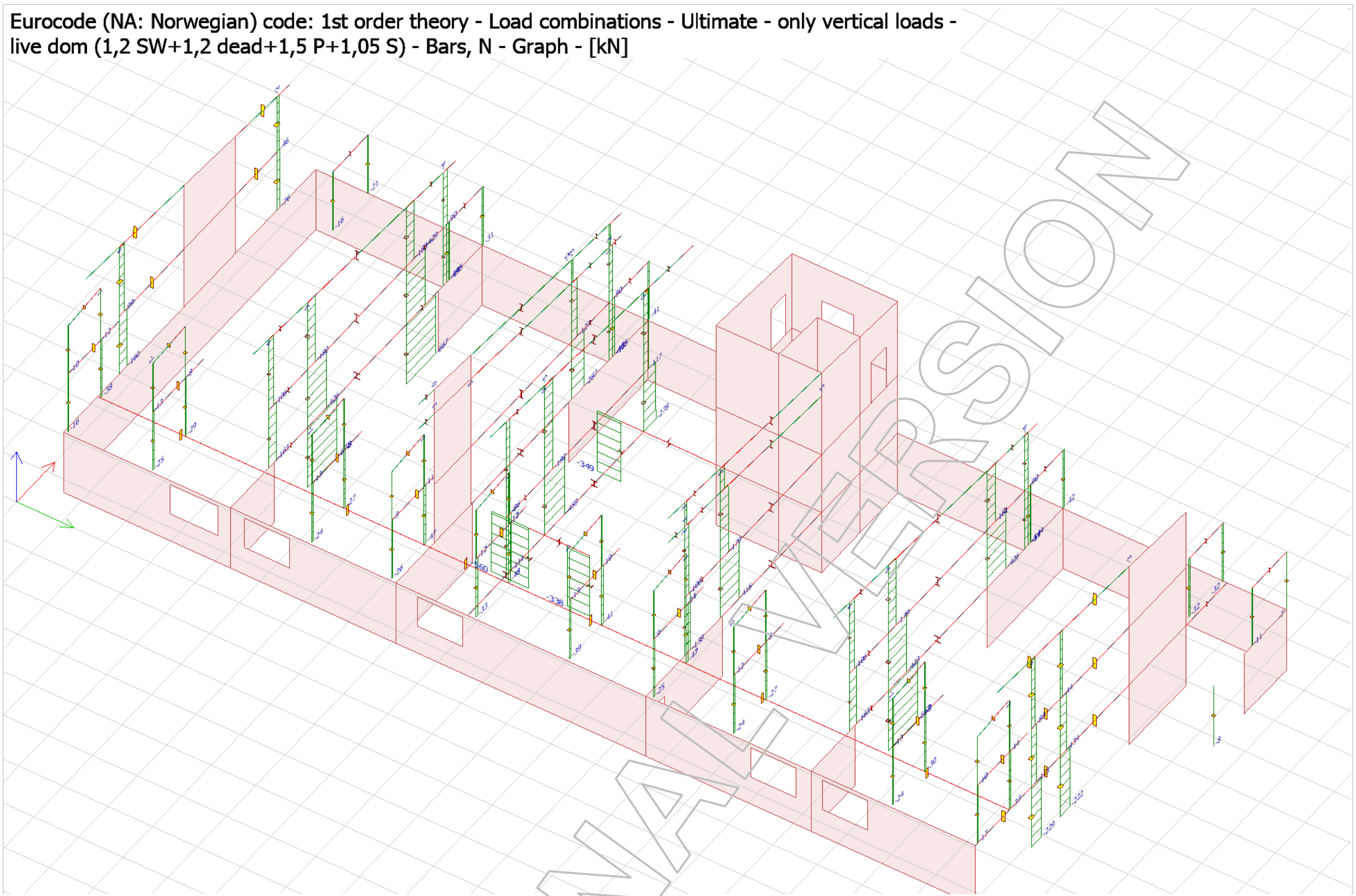
Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Service - only vertical loads (1,0 SW+1,0 dead+1,0 P+1,0 S) - Translational displacements - Graph - [mm]



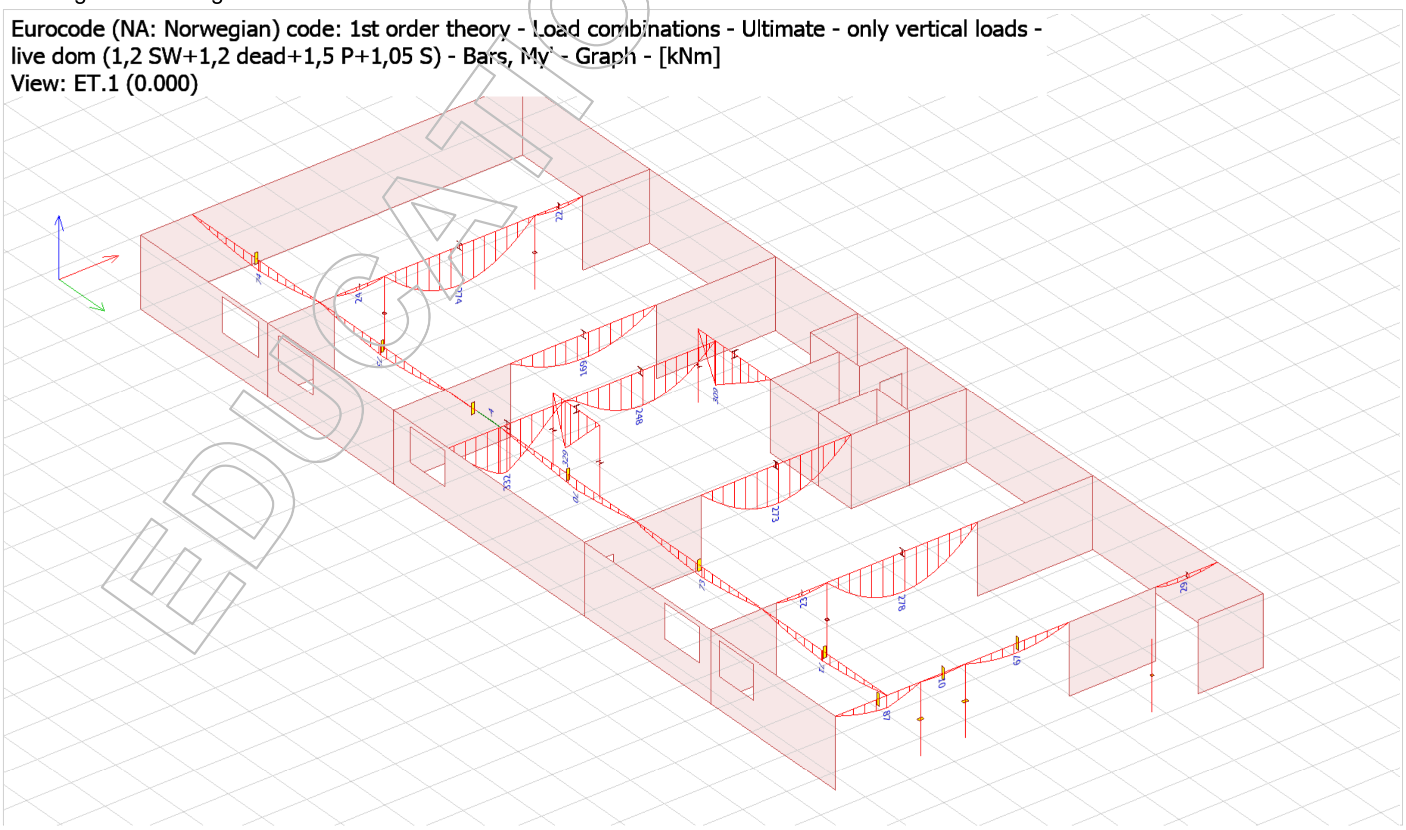
Shear force diagram



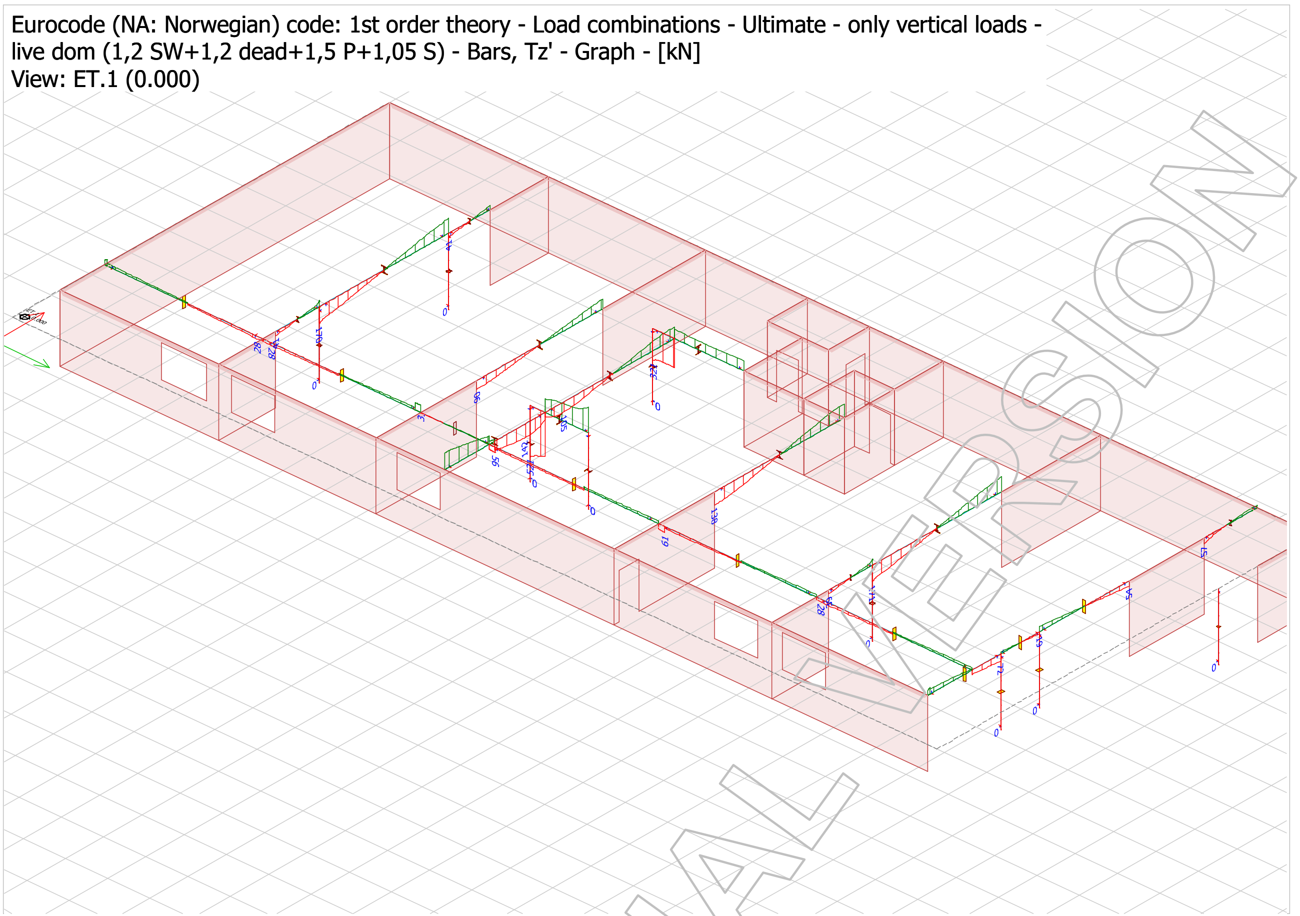
Axial force diagram



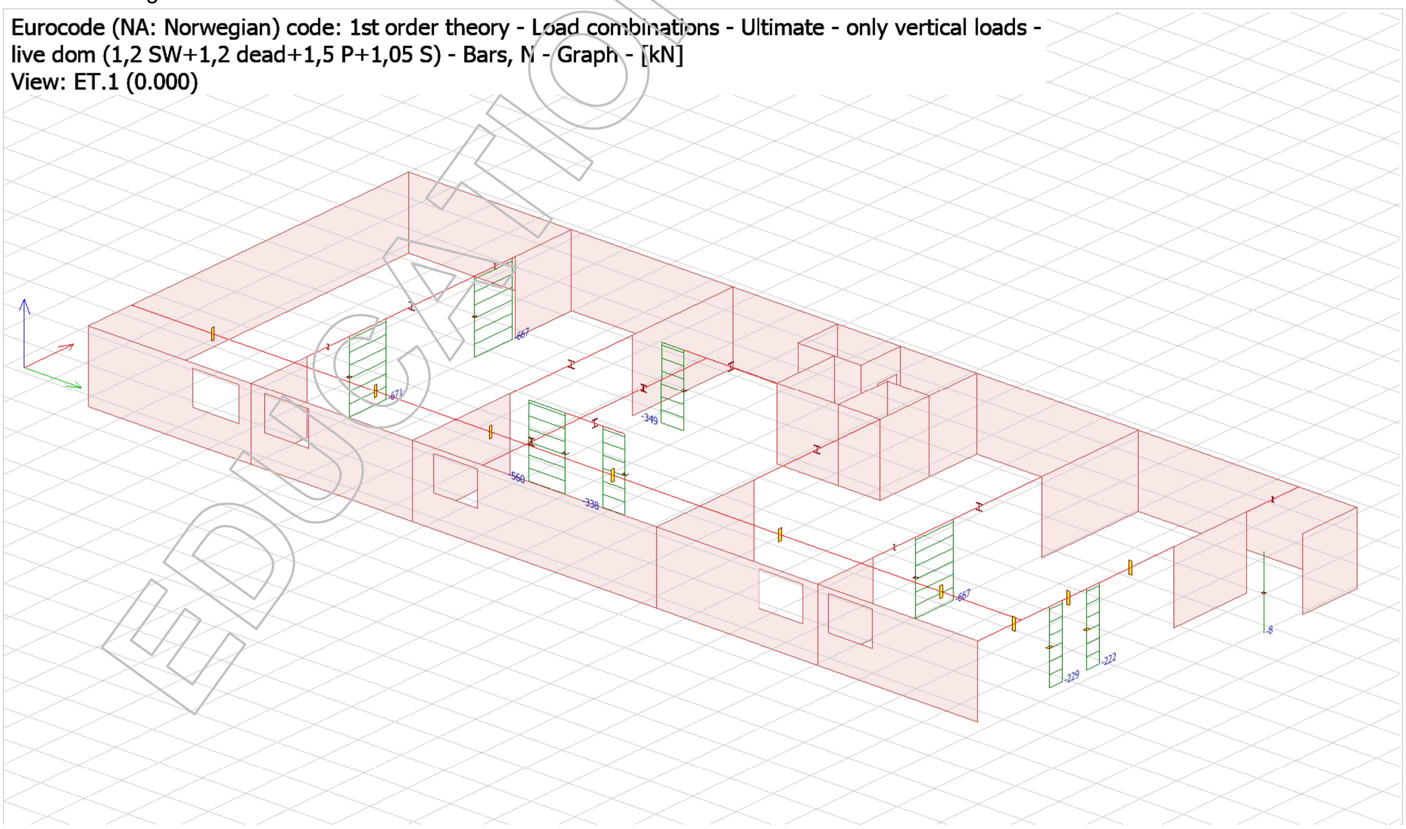
Bending moment diagram



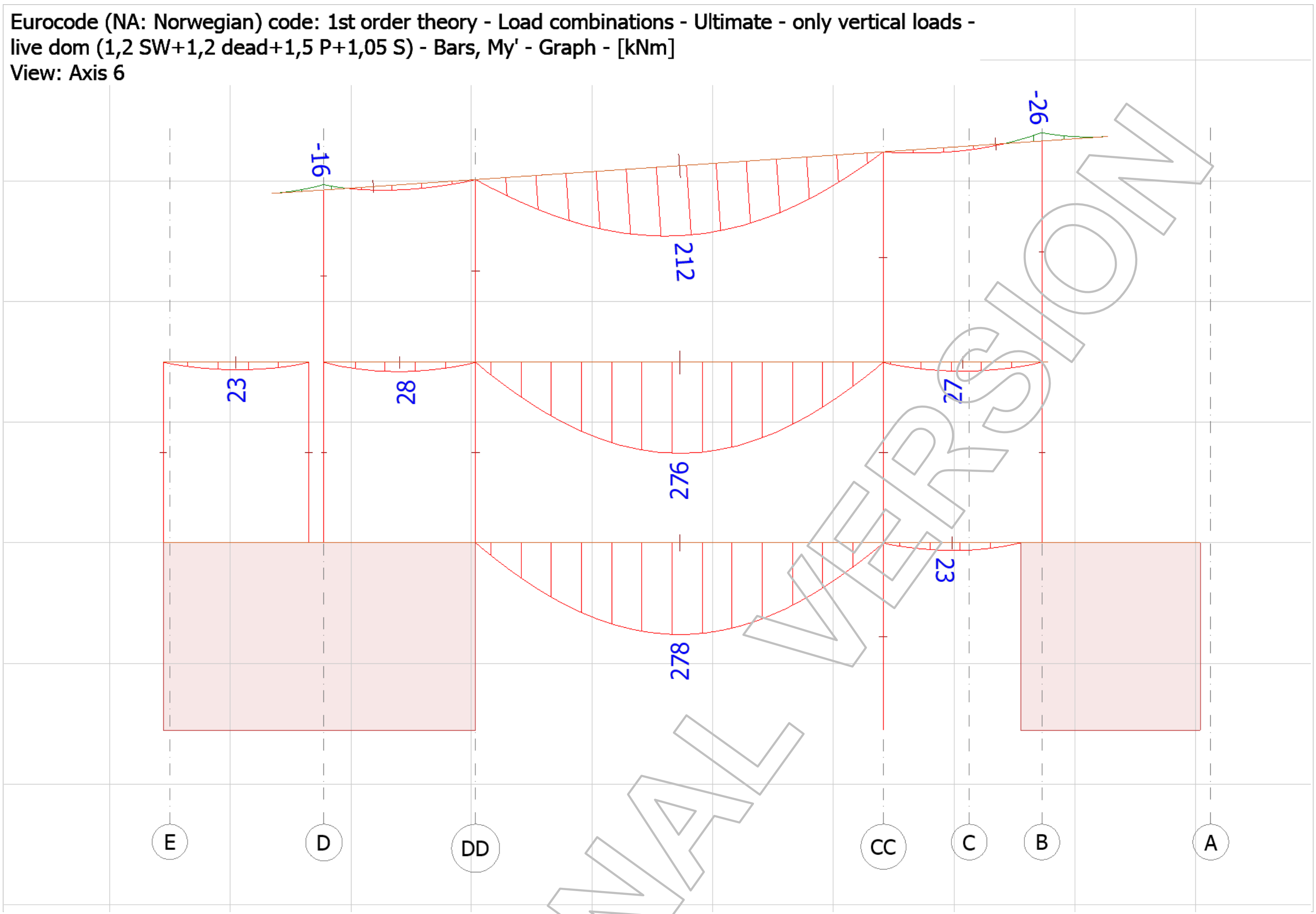
Shear force diagrag 1st floor



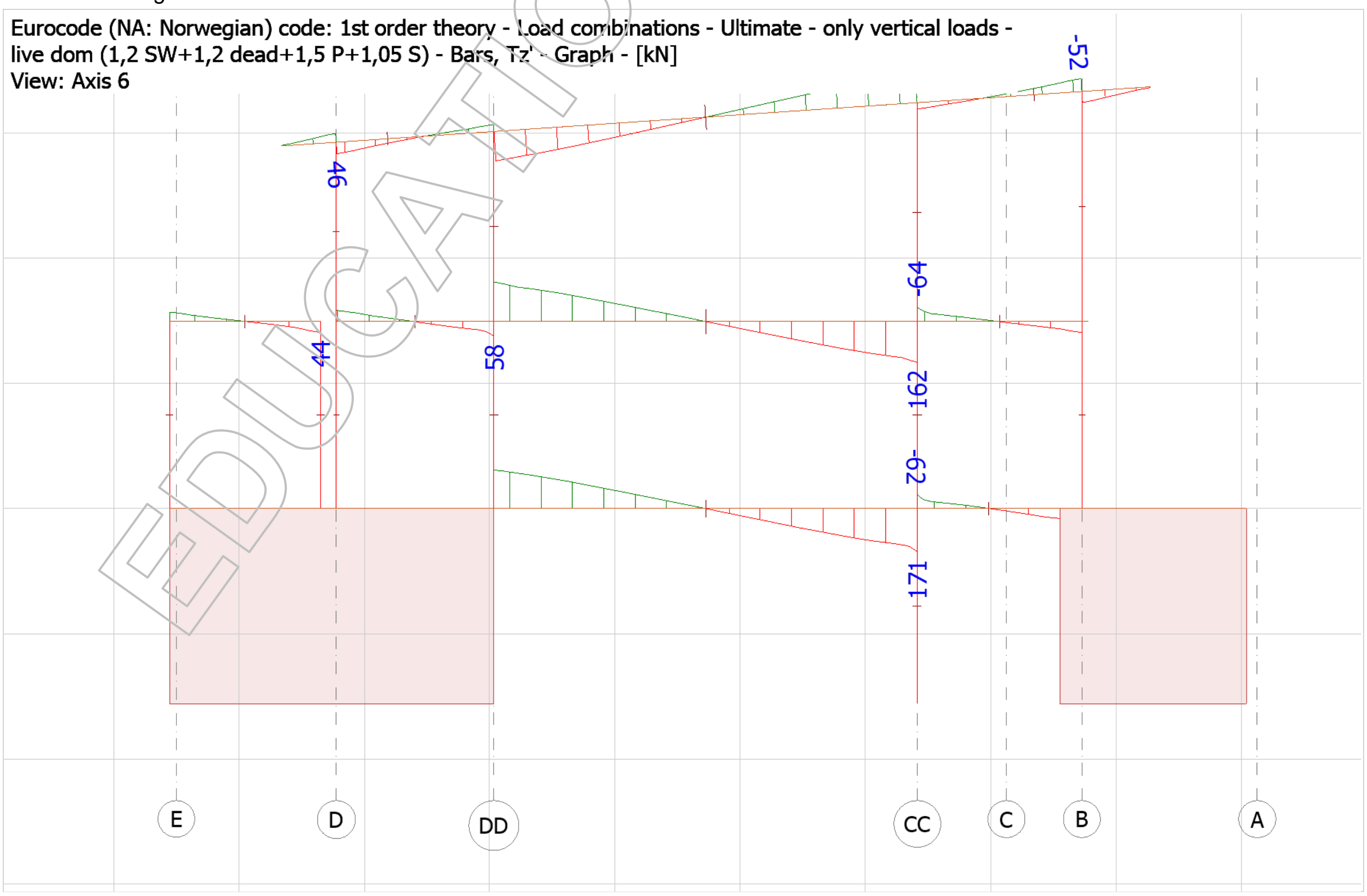
Axial force diagram 1st floor



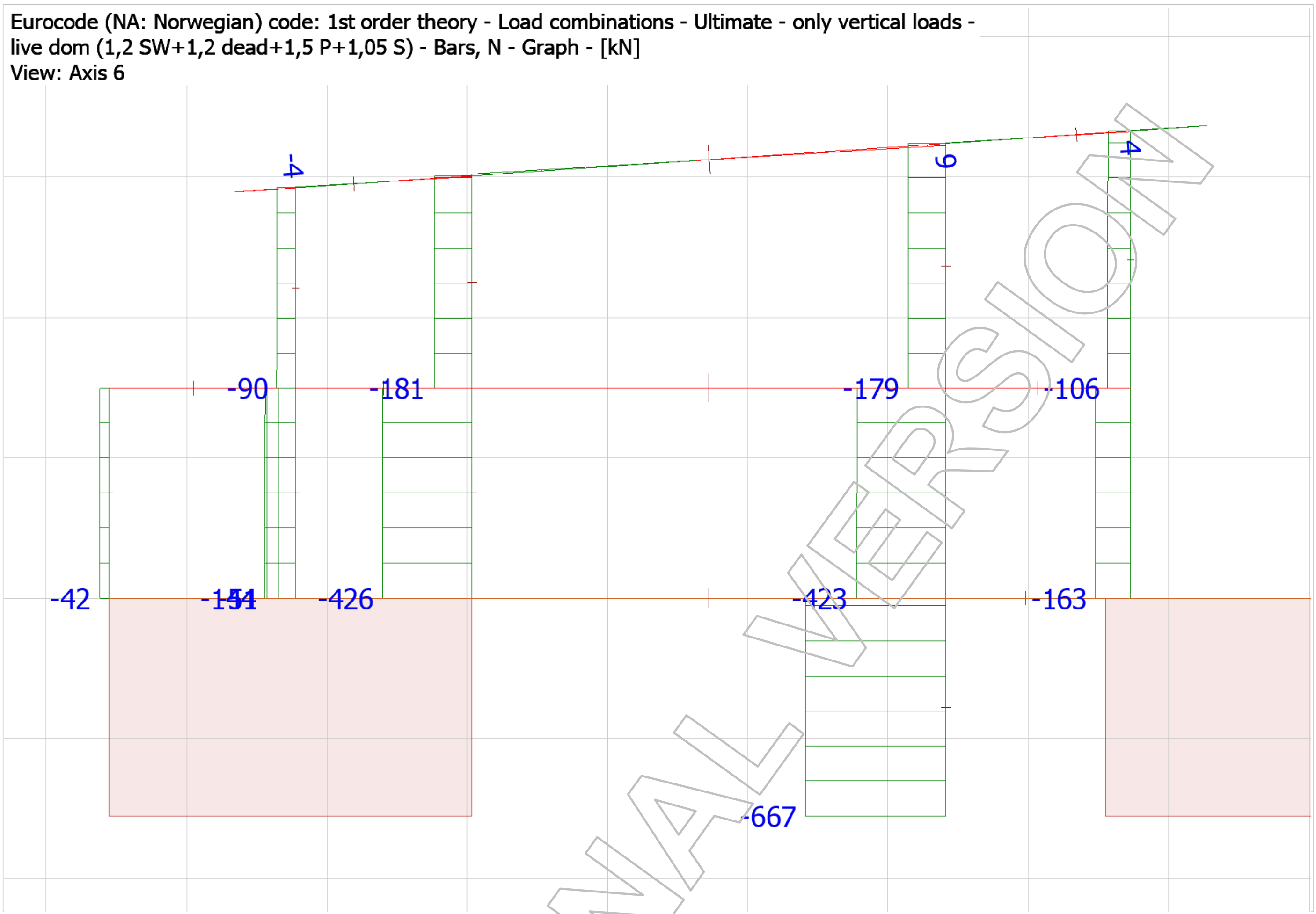
Bending moment diagram axis 6



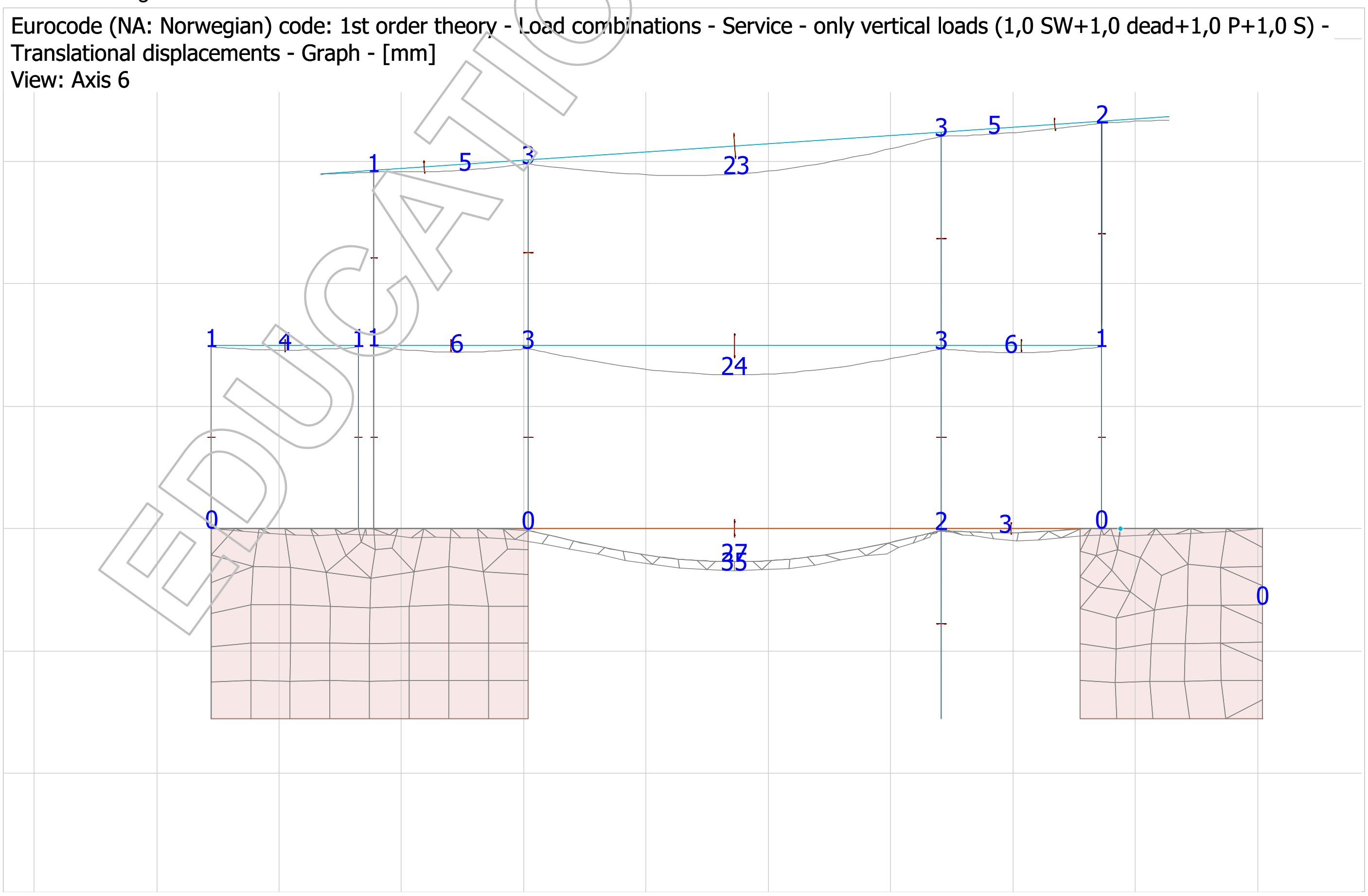
Shear force diagram axis 6



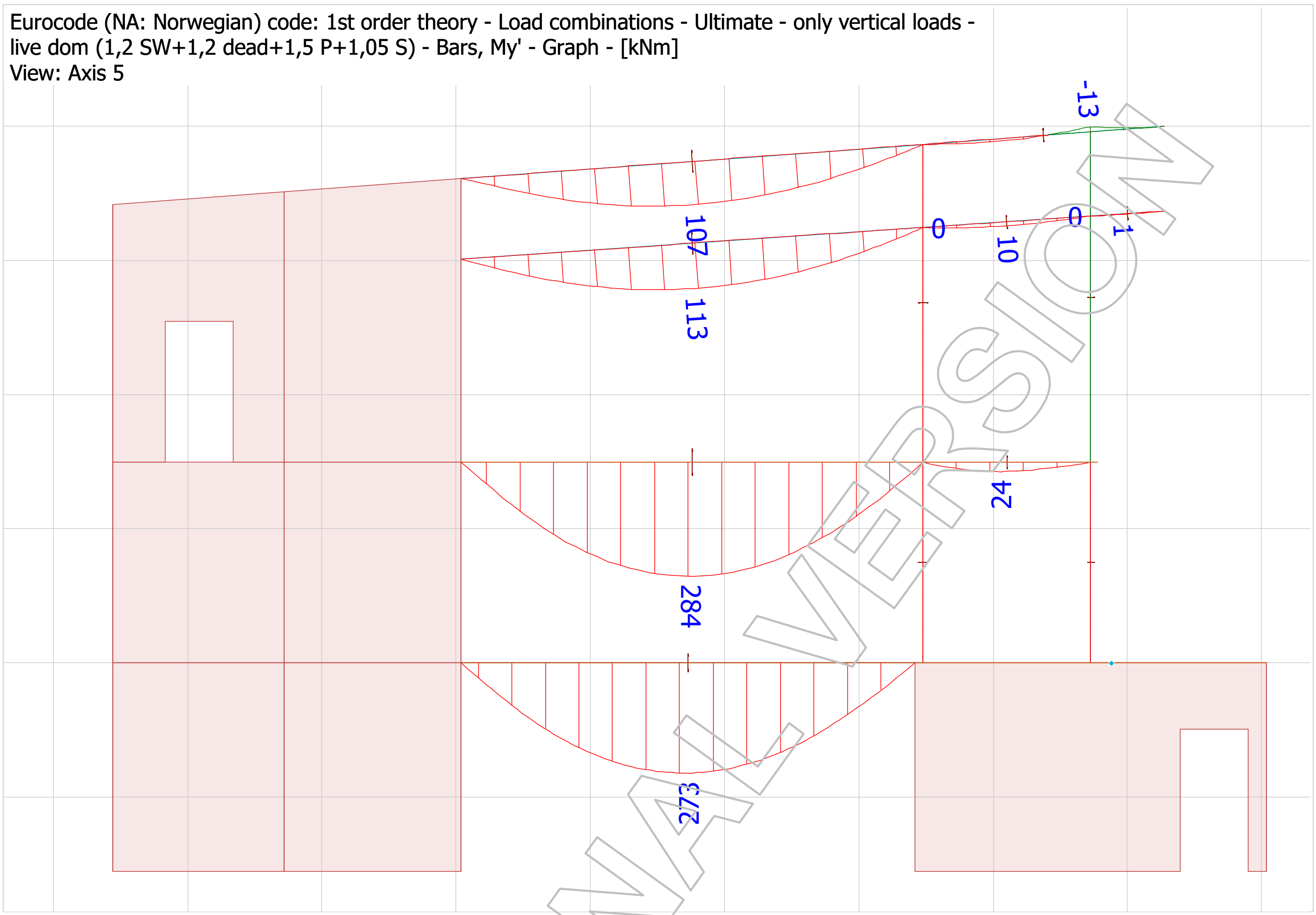
Normal force diagram axis 6



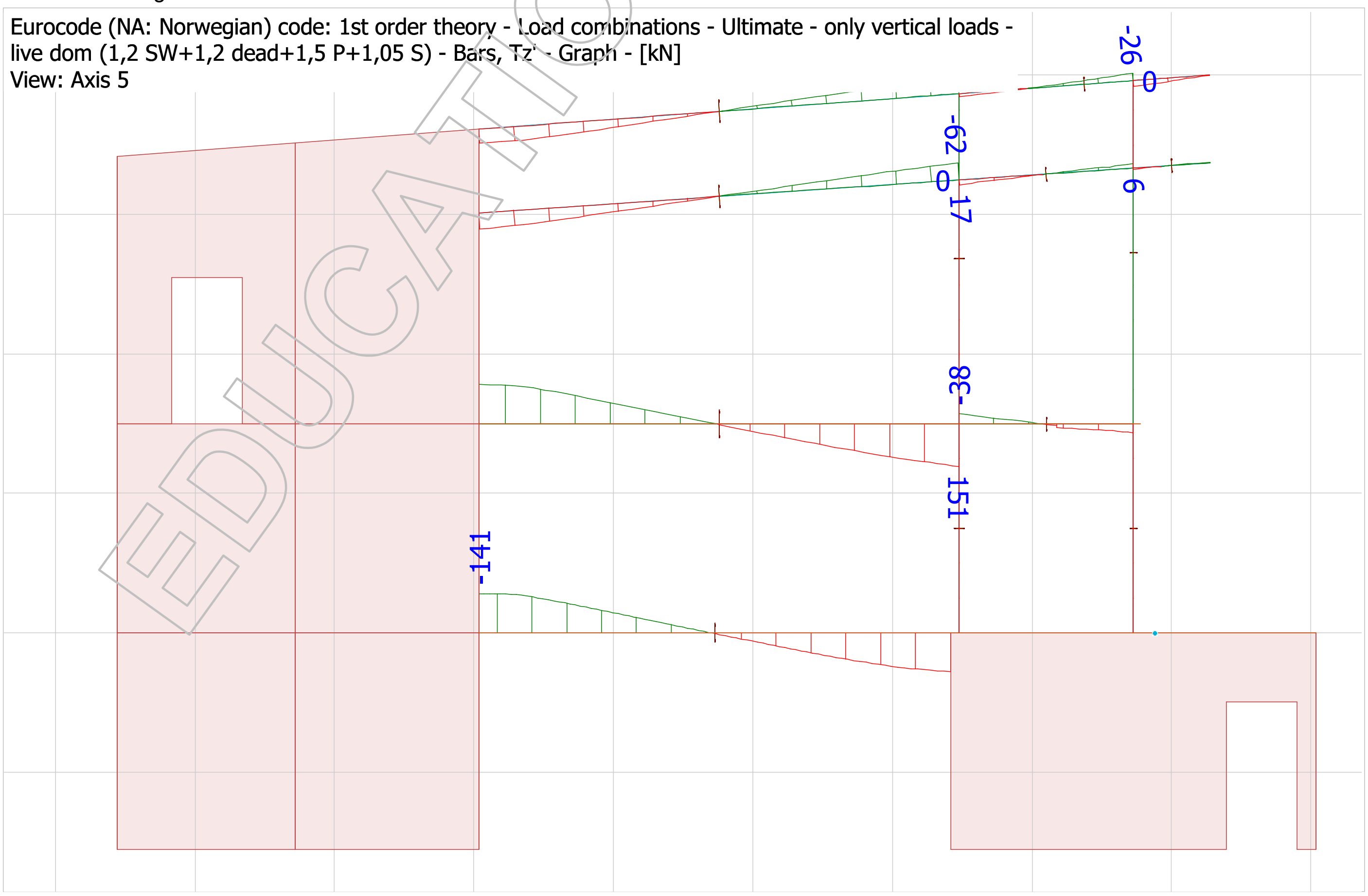
Deflection diagram axis 5



Moment diagram axis 5

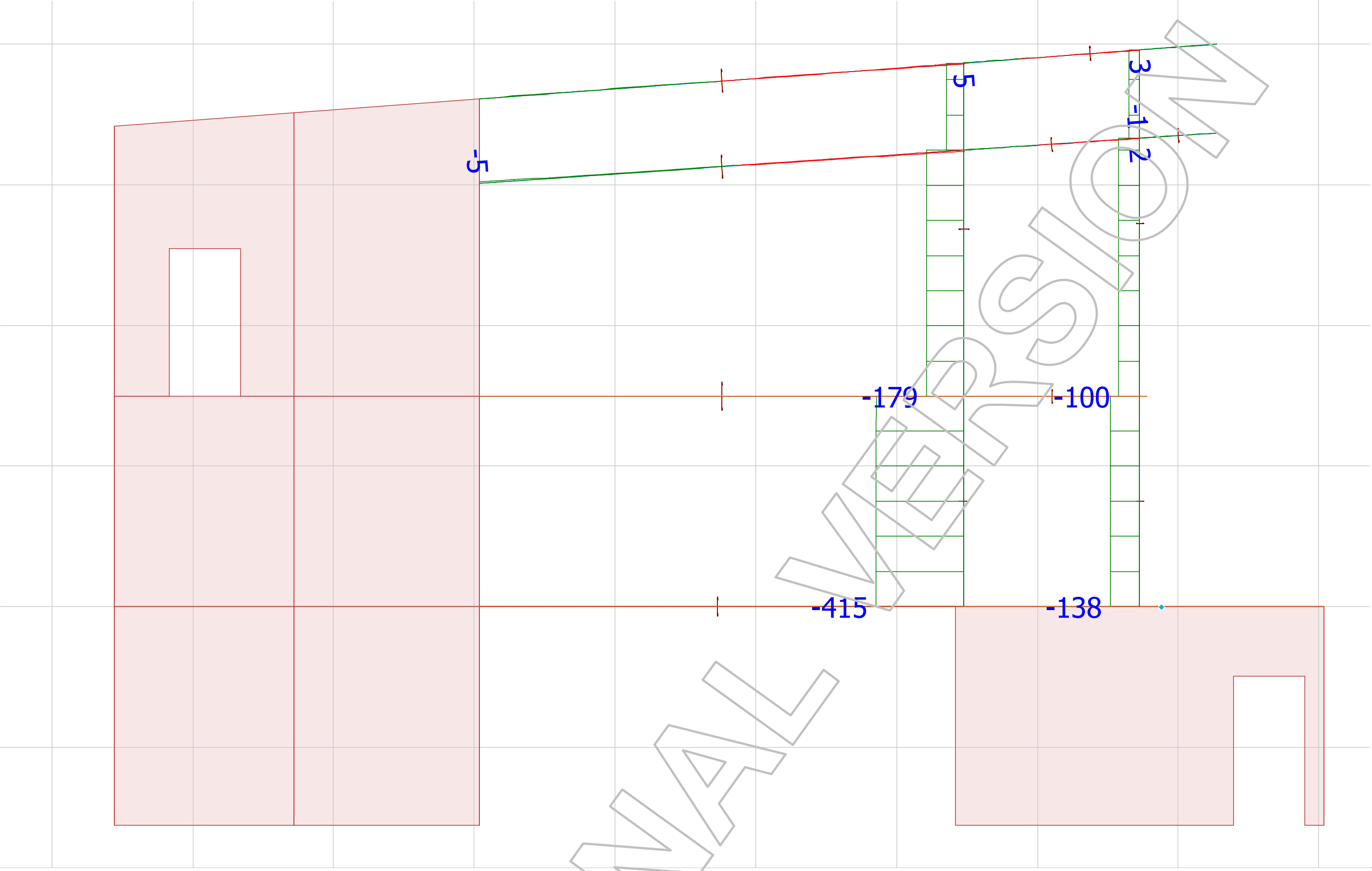


Shear force diagram axis 5



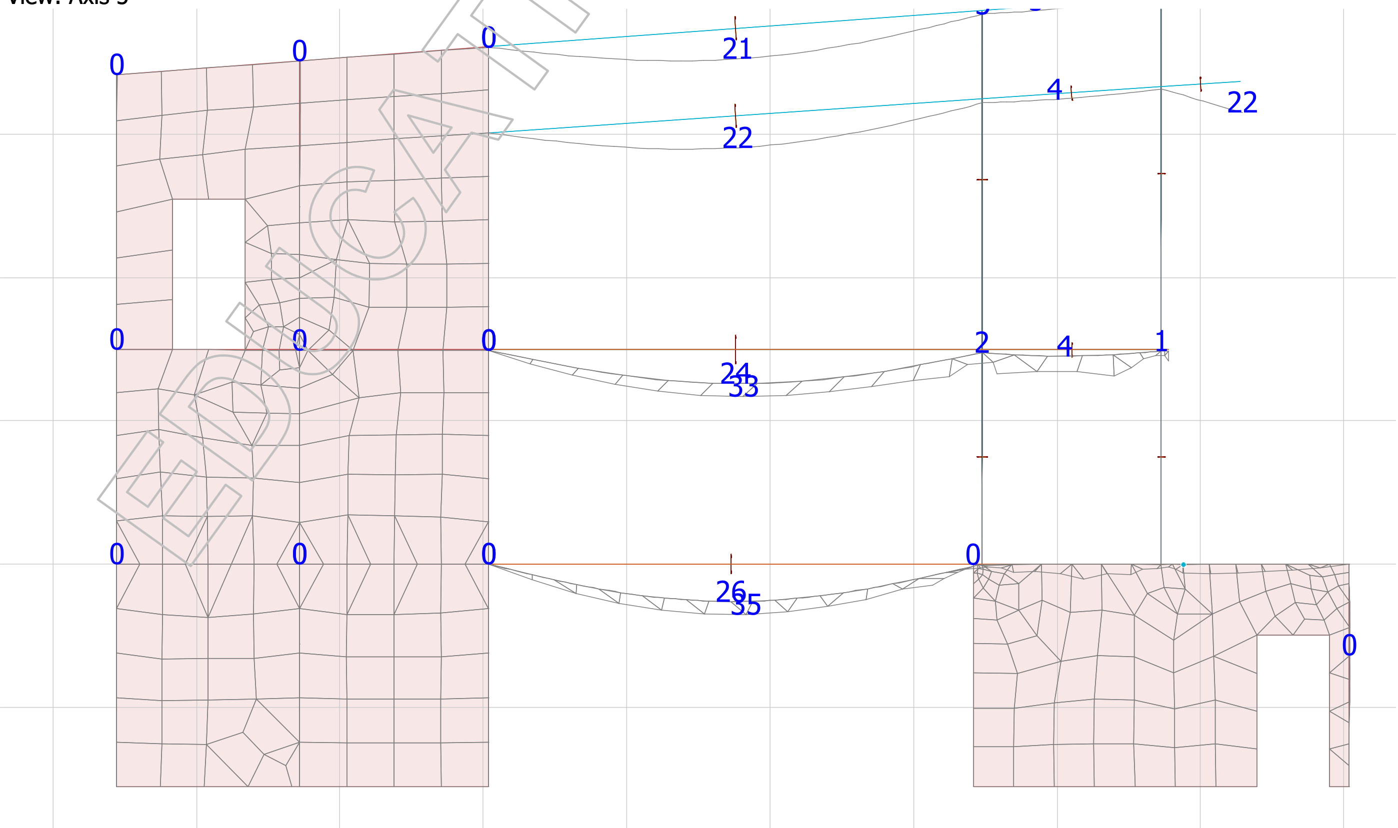
Normal force diagram axis 5

Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S) - Bars, N - Graph - [kN]
View: Axis 5

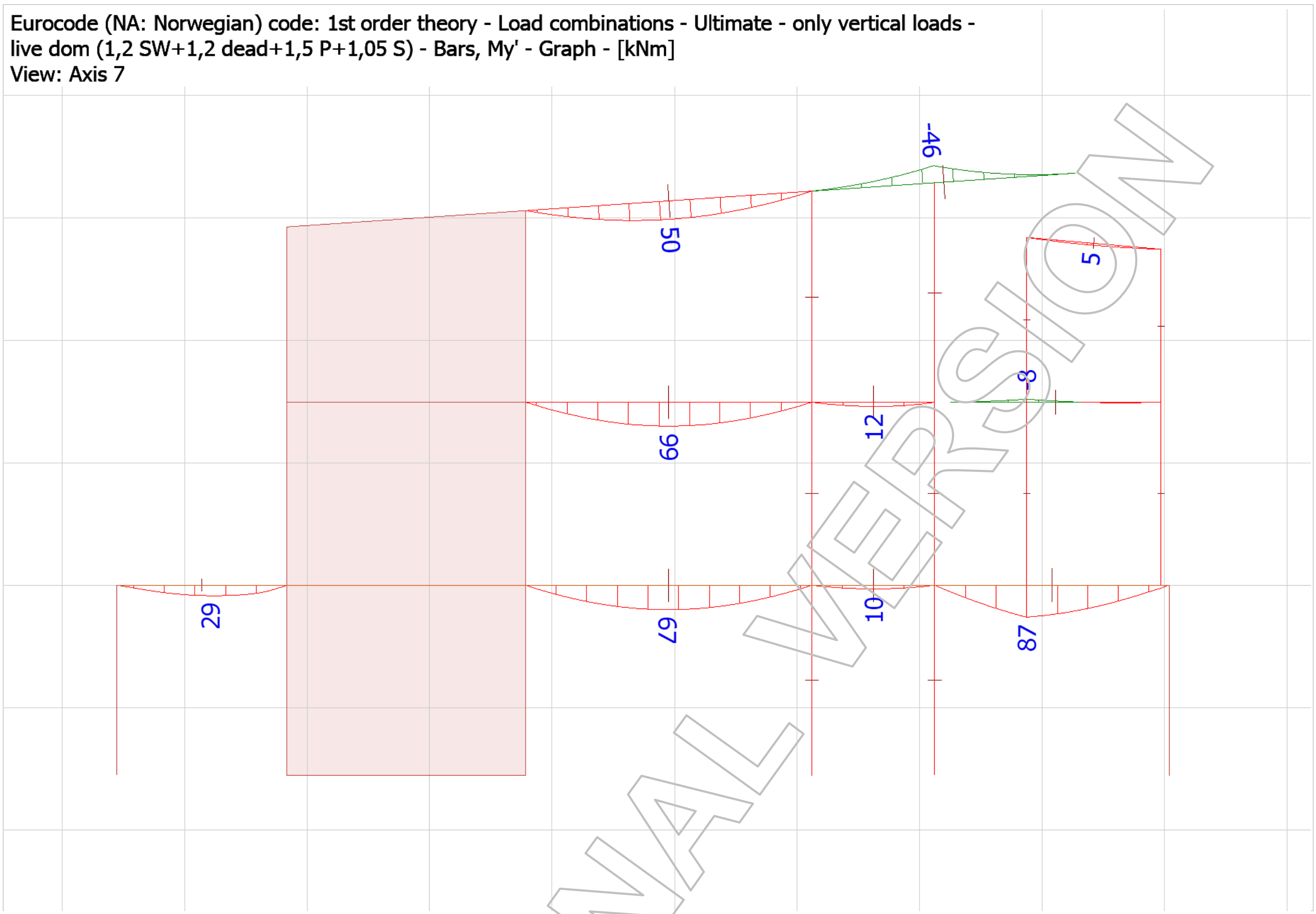


Deflection axis 5

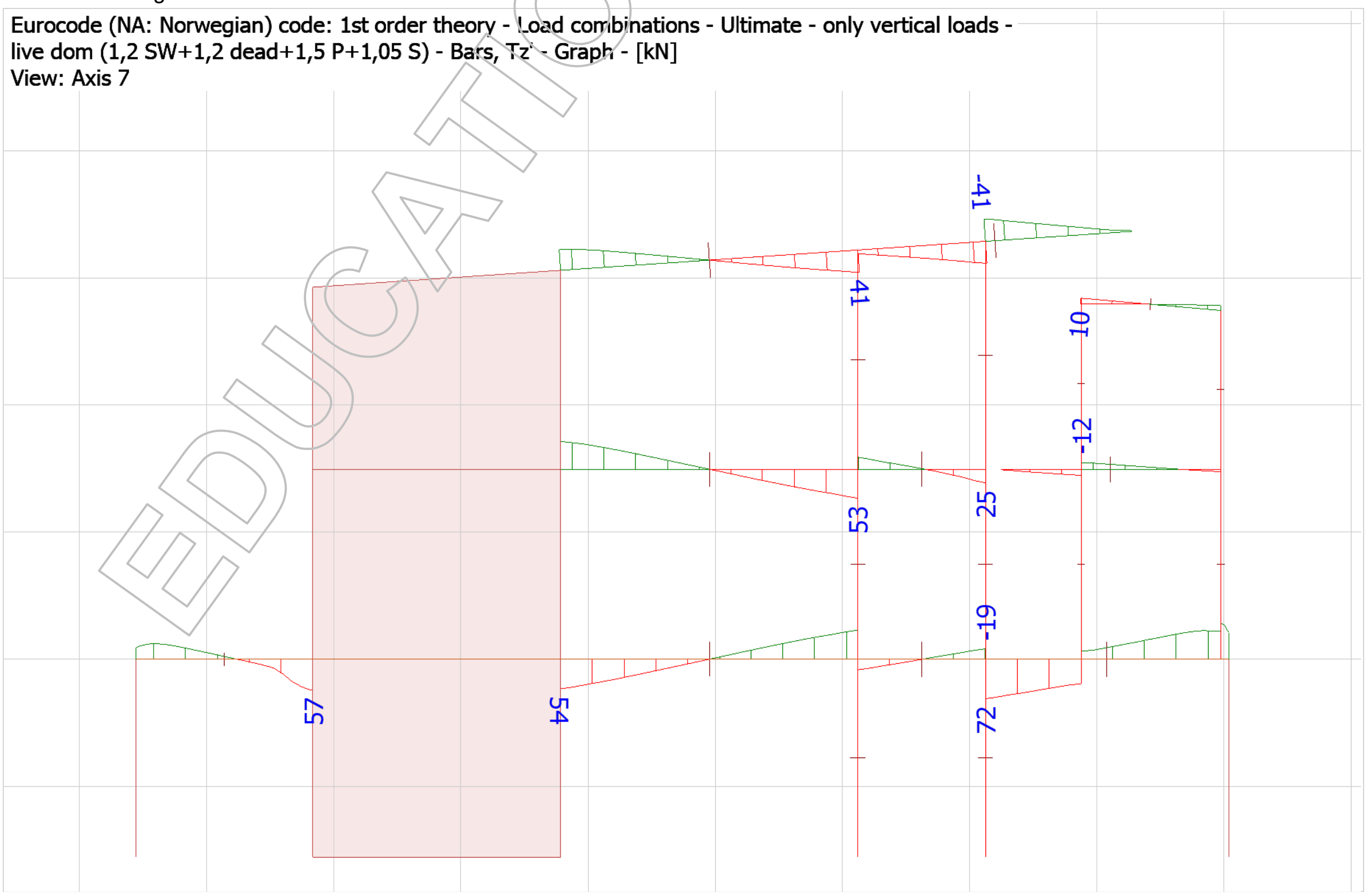
Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Service - only vertical loads (1,0 SW+1,0 dead+1,0 P+1,0 S) - Translational displacements - Graph - [mm]
View: Axis 5



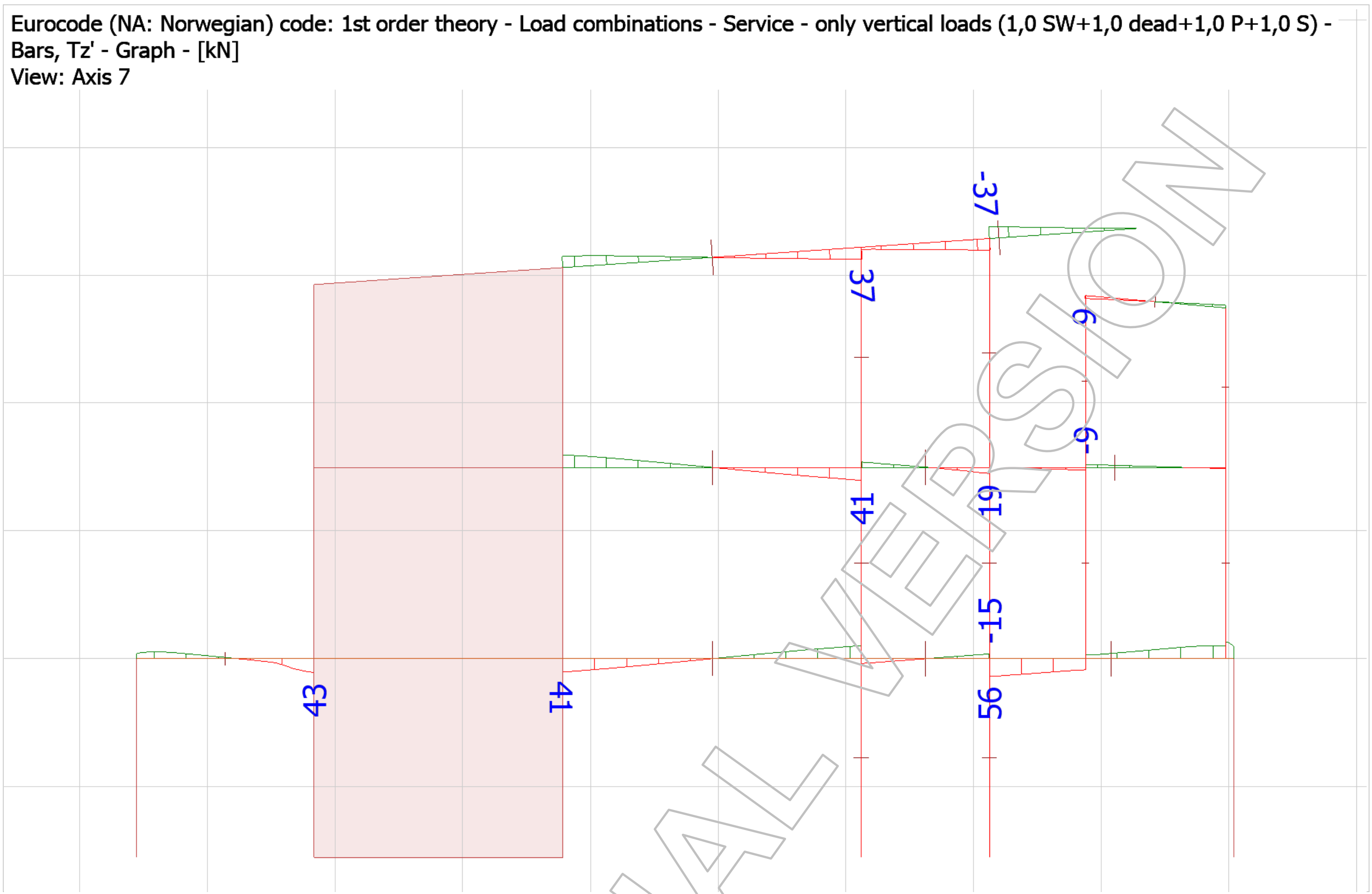
Bending moment diagram axis 7



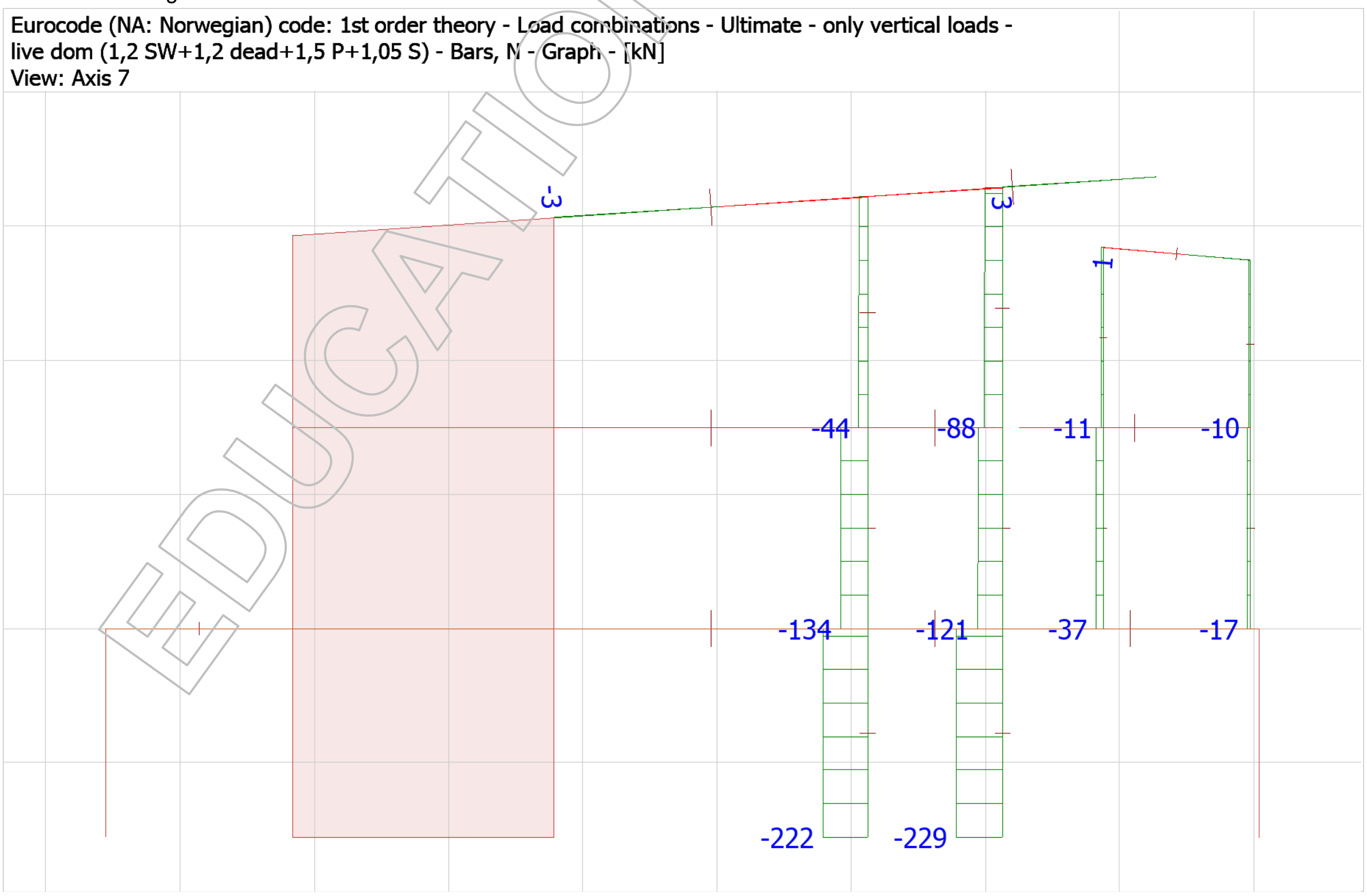
Shear force diagram axis 7



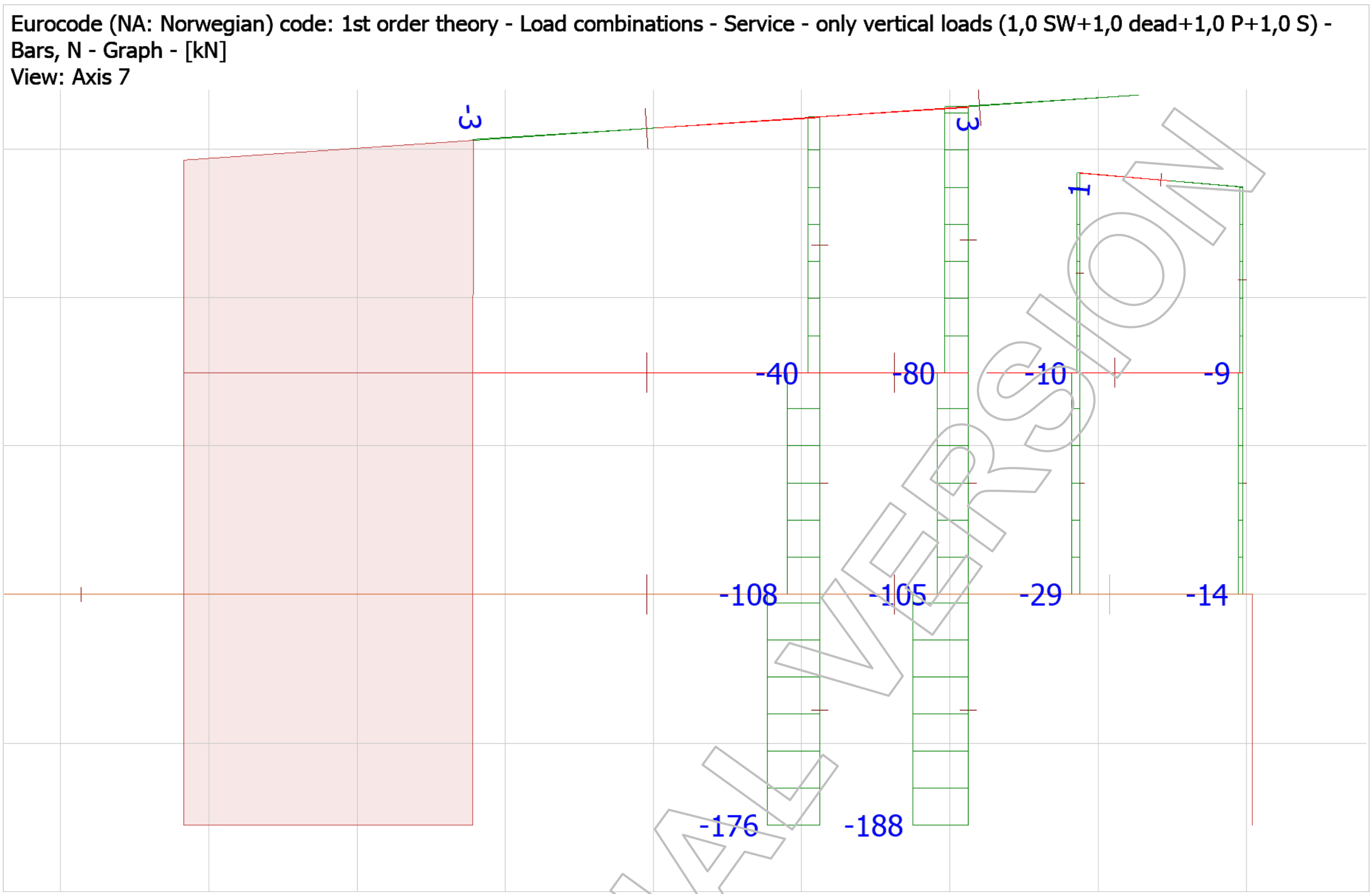
Characterstic shear force diagram axis7



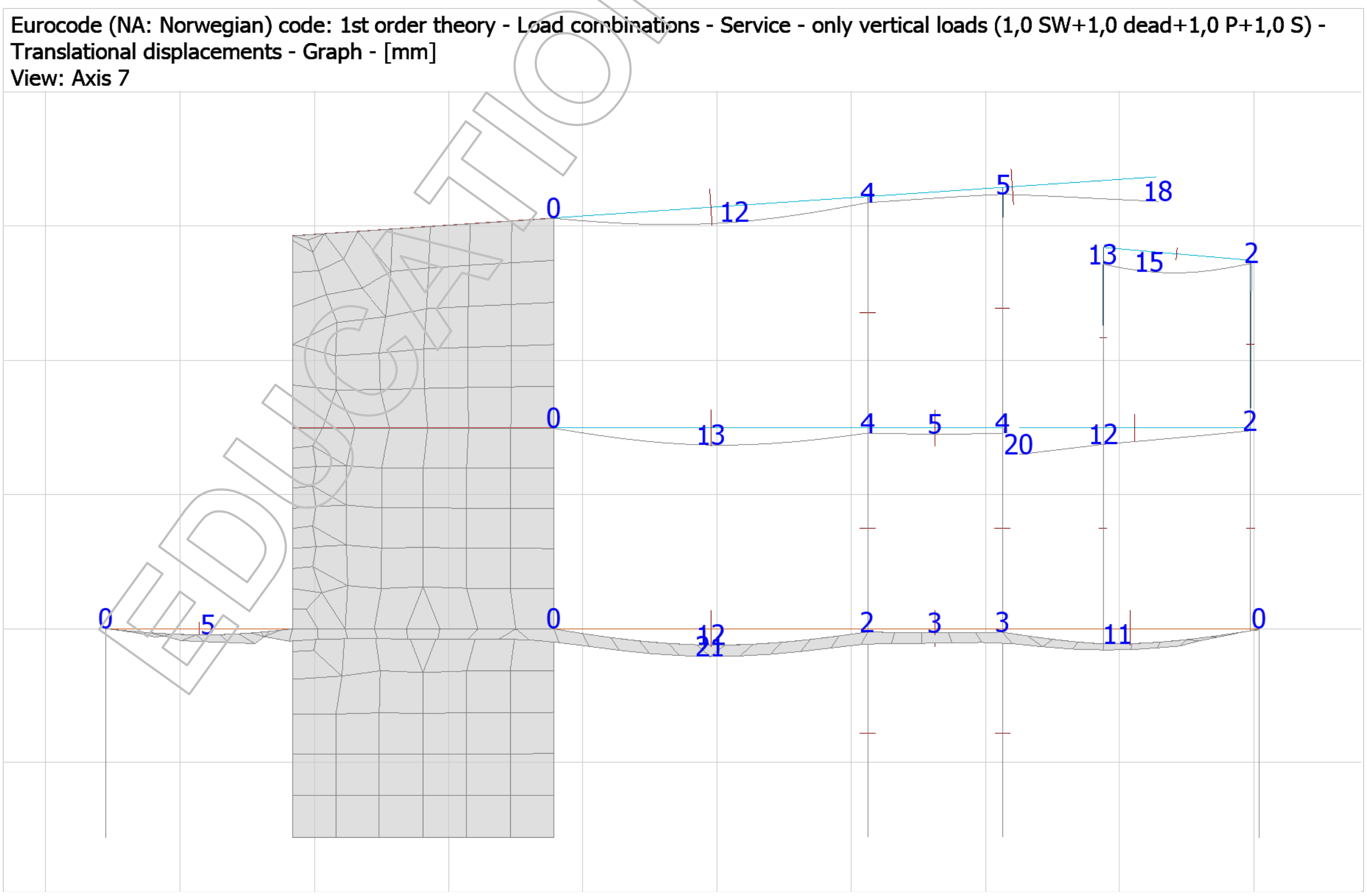
Normal force diagram axis 7



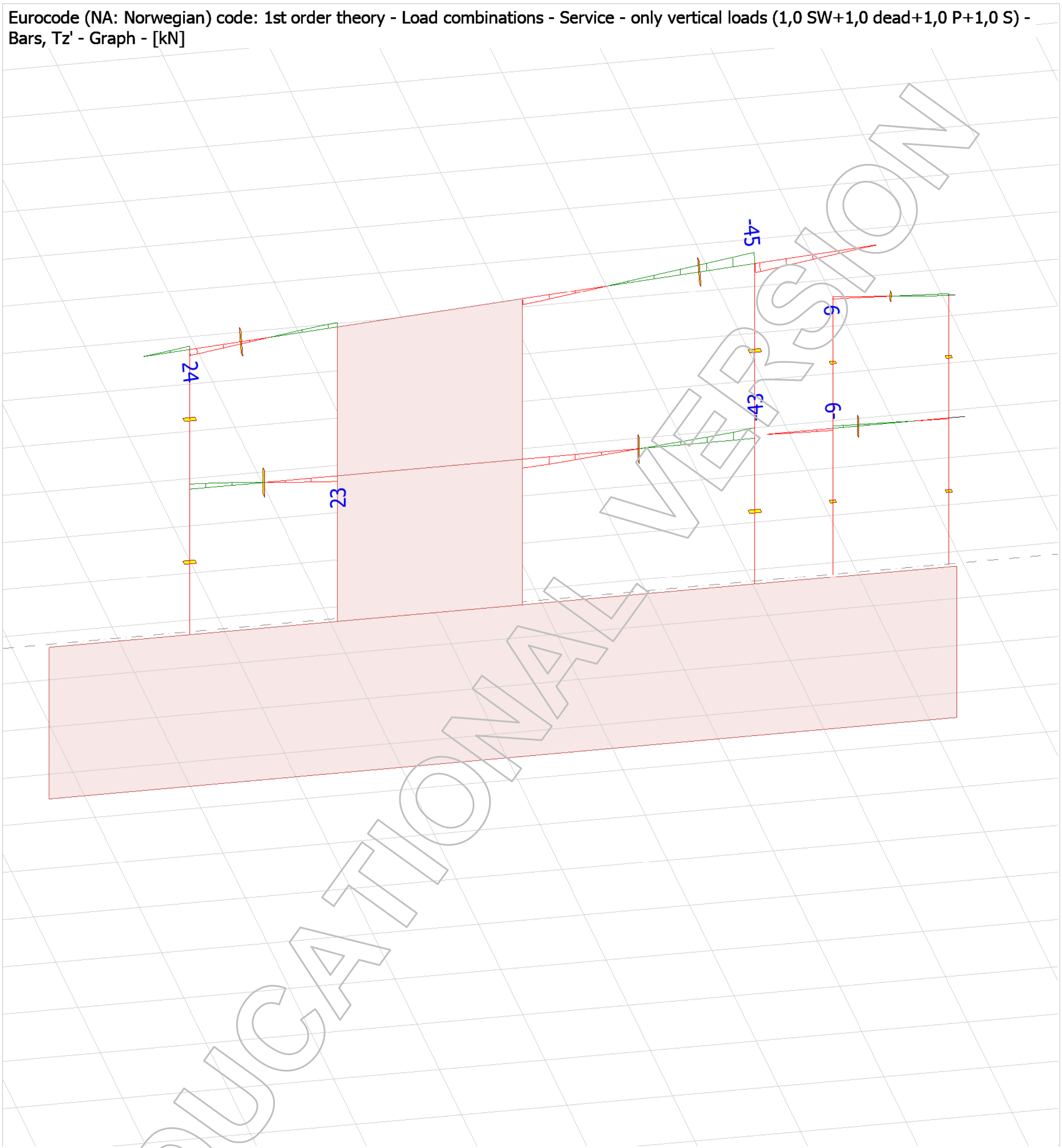
Charactersitc Normal force axis 7



Deflection axis 7



Characterstic shear force diagram axis1



2.2 Deflection

Max. of load combinations, Bars, Deflections, Quasi-permanent

Bar	Max.	x	Comb
[-]	[%]	[m]	[-]
B.1.1	8.592	2.306	SW + ...
B.2.1	15.495	2.132	SW + ...
B.3.1	14.709	2.132	SW + ...
B.4.1	2.703	1.681	SW + ...
B.5.1	4.648	2.135	SW + ...
B.6.1	47.071	3.452	SW + ...
B.7.1	44.105	1.065	SW + ...
B.8.1	45.276	1.065	SW + ...
B.9.1	41.881	1.102	SW + ...
B.10.1	48.432	1.065	SW + ...
B.11.1	49.234	1.065	SW + ...
B.12.1	41.864	1.102	SW + ...
B.13.1	43.870	1.065	SW + ...
B.14.1	19.297	1.205	SW + ...
B.15.1	34.282	6.714	SW + ...
B.16.1	24.977	1.087	SW + ...
B.17.1	22.786	1.113	SW + ...
B.18.1	24.065	1.233	SW + ...
B.19.1	83.898	3.377	SW + ...
B.20.1	64.586	2.657	SW + ...
B.21.1	35.835	1.893	SW + ...
B.22.1	74.246	3.371	SW + ...
B.23.1	28.029	1.156	SW + ...
B.24.1	83.305	3.380	SW + ...
B.25.1	84.874	3.381	SW + ...
B.26.1	51.918	2.340	SW + ...
B.27.1	6.517	1.002	SW + ...
B.28.1	22.607	2.550	SW + ...
B.29.1	50.805	3.277	SW + ...
B.30.1	43.059	2.199	SW + ...
B.31.1	17.648	1.205	SW + ...
B.32.1	33.242	1.189	SW + ...
B.33.1	69.249	3.363	SW + ...
B.34.1	32.084	1.386	SW + ...
B.35.1	32.960	1.260	SW + ...
B.36.1	44.340	3.442	SW + ...
B.37.1	15.385	1.795	SW + ...
B.38.1	70.116	3.380	SW + ...
B.39.1	13.741	1.819	SW + ...
B.40.1	72.858	3.444	SW + ...
B.41.1	32.638	1.234	SW + ...
B.42.1	32.845	1.162	SW + ...
B.43.1	20.487	1.205	SW + ...
B.44.1	4.771	1.180	SW + ...
B.45.1	13.419	1.180	SW + ...
B.46.1	7.533	1.002	SW + ...
B.47.1	50.803	2.341	SW + ...
B.48.1	14.032	1.532	SW + ...
B.49.1	43.331	1.102	SW + ...

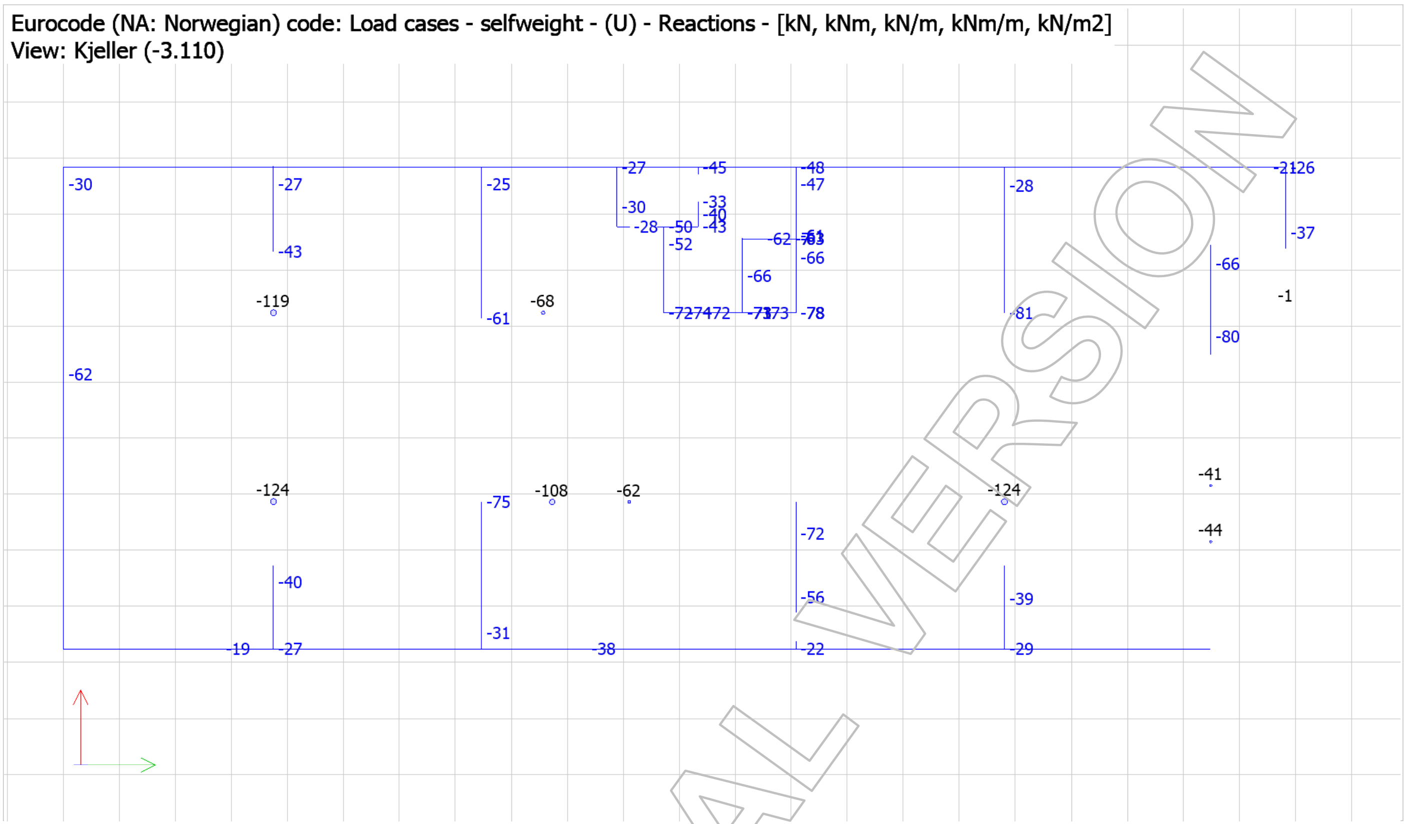
Bar	Max.	x	Comb
[-]	[%]	[m]	[-]
B.50.1	43.313	1.102	SW + ...
B.51.1	45.358	1.065	SW + ...
B.52.1	0.594	0.483	SW + ...
B.53.1	43.953	0.000	SW + ...
B.54.1	7.336	1.205	SW + ...
B.55.1	49.539	3.450	SW + ...
B.56.1	9.973	1.251	SW + ...
B.57.1	0.435	0.489	SW + ...
B.58.1	11.145	1.263	SW + ...
B.59.1	49.548	3.450	SW + ...
B.60.1	0.420	0.551	SW + ...
B.61.1	20.750	3.445	SW + ...
B.62.1	5.109	1.003	SW + ...
B.63.1	46.817	3.385	SW + ...
B.64.1	11.989	1.087	SW + ...
B.65.1	41.186	3.389	SW + ...
B.66.1	55.771	3.723	SW + ...
B.67.1	13.836	3.452	SW + ...
B.68.1	46.682	3.385	SW + ...
B.69.1	12.237	1.092	SW + ...
B.70.1	69.892	1.095	SW + ...
B.71.1	34.021	2.347	SW + ...
B.72.1	87.890	3.676	SW + ...
B.73.1	1.832	1.346	SW + ...
B.74.1	80.180	4.252	SW + ...
B.75.1	87.919	3.724	SW + ...
B.76.1	82.544	3.566	SW + ...
B.77.1	88.696	3.659	SW + ...
B.78.1	131.369	3.445	SW + ...
B.79.1	135.602	3.445	SW + ...
B.80.1	21.070	3.445	SW + ...
B.81.1	94.286	3.445	SW + ...
B.82.1	159.741	3.445	SW + ...
B.83.1	24.401	3.445	SW + ...
B.84.1	133.001	3.445	SW + ...
B.85.1	147.909	3.445	SW + ...
B.86.1	57.620	3.445	SW + ...
B.87.1	69.893	3.384	SW + ...
B.88.1	34.643	1.253	SW + ...
C.1.1	1.188	3.110	SW + ...
C.2.1	1.200	3.110	SW + ...
C.3.1	2.193	3.110	SW + ...
C.4.1	0.519	3.031	SW + ...
C.5.1	2.179	4.730	SW + ...
C.6.1	1.578	3.110	SW + ...
C.7.1	2.393	3.490	SW + ...
C.8.1	1.176	3.031	SW + ...
C.9.1	1.071	3.490	SW + ...
C.10.1	2.724	3.031	SW + ...

Bar	Max.	x	Comb
[-]	[%]	[m]	[-]
C.11.1	1.703	4.739	SW + ...
C.12.1	2.957	4.227	SW + ...
C.13.1	2.347	2.990	SW + ...
C.14.1	1.409	2.990	SW + ...
C.15.1	0.470	2.990	SW + ...
C.16.1	1.382	2.990	SW + ...
C.17.1	2.988	2.990	SW + ...
C.18.1	2.331	2.990	SW + ...
C.19.1	0.348	2.990	SW + ...
C.20.1	1.145	3.587	SW + ...
C.21.1	0.430	2.859	SW + ...
C.22.1	1.971	4.924	SW + ...
C.23.1	6.213	4.924	SW + ...
C.24.1	0.421	3.669	SW + ...
C.25.1	1.616	3.669	SW + ...
C.26.1	0.608	4.039	SW + ...
C.27.1	0.483	2.859	SW + ...
C.28.1	1.889	2.859	SW + ...
C.29.1	10.130	2.694	SW + ...
C.30.1	1.870	2.990	SW + ...
C.31.1	3.396	3.587	SW + ...
C.32.1	10.091	2.502	SW + ...
C.33.1	10.032	2.694	SW + ...
C.34.1	9.563	2.502	SW + ...
C.35.1	4.407	2.694	SW + ...
C.36.1	9.140	2.502	SW + ...
C.37.1	11.110	2.694	SW + ...
C.38.1	3.438	2.694	SW + ...
C.39.1	10.569	2.502	SW + ...
C.40.1	5.360	2.502	SW + ...
C.41.1	10.936	2.694	SW + ...
C.42.1	8.743	2.502	SW + ...
C.43.1	11.000	2.694	SW + ...
C.44.1	12.531	2.502	SW + ...
C.45.1	3.393	3.451	SW + ...
C.46.1	1.556	3.110	SW + ...
C.47.1	1.682	3.110	SW + ...
C.48.1	2.571	3.110	SW + ...
C.49.1	1.177	2.990	SW + ...
C.50.1	0.379	2.990	SW + ...
C.51.1	0.484	2.990	SW + ...
C.52.1	1.171	2.990	SW + ...
C.53.1	0.194	2.990	SW + ...
C.54.1	0.111	2.990	SW + ...
C.55.1	1.182	2.990	SW + ...

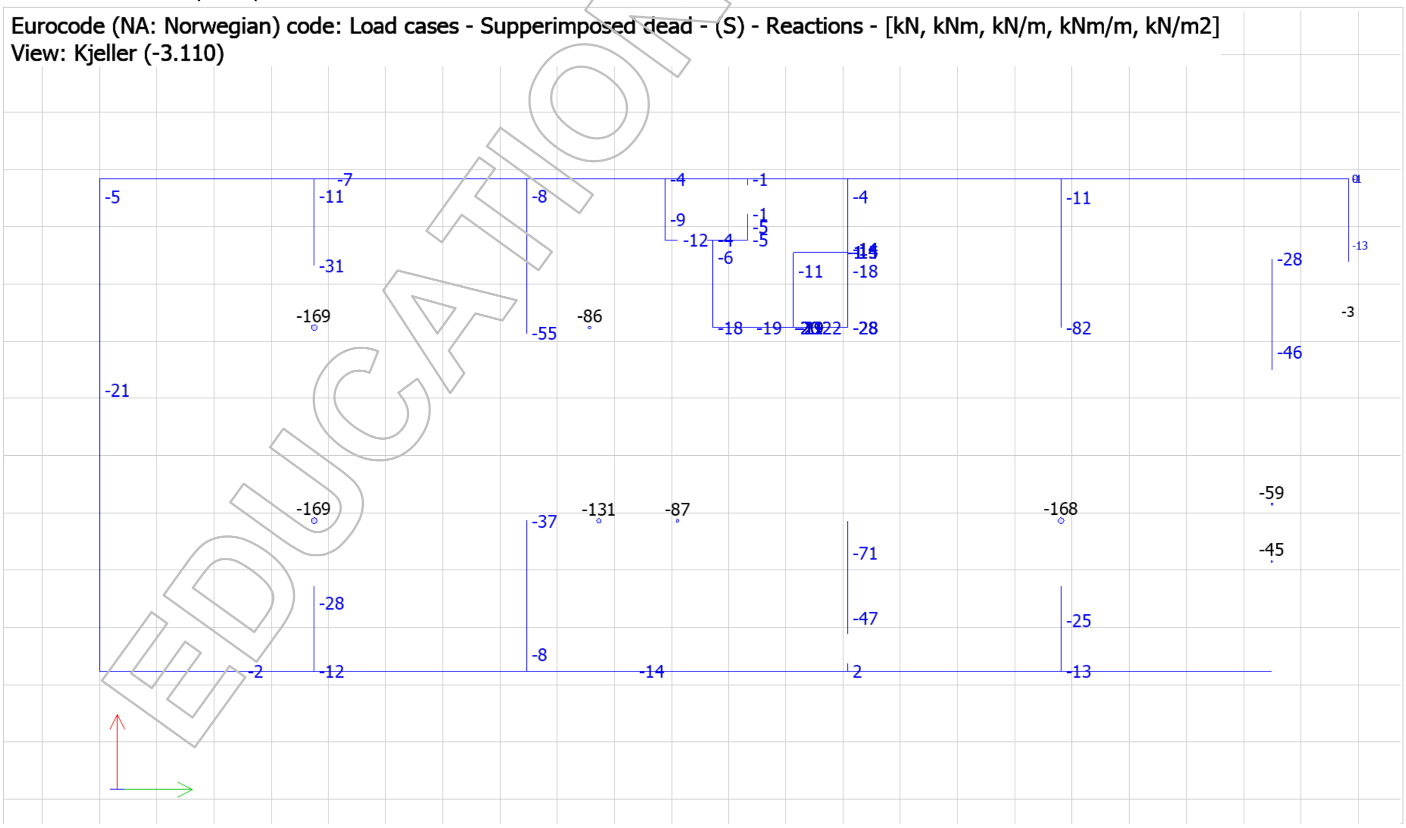
Bar	Max.	x	Comb
[-]	[%]	[m]	[-]
C.56.1	0.839	2.990	SW + ...
C.57.1	0.509	2.990	SW + ...
C.58.1	0.388	2.990	SW + ...
C.59.1	0.464	2.990	SW + ...
C.60.1	0.862	2.990	SW + ...
C.61.1	0.523	2.990	SW + ...
C.62.1	0.229	2.990	SW + ...
C.63.1	1.188	2.990	SW + ...
C.64.1	0.447	2.990	SW + ...
C.65.1	0.308	2.990	SW + ...
C.66.1	1.206	2.990	SW + ...
C.67.1	1.177	2.990	SW + ...
C.68.1	2.479	3.110	SW + ...
C.69.1	1.508	2.990	SW + ...
C.70.1	1.177	2.990	SW + ...
C.71.1	1.177	2.990	SW + ...
C.72.1	1.944	2.990	SW + ...
C.73.1	1.944	2.990	SW + ...
C.74.1	1.944	2.990	SW + ...
C.75.1	1.944	2.990	SW + ...
C.76.1	2.728	2.990	SW + ...
C.77.1	2.728	2.990	SW + ...
C.78.1	2.728	2.990	SW + ...
C.79.1	2.728	2.990	SW + ...
C.80.1	1.944	2.990	SW + ...
C.81.1	1.944	2.990	SW + ...
C.82.1	1.944	2.990	SW + ...
C.83.1	1.944	2.990	SW + ...
C.84.1	2.473	3.110	SW + ...
C.85.1	1.500	2.990	SW + ...
C.86.1	1.895	2.990	SW + ...
C.87.1	1.437	2.990	SW + ...
C.88.1	1.470	2.990	SW + ...
C.89.1	4.067	2.694	SW + ...
C.90.1	4.182	2.502	SW + ...
C.91.1	3.552	2.694	SW + ...
C.92.1	4.012	2.502	SW + ...
C.93.1	1.944	2.990	SW + ...
C.94.1	1.944	2.990	SW + ...
C.95.1	3.050	2.694	SW + ...
C.96.1	3.661	2.502	SW + ...
C.97.1	1.944	2.990	SW + ...
C.98.1	1.944	2.990	SW + ...
C.99.1	3.001	2.990	SW + ...

2.3 Reaction forces

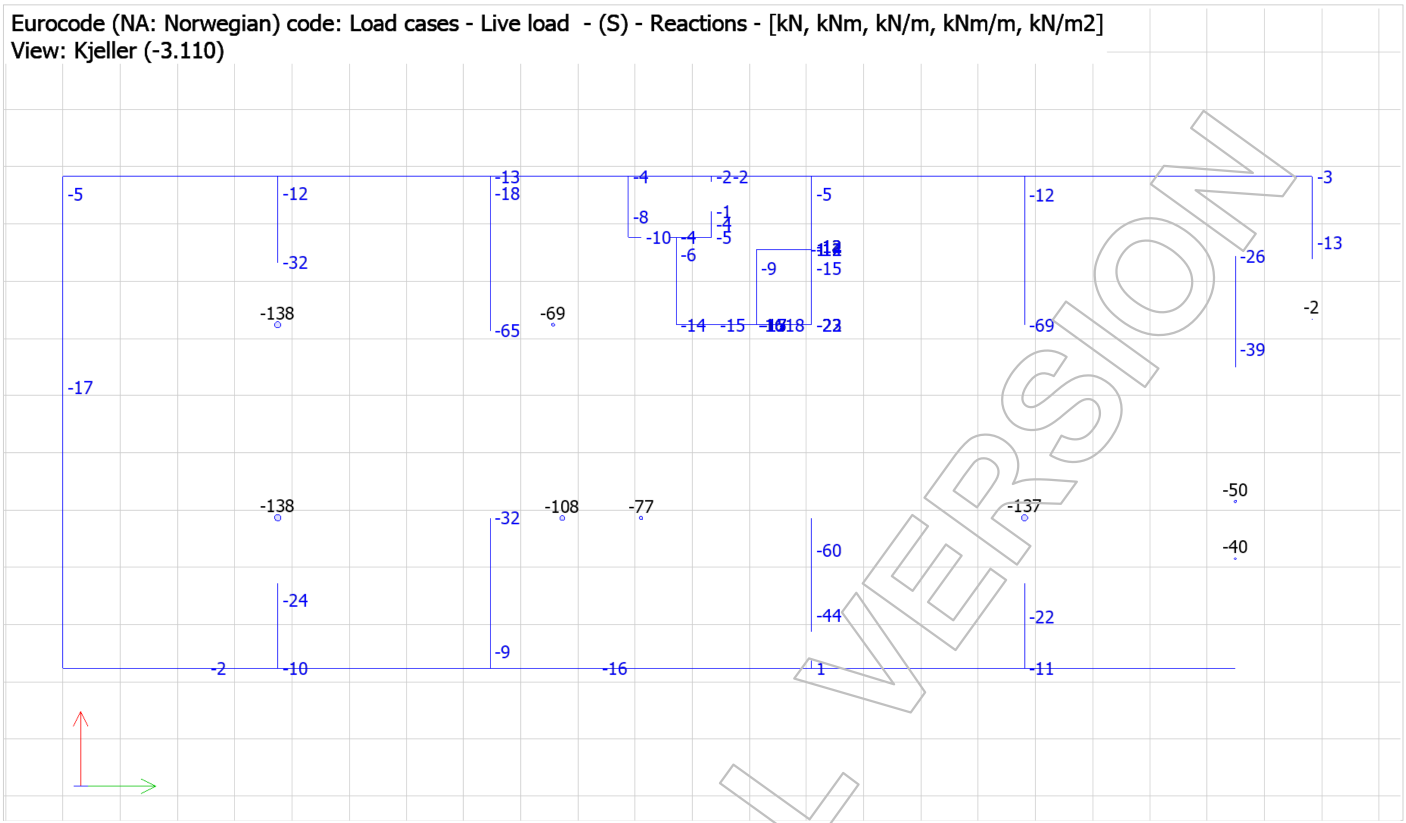
Reaction due to Selfweight



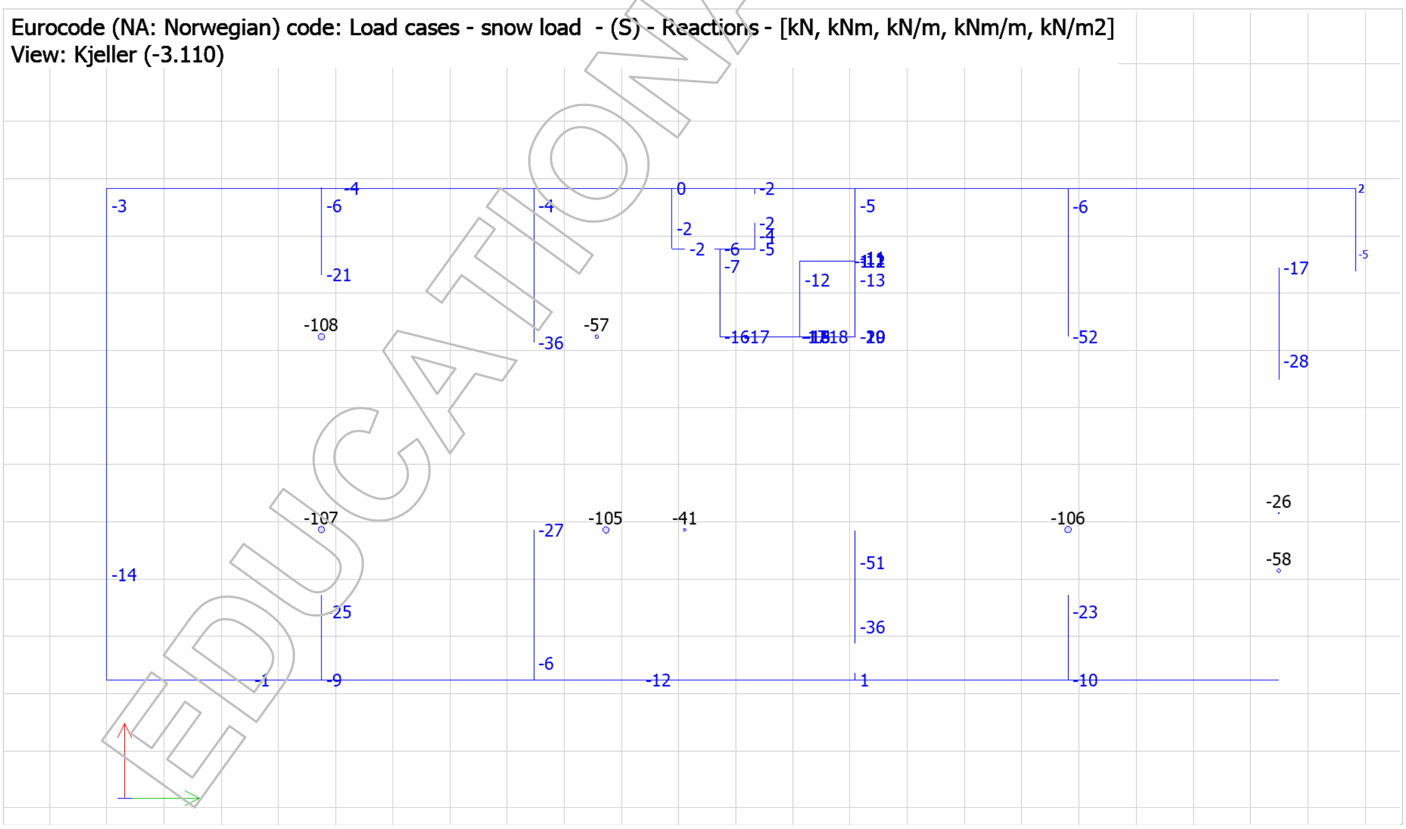
Reaction due to Superimposed dead load



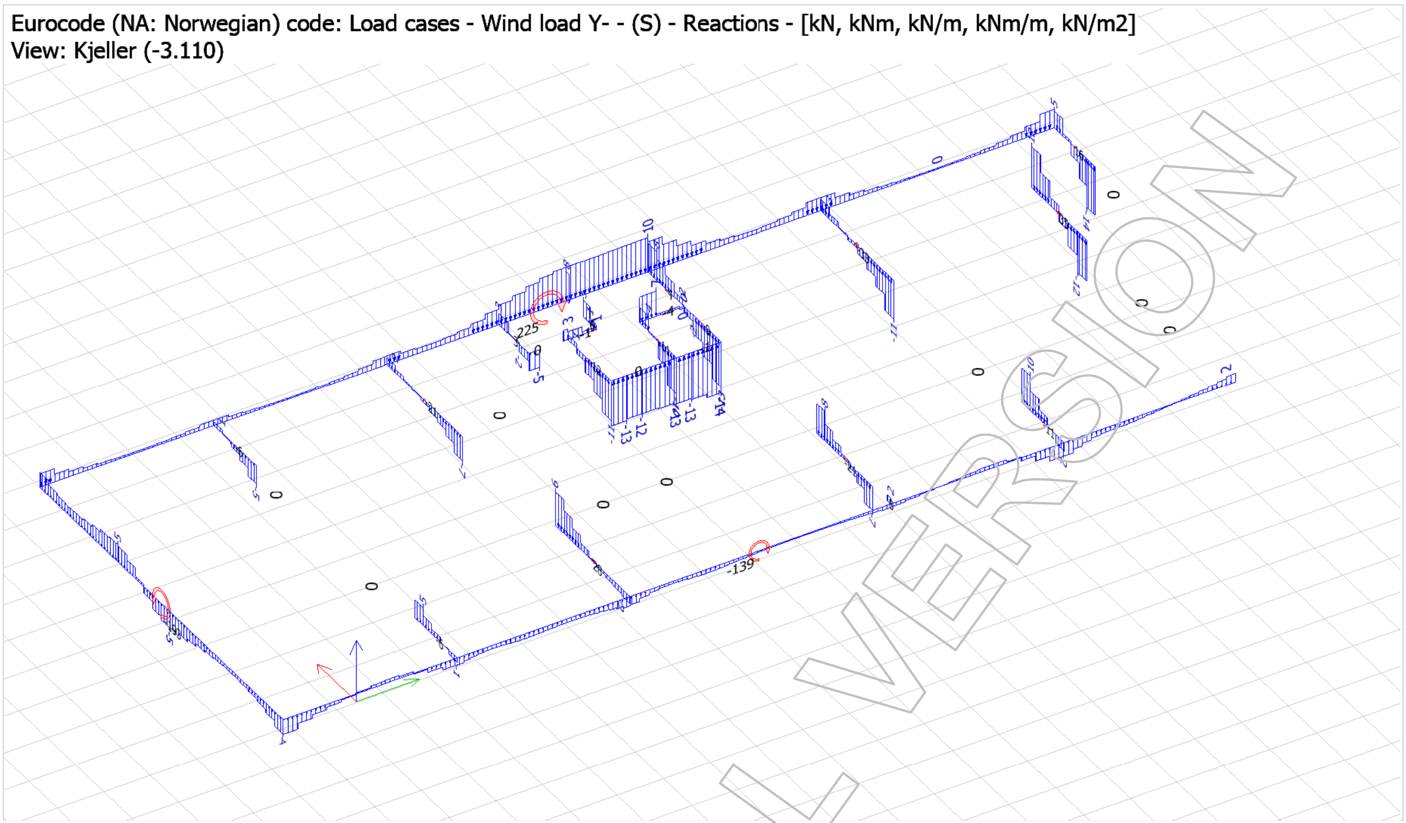
Reaction due to Live load



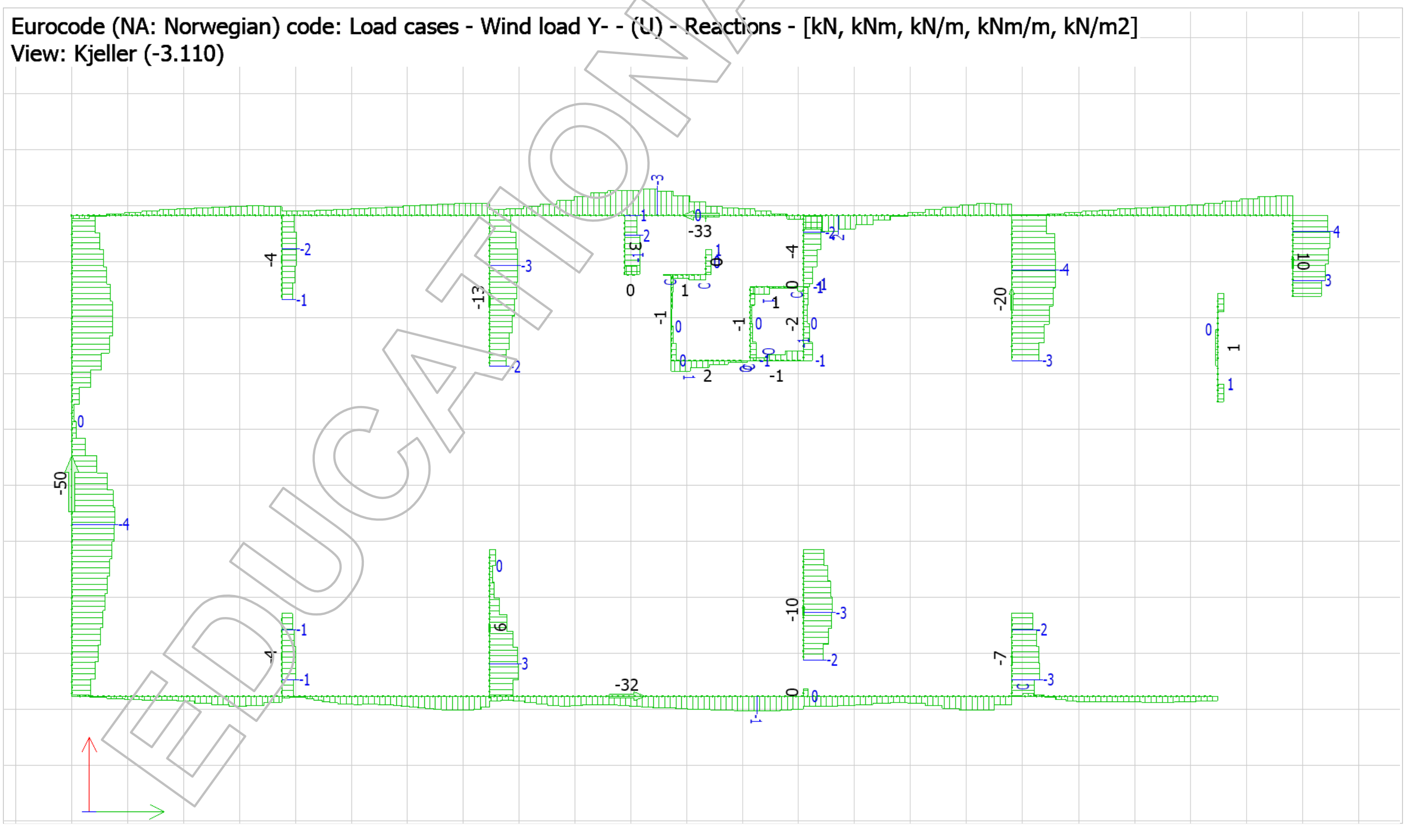
Reaction due to Snow



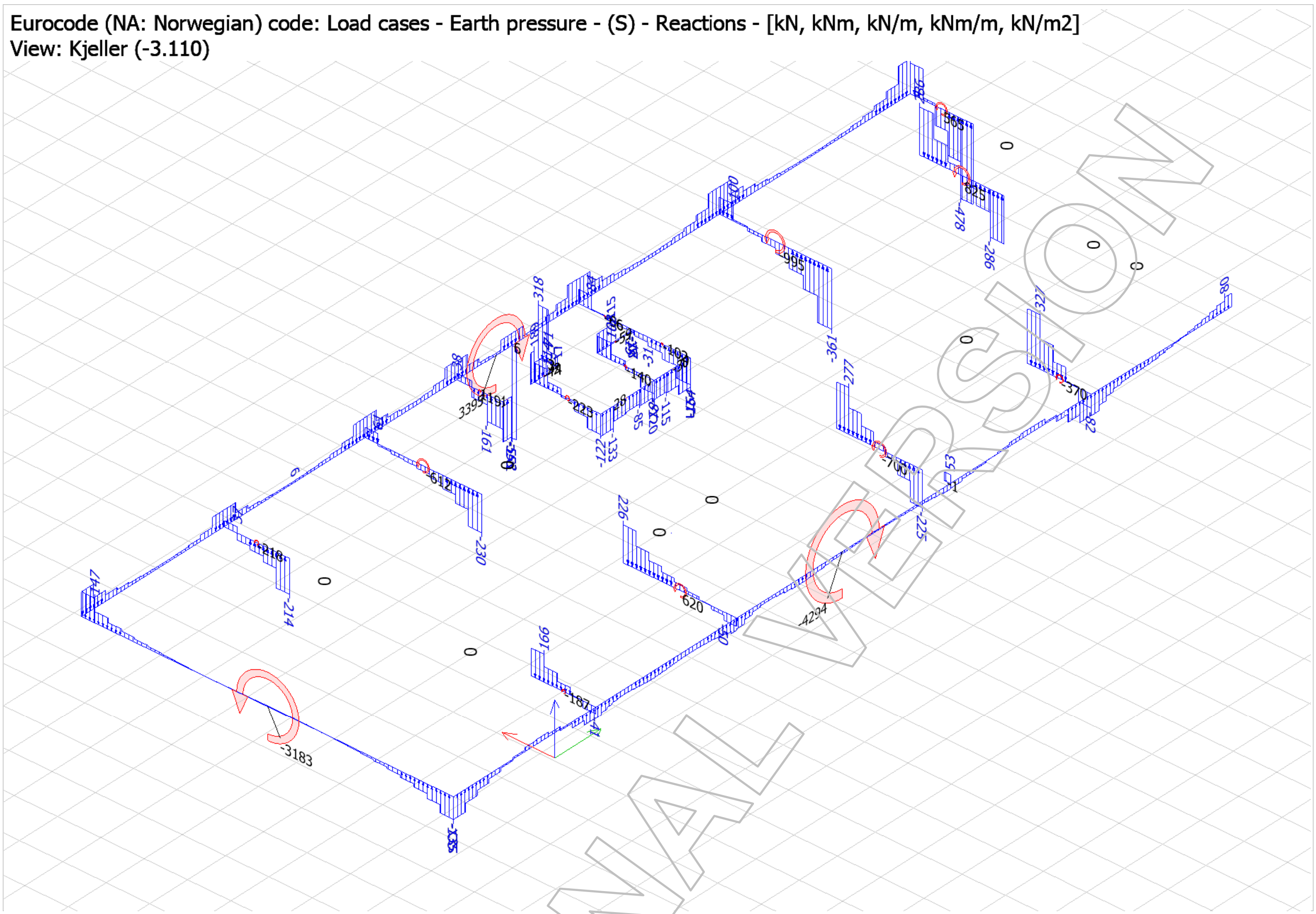
Reaction due to wind (FZ and My)



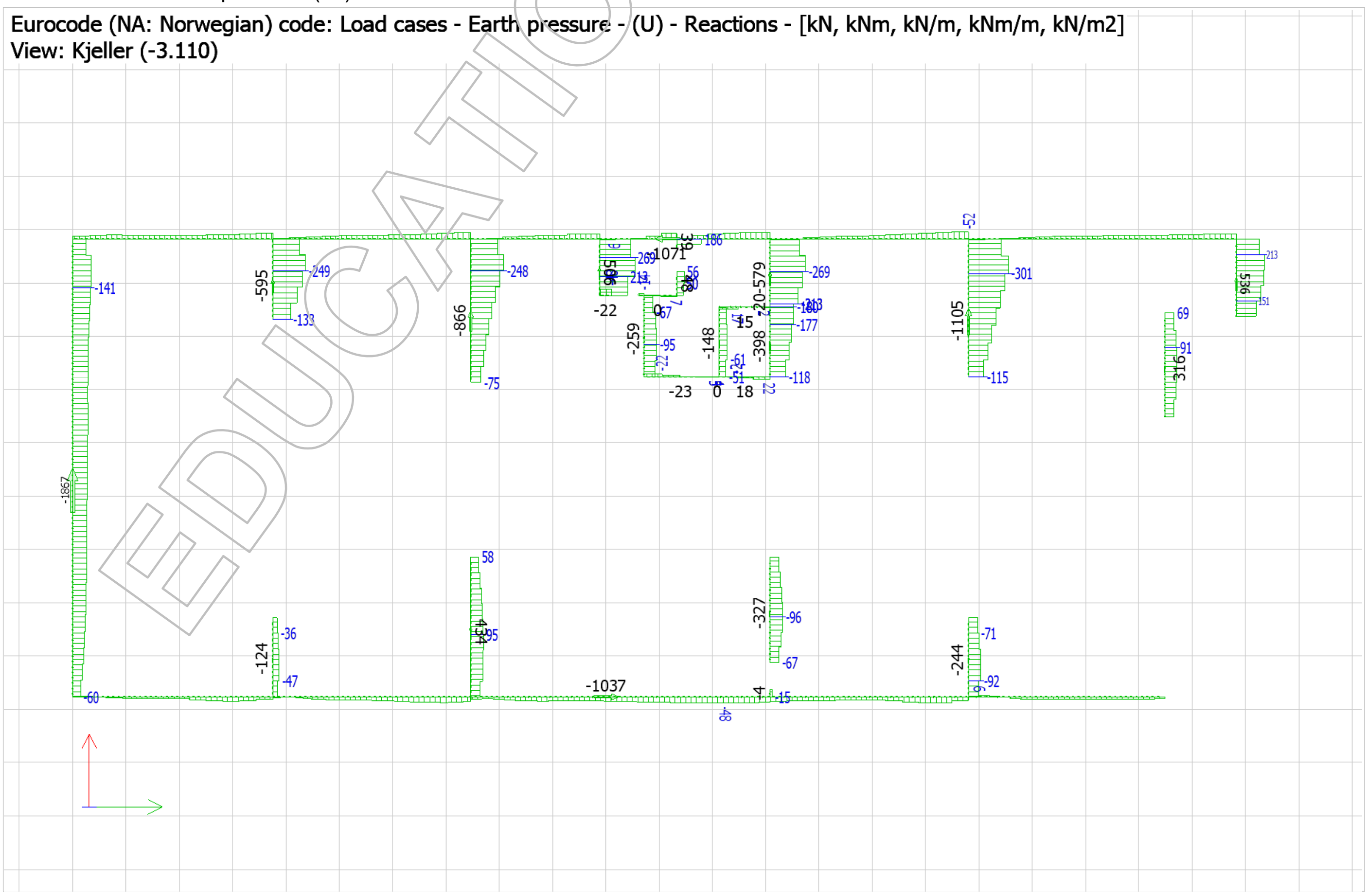
Reaction due to wind Fx



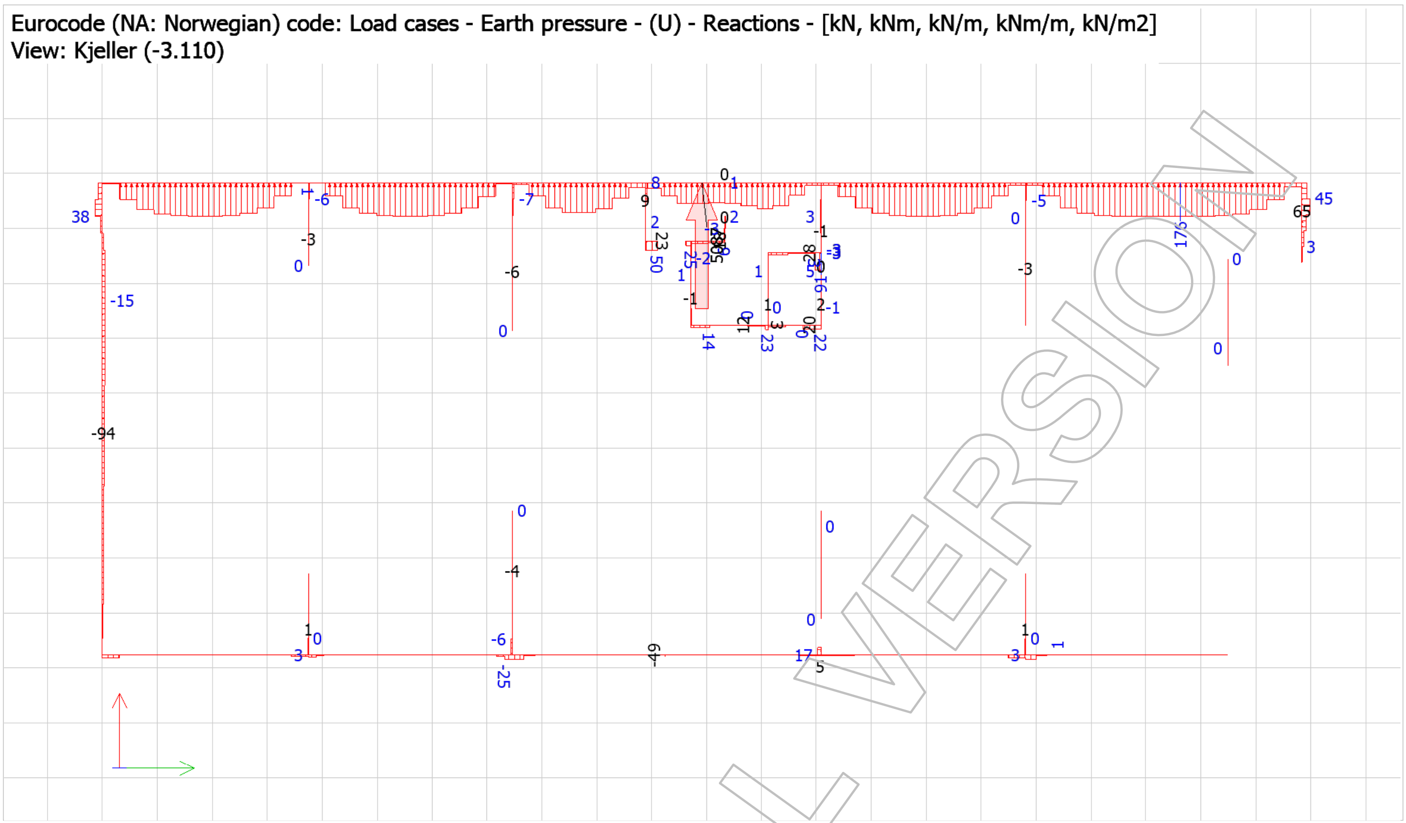
Reaction due to earth press (FZ and My)



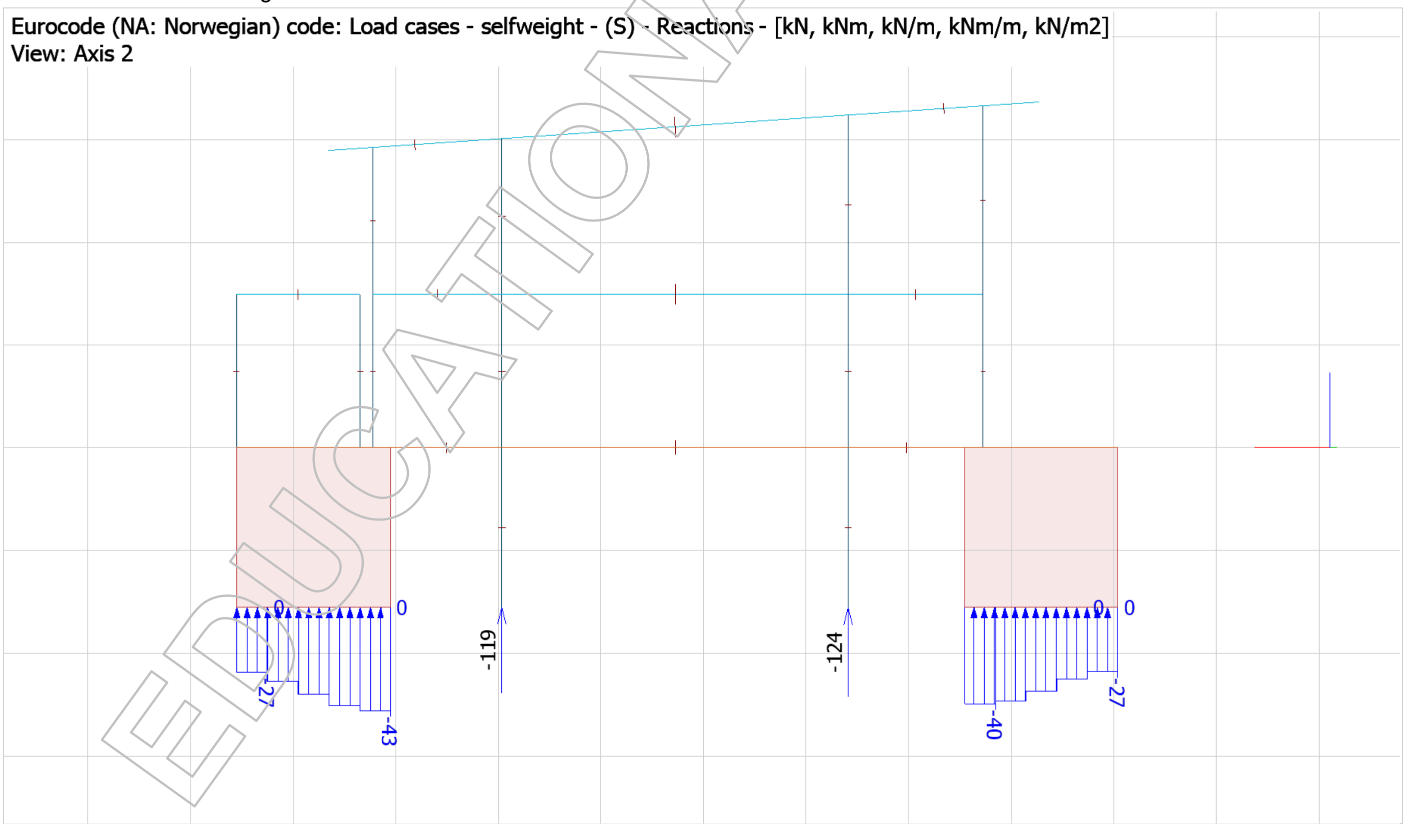
Reaction due to earth pressure (Fx)



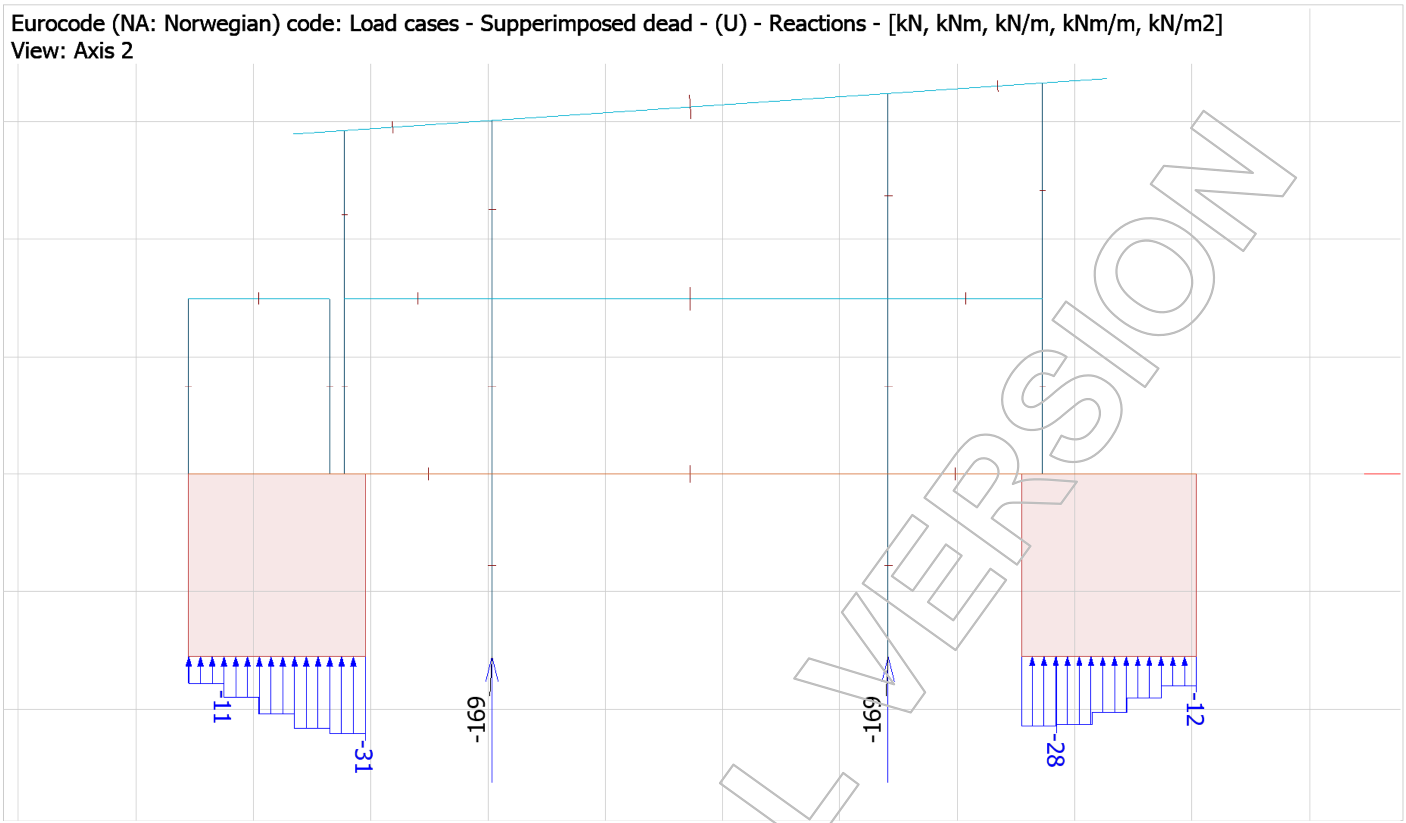
Reaction due to earth pressure (Fy)



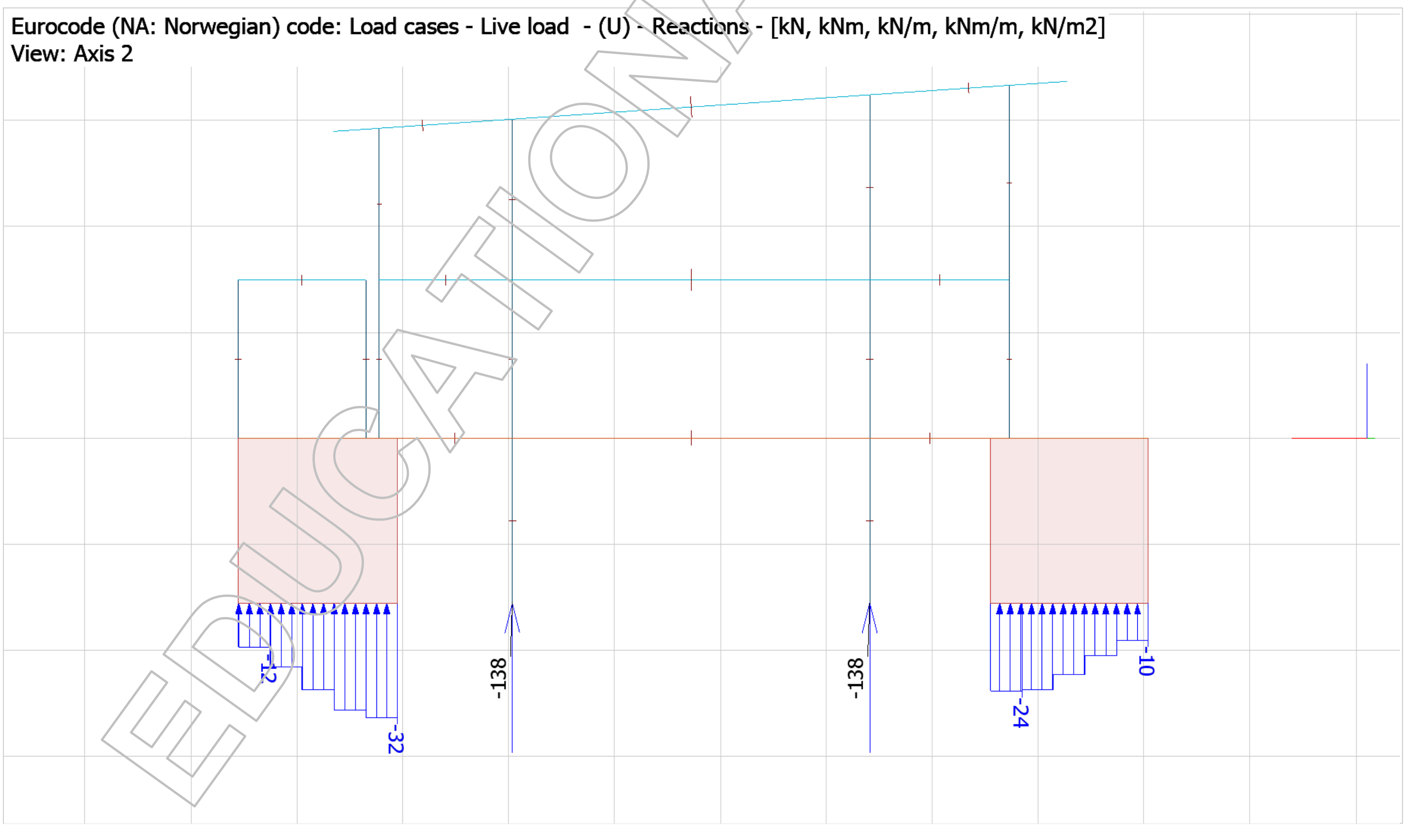
Reaction at axis 2 selfweight



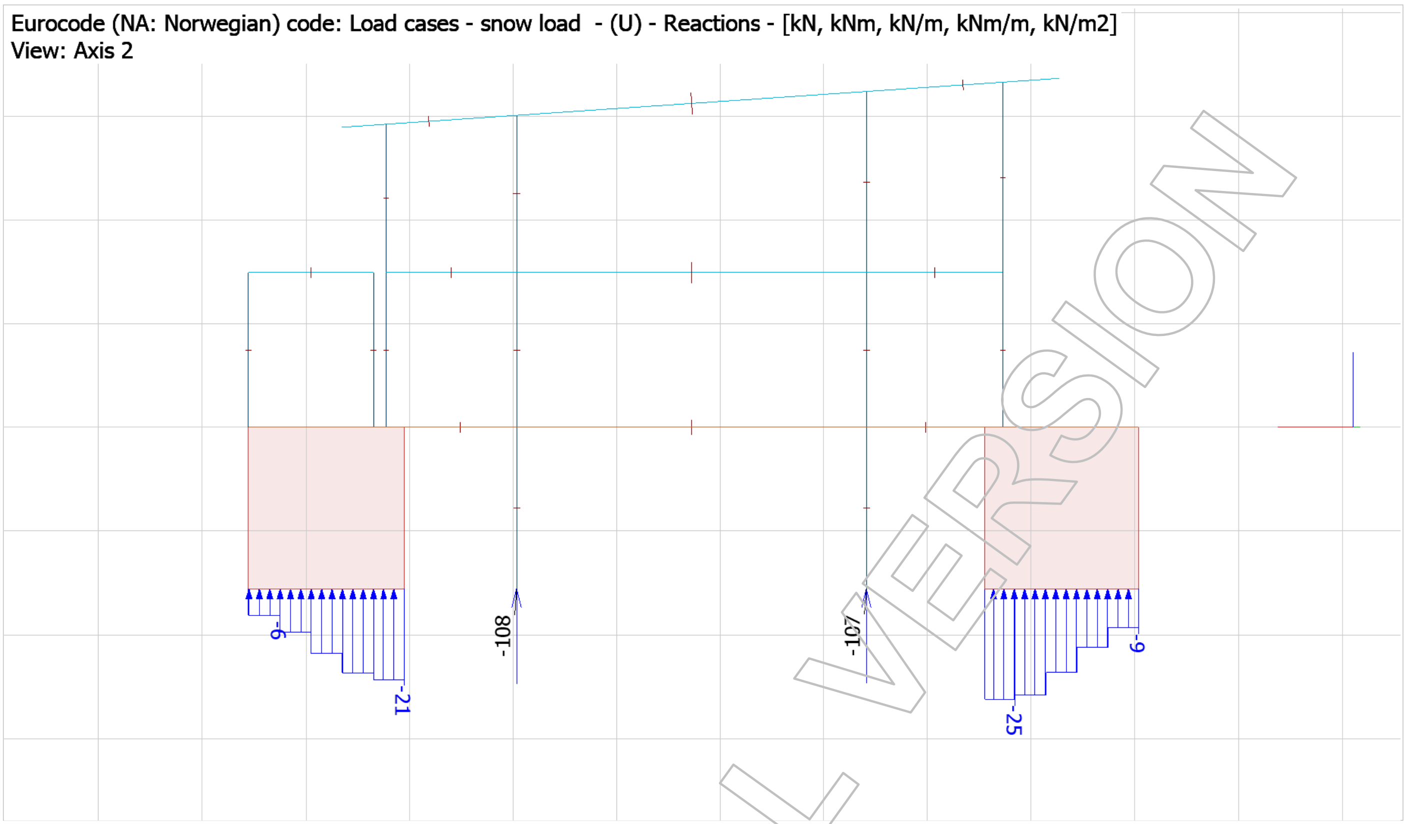
Reaction at axis 2 Superimposed dead



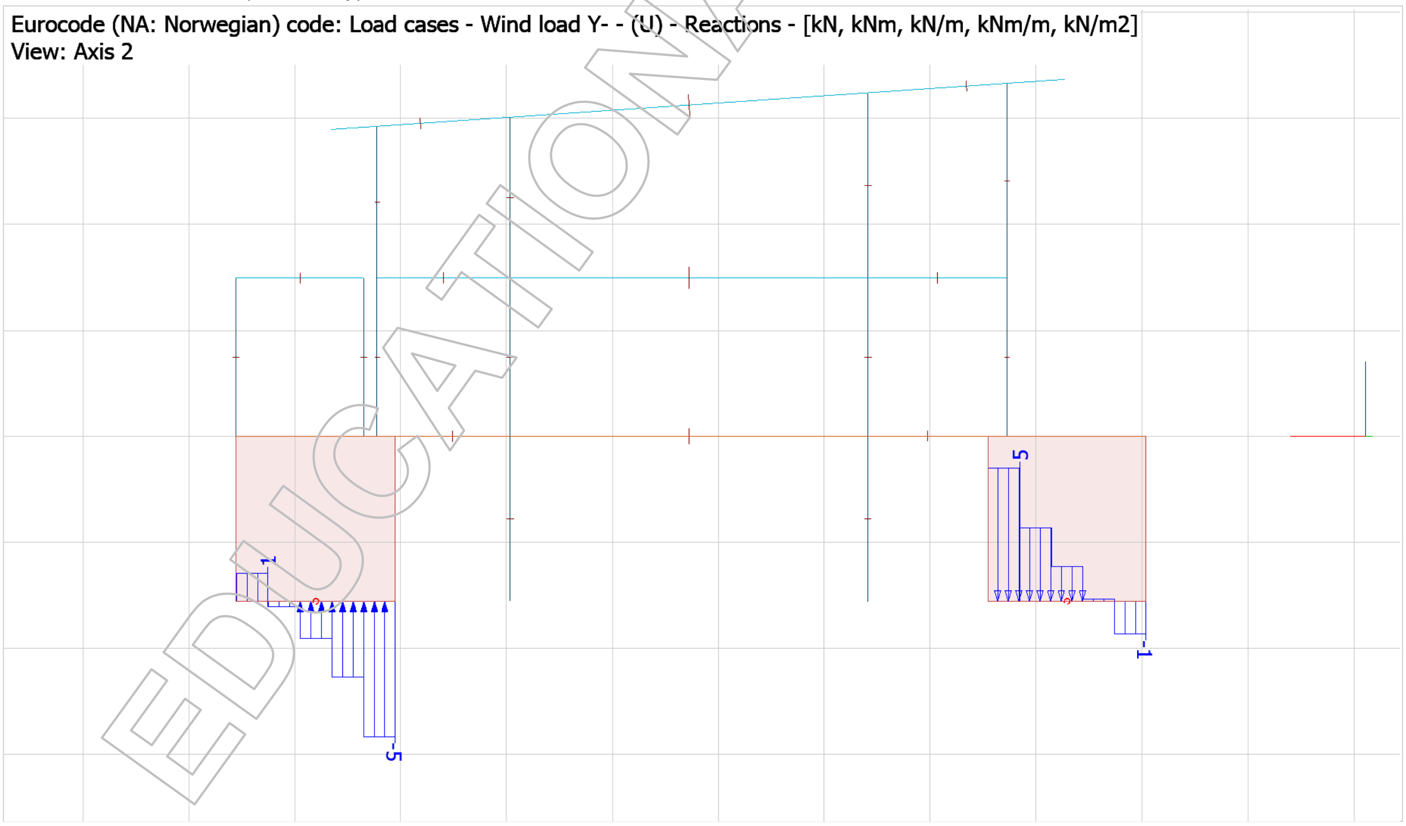
Reaction at axis 2 Live load



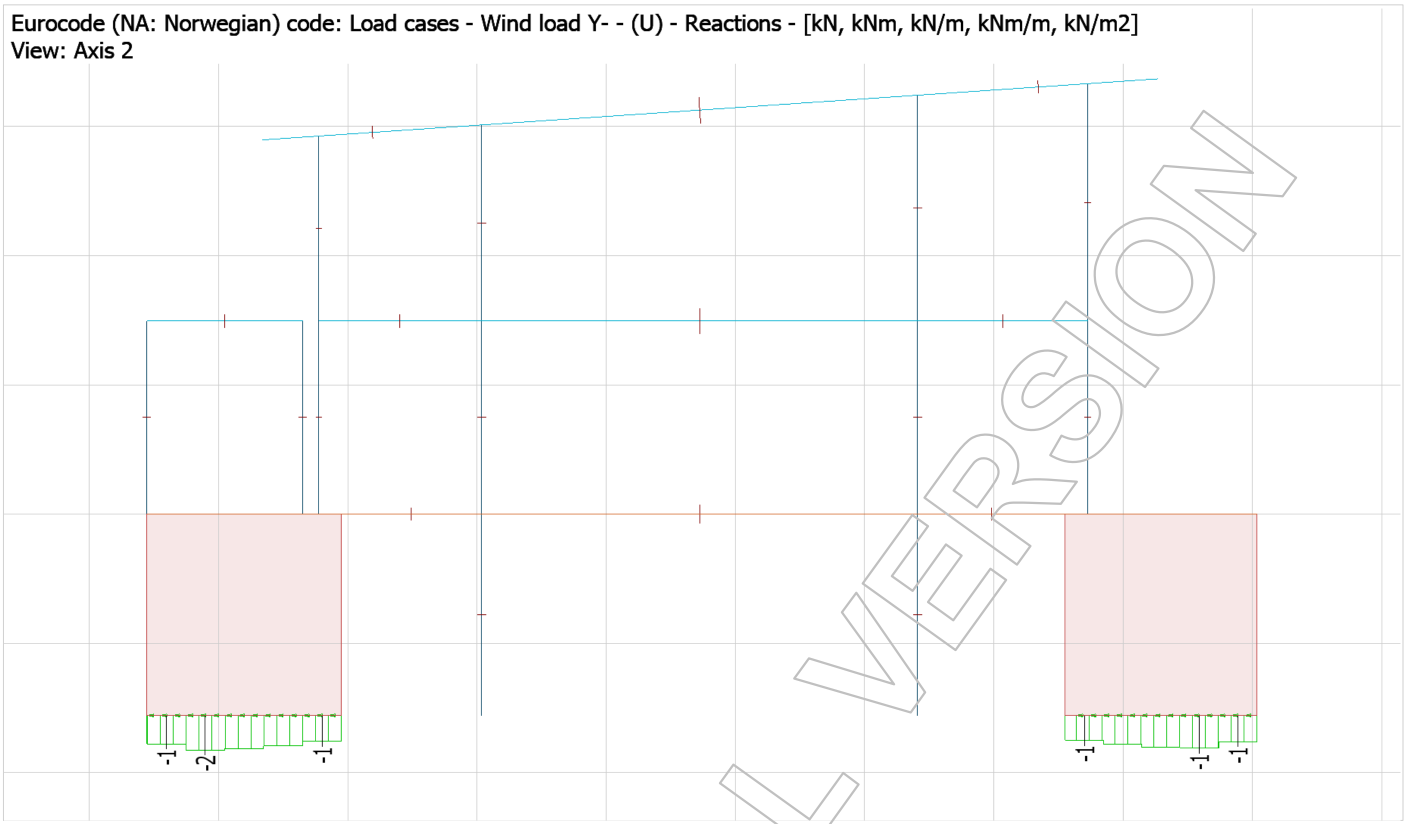
Reaction at axis 2 snow



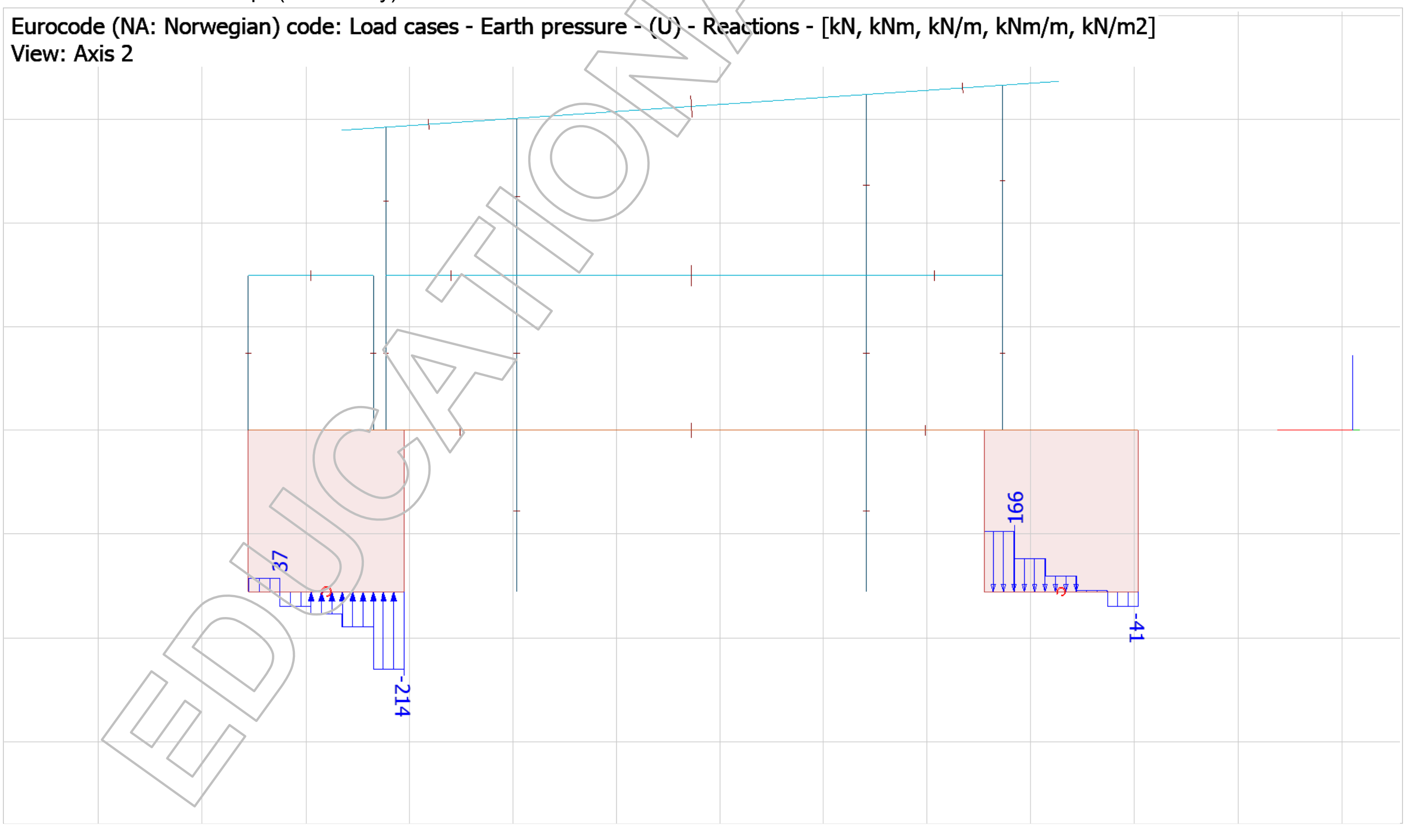
Reaction at axis 2 wind (Fz and My)



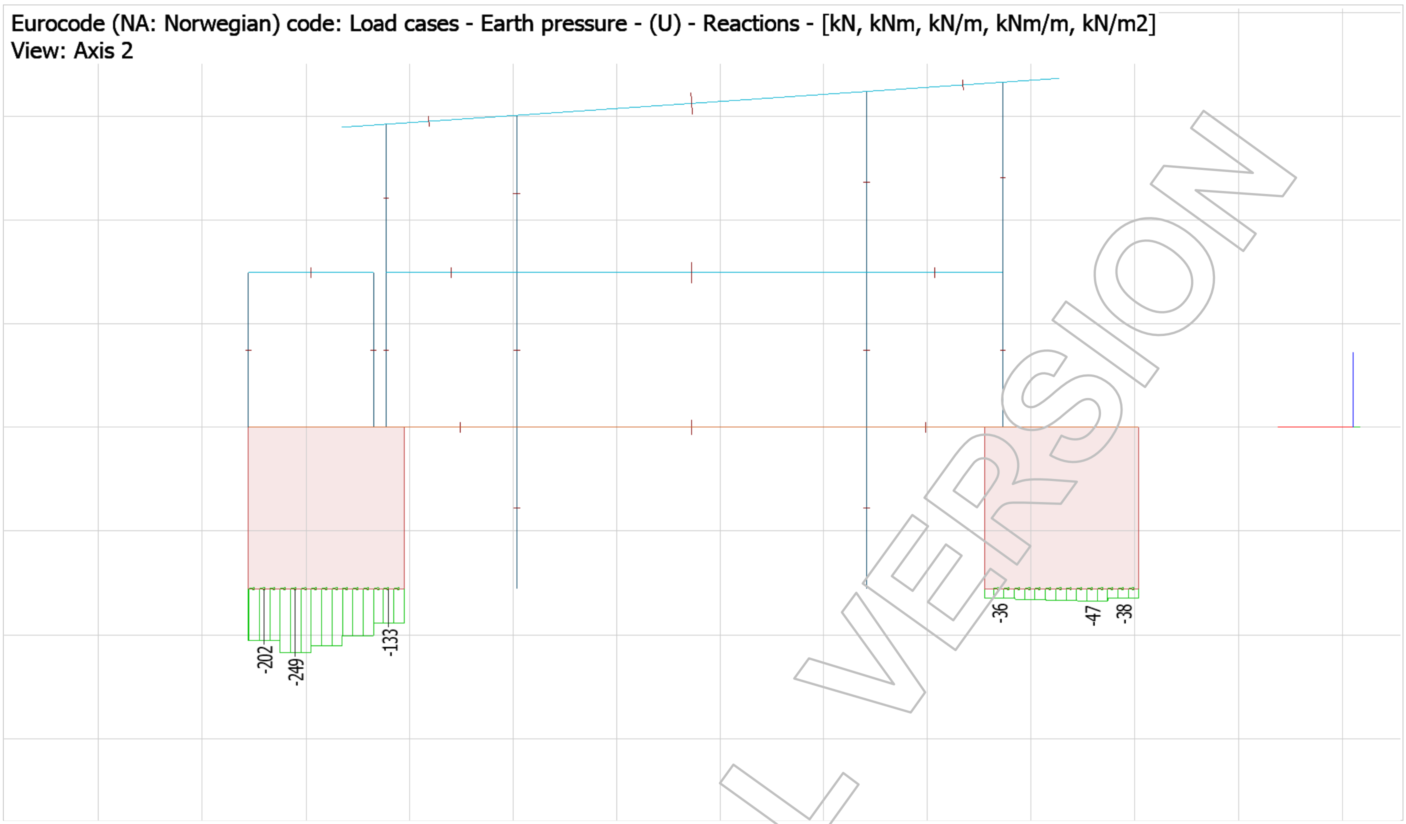
Reaction at axis 2 wind (Fx)



Reaction at axis 2 Earth pr (Fz and My)

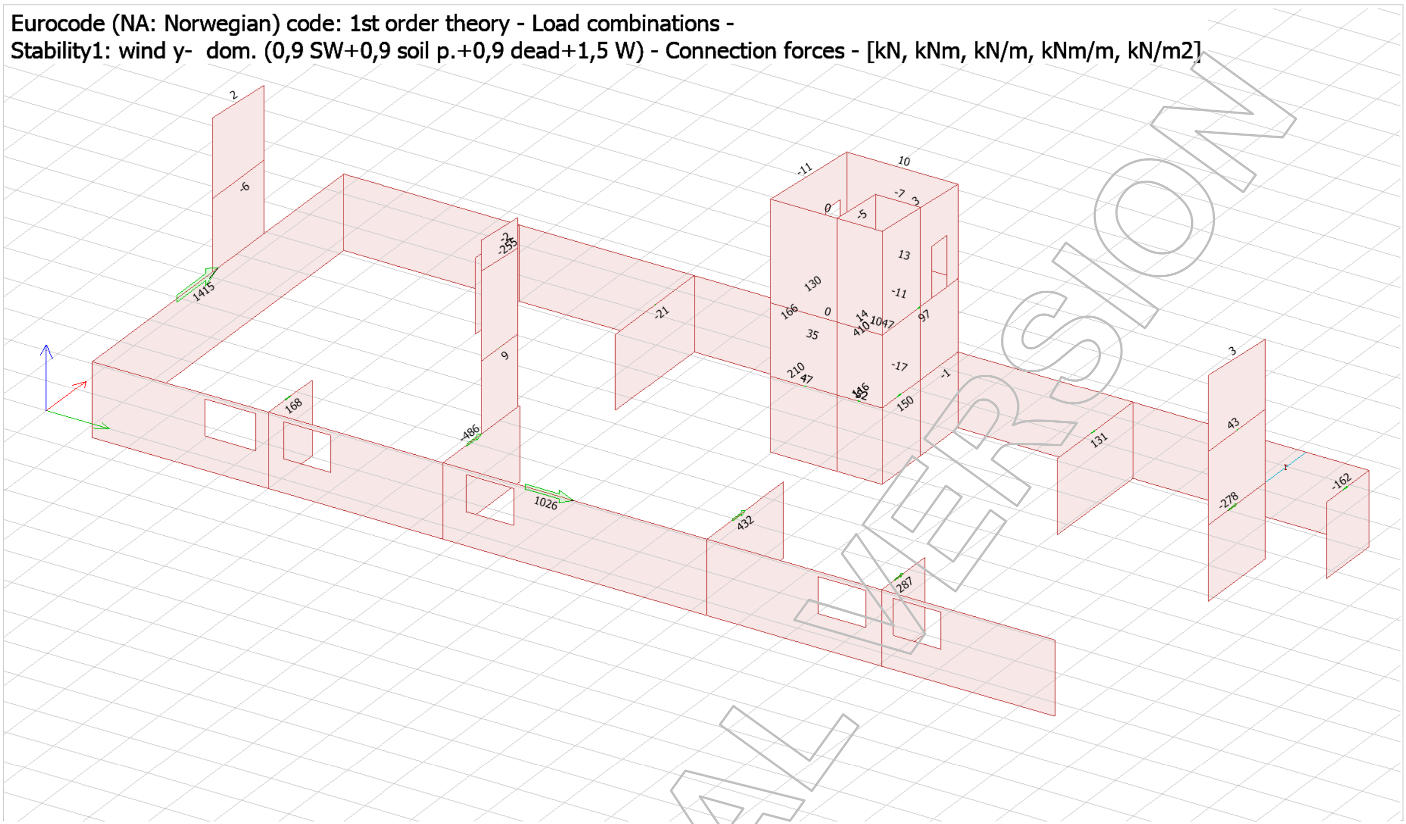


Reaction at axis 2 earth pressure (Fx)

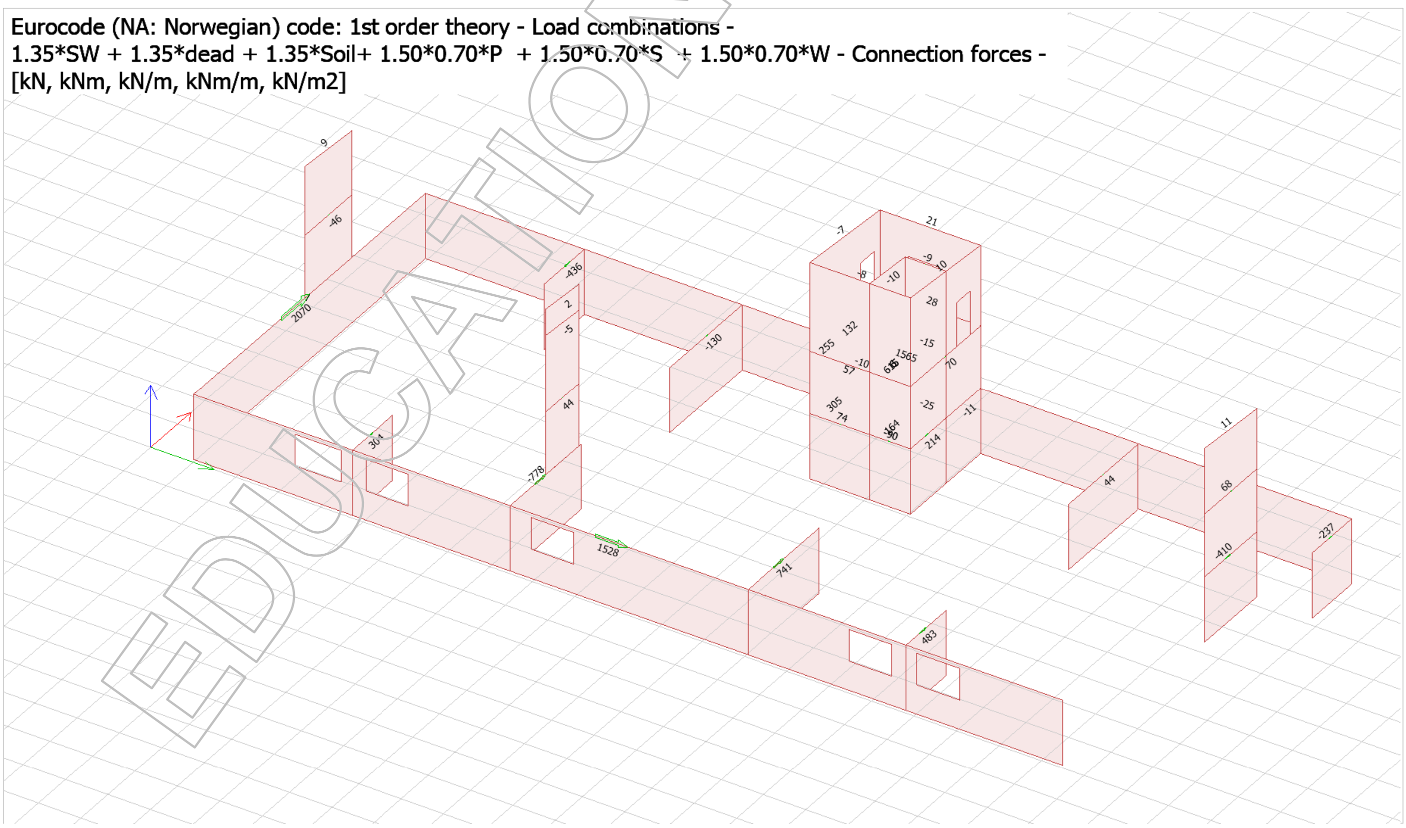


2.4 Connection forces at max. load combination

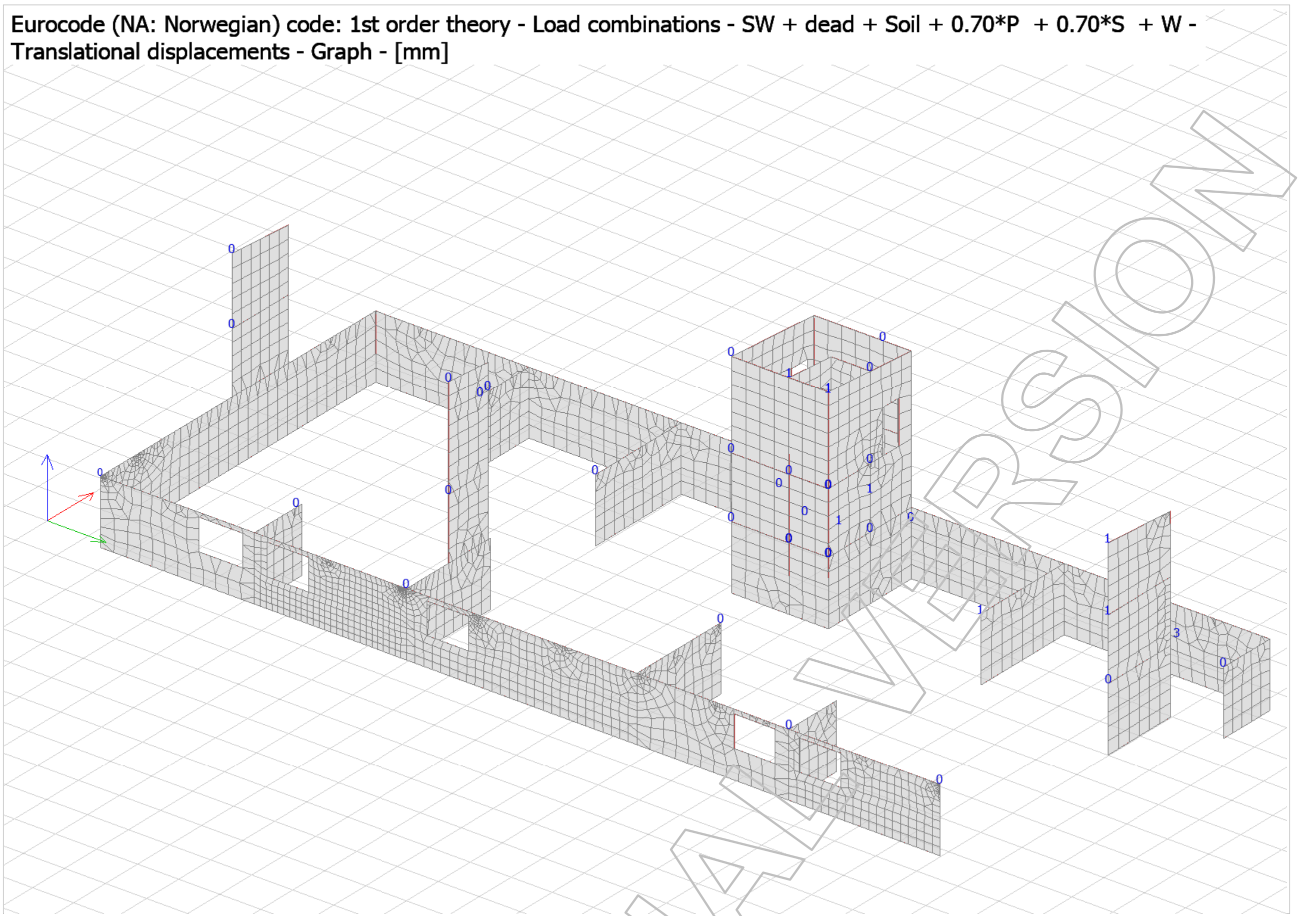
Connection forces FX due horzintal forc



Connection force at maximum comb.



Deflection walls



3 Steel design results

3.1 Utilization ratio

Max. of load combinations, Bar, Utilization

Member	Section	Status	Maximum	Combination
[-]	[-]	[-]	[%]	[-]
B.2.1	IPE 200	Real	53	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.3.1	IPE 200	Real	54	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.4.1	IPE 200	Real	6	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.5.1	IPE 200	Real	21	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.6.1	IPE 330	Real	50	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.14.1	IPE 200	Real	28	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.16.1	IPE 200	Real	31	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.17.1	IPE 200	Real	29	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.18.1	IPE 200	Real	30	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)
B.19.1	HE-B 280	Real	53	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.20.1	HE-B 280	Real	65	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.21.1	HE-B 300	Real	49	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.22.1	HE-B 280	Real	48	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.23.1	HE-B 300	Real	56	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.24.1	HE-B 280	Real	53	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.25.1	HE-B 280	Real	54	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.29.1	HE-B 280	Real	33	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.31.1	IPE 200	Real	26	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.32.1	IPE 200	Real	38	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.33.1	IPE 400	Real	62	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.34.1	IPE 200	Real	36	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.35.1	IPE 200	Real	38	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.36.1	IPE 400	Real	39	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.37.1	IPE 200	Real	36	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.38.1	IPE 400	Real	63	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.39.1	IPE 200	Real	30	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)
B.40.1	IPE 400	Real	64	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.41.1	IPE 200	Real	36	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.42.1	IPE 200	Real	38	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.43.1	IPE 200	Real	30	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.44.1	IPE 200	Real	7	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.45.1	IPE 200	Real	20	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.52.1	IPE 200	Real	3	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.54.1	IPE 200	Real	11	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.55.1	IPE 330	Real	52	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.56.1	IPE 200	Real	17	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.57.1	IPE 200	Real	3	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.58.1	IPE 200	Real	19	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.59.1	IPE 330	Real	52	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.60.1	IPE 200	Real	1	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.62.1	IPE 200	Real	30	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.63.1	IPE 400	Real	61	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.64.1	IPE 200	Real	65	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.65.1	IPE 400	Real	55	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.66.1	IPE 200	Real	57	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.67.1	IPE 330	Real	13	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.68.1	IPE 400	Real	60	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.69.1	IPE 200	Real	65	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...

Member	Section	Status	Maximum	Combination
[-]	[-]	[-]	[%]	[-]
B.70.1	IPE 200	Real	0	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
B.87.1	IPE 400	Real	63	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
B.88.1	IPE 200	Real	38	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
C.1.1	VKR 140x1...	Real	48	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
C.2.1	VKR 140x1...	Real	48	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
C.3.1	VKR 140x1...	Real	48	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
C.4.1	VKR 140x1...	Real	13	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.5.1	VKR 140x1...	Real	31	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.6.1	HE-A 200	Real	47	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
C.7.1	VKR 140x1...	Real	21	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.8.1	VKR 140x1...	Real	20	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.9.1	VKR 140x1...	Real	21	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.10.1	VKR 140x1...	Real	20	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.11.1	VKR 140x1...	Real	21	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.12.1	VKR 140x1...	Real	17	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.22.1	VKR 100x1...	Real	27	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.23.1	VKR 100x1...	Real	41	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.24.1	VKR 100x1...	Real	29	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.25.1	VKR 100x1...	Real	29	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.26.1	VKR 100x1...	Real	16	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.27.1	VKR 100x1...	Real	18	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.28.1	VKR 100x1...	Real	18	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.46.1	HE-A 200	Real	29	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
C.47.1	HE-A 200	Real	28	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70...
C.50.1	VKR 140x1...	Real	25	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.51.1	VKR 140x1...	Real	41	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.52.1	VKR 140x1...	Real	38	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.53.1	VKR 140x1...	Real	38	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.54.1	VKR 140x1...	Real	38	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.55.1	VKR 140x1...	Real	38	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.56.1	VKR 140x1...	Real	37	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.57.1	VKR 140x1...	Real	25	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.60.1	VKR 100x1...	Real	26	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.61.1	VKR 100x1...	Real	22	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.62.1	VKR 100x1...	Real	30	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.63.1	VKR 100x1...	Real	30	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.64.1	VKR 100x1...	Real	24	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.65.1	VKR 100x1...	Real	26	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...
C.66.1	VKR 100x1...	Real	26	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*...

Max. of load combinations, Joint, Utilization

ID	Solution	Utilization	Comb
[-]	[-]	[%]	[-]
SJ.1	BC1	93	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1....
SJ.2	BC1	59	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.3	BC5A	88	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.4	CB1	71	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.5	CB1	43	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.6	CB1	44	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.7	BC3	40	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.8	BC3	42	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...

ID	Solution	Utilization	Comb
[-]	[-]	[%]	[-]
SJ.9	BC3	24	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.10	BB3	37	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)
SJ.11	BB3	68	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1....
SJ.12	BB3	99	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.13	CB2	84	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.14	CB2	84	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.15	CB2	84	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.16	BC3	33	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.17	BC3	32	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.18	BC3	34	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.19	BC3	31	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...
SJ.20	BC3	34	0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1...

Max. of load combinations, Bar design group, Utilization

Group	Applied profile	Status	Max.	Min.	Note
[-]		[-]	[%]	[%]	[-]
HEA 200	HE-A 200	Real	47	28	OK
HEB 280	HE-B 280	Real	65	33	OK
HEB 300	HE-B 300	Real	56	49	OK
HUP 100x100x8	VKR 100x100x8	Real	41	16	OK
HUP 140x140x10	VKR 140x140x10	Real	48	48	OK
HUP 140x140x8	VKR 140x140x8	Real	41	13	OK
IPE 200 roof	IPE 200	Real	65	0	OK
IPE 330 roof	IPE 330	Real	52	13	OK
IPE 400 roof	IPE 400	Real	61	55	OK
IPE200 ..2.floo	IPE 200	Real	38	7	OK
IPE200..1st fl.	IPE 200	Real	38	29	OK
IPE400 ..2.floo	IPE 400	Real	64	39	OK

Group HEB 300, Maximum of group members
Maximum of load combinations

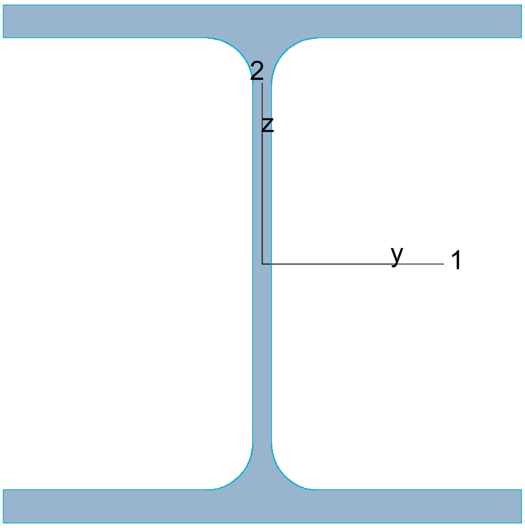
S 355

$E = 210000\ \mathrm{N/mm^2}$

$G = 80769\ \mathrm{N/mm^2}$

$\gamma_{M0,ult}$ = 1.05		$\gamma_{M0,acc/seis}$ = 1.00	
$\gamma_{M1,ult}$ = 1.05		$\gamma_{M1,acc/seis}$ = 1.00	
$\gamma_{M2,ult}$ = 1.25		$\gamma_{M2,acc/seis}$ = 1.00	

HE-B 300



P	= 1732	mm	f_y = 355 $\mathrm{N/mm^2}$
A	= 14908	$\mathrm{mm^2}$	ε = 0.81
I_y	= 2.517e+08	$\mathrm{mm^4}$	λ_1 = 76.40
I_z	= 8.563e+07	$\mathrm{mm^4}$	
I_1	= 2.517e+08	$\mathrm{mm^4}$	
I_2	= 8.563e+07	$\mathrm{mm^4}$	
$W_{pl,1}$	= 1.869e+06	$\mathrm{mm^3}$	
$W_{pl,2}$	= 8.703e+05	$\mathrm{mm^3}$	
$W_{el,min,1}$	= 1.678e+06	$\mathrm{mm^3}$	
$W_{el,min,2}$	= 5.709e+05	$\mathrm{mm^3}$	
i_1	= 130	mm	
i_2	= 76	mm	
I_t	= 1.874e+06	$\mathrm{mm^4}$	
I_w	= 1.651e+12	$\mathrm{mm^6}$	

Shear resistance, 1-1 - Part 1-1: 6.2.6, 6.2.8

Bar: B.23.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W', x = 0 mm

$\mathrm{Class}_N = 1, \quad \mathrm{Class}_{M1} = 1, \quad \mathrm{Class}_{M2} = 1$

$$V_{1,pl,Rd} = \frac{A_{1,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{12026 \cdot 355}{\sqrt{3} \cdot 1.05} = 2347.42 \ \mathrm{kN} \qquad (6.18)$$

$$V_{1,pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1.25 \ (f_y / \sqrt{3}) / \gamma_{M0}}} \cdot V_{1,pl,Rd} =$$

$$= \sqrt{1 - \frac{1.49}{1.25 \ (355 / \sqrt{3}) / 1.05}} \cdot 2347.42 = 2340.24 \ \mathrm{kN} \qquad (6.26)$$

$$\frac{V_{1,Ed}}{V_{1,pl,T,Rd}} = \frac{0.00}{2340.24} = 0.00 \le 1.00 \qquad (6.25) \quad \text{- OK}$$

Shear resistance, 2-2 - Part 1-1: 6.2.6, 6.2.8

Bar: B.23.1, LC: '0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W', x = 0 mm

$\text{Class}_{N} = 1, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$$V_{2,pl,Rd} = \frac{A_{2,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{4743 \cdot 355}{\sqrt{3} \cdot 1.05} = 925.79 \quad \text{kN} \qquad (6.18)$$

$$V_{2,pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1.25 \left(f_y / \sqrt{3} \right) / \gamma_{M0}}} \cdot V_{2,pl,Rd} =$$

$$= \sqrt{1 - \frac{1.49}{1.25 \left(355 / \sqrt{3} \right) / 1.05}} \cdot 925.79 = 922.96 \quad \text{kN} \qquad (6.26)$$

$$\frac{V_{2,Ed}}{V_{2,pl,T,Rd}} = \frac{520.71}{922.96} = 0.56 \le 1.00 \qquad (6.25) \quad \text{- OK}$$

Torsional resistance - Part 1-1: 6.2.7

Bar: B.23.1, LC: '0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W', x = 354 mm

$\text{Class}_{N} = 1, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$\tau_{max,unit} = 16.26 \ \frac{N/mm^2}{kN\,m}$ is calculated by FEM analysis.

$$T_{Rd} = \frac{f_y}{\sqrt{3} \cdot \tau_{max,unit} \cdot \gamma_{M0}} = \frac{355}{\sqrt{3} \cdot 16.26 \cdot 1.05} = 12.00 \quad \text{kN m}$$

$$\frac{T_{Ed}}{T_{Rd}} = \frac{0.16}{12.00} = 0.01 \le 1.00 \qquad (6.23) \quad \text{- OK}$$

Shear stress - Part 1-1: 6.2.6

Not relevant

Normal stress - Part 1-1: 6.2.1

Not relevant

Normal capacity - Part 1-1: 6.2

Bar: B.23.1, LC: '0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W', x = 708 mm

$\text{Class}_{N} = 1, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$V_{1,Ed} = 0.00 \ \text{kN} \le 0.5 \cdot V_{1,pl,T,Rd} = 0.5 \cdot 2344.83 = 1172.41 \ \text{kN} \rightarrow \rho_1 = 0.00$

$V_{2,Ed} = 452.00 \ \text{kN} \le 0.5 \cdot V_{2,pl,T,Rd} = 0.5 \cdot 924.76 = 462.38 \ \text{kN} \rightarrow \rho_1 = 0.00$

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{1,Ed}}{M_{1,Rd}} + \frac{M_{2,Ed}}{M_{2,Rd}} = \frac{0.00}{5040.25} + \frac{330.27}{631.79} + \frac{0.00}{294.23} = 0.52 \le 1.00 \qquad (6.2) \quad \text{- OK}$$

Flexural buckling, 1-1 - Part 1-1: 6.3.1

Bar: B.21.1, LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)', x = 0 mm

$\text{Class}_N = 1, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$$\bar{\lambda}_1 = \frac{L_{cr,1}}{i_1 \cdot \lambda_1} = \frac{1030}{130 \cdot 76.40} = 0.10 \qquad (6.50)$$

$\alpha_1 = 0.34$ (Buckling curve: b)

$$\varphi_1 = 0.5 \left[1 + \alpha_1 \cdot (\bar{\lambda}_1 - 0.2) + \bar{\lambda}_1^2\right] =$$

$$= 0.5 \left[1 + 0.34 \cdot (0.10 - 0.2) + 0.10^2\right] = 0.49$$

$$\chi_1 = \min\left(\frac{1}{\varphi_1 + \sqrt{\varphi_1^2 - \bar{\lambda}_1^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{0.49 + \sqrt{0.49^2 - 0.10^2}}, 1.0\right) = 1.00 \qquad (6.49)$$

$$N_{b,Rd,1} = \frac{\chi_1 \cdot A \cdot f_y}{\gamma_{M1}} = \frac{1.00 \cdot 14908 \cdot 355}{1.05} = 5040.25 \text{ kN} \qquad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,1}} = \frac{0.00}{5040.25} = 0.00 \leq 1.00 \qquad (6.46) \text{ - OK}$$

Flexural buckling, 2-2 - Part 1-1: 6.3.1

Bar: B.21.1, LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)', x = 0 mm

$\text{Class}_N = 1, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$$\bar{\lambda}_2 = \frac{L_{cr,2}}{i_2 \cdot \lambda_1} = \frac{0}{76 \cdot 76.40} = 0.00 \qquad (6.50)$$

$\alpha_2 = 0.49$ (Buckling curve: c)

$$\varphi_2 = 0.5 \left[1 + \alpha_2 \cdot (\bar{\lambda}_2 - 0.2) + \bar{\lambda}_2^2\right] =$$

$$= 0.5 \left[1 + 0.49 \cdot (0.00 - 0.2) + 0.00^2\right] = 0.45$$

$$\chi_2 = \min\left(\frac{1}{\varphi_2 + \sqrt{\varphi_2^2 - \bar{\lambda}_2^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{0.45 + \sqrt{0.45^2 - 0.00^2}}, 1.0\right) = 1.00 \qquad (6.49)$$

$$N_{b,Rd,2} = \frac{\chi_2 \cdot A \cdot f_y}{\gamma_{M1}} = \frac{1.00 \cdot 14908 \cdot 355}{1.05} = 5040.25 \text{ kN} \qquad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,2}} = \frac{0.00}{5040.25} = 0.00 \leq 1.00 \qquad (6.46) \text{ - OK}$$

Torsional-flexural buckling - Part 1-1: 6.3.1
Bar: B.21.1, LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)', x = 0 mm

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$i_0 = \sqrt{i_1^2 + i_2^2 + y_0^2 + z_0^2} = \sqrt{130^2 + 76^2 + 0^2 + 0^2} = 150 \text{ mm}$$

$$N_{cr,1} = \frac{\pi^2 \cdot E \cdot I_1}{L_{cr,1}^2} = \frac{\pi^2 \cdot 210000 \cdot 251656844}{1030^2} = 491646.94 \text{ kN}$$

$$N_{cr,2} = \frac{\pi^2 \cdot E \cdot I_2}{L_{cr,2}^2} = \frac{\pi^2 \cdot 210000 \cdot 85628301}{0^2} = 5040.25 \text{ kN}$$

$$N_{cr,T} = \frac{1}{i_0^2}\left(G \cdot I_t + \frac{\pi^2 \cdot E \cdot I_w}{L_t^2}\right) =$$

$$= \frac{1}{150^2}\left(80769 \cdot 1.874e{+}06 + \frac{\pi^2 \cdot 210000 \cdot 1.651e{+}12}{1030^2}\right) = 149255.31 \text{ kN}$$

$$i_0^2 (N - N_{cr,1})(N - N_{cr,2})(N - N_{cr,T}) - N^2 y_0^2 (N - N_{cr,2}) - N^2 z_0^2 (N - N_{cr,1}) =$$

$$= 150^2 (N - 491646.94)(N - 5040.25)(N - 149255.31) - N^2 0^2 (N - 5040.25) - N^2 0^2 (N - 491646.94$$

$$= 0$$

Smallest root of the above equation related to the torsional-flexural buckling:

$$N_{cr,TF} = 149255.31 \text{ kN}$$

$$N_{cr} = \min(N_{cr,T}, N_{cr,TF}) = \min(149255.31, 149255.31) = 149255.31 \text{ kN}$$

$$\bar{\lambda}_T = \sqrt{\frac{A \cdot f_y}{N_{cr}}} = \sqrt{\frac{14908 \cdot 355}{149255.31}} = 0.19 \quad (6.53)$$

$\alpha_T = 0.49$ (Buckling curve: c)

$$\varphi_T = 0.5\left[1 + \alpha_T \cdot (\bar{\lambda}_T - 0.2) + \bar{\lambda}_T^2\right] =$$

$$= 0.5\left[1 + 0.49 \cdot (0.19 - 0.2) + 0.19^2\right] = 0.51$$

$$\chi_T = \min\left(\frac{1}{\varphi_T + \sqrt{\varphi_T^2 - \bar{\lambda}_T^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{0.51 + \sqrt{0.51^2 - 0.19^2}}, 1.0\right) = 1.00 \quad (6.49)$$

$$N_{b,Rd,T} = \frac{\chi_T \cdot A \cdot f_y}{\gamma_{M1}} = \frac{1.00 \cdot 14908 \cdot 355}{1.05} = 5040.25 \text{ kN} \quad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,T}} = \frac{0.00}{5040.25} = 0.00 \le 1.00 \text{ - OK}$$

Lateral torsional buckling, top flange - Part 1-1: 6.3.2.2
Not relevant

Lateral torsional buckling, bottom flange - Part 1-1: 6.3.2.2
Bar: B.21.1, LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)', x = 0 mm

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$N_{cr,LT} = \frac{\pi^2 \cdot E \cdot I_z}{(k_z \cdot L_{cr})^2} = \frac{\pi^2 \cdot 2.100e{+}05 \cdot 8.563e{+}07}{(1.00 \cdot 1030)^2} = 167286.89 \quad kN$$

Loaded on top edge.

$$Z = (C_2 \cdot z_g - C_3 \cdot z_j) = (0.00 \cdot 150 - 0.94 \cdot 0) = 0.00 \quad mm$$

$$M_{cr} = C_1 \cdot N_{cr,LT} \cdot \left\{ \left[\left(\frac{k_z}{k_w} \right)^2 \cdot \frac{I_w}{I_z} + \frac{G \cdot I_t}{N_{cr,LT}} + Z^2 \right]^{0.5} - Z \right\} =$$

$$= 1.77 \cdot 1.673e{+}08 \cdot \left\{ \left[\left(\frac{1.00}{1.00} \right)^2 \cdot \frac{1.651e{+}12}{8.563e{+}07} + \frac{8.077e{+}04 \cdot 1.874e{+}06}{1.673e{+}08} + 0.00^2 \right]^{0.5} - 0.00 \right\} =$$

$$= 42068.91 \quad kN\,m$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y \cdot f_y}{M_{cr}}} = \sqrt{\frac{1868674 \cdot 355}{4.207e{+}10}} = 0.13$$

$\alpha_{LT} = 0.21$ (Buckling curve: a)

$$\varphi_{LT} = 0.5 \left[1 + \alpha_{LT} \cdot (\bar{\lambda}_{LT} - 0.2) + \bar{\lambda}_{LT}^2 \right] =$$

$$= 0.5 \left[1 + 0.21 \cdot (0.13 - 0.2) + 0.13^2 \right] = 0.50$$

$$\chi_{LT} = \min \left(\frac{1}{\varphi_{LT} + \sqrt{\varphi_{LT}^2 - \bar{\lambda}_{LT}^2}}, 1.0 \right) =$$

$$= \min \left(\frac{1}{0.50 + \sqrt{0.50^2 - 0.13^2}}, 1.0 \right) = 1.00 \qquad (6.56)$$

$$M_{y,b,Rd} = \frac{\chi_{LT} \cdot W_y \cdot f_y}{\gamma_{M1}} = \frac{1.00 \cdot 1868674 \cdot 355}{1.05} = 631.79 \quad kN\,m \qquad (6.55)$$

$$\frac{M_{1,Ed}}{M_{y,b,Rd}} = \frac{0.00}{631.79} = 0.00 \leq 1.00 \qquad (6.54) \quad \text{- OK}$$

Interaction between normal force and bending 1. - Part 1-1: 6.3.3
Not relevant

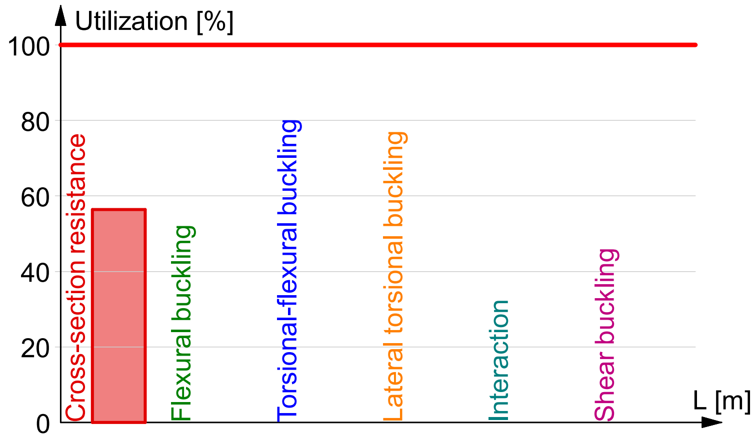
Interaction between normal force and bending 2. - Part 1-1: 6.3.3
Not relevant

Interaction between normal force and bending, 2nd order - Part 1-1: 6.3.3
Not relevant

Shear buckling - Part 1-5: 5

$$\frac{h_w}{t} = \frac{262}{11} = 23.8 \leq \frac{72}{\eta} \cdot \varepsilon = \frac{72}{1.20} \cdot 0.81 = 48.8 \rightarrow \quad \text{Not relevant}$$

Summary

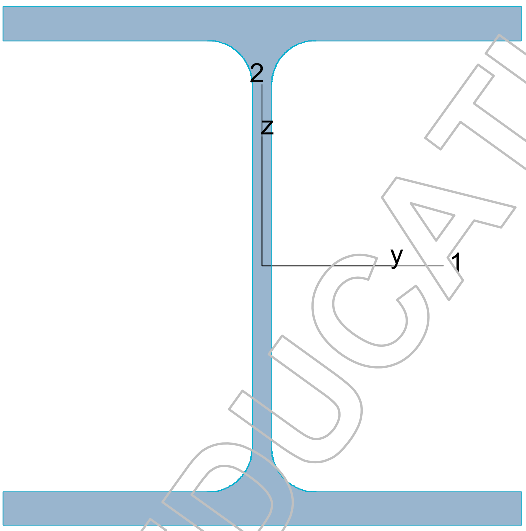


Group HEB 280, Maximum of group members
Maximum of load combinations

S 355

E	=	210000	N/mm^2			
G	=	80769	N/mm^2			
$\gamma_{M0,ult}$	=	1.05		$\gamma_{M0,acc/seis}$	=	1.00
$\gamma_{M1,ult}$	=	1.05		$\gamma_{M1,acc/seis}$	=	1.00
$\gamma_{M2,ult}$	=	1.25		$\gamma_{M2,acc/seis}$	=	1.00

HE-B 280



P	=	1618	mm	f_y	=	355	N/mm^2
A	=	13136	mm^2	ε	=	0.81	
I_y	=	1.927e+08	mm^4	λ_1	=	76.40	
I_z	=	6.595e+07	mm^4				
I_1	=	1.927e+08	mm^4				
I_2	=	6.595e+07	mm^4				
$W_{pl,1}$	=	1.534e+06	mm^3				
$W_{pl,2}$	=	7.177e+05	mm^3				
$W_{el,min,1}$	=	1.376e+06	mm^3				
$W_{el,min,2}$	=	4.710e+05	mm^3				
i_1	=	121	mm				
i_2	=	71	mm				
I_t	=	1.453e+06	mm^4				
I_w	=	1.107e+12	mm^6				

Shear resistance, 1-1 - Part 1-1: 6.2.6, 6.2.8

Bar: B.25.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 0 mm

$Class_{N} = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$V_{1,pl,Rd} = \frac{A_{1,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{10574 \cdot 355}{\sqrt{3} \cdot 1.05} = 2064.12 \quad kN \qquad (6.18)$$

$$V_{1,pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1.25 \left(f_y / \sqrt{3} \right) / \gamma_{M0}}} \cdot V_{1,pl,Rd} =$$

$$= \sqrt{1 - \frac{0.00}{1.25 \left(355 / \sqrt{3} \right) / 1.05}} \cdot 2064.12 = 2064.12 \quad kN \qquad (6.26)$$

$$\frac{V_{1,Ed}}{V_{1,pl,T,Rd}} = \frac{0.00}{2064.12} = 0.00 \leq 1.00 \qquad (6.25) \quad \text{- OK}$$

Shear resistance, 2-2 - Part 1-1: 6.2.6, 6.2.8

Bar: B.25.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 0 mm

$Class_{N} = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$V_{2,pl,Rd} = \frac{A_{2,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{4109 \cdot 355}{\sqrt{3} \cdot 1.05} = 802.16 \quad kN \qquad (6.18)$$

$$V_{2,pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1.25 \left(f_y / \sqrt{3} \right) / \gamma_{M0}}} \cdot V_{2,pl,Rd} =$$

$$= \sqrt{1 - \frac{0.00}{1.25 \left(355 / \sqrt{3} \right) / 1.05}} \cdot 802.16 = 802.16 \quad kN \qquad (6.26)$$

$$\frac{V_{2,Ed}}{V_{2,pl,T,Rd}} = \frac{170.73}{802.16} = 0.21 \leq 1.00 \qquad (6.25) \quad \text{- OK}$$

Torsional resistance - Part 1-1: 6.2.7

Bar: B.20.1, LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', x = 2920 mm

$Class_{N} = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$\tau_{max,unit} = 19.66 \ \frac{N/mm^2}{kN\,m}$$ is calculated by FEM analysis.

$$T_{Rd} = \frac{f_y}{\sqrt{3} \cdot \tau_{max,unit} \cdot \gamma_{M0}} = \frac{355}{\sqrt{3} \cdot 19.66 \cdot 1.05} = 9.93 \quad kN\,m$$

$$\frac{T_{Ed}}{T_{Rd}} = \frac{0.85}{9.93} = 0.09 \leq 1.00 \qquad (6.23) \quad \text{- OK}$$

Shear stress - Part 1-1: 6.2.6

Not relevant

Normal stress - Part 1-1: 6.2.1

Not relevant

Normal capacity - Part 1-1: 6.2

Bar: B.20.1, LC: '0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W', x = 2620 mm

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$V_{1,Ed} = 0.00 \text{ kN} \leq 0.5 \cdot V_{1,pl,T,Rd} = 0.5 \cdot 2051.05 = 1025.53 \text{ kN} \rightarrow \rho_1 = 0.00$

$V_{2,Ed} = 32.77 \text{ kN} \leq 0.5 \cdot V_{2,pl,T,Rd} = 0.5 \cdot 797.08 = 398.54 \text{ kN} \rightarrow \rho_1 = 0.00$

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{1,Ed}}{M_{1,Rd}} + \frac{M_{2,Ed}}{M_{2,Rd}} = \frac{0.00}{4441.37} + \frac{337.58}{518.78} + \frac{0.00}{242.64} = 0.65 \leq 1.00 \qquad (6.2) \text{ - OK}$$

Flexural buckling, 1-1 - Part 1-1: 6.3.1

Bar: B.19.1, LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)', x = 0 mm

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$\bar{\lambda}_1 = \frac{L_{cr,1}}{i_1 \cdot \lambda_1} = \frac{6754}{121 \cdot 76.40} = 0.73 \qquad (6.50)$$

$\alpha_1 = 0.34 \qquad$ (Buckling curve: b)

$$\varphi_1 = 0.5 \left[1 + \alpha_1 \cdot (\bar{\lambda}_1 - 0.2) + \bar{\lambda}_1^2\right] =$$

$$= 0.5 \left[1 + 0.34 \cdot (0.73 - 0.2) + 0.73^2\right] = 0.86$$

$$\chi_1 = \min\left(\frac{1}{\varphi_1 + \sqrt{\varphi_1^2 - \bar{\lambda}_1^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{0.86 + \sqrt{0.86^2 - 0.73^2}}, 1.0\right) = 0.77 \qquad (6.49)$$

$$N_{b,Rd,1} = \frac{\chi_1 \cdot A \cdot f_y}{\gamma_{M1}} = \frac{0.77 \cdot 13136 \cdot 355}{1.05} = 3404.57 \text{ kN} \qquad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,1}} = \frac{0.00}{3404.57} = 0.00 \leq 1.00 \qquad (6.46) \text{ - OK}$$

Flexural buckling, 2-2 - Part 1-1: 6.3.1

Bar: B.19.1, LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)', x = 0 mm

Class $_N$ = 1, Class $_{M1}$ = 1, Class $_{M2}$ = 1

$$\bar{\lambda}_2 = \frac{L_{cr,2}}{i_2 \cdot \lambda_1} = \frac{6754}{71 \cdot 76.40} = 1.25 \qquad (6.50)$$

$\alpha_2 = 0.49$ (Buckling curve: c)

$$\varphi_2 = 0.5 \left[1 + \alpha_2 \cdot (\bar{\lambda}_2 - 0.2) + \bar{\lambda}_2^2\right] =$$

$$= 0.5 \left[1 + 0.49 \cdot (1.25 - 0.2) + 1.25^2\right] = 1.54$$

$$\chi_2 = \min\left(\frac{1}{\varphi_2 + \sqrt{\varphi_2^2 - \bar{\lambda}_2^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{1.54 + \sqrt{1.54^2 - 1.25^2}}, 1.0\right) = 0.41 \qquad (6.49)$$

$$N_{b,Rd,2} = \frac{\chi_2 \cdot A \cdot f_y}{\gamma_{M1}} = \frac{0.41 \cdot 13136 \cdot 355}{1.05} = 1828.22 \text{ kN} \qquad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,2}} = \frac{0.00}{1828.22} = 0.00 \leq 1.00 \qquad (6.46) \text{ - OK}$$

Torsional-flexural buckling - Part 1-1: 6.3.1

Bar: B.19.1, LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)', x = 0 mm

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$i_0 = \sqrt{i_1^2 + i_2^2 + y_0^2 + z_0^2} = \sqrt{121^2 + 71^2 + 0^2 + 0^2} = 140 \text{ mm}$$

$$N_{cr,1} = \frac{\pi^2 \cdot E \cdot I_1}{L_{cr,1}^2} = \frac{\pi^2 \cdot 210000 \cdot 192702776}{6754^2} = 8755.90 \text{ kN}$$

$$N_{cr,2} = \frac{\pi^2 \cdot E \cdot I_2}{L_{cr,2}^2} = \frac{\pi^2 \cdot 210000 \cdot 65945220}{6754^2} = 2996.37 \text{ kN}$$

$$N_{cr,T} = \frac{1}{i_0^2}\left(G \cdot I_t + \frac{\pi^2 \cdot E \cdot I_w}{L_t^2}\right) =$$

$$= \frac{1}{140^2}\left(80769 \cdot 1.453e{+}06 + \frac{\pi^2 \cdot 210000 \cdot 1.107e{+}12}{6754^2}\right) = 8514.01 \text{ kN}$$

$$i_0^2 (N - N_{cr,1})(N - N_{cr,2})(N - N_{cr,T}) - N^2 y_0^2 (N - N_{cr,2}) - N^2 z_0^2 (N - N_{cr,1}) =$$

$$= 140^2 (N - 8755.90)(N - 2996.37)(N - 8514.01) - N^2 0^2 (N - 2996.37) - N^2 0^2 (N - 8755.90) =$$

$$= 0$$

Smallest root of the above equation related to the torsional-flexural buckling:

$$N_{cr,TF} = 8514.01 \text{ kN}$$

$$N_{cr} = \min(N_{cr,T}, N_{cr,TF}) = \min(8514.01, 8514.01) = 8514.01 \text{ kN}$$

$$\bar{\lambda}_T = \sqrt{\frac{A \cdot f_y}{N_{cr}}} = \sqrt{\frac{13136 \cdot 355}{8514.01}} = 0.74 \quad (6.53)$$

$\alpha_T = 0.49$ (Buckling curve: c)

$$\varphi_T = 0.5\left[1 + \alpha_T \cdot (\bar{\lambda}_T - 0.2) + \bar{\lambda}_T^2\right] =$$

$$= 0.5\left[1 + 0.49 \cdot (0.74 - 0.2) + 0.74^2\right] = 0.91$$

$$\chi_T = \min\left(\frac{1}{\varphi_T + \sqrt{\varphi_T^2 - \bar{\lambda}_T^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{0.91 + \sqrt{0.91^2 - 0.74^2}}, 1.0\right) = 0.70 \quad (6.49)$$

$$N_{b,Rd,T} = \frac{\chi_T \cdot A \cdot f_y}{\gamma_{M1}} = \frac{0.70 \cdot 13136 \cdot 355}{1.05} = 3107.78 \text{ kN} \quad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,T}} = \frac{0.00}{3107.78} = 0.00 \le 1.00 \text{ - OK}$$

Lateral torsional buckling, top flange - Part 1-1: 6.3.2.2

Not relevant

Lateral torsional buckling, bottom flange - Part 1-1: 6.3.2.2

Bar: B.19.1, LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)', x = 0 mm

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$N_{cr,LT} = \frac{\pi^2 \cdot E \cdot I_z}{(k_z \cdot L_{cr})^2} = \frac{\pi^2 \cdot 2.100e+05 \cdot 6.595e+07}{(1.00 \cdot 6754)^2} = 2996.37 \quad kN$$

Loaded on top edge.

$$Z = (C_2 \cdot z_g - C_3 \cdot z_j) = (0.45 \cdot 140 - 0.52 \cdot 0) = 63.00 \quad mm$$

$$M_{cr} = C_1 \cdot N_{cr,LT} \cdot \left\{ \left[\left(\frac{k_z}{k_w}\right)^2 \cdot \frac{I_w}{I_z} + \frac{G \cdot I_t}{N_{cr,LT}} + Z^2 \right]^{0.5} - Z \right\} =$$

$$= 1.13 \cdot 2.996e+06 \cdot \left\{ \left[\left(\frac{1.00}{1.00}\right)^2 \cdot \frac{1.107e+12}{6.595e+07} + \frac{8.077e+04 \cdot 1.453e+06}{2.996e+06} + 63.00^2 \right]^{0.5} - 63.00 \right\} =$$

$$= 615.47 \quad kN\,m$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y \cdot f_y}{M_{cr}}} = \sqrt{\frac{1534434 \cdot 355}{6.155e+08}} = 0.94$$

$\alpha_{LT} = 0.21$ (Buckling curve: a)

$$\varphi_{LT} = 0.5 \left[1 + \alpha_{LT} \cdot (\bar{\lambda}_{LT} - 0.2) + \bar{\lambda}_{LT}^2\right] =$$

$$= 0.5 \left[1 + 0.21 \cdot (0.94 - 0.2) + 0.94^2\right] = 1.02$$

$$\chi_{LT} = \min\left(\frac{1}{\varphi_{LT} + \sqrt{\varphi_{LT}^2 - \bar{\lambda}_{LT}^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{1.02 + \sqrt{1.02^2 - 0.94^2}}, 1.0\right) = 0.71 \qquad (6.56)$$

$$M_{y,b,Rd} = \frac{\chi_{LT} \cdot W_y \cdot f_y}{\gamma_{M1}} = \frac{0.71 \cdot 1534434 \cdot 355}{1.05} = 366.57 \quad kN\,m \qquad (6.55)$$

$$\frac{M_{1,Ed}}{M_{y,b,Rd}} = \frac{0.00}{366.57} = 0.00 \leq 1.00 \qquad (6.54) \quad \text{- OK}$$

Interaction between normal force and bending 1. - Part 1-1: 6.3.3

Not relevant

Interaction between normal force and bending 2. - Part 1-1: 6.3.3

Not relevant

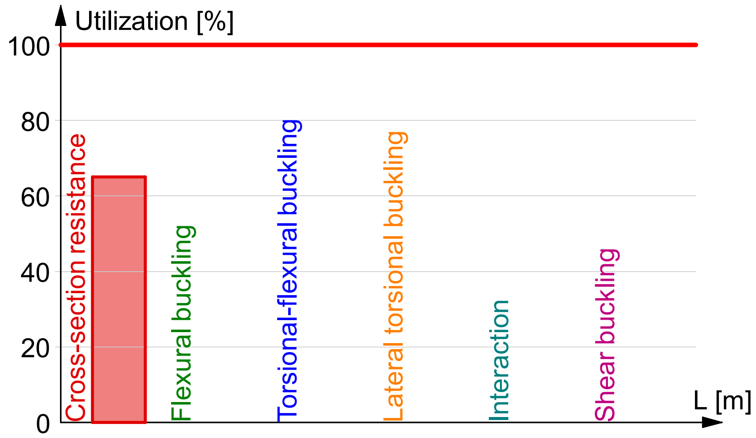
Interaction between normal force and bending, 2nd order - Part 1-1: 6.3.3

Not relevant

Shear buckling - Part 1-5: 5

$$\frac{h_w}{t} = \frac{244}{10} = 23.2 \leq \frac{72}{\eta} \cdot \varepsilon = \frac{72}{1.20} \cdot 0.81 = 48.8 \rightarrow \quad \text{Not relevant}$$

Summary

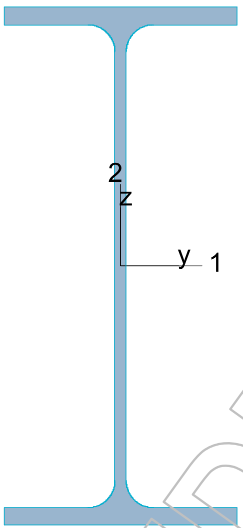


Group IPE400 ..2.floo, Maximum of group members Maximum of load combinations

S 355

E	=	210000	N/mm ^{2}			
G	=	80769	N/mm ^{2}			
$\gamma_{M0,ult}$	=	1.05		$\gamma_{M0,acc/seis}$	=	1.00
$\gamma_{M1,ult}$	=	1.05		$\gamma_{M1,acc/seis}$	=	1.00
$\gamma_{M2,ult}$	=	1.25		$\gamma_{M2,acc/seis}$	=	1.00

IPE 400



P	=	1467	mm	f_y	=	355	N/mm ^{2}
A	=	8446	mm ^{2}	ε	=	0.81	
I_y	=	2.313e+08	mm ^{4}	λ_1	=	76.40	
I_z	=	1.318e+07	mm ^{4}				
I_1	=	2.313e+08	mm ^{4}				
I_2	=	1.318e+07	mm ^{4}				
$W_{pl,1}$	=	1.307e+06	mm ^{3}				
$W_{pl,2}$	=	2.291e+05	mm ^{3}				
$W_{el,min,1}$	=	1.156e+06	mm ^{3}				
$W_{el,min,2}$	=	1.464e+05	mm ^{3}				
i_1	=	165	mm				
i_2	=	39	mm				
I_t	=	5.041e+05	mm ^{4}				
I_w	=	4.829e+11	mm ^{6}				

Shear resistance, 1-1 - Part 1-1: 6.2.6, 6.2.8

Bar: B.33.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 6754 mm

$Class_N = 2, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$V_{1,pl,Rd} = \frac{A_{1,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{5239 \cdot 355}{\sqrt{3} \cdot 1.05} = 1022.56 \quad kN \qquad (6.18)$$

$$V_{1,pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1.25 \left(f_y / \sqrt{3} \right) / \gamma_{M0}}} \cdot V_{1,pl,Rd} =$$

$$= \sqrt{1 - \frac{0.00}{1.25 \left(355 / \sqrt{3} \right) / 1.05}} \cdot 1022.56 = 1022.56 \quad kN \qquad (6.26)$$

$$\frac{V_{1,Ed}}{V_{1,pl,T,Rd}} = \frac{0.00}{1022.56} = 0.00 \le 1.00 \qquad (6.25) \quad \text{- OK}$$

Shear resistance, 2-2 - Part 1-1: 6.2.6, 6.2.8

Bar: B.33.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 6754 mm

$Class_N = 2, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$V_{2,pl,Rd} = \frac{A_{2,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{4269 \cdot 355}{\sqrt{3} \cdot 1.05} = 833.40 \quad kN \qquad (6.18)$$

$$V_{2,pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1.25 \left(f_y / \sqrt{3} \right) / \gamma_{M0}}} \cdot V_{2,pl,Rd} =$$

$$= \sqrt{1 - \frac{0.00}{1.25 \left(355 / \sqrt{3} \right) / 1.05}} \cdot 833.40 = 833.40 \quad kN \qquad (6.26)$$

$$\frac{V_{2,Ed}}{V_{2,pl,T,Rd}} = \frac{176.91}{833.40} = 0.21 \le 1.00 \qquad (6.25) \quad \text{- OK}$$

Torsional resistance - Part 1-1: 6.2.7

Bar: B.38.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 5794 mm

$Class_N = 2, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$\tau_{max,unit} = 44.65 \ \frac{N/mm^2}{kN\,m}$ is calculated by FEM analysis.

$$T_{Rd} = \frac{f_y}{\sqrt{3} \cdot \tau_{max,unit} \cdot \gamma_{M0}} = \frac{355}{\sqrt{3} \cdot 44.65 \cdot 1.05} = 4.37 \quad kN\,m$$

$$\frac{T_{Ed}}{T_{Rd}} = \frac{0.16}{4.37} = 0.04 \le 1.00 \qquad (6.23) \quad \text{- OK}$$

Shear stress - Part 1-1: 6.2.6

Not relevant

Normal stress - Part 1-1: 6.2.1

Not relevant

Normal capacity - Part 1-1: 6.2

Bar: B.40.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 3442 mm

$Class_N = 2, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$V_{1,Ed} = 0.00 \;\; kN \le 0.5 \cdot V_{1,pl,T,Rd} = 0.5 \cdot 1022.56 = 511.28 \;\; kN \rightarrow \rho_1 = 0.00$

$V_{2,Ed} = 1.43 \;\; kN \le 0.5 \cdot V_{2,pl,T,Rd} = 0.5 \cdot 833.40 = 416.70 \;\; kN \rightarrow \rho_1 = 0.00$

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{1,Ed}}{M_{1,Rd}} + \frac{M_{2,Ed}}{M_{2,Rd}} = \frac{0.00}{2855.67} + \frac{283.98}{441.94} + \frac{0.00}{77.47} = 0.64 \le 1.00 \qquad (6.2) \text{ - OK}$$

Flexural buckling, 1-1 - Part 1-1: 6.3.1

Bar: B.33.1, LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)', x = 0 mm

$Class_N = 2, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$\bar{\lambda}_1 = \frac{L_{cr,1}}{i_1 \cdot \lambda_1} = \frac{6754}{165 \cdot 76.40} = 0.53 \qquad (6.50)$$

$\alpha_1 = 0.21 \qquad$ (Buckling curve: a)

$$\varphi_1 = 0.5 \left[1 + \alpha_1 \cdot (\bar{\lambda}_1 - 0.2) + \bar{\lambda}_1^{\,2}\right] =$$

$$= 0.5 \left[1 + 0.21 \cdot (0.53 - 0.2) + 0.53^2\right] = 0.68$$

$$\chi_1 = \min\left(\frac{1}{\varphi_1 + \sqrt{\varphi_1^{\,2} - \bar{\lambda}_1^{\,2}}}, 1.0\right) =$$

$$= \min\left(\frac{1}{0.68 + \sqrt{0.68^2 - 0.53^2}}, 1.0\right) = 0.91 \qquad (6.49)$$

$$N_{b,Rd,1} = \frac{\chi_1 \cdot A \cdot f_y}{\gamma_{M1}} = \frac{0.91 \cdot 8446 \cdot 355}{1.05} = 2608.08 \;\; kN \qquad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,1}} = \frac{0.00}{2608.08} = 0.00 \le 1.00 \qquad (6.46) \text{ - OK}$$

Flexural buckling, 2-2 - Part 1-1: 6.3.1
Bar: B.33.1, LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)',   x = 0 mm

$\text{Class}_N = 2, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$$\bar{\lambda}_2 = \frac{L_{cr,2}}{i_2 \cdot \lambda_1} = \frac{0}{39 \cdot 76.40} = 0.00 \qquad (6.50)$$

$\alpha_2 = 0.34$ (Buckling curve: b)

$$\varphi_2 = 0.5\left[1 + \alpha_2 \cdot (\bar{\lambda}_2 - 0.2) + \bar{\lambda}_2^{\,2}\right] =$$

$$= 0.5\left[1 + 0.34 \cdot (0.00 - 0.2) + 0.00^2\right] = 0.47$$

$$\chi_2 = \min\left(\frac{1}{\varphi_2 + \sqrt{\varphi_2^{\,2} - \bar{\lambda}_2^{\,2}}}, 1.0\right) =$$

$$= \min\left(\frac{1}{0.47 + \sqrt{0.47^2 - 0.00^2}}, 1.0\right) = 1.00 \qquad (6.49)$$

$$N_{b,Rd,2} = \frac{\chi_2 \cdot A \cdot f_y}{\gamma_{M1}} = \frac{1.00 \cdot 8446 \cdot 355}{1.05} = 2855.67 \text{ kN} \qquad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,2}} = \frac{0.00}{2855.67} = 0.00 \leq 1.00 \qquad (6.46) \text{ - OK}$$

Torsional-flexural buckling - Part 1-1: 6.3.1

Bar: B.33.1, LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)', x = 0 mm

$\text{Class}_N = 2, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$$i_0 = \sqrt{i_1^2 + i_2^2 + y_0^2 + z_0^2} = \sqrt{165^2 + 39^2 + 0^2 + 0^2} = 170 \text{ mm}$$

$$N_{cr,1} = \frac{\pi^2 \cdot E \cdot I_1}{L_{cr,1}^2} = \frac{\pi^2 \cdot 210000 \cdot 231283781}{6754^2} = 10508.92 \text{ kN}$$

$$N_{cr,2} = \frac{\pi^2 \cdot E \cdot I_2}{L_{cr,2}^2} = \frac{\pi^2 \cdot 210000 \cdot 13178239}{0^2} = 2855.67 \text{ kN}$$

$$N_{cr,T} = \frac{1}{i_0^2}\left(G \cdot I_t + \frac{\pi^2 \cdot E \cdot I_w}{L_t^2}\right) =$$

$$= \frac{1}{170^2}\left(80769 \cdot 5.041e{+}05 + \frac{\pi^2 \cdot 210000 \cdot 4.829e{+}11}{6754^2}\right) = 2164.89 \text{ kN}$$

$$i_0^2 (N - N_{cr,1})(N - N_{cr,2})(N - N_{cr,T}) - N^2 y_0^2 (N - N_{cr,2}) - N^2 z_0^2 (N - N_{cr,1}) =$$

$$= 170^2 (N - 10508.92)(N - 2855.67)(N - 2164.89) - N^2 0^2 (N - 2855.67) - N^2 0^2 (N - 10508.92) =$$

$$= 0$$

Smallest root of the above equation related to the torsional-flexural buckling:

$$N_{cr,TF} = 2164.89 \text{ kN}$$

$$N_{cr} = \min(N_{cr,T}, N_{cr,TF}) = \min(2164.89, 2164.89) = 2164.89 \text{ kN}$$

$$\bar{\lambda}_T = \sqrt{\frac{A \cdot f_y}{N_{cr}}} = \sqrt{\frac{8446 \cdot 355}{2164.89}} = 1.18 \qquad (6.53)$$

$\alpha_T = 0.34$ (Buckling curve: b)

$$\varphi_T = 0.5\left[1 + \alpha_T \cdot (\bar{\lambda}_T - 0.2) + \bar{\lambda}_T^2\right] =$$

$$= 0.5\left[1 + 0.34 \cdot (1.18 - 0.2) + 1.18^2\right] = 1.36$$

$$\chi_T = \min\left(\frac{1}{\varphi_T + \sqrt{\varphi_T^2 - \bar{\lambda}_T^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{1.36 + \sqrt{1.36^2 - 1.18^2}}, 1.0\right) = 0.49 \qquad (6.49)$$

$$N_{b,Rd,T} = \frac{\chi_T \cdot A \cdot f_y}{\gamma_{M1}} = \frac{0.49 \cdot 8446 \cdot 355}{1.05} = 1401.66 \text{ kN} \qquad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,T}} = \frac{0.00}{1401.66} = 0.00 \le 1.00 \text{ - OK}$$

Lateral torsional buckling, top flange - Part 1-1: 6.3.2.2

Not relevant

Lateral torsional buckling, bottom flange - Part 1-1: 6.3.2.2

Bar: B.33.1, LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)', x = 0 mm

$\text{Class}_{N} = 2, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$$N_{cr,LT} = \frac{\pi^2 \cdot E \cdot I_z}{(k_z \cdot L_{cr})^2} = \frac{\pi^2 \cdot 2.100e{+}05 \cdot 1.318e{+}07}{(1.00 \cdot 6754)^2} = 598.78 \quad kN$$

Loaded on top edge.

$$Z = (C_2 \cdot z_g - C_3 \cdot z_j) = (0.45 \cdot 200 - 0.52 \cdot 0) = 90.00 \quad mm$$

$$M_{cr} = C_1 \cdot N_{cr,LT} \cdot \left\{ \left[\left(\frac{k_z}{k_w}\right)^2 \cdot \frac{I_w}{I_z} + \frac{G \cdot I_t}{N_{cr,LT}} + Z^2 \right]^{0.5} - Z \right\} =$$

$$= 1.13 \cdot 5.988e{+}05 \cdot \left\{ \left[\left(\frac{1.00}{1.00}\right)^2 \cdot \frac{4.829e{+}11}{1.318e{+}07} + \frac{8.077e{+}04 \cdot 5.041e{+}05}{5.988e{+}05} + 90.00^2 \right]^{0.5} - 90.00 \right\} =$$

$$= 166.30 \quad kN\,m$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y \cdot f_y}{M_{cr}}} = \sqrt{\frac{1307150 \cdot 355}{1.663e{+}08}} = 1.67$$

$\alpha_{LT} = 0.34$ (Buckling curve: b)

$$\varphi_{LT} = 0.5 \left[1 + \alpha_{LT} \cdot (\bar{\lambda}_{LT} - 0.2) + \bar{\lambda}_{LT}^2\right] =$$

$$= 0.5 \left[1 + 0.34 \cdot (1.67 - 0.2) + 1.67^2\right] = 2.15$$

$$\chi_{LT} = \min\left(\frac{1}{\varphi_{LT} + \sqrt{\varphi_{LT}^2 - \bar{\lambda}_{LT}^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{2.15 + \sqrt{2.15^2 - 1.67^2}}, 1.0\right) = 0.29 \qquad (6.56)$$

$$M_{y,b,Rd} = \frac{\chi_{LT} \cdot W_y \cdot f_y}{\gamma_{M1}} = \frac{0.29 \cdot 1307150 \cdot 355}{1.05} = 126.59 \quad kN\,m \qquad (6.55)$$

$$\frac{M_{1,Ed}}{M_{y,b,Rd}} = \frac{0.00}{126.59} = 0.00 \le 1.00 \qquad (6.54) \quad \text{- OK}$$

Interaction between normal force and bending 1. - Part 1-1: 6.3.3

Not relevant

Interaction between normal force and bending 2. - Part 1-1: 6.3.3

Not relevant

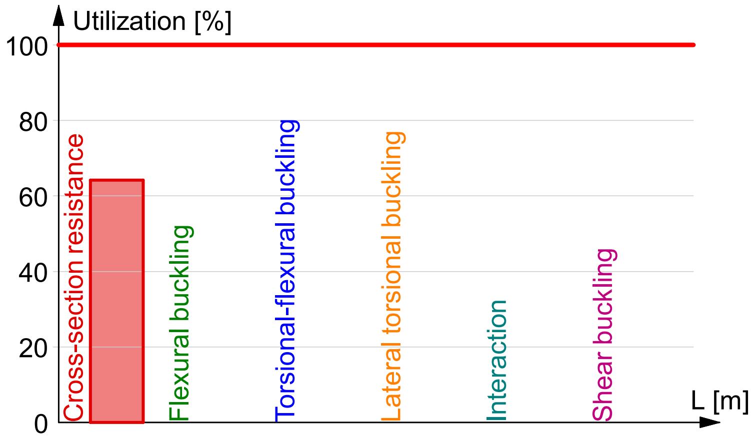
Interaction between normal force and bending, 2nd order - Part 1-1: 6.3.3

Not relevant

Shear buckling - Part 1-5: 5

$$\frac{h_w}{t} = \frac{373}{9} = 43.4 \le \frac{72}{\eta} \cdot \varepsilon = \frac{72}{1.20} \cdot 0.81 = 48.8 \rightarrow \quad \text{Not relevant}$$

Summary

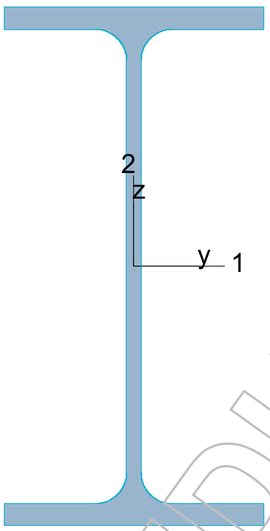


Group IPE200 ..2.floo, Maximum of group members Maximum of load combinations

S 355

E	=	210000	N/mm ^{2}				
G	=	80769	N/mm ^{2}				
$\gamma_{M0,ult}$	=	1.05		$\gamma_{M0,acc/seis}$	=	1.00	
$\gamma_{M1,ult}$	=	1.05		$\gamma_{M1,acc/seis}$	=	1.00	
$\gamma_{M2,ult}$	=	1.25		$\gamma_{M2,acc/seis}$	=	1.00	

IPE 200



P	=	768	mm	f_y	=	355	N/mm ^{2}
A	=	2848	mm ^{2}	ε	=	0.81	
I_y	=	1.943e+07	mm ^{4}	λ_1	=	76.40	
I_z	=	1.424e+06	mm ^{4}				
I_1	=	1.943e+07	mm ^{4}				
I_2	=	1.424e+06	mm ^{4}				
$W_{pl,1}$	=	2.206e+05	mm ^{3}				
$W_{pl,2}$	=	4.464e+04	mm ^{3}				
$W_{el,min,1}$	=	1.943e+05	mm ^{3}				
$W_{el,min,2}$	=	2.847e+04	mm ^{3}				
i_1	=	83	mm				
i_2	=	22	mm				
I_t	=	6.846e+04	mm ^{4}				
I_w	=	1.275e+10	mm ^{6}				

Shear resistance, 1-1 - Part 1-1: 6.2.6, 6.2.8
Bar: B.41.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 2626 mm

$Class_N = 2, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$V_{1,pl,Rd} = \frac{A_{1,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{1824 \cdot 355}{\sqrt{3} \cdot 1.05} = 355.97 \quad kN \qquad (6.18)$$

$$V_{1,pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1.25 \left(f_y / \sqrt{3} \right) / \gamma_{M0}}} \cdot V_{1,pl,Rd} =$$

$$= \sqrt{1 - \frac{0.00}{1.25 \left(355 / \sqrt{3} \right) / 1.05}} \cdot 355.97 = 355.97 \quad kN \qquad (6.26)$$

$$\frac{V_{1,Ed}}{V_{1,pl,T,Rd}} = \frac{0.00}{355.97} = 0.00 \le 1.00 \qquad (6.25) \quad \text{- OK}$$

Shear resistance, 2-2 - Part 1-1: 6.2.6, 6.2.8
Bar: B.41.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 2626 mm

$Class_N = 2, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$V_{2,pl,Rd} = \frac{A_{2,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{1400 \cdot 355}{\sqrt{3} \cdot 1.05} = 273.28 \quad kN \qquad (6.18)$$

$$V_{2,pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1.25 \left(f_y / \sqrt{3} \right) / \gamma_{M0}}} \cdot V_{2,pl,Rd} =$$

$$= \sqrt{1 - \frac{0.00}{1.25 \left(355 / \sqrt{3} \right) / 1.05}} \cdot 273.28 = 273.28 \quad kN \qquad (6.26)$$

$$\frac{V_{2,Ed}}{V_{2,pl,T,Rd}} = \frac{64.53}{273.28} = 0.24 \le 1.00 \qquad (6.25) \quad \text{- OK}$$

Torsional resistance - Part 1-1: 6.2.7
Bar: B.37.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 2620 mm

$Class_N = 2, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$\tau_{max,unit} = 203.09 \ \frac{N/mm^2}{kN\,m}$ is calculated by FEM analysis.

$$T_{Rd} = \frac{f_y}{\sqrt{3} \cdot \tau_{max,unit} \cdot \gamma_{M0}} = \frac{355}{\sqrt{3} \cdot 203.09 \cdot 1.05} = 0.96 \quad kN\,m$$

$$\frac{T_{Ed}}{T_{Rd}} = \frac{0.00}{0.96} = 0.00 \le 1.00 \qquad (6.23) \quad \text{- OK}$$

Shear stress - Part 1-1: 6.2.6
Not relevant

Normal stress - Part 1-1: 6.2.1
Not relevant

Normal capacity - Part 1-1: 6.2

Bar: B.32.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 1264 mm

$\text{Class}_N = 2, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$V_{1,Ed} = 0.00 \text{ kN} \leq 0.5 \cdot V_{1,pl,T,Rd} = 0.5 \cdot 355.97 = 177.98 \text{ kN} \rightarrow \rho_1 = 0.00$

$V_{2,Ed} = 0.69 \text{ kN} \leq 0.5 \cdot V_{2,pl,T,Rd} = 0.5 \cdot 273.28 = 136.64 \text{ kN} \rightarrow \rho_1 = 0.00$

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{1,Ed}}{M_{1,Rd}} + \frac{M_{2,Ed}}{M_{2,Rd}} = \frac{0.00}{963.03} + \frac{28.60}{74.60} + \frac{0.00}{15.09} = 0.38 \leq 1.00 \quad (6.2) \text{ - OK}$$

Flexural buckling, 1-1 - Part 1-1: 6.3.1

Bar: B.32.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 4 mm

$\text{Class}_N = 2, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$$\bar{\lambda}_1 = \frac{L_{cr,1}}{i_1 \cdot \lambda_1} = \frac{4}{83 \cdot 76.40} = 0.00 \quad (6.50)$$

$\alpha_1 = 0.21 \quad$ (Buckling curve: a)

$$\varphi_1 = 0.5 \left[1 + \alpha_1 \cdot (\bar{\lambda}_1 - 0.2) + \bar{\lambda}_1^2\right] =$$

$$= 0.5 \left[1 + 0.21 \cdot (0.00 - 0.2) + 0.00^2\right] = 0.48$$

$$\chi_1 = \min\left(\frac{1}{\varphi_1 + \sqrt{\varphi_1^2 - \bar{\lambda}_1^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{0.48 + \sqrt{0.48^2 - 0.00^2}}, 1.0\right) = 1.00 \quad (6.49)$$

$$N_{b,Rd,1} = \frac{\chi_1 \cdot A \cdot f_y}{\gamma_{M1}} = \frac{1.00 \cdot 2848 \cdot 355}{1.05} = 963.03 \text{ kN} \quad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,1}} = \frac{0.00}{963.03} = 0.00 \leq 1.00 \quad (6.46) \text{ - OK}$$

Flexural buckling, 2-2 - Part 1-1: 6.3.1

Bar: B.32.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 4 mm

Class $_N$ = 2, Class $_{M1}$ = 1, Class $_{M2}$ = 1

$$\bar{\lambda}_2 = \frac{L_{cr,2}}{i_2 \cdot \lambda_1} = \frac{0}{22 \cdot 76.40} = 0.00 \qquad (6.50)$$

$\alpha_2 = 0.34$ (Buckling curve: b)

$$\varphi_2 = 0.5\left[1 + \alpha_2 \cdot (\bar{\lambda}_2 - 0.2) + \bar{\lambda}_2^2\right] =$$

$$= 0.5\left[1 + 0.34 \cdot (0.00 - 0.2) + 0.00^2\right] = 0.47$$

$$\chi_2 = \min\left(\frac{1}{\varphi_2 + \sqrt{\varphi_2^2 - \bar{\lambda}_2^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{0.47 + \sqrt{0.47^2 - 0.00^2}}, 1.0\right) = 1.00 \qquad (6.49)$$

$$N_{b,Rd,2} = \frac{\chi_2 \cdot A \cdot f_y}{\gamma_{M1}} = \frac{1.00 \cdot 2848 \cdot 355}{1.05} = 963.03 \text{ kN} \qquad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,2}} = \frac{0.00}{963.03} = 0.00 \leq 1.00 \qquad (6.46) \text{ - OK}$$

Torsional-flexural buckling - Part 1-1: 6.3.1

Bar: B.32.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 4 mm

$Class_N = 2$, $Class_{M1} = 1$, $Class_{M2} = 1$

$$i_0 = \sqrt{i_1^2 + i_2^2 + y_0^2 + z_0^2} = \sqrt{83^2 + 22^2 + 0^2 + 0^2} = 86 \text{ mm}$$

$$N_{cr,1} = \frac{\pi^2 \cdot E \cdot I_1}{L_{cr,1}^2} = \frac{\pi^2 \cdot 210000 \cdot 19431689}{4^2} = 2512363122.24 \text{ kN}$$

$$N_{cr,2} = \frac{\pi^2 \cdot E \cdot I_2}{L_{cr,2}^2} = \frac{\pi^2 \cdot 210000 \cdot 1423683}{0^2} = 963.03 \text{ kN}$$

$$N_{cr,T} = \frac{1}{i_0^2}\left(G \cdot I_t + \frac{\pi^2 \cdot E \cdot I_w}{L_t^2}\right) =$$

$$= \frac{1}{86^2}\left(80769 \cdot 6.846e{+}04 + \frac{\pi^2 \cdot 210000 \cdot 1.275e{+}10}{4^2}\right) = 225080249.35 \text{ kN}$$

$$i_0^2 \,(N - N_{cr,1})\,(N - N_{cr,2})\,(N - N_{cr,T}) - N^2 y_0^2 \,(N - N_{cr,2}) - N^2 z_0^2 \,(N - N_{cr,1}) =$$

$$= 86^2 \,(N - 2512363122.24)\,(N - 963.03)\,(N - 225080249.35) - N^2\, 0^2 \,(N - 963.03) - N^2\, 0^2 \,(N - 25123$$

$$= 0$$

Smallest root of the above equation related to the torsional-flexural buckling:

$$N_{cr,TF} = 225080249.35 \text{ kN}$$

$$N_{cr} = \min(N_{cr,T}, N_{cr,TF}) = \min(225080249.35, 225080249.35) = 225080249.35 \text{ kN}$$

$$\bar{\lambda}_T = \sqrt{\frac{A \cdot f_y}{N_{cr}}} = \sqrt{\frac{2848 \cdot 355}{225080249.35}} = 0.00 \qquad (6.53)$$

$\alpha_T = 0.34$ (Buckling curve: b)

$$\varphi_T = 0.5\left[1 + \alpha_T \cdot (\bar{\lambda}_T - 0.2) + \bar{\lambda}_T^2\right] =$$

$$= 0.5\left[1 + 0.34 \cdot (0.00 - 0.2) + 0.00^2\right] = 0.47$$

$$\chi_T = \min\left(\frac{1}{\varphi_T + \sqrt{\varphi_T^2 - \bar{\lambda}_T^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{0.47 + \sqrt{0.47^2 - 0.00^2}}, 1.0\right) = 1.00 \qquad (6.49)$$

$$N_{b,Rd,T} = \frac{\chi_T \cdot A \cdot f_y}{\gamma_{M1}} = \frac{1.00 \cdot 2848 \cdot 355}{1.05} = 963.03 \text{ kN} \qquad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,T}} = \frac{0.00}{963.03} = 0.00 \le 1.00 \text{ - OK}$$

Lateral torsional buckling, top flange - Part 1-1: 6.3.2.2

Bar: B.37.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 1480 mm

$Class_N = 2, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$N_{cr,LT} = \frac{\pi^2 \cdot E \cdot I_z}{(k_z \cdot L_{cr})^2} = \frac{\pi^2 \cdot 2.100e+05 \cdot 1.424e+06}{(1.00 \cdot 1520)^2} = 1277.16 \quad kN$$

Loaded on top edge.

$$Z = (C_2 \cdot z_g - C_3 \cdot z_j) = (0.16 \cdot 100 - 0.75 \cdot 0) = 16.37 \quad mm$$

$$M_{cr} = C_1 \cdot N_{cr,LT} \cdot \left\{ \left[\left(\frac{k_z}{k_w} \right)^2 \cdot \frac{I_w}{I_z} + \frac{G \cdot I_t}{N_{cr,LT}} + Z^2 \right]^{0.5} - Z \right\} =$$

$$= 1.21 \cdot 1.277e+06 \cdot \left\{ \left[\left(\frac{1.00}{1.00} \right)^2 \cdot \frac{1.275e+10}{1.424e+06} + \frac{8.077e+04 \cdot 6.846e+04}{1.277e+06} + 16.37^2 \right]^{0.5} - 16.37 \right\} =$$

$$= 154.58 \quad kN\,m$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y \cdot f_y}{M_{cr}}} = \sqrt{\frac{220638 \cdot 355}{1.546e+08}} = 0.71$$

$\alpha_{LT} = 0.21$ (Buckling curve: a)

$$\varphi_{LT} = 0.5 \left[1 + \alpha_{LT} \cdot (\bar{\lambda}_{LT} - 0.2) + \bar{\lambda}_{LT}^2 \right] =$$

$$= 0.5 \left[1 + 0.21 \cdot (0.71 - 0.2) + 0.71^2 \right] = 0.81$$

$$\chi_{LT} = \min\left(\frac{1}{\varphi_{LT} + \sqrt{\varphi_{LT}^2 - \bar{\lambda}_{LT}^2}}, 1.0 \right) =$$

$$= \min\left(\frac{1}{0.81 + \sqrt{0.81^2 - 0.71^2}}, 1.0 \right) = 0.84 \qquad (6.56)$$

$$M_{y,b,Rd} = \frac{\chi_{LT} \cdot W_y \cdot f_y}{\gamma_{M1}} = \frac{0.84 \cdot 220638 \cdot 355}{1.05} = 62.82 \quad kN\,m \qquad (6.55)$$

$$\frac{M_{1,Ed}}{M_{y,b,Rd}} = \frac{22.54}{62.82} = 0.36 \leq 1.00 \qquad (6.54) \quad - OK$$

Lateral torsional buckling, bottom flange - Part 1-1: 6.3.2.2

Bar: B.14.1, LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)', x = 0 mm

$Class_{N} = 2, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$N_{cr,LT} = \frac{\pi^2 \cdot E \cdot I_z}{(k_z \cdot L_{cr})^2} = \frac{\pi^2 \cdot 2.100e{+}05 \cdot 1.424e{+}06}{(1.00 \cdot 2409)^2} = 508.46 \text{ kN}$$

Loaded on top edge.

$$Z = (C_2 \cdot z_g - C_3 \cdot z_j) = (0.45 \cdot 100 - 0.52 \cdot 0) = 45.00 \text{ mm}$$

$$M_{cr} = C_1 \cdot N_{cr,LT} \cdot \left\{ \left[\left(\frac{k_z}{k_w}\right)^2 \cdot \frac{I_w}{I_z} + \frac{G \cdot I_t}{N_{cr,LT}} + Z^2 \right]^{0.5} - Z \right\} =$$

$$= 1.13 \cdot 5.085e{+}05 \cdot \left\{ \left[\left(\frac{1.00}{1.00}\right)^2 \cdot \frac{1.275e{+}10}{1.424e{+}06} + \frac{8.077e{+}04 \cdot 6.846e{+}04}{5.085e{+}05} + 45.00^2 \right]^{0.5} - 45.00 \right\} =$$

$$= 59.08 \text{ kN m}$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y \cdot f_y}{M_{cr}}} = \sqrt{\frac{220638 \cdot 355}{5.908e{+}07}} = 1.15$$

$\alpha_{LT} = 0.21$ (Buckling curve: a)

$$\varphi_{LT} = 0.5 \left[1 + \alpha_{LT} \cdot (\bar{\lambda}_{LT} - 0.2) + \bar{\lambda}_{LT}^2 \right] =$$

$$= 0.5 \left[1 + 0.21 \cdot (1.15 - 0.2) + 1.15^2 \right] = 1.26$$

$$\chi_{LT} = \min\left(\frac{1}{\varphi_{LT} + \sqrt{\varphi_{LT}^2 - \bar{\lambda}_{LT}^2}}, 1.0 \right) =$$

$$= \min\left(\frac{1}{1.26 + \sqrt{1.26^2 - 1.15^2}}, 1.0 \right) = 0.56 \qquad (6.56)$$

$$M_{y,b,Rd} = \frac{\chi_{LT} \cdot W_y \cdot f_y}{\gamma_{M1}} = \frac{0.56 \cdot 220638 \cdot 355}{1.05} = 41.88 \text{ kN m} \qquad (6.55)$$

$$\frac{M_{1,Ed}}{M_{y,b,Rd}} = \frac{0.00}{41.88} = 0.00 \le 1.00 \qquad (6.54) \text{ - OK}$$

Interaction between normal force and bending 1. - Part 1-1: 6.3.3

Bar: B.37.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 1480 mm

Class $_N$ = 2, Class $_{M1}$ = 1, Class $_{M2}$ = 1

k_{ij} factors are calculated according to Method 1

C_{my} = 1.00 C_{yy} = 1.00

C_{mz} = 1.00 C_{yz} = 0.83

C_{mLT} = 1.00 C_{zy} = 1.00

C_{zz} = 0.70

$M_{2,Rk} = f_y \cdot W_{pl,2} = 355 \cdot 44640 = 15.85$ kN m

$$\frac{N_{Ed}^{comp}}{N_{b,Rd,1}} + k_{11} \cdot \frac{M_{1,Ed}}{M_{y,b,Rd}} + k_{12} \cdot \frac{M_{2,Ed}}{\frac{M_{2,Rk}}{\gamma_{M1}}} =$$

$$= \frac{0.00}{954.34} + 1.00 \cdot \frac{22.54}{62.82} + 0.83 \cdot \frac{0.00}{\frac{15.85}{1.05}} = 0.36 \le 1.00 \qquad (6.61) \text{ - OK}$$

Interaction between normal force and bending 2. - Part 1-1: 6.3.3

Bar: B.37.1, LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W', x = 1480 mm

Class $_N$ = 2, Class $_{M1}$ = 1, Class $_{M2}$ = 1

k_{ij} factors are calculated according to Method 1

C_{my} = 1.00 C_{yy} = 1.00

C_{mz} = 1.00 C_{yz} = 0.83

C_{mLT} = 1.00 C_{zy} = 1.00

C_{zz} = 0.70

$M_{2,Rk} = f_y \cdot W_{pl,2} = 355 \cdot 44640 = 15.85$ kN m

$$\frac{N_{Ed}^{comp}}{N_{b,Rd,2}} + k_{21} \cdot \frac{M_{1,Ed}}{M_{y,b,Rd}} + k_{22} \cdot \frac{M_{2,Ed}}{\frac{M_{2,Rk}}{\gamma_{M1}}} =$$

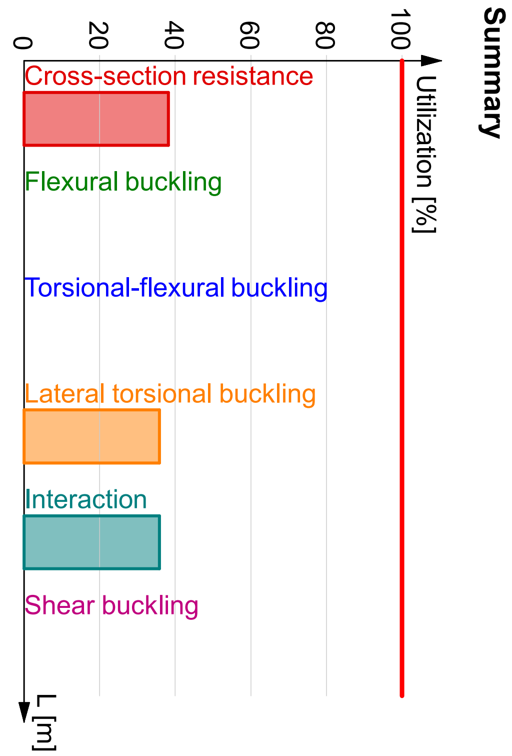
$$= \frac{0.00}{642.97} + 0.52 \cdot \frac{22.54}{62.82} + 1.44 \cdot \frac{0.00}{\frac{15.85}{1.05}} = 0.19 \le 1.00 \qquad (6.62) \text{ - OK}$$

Interaction between normal force and bending, 2nd order - Part 1-1: 6.3.3

Not relevant

Shear buckling - Part 1-5: 5

$$\frac{h_w}{t} = \frac{183}{6} = 32.7 \le \frac{72}{\eta} \cdot \varepsilon = \frac{72}{1.20} \cdot 0.81 = 48.8 \rightarrow \quad \text{Not relevant}$$


Summary
Utilization [%]
0
20
40
60
80
100
Cross-section resistance
Flexural buckling
Torsional-flexural buckling
Lateral torsional buckling
Interaction
Shear buckling
L [m]

4 Timber design results

4.1 Utilization ratio

Max. of load combinations, Bar, Utilization

Member	Section	Status	Maximum	Combination
[-]	[-]	[-]	[%]	[-]
B.1.1	Glulam 140x540	Real	25	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.7.1	Glulam 115x180	Real	34	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.8.1	Glulam 115x180	Real	35	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.9.1	Glulam 115x180	Real	31	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.10.1	Glulam 115x180	Real	37	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.11.1	Glulam 115x180	Real	37	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.12.1	Glulam 115x180	Real	31	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.13.1	Glulam 115x180	Real	34	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.15.1	Glulam 140x540	Real	47	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.26.1	Glulam 140x540	Real	49	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.27.1	Glulam 140x540	Real	17	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.28.1	Glulam 140x540	Real	66	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.30.1	Glulam 140x540	Real	51	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.46.1	Glulam 140x540	Real	23	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.47.1	Glulam 140x540	Real	48	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.48.1	Glulam 140x540	Real	27	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.49.1	Glulam 115x180	Real	33	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.50.1	Glulam 115x180	Real	33	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.51.1	Glulam 115x180	Real	35	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.53.1	Glulam 140x540	Real	38	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.61.1	Glulam 115x405	Real	31	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.71.1	Glulam 140x540	Real	38	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
B.72.1	Glulam 140x495	Real	76	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.73.1	Glulam 140x495	Real	7	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.74.1	Glulam 140x495	Real	55	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.75.1	Glulam 140x495	Real	64	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.76.1	Glulam 140x495	Real	52	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.77.1	Glulam 140x495	Real	63	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.78.1	Glulam 115x405	Real	15	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.79.1	Glulam 115x405	Real	15	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.80.1	Glulam 115x405	Real	18	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.81.1	Glulam 115x405	Real	31	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.82.1	Glulam 115x405	Real	28	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.83.1	Glulam 115x405	Real	32	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.84.1	Glulam 115x405	Real	15	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.85.1	Glulam 115x405	Real	16	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
B.86.1	Glulam 115x405	Real	18	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.13.1	Glulam 115x115	Real	40	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.14.1	Glulam 115x115	Real	38	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.15.1	Glulam 115x115	Real	42	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.16.1	Glulam 115x115	Real	34	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.17.1	Glulam 115x115	Real	17	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.18.1	Glulam 115x115	Real	25	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.19.1	Glulam 115x115	Real	34	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.20.1	Glulam 140x225	Real	34	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.21.1	Glulam 140x225	Real	11	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.29.1	Glulam 115x115	Real	6	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.30.1	Glulam 115x115	Real	6	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...

Member	Section	Status	Maximum	Combination
[-]	[-]	[-]	[%]	[-]
C.31.1	Glulam 140x225	Real	30	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.32.1	Glulam 115x115	Real	8	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.33.1	Glulam 115x115	Real	6	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.34.1	Glulam 115x115	Real	8	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.35.1	Glulam 115x115	Real	9	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.36.1	Glulam 115x115	Real	8	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.37.1	Glulam 115x115	Real	7	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.38.1	Glulam 115x115	Real	8	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.39.1	Glulam 115x115	Real	8	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.40.1	Glulam 115x115	Real	7	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.41.1	Glulam 115x115	Real	6	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.42.1	Glulam 115x115	Real	8	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.43.1	Glulam 115x115	Real	8	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.44.1	Glulam 115x115	Real	8	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.45.1	Glulam 140x225	Real	14	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.48.1	Glulam 115x115	Real	7	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.49.1	Glulam 115x115	Real	31	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.58.1	Glulam 140x225	Real	40	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.59.1	Glulam 140x225	Real	19	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.67.1	Glulam 115x115	Real	23	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.68.1	Glulam 140x225	Real	60	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.69.1	Glulam 140x225	Real	30	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.70.1	Glulam 115x115	Real	13	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.71.1	Glulam 115x115	Real	20	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.72.1	Glulam 115x115	Real	22	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.73.1	Glulam 115x115	Real	20	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.74.1	Glulam 115x115	Real	39	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.75.1	Glulam 115x115	Real	27	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.76.1	Glulam 115x115	Real	24	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.77.1	Glulam 115x115	Real	30	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.78.1	Glulam 115x115	Real	20	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.79.1	Glulam 115x115	Real	14	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.80.1	Glulam 115x115	Real	22	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.81.1	Glulam 115x115	Real	20	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.82.1	Glulam 115x115	Real	33	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.83.1	Glulam 115x115	Real	32	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.84.1	Glulam 140x225	Real	59	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.85.1	Glulam 140x225	Real	33	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.86.1	Glulam 115x115	Real	9	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.87.1	Glulam 115x115	Real	26	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.88.1	Glulam 115x115	Real	26	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.89.1	Glulam 115x115	Real	8	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.90.1	Glulam 115x115	Real	7	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.91.1	Glulam 115x115	Real	8	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.92.1	Glulam 115x115	Real	6	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.93.1	Glulam 115x115	Real	39	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.94.1	Glulam 115x115	Real	21	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.95.1	Glulam 115x115	Real	8	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.96.1	Glulam 115x115	Real	6	0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*...
C.97.1	Glulam 115x115	Real	38	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.98.1	Glulam 115x115	Real	20	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...
C.99.1	Glulam 115x115	Real	13	Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P...

Group	Applied profile	Status	Max.	Min.	Note
[-]		[-]	[%]	[%]	[-]
GLT 115x115	Glulam 115x115	Real	42	6	OK
GLT 115x180	Glulam 115x180	Real	37	31	OK
GLT 115x405	Glulam 115x405	Real	32	15	OK
GLT 140x225	Glulam 140x225	Real	60	11	OK
GLT 140x495	Glulam 140x495	Real	76	7	OK
GLT 140x540	Glulam 140x540	Real	66	17	OK

4.2 Detail calculations

Group GLT 140x540, B.71.1
Maximum of load combinations

GL 30c

(Glued laminated), Service class 2

$E_{0,05}$ = 10800 N/mm^2

$G_{0,05}$ = 540 N/mm^2

γ_M = 1.15

$\gamma_{M,acc./seis.}$ = 1.00

k_{sys} = 1.00

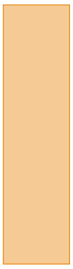
$f_{t,90,k}$ = 0.50 N/mm^2

$f_{c,0,k}$ = 24.50 N/mm^2

$f_{c,90,k}$ = 2.50 N/mm^2

$f_{v,k}$ = 3.50 N/mm^2

Glulam 140x540



A = 75600 mm^2

W_1 = 6.804e+06 mm^3

W_2 = 1.764e+06 mm^3

i_1 = 156 mm

i_2 = 40 mm

I_2 = 1.235e+08 mm^4

I_t = 4.132e+08 mm^4

$f_{t,0,k}$ = 19.71 N/mm^2

$f_{m,1,k}$ = 30.32 N/mm^2

$f_{m,2,k}$ = 33.00 N/mm^2

Combined bending and axial tension - 6.2.3

LC: '0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W', k_{mod} =

$$\frac{\sigma_{t,0,d}}{f_{t,0,d}} + \frac{\sigma_{m,1,d}}{f_{m,1,d}} + k_m \frac{\sigma_{m,2,d}}{f_{m,2,d}} = \frac{0.01}{18.85} + \frac{8.91}{29.00} + 0.70\,\frac{0.00}{31.57} = 0.31 \leq 1.00 \quad (6.17) \text{ - OK}$$

$$\frac{\sigma_{t,0,d}}{f_{t,0,d}} + k_m \frac{\sigma_{m,1,d}}{f_{m,1,d}} + \frac{\sigma_{m,2,d}}{f_{m,2,d}} = \frac{0.01}{18.85} + 0.70\,\frac{8.91}{29.00} + \frac{0.00}{31.57} = 0.22 \leq 1.00 \quad (6.18) \text{ - OK}$$

Combined bending and axial compression - 6.1.4, 6.2.4

LC: '0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W', k_{mod} =

$\sigma_{c,0,d} = 0.00 \ N/mm^2 \leq f_{c,0,d} = 23.43 \ N/mm^2$ (6.2) - OK

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + \frac{\sigma_{m,1,d}}{f_{m,1,d}} + k_m \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \left(\frac{0.00}{23.43}\right)^2 + \frac{9.38}{29.00} + 0.70 \ \frac{0.00}{31.57} = 0.32 \leq 1.00$$ (6.19) - OK

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + k_m \frac{\sigma_{m,1,d}}{f_{m,1,d}} + \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \left(\frac{0.00}{23.43}\right)^2 + 0.70 \ \frac{9.38}{29.00} + \frac{0.00}{31.57} = 0.23 \leq 1.00$$ (6.20) - OK

Combined shear and torsion - 6.1.7, 6.1.8

LC: '0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W', k_{mod} =

$\tau_d = 1.28 \ N/mm^2 \leq f_{v,d} = 3.35 \ N/mm^2$ (6.13) - OK

Flexural buckling around axis 1 - 6.3.2

LC: '0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W', k_{mod} =

$\beta_c = 0.1$ (6.29)

$$\lambda_1 = \frac{l_0}{i_1} = \frac{4690}{156} = 30.09$$

$$\lambda_{rel,1} = \frac{\lambda_1}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{30.09}{\pi}\sqrt{\frac{24.50}{10800}} = 0.456$$ (6.21)

$$k_1 = 0.5\left(1 + \beta_c\left(\lambda_{rel,1} - 0.3\right) + \lambda_{rel,1}^2\right) =$$

$$= 0.5\left(1 + 0.1\left(0.456 - 0.3\right) + 0.456^2\right) = 0.612$$ (6.27)

$$k_{c,1} = \frac{1}{k_1 + \sqrt{k_1^2 - \lambda_{rel,1}^2}} = \frac{1}{0.612 + \sqrt{0.612^2 - 0.456^2}} = 0.981$$ (6.25)

$$\frac{\sigma_{c,0,d}}{k_{c,1} \cdot f_{c,0,d}} + \frac{\sigma_{m,1,d}}{f_{m,1,d}} + k_m \cdot \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \frac{0.00}{0.981 \cdot 23.43} + \frac{9.38}{29.00} + 0.70 \cdot \frac{0.00}{31.57} = 0.32 \leq 1.00$$ (6.23) - OK

Flexural buckling around axis 2 - 6.3.2

LC: '0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W', k_{mod} =

$\beta_c = 0.1 \qquad (6.29)$

$$\lambda_2 = \frac{l_0}{i_2} = \frac{4690}{40} = 116.05$$

$$\lambda_{rel,2} = \frac{\lambda_2}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{116.05}{\pi}\sqrt{\frac{24.50}{10800}} = 1.759 \qquad (6.22)$$

$$k_2 = 0.5\left(1 + \beta_c\left(\lambda_{rel,2} - 0.3\right) + \lambda_{rel,2}^{\ 2}\right) =$$

$$= 0.5\left(1 + 0.1\left(1.759 - 0.3\right) + 1.759^{\ 2}\right) = 2.121 \qquad (6.28)$$

$$k_{c,2} = \frac{1}{k_2 + \sqrt{k_2^{\ 2} - \lambda_{rel,2}^{\ 2}}} = \frac{1}{2.121 + \sqrt{2.121^{\ 2} - 1.759^{\ 2}}} = 0.303 \qquad (6.26)$$

$$\frac{\sigma_{c,0,d}}{k_{c,2} \cdot f_{c,0,d}} + k_m \cdot \frac{\sigma_{m,1,d}}{f_{m,1,d}} + \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \frac{0.00}{0.303 \cdot 23.43} + 0.70 \cdot \frac{9.38}{29.00} + \frac{0.00}{31.57} = 0.23 \leq 1.00 \qquad (6.24) \text{ - OK}$$

Lateral torsional buckling - 6.3.3

Not relevant

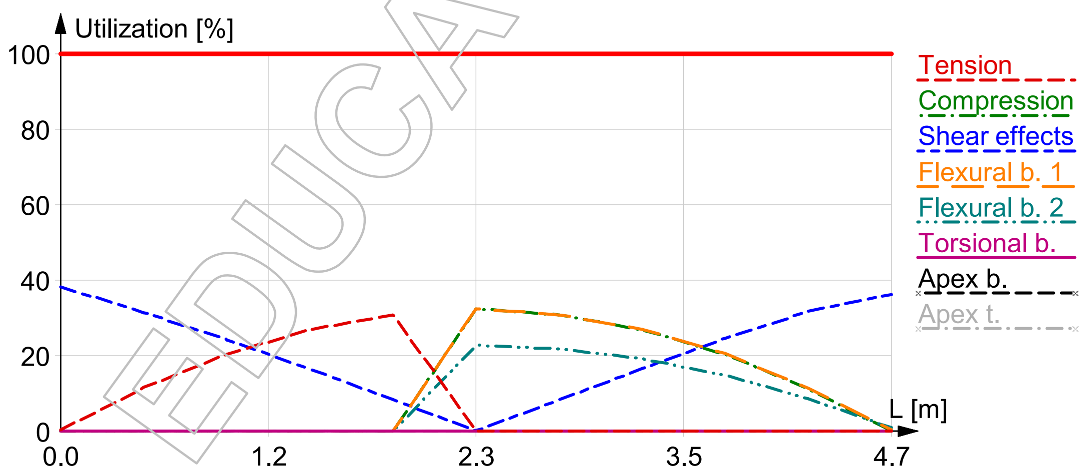
Bending at apex - 6.4.3

Not relevant

Tension at apex - 6.4.3

Not relevant

Summary

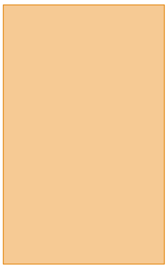


Group GLT 140x225, C.68.1
Maximum of load combinations

GL 30c
(Glued laminated), Service class 2

$E_{0,05}$	=	10800	N/mm^2	$f_{t,90,k}$	=	0.50	N/mm^2
$G_{0,05}$	=	540	N/mm^2	$f_{c,0,k}$	=	24.50	N/mm^2
γ_M	=	1.15		$f_{c,90,k}$	=	2.50	N/mm^2
$\gamma_{M,acc./seis.}$	=	1.00		$f_{v,k}$	=	3.50	N/mm^2
k_{sys}	=	1.00					

Glulam 140x225



A	=	31500	mm^2	$f_{t,0,k}$	=	21.45	N/mm^2
W_1	=	1.181e+06	mm^3	$f_{m,1,k}$	=	33.00	N/mm^2
W_2	=	7.350e+05	mm^3	$f_{m,2,k}$	=	33.00	N/mm^2
i_1	=	65	mm				
i_2	=	40	mm				
I_2	=	5.145e+07	mm^4				
I_t	=	1.261e+08	mm^4				

Combined bending and axial tension - 6.2.3
Not relevant

Combined bending and axial compression - 6.1.4, 6.2.4
LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', k_{mod} = 0.90 , x = 0.00

$\sigma_{c,0,d}$ = 7.27 N/mm^2 $\leq f_{c,0,d}$ = 19.17 N/mm^2 (6.2) - OK

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + \frac{\sigma_{m,1,d}}{f_{m,1,d}} + k_m \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \left(\frac{7.27}{19.17}\right)^2 + \frac{0.00}{25.83} + 0.70\ \frac{0.00}{25.83} = 0.14 \leq 1.00 \qquad (6.19) \text{ - OK}$$

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + k_m \frac{\sigma_{m,1,d}}{f_{m,1,d}} + \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \left(\frac{7.27}{19.17}\right)^2 + 0.70\ \frac{0.00}{25.83} + \frac{0.00}{25.83} = 0.14 \leq 1.00 \qquad (6.20) \text{ - OK}$$

Combined shear and torsion - 6.1.7, 6.1.8
LC: '1.35*SW + 1.35*dead + 1.35*Soil+ 1.50*0.70*P + 1.50*0.70*S + 1.50*0.70*W', k_{mod} = 1.10 , x

τ_d = 0.00 N/mm^2 $\leq f_{v,d}$ = 3.35 N/mm^2 (6.13) - OK

Flexural buckling around axis 1 - 6.3.2

LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', k_{mod} = 0.90 , x = 0.00

$\beta_c = 0.1$ (6.29)

$$\lambda_1 = \frac{l_0}{i_1} = \frac{3110}{65} = 47.88$$

$$\lambda_{rel,1} = \frac{\lambda_1}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{47.88}{\pi}\sqrt{\frac{24.50}{10800}} = 0.726 \quad (6.21)$$

$$k_1 = 0.5\left(1 + \beta_c\,(\lambda_{rel,1} - 0.3) + \lambda_{rel,1}^{\ 2}\right) =$$

$$= 0.5\left(1 + 0.1\ (0.726 - 0.3) + 0.726^{\ 2}\right) = 0.785 \quad (6.27)$$

$$k_{c,1} = \frac{1}{k_1 + \sqrt{k_1^{\ 2} - \lambda_{rel,1}^{\ 2}}} = \frac{1}{0.785 + \sqrt{0.785^{\ 2} - 0.726^{\ 2}}} = 0.923 \quad (6.25)$$

$$\frac{\sigma_{c,0,d}}{k_{c,1}\cdot f_{c,0,d}} + \frac{\sigma_{m,1,d}}{f_{m,1,d}} + k_m\cdot\frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \frac{7.27}{0.923\ \cdot 19.17} + \frac{0.00}{25.83} + 0.70\ \cdot\frac{0.00}{25.83} = 0.41 \le 1.00 \quad (6.23)\ \text{- OK}$$

Flexural buckling around axis 2 - 6.3.2

LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', k_{mod} = 0.90 , x = 0.00

$\beta_c = 0.1$ (6.29)

$$\lambda_2 = \frac{l_0}{i_2} = \frac{3110}{40} = 76.95$$

$$\lambda_{rel,2} = \frac{\lambda_2}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{76.95}{\pi}\sqrt{\frac{24.50}{10800}} = 1.167 \quad (6.22)$$

$$k_2 = 0.5\left(1 + \beta_c\,(\lambda_{rel,2} - 0.3) + \lambda_{rel,2}^{\ 2}\right) =$$

$$= 0.5\left(1 + 0.1\ (1.167 - 0.3) + 1.167^{\ 2}\right) = 1.224 \quad (6.28)$$

$$k_{c,2} = \frac{1}{k_2 + \sqrt{k_2^{\ 2} - \lambda_{rel,2}^{\ 2}}} = \frac{1}{1.224 + \sqrt{1.224^{\ 2} - 1.167^{\ 2}}} = 0.627 \quad (6.26)$$

$$\frac{\sigma_{c,0,d}}{k_{c,2}\cdot f_{c,0,d}} + k_m\cdot\frac{\sigma_{m,1,d}}{f_{m,1,d}} + \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \frac{7.27}{0.627\ \cdot 19.17} + 0.70\ \cdot\frac{0.00}{25.83} + \frac{0.00}{25.83} = 0.60 \le 1.00 \quad (6.24)\ \text{- OK}$$

Lateral torsional buckling - 6.3.3

Not relevant

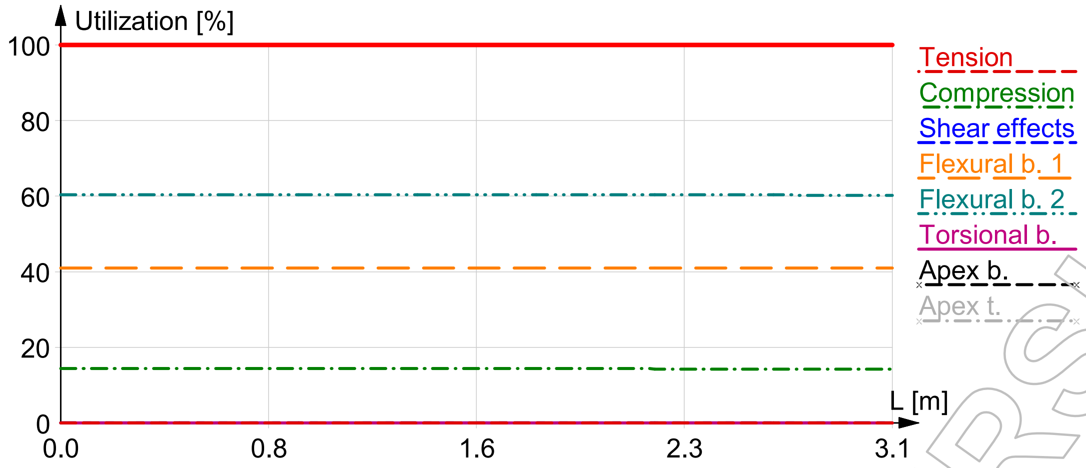
Bending at apex - 6.4.3

Not relevant

Tension at apex - 6.4.3

Not relevant

Summary



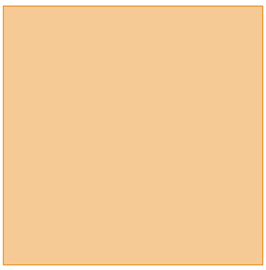
Group GLT 115x115, C.93.1
Maximum of load combinations

GL 30c

(Glued laminated), Service class 2

$E_{0,05}$	=	10800	N/mm^2	$f_{t,90,k}$	=	0.50	N/mm^2
$G_{0,05}$	=	540	N/mm^2	$f_{c,0,k}$	=	24.50	N/mm^2
γ_M	=	1.15		$f_{c,90,k}$	=	2.50	N/mm^2
$\gamma_{M,acc./seis.}$	=	1.00		$f_{v,k}$	=	3.50	N/mm^2
k_{sys}	=	1.00					

Glulam 115x115



A	=	13225	mm^2	$f_{t,0,k}$	=	21.45	N/mm^2
W_1	=	2.535e+05	mm^3	$f_{m,1,k}$	=	33.00	N/mm^2
W_2	=	2.535e+05	mm^3	$f_{m,2,k}$	=	33.00	N/mm^2
i_1	=	33	mm				
i_2	=	33	mm				
I_2	=	1.458e+07	mm^4				
I_t	=	2.459e+07	mm^4				

Combined bending and axial tension - 6.2.3

Not relevant

Combined bending and axial compression - 6.1.4, 6.2.4

LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', k_{mod} = 0.90 , x = 0.00

$\sigma_{c,0,d} = 3.59 \ N/mm^2 \leq f_{c,0,d} = 19.17 \ N/mm^2$ (6.2) - OK

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + \frac{\sigma_{m,1,d}}{f_{m,1,d}} + k_m \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \left(\frac{3.59}{19.17}\right)^2 + \frac{0.00}{25.83} + 0.70 \ \frac{0.00}{25.83} = 0.04 \leq 1.00 \qquad (6.19) \ \text{- OK}$$

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + k_m \frac{\sigma_{m,1,d}}{f_{m,1,d}} + \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \left(\frac{3.59}{19.17}\right)^2 + 0.70 \ \frac{0.00}{25.83} + \frac{0.00}{25.83} = 0.04 \leq 1.00 \qquad (6.20) \ \text{- OK}$$

Combined shear and torsion - 6.1.7, 6.1.8

LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)', k_{mod} = 1.10 , x = 0.00 mm

$\tau_d = 0.00 \ N/mm^2 \leq f_{v,d} = 3.35 \ N/mm^2$ (6.13) - OK

Flexural buckling around axis 1 - 6.3.2

LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', k_{mod} = 0.90 , x = 0.00

$\beta_c = 0.1$ (6.29)

$$\lambda_1 = \frac{l_0}{i_1} = \frac{2990}{33} = 90.07$$

$$\lambda_{rel,1} = \frac{\lambda_1}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{90.07}{\pi}\sqrt{\frac{24.50}{10800}} = 1.365 \qquad (6.21)$$

$$k_1 = 0.5\left(1 + \beta_c\left(\lambda_{rel,1} - 0.3\right) + \lambda_{rel,1}^2\right) =$$

$$= 0.5\left(1 + 0.1\left(1.365 - 0.3\right) + 1.365^2\right) = 1.486 \qquad (6.27)$$

$$k_{c,1} = \frac{1}{k_1 + \sqrt{k_1^2 - \lambda_{rel,1}^2}} = \frac{1}{1.486 + \sqrt{1.486^2 - 1.365^2}} = 0.483 \qquad (6.25)$$

$$\frac{\sigma_{c,0,d}}{k_{c,1} \cdot f_{c,0,d}} + \frac{\sigma_{m,1,d}}{f_{m,1,d}} + k_m \cdot \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \frac{3.59}{0.483 \cdot 19.17} + \frac{0.00}{25.83} + 0.70 \cdot \frac{0.00}{25.83} = 0.39 \leq 1.00 \qquad (6.23) \ \text{- OK}$$

Flexural buckling around axis 2 - 6.3.2

LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', $k_{mod} = 0.90$, $x = 0.00$

$\beta_c = 0.1$ (6.29)

$$\lambda_2 = \frac{l_0}{i_2} = \frac{2990}{33} = 90.07$$

$$\lambda_{rel,2} = \frac{\lambda_2}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{90.07}{\pi}\sqrt{\frac{24.50}{10800}} = 1.365 \quad (6.22)$$

$$k_2 = 0.5\left(1 + \beta_c(\lambda_{rel,2} - 0.3) + \lambda_{rel,2}^2\right) =$$

$$= 0.5\left(1 + 0.1\,(1.365 - 0.3) + 1.365^2\right) = 1.486 \quad (6.28)$$

$$k_{c,2} = \frac{1}{k_2 + \sqrt{k_2^2 - \lambda_{rel,2}^2}} = \frac{1}{1.486 + \sqrt{1.486^2 - 1.365^2}} = 0.483 \quad (6.26)$$

$$\frac{\sigma_{c,0,d}}{k_{c,2} \cdot f_{c,0,d}} + k_m \cdot \frac{\sigma_{m,1,d}}{f_{m,1,d}} + \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \frac{3.59}{0.483 \cdot 19.17} + 0.70 \cdot \frac{0.00}{25.83} + \frac{0.00}{25.83} = 0.39 \leq 1.00 \quad (6.24) \text{ - OK}$$

Lateral torsional buckling - 6.3.3

Not relevant

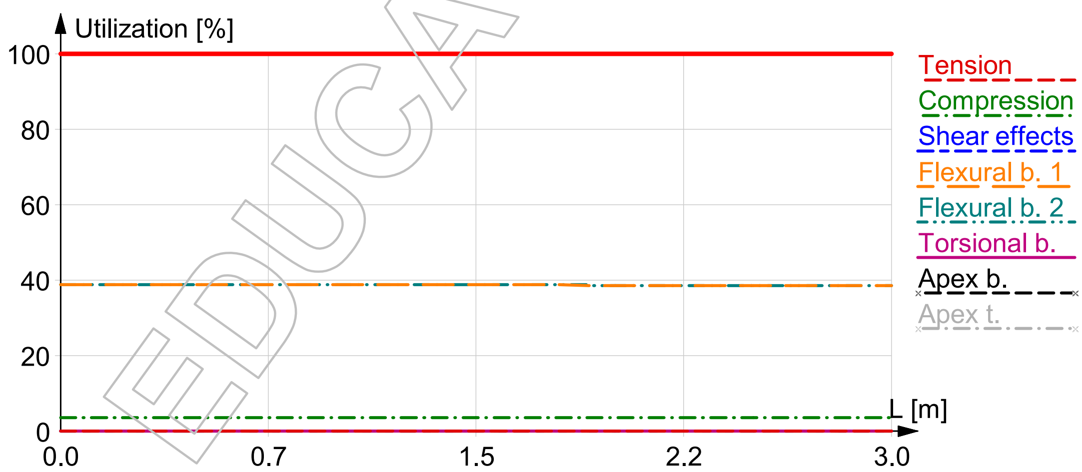
Bending at apex - 6.4.3

Not relevant

Tension at apex - 6.4.3

Not relevant

Summary

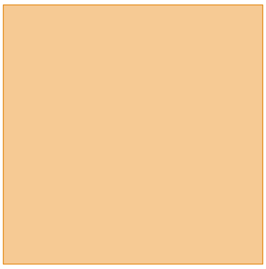


Group GLT 115x115, C.15.1
Maximum of load combinations

GL 30c
(Glued laminated), Service class 2

$E_{0,05}$	=	10800	N/mm^2	$f_{t,90,k}$	=	0.50	N/mm^2
$G_{0,05}$	=	540	N/mm^2	$f_{c,0,k}$	=	24.50	N/mm^2
γ_M	=	1.15		$f_{c,90,k}$	=	2.50	N/mm^2
$\gamma_{M,acc./seis.}$	=	1.00		$f_{v,k}$	=	3.50	N/mm^2
k_{sys}	=	1.00					

Glulam 115x115



A	=	13225	mm^2	$f_{t,0,k}$	=	21.45	N/mm^2
W_1	=	2.535e+05	mm^3	$f_{m,1,k}$	=	33.00	N/mm^2
W_2	=	2.535e+05	mm^3	$f_{m,2,k}$	=	33.00	N/mm^2
i_1	=	33	mm				
i_2	=	33	mm				
I_2	=	1.458e+07	mm^4				
I_t	=	2.459e+07	mm^4				

Combined bending and axial tension - 6.2.3
Not relevant

Combined bending and axial compression - 6.1.4, 6.2.4
LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', k_{mod} = 0.90 , x = 0.00

$\sigma_{c,0,d}$ = 3.88 $N/mm^2 \leq f_{c,0,d}$ = 19.17 N/mm^2 (6.2) - OK

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + \frac{\sigma_{m,1,d}}{f_{m,1,d}} + k_m \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \left(\frac{3.88}{19.17}\right)^2 + \frac{0.00}{25.83} + 0.70\ \frac{0.00}{25.83} = 0.04 \leq 1.00 \qquad (6.19) \ \text{- OK}$$

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + k_m \frac{\sigma_{m,1,d}}{f_{m,1,d}} + \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \left(\frac{3.88}{19.17}\right)^2 + 0.70\ \frac{0.00}{25.83} + \frac{0.00}{25.83} = 0.04 \leq 1.00 \qquad (6.20) \ \text{- OK}$$

Combined shear and torsion - 6.1.7, 6.1.8
LC: '1.35*SW + 1.35*dead + 1.35*Soil+ 1.50*0.70*P + 1.50*0.70*S + 1.50*0.70*W', k_{mod} = 1.10 , x

τ_d = 0.00 $N/mm^2 \leq f_{v,d}$ = 3.35 N/mm^2 (6.13) - OK

Flexural buckling around axis 1 - 6.3.2

LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', $k_{mod} = 0.90$, $x = 0.00$

$\beta_c = 0.1$ (6.29)

$$\lambda_1 = \frac{l_0}{i_1} = \frac{2990}{33} = 90.07$$

$$\lambda_{rel,1} = \frac{\lambda_1}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{90.07}{\pi}\sqrt{\frac{24.50}{10800}} = 1.365 \qquad (6.21)$$

$$k_1 = 0.5\left(1 + \beta_c\,(\lambda_{rel,1} - 0.3) + \lambda_{rel,1}^{\ 2}\right) =$$

$$= 0.5\left(1 + 0.1\,(1.365 - 0.3) + 1.365^{\ 2}\right) = 1.486 \qquad (6.27)$$

$$k_{c,1} = \frac{1}{k_1 + \sqrt{k_1^{\ 2} - \lambda_{rel,1}^{\ 2}}} = \frac{1}{1.486 + \sqrt{1.486^{\ 2} - 1.365^{\ 2}}} = 0.483 \qquad (6.25)$$

$$\frac{\sigma_{c,0,d}}{k_{c,1}\cdot f_{c,0,d}} + \frac{\sigma_{m,1,d}}{f_{m,1,d}} + k_m\cdot\frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \frac{3.88}{0.483\cdot 19.17} + \frac{0.00}{25.83} + 0.70\cdot\frac{0.00}{25.83} = 0.42 \le 1.00 \qquad (6.23)\ \text{- OK}$$

Flexural buckling around axis 2 - 6.3.2

LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', $k_{mod} = 0.90$, $x = 0.00$

$\beta_c = 0.1$ (6.29)

$$\lambda_2 = \frac{l_0}{i_2} = \frac{2990}{33} = 90.07$$

$$\lambda_{rel,2} = \frac{\lambda_2}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{90.07}{\pi}\sqrt{\frac{24.50}{10800}} = 1.365 \qquad (6.22)$$

$$k_2 = 0.5\left(1 + \beta_c\,(\lambda_{rel,2} - 0.3) + \lambda_{rel,2}^{\ 2}\right) =$$

$$= 0.5\left(1 + 0.1\,(1.365 - 0.3) + 1.365^{\ 2}\right) = 1.486 \qquad (6.28)$$

$$k_{c,2} = \frac{1}{k_2 + \sqrt{k_2^{\ 2} - \lambda_{rel,2}^{\ 2}}} = \frac{1}{1.486 + \sqrt{1.486^{\ 2} - 1.365^{\ 2}}} = 0.483 \qquad (6.26)$$

$$\frac{\sigma_{c,0,d}}{k_{c,2}\cdot f_{c,0,d}} + k_m\cdot\frac{\sigma_{m,1,d}}{f_{m,1,d}} + \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \frac{3.88}{0.483\cdot 19.17} + 0.70\cdot\frac{0.00}{25.83} + \frac{0.00}{25.83} = 0.42 \le 1.00 \qquad (6.24)\ \text{- OK}$$

Lateral torsional buckling - 6.3.3

Not relevant

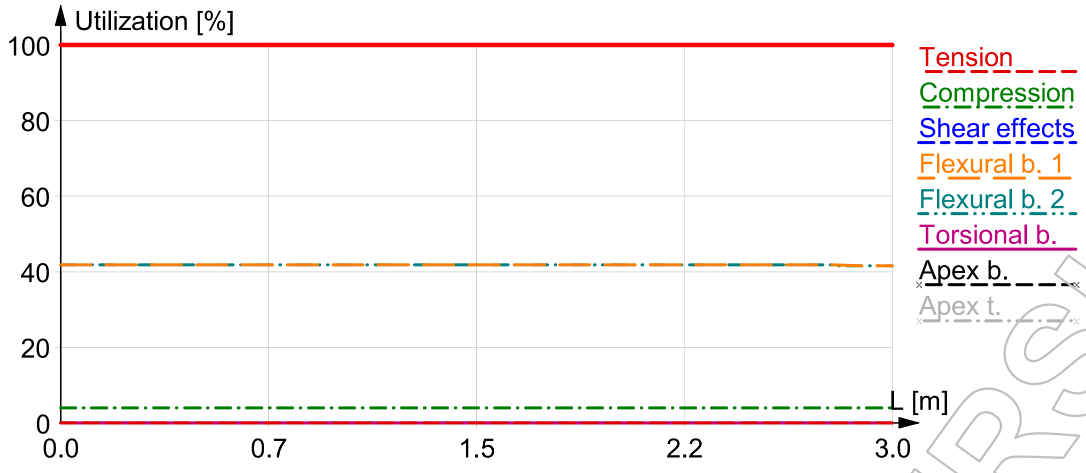
Bending at apex - 6.4.3

Not relevant

Tension at apex - 6.4.3

Not relevant

Summary



Group GLT 140x540, B.28.1
Maximum of load combinations

GL 30c

(Glued laminated), Service class 2

$E_{0,05}$	=	10800	N/mm^2	$f_{t,90,k}$	=	0.50	N/mm^2
$G_{0,05}$	=	540	N/mm^2	$f_{c,0,k}$	=	24.50	N/mm^2
γ_M	=	1.15		$f_{c,90,k}$	=	2.50	N/mm^2
$\gamma_{M,acc./seis.}$	=	1.00		$f_{v,k}$	=	3.50	N/mm^2
k_{sys}	=	1.00					

Glulam 140x540

A	=	75600	mm^2	$f_{t,0,k}$	=	19.71	N/mm^2
W_1	=	6.804e+06	mm^3	$f_{m,1,k}$	=	30.32	N/mm^2
W_2	=	1.764e+06	mm^3	$f_{m,2,k}$	=	33.00	N/mm^2
i_1	=	156	mm				
i_2	=	40	mm				
I_2	=	1.235e+08	mm^4				
I_t	=	4.132e+08	mm^4				

Combined bending and axial tension - 6.2.3

Not relevant

Combined bending and axial compression - 6.1.4, 6.2.4

LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', $k_{mod} = 0.90$, $x = 1499$

$\sigma_{c,0,d} = 0.00\ \mathrm{N/mm^2} \le f_{c,0,d} = 19.17\ \mathrm{N/mm^2}$ (6.2) - OK

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + \frac{\sigma_{m,1,d}}{f_{m,1,d}} + k_m \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \left(\frac{0.00}{19.17}\right)^2 + \frac{12.82}{23.73} + 0.70\ \frac{0.00}{25.83} = 0.54 \le 1.00 \quad (6.19)\ \text{- OK}$$

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + k_m \frac{\sigma_{m,1,d}}{f_{m,1,d}} + \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \left(\frac{0.00}{19.17}\right)^2 + 0.70\ \frac{12.82}{23.73} + \frac{0.00}{25.83} = 0.38 \le 1.00 \quad (6.20)\ \text{- OK}$$

Combined shear and torsion - 6.1.7, 6.1.8

LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', $k_{mod} = 0.90$, $x = 0.00$

$\tau_d = 1.80\ \mathrm{N/mm^2} \le f_{v,d} = 2.74\ \mathrm{N/mm^2}$ (6.13) - OK

Flexural buckling around axis 1 - 6.3.2

LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', $k_{mod} = 0.90$, $x = 1499$

$\beta_c = 0.1$ (6.29)

$$\lambda_1 = \frac{l_0}{i_1} = \frac{1500}{156} = 9.62$$

$$\lambda_{rel,1} = \frac{\lambda_1}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{9.62}{\pi}\sqrt{\frac{24.50}{10800}} = 0.300 \quad (6.21)$$

$$k_1 = 0.5\left(1 + \beta_c\,(\lambda_{rel,1} - 0.3) + \lambda_{rel,1}^{\ 2}\right) =$$

$$= 0.5\left(1 + 0.1\ (0.300 - 0.3) + 0.300^{\ 2}\right) = 0.545 \quad (6.27)$$

$$k_{c,1} = \frac{1}{k_1 + \sqrt{k_1^{\ 2} - \lambda_{rel,1}^{\ 2}}} = \frac{1}{0.545 + \sqrt{0.545^{\ 2} - 0.300^{\ 2}}} = 1.000 \quad (6.25)$$

$$\frac{\sigma_{c,0,d}}{k_{c,1}\cdot f_{c,0,d}} + \frac{\sigma_{m,1,d}}{f_{m,1,d}} + k_m \cdot \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \frac{0.00}{1.000 \cdot 19.17} + \frac{12.82}{23.73} + 0.70 \cdot \frac{0.00}{25.83} = 0.54 \le 1.00 \quad (6.23)\ \text{- OK}$$

Flexural buckling around axis 2 - 6.3.2

LC: 'Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)', $k_{mod} = 0.90$, x = 1499

$\beta_c = 0.1$ (6.29)

$$\lambda_2 = \frac{l_0}{i_2} = \frac{0}{40} = 0.00$$

$$\lambda_{rel,2} = \frac{\lambda_2}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{0.00}{\pi}\sqrt{\frac{24.50}{10800}} = 0.300 \quad (6.22)$$

$$k_2 = 0.5\left(1 + \beta_c\,(\lambda_{rel,2} - 0.3) + \lambda_{rel,2}^{\;2}\right) =$$

$$= 0.5\left(1 + 0.1\,(0.300 - 0.3) + 0.300^2\right) = 0.545 \quad (6.28)$$

$$k_{c,2} = \frac{1}{k_2 + \sqrt{k_2^{\;2} - \lambda_{rel,2}^{\;2}}} = \frac{1}{0.545 + \sqrt{0.545^2 - 0.300^2}} = 1.000 \quad (6.26)$$

$$\frac{\sigma_{c,0,d}}{k_{c,2}\cdot f_{c,0,d}} + k_m \cdot \frac{\sigma_{m,1,d}}{f_{m,1,d}} + \frac{\sigma_{m,2,d}}{f_{m,2,d}} =$$

$$= \frac{0.00}{1.000 \cdot 19.17} + 0.70 \cdot \frac{12.82}{23.73} + \frac{0.00}{25.83} = 0.38 \le 1.00 \quad (6.24) \text{ - OK}$$

Lateral torsional buckling - 6.3.3

Not relevant

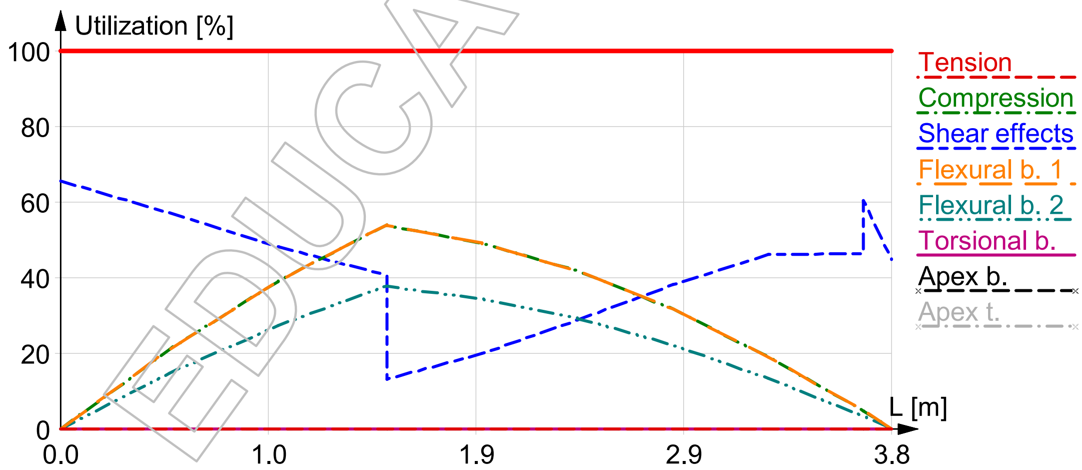
Bending at apex - 6.4.3

Not relevant

Tension at apex - 6.4.3

Not relevant

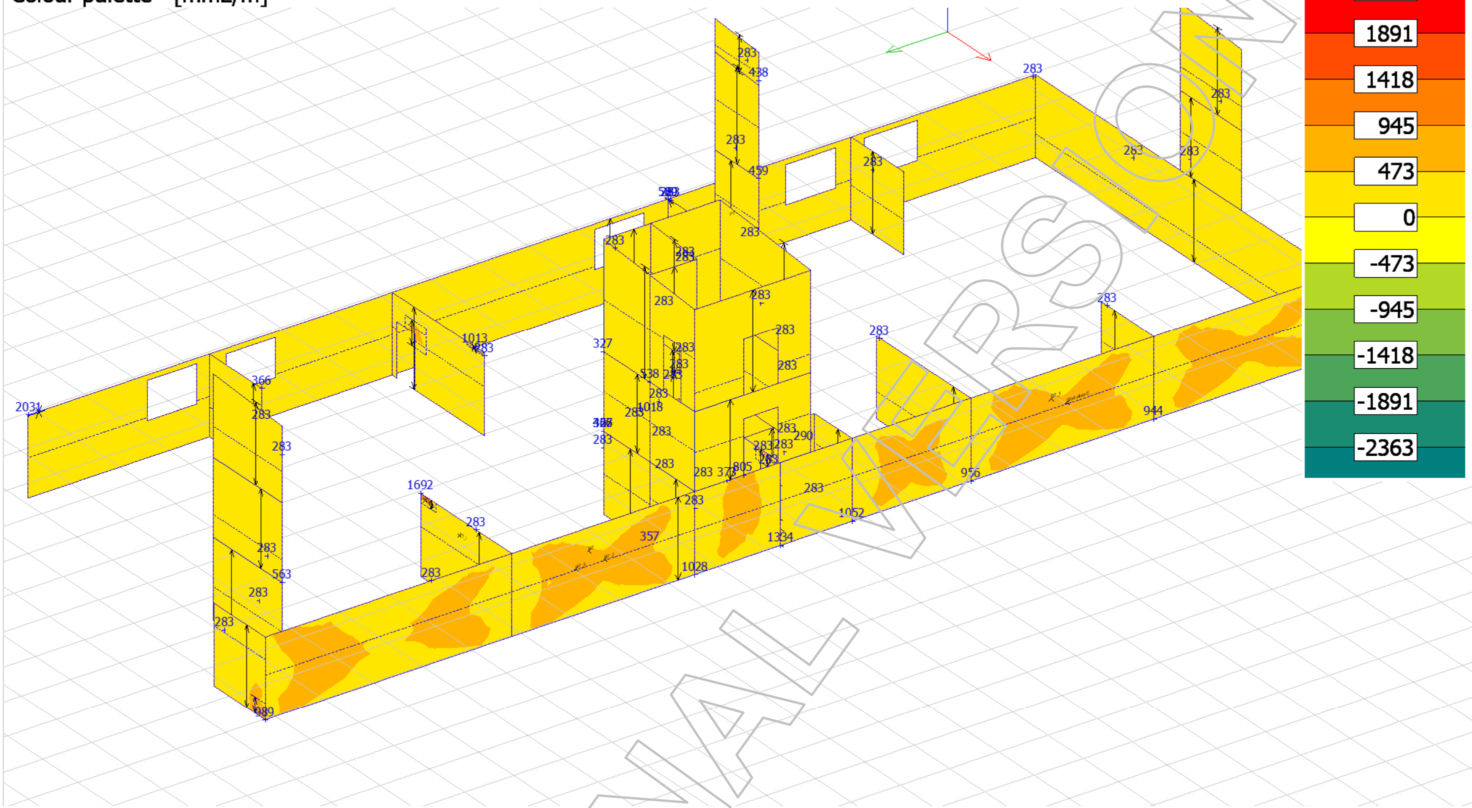
Summary



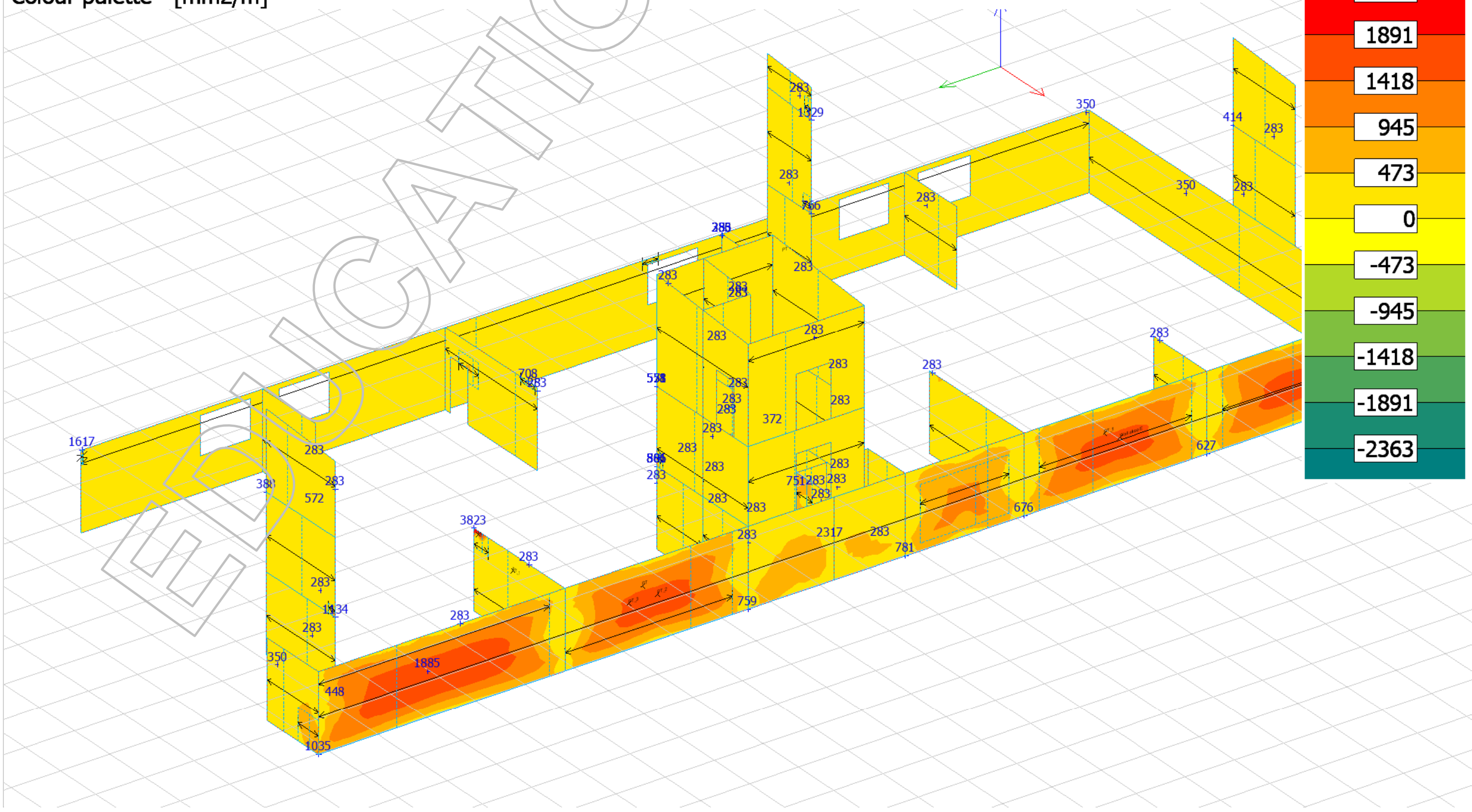
5 RCC design

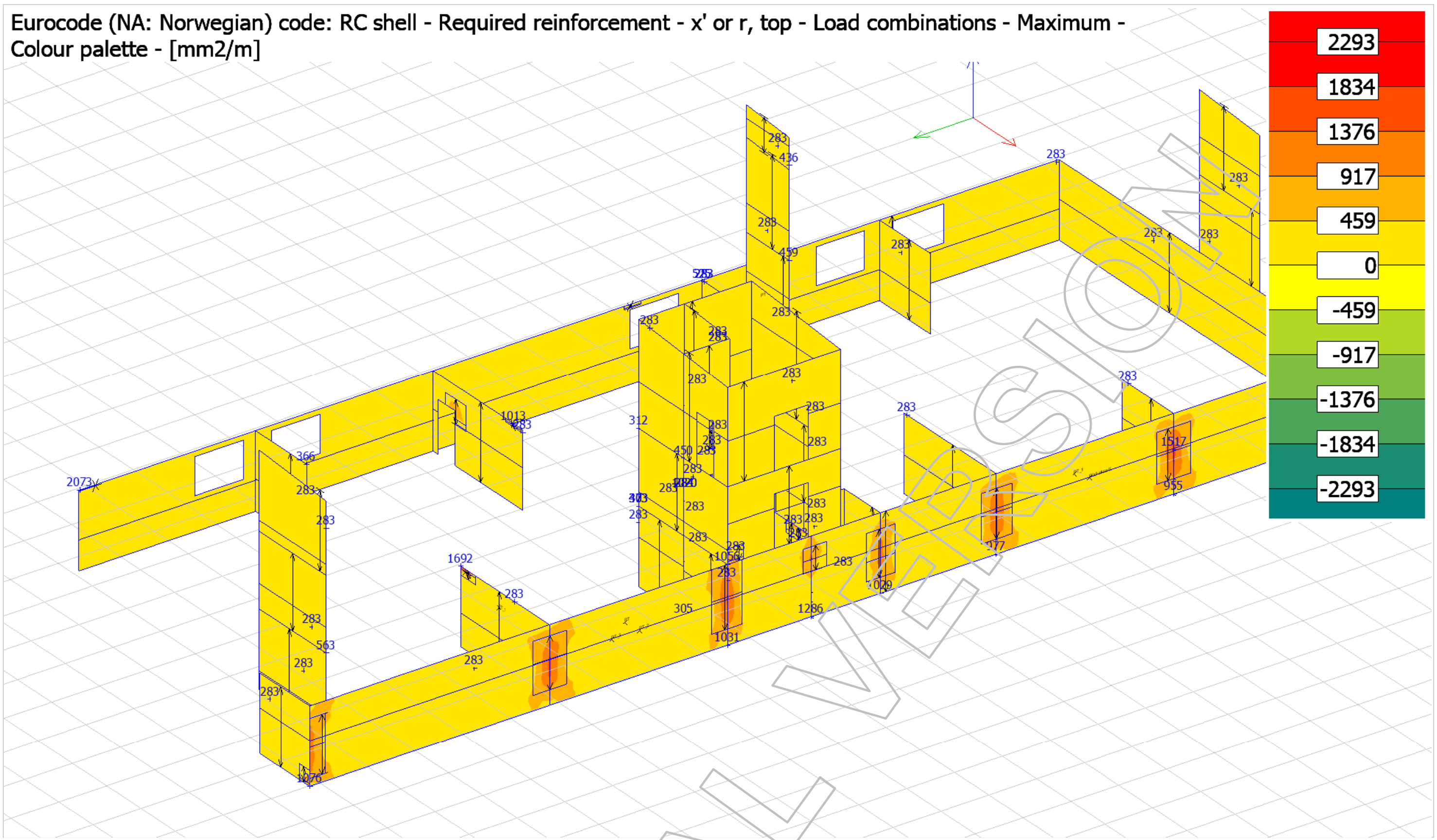
5.1 Reinforcement detail

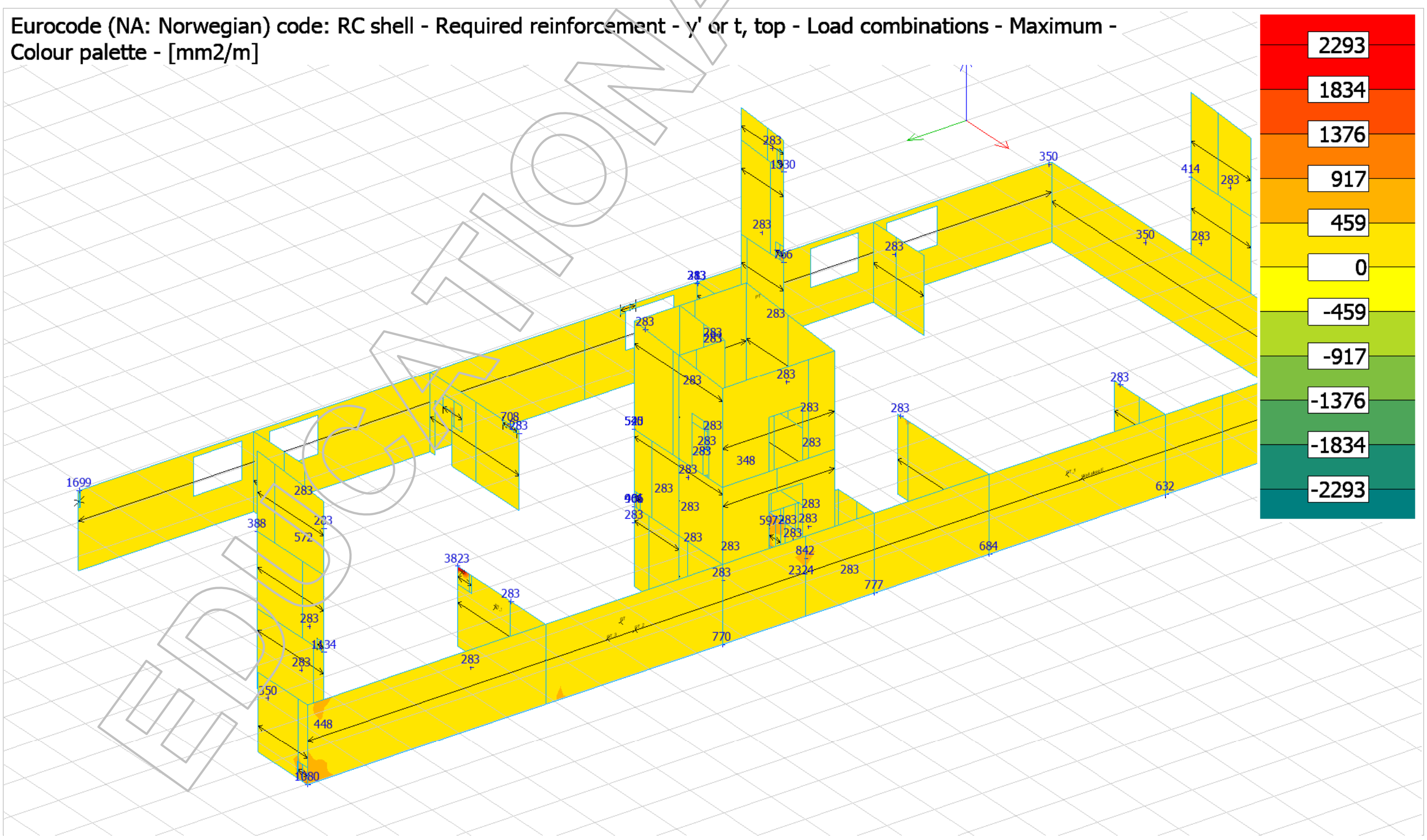
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, bottom - Load combinations - Maximum - Colour palette - [mm2/m]



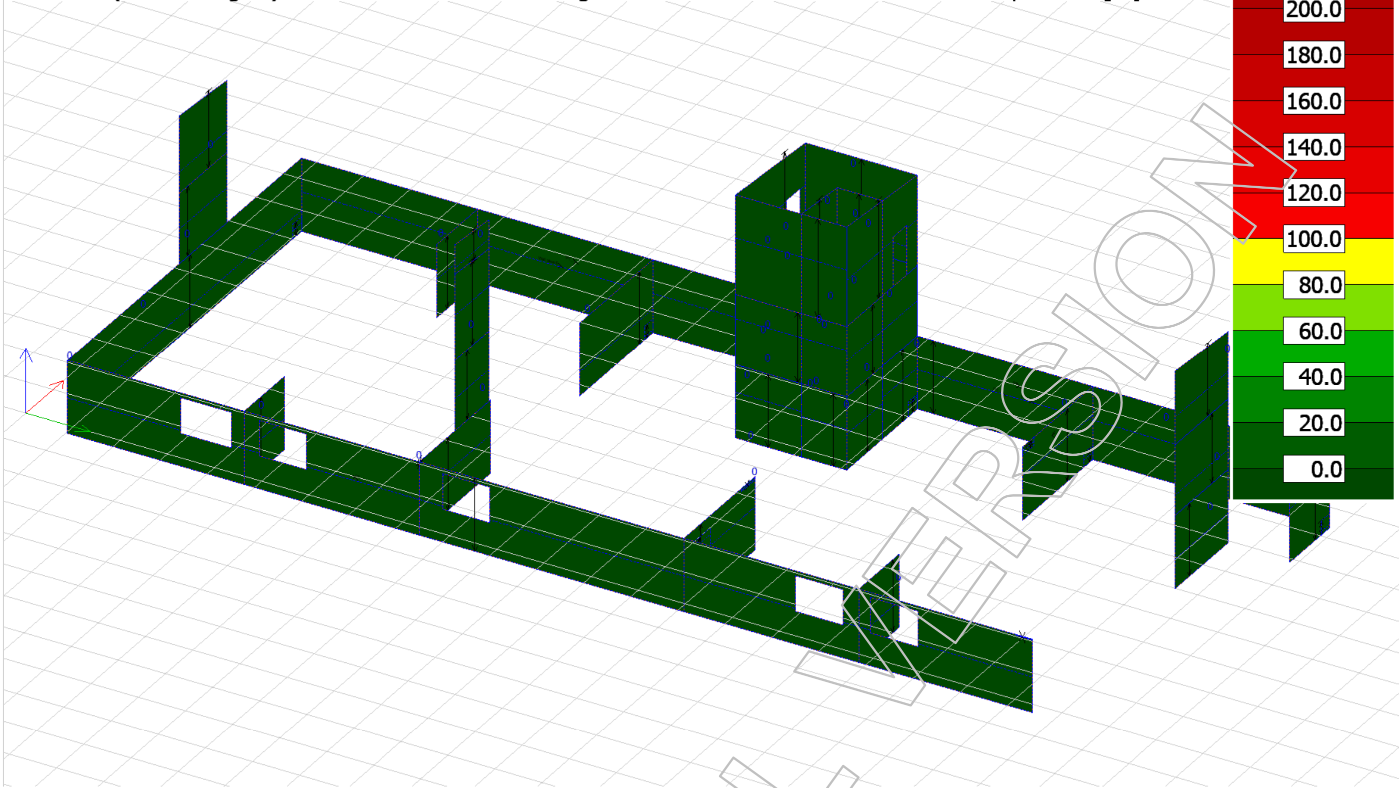
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, bottom - Load combinations - Maximum - Colour palette - [mm2/m]



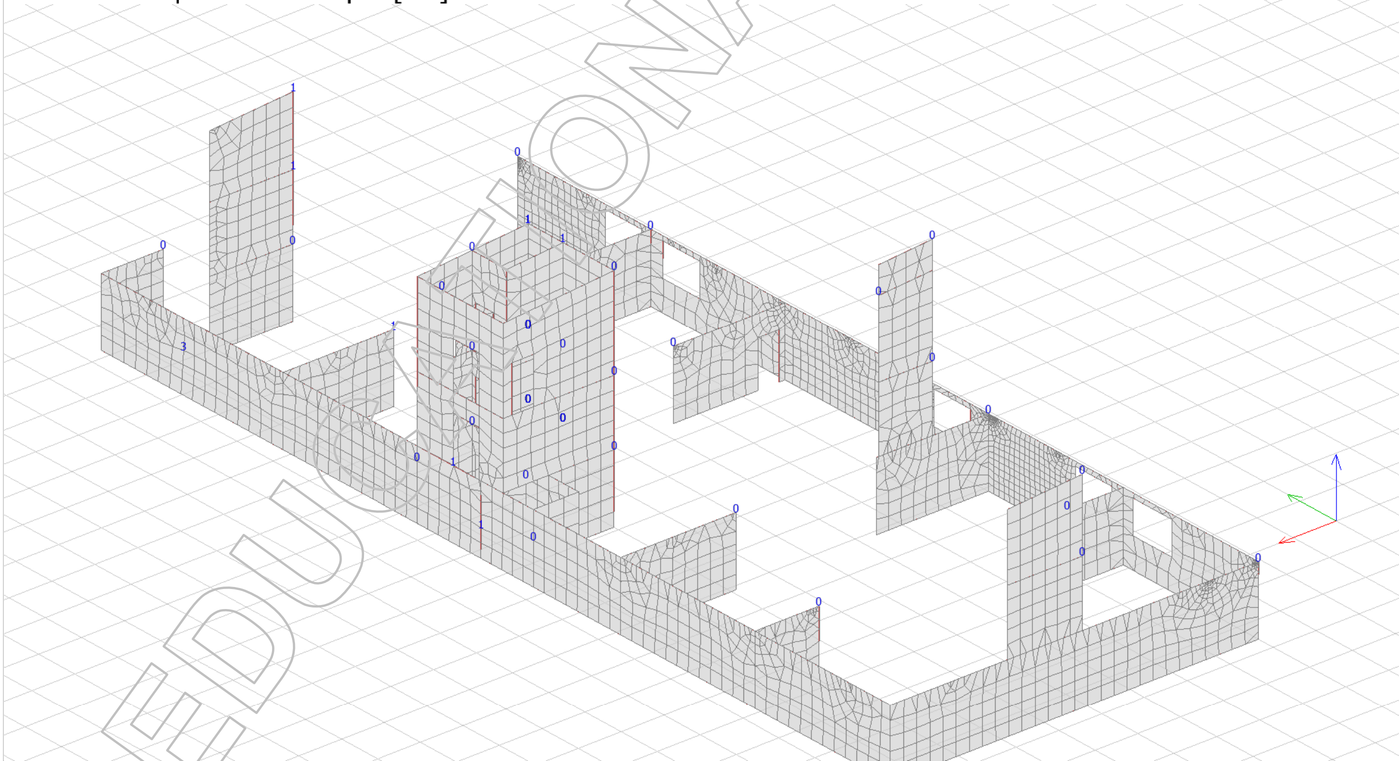

Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, top - Load combinations - Maximum - Colour palette - [mm2/m]
2293
1834
1376
917
459
0
-459
-917
-1376
-1834
-2293

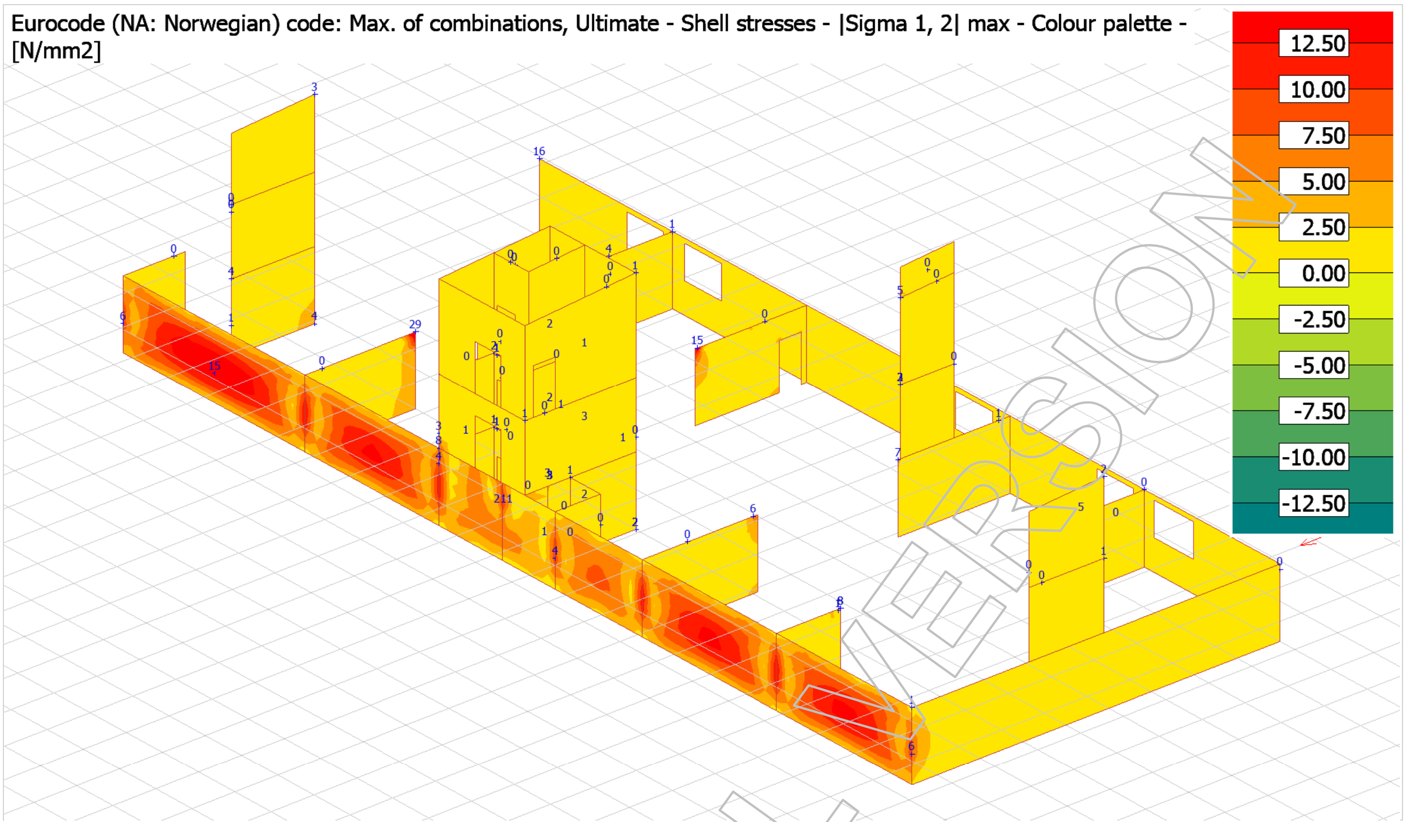

Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, top - Load combinations - Maximum - Colour palette - [mm2/m]
2293
1834
1376
917
459
0
-459
-917
-1376
-1834
-2293

Eurocode (NA: Norwegian) code: RC shell - Shell buckling - Load combinations - Maximum - Colour palette - [%]



Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - SW + dead + Soil + 0.70*P + 0.70*S + W -
Translational displacements - Graph - [mm]





Max. of load combinations, Shell, Utilization

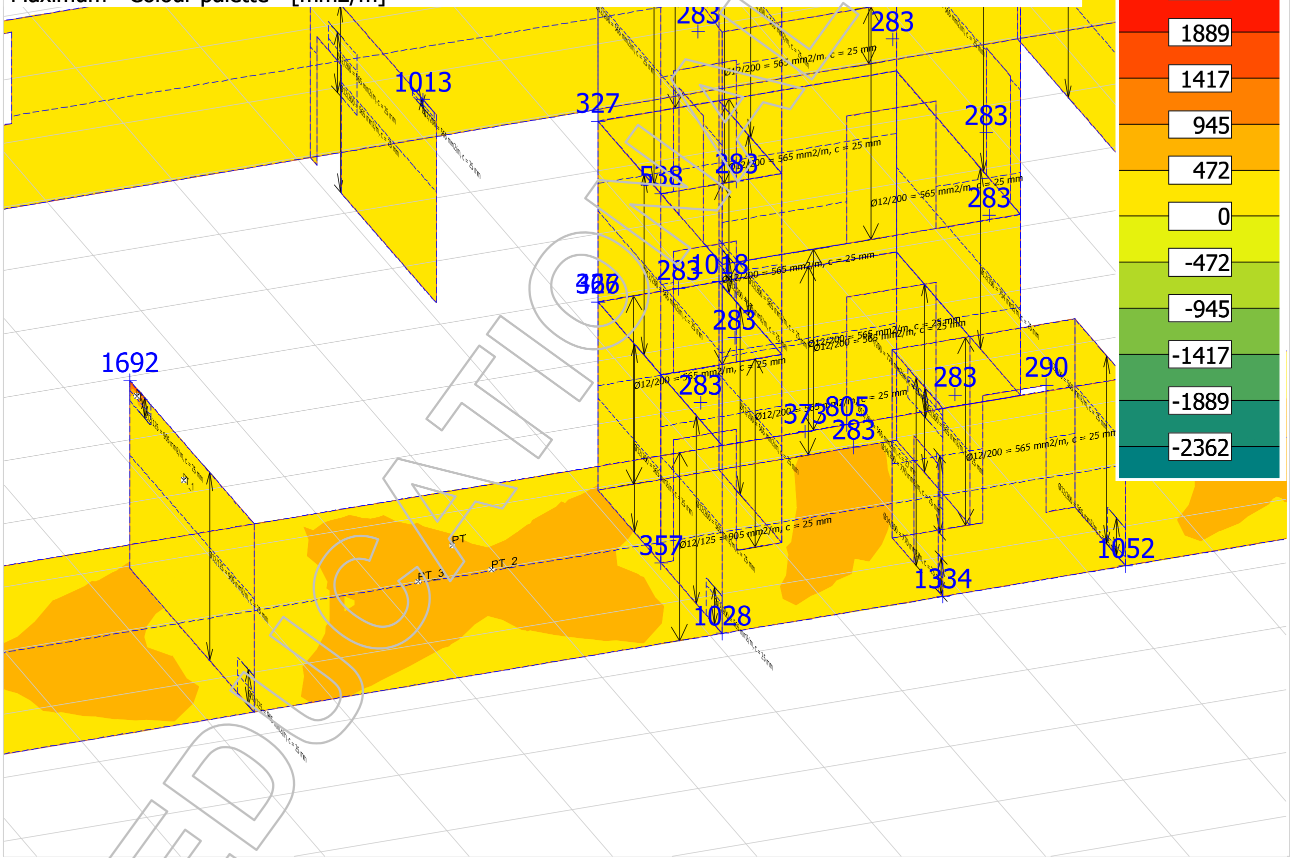
Shell	Max.	Combination	RBX	RBY	RTX	RTY
[-]	[%]	[-]	[%]	[%]	[%]	[%]
W.1.1	101	1.35*SW +...	89	97	101	93
W.2.1	99	1.35*SW +...	91	95	99	99
W.3.1	99	Ultimate - o...	93	99	93	99
W.4.1	94	1.35*SW +...	91	93	91	94
W.5.1	50	Stability1: ...	50	50	50	50
W.6.1	50	1.35*SW +...	50	50	50	50
W.7.1	50	Stability1: ...	50	50	50	50
W.8.1	50	Stability1: ...	50	50	50	50
W.9.1	95	1.35*SW +...	51	92	50	95
W.10.1	99	1.35*SW +...	99	96	96	94
W.11.1	96	1.35*SW +...	93	96	91	95
W.12.1	99	1.35*SW +...	95	93	95	99
W.13.1	89	1.35*SW +...	57	89	57	89
W.14.1	50	Stability1: ...	50	50	50	50
W.15.1	98	1.35*SW +...	98	63	93	55
W.16.1	97	Ultimate - o...	90	97	90	97
W.17.1	91	1.35*SW +...	88	90	90	91
W.18.1	99	1.35*SW +...	87	83	99	89
W.19.1	95	0.89*1.35*...	83	92	84	95
W.20.1	90	0.89*1.35*...	58	90	54	82
W.21.1	90	1.35*SW +...	90	50	90	50
W.22.1	50	Stability1: ...	50	50	50	50
W.23.1	49	0.89*1.35*...	38	49	38	46
W.24.1	50	Stability1: ...	50	50	50	50
W.25.1	95	0.89*1.35*...	43	76	55	95
W.26.1	99	0.89*1.35*...	95	99	80	93
W.27.1	93	1.35*SW +...	66	50	93	50

Shell	Max.	Combination	RBX	RBY	RTX	RTY
[-]	[%]	[-]	[%]	[%]	[%]	[%]
W.28.1	99	Ultimate - o...	97	92	96	99
W.29.1	50	Stability1: ...	50	50	50	50
W.30.1	63	1.35*SW +...	63	50	54	50
W.31.1	50	Stability1: ...	50	50	50	50
W.32.1	73	Ultimate - o...	50	73	50	73
W.33.1	69	Ultimate - o...	50	69	50	69
W.34.1	50	Stability1: ...	50	50	50	50
W.35.1	50	Stability1: ...	50	50	50	50
W.36.1	79	1.35*SW +...	50	79	50	79
W.37.1	99	Ultimate - o...	99	96	99	96
W.38.1	50	Stability1: ...	50	50	50	50
W.39.1	50	Stability1: ...	50	50	50	50
W.40.1	94	0.89*1.35*...	81	94	81	94
W.41.1	99	0.89*1.35*...	77	99	77	99

5.2 Detail calculation

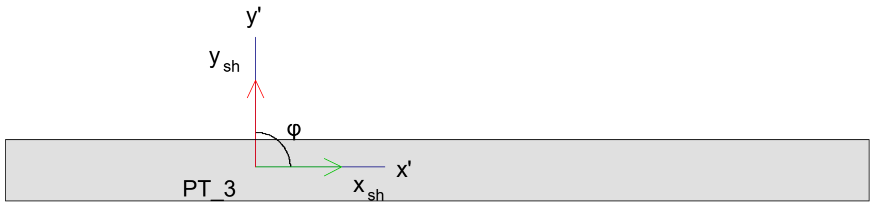
Wall axis E

Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, bottom - Load combinations - Maximum - Colour palette - [mm2/m]



W.1.1 - PT_3
Maximum of load combinations

Geometry



1.00 m

x_{sh}, y_{sh} : local coordinate system of shell
x', y': reinforcement directions

Global coordinates:
x = 30.39 m
y = 21.32 m
z = -1.39 m

Reinforcement directions:
φ = 90.00 °

Thickness:
t = 0.25 m

Concrete (EN 1992-1-1: 3.1.7)

C35/45

f_{ck} = 35.00 N/mm^2 ε_{c2} = 0.00200 ε_{cu3} = 0.0035 φ_{ef} = 0.00

f_{ctm} = 3.20 N/mm^2 E_{cm} = 34000 N/mm^2

$\gamma_{C,U}$ = 1.50 $\gamma_{C,Ua}$ = 1.20 α_{cc} = 1.00

$\lambda = 0.8 - \max(f_{ck} - 50, 0) / 400 =$
$= 0.8 - \max(35.00 - 50, 0) / 400 = 0.80$ (3.19, 3.20)

$\eta = 1.0 - \max(f_{ck} - 50, 0) / 200 =$
$= 1.0 - \max(35.00 - 50, 0) / 200 = 1.00$ (3.21, 3.22)

$f_{cd,U} = \eta \cdot \alpha_{cc} \cdot f_{ck} / \gamma_{C,U} = 1.00 \cdot 1.00 \cdot 35.00 / 1.50 = 23.33$ N/mm^2 (3.15) + Fig. 3.5

$f_{cd,Ua} = \eta \cdot \alpha_{cc} \cdot f_{ck} / \gamma_{C,Ua} = 1.00 \cdot 1.00 \cdot 35.00 / 1.20 =$
$= 29.17$ N/mm^2 (3.15) + Fig. 3.5

$\varepsilon_{yd} = (1 - \lambda) \cdot \varepsilon_{cu3} = (1 - 0.80) \cdot 0.0035 = 0.0007$ Fig. 3.5

Applied reinforcement

Face, direction	Quality	Diameter [mm]	Cover [mm]	Spacing [mm]	Area [mm^2/m]
Bottom, x'	B500C	12	25	125	905
Bottom, y'	B500C	12	37	125	905
Bottom, y'	B500C	14	37	125	1232
Top, x'	B500C	12	25	125	905
Top, y'	B500C	12	37	125	905

Equivalent reinforcement

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
Quality	B500C	B500C	B500C	B500C
Diameter [mm]	12	13	12	12
Cover [mm]	25	37	25	37
c = Cover + $\Phi/2$ [mm]	31	44	31	43
E_s [N/mm ^{2}]	200000	200000	200000	200000
Applied, UL [mm ^{2}/m]	905	2136	905	905
$f_{sy,UL}$ [N/mm ^{2}]	435	435	435	435
Applied, SL [mm ^{2}/m]	905	2136	905	905
$f_{sy,SL}$ [N/mm ^{2}]	500	500	500	500

Equivalent reinforcement calculation is based on calculation parameter data.

Other calculation parameter data

Allowed crackwidth, top: 1.00 mm
Allowed crackwidth, bottom: 1.00 mm
Minimum reinforcement: Yes
Compressed reinf.: No

Required reinforcement, bottom x'

LC: '1.35*SW + 1.35*dead + 1.35*Soil+ 1.50*0.70*P + 1.50*0.70*S + 1.50*0.70*W'

Internal forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x,sh}$ = 46.52	$n_{x,sh}$ = -0.13
$m_{y,sh}$ = 117.13	$n_{y,sh}$ = -4.76
$m_{xy,sh}$ = 4.00	$n_{xy,sh}$ = -48.20

Design forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x',bot}$ = 50.52	$n_{x',+}$ = 48.07
$m_{y',bot}$ = 121.13	$n_{y',+}$ = 43.44
$m_{x',top}$ = 0.00	$n_{x',-}$ = -48.32
$m_{y',top}$ = 0.00	$n_{y',-}$ = -52.95

Calculation is based on Wood-Armer and Nemeth methods.

Maximum reinforcement

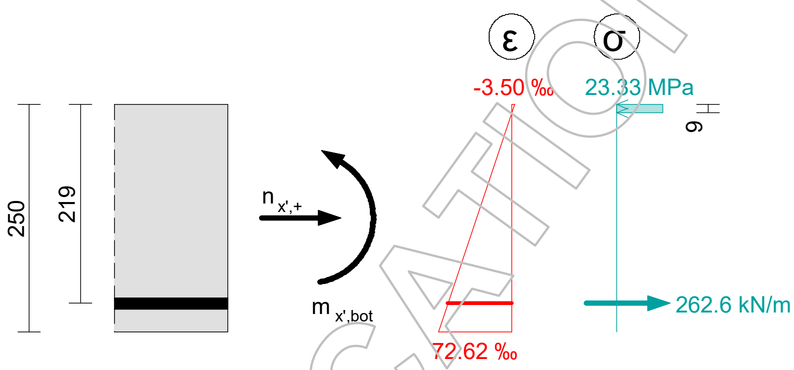
$A_{s,max} = 0.04 \cdot b \cdot t = 0.04 \cdot 1000 \cdot 250 = 10000 \ mm^2/m$ (EN 1992-1-1 9.6.2(1))

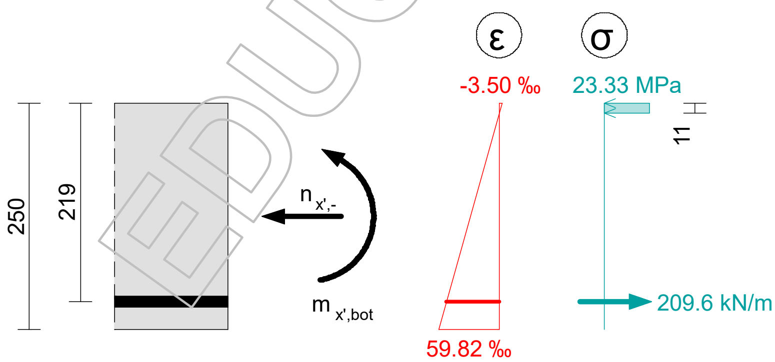
Calculation of required reinforcement from different m-n combinations

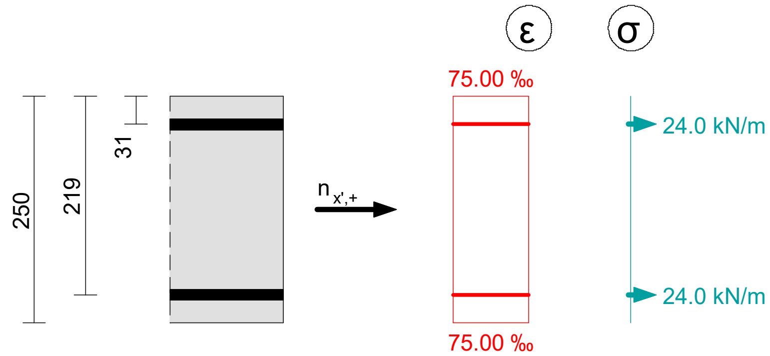
Face, direction	Bottom, x'	Bottom, x'	Top, x'	Top, x'	Bottom, y'	Bottom, y'	Top, y'	Top, y'
Sign of n	+	-	+	-	+	-	+	-
$m_{[dir][face]}$ [kN m/m]	50.52	50.52	0.00	0.00	121.13	121.13	0.00	0.00
$n_{[dir][face]}$ [kN/m]	48.07	-48.32	48.07	-48.32	43.44	-52.95	43.44	-52.95
Case	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.
$A_{sb,x'}$ [mm^2/m]	604	482	55	0	-	-	-	-
$A_{sb,y'}$ [mm^2/m]	-	-	-	-	1498	1377	50	0
$A_{st,x'}$ [mm^2/m]	0	0	55	0	-	-	-	-
$A_{st,y'}$ [mm^2/m]	-	-	-	-	0	0	50	0

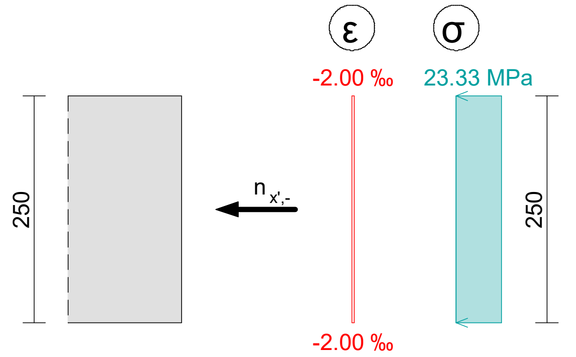
Necessary reinforcement is calculated by considering equivalent reinforcement data.

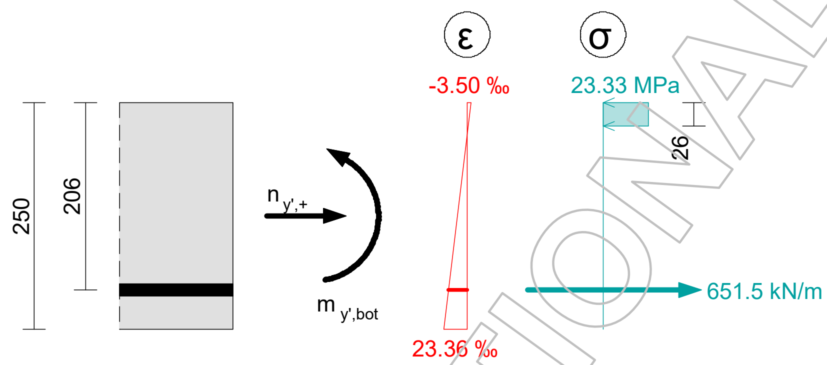
If no reinforcement is required, the ultimate resistance of the concrete section is represented in the stress figures.

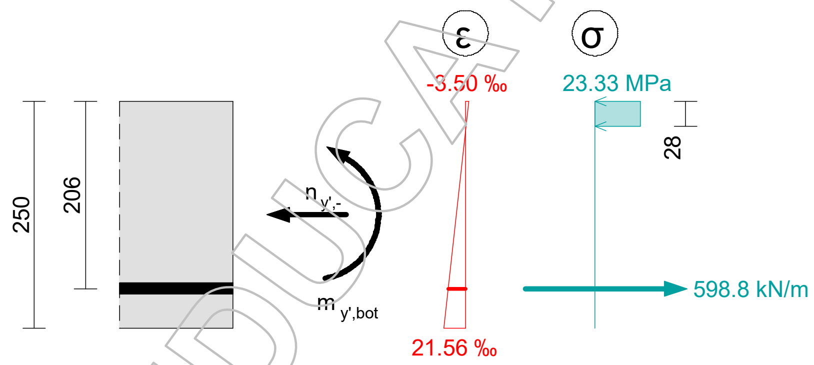


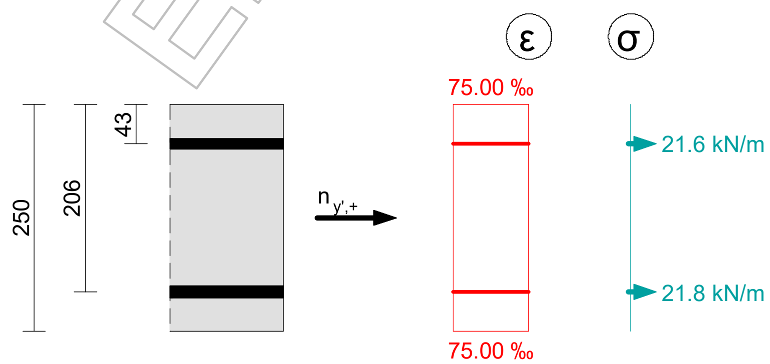


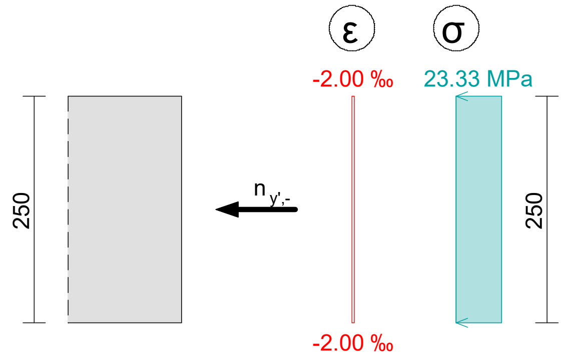

ε
σ
75.00 ‰
24.0 kN/m
250
219
31
n x',+
24.0 kN/m
75.00 ‰


ε
σ
-2.00 ‰
23.33 MPa
250
n x',-
250
-2.00 ‰


ε
σ
-3.50 ‰
23.33 MPa
26
250
206
n y',+
m y',bot
651.5 kN/m
23.36 ‰


ε
σ
-3.50 ‰
23.33 MPa
28
250
206
n y',-
m y',bot
598.8 kN/m
21.56 ‰


ε
σ
75.00 ‰
43
21.6 kN/m
250
206
n y',+
21.8 kN/m
75.00 ‰



Minimum reinforcement

$A_{s,min,vertical}$ = 0.002 · A_c (EN 1992-1-1 9.6.2(1))

$A_{s,min,horizontal}$ = max (0.001 · A_c, 0.25 · $A_{s,required,vertical}$) (EN 1992-1-1 9.6.3(1))

$s_{max,walls,vertical}$ = min (3 · t, 400) (EN 1992-1-1 9.6.2(3))

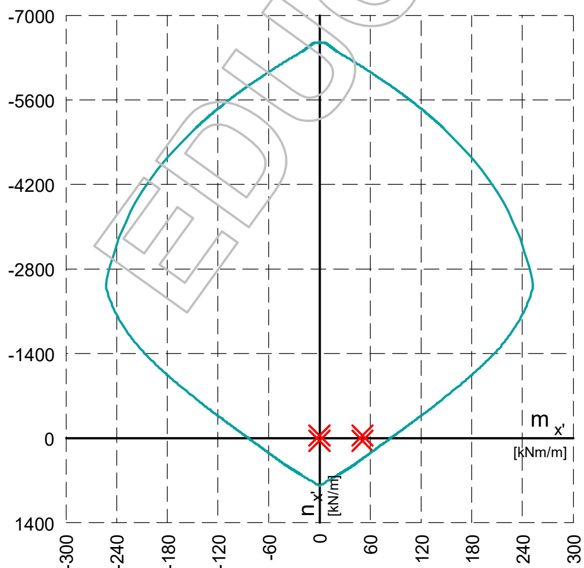
$s_{max,walls,horizontal}$ = 400 mm (EN 1992-1-1 9.6.3(2))

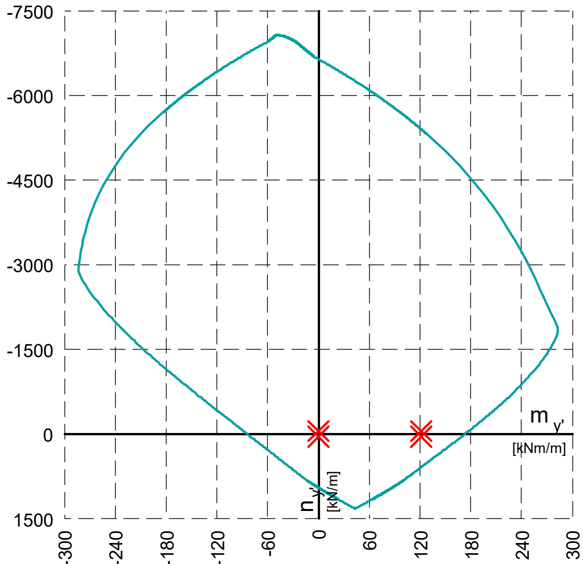
$A_{s,min,smax}$ = 1000 / s_{max} · Φ^2 · π / 4

$A_{s,min,final}$ = max ($A_{s,min}$, $A_{s,min,smax}$)

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,min}$ [mm^2/m]	375	250	125	250
Type	Horizontal	Vertical	Horizontal	Vertical
s_{max} [mm]	400	400	400	400
Φ [mm]	12	12	12	12
$A_{s,min,smax}$ [mm^2/m]	283	283	283	283
$A_{s,min,final}$ [mm^2/m]	375	283	283	283

Interaction curves based on applied reinforcement





Utilization

$A_{s,req}$ = max ($A_{s,calc}$, $A_{s,min,final}$)

$A_{s,missing}$ = $A_{s,req}$ - $A_{s,applied}$

Utilization = $A_{s,req}$ / $A_{s,applied}$ · 100

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,req}$ [mm ^{2}/m]	604	1498	283	283
$A_{s,applied}$ [mm ^{2}/m]	905	2136	905	905
$A_{s,missing}$ [mm ^{2}/m]	-	-	-	-
Utilization [%]	67	70	31	31

The amount of required reinforcement is based on an optimum calculation because several solutions are possible.

Required reinforcement, bottom y'

LC: '1.35*SW + 1.35*dead + 1.35*Soil+ 1.50*0.70*P + 1.50*0.70*S + 1.50*0.70*W'

Internal forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x,sh}$ = 46.52	$n_{x,sh}$ = -0.13
$m_{y,sh}$ = 117.13	$n_{y,sh}$ = -4.76
$m_{xy,sh}$ = 4.00	$n_{xy,sh}$ = -48.20

Design forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x',bot}$ = 50.52	$n_{x',+}$ = 48.07
$m_{y',bot}$ = 121.13	$n_{y',+}$ = 43.44
$m_{x',top}$ = 0.00	$n_{x',-}$ = -48.32
$m_{y',top}$ = 0.00	$n_{y',-}$ = -52.95

Calculation is based on Wood-Armer and Nemeth methods.

Maximum reinforcement

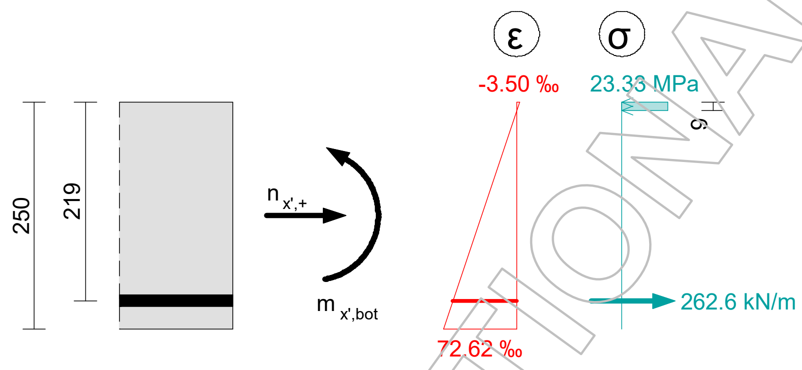
$A_{s,max}$ = 0.04 · b · t = 0.04 · 1000 · 250 = 10000 mm ^{2}/m (EN 1992-1-1 9.6.2(1))

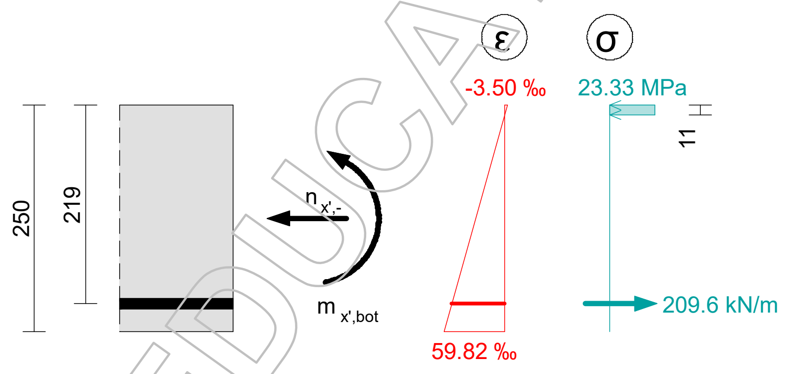
Calculation of required reinforcement from different m-n combinations

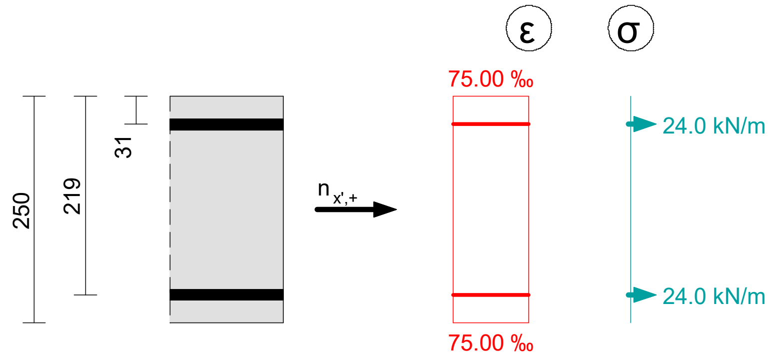
Face, direction	Bottom, x'	Bottom, x'	Top, x'	Top, x'	Bottom, y'	Bottom, y'	Top, y'	Top, y'
Sign of n	+	-	+	-	+	-	+	-
$m_{[dir][face]}$ [kN m/m]	50.52	50.52	0.00	0.00	121.13	121.13	0.00	0.00
$n_{[dir][face]}$ [kN/m]	48.07	-48.32	48.07	-48.32	43.44	-52.95	43.44	-52.95
Case	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.
$A_{sb,x'}$ [mm ^{2}/m]	604	482	55	0	-	-	-	-
$A_{sb,y'}$ [mm ^{2}/m]	-	-	-	-	1498	1377	50	0
$A_{st,x'}$ [mm ^{2}/m]	0	0	55	0	-	-	-	-
$A_{st,y'}$ [mm ^{2}/m]	-	-	-	-	0	0	50	0

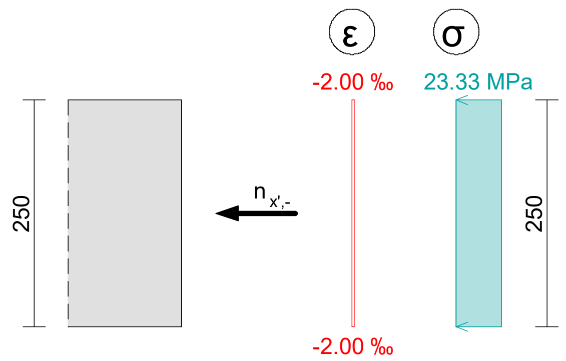
Necessary reinforcement is calculated by considering equivalent reinforcement data.

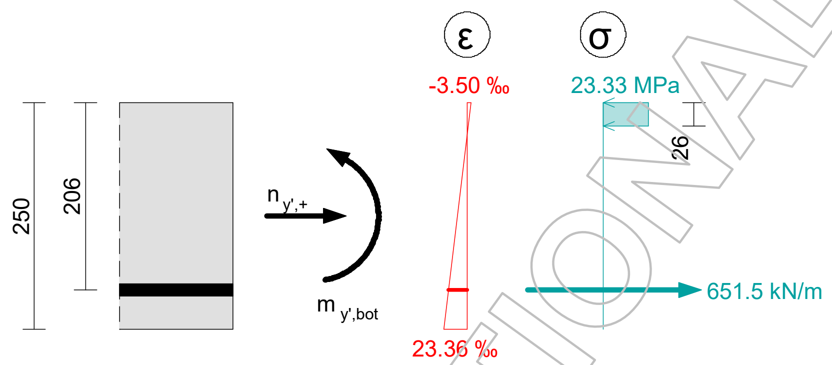
If no reinforcement is required, the ultimate resistance of the concrete section is represented in the stress figures.

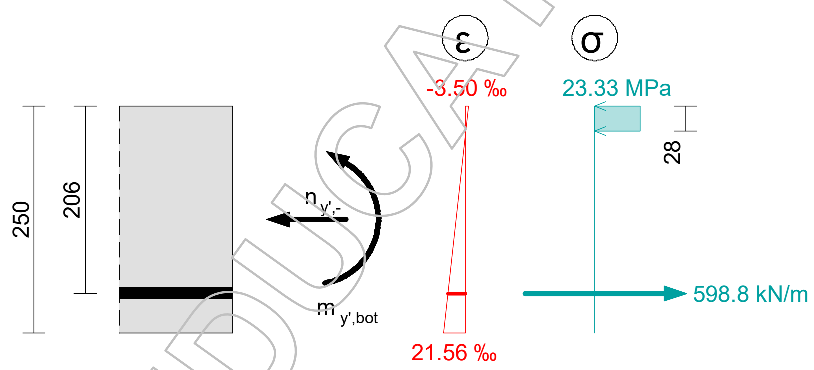


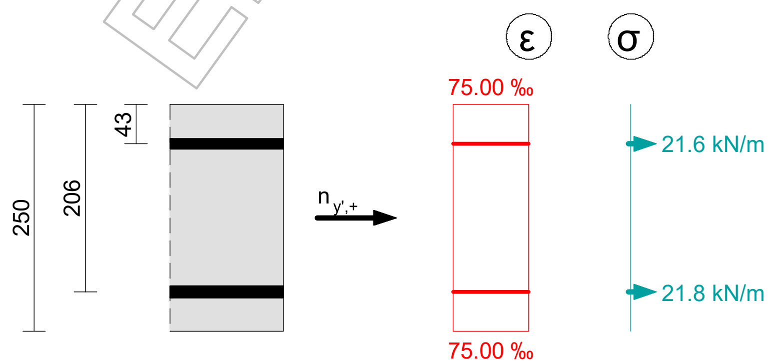


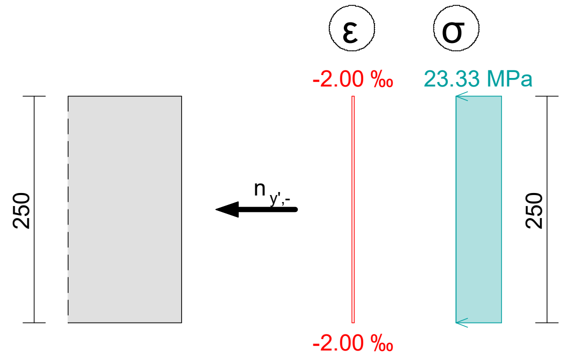

ε
σ
75.00 ‰
24.0 kN/m
250
219
31
n x',+
24.0 kN/m
75.00 ‰


ε
σ
-2.00 ‰
23.33 MPa
250
n x',-
250
-2.00 ‰


ε
σ
-3.50 ‰
23.33 MPa
26
250
206
n y',+
m y',bot
651.5 kN/m
23.36 ‰


ε
σ
-3.50 ‰
23.33 MPa
28
250
206
n y',-
m y',bot
598.8 kN/m
21.56 ‰


ε
σ
75.00 ‰
21.6 kN/m
250
206
43
n y',+
21.8 kN/m
75.00 ‰



Minimum reinforcement

$A_{s,min,vertical} = 0.002 \cdot A_c$ (EN 1992-1-1 9.6.2(1))

$A_{s,min,horizontal} = \max(0.001 \cdot A_c, 0.25 \cdot A_{s,required,vertical})$ (EN 1992-1-1 9.6.3(1))

$s_{max,walls,vertical} = \min(3 \cdot t, 400)$ (EN 1992-1-1 9.6.2(3))

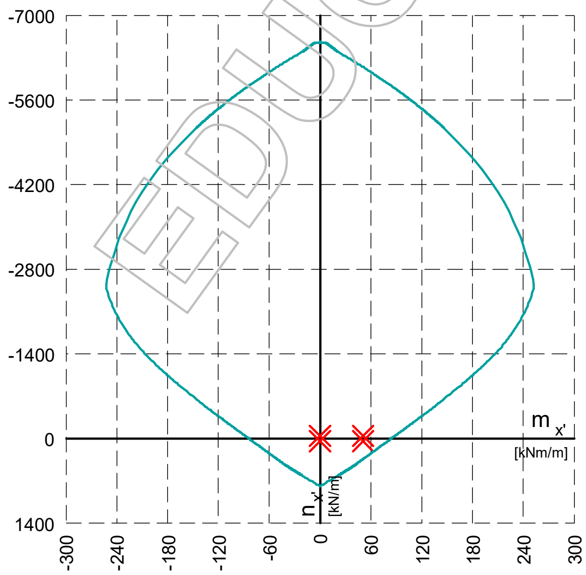
$s_{max,walls,horizontal} = 400$ mm (EN 1992-1-1 9.6.3(2))

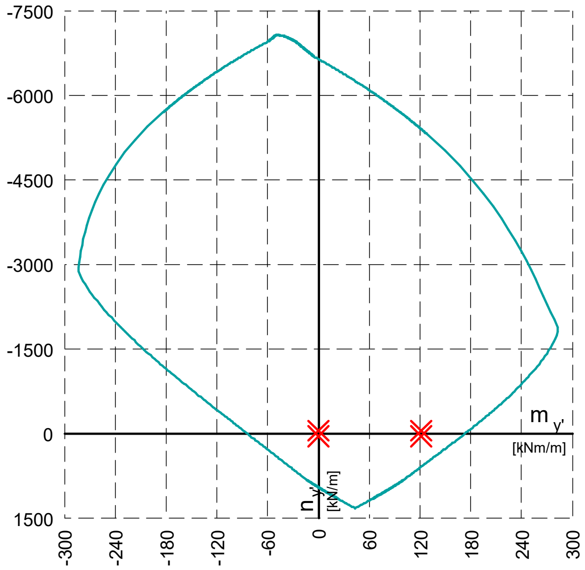
$A_{s,min,smax} = 1000 / s_{max} \cdot \Phi^2 \cdot \pi / 4$

$A_{s,min,final} = \max(A_{s,min}, A_{s,min,smax})$

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,min}$ [mm ^{2}/m]	375	250	125	250
Type	Horizontal	Vertical	Horizontal	Vertical
s_{max} [mm]	400	400	400	400
Φ [mm]	12	12	12	12
$A_{s,min,smax}$ [mm ^{2}/m]	283	283	283	283
$A_{s,min,final}$ [mm ^{2}/m]	375	283	283	283

Interaction curves based on applied reinforcement





Utilization

$A_{s,req}$ = max ($A_{s,calc}$, $A_{s,min,final}$)

$A_{s,missing}$ = $A_{s,req}$ - $A_{s,applied}$

Utilization = $A_{s,req}$ / $A_{s,applied}$ · 100

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,req}$ [mm ^{2}/m]	604	1498	283	283
$A_{s,applied}$ [mm ^{2}/m]	905	2136	905	905
$A_{s,missing}$ [mm ^{2}/m]	-	-	-	-
Utilization [%]	67	70	31	31

The amount of required reinforcement is based on an optimum calculation because several solutions are possible.

Required reinforcement, top x'

LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)'

Internal forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x,sh}$ = 31.00	$n_{x,sh}$ = 0.84
$m_{y,sh}$ = 78.13	$n_{y,sh}$ = -0.20
$m_{xy,sh}$ = 2.66	$n_{xy,sh}$ = -32.59

Design forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x',bot}$ = 33.66	$n_{x',+}$ = 33.42
$m_{y',bot}$ = 80.79	$n_{y',+}$ = 32.39
$m_{x',top}$ = 0.00	$n_{x',-}$ = -31.75
$m_{y',top}$ = 0.00	$n_{y',-}$ = -32.78

Calculation is based on Wood-Armer and Nemeth methods.

Maximum reinforcement

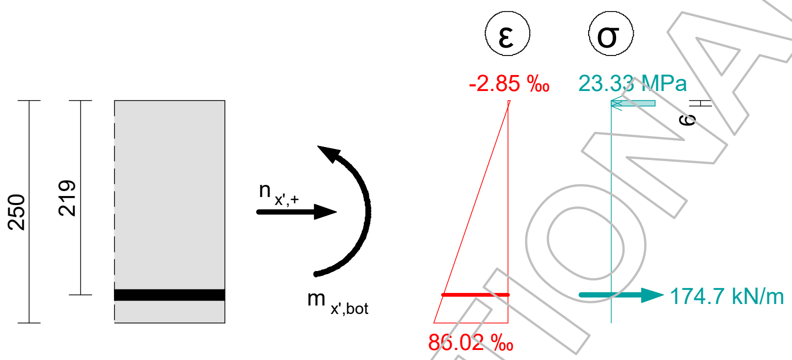
$A_{s,max}$ = 0.04 · b · t = 0.04 · 1000 · 250 = 10000 mm ^{2}/m (EN 1992-1-1 9.6.2(1))

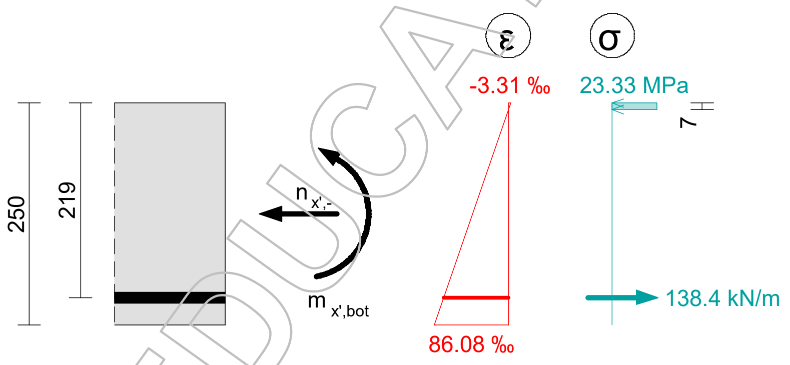
Calculation of required reinforcement from different m-n combinations

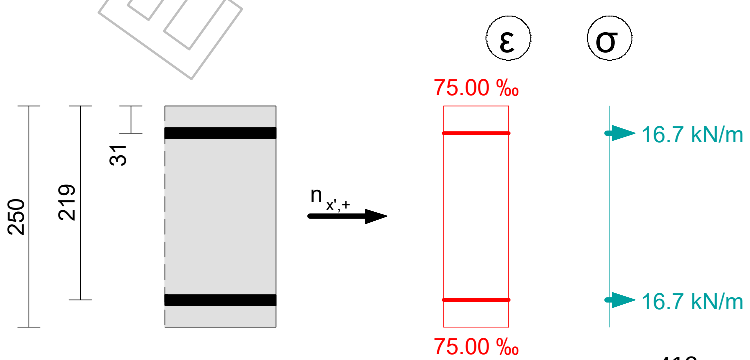
Face, direction	Bottom, x'	Bottom, x'	Top, x'	Top, x'	Bottom, y'	Bottom, y'	Top, y'	Top, y'
Sign of n	+	-	+	-	+	-	+	-
$m_{[dir][face]}$ [kN m/m]	33.66	33.66	0.00	0.00	80.79	80.79	0.00	0.00
$n_{[dir][face]}$ [kN/m]	33.42	-31.75	33.42	-31.75	32.39	-32.78	32.39	-32.78
Case	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.
$A_{sb,x'}$ [mm²/m]	402	318	38	0	-	-	-	-
$A_{sb,y'}$ [mm²/m]	-	-	-	-	983	897	37	0
$A_{st,x'}$ [mm²/m]	0	0	38	0	-	-	-	-
$A_{st,y'}$ [mm²/m]	-	-	-	-	0	0	37	0

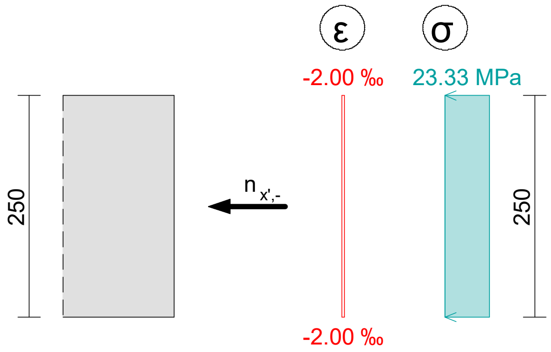
Necessary reinforcement is calculated by considering equivalent reinforcement data.

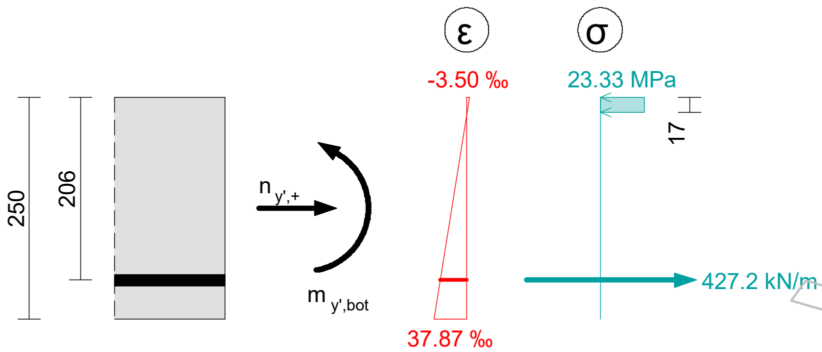
If no reinforcement is required, the ultimate resistance of the concrete section is represented in the stress figures.

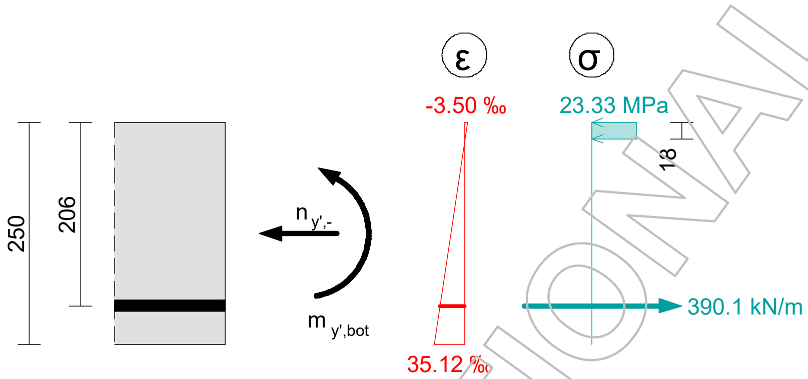


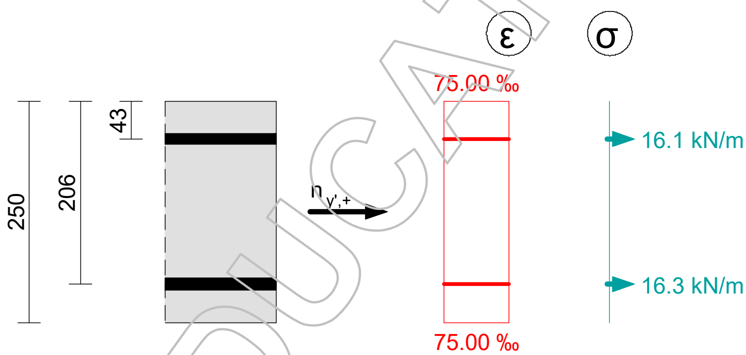


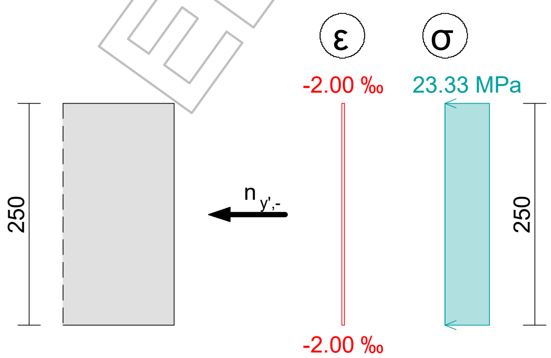



ε
σ
-2.00 ‰
23.33 MPa
250
n x',-
250
-2.00 ‰


ε
σ
-3.50 ‰
23.33 MPa
17
250
206
n y',+
m y',bot
427.2 kN/m
37.87 ‰


ε
σ
-3.50 ‰
23.33 MPa
18
250
206
n y',-
m y',bot
390.1 kN/m
35.12 ‰


ε
σ
75.00 ‰
43
250
206
n y',+
16.1 kN/m
16.3 kN/m
75.00 ‰


ε
σ
-2.00 ‰
23.33 MPa
250
n y',-
250
-2.00 ‰

Minimum reinforcement

$A_{s,min,vertical} = 0.002 \cdot A_c$ (EN 1992-1-1 9.6.2(1))

$A_{s,min,horizontal} = max(0.001 \cdot A_c, 0.25 \cdot A_{s,required,vertical})$ (EN 1992-1-1 9.6.3(1))

$s_{max,walls,vertical} = min(3 \cdot t, 400)$ (EN 1992-1-1 9.6.2(3))

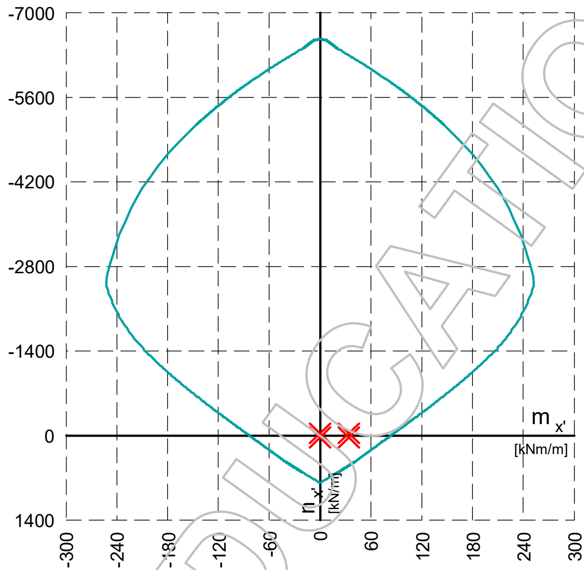
$s_{max,walls,horizontal} = 400$ mm (EN 1992-1-1 9.6.3(2))

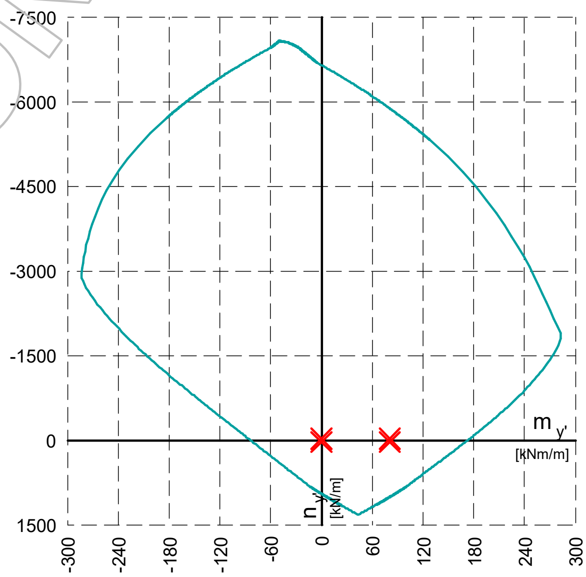
$A_{s,min,smax} = 1000 / s_{max} \cdot \Phi^2 \cdot \pi / 4$

$A_{s,min,final} = max(A_{s,min}, A_{s,min,smax})$

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,min}$ [mm ^{2}/m]	246	250	125	250
Type	Horizontal	Vertical	Horizontal	Vertical
s_{max} [mm]	400	400	400	400
Φ [mm]	12	12	12	12
$A_{s,min,smax}$ [mm ^{2}/m]	283	283	283	283
$A_{s,min,final}$ [mm ^{2}/m]	283	283	283	283

Interaction curves based on applied reinforcement





Utilization

$A_{s,req}$ = max ($A_{s,calc}$, $A_{s,min,final}$)

$A_{s,missing}$ = $A_{s,req}$ - $A_{s,applied}$

Utilization = $A_{s,req}$ / $A_{s,applied}$ · 100

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,req}$ [mm ^{2}/m]	402	983	283	283
$A_{s,applied}$ [mm ^{2}/m]	905	2136	905	905
$A_{s,missing}$ [mm ^{2}/m]	-	-	-	-
Utilization [%]	44	46	31	31

The amount of required reinforcement is based on an optimum calculation because several solutions are possible.

Required reinforcement, top y'

LC: 'Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)'

Internal forces

Moments [kN m /m]	Normal forces [kN /m]
$m_{x,sh}$ = 31.00	$n_{x,sh}$ = 0.84
$m_{y,sh}$ = 78.13	$n_{y,sh}$ = -0.20
$m_{xy,sh}$ = 2.66	$n_{xy,sh}$ = -32.59

Design forces

Moments [kN m /m]	Normal forces [kN /m]
$m_{x',bot}$ = 33.66	$n_{x',+}$ = 33.42
$m_{y',bot}$ = 80.79	$n_{y',+}$ = 32.39
$m_{x',top}$ = 0.00	$n_{x',-}$ = -31.75
$m_{y',top}$ = 0.00	$n_{y',-}$ = -32.78

Calculation is based on Wood-Armer and Nemeth methods.

Maximum reinforcement

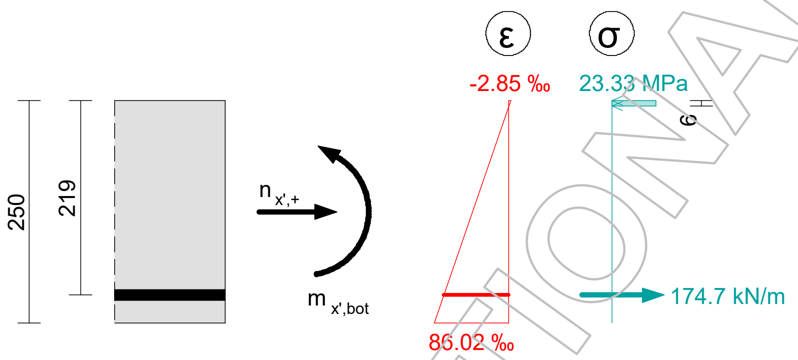
$A_{s,max}$ = 0.04 · b · t = 0.04 · 1000 · 250 = 10000 mm ^{2}/m (EN 1992-1-1 9.6.2(1))

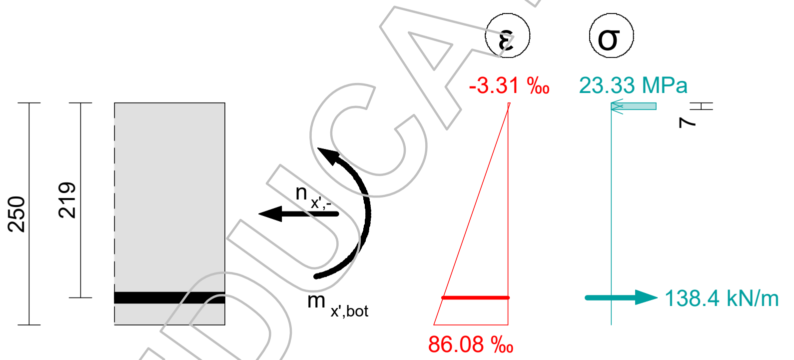
Calculation of required reinforcement from different m-n combinations

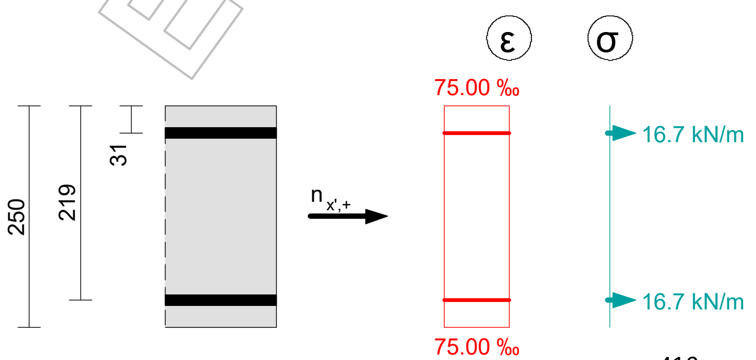
Face, direction	Bottom, x'	Bottom, x'	Top, x'	Top, x'	Bottom, y'	Bottom, y'	Top, y'	Top, y'
Sign of n	+	-	+	-	+	-	+	-
$m_{[dir][face]}$ [kN m/m]	33.66	33.66	0.00	0.00	80.79	80.79	0.00	0.00
$n_{[dir][face]}$ [kN/m]	33.42	-31.75	33.42	-31.75	32.39	-32.78	32.39	-32.78
Case	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.
$A_{sb,x'}$ [mm ^{2}/m]	402	318	38	0	-	-	-	-
$A_{sb,y'}$ [mm ^{2}/m]	-	-	-	-	983	897	37	0
$A_{st,x'}$ [mm ^{2}/m]	0	0	38	0	-	-	-	-
$A_{st,y'}$ [mm ^{2}/m]	-	-	-	-	0	0	37	0

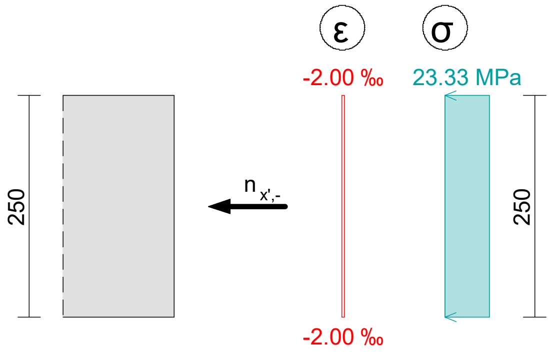
Necessary reinforcement is calculated by considering equivalent reinforcement data.

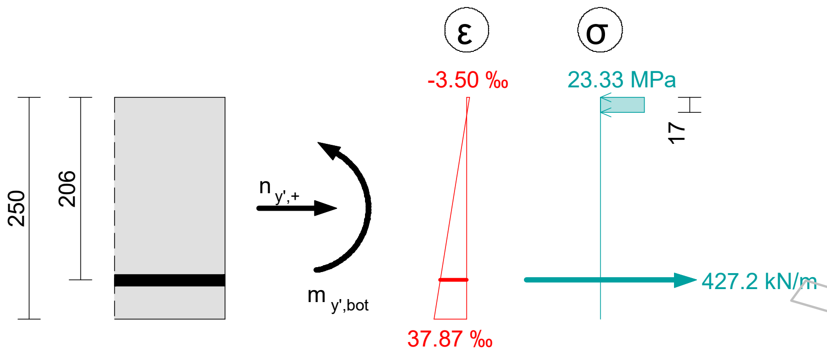
If no reinforcement is required, the ultimate resistance of the concrete section is represented in the stress figures.

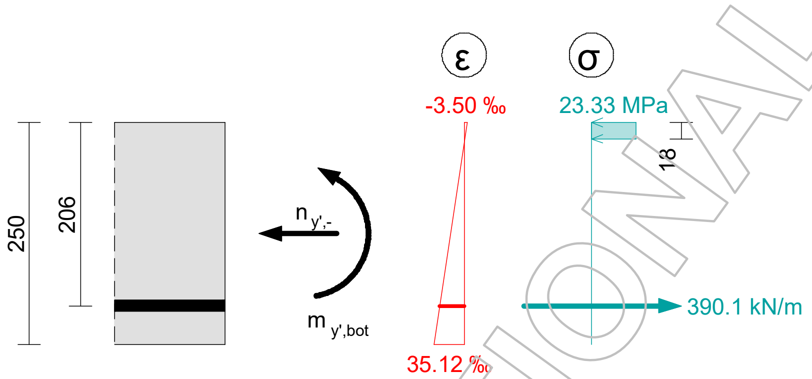


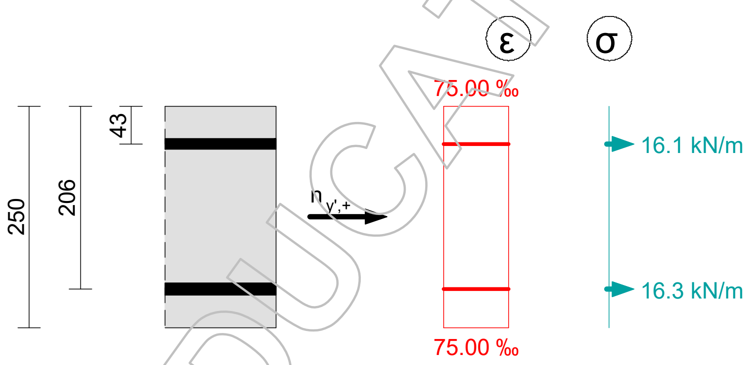


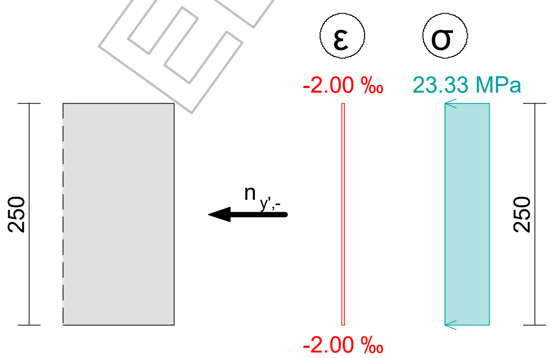



ε
σ
-2.00 ‰
23.33 MPa
250
n x',-
250
-2.00 ‰


ε
σ
-3.50 ‰
23.33 MPa
17
250
206
n y',+
m y',bot
427.2 kN/m
37.87 ‰


ε
σ
-3.50 ‰
23.33 MPa
18
250
206
n y',-
m y',bot
390.1 kN/m
35.12 ‰


ε
σ
75.00 ‰
43
250
206
n y',+
16.1 kN/m
16.3 kN/m
75.00 ‰


ε
σ
-2.00 ‰
23.33 MPa
250
n y',-
250
-2.00 ‰

Minimum reinforcement

$A_{s,min,vertical}$ = 0.002 · A_c (EN 1992-1-1 9.6.2(1))

$A_{s,min,horizontal}$ = max (0.001 · A_c, 0.25 · $A_{s,required,vertical}$) (EN 1992-1-1 9.6.3(1))

$s_{max,walls,vertical}$ = min (3 · t, 400) (EN 1992-1-1 9.6.2(3))

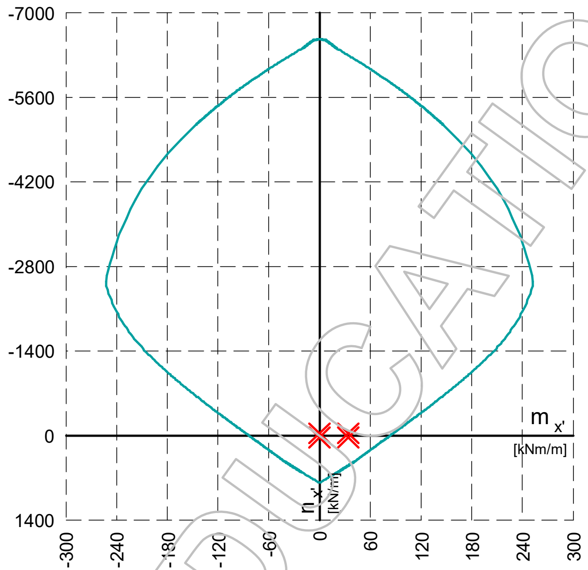
$s_{max,walls,horizontal}$ = 400 mm (EN 1992-1-1 9.6.3(2))

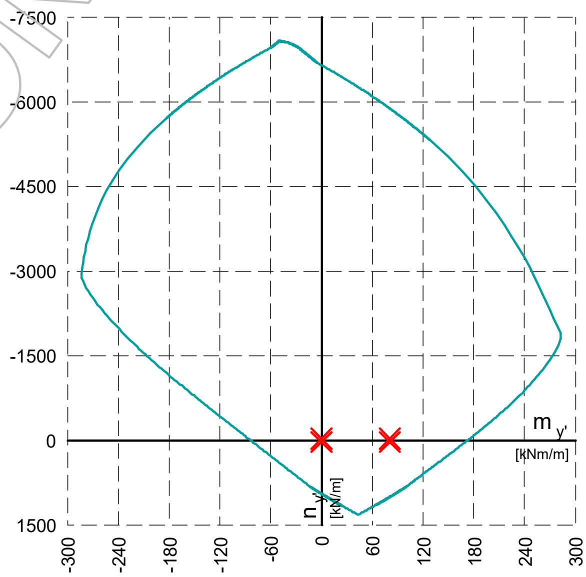
$A_{s,min,smax}$ = 1000 / s_{max} · Φ^2 · π / 4

$A_{s,min,final}$ = max ($A_{s,min}$, $A_{s,min,smax}$)

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,min}$ [mm ^{2}/m]	246	250	125	250
Type	Horizontal	Vertical	Horizontal	Vertical
s_{max} [mm]	400	400	400	400
Φ [mm]	12	12	12	12
$A_{s,min,smax}$ [mm ^{2}/m]	283	283	283	283
$A_{s,min,final}$ [mm ^{2}/m]	283	283	283	283

Interaction curves based on applied reinforcement





Utilization

$A_{s,req}$ = max ($A_{s,calc}$, $A_{s,min,final}$)

$A_{s,missing}$ = $A_{s,req}$ - $A_{s,applied}$

Utilization = $A_{s,req}$ / $A_{s,applied}$ · 100

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,req}$ [mm ^{2}/m]	402	983	283	283
$A_{s,applied}$ [mm ^{2}/m]	905	2136	905	905
$A_{s,missing}$ [mm ^{2}/m]	-	-	-	-
Utilization [%]	44	46	31	31

The amount of required reinforcement is based on an optimum calculation because several solutions are possible.

Shear capacity

LC: '1.35*SW + 1.35*dead + 1.35*Soil+ 1.50*0.70*P + 1.50*0.70*S + 1.50*0.70*W'

Internal forces

Normal forces [kN /m]	Shear forces [kN /m]
$n_{x,sh}$ = -0.13	$v_{xz,sh}$ = -23.36
$n_{y,sh}$ = -4.76	$v_{yz,sh}$ = 28.09
$n_{xy,sh}$ = -48.20	

Design forces

$$v_{max} = \sqrt{v_{xz,sh}^2 + v_{yz,sh}^2} = \sqrt{-23.36^2 + 28.09^2} = 36.54 \text{ kN /m}$$

$$\alpha = \text{atan}\left(\frac{v_{yz,sh}}{v_{xz,sh}}\right) = \text{atan}\left(\frac{28.09}{-23.36}\right) = -50.25 \ °$$

n_α = 44.53 kN /m

Calculation of shear capacity in the main direction (EN 1992-1-1: 6.2.2)

$A_{s,\alpha} = 1633 \ \ mm^2/m$

$d_{eff} = \frac{d_x + d_y}{2} = \frac{219 + 206}{2} = 213 \ \ mm$

$\rho_\alpha = \min\left(\frac{A_{s,\alpha}}{d_{eff}}, 0.02\right) = \min\left(\frac{1633}{213}, 0.02\right) = 0.00768$

$\sigma_\alpha = \frac{n_\alpha}{t} = \frac{44.53}{0.25} = 0.1781 \ \ N/mm^2$

$\sigma_{cp,\alpha} = \min(-(\sigma_\alpha), 0.2 \cdot f_{cd,U}) = \min(-(0.1781), 0.2 \cdot 23.33) = -0.1781 \ \ N/mm^2$ *

$C_{Rd,c} = \frac{0.15}{\gamma_{C,U}} = \frac{0.15}{1.5} = 0.10$

$k = \min\left(1 + \sqrt{\frac{200}{d_{eff}}}, 2.0\right) = \min\left(1 + \sqrt{\frac{200}{213}}, 2.0\right) = 1.97$

$k_1 = 0.30$

$v_{min} = 0.035 \cdot k^{3/2} \cdot f_{ck}^{1/2} = 0.035 \cdot 1.97^{3/2} \cdot 35.00^{1/2} = 0.5724$ (6.3.N)

$v_{Rd,c} = \max\left(C_{Rd,c} \cdot k \cdot (100.0 \cdot \rho_\alpha \cdot f_{ck})^{1/3} + k_1 \cdot \sigma_{cp,\alpha}, v_{min} + k_1 \cdot \sigma_{cp,\alpha}\right) \cdot d_{eff} =$

$= \max\left(0.10 \cdot 1.97 \cdot (100.0 \cdot 0.00768 \cdot 35.00)^{1/3} + 0.30 \cdot -0.1781, 0.5724 + 0.30 \cdot -0.1781\right) \cdot 213$

$= 114.12 \ \ kN/m$ (6.2.a, 6.2.b)

$v_{Rd,c} > v_{max} \rightarrow$ Utilization $= \frac{v_{max}}{v_{Rd,c}} \cdot 100 = \frac{36.54}{114.12} \cdot 100 = 32 \ \%$

* EN 1992-1-1: 6.2.2 considers tension forces with negative sign.

Shell buckling

Not calculated, there is no relevant buckling region at the point.

Crack width, bottom

LC: 'SW + dead + Soil + 0.30*P + 0.30*S + 0.20*W'

Internal forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x,sh}$ = 34.45	$n_{x,sh}$ = -0.07
$m_{y,sh}$ = 86.80	$n_{y,sh}$ = -2.03
$m_{xy,sh}$ = 2.95	$n_{xy,sh}$ = -34.94

Direction of crack width

$\alpha_{bottom} = 92.93 \ \ °$

No crack on top face.

Calculated by Gvozdiev method.

Stresses

Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
n [kN/m]	1.54	-3.64	-	-
m [kN m/m]	86.36	34.89	-	-
$A_{s,eq[face]}$ [mm²/m]	2133	908	-	-
$c_{\alpha[face]}$ [mm]	44	31	-	-
$A_{s,eq[other\ face]}$ [mm²/m]	905	905	-	-
$c_{\alpha[other\ face]}$ [mm]	43	31	-	-
$\sigma_{I,c[face]}$ [N/mm²]	7.48	3.11	-	-
$\sigma_{I,c[other\ face]}$ [N/mm²]	-7.73	-3.14	-	-
$\sigma_{II,s[face]}$ [N/mm²]	218.54	-	-	-
$\sigma_{II,s[other\ face]}$ [N/mm²]	0.00	-	-	-
x_{II} [mm]	59.23	-	-	-
Evaluation*	Cracked	Not cracked	Not cracked	Not cracked

*No reinf: $A_{s,eq} \leq 0$

Not cracked: $(\sigma_{I,c[bottom]} \leq f_{ctm}$ and $\sigma_{I,c[top]} \leq f_{ctm})$ or $x_{II} \leq 0$ or $x_{II} > t$

Cracked: otherwise

Crack width

$$A_{c,eff} = \min\left(t/2,\ 2.5 \cdot c_\alpha,\ (t - x_{II})/3,\ c_\alpha + 1.5 \cdot \Phi_\alpha\right)$$

$$\rho_{p,eff} = A_s / A_{c,eff}$$

$$\varepsilon = \max\left(\frac{\sigma_{II,s} - \frac{0.4 \cdot f_{ctm}}{\rho_{p,eff}} \cdot \left(1 + \frac{E_s}{E_{c,m}} \cdot \rho_{p,eff}\right)}{E_s},\ \frac{0.6 \cdot \sigma_{II,s}}{E_s}\right)$$

$$k_2 = \frac{\varepsilon_{bottom} + \varepsilon_{top}}{2 \cdot \max(\varepsilon_{bottom}, \varepsilon_{top})}$$

$$s_\alpha \leq 5 \cdot c_\alpha \rightarrow s_{r,max} = k_3 \cdot (c_\alpha - \Phi_\alpha / 2) + k_1 \cdot k_2 \cdot k_4 \cdot \Phi_\alpha \cdot \frac{A_{c,eff}}{A_s}$$

$$s_\alpha > 5 \cdot c_\alpha \rightarrow s_{r,max} = 1.3 \cdot (t - x_{II})$$

$$c_w = s_{r,max} \cdot \varepsilon_{[face]}$$

Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
$A_{c,eff[face]}$ [mm²/m]	63176	-	-	-

Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
$\rho_{p,eff[face]}$	0.03376	-	-	-
$\varepsilon_{[face]}$	0.00087	-	-	-
$A_{c,eff[other face]}$ [mm²/m]	62582	-	-	-
$\varepsilon_{[other face]}$	0.00	-	-	-
Φ_{dir} [mm]	13	-	-	-
s_{dir} [mm]	63	-	-	-
k_1	0.80	-	-	-
k_2	0.50	-	-	-
k_3	3.40	-	-	-
k_4	0.425	-	-	-
$s_{r,max}$ [mm]	191.72	-	-	-
c_w [mm]	0.17	-	-	-

Utilization

Utilization $= c_w / c_{w,lim} \cdot 100$

Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
$c_{w,lim}$ [mm]	1.00	1.00	1.00	1.00
Utilization [%]	17	-	-	-

Crack width, top

LC: 'SW + dead + Soil + 0.30*P + 0.30*S + 0.20*W'

Internal forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x,sh}$ = 34.45	$n_{x,sh}$ = -0.07
$m_{y,sh}$ = 86.80	$n_{y,sh}$ = -2.03
$m_{xy,sh}$ = 2.95	$n_{xy,sh}$ = -34.94

Direction of crack width

α_{bottom} = 92.93 °

No crack on top face.

Calculated by Gvozdiev method.

Stresses

Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
n [kN/m]	1.54	-3.64	-	-
m [kNm/m]	86.36	34.89	-	-
$A_{s,eq[face]}$ [mm^2/m]	2133	908	-	-
$c_{\alpha[face]}$ [mm]	44	31	-	-
$A_{s,eq[other face]}$ [mm^2/m]	905	905	-	-
$c_{\alpha[other face]}$ [mm]	43	31	-	-
$\sigma_{I,c[face]}$ [N/mm^2]	7.48	3.11	-	-
$\sigma_{I,c[other face]}$ [N/mm^2]	-7.73	-3.14	-	-
$\sigma_{II,s[face]}$ [N/mm^2]	218.54	-	-	-
$\sigma_{II,s[other face]}$ [N/mm^2]	0.00	-	-	-
x_{II} [mm]	59.23	-	-	-
Evaluation*	Cracked	Not cracked	Not cracked	Not cracked

*No reinf: $A_{s,eq} \leq 0$

Not cracked: $(\sigma_{I,c[bottom]} \leq f_{ctm}$ and $\sigma_{I,c[top]} \leq f_{ctm})$ or $x_{II} \leq 0$ or $x_{II} > t$

Cracked: otherwise

Crack width

$$A_{c,eff} = \min(t/2,\ 2.5 \cdot c_\alpha,\ (t - x_{II})/3,\ c_\alpha + 1.5 \cdot \Phi_\alpha)$$

$$\rho_{p,eff} = A_s / A_{c,eff}$$

$$\varepsilon = \max\left(\frac{\sigma_{II,s} - \frac{0.4 \cdot f_{ctm}}{\rho_{p,eff}} \cdot \left(1 + \frac{E_s}{E_{c,m}} \cdot \rho_{p,eff}\right)}{E_s},\ \frac{0.6 \cdot \sigma_{II,s}}{E_s}\right)$$

$$k_2 = \frac{\varepsilon_{bottom} + \varepsilon_{top}}{2 \cdot \max(\varepsilon_{bottom}, \varepsilon_{top})}$$

$$s_\alpha \leq 5 \cdot c_\alpha \rightarrow s_{r,max} = k_3 \cdot (c_\alpha - \Phi_\alpha / 2) + k_1 \cdot k_2 \cdot k_4 \cdot \Phi_\alpha \cdot \frac{A_{c,eff}}{A_s}$$

$$s_\alpha > 5 \cdot c_\alpha \rightarrow s_{r,max} = 1.3 \cdot (t - x_{II})$$

$$c_w = s_{r,max} \cdot \varepsilon_{[face]}$$

Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
$A_{c,eff[face]}$ [mm^2/m]	63176	-	-	-

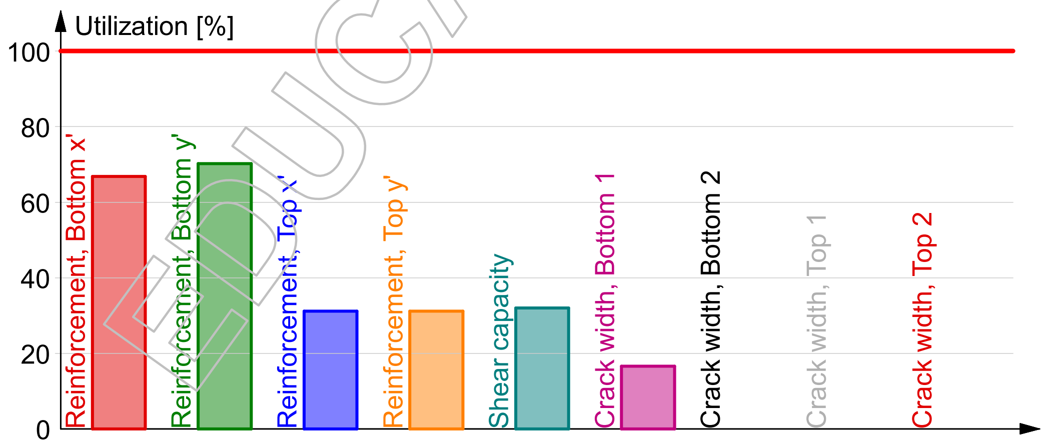
Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
$\rho_{p,eff[face]}$	0.03376	-	-	-
$\varepsilon_{[face]}$	0.00087	-	-	-
$A_{c,eff[other\ face]}$ [mm^2/m]	62582	-	-	-
$\varepsilon_{[other\ face]}$	0.00	-	-	-
Φ_{dir} [mm]	13	-	-	-
s_{dir} [mm]	63	-	-	-
k_1	0.80	-	-	-
k_2	0.50	-	-	-
k_3	3.40	-	-	-
k_4	0.425	-	-	-
$s_{r,max}$ [mm]	191.72	-	-	-
c_w [mm]	0.17	-	-	-

Utilization

Utilization $= c_w / c_{w,lim} \cdot 100$

Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
$c_{w,lim}$ [mm]	1.00	1.00	1.00	1.00
Utilization [%]	17	-	-	-

Summary



6 Connection design

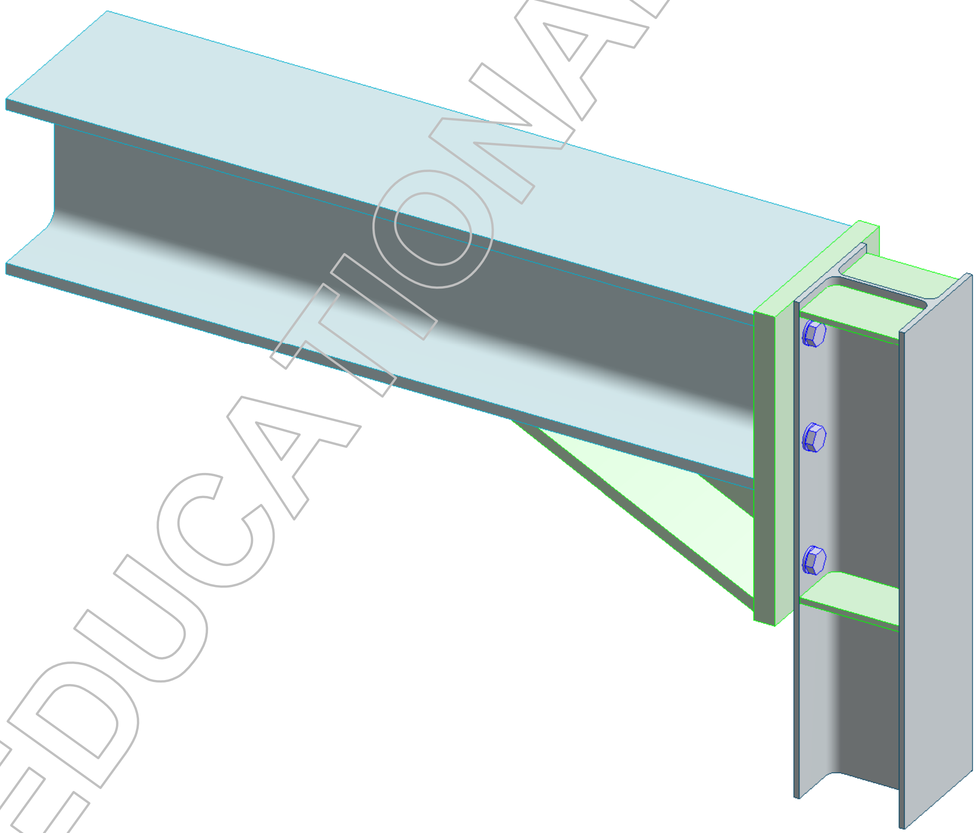
6.1 Column/bean and beam/beam connection

Max. of load combinations, Joint, Utilization

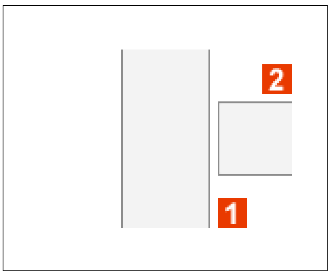
ID	Solution	Utilization	Comb
[-]	[-]	[%]	[-]
SJ.1	BC1	93	0.89*1.35*SW...
SJ.2	BC1	59	0.89*1.35*SW ...
SJ.3	BC5A	88	0.89*1.35*SW ...
SJ.4	CB1	71	0.89*1.35*SW ...
SJ.5	CB1	43	0.89*1.35*SW ...
SJ.6	CB1	44	0.89*1.35*SW ...
SJ.7	BC3	40	0.89*1.35*SW ...
SJ.8	BC3	42	0.89*1.35*SW ...
SJ.9	BC3	24	0.89*1.35*SW ...
SJ.10	BB3	37	Ultimate - only ...

ID	Solution	Utilization	Comb
[-]	[-]	[%]	[-]
SJ.11	BB3	68	0.89*1.35*SW...
SJ.12	BB3	99	0.89*1.35*SW ...
SJ.13	CB2	84	0.89*1.35*SW ...
SJ.14	CB2	84	0.89*1.35*SW ...
SJ.15	CB2	84	0.89*1.35*SW ...
SJ.16	BC3	33	0.89*1.35*SW ...
SJ.17	BC3	32	0.89*1.35*SW ...
SJ.18	BC3	34	0.89*1.35*SW ...
SJ.19	BC3	31	0.89*1.35*SW ...
SJ.20	BC3	34	0.89*1.35*SW ...

SJ.3.1
Maximum of load combinations

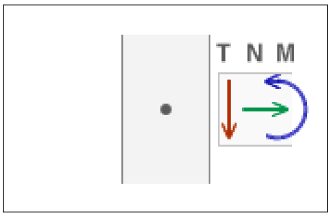


Member data



	Member 1	Member 2
Cross-section	HE-A 200	HE-B 300
Material	S 355	S 355
γ_{M0}	1.05	1.05
γ_{M1}	1.05	1.05
γ_{M2}	1.25	1.25
γ_{M5}	1.00	1.00

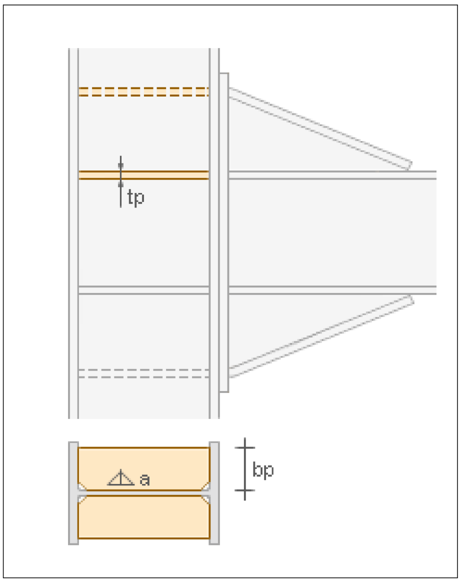
Load combinations



	No	Name	N [kN]	T [kN]	M [kNm]
X	1	SJ.3.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)	0.00	101	0.00
X	2	SJ.3.1: Staility2: 0,9G+1,5W+Hi (including misalignment load)	0.00	101	0.00
X	3	SJ.3.1: Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)	0.00	258	0.00
X	4	SJ.3.1: 1.35*SW + 1.35*dead + 1.35*Soil+ 1.50*0.70*P + 1.50*0.70*S + 1.50*0.70*W	0.00	249	0.00
X	5	SJ.3.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W	0.00	258	0.00
X	6	SJ.3.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W	0.00	249	0.00
X	7	SJ.3.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P+ 1.50*0.70*S + 1.50*W	0.00	233	0.00

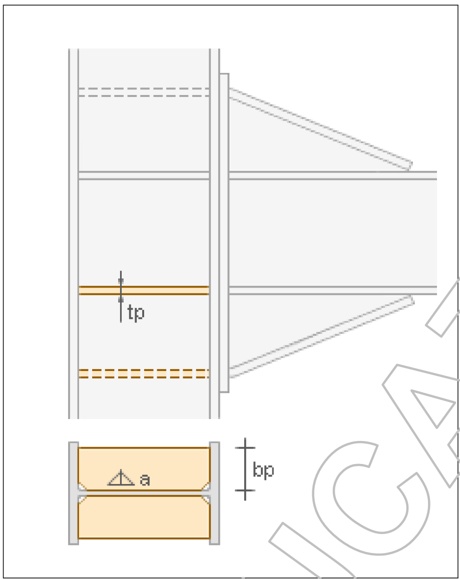
Column

Top stiffener



Apply	Yes
Material	S 355
γ_{M0}	1.00
γ_{M1}	1.00
γ_{M2}	1.25
γ_{M5}	1.00
tp [mm]	10
bp [mm]	96
Place at haunch	No
a [mm]	6.0

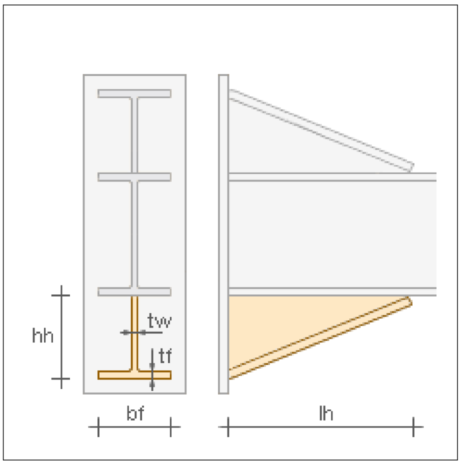
Bottom stiffener



Apply	Yes
Material	S 355
γ_{M0}	1.00
γ_{M1}	1.00
γ_{M2}	1.25
γ_{M5}	1.00
tp [mm]	10
bp [mm]	96
Place at haunch	Yes
a [mm]	6.0

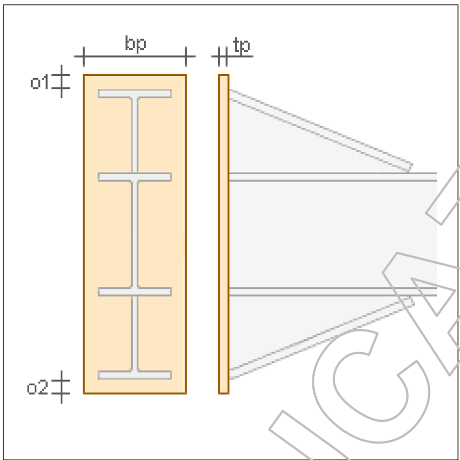
Beam

Bottom haunch



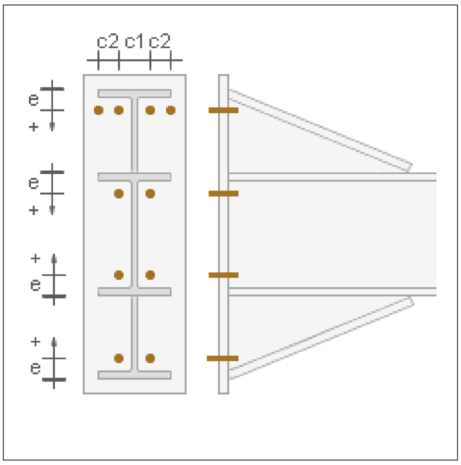
Apply	Yes
Material	S 355
γ_{M0}	1.05
γ_{M1}	1.05
γ_{M2}	1.25
γ_{M5}	1.00
hh [mm]	210
lh [mm]	420
tw [mm]	12
Apply flange	Yes
bf [mm]	300
tf [mm]	20

End-plate



Material	S 355
γ_{M0}	1.05
γ_{M1}	1.05
γ_{M2}	1.25
γ_{M5}	1.00
tp [mm]	36
bp [mm]	310
o1 [mm]	10
o2 [mm]	10
Weld buttering (EN 1993-1-10: Table 3.2/b)	No
Preheating (> 100 °C)	No

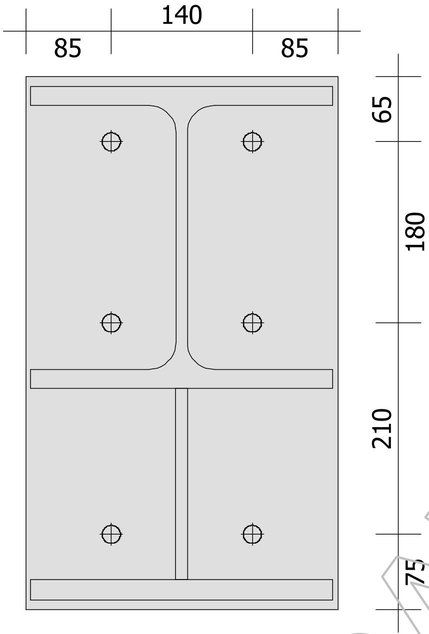
Bolts



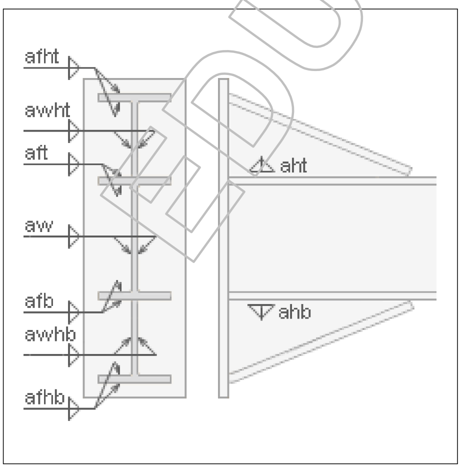
Size	HR-M22
Quality	8.8
Prestressed	No
Flip	Yes
Washer at nut	No
Washer at bolt head	Yes
c1 [mm]	140
c2 [mm]	55

Placed relative to:	n	e [mm]
Bottom haunch	2	65
Top flange	2	55
Bottom flange	2	65

Bolt arrangement



Welds



afht [mm]	12
awht [mm]	8.0
aft [mm]	6.0
aw [mm]	4.0
afb [mm]	6.0
awhb [mm]	8.0
afhb [mm]	12
aht [mm]	8.0
ahb [mm]	8.0

Calculation

Tension boltrows for shear	No

Warning: The selected joint type cannot handle all internal forces acting on the connected structural elements.

LC3: Bar 1 (Mt)

LC4: Bar 1 (Mt)

LC5: Bar 1 (Mt)

LC6: Bar 1 (Mt)

LC7: Bar 1 (Mt)

Joint utilization: 88 % (LC: 'SJ.3.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*V

Moment resistance and stiffness (EN 1993-1-8: [6.2.7]): 0 % (LC: 'SJ.3.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dea

End-plate internal forces: N = 0.00 kN, T = 101.18 kN, M = 0.00 kNm

T stub 1

Parameters and effective lengths at the end-plate

m = 60 mm, e = 85 mm, m_2 = 29 mm, p = 180 mm

$l_{eff,cp}$ = 377 mm, $l_{eff,nc}$ = 463 mm, $l_{eff,1}$ = 377 mm, $l_{eff,2}$ = 463 mm

$g_{l,eff,cp}$ = 368 mm, $g_{l,eff,nc}$ = 380 mm

Parameters and effective lengths at the column flange

m = 52 mm, e = 30 mm, m_2 = 34 mm, p = 180 mm

$l_{eff,cp}$ = 329 mm, $l_{eff,nc}$ = 275 mm, $l_{eff,1}$ = 275 mm, $l_{eff,2}$ = 275 mm

$g_{l,eff,cp}$ = 344 mm, $g_{l,eff,nc}$ = 241 mm

Individual capacities

$F_{T,Rd,ep}$ = 349.06 kN, Failure mode: 3

$F_{t,wb,Rd}$ = 1401.45 kN

$F_{T,Rd,cf}$ = 177.36 kN, Failure mode: 1

$F_{t,wc,Rd}$ = 400.83 kN

Final T-stub capacity: $F_{T,Rd}$ = 177.36 kN

T stub 2

Parameters and effective lengths at the end-plate

m = 60 mm, e = 85 mm, p = 195 mm

$l_{eff,cp}$ = 377 mm, $l_{eff,nc}$ = 346 mm, $l_{eff,1}$ = 346 mm, $l_{eff,2}$ = 346 mm

$g_{l,eff,cp}$ = 390 mm, $g_{l,eff,nc}$ = 195 mm

Parameters and effective lengths at the column flange

m = 52 mm, e = 30 mm, p = 195 mm

$l_{eff,cp}$ = 329 mm, $l_{eff,nc}$ = 247 mm, $l_{eff,1}$ = 247 mm, $l_{eff,2}$ = 247 mm

$g_{l,eff,cp}$ = 390 mm, $g_{l,eff,nc}$ = 195 mm

Individual capacities

$F_{T,Rd,ep}$ = 349.06 kN, Failure mode: 3

$F_{t,wb,Rd}$ = 1287.34 kN

$F_{T,Rd,cf}$ = 159.46 kN, Failure mode: 1

$F_{t,wc,Rd}$ = 381.38 kN

Group (1- 2) capacities

Effective parameters at the end-plate

$l_{eff,1,g}$ = 575 mm, $l_{eff,2,g}$ = 575 mm

Effective parameters at the column flange

$l_{eff,1,g}$ = 436 mm, $l_{eff,2,g}$ = 436 mm

$F_{T,Rd,ep}$ = 698.11 kN, Failure mode: 3

$F_{t,wb,Rd}$ = 2138.99 kN

$F_{T,Rd,cf}$ = 281.70 kN, Failure mode: 1

$F_{t,wc,Rd}$ = 467.93 kN

T-stub capacities in group (1- 2)

$F_{T,Rd,ep}$ = 520.75 kN

$F_{t,wb,Rd}$ = 1961.63 kN

$F_{T,Rd,cf}$ = 104.33 kN

$F_{t,wc,Rd}$ = 290.57 kN

Final T-stub capacity: $F_{T,Rd}$ = 104.33 kN

Column web shear resistance

$V_{wp,web,Rd}$ = 317.65 kN, $V_{wp,add,Rd}$ = 14.06 kN

$V_{wp,Rd}$ = 331.71 kN, β = 1.00, $F_{c,ws,Rd}$ = 331.71 kN

Beam web and flange compression resistance

Compressed haunch with web and flange plate is applied.

Compressed bar flange is neglected in the calculation.

W = 1790369 mm^3

$M_{c,Rd}$ = 605.32 kNm

$F_{c,fb,Rd}$ = 1234.08 kN

Beam web transverse compression resistance

$b_{eff,c,wc}$ = 275 mm, ω = 0.81, ρ = 0.91

k_{wc} = 0.70

$F_{c,wc,Rd}$ = 527.96 kN

Bolt-row capacities

$F_{t1,Rd}$ = 177.36 kN, h = 445 mm

$F_{t2,Rd}$ = 104.33 kN, h = 265 mm

$F_{t3,Rd}$ = 0.00 kN, h = 55 mm

Joint moment capacity: M_{Rd} = 106.57 kNm

Stiffness calculation (EN 1993-1-8: [6.3])

S_j = 28561 kNm/rad, $S_{j,ini}$ = 28561 kNm/rad, m = 1.00

k_1 = 1.8 mm

A_{vc} = 1808 mm^2, β = 1.00

k_{eq} = 1.9 mm

t_{wc} = 6 mm, d_c = 134 mm, t_{fc} = 10 mm

Boltrow 1, l: k_3 = 9.3 mm, k_4 = 1.5 mm, k_5 = 71.7 mm, $k_{eff,r}$ = 1.1 mm ($b_{eff,t,wc}$ = 275 mm, l_{eff} = 241 mm

Boltrow 2, l: k_3 = 8.4 mm, k_4 = 1.2 mm, k_5 = 38.0 mm, $k_{eff,r}$ = 0.9 mm ($b_{eff,t,wc}$ = 247 mm, l_{eff} = 195 mm

k_{10} = 7.4 mm, for all boltrows

A_s = 303 mm^2, L_b = 66 mm

z_{eq} = 385 mm

Shear resistance (EN 1993-1-8: [3.6.1]): 88 % (LC: 'SJ.3.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*

V_{Ed} = 257.75 kN

$F_{v,Rd}$ = 145.97 kN (unthreaded)

$F_{b,Rd,end\text{-}plate,row\ 3}$ = 807.84 kN (α_b = 1.00, k_1 = 2.50)

$F_{b,Rd,Flange,row\ 3}$ = 161.57 kN (α_b = 1.00, k_1 = 1.80)

V_{Rd} = 291.94 kN

Compressed stiffener resistance (EN 1993-1-1: [6.2.4], EN 1993-1-5: [9.1]): 27 % (LC: 'SJ.3.1: Stability1: wind y- dom. (0,9 SW

F = 281.70 kN

$F_{c,Rd}$ = 1053.34 kN

Compressed stiffener (checked for plate strength) weld resistance (EN 1993-1-8: [4.5.3.2; (1)]): 64 % (LC: 'SJ.3.1: Stability1: w

σ_{pp} = 0.00 N/mm^2, τ_{pp} = 0.00 N/mm^2, τ_{pl} = 167.06 N/mm^2

$\sigma_{Rd,1}$ = 453.33 N/mm^2, $\sigma_{Rd,2}$ = 367.20 N/mm^2

Tensioned stiffener resistance: Not relevant

Web tension resistance is not decesive in the moment resistance calculation.

Tensioned stiffener (checked for plate strength) weld resistance: Not relevant

Beam bottom flange weld resistance: Not relevant

Beam top flange weld resistance: Not relevant

Beam web weld resistance (EN 1993-1-8: [4.5.3.2; (1)]): 59 % (LC: 'SJ.3.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil +

σ_{pp} = 0.00 N/mm^2, τ_{pp} = 0.00 N/mm^2, τ_{pl} = 154.90 N/mm^2

$\sigma_{Rd,1}$ = 453.33 N/mm^2, $\sigma_{Rd,2}$ = 367.20 N/mm^2

Beam Bottom haunch weld check for plate strength (EN 1993-1-8: [4.5.3]): 80 % (LC: 'SJ.3.1: Stability1: wind y- dom. (0,9 SW

a = 8.00 mm

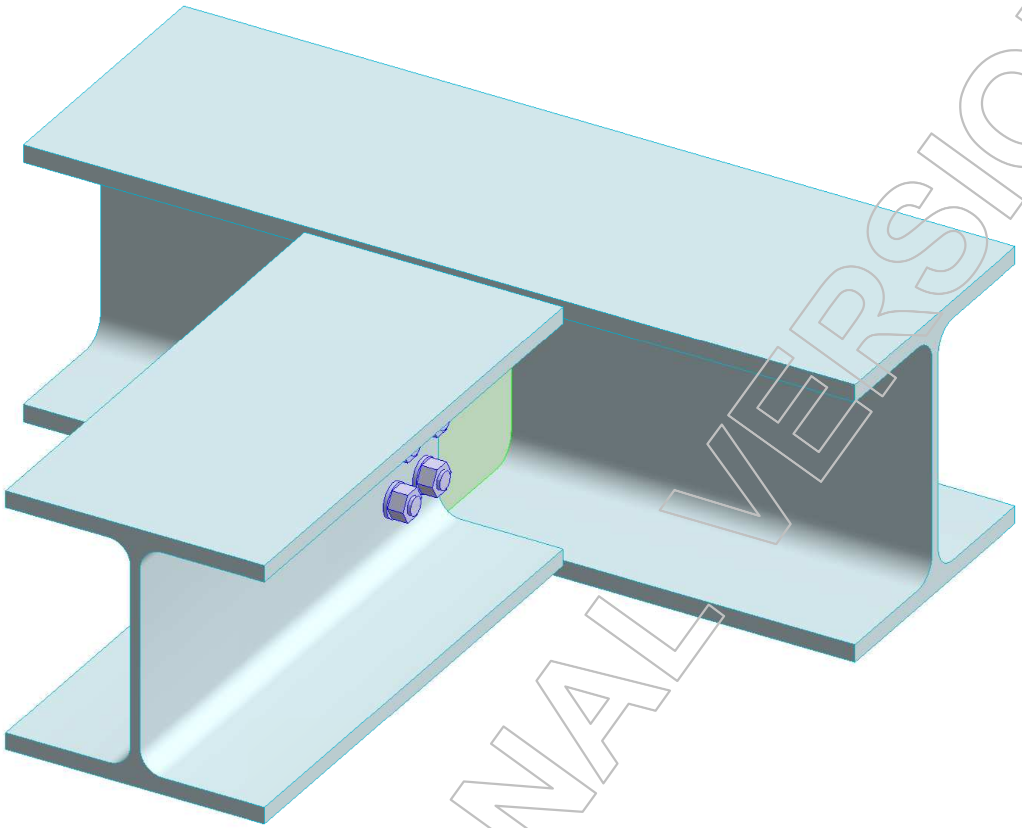
a_{min} = 6.4 mm

Through-thickness requirements (EN 1993-1-10: [3.2; (2)])

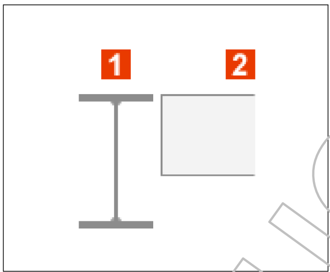
Z_a = 3.00, Z_b = 0.00, Z_c = 8.00, Z_d = 0.00, Z_e = 0.00

Z_{Ed} = 11.00

SJ.12.1
Maximum of load combinations

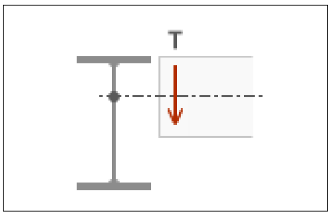


Member data



	Member 1	Member 2
Cross-section	HE-B 300	HE-B 280
Material	S 355	S 355
γ_{M0}	1.05	1.05
γ_{M1}	1.05	1.05
γ_{M2}	1.25	1.25
γ_{M5}	1.00	1.00

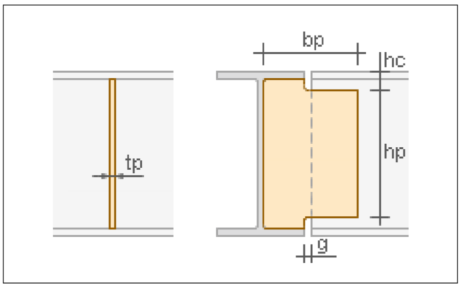
Load combinations



	No	Name	T [kN]
X	1	SJ.12.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)	52
X	2	SJ.12.1: Staility2: 0,9G+1,5W+Hi (including misalignment load)	52
X	3	SJ.12.1: Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)	117
X	4	SJ.12.1: 1.35*SW + 1.35*dead + 1.35*Soil+ 1.50*0.70*P + 1.50*0.70*S + 1.50*0.70*W	111
X	5	SJ.12.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W	117
X	6	SJ.12.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W	100
X	7	SJ.12.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P+ 1.50*0.70*S + 1.50*W	102

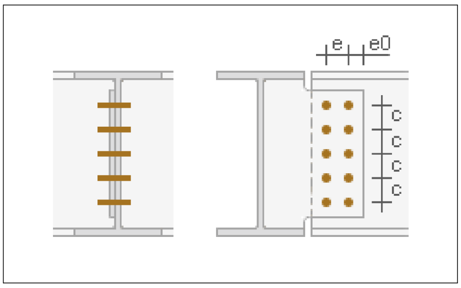
Beam

Fin plate



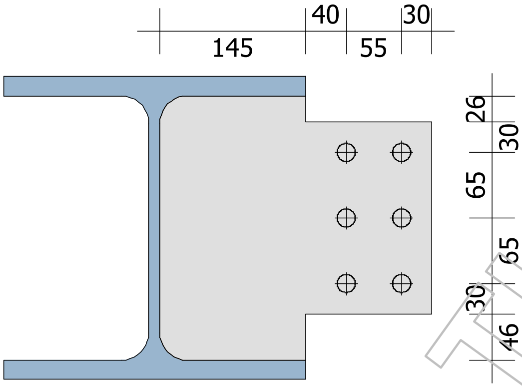
Material	S 355
γ_{M0}	1.05
γ_{M1}	1.05
γ_{M2}	1.25
γ_{M5}	1.00
tp [mm]	16
bp [mm]	270
hc [mm]	45
hp [mm]	190
g [mm]	10

Bolts

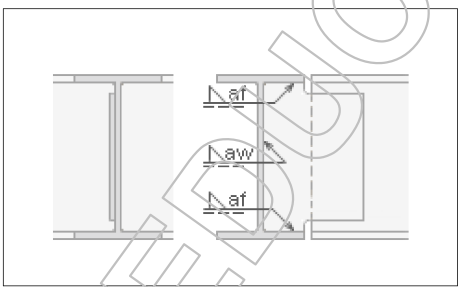


Size	HR-M20
Quality	8.8
Prestressed	No
Flip	No
Washer at nut	Yes
Washer at bolt head	Yes
n column	3
n row	2
c [mm]	65
e0 [mm]	30
e [mm]	55

Bolt arrangement



Welds



af [mm]	4.0
aw [mm]	4.0

Warning: The selected joint type cannot handle all internal forces acting on the connected structural elements.

LC3: Bar 1 (Mt)

LC4: Bar 1 (Mt)

LC5: Bar 1 (Mt)

LC6: Bar 1 (Mt)

LC7: Bar 1 (Mt)

Joint utilization: 99 % (LC: 'SJ.12.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*

Bolt shear resistance (Fin plate) (EN 1993-1-8: [3.6.1]): 99 % (LC: 'SJ.12.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil +

V = 117.36 kN, H = 0.00 kN, M = 0.00 kNm, e = 218 mm

$F_{v,max}$ = 93.60 kN, $F_{v,max,H}$ = 77.57 kN, $F_{v,max,V}$ = 52.38 kN

Decisive bolt: column 1, row 2

$F_{v,Rd}$ = 94.08 kN (threaded)

$F_{b,Rd,bar,V}$ = 113.33 kN (α_b = 0.73, k_1 = 1.80)

$F_{b,Rd,plate,V}$ = 106.82 kN (α_b = 0.45, k_1 = 1.80)

$F_{b,Rd,bar,H}$ = 96.47 kN (α_b = 0.46, k_1 = 2.44)

$F_{b,Rd,plate,H}$ = 161.32 kN (α_b = 0.58, k_1 = 2.12)

Block tearing resistance (EN 1993-1-8: [3.10.2]): 30 % (LC: 'SJ.12.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*

Fracture line 1 for shear

A_{nt} = 0 mm, A_{nv} = 1984 mm, $V_{eff,2,Rd}$ = 387.28 kN

Fracture line 2 for shear

A_{nt} = 832 mm, A_{nv} = 1680 mm, $V_{eff,2,Rd}$ = 497.66 kN

Fin plate moment resistance (Ref.6: [3.5.2.2], Ref.1: [3.6.2.1]): 89 % (LC: 'SJ.12.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.3

V = 117.36 kN, N = 0.00 kN, M = 0.00 kNm

e_0 = 218 mm, t_p = 16 mm

Gross section utilization: 52 %

e = 218 mm, h = 190 mm

Net section utilization: 89 %

e_{net} = 190 mm, h_{net} = 124 mm

Beam 1 web (Fin plate) weld resistance (EN 1993-1-8: [4.5.3.2; (1)]): 21 % (LC: 'SJ.12.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.

σ_{pp} = 0.00 N/mm^2, τ_{pp} = 0.00 N/mm^2, τ_{pl} = 55.99 N/mm^2

$\sigma_{Rd,1}$ = 453.33 N/mm^2, $\sigma_{Rd,2}$ = 367.20 N/mm^2

Beam 1 flange (Fin plate) weld resistance (EN 1993-1-8: [4.5.3.2; (1)]): 17 % (LC: 'SJ.12.1: 0.89*1.35*SW + 0.89*1.35*dead +

σ_{pp} = 0.00 N/mm^2, τ_{pp} = 0.00 N/mm^2, τ_{pl} = 45.21 N/mm^2

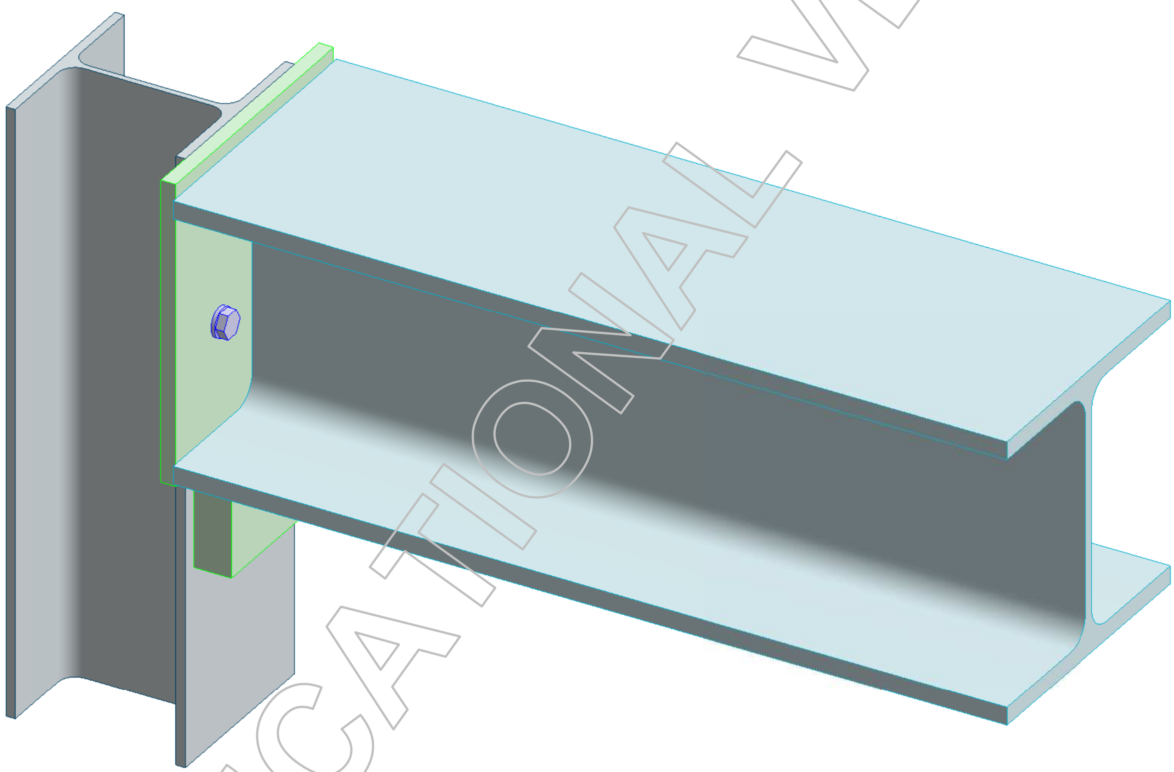
$\sigma_{Rd,1}$ = 453.33 N/mm^2, $\sigma_{Rd,2}$ = 367.20 N/mm^2

References

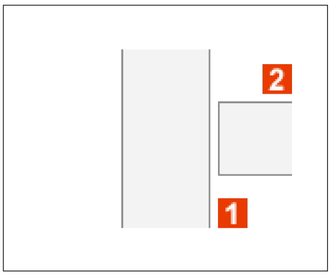
Ref.1: The Swedish Institute of Steel Construction, Detail Handbook, Publication 184

Ref.6: The Swedish Institute of Steel Construction, Detail Handbook, Publication 189

SJ.1.1
Maximum of load combinations

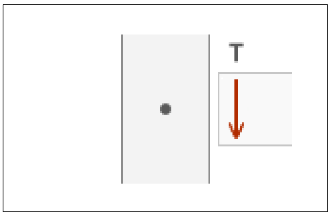


Member data



	Member 1	Member 2
Cross-section	HE-A 200	HE-B 300
Material	S 355	S 355
γ_{M0}	1.05	1.05
γ_{M1}	1.05	1.05
γ_{M2}	1.25	1.25
γ_{M5}	1.00	1.00

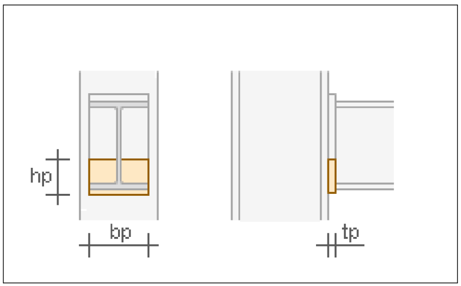
Load combinations



	No	Name	T [kN]
X	1	SJ.1.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)	199
X	2	SJ.1.1: Staility2: 0,9G+1,5W+Hi (including misalignment load)	199
X	3	SJ.1.1: Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)	521
X	4	SJ.1.1: 1.35*SW + 1.35*dead + 1.35*Soil+ 1.50*0.70*P + 1.50*0.70*S + 1.50*0.70*W	508
X	5	SJ.1.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W	521
X	6	SJ.1.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W	521
X	7	SJ.1.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P+ 1.50*0.70*S + 1.50*W	476

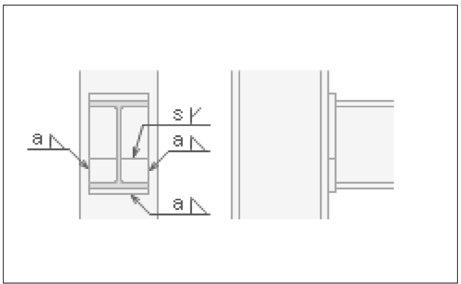
Column

Heel



Apply	Yes
Material	S 355
γ_{M0}	1.00
γ_{M1}	1.00
γ_{M2}	1.25
γ_{M5}	1.00
tp [mm]	40
bp [mm]	170
hp [mm]	120

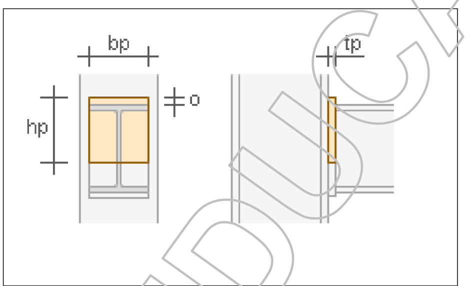
Heel welds



s [mm]	10
a [mm]	10
Horizontal welds	None

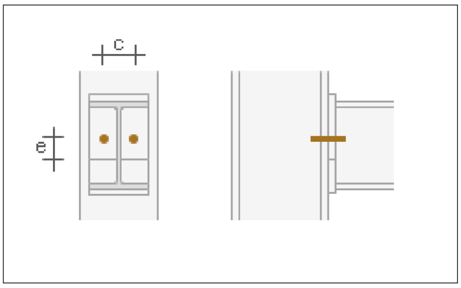
Beam

End-plate



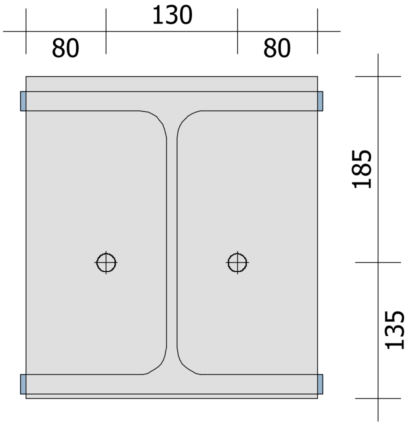
Material	S 355
γ_{M0}	1.05
γ_{M1}	1.05
γ_{M2}	1.25
γ_{M5}	1.00
tp [mm]	16
bp [mm]	290
hp [mm]	320
o [mm]	15

Bolts

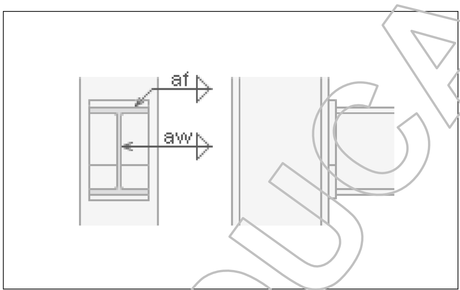


Size	HR-M16
Quality	8.8
Prestressed	No
Flip	No
Washer at nut	Yes
Washer at bolt head	Yes
c [mm]	130
e [mm]	135

Bolt arrangement



Welds



af [mm]	6.0
aw [mm]	5.0

Joint utilization: 93 % (LC: 'SJ.1.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W

Beam web shear resistance (EN 1993-1-1: [6.2.6]): 93 % (LC: 'SJ.1.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50

V_{Ed} = 520.71 kN

V_{Rd} = 562.56 kN

End-plate web weld resistance (EN 1993-1-8: [4.5.3.2; (1)]): 76 % (LC: 'SJ.1.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*So

σ_{pp} = 0.00 N/mm^2, τ_{pp} = 0.00 N/mm^2, τ_{pl} = 198.74 N/mm^2

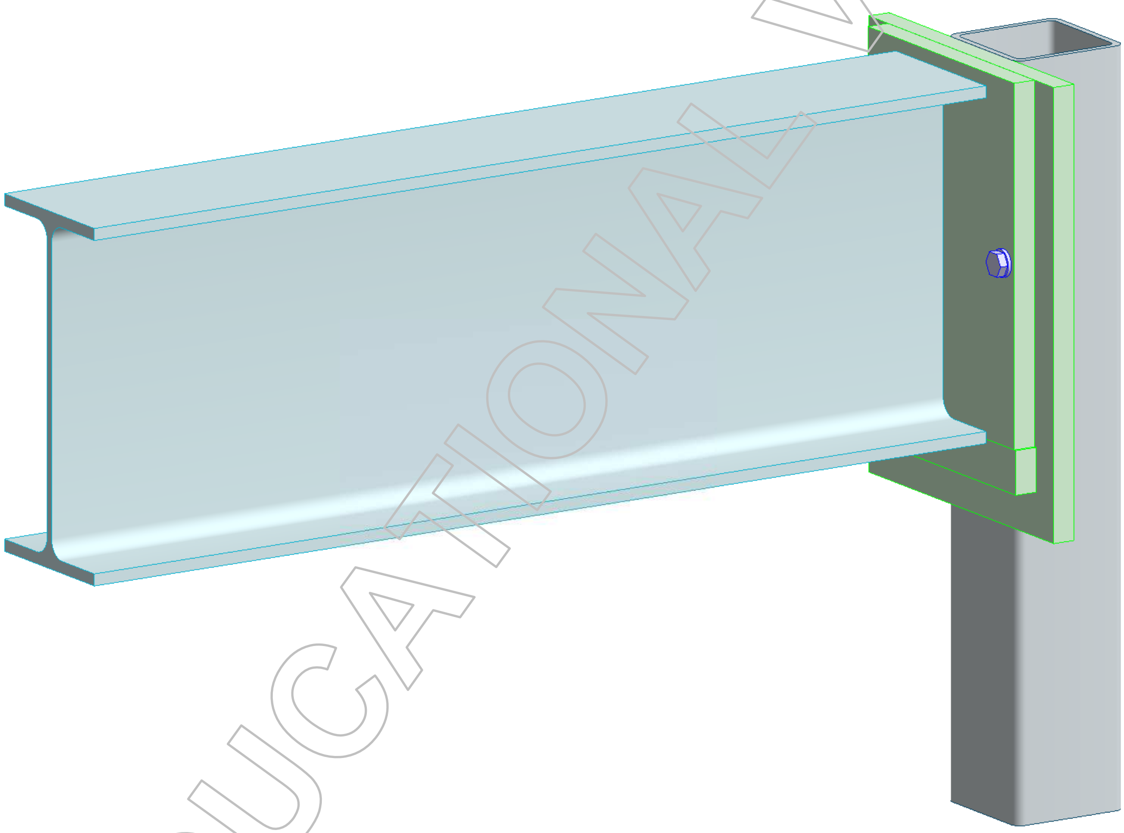
$\sigma_{Rd,1}$ = 453.33 N/mm^2, $\sigma_{Rd,2}$ = 367.20 N/mm^2

Heel weld resistance (EN 1993-1-8: [4.5.3]): 83 % (LC: 'SJ.1.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*F

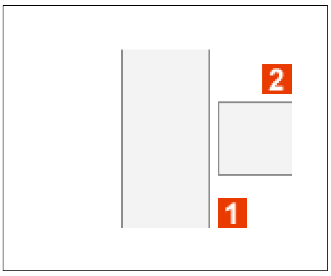
V = 520.71 kN, V_{Rd} = 628.16 kN

End-plate bolts resistance: Not relevant

SJ.16.1
Maximum of load combinations

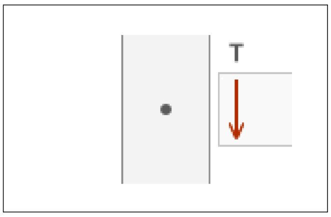


Member data



	Member 1	Member 2
Cross-section	VKR 140x140x8	IPE 400
Material	S 355	S 355
γ_{M0}	1.05	1.05
γ_{M1}	1.05	1.05
γ_{M2}	1.25	1.25
γ_{M5}	1.00	1.00
Rotated	No	No

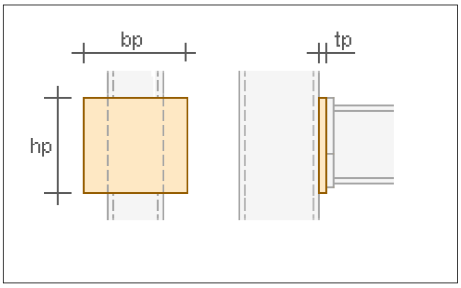
Load combinations



	No	Name	T [kN]
X	1	SJ.16.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)	67
X	2	SJ.16.1: Staility2: 0,9G+1,5W+Hi (including misalignment load)	67
X	3	SJ.16.1: Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)	154
X	4	SJ.16.1: 1.35*SW + 1.35*dead + 1.35*Soil+ 1.50*0.70*P + 1.50*0.70*S + 1.50*0.70*W	146
X	5	SJ.16.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W	154
X	6	SJ.16.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W	135
X	7	SJ.16.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P+ 1.50*0.70*S + 1.50*W	135

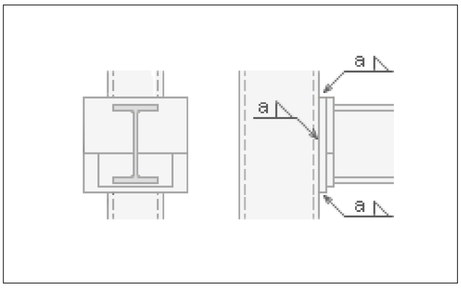
Column

Cover plate



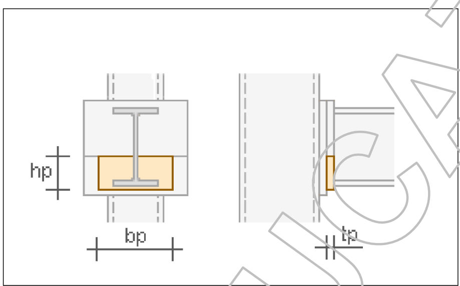
Material	S 355
γ_{M0}	1.05
γ_{M1}	1.05
γ_{M2}	1.25
γ_{M5}	1.00
tp [mm]	26
bp [mm]	370
hp [mm]	510

Cover welds



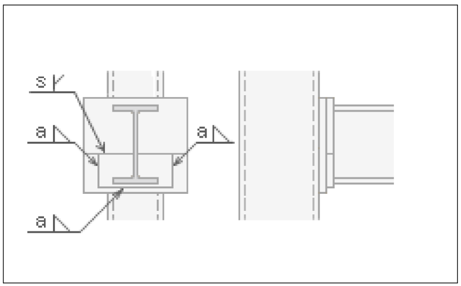
a [mm]	10
Horizontal welds	None

Heel



Apply	Yes
Material	S 355
γ_{M0}	1.05
γ_{M1}	1.05
γ_{M2}	1.25
γ_{M5}	1.00
tp [mm]	26
bp [mm]	300
hp [mm]	50

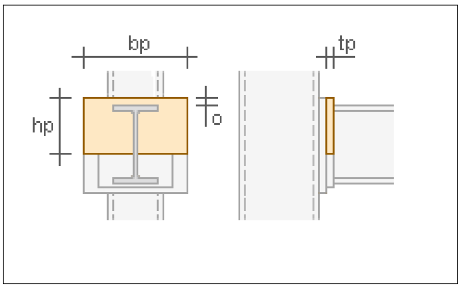
Heel welds



s [mm]	18
a [mm]	18
Horizontal welds	None

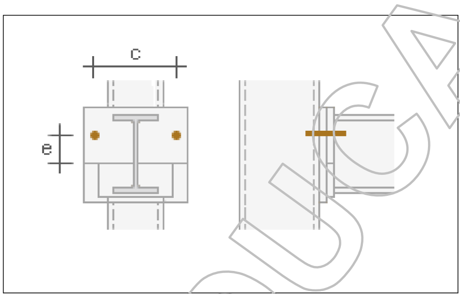
Beam

End-plate



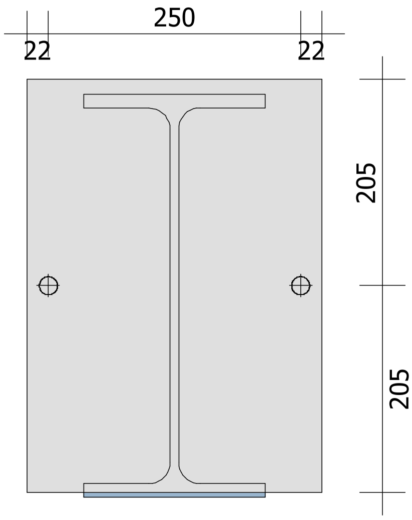
Material	S 355
γ_{M0}	1.05
γ_{M1}	1.05
γ_{M2}	1.25
γ_{M5}	1.00
tp [mm]	26
bp [mm]	293
hp [mm]	410
o [mm]	15

Bolts

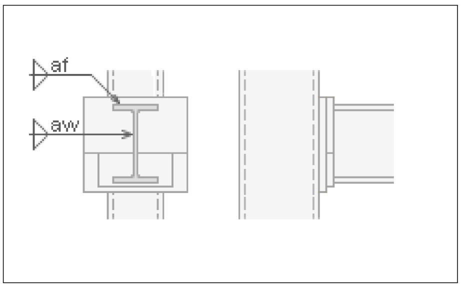


Size	HR-M16
Quality	8.8
Prestressed	No
Flip	No
Washer at nut	Yes
Washer at bolt head	Yes
c [mm]	250
e [mm]	205

Bolt arrangement



Welds



af [mm]	9.0
aw [mm]	6.0

Joint utilization: 33 % (LC: 'SJ.16.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*

Beam web shear resistance (EN 1993-1-1: [6.2.6]): 25 % (LC: 'SJ.16.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.5

V_{Ed} = 154.26 kN

V_{Rd} = 626.16 kN

Beam web (End-plate) weld resistance (EN 1993-1-8: [4.5.3.2; (1)]): 13 % (LC: 'SJ.16.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.8

σ_{pp} = 0.00 N/mm^2, τ_{pp} = 0.00 N/mm^2, τ_{pl} = 34.46 N/mm^2

$\sigma_{Rd,1}$ = 453.33 N/mm^2, $\sigma_{Rd,2}$ = 367.20 N/mm^2

Heel weld resistance (EN 1993-1-8: [4.5.3]): 33 % (LC: 'SJ.16.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P +

V = 154.26 kN, V_{Rd} = 471.12 kN

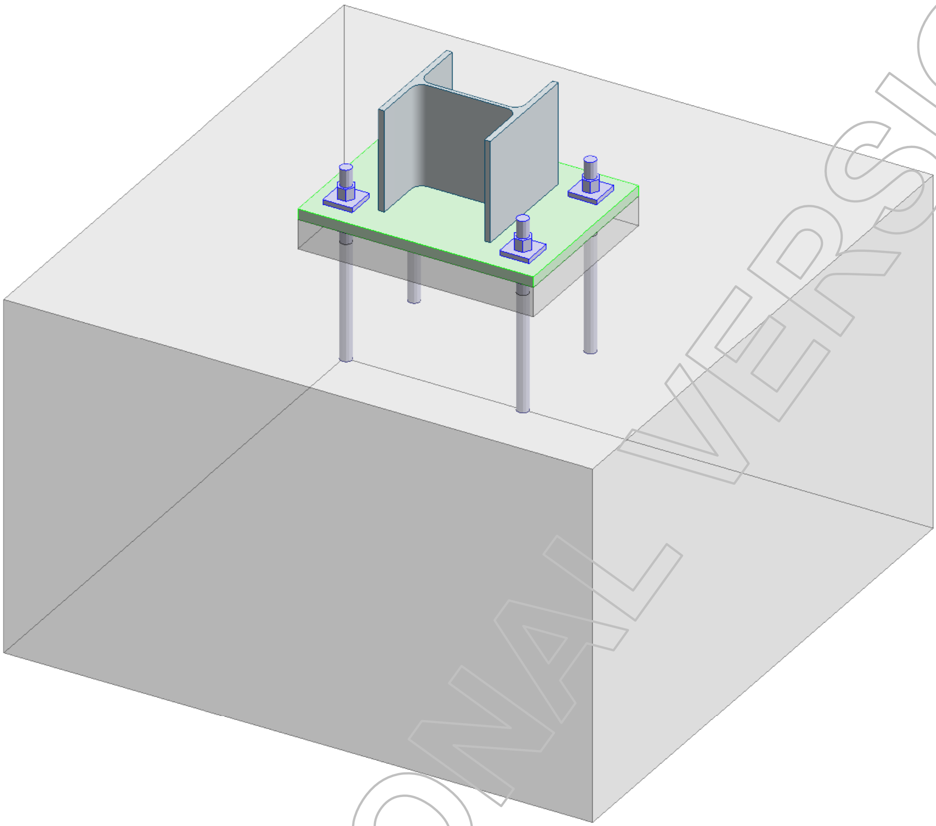
End-plate bolts resistance: Not relevant

Cover plate (flange) weld resistance (EN 1993-1-8: [4.5.3]): 6 % (LC: 'SJ.16.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*So

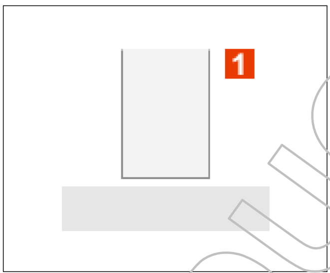
V = 154.26 kN, V_{Rd} = 2669.67 kN

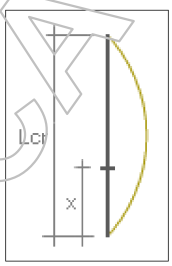
6.2 Column base connection

SJ.6.1
Maximum of load combinations



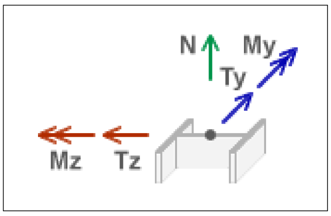
Member data





	Member 1
Cross-section	HE-A 200
Material	S 355
γ_{M0}	1.05
γ_{M1}	1.05
γ_{M2}	1.25
γ_{M5}	1.00
Lcr, y [m]	6.00
Lcr, z [m]	6.00

Load combinations

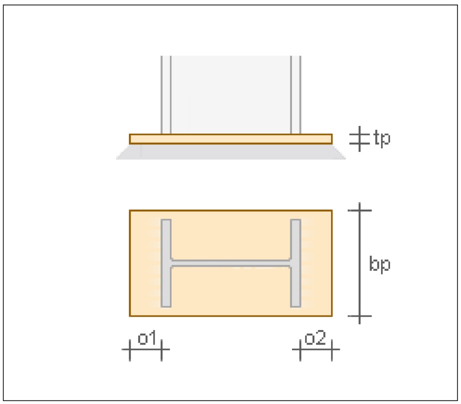


	No	Name
X	1	SJ.6.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)
X	2	SJ.6.1: Staility2: 0,9G+1,5W+Hi (including misalignment load)
X	3	SJ.6.1: Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)
X	4	SJ.6.1: 1.35*SW + 1.35*dead + 1.35*Soil+ 1.50*0.70*P + 1.50*0.70*S + 1.50*0.70*W
X	5	SJ.6.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W
X	6	SJ.6.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W
X	7	SJ.6.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P+ 1.50*0.70*S + 1.50*W

	2nd order calculation	N [kN]	Ty [kN]	Tz [kN]	My [kNm]	Mz [kNm]
X		-139	0.00	0.00	0.00	0.00
X		-139	0.00	0.00	0.00	0.00
X		-349	0.00	0.00	0.00	0.00
X		-341	0.00	0.00	0.00	0.00
X		-349	0.00	0.00	0.00	0.00
X		-344	0.00	0.00	0.00	0.00
X		-318	0.00	0.00	0.00	0.00

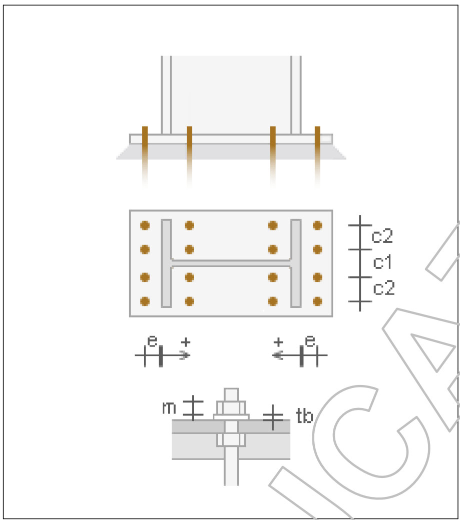
Column

Base plate



Material	S 355
γ_{M0}	1.00
γ_{M1}	1.00
γ_{M2}	1.25
γ_{M5}	1.00
tp [mm]	18
bp [mm]	310
o1 [mm]	105
o2 [mm]	105
Weld buttering (EN 1993-1-10: Table 3.2/b)	No
Preheating (> 100 °C)	No

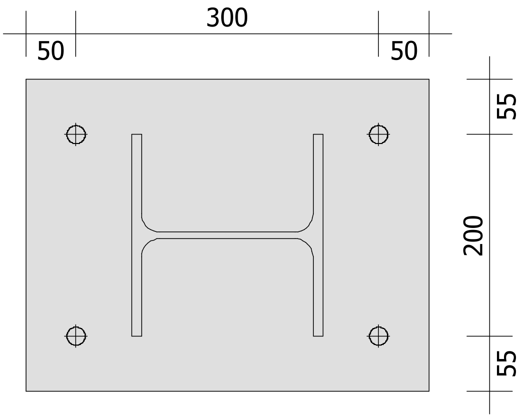
Anchor bolts



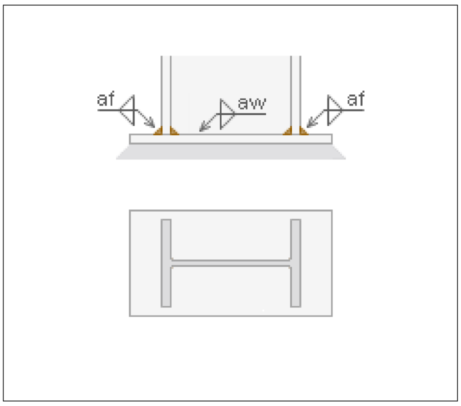
Size	M20
Anchor quality	8.8
γ_{M2}	1.25
m [mm]	20
tb [mm]	8
Use maximum for Ft,Rd	Yes
Ft,Rd [kN]	141.12
c1 [mm]	200
c2 [mm]	55

Placed relative to:	n	e [mm]
Top flange	2	-55
Bottom flange	2	-55

Bolt arrangement



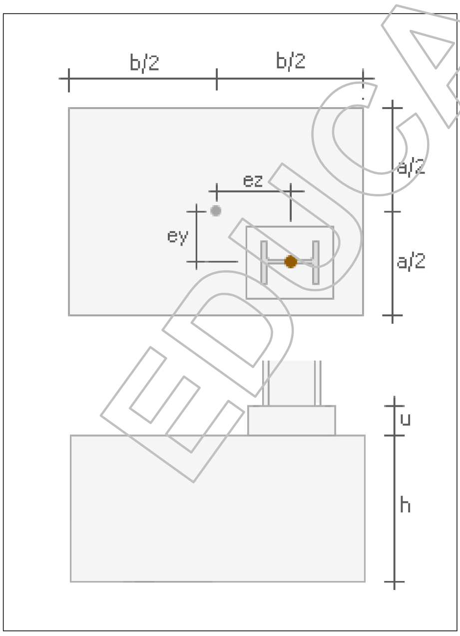
Welds



af [mm]	6.0
aw [mm]	4.0

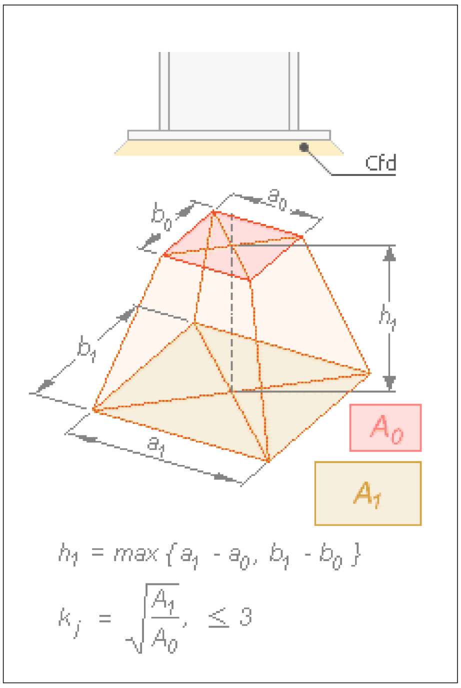
Foundation

Material and geometry



Material	C30/37
γ_C	1.50
a [mm]	1000
b [mm]	1000
h [mm]	600
ey	0
ez	0
u [mm]	50

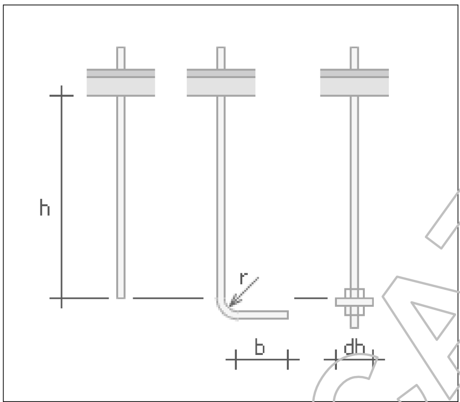
Calculation parameters



Friction coefficient (Cfd)	0.00
Beta j	0.67
kj	1.00

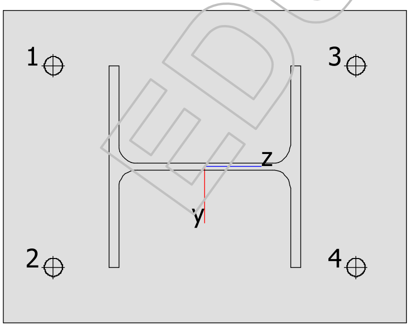
Anchor-concrete interaction

Anchor geometry

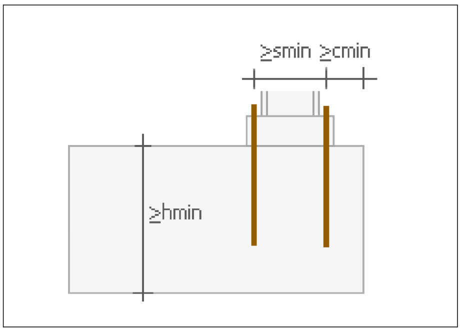


Type	Straight
Surface	Ribbed
h [mm]	200
b [mm]	50
r [mm]	140
dh [mm]	50

Bolt numbering



Calculations



Check requested	Yes
Concrete is cracked	Yes
gamma,Mp	1.50
gamma,Mc	1.50
gamma,Msp	1.50
kcr	8.50
kucr	11.90
Ignore cone-failure	No
Ignore splitting-failure	No
cmin [mm]	50
smin [mm]	80
hmin [mm]	260

Joint utilization: 44 % (LC: 'SJ.6.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W

2nd order effect (EN 1993-1-1: [6.3])

α = 0.49, λ = 1.58, φ = 2.08, χ = 0.29

ΔM = 52.37 * M

Base plate normal force - moment resistance (EN 1993-1-8: [6.2.8]): 33 % (LC: 'SJ.6.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.8

Compression capacity, for positive moment

f_{jd} = 13.400 N/mm^2 (EN 1992-1-1: [6.7; (2)])

c = 53 mm, l_{eff} = 307 mm, b_{eff} = 117 mm

$F_{C,Rd}$ = 481.20 kN

$l_{eff,w}$ = 63 mm, $b_{eff,w}$ = 113 mm

$F_{C,Rd,w}$ = 95.83 kN

Compression capacity, for negative moment

f_{jd} = 13.400 N/mm^2 (EN 1992-1-1: [6.7; (2)])

c = 53 mm, l_{eff} = 307 mm, b_{eff} = 117 mm

$F_{C,Rd}$ = 481.20 kN

$l_{eff,w}$ = 63 mm, $b_{eff,w}$ = 113 mm

$F_{C,Rd,w}$ = 95.83 kN

Column web and flange compression resistance

No compressed haunch is applied.

Column section moment resistance

$W = 429483\ mm^3$

$M_{c,Rd} = 145.21$ kNm

$F_{c,fb,Rd} = 806.70$ kN

$N_{0,Rd} = 962.40$ kN, $N_{max,Rd} = 1058.23$ kN

Anchors must be checked for adequate elongation.

Anchorage tension resistance (Ref.8: [2.4.1]): 0 % (LC: 'SJ.6.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)'

There are no tensioned anchors

Shear resistance (EN 1993-1-8: [6.2.2; (5)]): 0 % (LC: 'SJ.6.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)')

$F_{v,Ed,y} = -0.00$ kN, $F_{v,Ed,z} = -0.00$ kN, $F_{v,Ed} = 0.00$ kN

Anchor 1. $F_{1,vb,Rd,y} = 367.20$ kN, $F_{1,vb,Rd,z} = 367.20$ kN, $N_{Ed} = -3.19$ kN

Anchor 2. $F_{1,vb,Rd,y} = 306.00$ kN, $F_{1,vb,Rd,z} = 367.20$ kN, $N_{Ed} = -3.19$ kN

Anchor 3. $F_{1,vb,Rd,y} = 367.20$ kN, $F_{1,vb,Rd,z} = 278.18$ kN, $N_{Ed} = -3.19$ kN

Anchor 4. $F_{1,vb,Rd,y} = 306.00$ kN, $F_{1,vb,Rd,z} = 278.18$ kN, $N_{Ed} = -3.19$ kN

$F_{f,Rd} = -0.00$ kN, $F_{2,vb,Rd} = 38.89$ kN, $F_{t,Rd} = 141.12$ kN

Shear resistances of tensioned anchors are reduced by factor $(1 - N_{Ed} / 1.4F_{t,Rd})$

$F_{v,Rd,y} = 155.55$ kN, $F_{v,Rd,z} = 155.55$ kN, $F_{2,v,Rd} = 155.55$ kN

Flange (at the corner) weld resistance (EN 1993-1-8: [4.5.3.2; (1)]): 44 % (LC: 'SJ.6.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89

$\sigma = 161.60\ N/mm^2$, $\tau_{pp} = 0.00\ N/mm^2$, $\tau_{pl} = 0.00\ N/mm^2$

$\sigma_{Rd,1} = 453.33\ N/mm^2$, $\sigma_{Rd,2} = 367.20\ N/mm^2$

Flange (at the web) weld resistance (EN 1993-1-8: [4.5.3.2; (1)]): 44 % (LC: 'SJ.6.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.

$\sigma = 161.60\ N/mm^2$, $\tau_{pp} = 0.00\ N/mm^2$, $\tau_{pl} = 0.00\ N/mm^2$

$\sigma_{Rd,1} = 453.33\ N/mm^2$, $\sigma_{Rd,2} = 367.20\ N/mm^2$

Web weld resistance: Not relevant

Through-thickness requirements (EN 1993-1-10: [3.2; (2)])

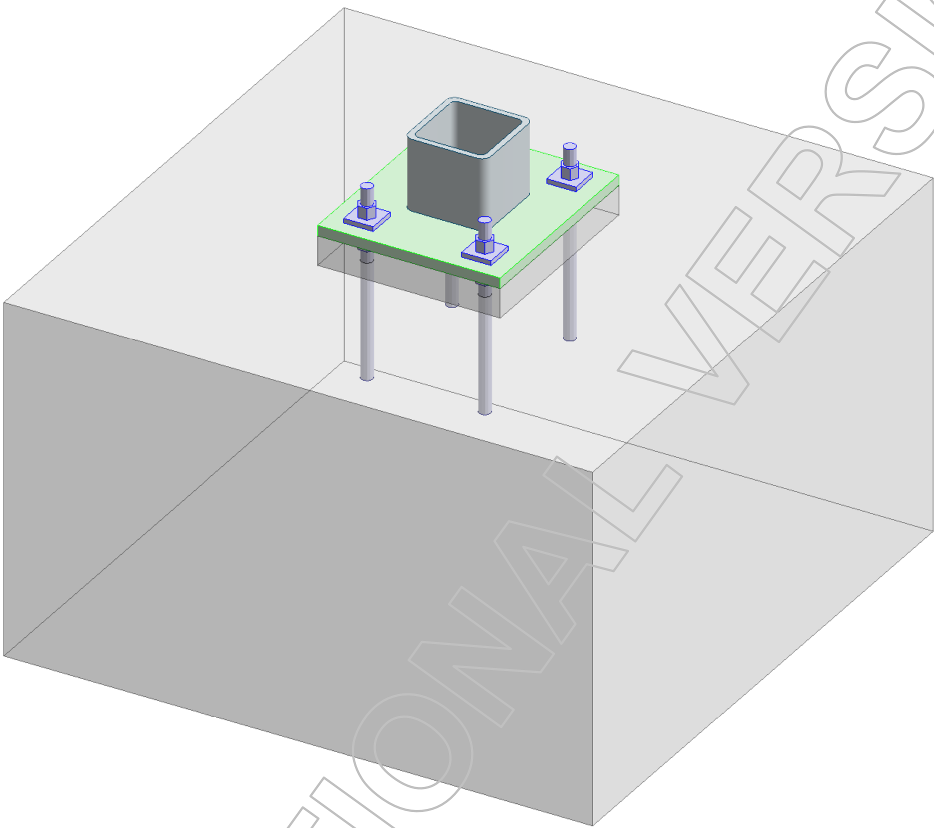
$Z_a = 3.00$, $Z_b = 0.00$, $Z_c = 4.00$, $Z_d = 0.00$, $Z_e = 0.00$

$Z_{Ed} = 7.00$

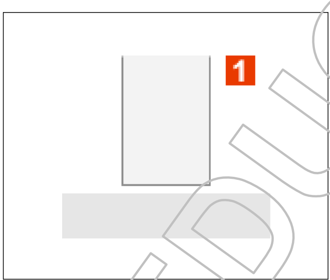
References

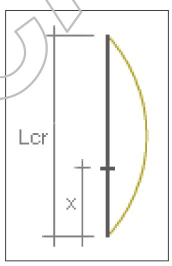
Ref.8: The Swedish Institute of Steel Construction, Detail Handbook, Publication 183

SJ.13.1
Maximum of load combinations



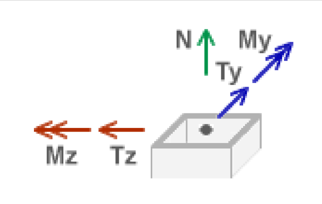
Member data





	Member 1
Cross-section	VKR 140x140x10
Material	S 355
γ_{M0}	1.05
γ_{M1}	1.05
γ_{M2}	1.25
γ_{M5}	1.00
Lcr, y [m]	6.00
Lcr, z [m]	6.00

Load combinations

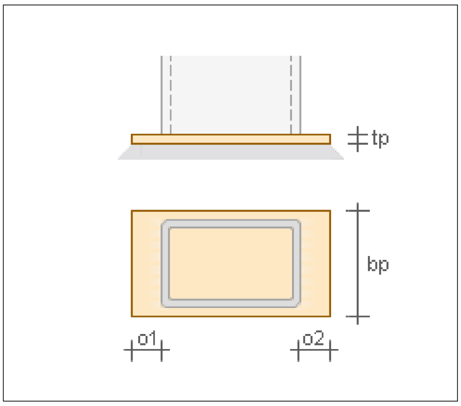


	No	Name
X	1	SJ.13.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)
X	2	SJ.13.1: Staility2: 0,9G+1,5W+Hi (including misalignment load)
X	3	SJ.13.1: Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)
X	4	SJ.13.1: 1.35*SW + 1.35*dead + 1.35*Soil+ 1.50*0.70*P + 1.50*0.70*S + 1.50*0.70*W
X	5	SJ.13.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W
X	6	SJ.13.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W
X	7	SJ.13.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P+ 1.50*0.70*S + 1.50*W

	2nd order calculation	N [kN]	Ty [kN]	Tz [kN]	My [kNm]	Mz [kNm]
X		-264	0.00	0.00	0.00	0.00
X		-264	0.00	0.00	0.00	0.00
X		-671	0.00	0.00	0.00	0.00
X		-653	0.00	0.00	0.00	0.00
X		-671	0.00	0.00	0.00	0.00
X		-657	0.00	0.00	0.00	0.00
X		-609	0.00	0.00	0.00	0.00

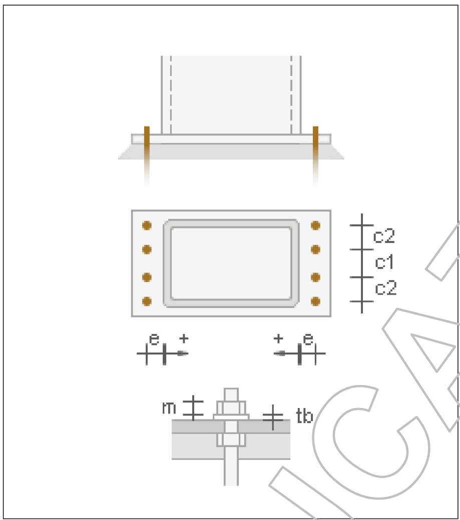
Column

Base plate



Material	S 355
γ_{M0}	1.05
γ_{M1}	1.05
γ_{M2}	1.25
γ_{M5}	1.00
tp [mm]	18
bp [mm]	310
o1 [mm]	105
o2 [mm]	105
Weld buttering (EN 1993-1-10: Table 3.2/b)	No
Preheating (> 100 °C)	No

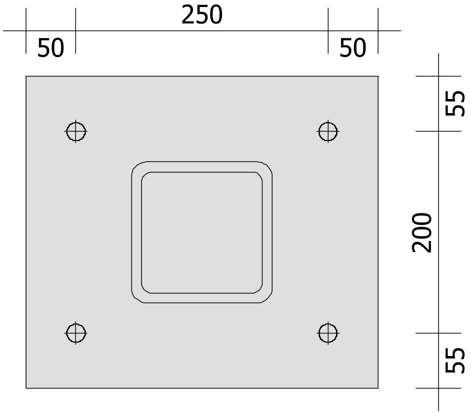
Anchor bolts



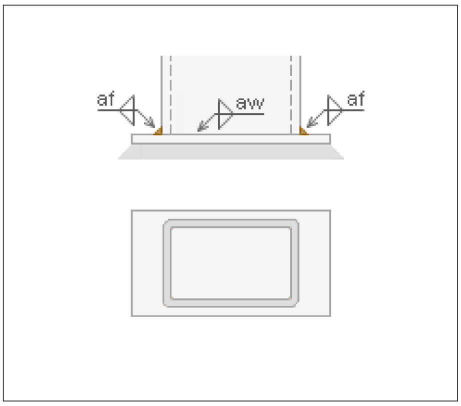
Size	M20
Anchor quality	8.8
γ_{M2}	1.25
m [mm]	20
tb [mm]	8
Use maximum for Ft,Rd	Yes
Ft,Rd [kN]	141.12
c1 [mm]	200
c2 [mm]	55

Placed relative to:	n	e [mm]
Top flange	2	-55
Bottom flange	2	-55

Bolt arrangement



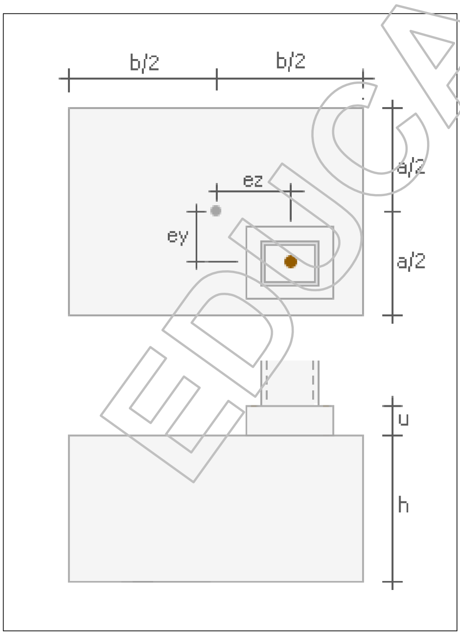
Welds



af [mm]	12
aw [mm]	10

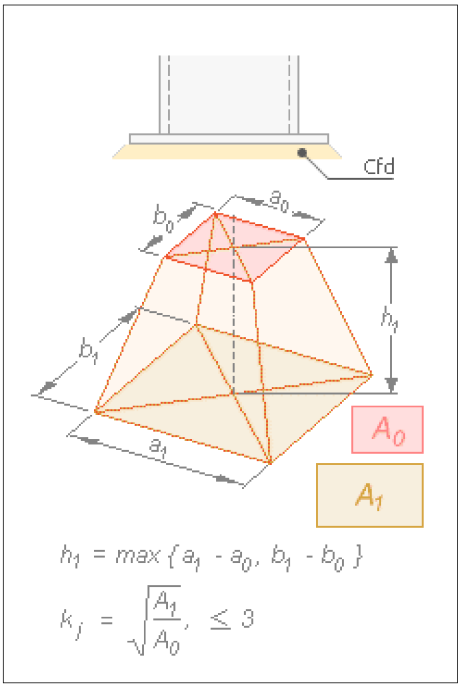
Foundation

Material and geometry



Material	C30/37
γ_C	1.50
a [mm]	1000
b [mm]	1000
h [mm]	600
ey	0
ez	0
u [mm]	50

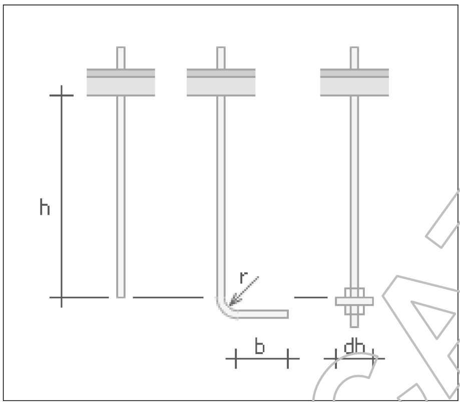
Calculation parameters



Friction coefficient (Cfd)	0.00
Beta j	0.67
kj	1.00

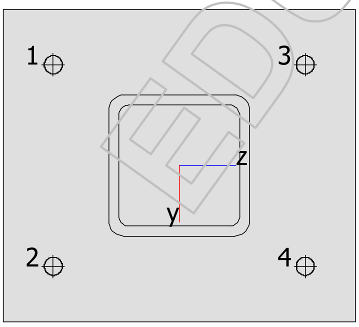
Anchor-concrete interaction

Anchor geometry

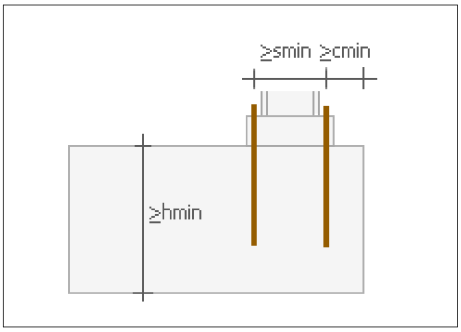


Type	Straight
Surface	Ribbed
h [mm]	200
b [mm]	50
r [mm]	140
dh [mm]	50

Bolt numbering



Calculations



Check requested	Yes
Concrete is cracked	Yes
gamma,Mp	1.50
gamma,Mc	1.50
gamma,Msp	1.50
kcr	8.50
kucr	11.90
Ignore cone-failure	No
Ignore splitting-failure	No
cmin [mm]	50
smin [mm]	80
hmin [mm]	260

Joint utilization: 84 % (LC: 'SJ.13.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*

2nd order effect (EN 1993-1-1: [6.3])

α = 0.21, λ = 1.49, φ = 1.74, χ = 0.38

ΔM = 56.86 * M

Base plate normal force - moment resistance (EN 1993-1-8: [6.2.8]): 84 % (LC: 'SJ.13.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.

Compression capacity, for positive moment

f_{jd} = 13.400 N/mm^2 (EN 1992-1-1: [6.7; (2)])

c = 52 mm, l_{eff} = 244 mm, b_{eff} = 114 mm

$F_{C,Rd}$ = 374.67 kN

$l_{eff,w}$ = 16 mm, $b_{eff,w}$ = 114 mm

$F_{C,Rd,w}$ = 47.83 kN

Compression capacity, for negative moment

f_{jd} = 13.400 N/mm^2 (EN 1992-1-1: [6.7; (2)])

c = 52 mm, l_{eff} = 244 mm, b_{eff} = 114 mm

$F_{C,Rd}$ = 374.67 kN

$l_{eff,w}$ = 16 mm, $b_{eff,w}$ = 114 mm

$F_{C,Rd,w}$ = 47.83 kN

Column web and flange compression resistance

No compressed haunch is applied.

Column section moment resistance

$W = 246091\ mm^3$

$M_{c,Rd} = 83.20$ kNm

$F_{c,fb,Rd} = 640.01$ kN

$N_{0,Rd} = 749.33$ kN, $N_{max,Rd} = 797.16$ kN

Anchors must be checked for adequate elongation.

Anchorage tension resistance (Ref.8: [2.4.1]): 0 % (LC: 'SJ.13.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W

There are no tensioned anchors

Shear resistance (EN 1993-1-8: [6.2.2; (5)]): 0 % (LC: 'SJ.13.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)'

$F_{v,Ed,y} = -0.00$ kN, $F_{v,Ed,z} = -0.00$ kN, $F_{v,Ed} = 0.00$ kN

Anchor 1. $F_{1,vb,Rd,y} = 367.20$ kN, $F_{1,vb,Rd,z} = 367.20$ kN, $N_{Ed} = -6.82$ kN

Anchor 2. $F_{1,vb,Rd,y} = 306.00$ kN, $F_{1,vb,Rd,z} = 367.20$ kN, $N_{Ed} = -6.82$ kN

Anchor 3. $F_{1,vb,Rd,y} = 367.20$ kN, $F_{1,vb,Rd,z} = 278.18$ kN, $N_{Ed} = -6.82$ kN

Anchor 4. $F_{1,vb,Rd,y} = 306.00$ kN, $F_{1,vb,Rd,z} = 278.18$ kN, $N_{Ed} = -6.82$ kN

$F_{f,Rd} = -0.00$ kN, $F_{2,vb,Rd} = 38.89$ kN, $F_{t,Rd} = 141.12$ kN

Shear resistances of tensioned anchors are reduced by factor $(1 - N_{Ed} / 1.4F_{t,Rd})$

$F_{v,Rd,y} = 155.55$ kN, $F_{v,Rd,z} = 155.55$ kN, $F_{2,v,Rd} = 155.55$ kN

Flange (at the web) weld resistance (EN 1993-1-8: [4.5.3.2; (1)]): 15 % (LC: 'SJ.13.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*

$\sigma = 33.49\ N/mm^2$, $\tau_{pp} = 33.49\ N/mm^2$, $\tau_{pl} = 0.00\ N/mm^2$

$\sigma_{Rd,1} = 453.33\ N/mm^2$, $\sigma_{Rd,2} = 367.20\ N/mm^2$

Web weld resistance (EN 1993-1-8: [4.5.3.2; (1)]): 18 % (LC: 'SJ.13.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.5

$\sigma = 40.19\ N/mm^2$, $\tau_{pp} = 40.19\ N/mm^2$, $\tau_{pl} = 0.00\ N/mm^2$

$\sigma_{Rd,1} = 453.33\ N/mm^2$, $\sigma_{Rd,2} = 367.20\ N/mm^2$

Through-thickness requirements (EN 1993-1-10: [3.2; (2)])

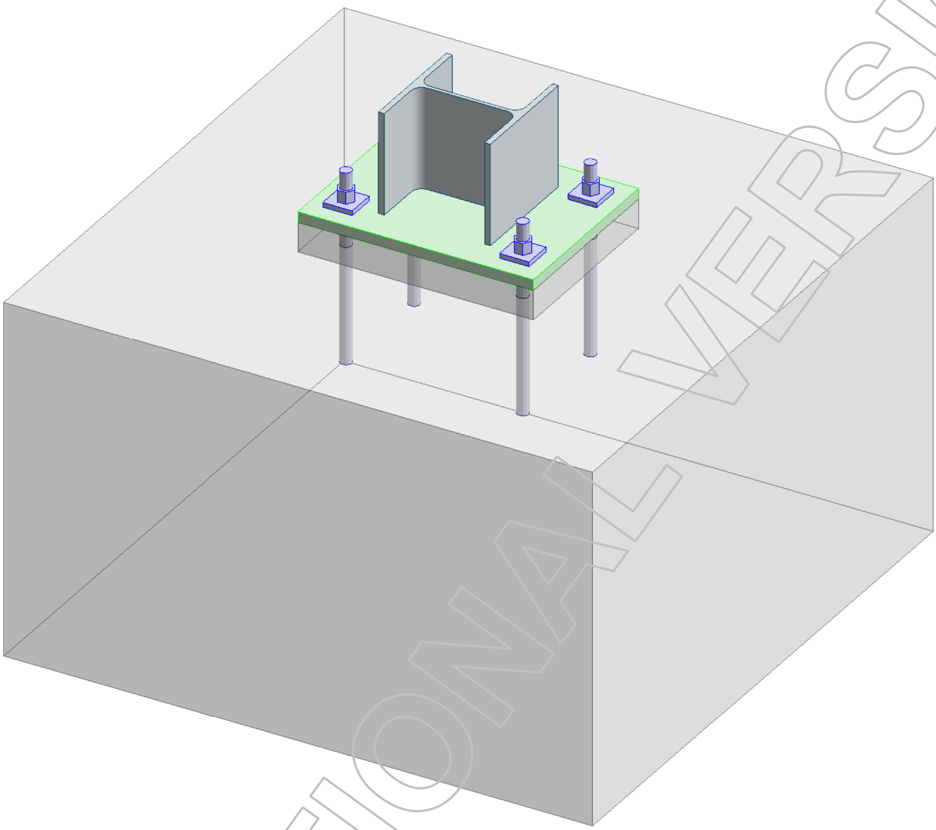
$Z_a = 6.00$, $Z_b = 0.00$, $Z_c = 4.00$, $Z_d = 0.00$, $Z_e = 0.00$

$Z_{Ed} = 10.00$

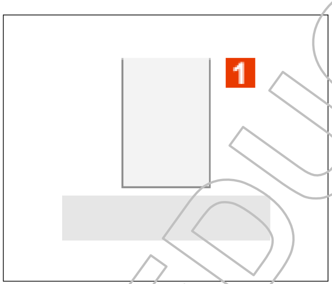
References

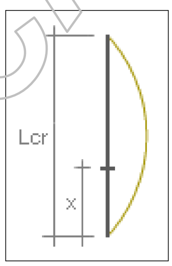
Ref.8: The Swedish Institute of Steel Construction, Detail Handbook, Publication 183

SJ.4.1
Maximum of load combinations



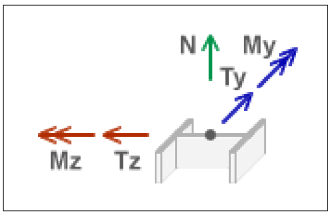
Member data





	Member 1
Cross-section	HE-A 200
Material	S 355
γ_{M0}	1.05
γ_{M1}	1.05
γ_{M2}	1.25
γ_{M5}	1.00
Lcr, y [m]	6.00
Lcr, z [m]	6.00

Load combinations

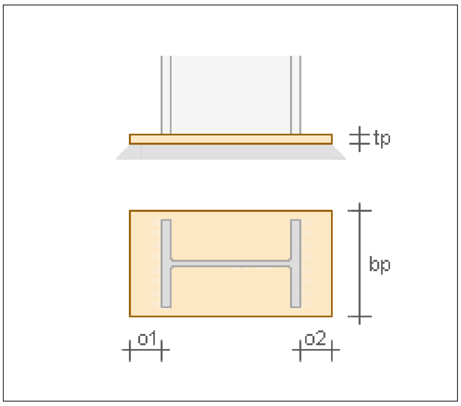


	No	Name
X	1	SJ.4.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)
X	2	SJ.4.1: Staility2: 0,9G+1,5W+Hi (including misalignment load)
X	3	SJ.4.1: Ultimate - only vertical loads - live dom (1,2 SW+1,2 dead+1,5 P+1,05 S)
X	4	SJ.4.1: 1.35*SW + 1.35*dead + 1.35*Soil+ 1.50*0.70*P + 1.50*0.70*S + 1.50*0.70*W
X	5	SJ.4.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W
X	6	SJ.4.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W
X	7	SJ.4.1: 0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*0.70*P+ 1.50*0.70*S + 1.50*W

	2nd order calculation	N [kN]	Ty [kN]	Tz [kN]	My [kNm]	Mz [kNm]
X		-215	0.00	0.00	0.00	0.00
X		-215	0.00	0.00	0.00	0.00
X		-560	0.00	0.00	0.00	0.00
X		-547	0.00	0.00	0.00	0.00
X		-560	0.00	0.00	0.00	0.00
X		-559	0.00	0.00	0.00	0.00
X		-511	0.00	0.00	0.00	0.00

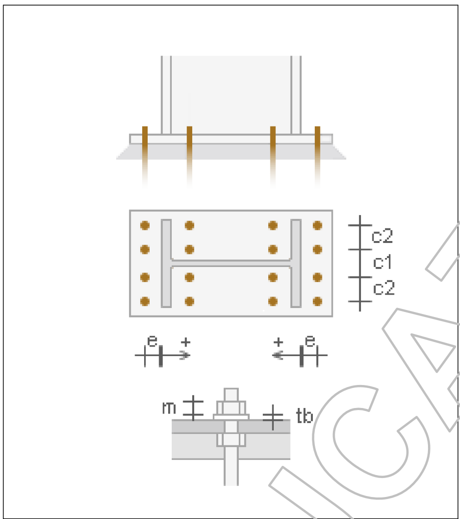
Column

Base plate



Material	S 355
γ_{M0}	1.00
γ_{M1}	1.00
γ_{M2}	1.25
γ_{M5}	1.00
tp [mm]	18
bp [mm]	310
o1 [mm]	105
o2 [mm]	105
Weld buttering (EN 1993-1-10: Table 3.2/b)	No
Preheating (> 100 °C)	No

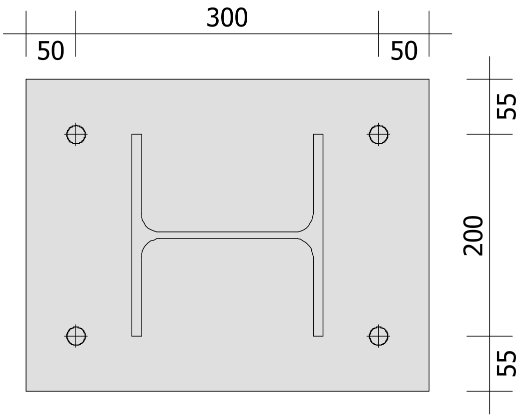
Anchor bolts



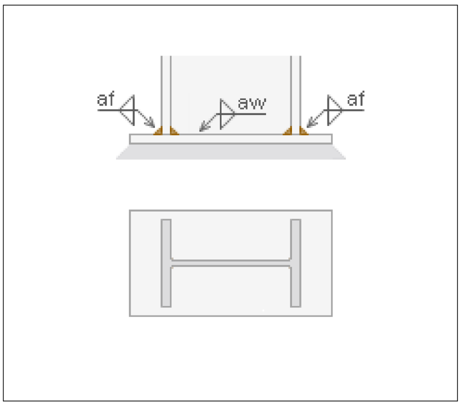
Size	M20
Anchor quality	8.8
γ_{M2}	1.25
m [mm]	20
tb [mm]	8
Use maximum for Ft,Rd	Yes
Ft,Rd [kN]	141.12
c1 [mm]	200
c2 [mm]	55

Placed relative to:	n	e [mm]
Top flange	2	-55
Bottom flange	2	-55

Bolt arrangement



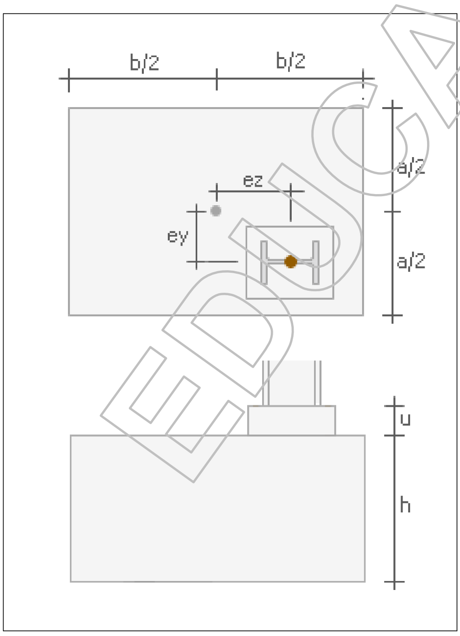
Welds



af [mm]	6.0
aw [mm]	4.0

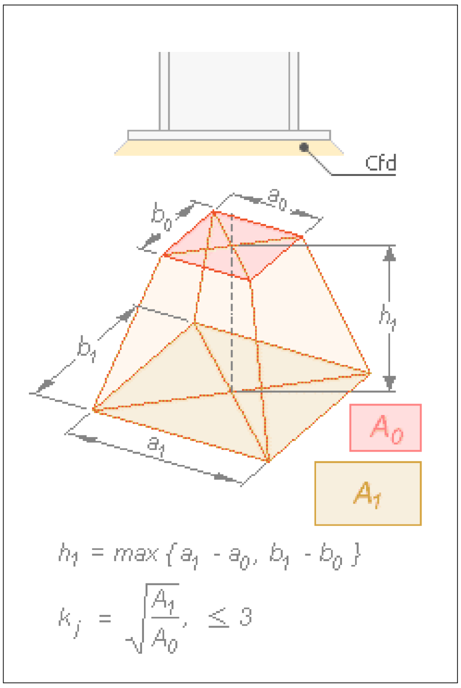
Foundation

Material and geometry



Material	C30/37
γ_C	1.50
a [mm]	1000
b [mm]	1000
h [mm]	600
ey	0
ez	0
u [mm]	50

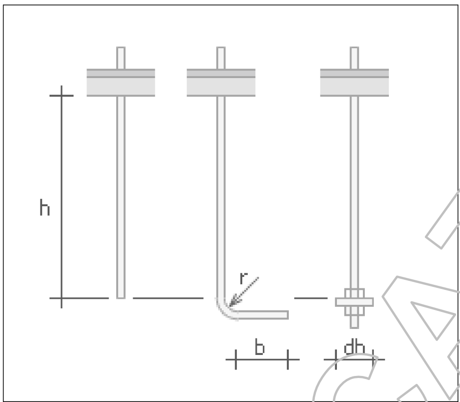
Calculation parameters



Friction coefficient (Cfd)	0.00
Beta j	0.67
kj	1.00

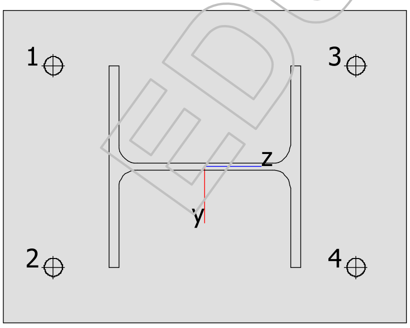
Anchor-concrete interaction

Anchor geometry

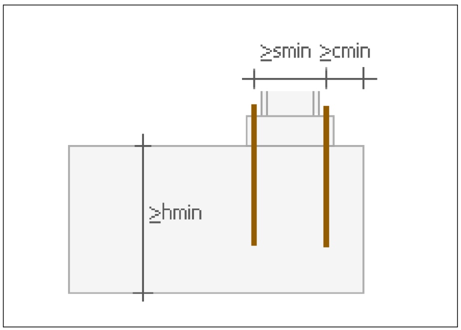


Type	Straight
Surface	Ribbed
h [mm]	200
b [mm]	50
r [mm]	140
dh [mm]	50

Bolt numbering



Calculations



Check requested	Yes
Concrete is cracked	Yes
gamma,Mp	1.50
gamma,Mc	1.50
gamma,Msp	1.50
kcr	8.50
kucr	11.90
Ignore cone-failure	No
Ignore splitting-failure	No
cmin [mm]	50
smin [mm]	80
hmin [mm]	260

Joint utilization: 71 % (LC: 'SJ.4.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.35*Soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W

2nd order effect (EN 1993-1-1: [6.3])

α = 0.49, λ = 1.58, φ = 2.08, χ = 0.29

ΔM = 52.37 * M

Base plate normal force - moment resistance (EN 1993-1-8: [6.2.8]): 53 % (LC: 'SJ.4.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.8

Compression capacity, for positive moment

f_{jd} = 13.400 N/mm^2 (EN 1992-1-1: [6.7; (2)])

c = 53 mm, l_{eff} = 307 mm, b_{eff} = 117 mm

$F_{C,Rd}$ = 481.20 kN

$l_{eff,w}$ = 63 mm, $b_{eff,w}$ = 113 mm

$F_{C,Rd,w}$ = 95.83 kN

Compression capacity, for negative moment

f_{jd} = 13.400 N/mm^2 (EN 1992-1-1: [6.7; (2)])

c = 53 mm, l_{eff} = 307 mm, b_{eff} = 117 mm

$F_{C,Rd}$ = 481.20 kN

$l_{eff,w}$ = 63 mm, $b_{eff,w}$ = 113 mm

$F_{C,Rd,w}$ = 95.83 kN

Column web and flange compression resistance

No compressed haunch is applied.

Column section moment resistance

$W = 429483\ mm^3$

$M_{c,Rd} = 145.21$ kNm

$F_{c,fb,Rd} = 806.70$ kN

$N_{0,Rd} = 962.40$ kN, $N_{max,Rd} = 1058.23$ kN

Anchors must be checked for adequate elongation.

Anchorage tension resistance (Ref.8: [2.4.1]): 0 % (LC: 'SJ.4.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)'

There are no tensioned anchors

Shear resistance (EN 1993-1-8: [6.2.2; (5)]): 0 % (LC: 'SJ.4.1: Stability1: wind y- dom. (0,9 SW+0,9 soil p.+0,9 dead+1,5 W)')

$F_{v,Ed,y} = -0.00$ kN, $F_{v,Ed,z} = -0.00$ kN, $F_{v,Ed} = 0.00$ kN

Anchor 1. $F_{1,vb,Rd,y} = 367.20$ kN, $F_{1,vb,Rd,z} = 367.20$ kN, $N_{Ed} = -4.92$ kN

Anchor 2. $F_{1,vb,Rd,y} = 306.00$ kN, $F_{1,vb,Rd,z} = 367.20$ kN, $N_{Ed} = -4.92$ kN

Anchor 3. $F_{1,vb,Rd,y} = 367.20$ kN, $F_{1,vb,Rd,z} = 278.18$ kN, $N_{Ed} = -4.92$ kN

Anchor 4. $F_{1,vb,Rd,y} = 306.00$ kN, $F_{1,vb,Rd,z} = 278.18$ kN, $N_{Ed} = -4.92$ kN

$F_{f,Rd} = -0.00$ kN, $F_{2,vb,Rd} = 38.89$ kN, $F_{t,Rd} = 141.12$ kN

Shear resistances of tensioned anchors are reduced by factor $(1 - N_{Ed} / 1.4F_{t,Rd})$

$F_{v,Rd,y} = 155.55$ kN, $F_{v,Rd,z} = 155.55$ kN, $F_{2,v,Rd} = 155.55$ kN

Flange (at the corner) weld resistance (EN 1993-1-8: [4.5.3.2; (1)]): 71 % (LC: 'SJ.4.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89

$\sigma = 259.19\ N/mm^2$, $\tau_{pp} = 0.00\ N/mm^2$, $\tau_{pl} = 0.00\ N/mm^2$

$\sigma_{Rd,1} = 453.33\ N/mm^2$, $\sigma_{Rd,2} = 367.20\ N/mm^2$

Flange (at the web) weld resistance (EN 1993-1-8: [4.5.3.2; (1)]): 71 % (LC: 'SJ.4.1: 0.89*1.35*SW + 0.89*1.35*dead + 0.89*1.

$\sigma = 259.19\ N/mm^2$, $\tau_{pp} = 0.00\ N/mm^2$, $\tau_{pl} = 0.00\ N/mm^2$

$\sigma_{Rd,1} = 453.33\ N/mm^2$, $\sigma_{Rd,2} = 367.20\ N/mm^2$

Web weld resistance: Not relevant

Through-thickness requirements (EN 1993-1-10: [3.2; (2)])

$Z_a = 3.00$, $Z_b = 0.00$, $Z_c = 4.00$, $Z_d = 0.00$, $Z_e = 0.00$

$Z_{Ed} = 7.00$

References

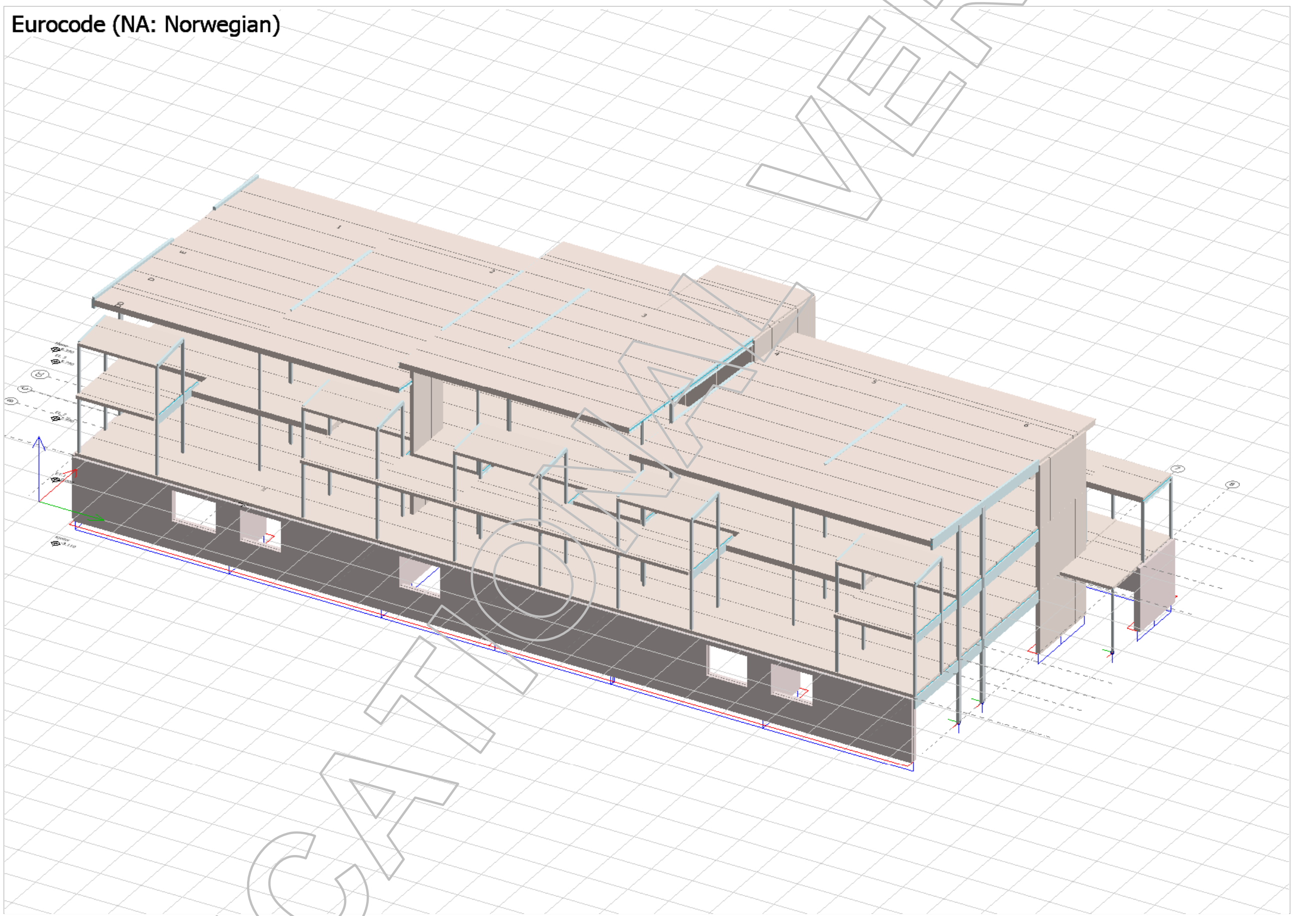
Ref.8: The Swedish Institute of Steel Construction, Detail Handbook, Publication 183

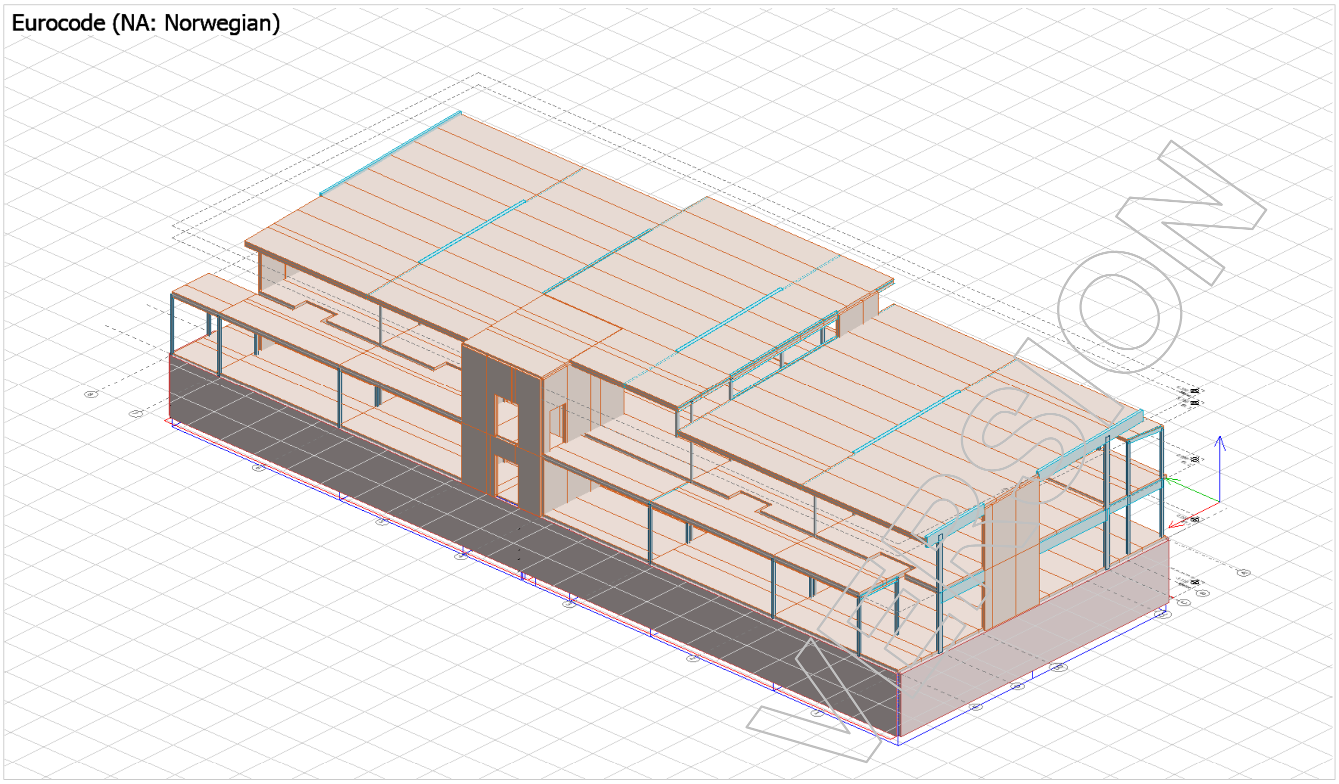
FEM-design results for option3

Contents

1 Structure

3D modell





Load cases

No.	Name	Type	Duration class
1	selfweight	+Struc. dead load	Permanent
2	Supperimposed dead	Ordinary	Permanent
3	Live load	Ordinary	Permanent
4	snow load	Ordinary	Short-term
5	Wind load Y-	Ordinary	Instantaneous
6	Earth pressure	Ordinary	Permanent
7	Misalignement load Hi	Ordinary	Permanent

Surface loads (Ordinary)

No.	q1	q2	q3	Load case	Comment	Applied on Ecc	Assigned	Intensity
[-]	[kN/m2]	[kN/m2]	[kN/m2]	[-]	[-]	[-]	[-]	[-]
1	2.220	2.220	2.220	Supperi...		No	-	Action
2	2.220	2.220	2.220	Supperi...		No	-	Action
3	2.220	2.220	2.220	Supperi...		No	-	Action
4	2.200	2.200	2.200	Supperi...		No	-	Action
5	2.200	2.200	2.200	Supperi...		No	-	Action
6	2.200	2.200	2.200	Supperi...		No	-	Action
7	2.200	2.200	2.200	Supperi...		No	-	Action
8	0.500	0.500	0.500	Supperi...		No	-	Action
9	0.500	0.500	0.500	Supperi...		No	-	Action
10	0.500	0.500	0.500	Supperi...		No	-	Action
11	0.500	0.500	0.500	Supperi...		No	-	Action
12	0.500	0.500	0.500	Supperi...		No	-	Action
13	0.500	0.500	0.500	Supperi...		No	-	Action
14	0.500	0.500	0.500	Supperi...		No	-	Action
15	0.500	0.500	0.500	Supperi...		No	-	Action
16	0.500	0.500	0.500	Supperi...		No	-	Action
17	0.500	0.500	0.500	Supperi...		No	-	Action
18	0.500	0.500	0.500	Supperi...		No	-	Action
19	0.500	0.500	0.500	Supperi...		No	-	Action

No.	q1	q2	q3	Load case	Comment	Applied on Ecc	Assigned	Intensity
[-]	[kN/m2]	[kN/m2]	[kN/m2]	[-]	[-]	[-]	[-]	[-]
20	0.500	0.500	0.500	Supperi...		No	-	Action
21	0.500	0.500	0.500	Supperi...		No	-	Action
22	0.500	0.500	0.500	Supperi...		No	-	Action
23	0.500	0.500	0.500	Supperi...		No	-	Action
24	0.500	0.500	0.500	Supperi...		No	-	Action
25	0.500	0.500	0.500	Supperi...		No	-	Action
26	0.500	0.500	0.500	Supperi...		No	-	Action
27	0.500	0.500	0.500	Supperi...		No	-	Action
28	0.500	0.500	0.500	Supperi...		No	-	Action
29	0.500	0.500	0.500	Supperi...		No	-	Action
30	0.500	0.500	0.500	Supperi...		No	-	Action
31	2.000	2.000	2.000	Live load		No	-	Action
32	2.000	2.000	2.000	Live load		No	-	Action
33	2.000	2.000	2.000	Live load		No	-	Action
34	2.000	2.000	2.000	Live load		No	-	Action
35	2.000	2.000	2.000	Live load		No	-	Action
36	2.000	2.000	2.000	Live load		No	-	Action
37	2.000	2.000	2.000	Live load		No	-	Action
38	2.000	2.000	2.000	Live load		No	-	Action
39	2.000	2.000	2.000	Live load		No	-	Action
40	2.000	2.000	2.000	Live load		No	-	Action
41	2.000	2.000	2.000	Live load		No	-	Action
42	2.000	2.000	2.000	Live load		No	-	Action
43	2.000	2.000	2.000	Live load		No	-	Action
44	2.000	2.000	2.000	Live load		No	-	Action
45	2.000	2.000	2.000	Live load		No	-	Action
46	2.000	2.000	2.000	Live load		No	-	Action
47	2.000	2.000	2.000	Live load		No	-	Action
48	2.000	2.000	2.000	Live load		No	-	Action
49	2.000	2.000	2.000	Live load		No	-	Action
50	2.000	2.000	2.000	Live load		No	-	Action
51	3.200	3.200	3.200	snow lo...		No	-	Action
52	3.200	3.200	3.200	snow lo...		No	-	Action
53	3.200	3.200	3.200	snow lo...		No	-	Action
54	3.200	3.200	3.200	snow lo...		No	-	Action
55	3.200	3.200	3.200	snow lo...		No	-	Action
56	3.200	3.200	3.200	snow lo...		No	-	Action
57	3.200	3.200	3.200	snow lo...		No	-	Action
58	3.200	3.200	3.200	snow lo...		No	-	Action
59	3.200	3.200	3.200	snow lo...		No	-	Action
60	3.200	3.200	3.200	snow lo...		No	-	Action
61	0.500	0.500	0.500	Supperi...		No	-	Action
62	3.200	3.200	3.200	snow lo...		No	-	Action
63	2.220	2.220	2.220	Supperi...		No	-	Action
64	2.220	2.220	2.220	Supperi...		No	-	Action
65	2.000	2.000	2.000	Live load		No	-	Action
66	2.000	2.000	2.000	Live load		No	-	Action
67	2.000	2.000	2.000	Live load		No	-	Action
68	2.000	2.000	2.000	Live load		No	-	Action
69	2.000	2.000	2.000	Live load		No	-	Action
70	2.220	2.220	2.220	Supperi...		No	-	Action
71	2.220	2.220	2.220	Supperi...		No	-	Action
72	2.220	2.220	2.220	Supperi...		No	-	Action
73	2.200	2.200	2.200	Supperi...		No	-	Action

No.	q1	q2	q3	Load case	Comment	Applied on Ecc	Assigned	Intensity
[-]	[kN/m2]	[kN/m2]	[kN/m2]	[-]	[-]	[-]	[-]	[-]
74	2.200	2.200	2.200	Supperi...		No	-	Action
75	2.000	2.000	2.000	Live load		No	-	Action
76	2.000	2.000	2.000	Live load		No	-	Action

Surface loads (Soil/Hydrostatic pressure)

No.	z0	q0	qh	qbottom	qtop	Load case	Comment	Applied on Ecc	Assigned	Intensity
[-]	[m]	[kN/m2]	[kN/m2/m]	[kN/m2]	[kN/m2]	[-]	[-]	[-]	[-]	[-]
1	3.100	1.650	21.300	133.923	67.680	Earth pr...		No	-	Action

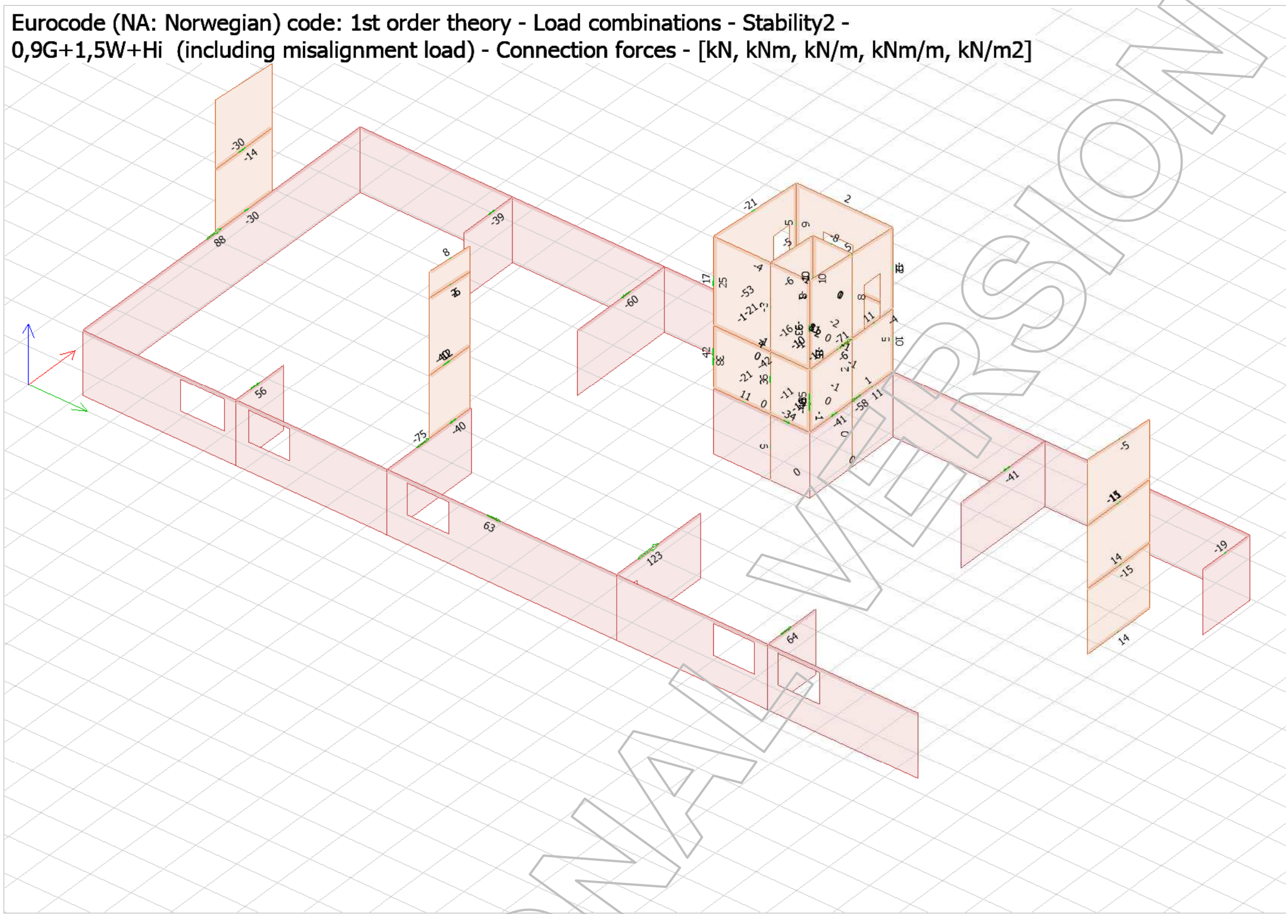
Load combinations

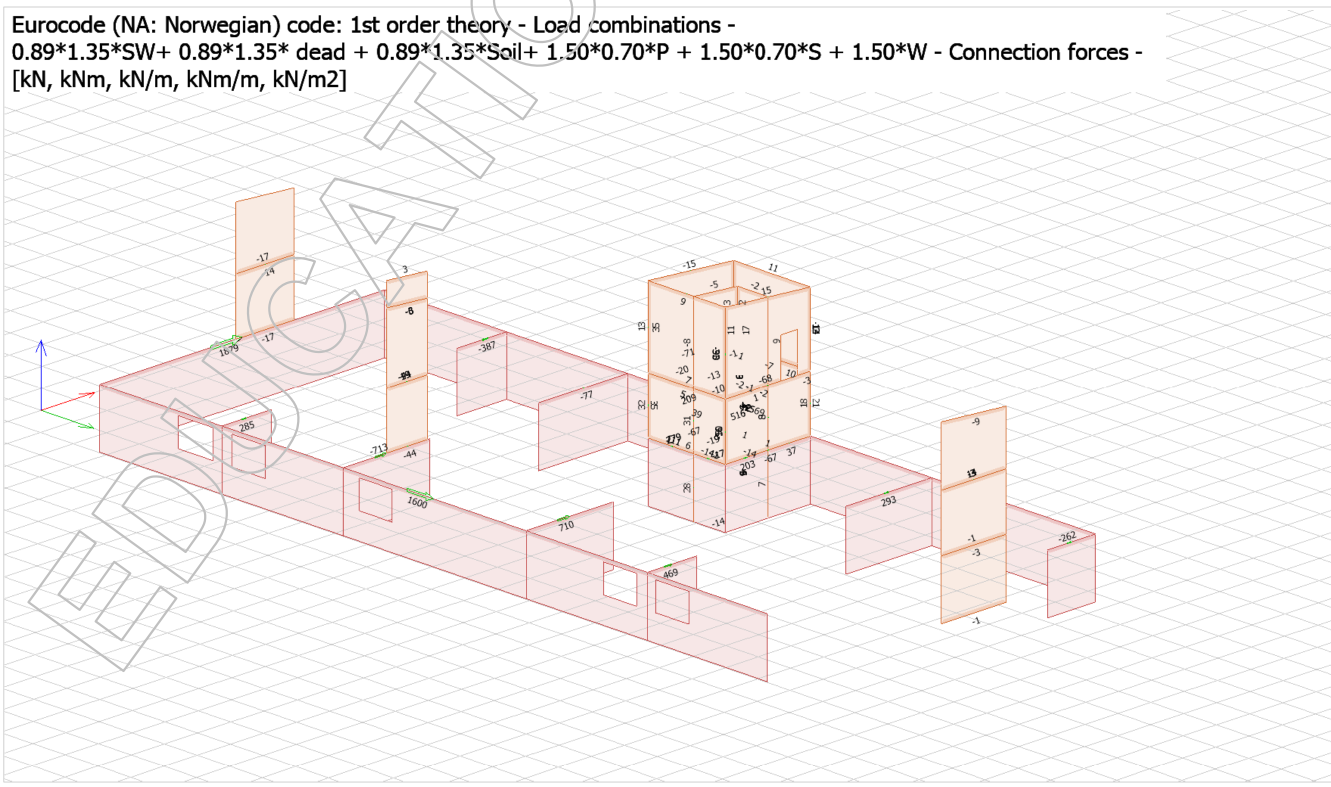
No.	Name	Type	Factor	Load cases
1	Stabil...	Ultimate	0.900	selfweight (+St...
			0.900	Earth pressure
			0.900	Supperimposed...
			1.500	Wind load Y-
2	Stabil...	Ultimate	0.900	selfweight (+St...
			0.900	Supperimposed...
			1.500	Wind load Y-
			1.000	Misalignement l...
3	Servi...	Charact...	1.000	selfweight (+St...
			1.000	Supperimposed...
			1.000	Live load
			1.000	snow load
4	Ultim...	Ultimate	1.200	selfweight (+St...
			1.200	Supperimposed...
			1.500	Live load
			1.050	snow load
5	1.35*...	Ultimate	1.350	selfweight (+St...
			1.350	Supperimposed...
			1.350	Earth pressure
			1.050	Live load
			1.050	snow load
			1.050	Wind load Y-
6	0.89*...	Ultimate	1.202	selfweight (+St...
			1.202	Supperimposed...
			1.202	Earth pressure
			1.500	Live load
			1.050	snow load
			1.050	Wind load Y-
7	0.89*...	Ultimate	1.202	selfweight (+St...
			1.202	Supperimposed...
			1.202	Earth pressure
			1.050	Live load
			1.500	snow load
			1.050	Wind load Y-
8	0.89*...	Ultimate	1.202	selfweight (+St...
			1.202	Supperimposed...
			1.202	Earth pressure
			1.050	Live load
			1.050	snow load
			1.500	Wind load Y-
9	1,0S...	Charact...	1.000	selfweight (+St...
			1.000	Supperimposed...
			1.000	Earth pressure
			1.000	Live load
			0.700	snow load
			0.700	Wind load Y-
10	1,0S...	Charact...	1.000	selfweight (+St...
			1.000	Supperimposed...
			1.000	Earth pressure
			0.700	Live load
			1.000	snow load
			0.700	Wind load Y-
11	1,0S...	Charact...	1.000	selfweight (+St...
			1.000	Supperimposed...
			1.000	Earth pressure
			0.700	Live load
			0.700	snow load
			1.000	Wind load Y-
12	1,0S...	Quasi-p...	1.000	selfweight (+St...
			1.000	Supperimposed...
			1.000	Earth pressure
			0.300	Live load
			0.300	snow load
			0.200	Wind load Y-
13	1,0 S...	Frequent	1.000	selfweight (+St...
			1.000	Supperimposed...
			1.000	Earth pressure
			0.500	Live load
			0.300	snow load
			0.200	Wind load Y-
14	1,0 S...	Frequent	1.000	selfweight (+St...
			1.000	Supperimposed...
			1.000	Earth pressure
			0.300	Live load
			0.500	snow load
			0.200	Wind load Y-
15	1,0 S...	Frequent	1.000	selfweight (+St...
			1.000	Supperimposed...
			1.000	Earth pressure
			0.300	Live load
			0.300	snow load
			0.500	Wind load Y-

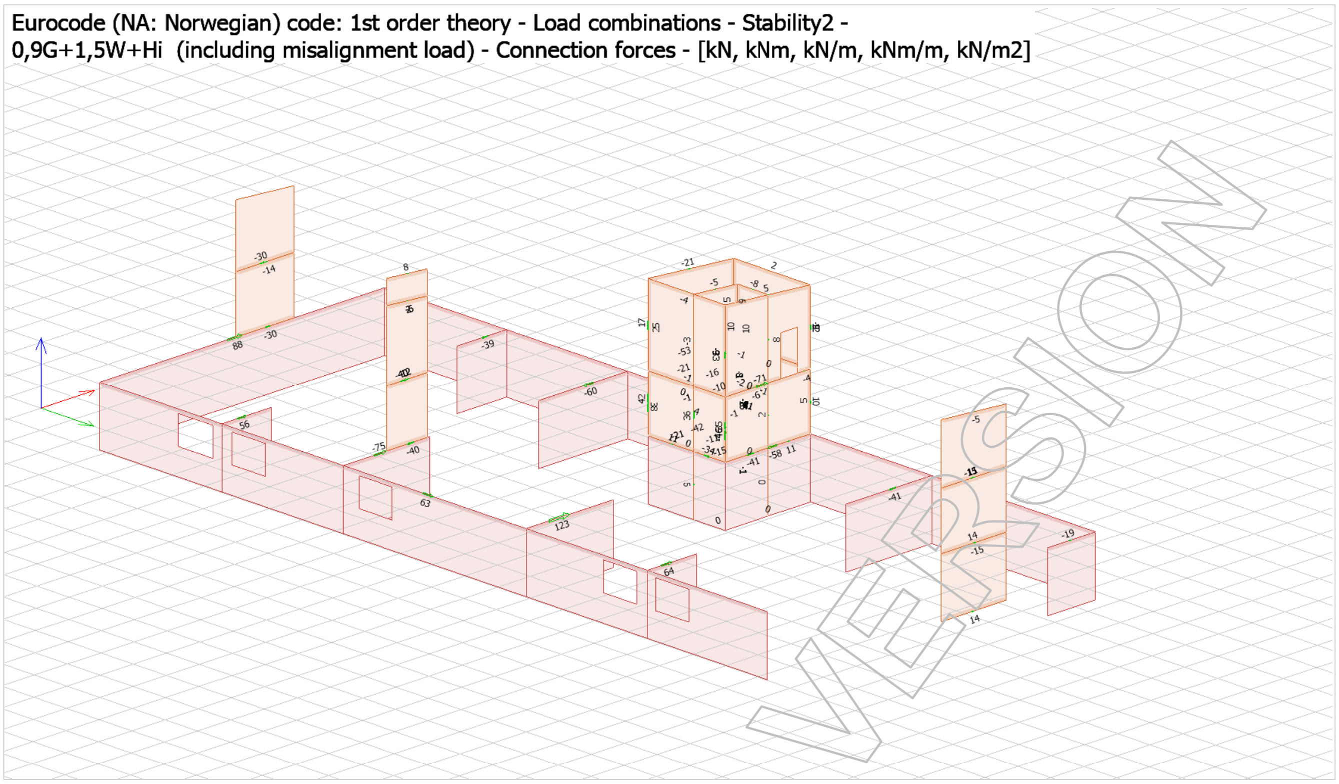
2 Analysis results

2.1 Connection forces

Connection forces from horizontal force







Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - Stability2 - 0,9G+1,5W+Hi (including misalignment load) - Connection forces - [kN, kNm, kN/m, kNm/m, kN/m2]

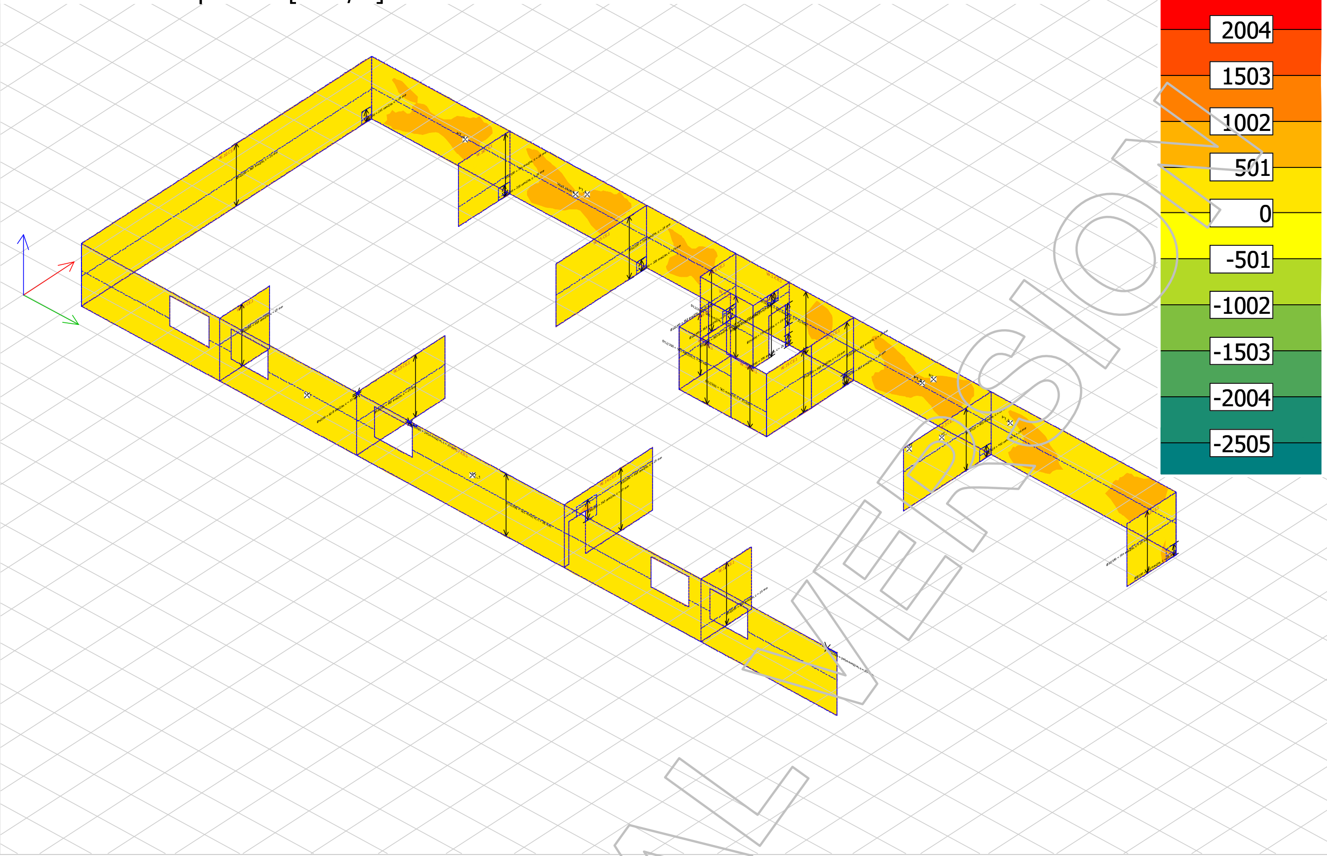
3 Design results

3.1 RCC design

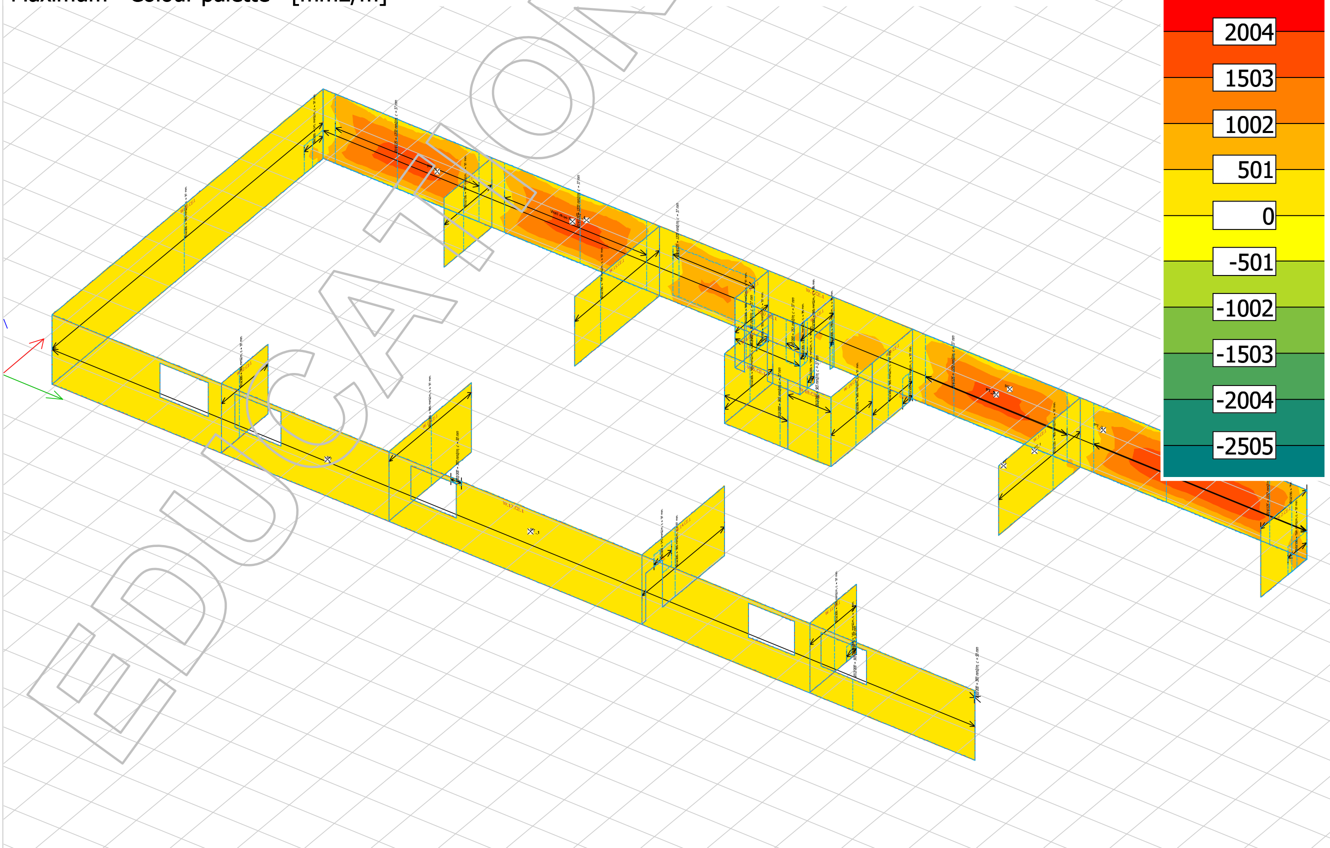
Walls

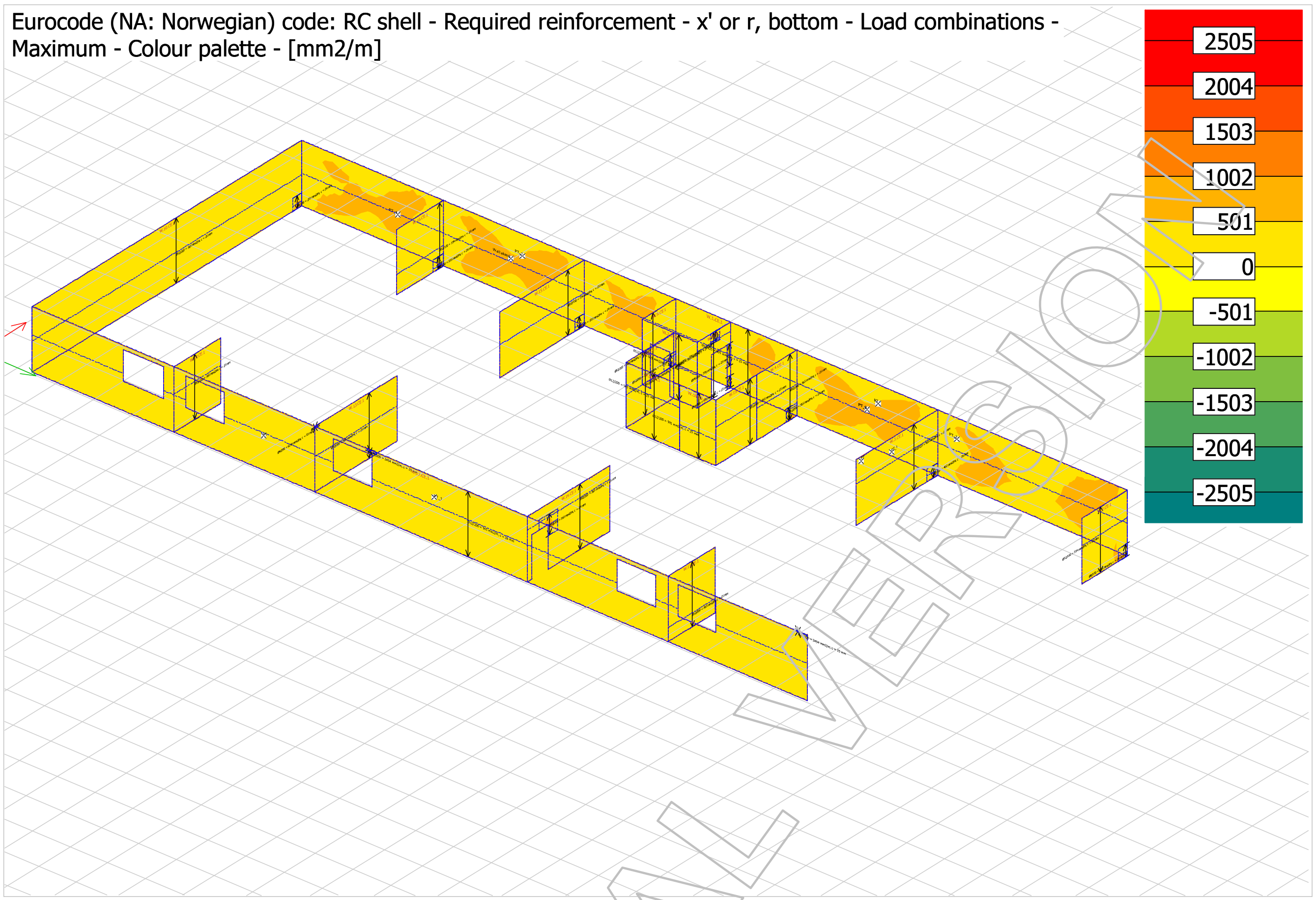
ID	Material	t1	t2	E2 / E1	Alpha	Ecc.	Ecc. calc.	Ecc. crack.	Length	Height
[-]	[-]	[m]	[m]	[-]	[rad]	[m]	[-]	[-]	[m]	[m]
W.1.1	C35/45	0.250	0.250	1.000	0.000	0.000	No	No	43.660	3.110
W.2.1	C35/45	0.350	0.350	1.000	0.000	0.000	No	No	2.902	3.110
W.3.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	5.180	3.110
W.4.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	2.550	3.110
W.5.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	2.820	3.110
W.6.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	3.060	3.110
W.7.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	2.900	3.110
W.8.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	2.120	3.110
W.9.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	2.120	3.110
W.10.1	C35/45	0.350	0.350	1.000	0.000	0.000	No	No	17.185	3.110
W.11.1	C35/45	0.250	0.250	1.000	0.000	0.000	No	No	2.975	3.110
W.12.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	2.975	3.110
W.13.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	5.245	3.110
W.14.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	5.245	3.110
W.15.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	5.380	3.110
W.16.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	3.010	3.110
W.17.1	C35/45	0.350	0.350	1.000	0.000	0.000	No	No	40.985	3.110
W.18.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	1.920	3.110
W.19.1	C35/45	0.220	0.220	1.000	0.000	0.000	No	No	2.630	3.110

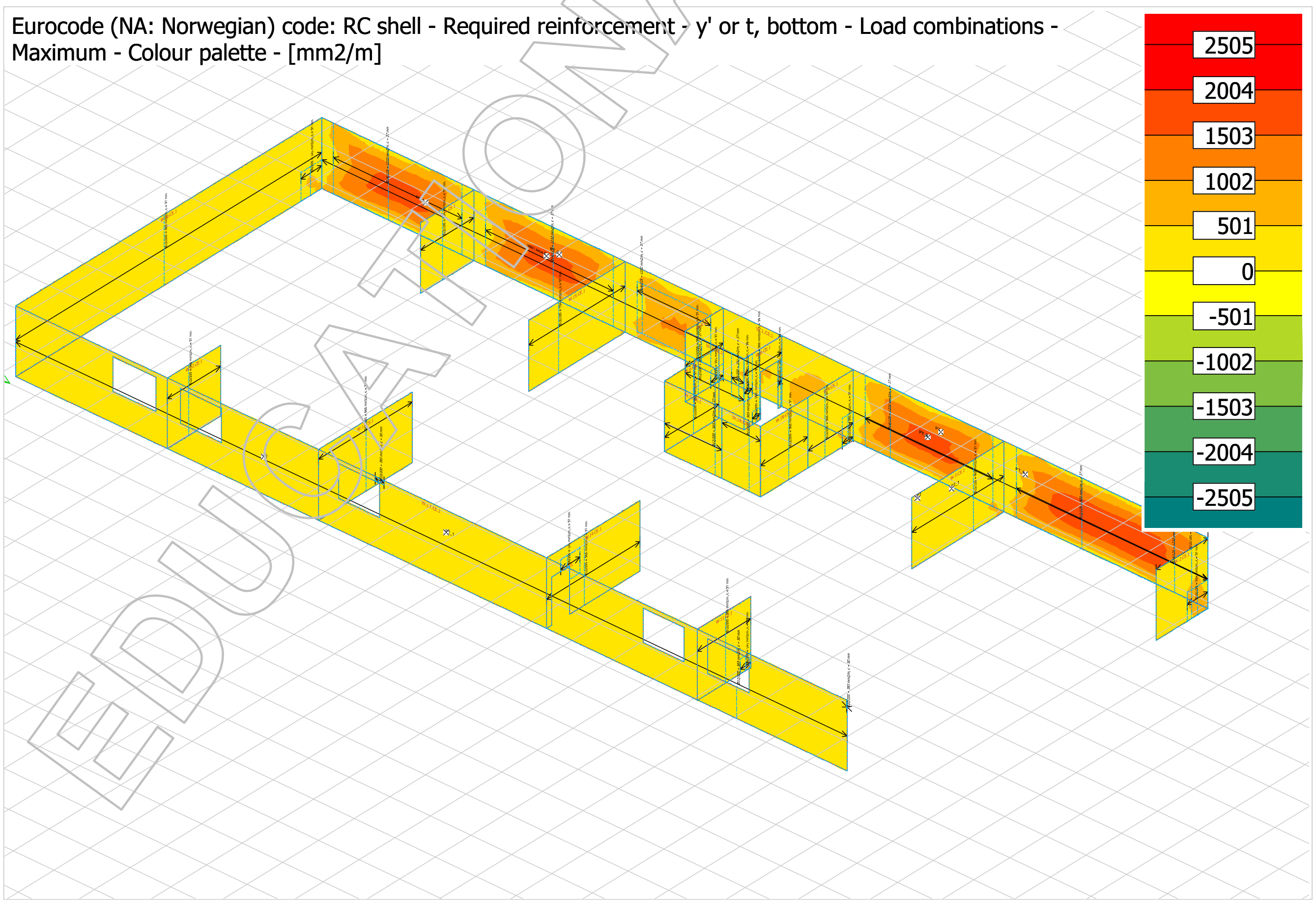
Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, bottom - Load combinations - Maximum - Colour palette - [mm2/m]



Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, bottom - Load combinations - Maximum - Colour palette - [mm2/m]



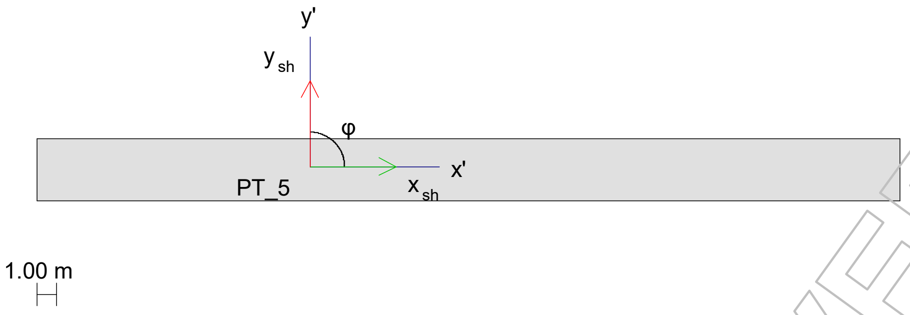

Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - x' or r, bottom - Load combinations - Maximum - Colour palette - [mm2/m]
2505
2004
1503
1002
501
0
-501
-1002
-1503
-2004
-2505


Eurocode (NA: Norwegian) code: RC shell - Required reinforcement - y' or t, bottom - Load combinations - Maximum - Colour palette - [mm2/m]
2505
2004
1503
1002
501
0
-501
-1002
-1503
-2004
-2505

Wall in Axis E

W.1.1 - PT_5
Maximum of load combinations

Geometry



x_{sh} , y_{sh} : local coordinate system of shell
x', y': reinforcement directions

Global coordinates:
x = 29.22 m
y = 21.32 m
z = -1.40 m

Reinforcement directions:
φ = 90.00 °

Thickness:
t = 0.25 m

Concrete (EN 1992-1-1: 3.1.7)
C35/45

f_{ck} = 35.00 N/mm^2 ε_{c2} = 0.00200 ε_{cu3} = 0.0035 φ_{ef} = 0.00

f_{ctm} = 3.20 N/mm^2 E_{cm} = 34000 N/mm^2

$\gamma_{C,U}$ = 1.50 $\gamma_{C,Ua}$ = 1.20 α_{cc} = 1.00

$\lambda = 0.8 - \max(f_{ck} - 50, 0) / 400 =$
$= 0.8 - \max(35.00 - 50, 0) / 400 = 0.80$ (3.19, 3.20)

$\eta = 1.0 - \max(f_{ck} - 50, 0) / 200 =$
$= 1.0 - \max(35.00 - 50, 0) / 200 = 1.00$ (3.21, 3.22)

$f_{cd,U} = \eta \cdot \alpha_{cc} \cdot f_{ck} / \gamma_{C,U} = 1.00 \cdot 1.00 \cdot 35.00 / 1.50 = 23.33\ N/mm^2$ (3.15) + Fig. 3.5

$f_{cd,Ua} = \eta \cdot \alpha_{cc} \cdot f_{ck} / \gamma_{C,Ua} = 1.00 \cdot 1.00 \cdot 35.00 / 1.20 =$
$= 29.17\ N/mm^2$ (3.15) + Fig. 3.5

$\varepsilon_{yd} = (1 - \lambda) \cdot \varepsilon_{cu3} = (1 - 0.80) \cdot 0.0035 = 0.0007$ Fig. 3.5

Applied reinforcement

Face, direction	Quality	Diameter [mm]	Cover [mm]	Spacing [mm]	Area [mm^2/m]
Bottom, x'	B500C	12	25	125	905
Bottom, y'	B500C	12	37	125	905
Bottom, y'	B500C	14	37	125	1232
Top, x'	B500C	12	25	125	905
Top, y'	B500C	12	37	125	905

Equivalent reinforcement

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
Quality	B500C	B500C	B500C	B500C
Diameter [mm]	12	13	12	12
Cover [mm]	25	37	25	37
c = Cover + Φ/2 [mm]	31	44	31	43
E_s [N/mm^2]	200000	200000	200000	200000
Applied, UL [mm^2/m]	905	2136	905	905
$f_{sy,UL}$ [N/mm^2]	435	435	435	435
Applied, SL [mm^2/m]	905	2136	905	905
$f_{sy,SL}$ [N/mm^2]	500	500	500	500

Equivalent reinforcement calculation is based on calculation parameter data.

Other calculation parameter data

Allowed crackwidth, top:	1.00 mm	Minimum reinforcement:	Yes
Allowed crackwidth, bottom:	1.00 mm	Compressed reinf.:	No

Required reinforcement, bottom x'

LC: '1.35*SW + 1.35* dead + 1.35*soil + 1.50*0.70*P+ 1.50*0.70*S + 1.50*0.70*W'

Internal forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x,sh}$ = 45.63	$n_{x,sh}$ = 6.15
$m_{y,sh}$ = 128.96	$n_{y,sh}$ = -9.45
$m_{xy,sh}$ = -0.19	$n_{xy,sh}$ = -40.47

Design forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x',bot}$ = 45.83	$n_{x',+}$ = 46.63
$m_{y',bot}$ = 129.15	$n_{y',+}$ = 31.03
$m_{x',top}$ = 0.00	$n_{x',-}$ = -34.32
$m_{y',top}$ = 0.00	$n_{y',-}$ = -49.92

Calculation is based on Wood-Armer and Nemeth methods.

Maximum reinforcement

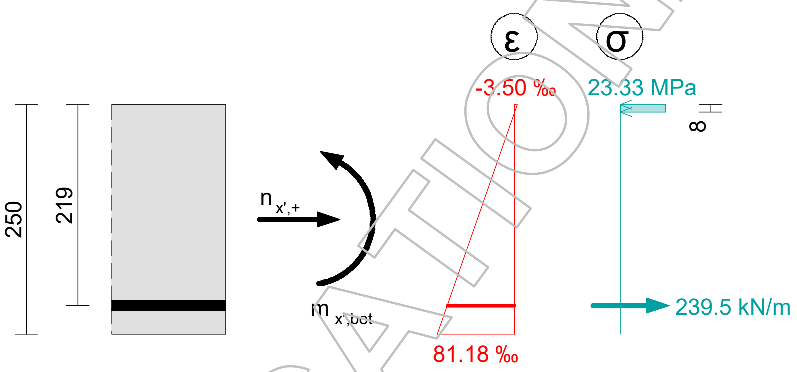
$A_{s,max} = 0.04 \cdot b \cdot t = 0.04 \cdot 1000 \cdot 250 = 10000 \ mm^2/m$ (EN 1992-1-1 9.6.2(1))

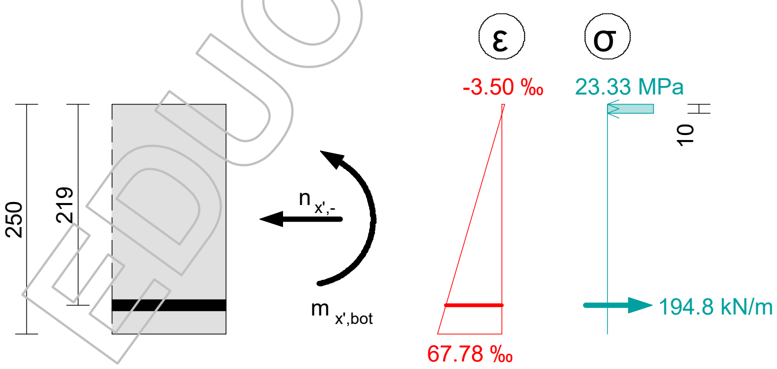
Calculation of required reinforcement from different m-n combinations

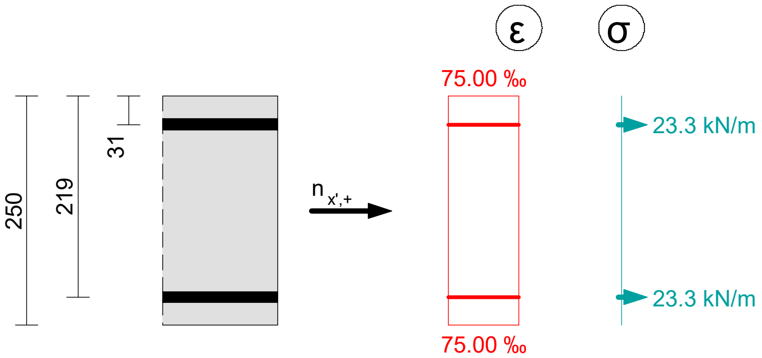
Face, direction	Bottom, x'	Bottom, x'	Top, x'	Top, x'	Bottom, y'	Bottom, y'	Top, y'	Top, y'
Sign of n	+	-	+	-	+	-	+	-
$m_{[dir][face]}$ [kN m/m]	45.83	45.83	0.00	0.00	129.15	129.15	0.00	0.00
$n_{[dir][face]}$ [kN/m]	46.63	-34.32	46.63	-34.32	31.03	-49.92	31.03	-49.92
Case	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.
$A_{sb,x'}$ [mm ^{2}/m]	551	448	54	0	-	-	-	-
$A_{sb,y'}$ [mm ^{2}/m]	-	-	-	-	1586	1485	36	0
$A_{st,x'}$ [mm ^{2}/m]	0	0	54	0	-	-	-	-
$A_{st,y'}$ [mm ^{2}/m]	-	-	-	-	0	0	36	0

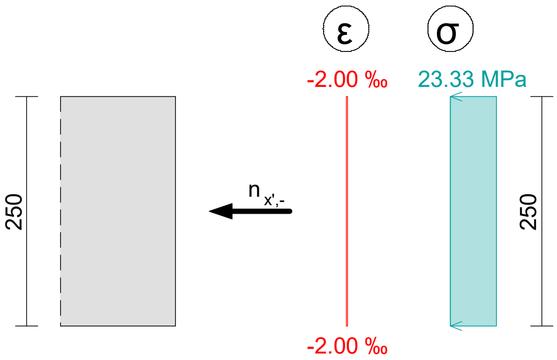
Necessary reinforcement is calculated by considering equivalent reinforcement data.

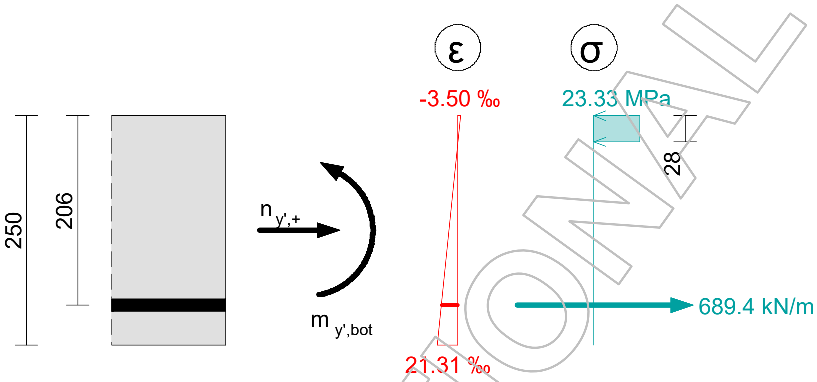
If no reinforcement is required, the ultimate resistance of the concrete section is represented in the stress figures.

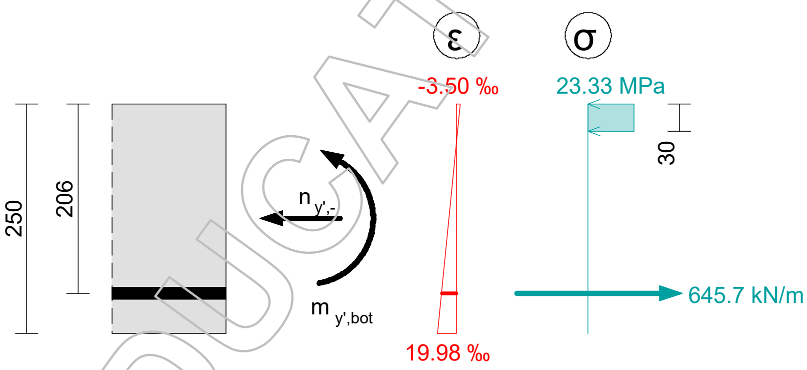


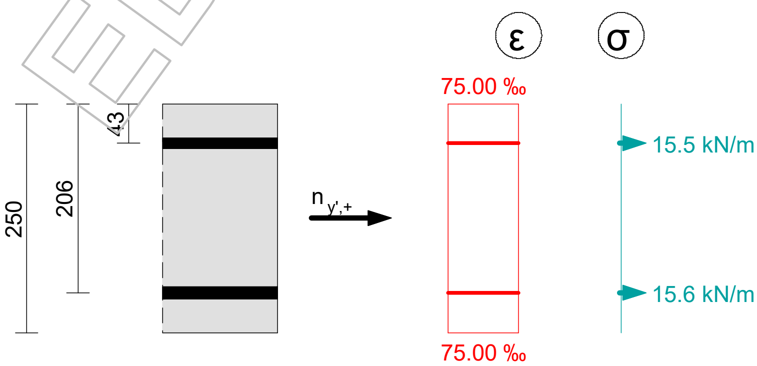


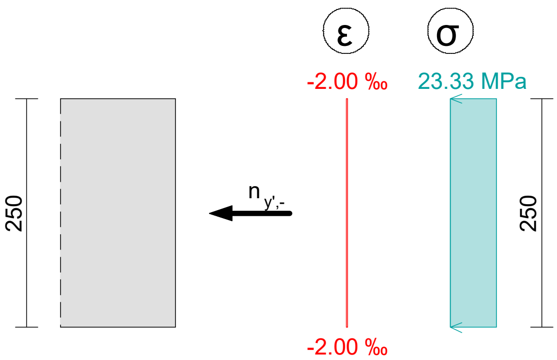

ε
σ
75.00 ‰
23.3 kN/m
250
219
31
$n_{x',+}$
23.3 kN/m
75.00 ‰


ε
σ
-2.00 ‰
23.33 MPa
250
$n_{x',-}$
250
-2.00 ‰


ε
σ
-3.50 ‰
23.33 MPa
28
250
206
$n_{y',+}$
$m_{y',bot}$
689.4 kN/m
21.31 ‰


ε
σ
-3.50 ‰
23.33 MPa
30
250
206
$n_{y',-}$
$m_{y',bot}$
645.7 kN/m
19.98 ‰


ε
σ
75.00 ‰
15.5 kN/m
43
250
206
$n_{y',+}$
15.6 kN/m
75.00 ‰



Minimum reinforcement

$A_{s,min,vertical} = 0.002 \cdot A_c$ (EN 1992-1-1 9.6.2(1))

$A_{s,min,horizontal} = \max(0.001 \cdot A_c, 0.25 \cdot A_{s,required,vertical})$ (EN 1992-1-1 9.6.3(1))

$s_{max,walls,vertical} = \min(3 \cdot t, 400)$ (EN 1992-1-1 9.6.2(3))

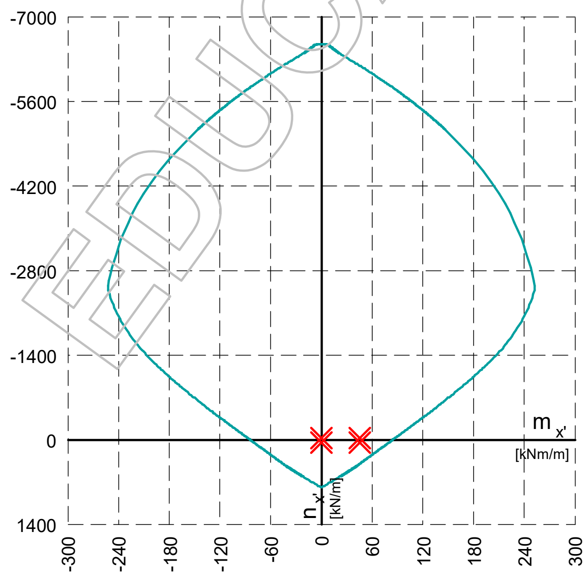
$s_{max,walls,horizontal} = 400$ mm (EN 1992-1-1 9.6.3(2))

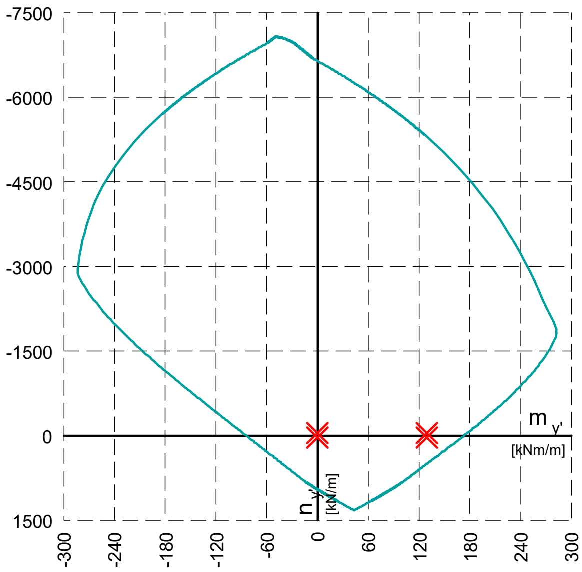
$A_{s,min,smax} = 1000 / s_{max} \cdot \Phi^2 \cdot \pi / 4$

$A_{s,min,final} = \max(A_{s,min}, A_{s,min,smax})$

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,min}$ [mm²/m]	396	250	125	250
Type	Horizontal	Vertical	Horizontal	Vertical
s_{max} [mm]	400	400	400	400
Φ [mm]	12	12	12	12
$A_{s,min,smax}$ [mm²/m]	283	283	283	283
$A_{s,min,final}$ [mm²/m]	396	283	283	283

Interaction curves based on applied reinforcement





Utilization

$A_{s,req}$ = max ($A_{s,calc}$, $A_{s,min,final}$)

$A_{s,missing}$ = $A_{s,req}$ - $A_{s,applied}$

Utilization = $A_{s,req}$ / $A_{s,applied}$ · 100

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,req}$ [mm ^{2}/m]	551	1586	283	283
$A_{s,applied}$ [mm ^{2}/m]	905	2136	905	905
$A_{s,missing}$ [mm ^{2}/m]	-	-	-	-
Utilization [%]	61	74	31	31

The amount of required reinforcement is based on an optimum calculation because several solutions are possible.

Required reinforcement, bottom y'

LC: '1.35*SW + 1.35* dead + 1.35*soil + 1.50*0.70*P+ 1.50*0.70*S + 1.50*0.70*W'

Internal forces

Moments [kN m /m]	Normal forces [kN /m]
$m_{x,sh}$ = 45.63	$n_{x,sh}$ = 6.15
$m_{y,sh}$ = 128.96	$n_{y,sh}$ = -9.45
$m_{xy,sh}$ = -0.19	$n_{xy,sh}$ = -40.47

Design forces

Moments [kN m /m]	Normal forces [kN /m]
$m_{x',bot}$ = 45.83	$n_{x',+}$ = 46.63
$m_{y',bot}$ = 129.15	$n_{y',+}$ = 31.03
$m_{x',top}$ = 0.00	$n_{x',-}$ = -34.32
$m_{y',top}$ = 0.00	$n_{y',-}$ = -49.92

Calculation is based on Wood-Armer and Nemeth methods.

Maximum reinforcement

$A_{s,max}$ = 0.04 · b · t = 0.04 · 1000 · 250 = 10000 mm ^{2}/m (EN 1992-1-1 9.6.2(1))

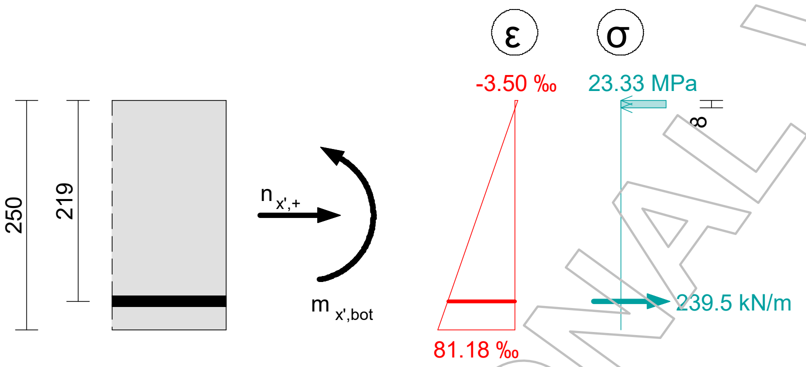
Calculation of required reinforcement from different m-n combinations

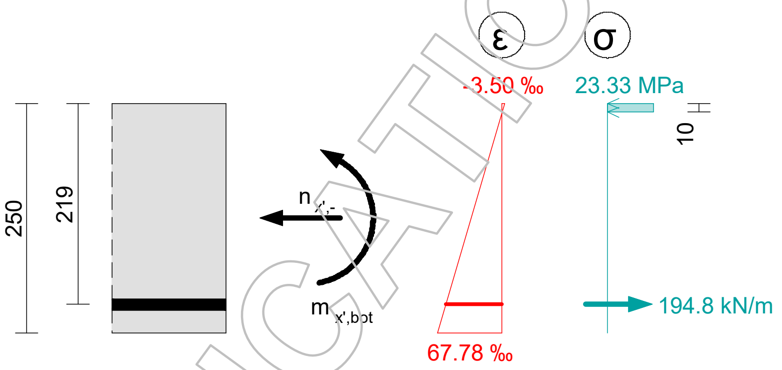
Face, direction	Bottom, x'	Bottom, x'	Top, x'	Top, x'	Bottom, y'	Bottom, y'	Top, y'	Top, y'
Sign of n	+	-	+	-	+	-	+	-

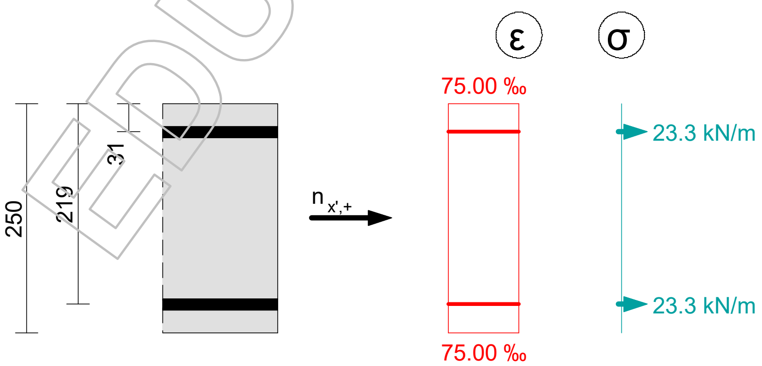
Face, direction	Bottom, x'	Bottom, x'	Top, x'	Top, x'	Bottom, y'	Bottom, y'	Top, y'	Top, y'
$m_{[dir][face]}$ [kN m/m]	45.83	45.83	0.00	0.00	129.15	129.15	0.00	0.00
$n_{[dir][face]}$ [kN/m]	46.63	-34.32	46.63	-34.32	31.03	-49.92	31.03	-49.92
Case	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.
$A_{sb,x'}$ [mm ^{2}/m]	551	448	54	0	-	-	-	-
$A_{sb,y'}$ [mm ^{2}/m]	-	-	-	-	1586	1485	36	0
$A_{st,x'}$ [mm ^{2}/m]	0	0	54	0	-	-	-	-
$A_{st,y'}$ [mm ^{2}/m]	-	-	-	-	0	0	36	0

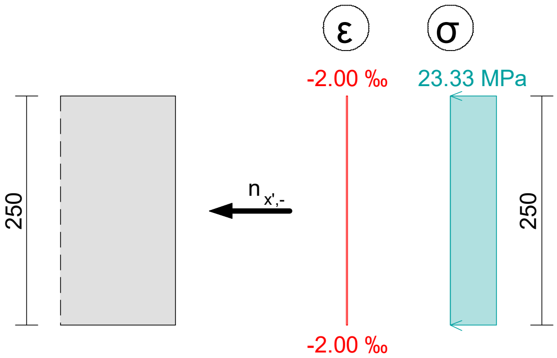
Necessary reinforcement is calculated by considering equivalent reinforcement data.

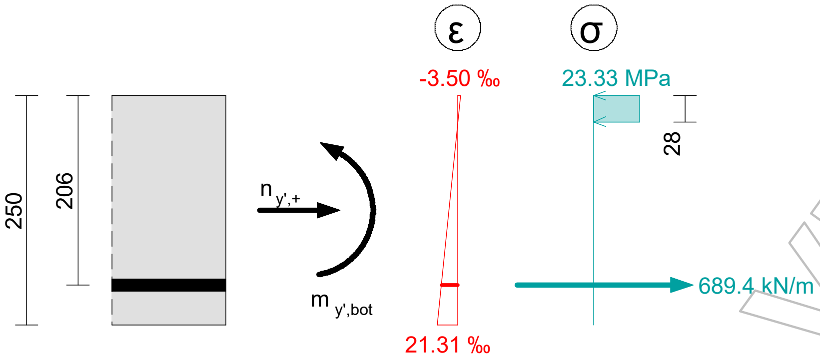
If no reinforcement is required, the ultimate resistance of the concrete section is represented in the stress figures.

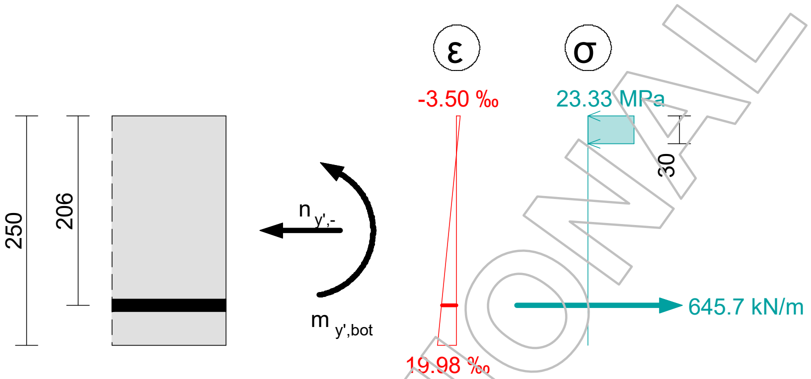


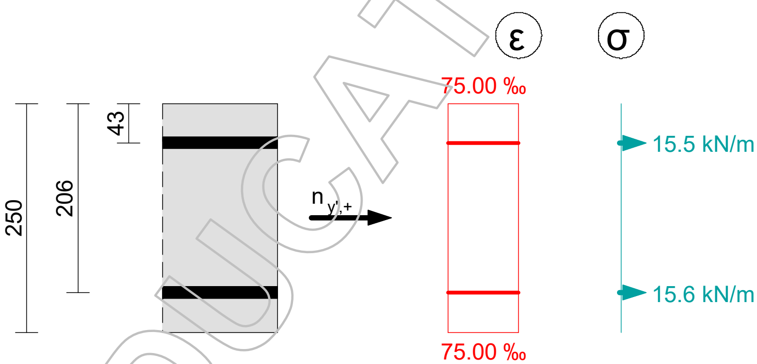


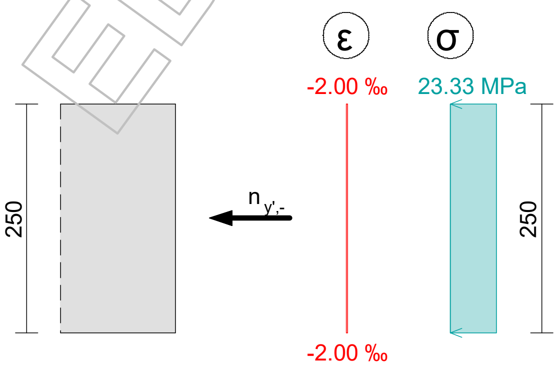



ε
σ
-2.00 ‰
23.33 MPa
250
$n_{x',-}$
250
-2.00 ‰


ε
σ
-3.50 ‰
23.33 MPa
28
250
206
$n_{y',+}$
$m_{y',bot}$
689.4 kN/m
21.31 ‰


ε
σ
-3.50 ‰
23.33 MPa
30
250
206
$n_{y',-}$
$m_{y',bot}$
645.7 kN/m
19.98 ‰


ε
σ
75.00 ‰
43
250
206
$n_{y',+}$
15.5 kN/m
15.6 kN/m
75.00 ‰


ε
σ
-2.00 ‰
23.33 MPa
250
$n_{y',-}$
250
-2.00 ‰

Minimum reinforcement

$A_{s,min,vertical} = 0.002 \cdot A_c$ (EN 1992-1-1 9.6.2(1))

$A_{s,min,horizontal} = \max(0.001 \cdot A_c, 0.25 \cdot A_{s,required,vertical})$ (EN 1992-1-1 9.6.3(1))

$s_{max,walls,vertical} = \min(3 \cdot t, 400)$ (EN 1992-1-1 9.6.2(3))

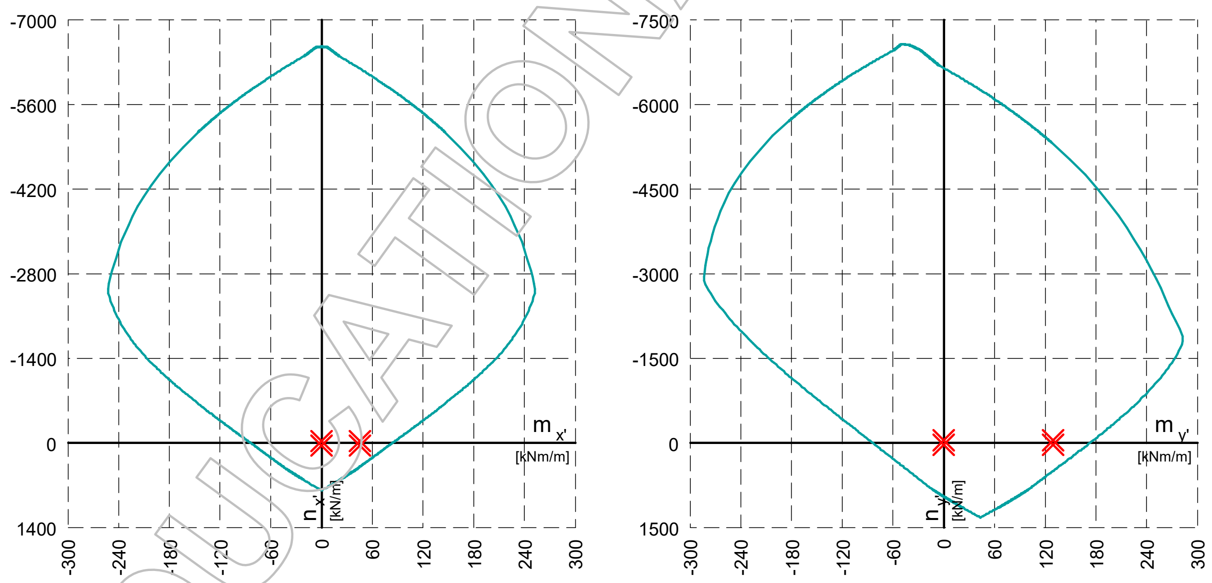
$s_{max,walls,horizontal} = 400$ mm (EN 1992-1-1 9.6.3(2))

$A_{s,min,smax} = 1000 / s_{max} \cdot \Phi^2 \cdot \pi / 4$

$A_{s,min,final} = \max(A_{s,min}, A_{s,min,smax})$

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,min}$ [mm ^{2}/m]	396	250	125	250
Type	Horizontal	Vertical	Horizontal	Vertical
s_{max} [mm]	400	400	400	400
Φ [mm]	12	12	12	12
$A_{s,min,smax}$ [mm ^{2}/m]	283	283	283	283
$A_{s,min,final}$ [mm ^{2}/m]	396	283	283	283

Interaction curves based on applied reinforcement



Utilization

$A_{s,req} = \max(A_{s,calc}, A_{s,min,final})$

$A_{s,missing} = A_{s,req} - A_{s,applied}$

$\text{Utilization} = A_{s,req} / A_{s,applied} \cdot 100$

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,req}$ [mm ^{2}/m]	551	1586	283	283

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,applied}$ [mm^2/m]	905	2136	905	905
$A_{s,missing}$ [mm^2/m]	-	-	-	-
Utilization [%]	61	74	31	31

The amount of required reinforcement is based on an optimum calculation because several solutions are possible.

Required reinforcement, top x'

LC: 'Stability1 - wind y- dom. (0,9 SW+0,9 Soil+0,9 dead+1,5 W)'

Internal forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x,sh}$ = 30.42	$n_{x,sh}$ = 5.40
$m_{y,sh}$ = 85.98	$n_{y,sh}$ = -3.24
$m_{xy,sh}$ = -0.13	$n_{xy,sh}$ = -27.59

Design forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x',bot}$ = 30.55	$n_{x',+}$ = 32.99
$m_{y',bot}$ = 86.11	$n_{y',+}$ = 24.35
$m_{x',top}$ = 0.00	$n_{x',-}$ = -22.19
$m_{y',top}$ = 0.00	$n_{y',-}$ = -30.84

Calculation is based on Wood-Armer and Nemeth methods.

Maximum reinforcement

$A_{s,max}$ = 0.04 · b · t = 0.04 · 1000 · 250 = 10000 mm^2/m (EN 1992-1-1 9.6.2(1))

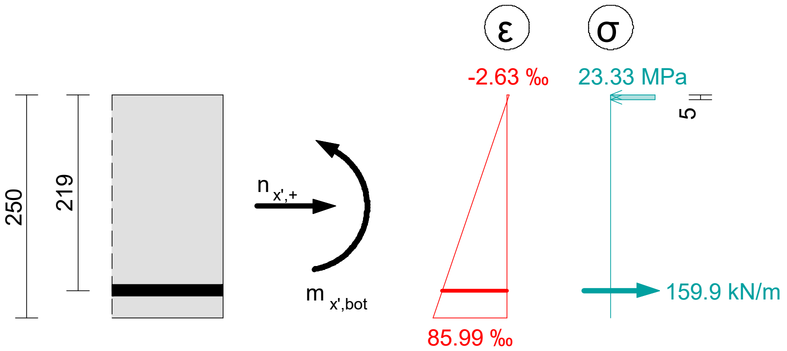
Calculation of required reinforcement from different m-n combinations

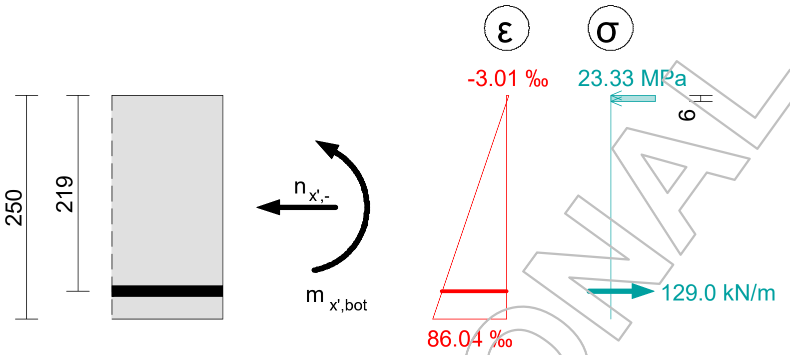
Face, direction	Bottom, x'	Bottom, x'	Top, x'	Top, x'	Bottom, y'	Bottom, y'	Top, y'	Top, y'
Sign of n	+	-	+	-	+	-	+	-
$m_{[dir][face]}$ [kN m/m]	30.55	30.55	0.00	0.00	86.11	86.11	0.00	0.00
$n_{[dir][face]}$ [kN/m]	32.99	-22.19	32.99	-22.19	24.35	-30.84	24.35	-30.84
Case	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.
$A_{sb,x'}$ [mm^2/m]	368	297	38	0	-	-	-	-
$A_{sb,y'}$ [mm^2/m]	-	-	-	-	1037	965	28	0

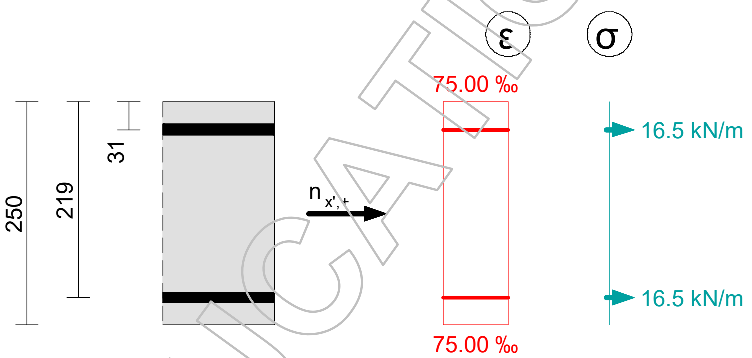
Face, direction	Bottom, x'	Bottom, x'	Top, x'	Top, x'	Bottom, y'	Bottom, y'	Top, y'	Top, y'
$A_{st,x'}$ [mm ^{2}/m]	0	0	38	0	-	-	-	-
$A_{st,y'}$ [mm ^{2}/m]	-	-	-	-	0	0	28	0

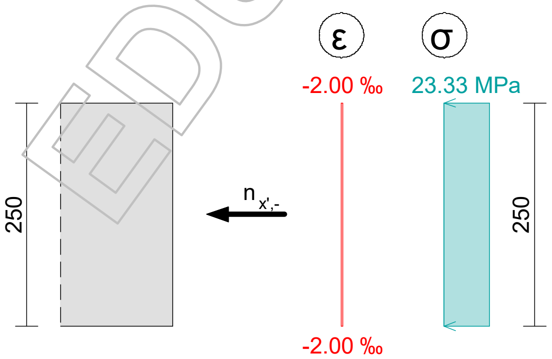
Necessary reinforcement is calculated by considering equivalent reinforcement data.

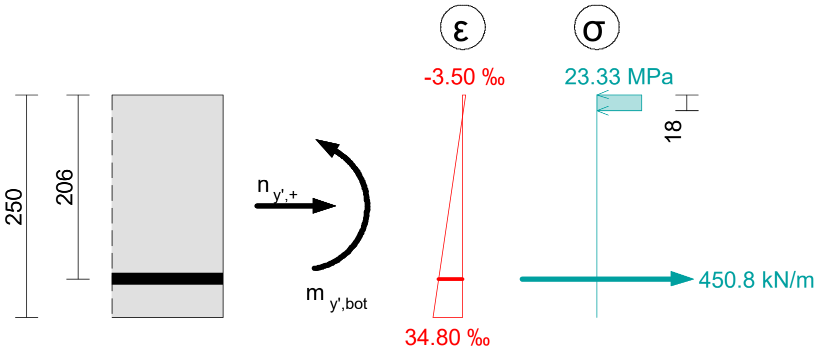
If no reinforcement is required, the ultimate resistance of the concrete section is represented in the stress figures.

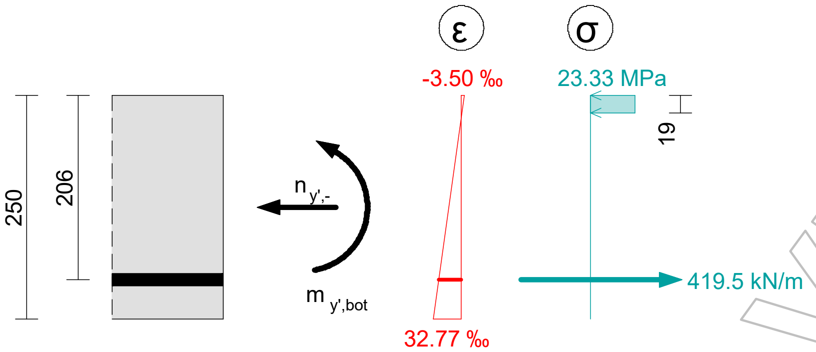


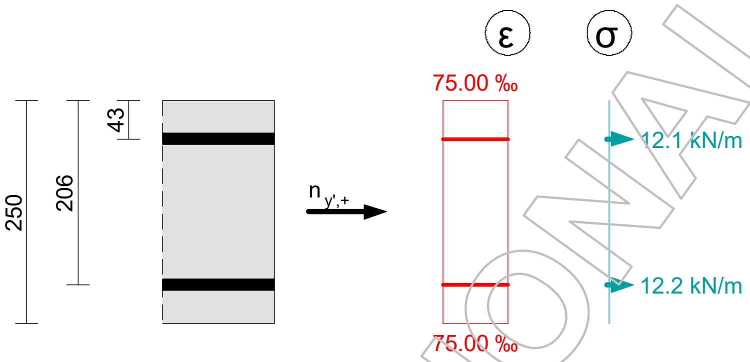


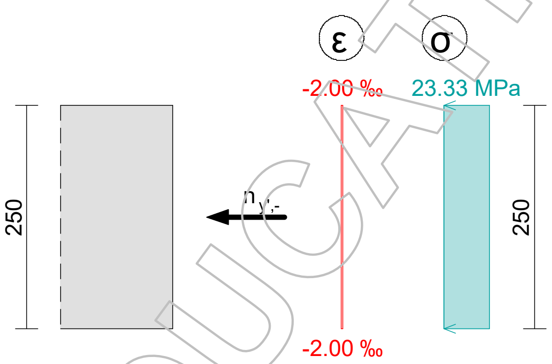












Minimum reinforcement

$A_{s,min,vertical} = 0.002 \cdot A_c$ (EN 1992-1-1 9.6.2(1))

$A_{s,min,horizontal} = \max(0.001 \cdot A_c, 0.25 \cdot A_{s,required,vertical})$ (EN 1992-1-1 9.6.3(1))

$s_{max,walls,vertical} = \min(3 \cdot t, 400)$ (EN 1992-1-1 9.6.2(3))

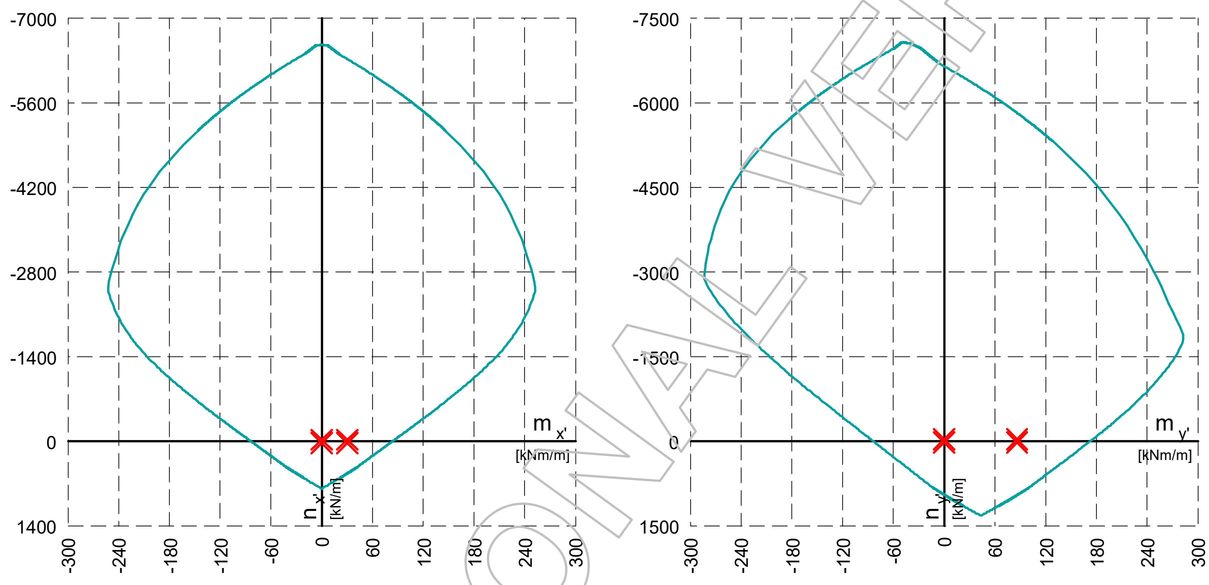
$s_{max,walls,horizontal} = 400$ mm (EN 1992-1-1 9.6.3(2))

$A_{s,min,smax} = 1000 / s_{max} \cdot \Phi^2 \cdot \pi / 4$

$A_{s,min,final} = \max(A_{s,min}, A_{s,min,smax})$

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,min}$ [mm ^{2}/m]	259	250	125	250
Type	Horizontal	Vertical	Horizontal	Vertical
s_{max} [mm]	400	400	400	400
Φ [mm]	12	12	12	12
$A_{s,min,smax}$ [mm ^{2}/m]	283	283	283	283
$A_{s,min,final}$ [mm ^{2}/m]	283	283	283	283

Interaction curves based on applied reinforcement



Utilization

$A_{s,req} = \max(A_{s,calc}, A_{s,min,final})$

$A_{s,missing} = A_{s,req} - A_{s,applied}$

Utilization $= A_{s,req} / A_{s,applied} \cdot 100$

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,req}$ [mm ^{2}/m]	368	1037	283	283
$A_{s,applied}$ [mm ^{2}/m]	905	2136	905	905
$A_{s,missing}$ [mm ^{2}/m]	-	-	-	-
Utilization [%]	41	49	31	31

The amount of required reinforcement is based on an optimum calculation because several solutions are possible.

Required reinforcement, top y'

LC: 'Stability1 - wind y- dom. (0,9 SW+0,9 Soil+0,9 dead+1,5 W)'

Internal forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x,sh}$ = 30.42	$n_{x,sh}$ = 5.40
$m_{y,sh}$ = 85.98	$n_{y,sh}$ = -3.24
$m_{xy,sh}$ = -0.13	$n_{xy,sh}$ = -27.59

Design forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x',bot}$ = 30.55	$n_{x',+}$ = 32.99
$m_{y',bot}$ = 86.11	$n_{y',+}$ = 24.35
$m_{x',top}$ = 0.00	$n_{x',-}$ = -22.19
$m_{y',top}$ = 0.00	$n_{y',-}$ = -30.84

Calculation is based on Wood-Armer and Nemeth methods.

Maximum reinforcement

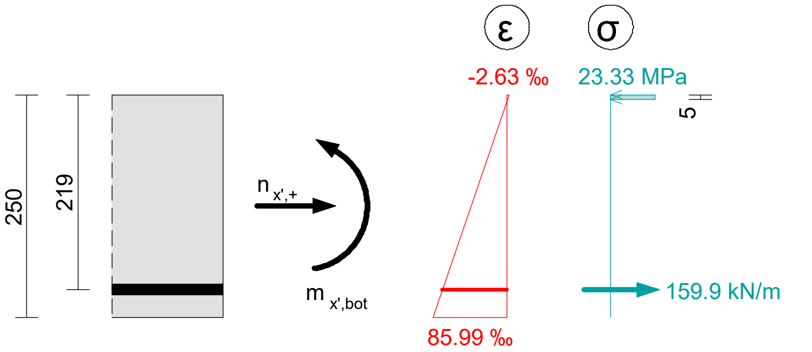
$A_{s,max}$ = 0.04 · b · t = 0.04 · 1000 · 250 = 10000 mm ^{2}/m (EN 1992-1-1 9.6.2(1))

Calculation of required reinforcement from different m-n combinations

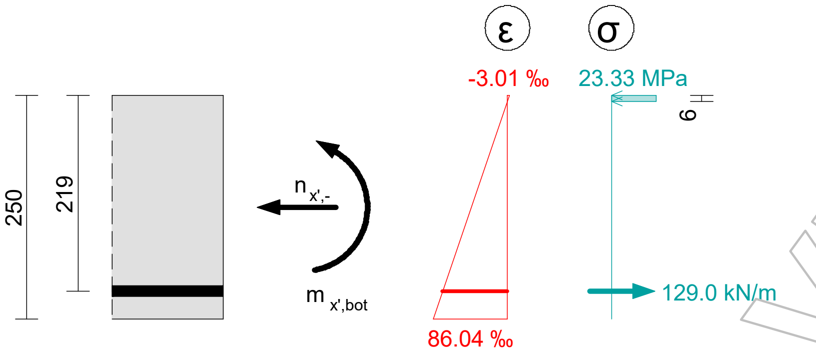
Face, direction	Bottom, x'	Bottom, x'	Top, x'	Top, x'	Bottom, y'	Bottom, y'	Top, y'	Top, y'
Sign of n	+	-	+	-	+	-	+	-
$m_{[dir][face]}$ [kN m/m]	30.55	30.55	0.00	0.00	86.11	86.11	0.00	0.00
$n_{[dir][face]}$ [kN/m]	32.99	-22.19	32.99	-22.19	24.35	-30.84	24.35	-30.84
Case	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.	Tension reinf.	Tension reinf.	Centric tens.	Fully compr.
$A_{sb,x'}$ [mm ^{2}/m]	368	297	38	0	-	-	-	-
$A_{sb,y'}$ [mm ^{2}/m]	-	-	-	-	1037	965	28	0
$A_{st,x'}$ [mm ^{2}/m]	0	0	38	0	-	-	-	-
$A_{st,y'}$ [mm ^{2}/m]	-	-	-	-	0	0	28	0

Necessary reinforcement is calculated by considering equivalent reinforcement data.

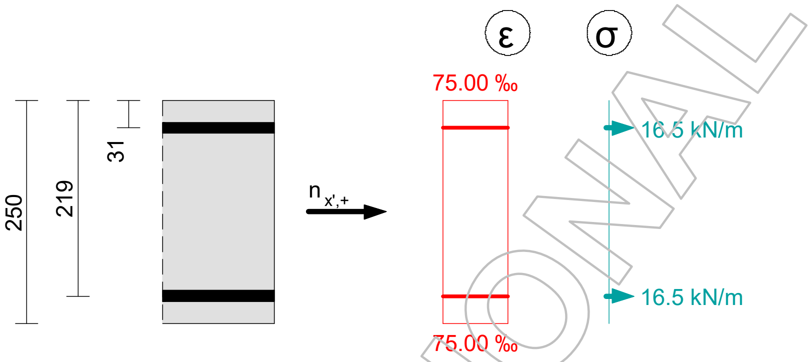
If no reinforcement is required, the ultimate resistance of the concrete section is represented in the stress figures.



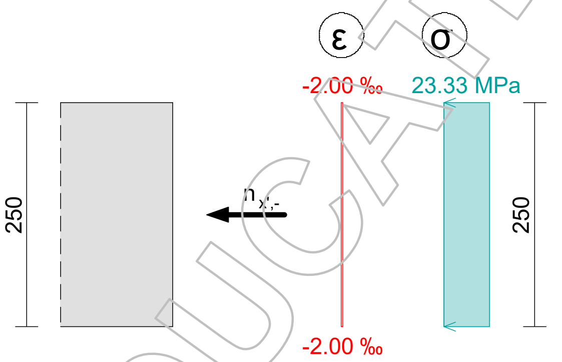
ε
σ
-2.63 ‰
23.33 MPa
5
250
219
n x',+
m x',bot
159.9 kN/m
85.99 ‰



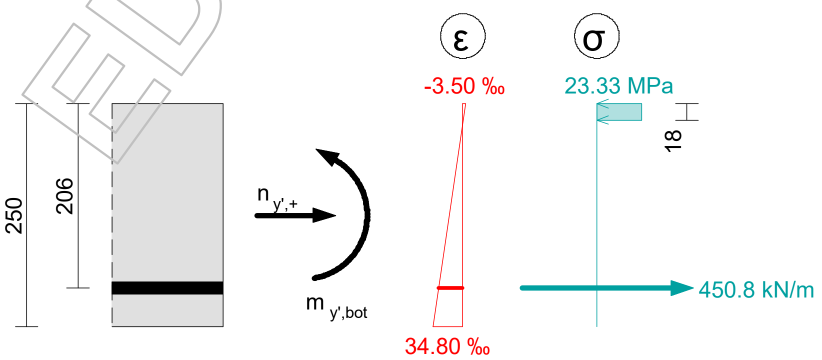
ε
σ
-3.01 ‰
23.33 MPa
6
250
219
n x',-
m x',bot
129.0 kN/m
86.04 ‰



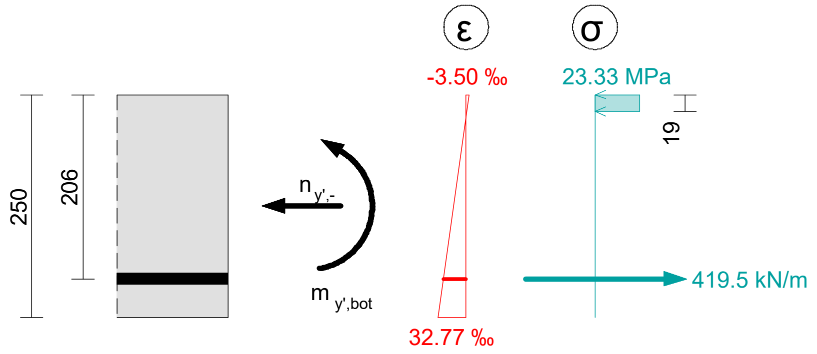
ε
σ
75.00 ‰
250
219
31
n x',+
16.5 kN/m
16.5 kN/m
75.00 ‰

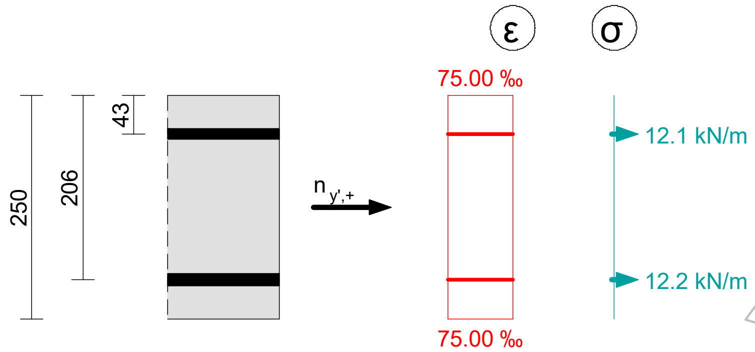


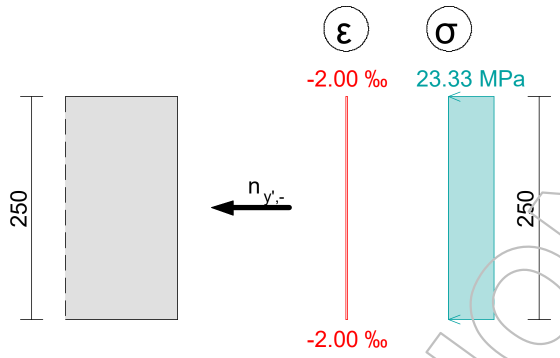
ε
σ
-2.00 ‰
23.33 MPa
250
n x',-
250
-2.00 ‰



ε
σ
-3.50 ‰
23.33 MPa
18
250
206
n y',+
m y',bot
450.8 kN/m
34.80 ‰







Minimum reinforcement

$A_{s,min,vertical} = 0.002 \cdot A_c$ (EN 1992-1-1 9.6.2(1))

$A_{s,min,horizontal} = \max(0.001 \cdot A_c, 0.25 \cdot A_{s,required,vertical})$ (EN 1992-1-1 9.6.3(1))

$s_{max,walls,vertical} = \min(3 \cdot t, 400)$ (EN 1992-1-1 9.6.2(3))

$s_{max,walls,horizontal} = 400$ mm (EN 1992-1-1 9.6.3(2))

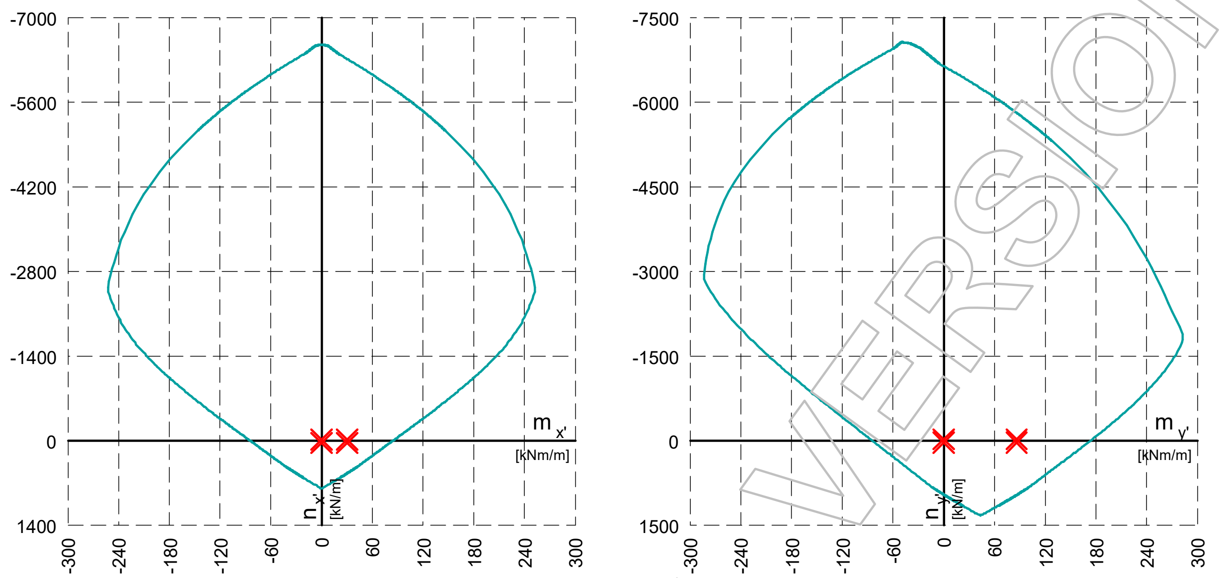
$A_{s,min,smax} = 1000 / s_{max} \cdot \Phi^2 \cdot \pi / 4$

$A_{s,min,final} = \max(A_{s,min}, A_{s,min,smax})$

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,min}$ [mm^2/m]	259	250	125	250
Type	Horizontal	Vertical	Horizontal	Vertical
s_{max} [mm]	400	400	400	400
Φ [mm]	12	12	12	12
$A_{s,min,smax}$ [mm^2/m]	283	283	283	283

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,min,final}$ [mm ^{2}/m]	283	283	283	283

Interaction curves based on applied reinforcement



Utilization

$A_{s,req}$ = max ($A_{s,calc}$, $A_{s,min,final}$)

$A_{s,missing}$ = $A_{s,req}$ - $A_{s,applied}$

Utilization = $A_{s,req}$ / $A_{s,applied}$ · 100

Face, direction	Bottom, x'	Bottom, y'	Top, x'	Top, y'
$A_{s,req}$ [mm ^{2}/m]	368	1037	283	283
$A_{s,applied}$ [mm ^{2}/m]	905	2136	905	905
$A_{s,missing}$ [mm ^{2}/m]	-	-	-	-
Utilization [%]	41	49	31	31

The amount of required reinforcement is based on an optimum calculation because several solutions are possible.

Shear capacity

LC: '1.35*SW + 1.35* dead + 1.35*soil + 1.50*0.70*P+ 1.50*0.70*S + 1.50*0.70*W'

Internal forces

Normal forces [kN /m]	Shear forces [kN /m]
$n_{x,sh}$ = 6.15	$v_{xz,sh}$ = 0.68
$n_{y,sh}$ = -9.45	$v_{yz,sh}$ = 29.86
$n_{xy,sh}$ = -40.47	

Design forces

$$v_{max} = \sqrt{v_{xz,sh}^{\ 2} + v_{yz,sh}^{\ 2}} = \sqrt{0.68^{\ 2} + 29.86^{\ 2}} = 29.87 \quad kN/m$$

$$\alpha = atan\left(\frac{v_{yz,sh}}{v_{xz,sh}}\right) = atan\left(\frac{29.86}{0.68}\right) = 88.69 \quad °$$

$$n_{\alpha} = -11.29 \quad kN/m$$

Calculation of shear capacity in the main direction (EN 1992-1-1: 6.2.2)

$$A_{s,\alpha} = 2136 \quad mm^{2}/m$$

$$d_{eff} = \frac{d_x + d_y}{2} = \frac{219 + 206}{2} = 213 \quad mm$$

$$\rho_{\alpha} = min\left(\frac{A_{s,\alpha}}{d_{eff}}, 0.02\right) = min\left(\frac{2136}{213}, 0.02\right) = 0.01004$$

$$\sigma_{\alpha} = \frac{n_{\alpha}}{t} = \frac{-11.29}{0.25} = -0.0452 \quad N/mm^{2}$$

$$\sigma_{cp,\alpha} = min\left(-(\sigma_{\alpha}), 0.2 \cdot f_{cd,U}\right) = min\left(-(-0.0452), 0.2 \cdot 23.33\right) = 0.0452 \quad N/mm^{2} \quad *$$

$$C_{Rd,c} = \frac{0.15}{\gamma_{C,U}} = \frac{0.15}{1.5} = 0.10$$

$$k = min\left(1 + \sqrt{\frac{200}{d_{eff}}}, 2.0\right) = min\left(1 + \sqrt{\frac{200}{213}}, 2.0\right) = 1.97$$

$$k_1 = 0.15$$

$$v_{min} = 0.035 \cdot k^{3/2} \cdot f_{ck}^{\ 1/2} = 0.035 \cdot 1.97^{\ 3/2} \cdot 35.00^{\ 1/2} = 0.5724 \qquad (6.3.N)$$

$$v_{Rd,c} = max\left(C_{Rd,c} \cdot k \cdot (100.0 \cdot \rho_{\alpha} \cdot f_{ck})^{1/3} + k_1 \cdot \sigma_{cp,\alpha}, v_{min} + k_1 \cdot \sigma_{cp,\alpha}\right) \cdot d_{eff} =$$

$$= max\left(0.10 \cdot 1.97 \cdot (100.0 \cdot 0.01004 \cdot 35.00)^{1/3} + 0.15 \cdot 0.0452, 0.5724 + 0.15 \cdot 0.0452\right) \cdot 21$$

$$= 138.67 \quad kN/m \qquad (6.2.a, 6.2.b)$$

$$v_{Rd,c} > v_{max} \rightarrow \text{Utilization} = \frac{v_{max}}{v_{Rd,c}} \cdot 100 = \frac{29.87}{138.67} \cdot 100 = 22 \ \%$$

* EN 1992-1-1: 6.2.2 considers tension forces with negative sign.

Shell buckling

Not calculated, there is no relevant buckling region at the point.

Crack width, bottom

LC: '1,0SW+ 1,0 dead + 1,0 Soil + 0.30*P + 0.30*S + 0.20*W'

Internal forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x,sh}$ = 33.79	$n_{x,sh}$ = 4.47
$m_{y,sh}$ = 95.54	$n_{y,sh}$ = -5.50
$m_{xy,sh}$ = -0.15	$n_{xy,sh}$ = -29.51

Direction of crack width

α_{bottom} = 112.66 °

No crack on top face.

Calculated by Gvozdiev method.

Stresses

Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
n [kN/m]	16.96	-17.99	-	-
m [kN m/m]	86.48	42.85	-	-
$A_{s,eq[face]}$ [mm^2/m]	1954	1088	-	-
$c_{\alpha[face]}$ [mm]	43	35	-	-
$A_{s,eq[other\ face]}$ [mm^2/m]	905	905	-	-
$c_{\alpha[other\ face]}$ [mm]	41	33	-	-
$\sigma_{I,c[face]}$ [N/mm^2]	7.58	3.75	-	-
$\sigma_{I,c[other\ face]}$ [N/mm^2]	-7.68	-3.91	-	-
$\sigma_{II,s[face]}$ [N/mm^2]	241.10	189.37	-	-
$\sigma_{II,s[other\ face]}$ [N/mm^2]	0.00	0.00	-	-
x_{II} [mm]	56.40	46.84	-	-
Evaluation*	Cracked	Cracked	Not cracked	Not cracked

*No reinf: $A_{s,eq} \leq 0$

Not cracked: $(\sigma_{I,c[bottom]} \leq f_{ctm}$ and $\sigma_{I,c[top]} \leq f_{ctm})$ or $x_{II} \leq 0$ or $x_{II} > t$

Cracked: otherwise

Crack width

$$A_{c,eff} = \min\left(t/2,\ 2.5 \cdot c_\alpha,\ (t - x_{II})/3,\ c_\alpha + 1.5 \cdot \Phi_\alpha\right)$$

$$\rho_{p,eff} = A_s / A_{c,eff}$$

$$\varepsilon = \max\left(\frac{\sigma_{II,s} - \frac{0.4 \cdot f_{ctm}}{\rho_{p,eff}} \cdot \left(1 + \frac{E_s}{E_{c,m}} \cdot \rho_{p,eff}\right)}{E_s},\ \frac{0.6 \cdot \sigma_{II,s}}{E_s}\right)$$

$$k_2 = \frac{\varepsilon_{bottom} + \varepsilon_{top}}{2 \cdot \max(\varepsilon_{bottom}, \varepsilon_{top})}$$

$$s_\alpha \leq 5 \cdot c_\alpha \rightarrow s_{r,max} = k_3 \cdot (c_\alpha - \Phi_\alpha / 2) + k_1 \cdot k_2 \cdot k_4 \cdot \Phi_\alpha \cdot \frac{A_{c,eff}}{A_s}$$

$$s_\alpha > 5 \cdot c_\alpha \rightarrow s_{r,max} = 1.3 \cdot (t - x_{II})$$

$$c_w = s_{r,max} \cdot \varepsilon_{[face]}$$

Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
$A_{c,eff[face]}$ [mm²/m]	62207	53109	-	-
$\rho_{p,eff[face]}$	0.03140	0.02048	-	-
$\varepsilon_{[face]}$	0.00096	0.00060	-	-
$A_{c,eff[other\ face]}$ [mm²/m]	60714	51224	-	-
$\varepsilon_{[other\ face]}$	0.00	0.00	-	-
Φ_{dir} [mm]	13	12	-	-
s_{dir} [mm]	68	109	-	-
k_1	0.80	0.80	-	-
k_2	0.50	0.50	-	-
k_3	3.40	3.40	-	-
k_4	0.425	0.425	-	-
$s_{r,max}$ [mm]	193.48	199.04	-	-
c_w [mm]	0.19	0.12	-	-

Utilization

Utilization $= c_w / c_{w,lim} \cdot 100$

Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
$c_{w,lim}$ [mm]	1.00	1.00	1.00	1.00
Utilization [%]	19	12	-	-

Crack width, top

LC: '1,0SW+ 1,0 dead + 1,0 Soil + 0.30*P + 0.30*S + 0.20*W'

Internal forces

Moments [kN m/m]	Normal forces [kN/m]
$m_{x,sh}$ = 33.79	$n_{x,sh}$ = 4.47
$m_{y,sh}$ = 95.54	$n_{y,sh}$ = -5.50
$m_{xy,sh}$ = -0.15	$n_{xy,sh}$ = -29.51

Direction of crack width

α_{bottom} = 112.66 °

No crack on top face.

Calculated by Gvozdiev method.

Stresses

Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
n [kN/m]	16.96	-17.99	-	-
m [kN m/m]	86.48	42.85	-	-
$A_{s,eq[face]}$ [mm²/m]	1954	1088	-	-
$c_{\alpha[face]}$ [mm]	43	35	-	-
$A_{s,eq[other face]}$ [mm²/m]	905	905	-	-
$c_{\alpha[other face]}$ [mm]	41	33	-	-
$\sigma_{I,c[face]}$ [N/mm²]	7.58	3.75	-	-
$\sigma_{I,c[other face]}$ [N/mm²]	-7.68	-3.91	-	-
$\sigma_{II,s[face]}$ [N/mm²]	241.10	189.37	-	-
$\sigma_{II,s[other face]}$ [N/mm²]	0.00	0.00	-	-
x_{II} [mm]	56.40	46.84	-	-
Evaluation*	Cracked	Cracked	Not cracked	Not cracked

*No reinf: $A_{s,eq} \leq 0$

Not cracked: $(\sigma_{I,c[bottom]} \leq f_{ctm}$ and $\sigma_{I,c[top]} \leq f_{ctm})$ or $x_{II} \leq 0$ or $x_{II} > t$

Cracked: otherwise

Crack width

$$A_{c,eff} = \min\left(t/2,\ 2.5 \cdot c_\alpha,\ (t - x_{II})/3,\ c_\alpha + 1.5 \cdot \Phi_\alpha\right)$$

$$\rho_{p,eff} = A_s / A_{c,eff}$$

$$\varepsilon = \max\left(\frac{\sigma_{II,s} - \frac{0.4 \cdot f_{ctm}}{\rho_{p,eff}} \cdot \left(1 + \frac{E_s}{E_{c,m}} \cdot \rho_{p,eff}\right)}{E_s}, \frac{0.6 \cdot \sigma_{II,s}}{E_s}\right)$$

$$k_2 = \frac{\varepsilon_{bottom} + \varepsilon_{top}}{2 \cdot \max(\varepsilon_{bottom}, \varepsilon_{top})}$$

$$s_\alpha \leq 5 \cdot c_\alpha \rightarrow s_{r,max} = k_3 \cdot (c_\alpha - \Phi_\alpha / 2) + k_1 \cdot k_2 \cdot k_4 \cdot \Phi_\alpha \cdot \frac{A_{c,eff}}{A_s}$$

$$s_\alpha > 5 \cdot c_\alpha \rightarrow s_{r,max} = 1.3 \cdot (t - x_{II})$$

$$c_w = s_{r,max} \cdot \varepsilon_{[face]}$$

Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
$A_{c,eff[face]}$ [mm²/m]	62207	53109	-	-
$\rho_{p,eff[face]}$	0.03140	0.02048	-	-

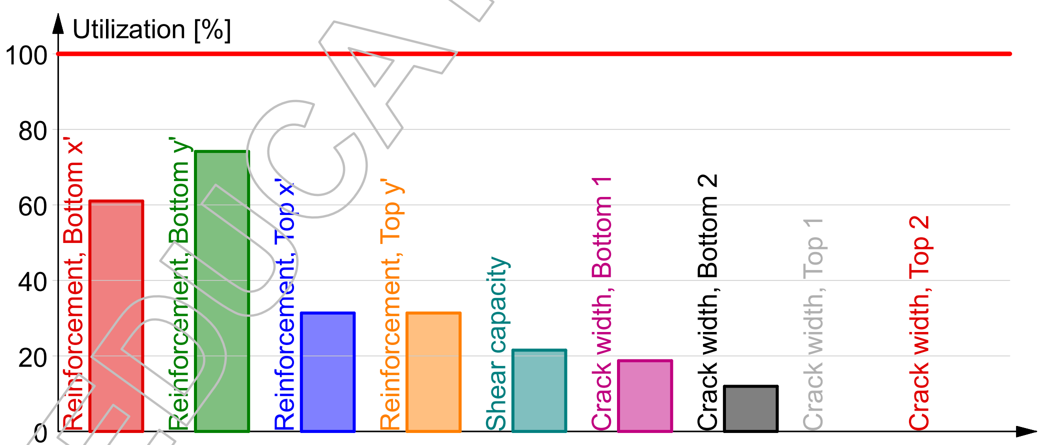
Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
$\varepsilon_{[face]}$	0.00096	0.00060	-	-
$A_{c,eff[other\ face]}$ [mm²/m]	60714	51224	-	-
$\varepsilon_{[other\ face]}$	0.00	0.00	-	-
Φ_{dir} [mm]	13	12	-	-
s_{dir} [mm]	68	109	-	-
k_1	0.80	0.80	-	-
k_2	0.50	0.50	-	-
k_3	3.40	3.40	-	-
k_4	0.425	0.425	-	-
$s_{r,max}$ [mm]	193.48	199.04	-	-
c_w [mm]	0.19	0.12	-	-

Utilization

Utilization $= c_w / c_{w,lim} \cdot 100$

Face, direction	Bottom, α	Bottom, α+90°	Top, α	Top, α+90°
$c_{w,lim}$ [mm]	1.00	1.00	1.00	1.00
Utilization [%]	19	12	-	-

Summary

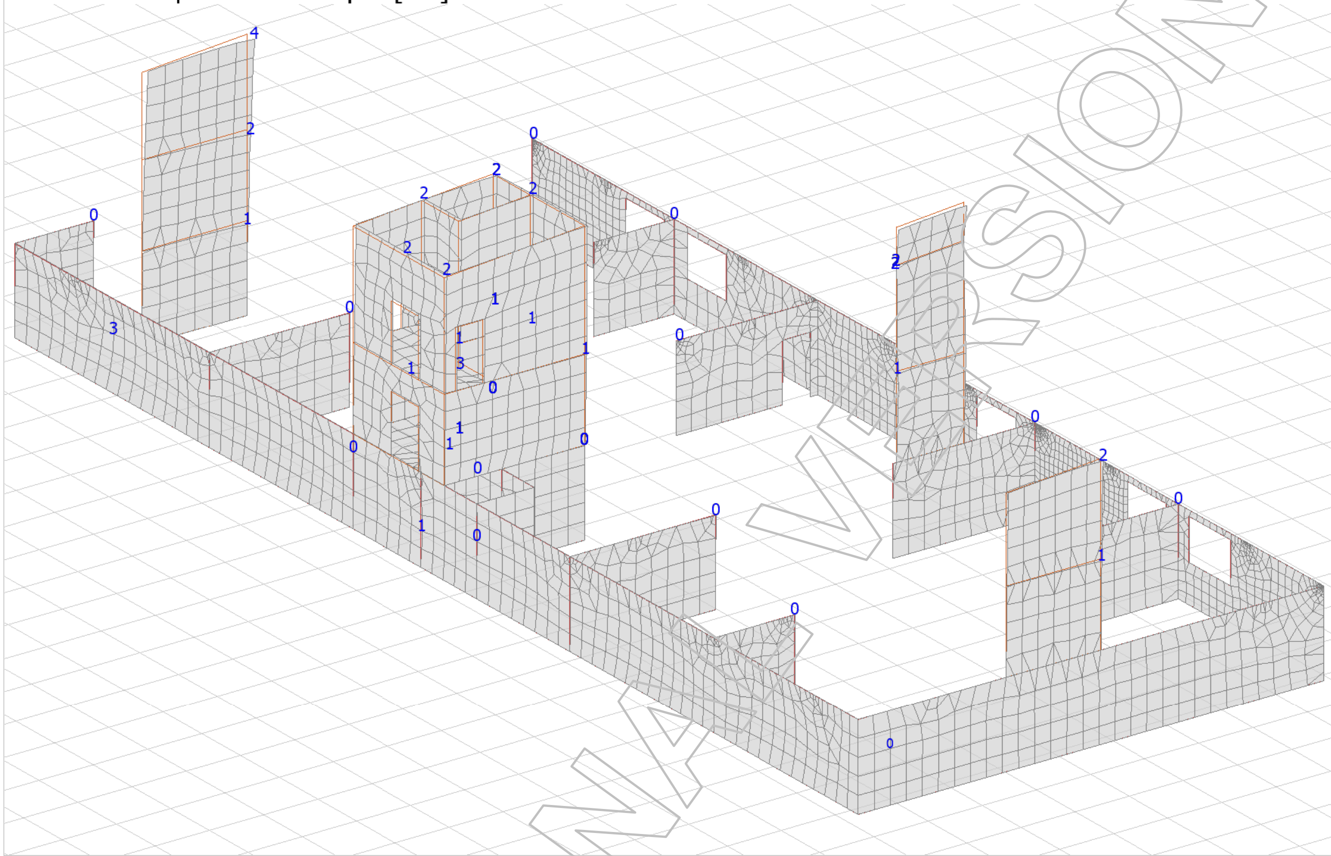


3.2 Cross-laminated walls

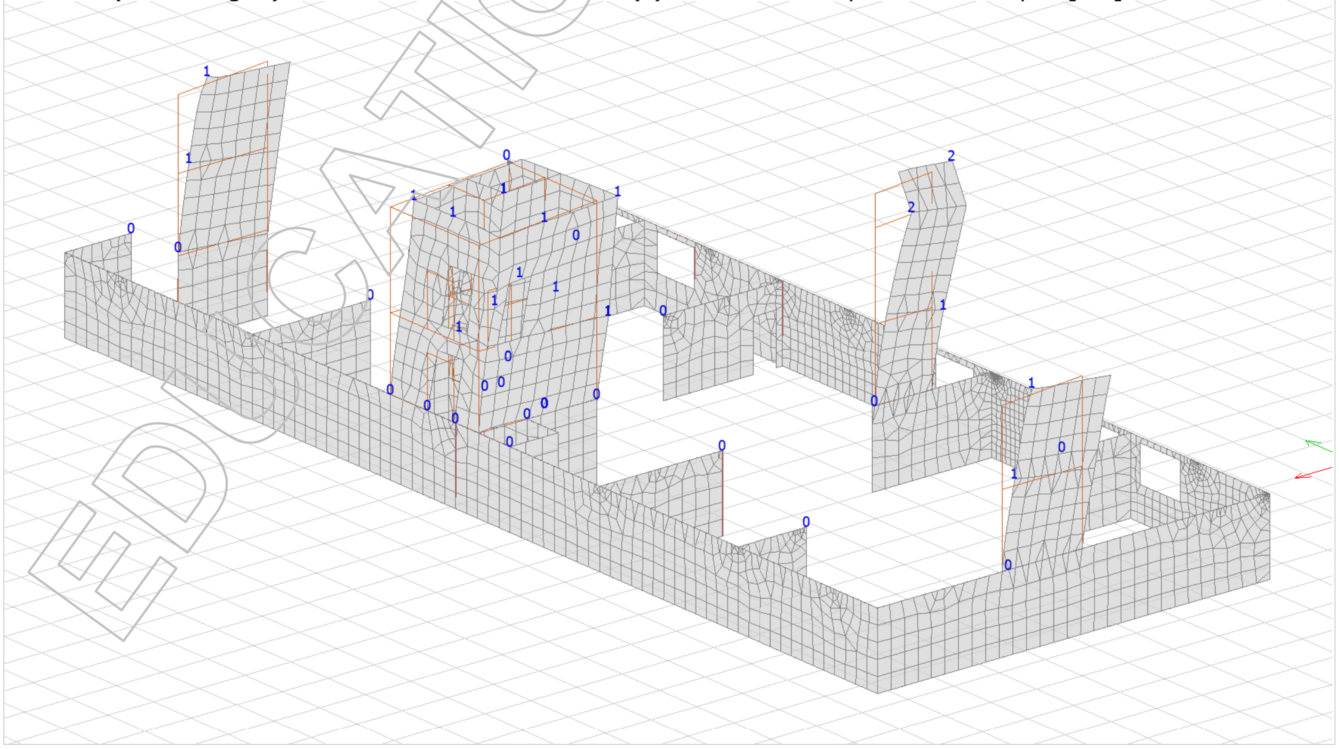
3.2.1 Horizontal deformation on walls

Horizontal deformation on CLT walls

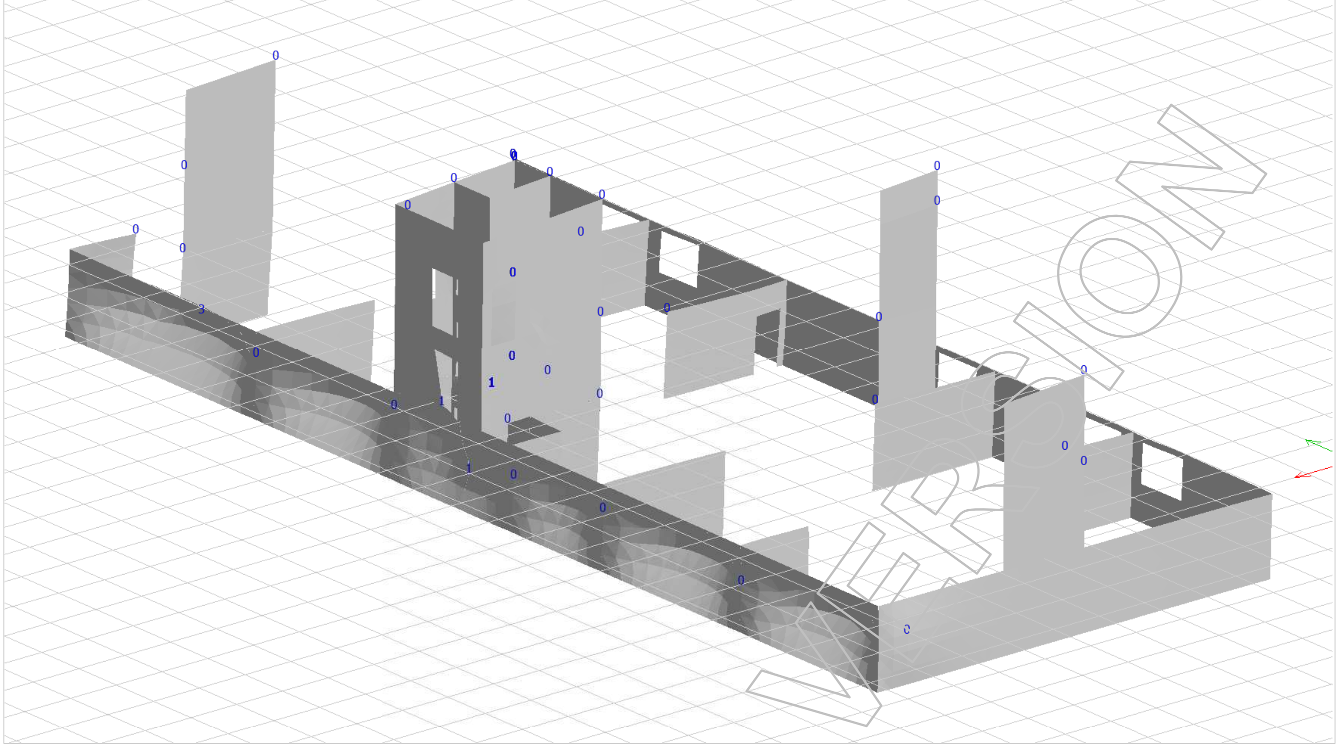
Eurocode (NA: Norwegian) code: 1st order theory - Load combinations - 1,0SW+ 1,0 dead + 1,0 Soil + 0.70*P + 0.70*S + W - Translational displacements - Graph - [mm]



Eurocode (NA: Norwegian) code: Load cases - Wind load Y- - (U) - Translational displacements - Graph - [mm]



Eurocode (NA: Norwegian) code: Load cases - Earth pressure - (U) - Translational displacements - Graph - [mm]



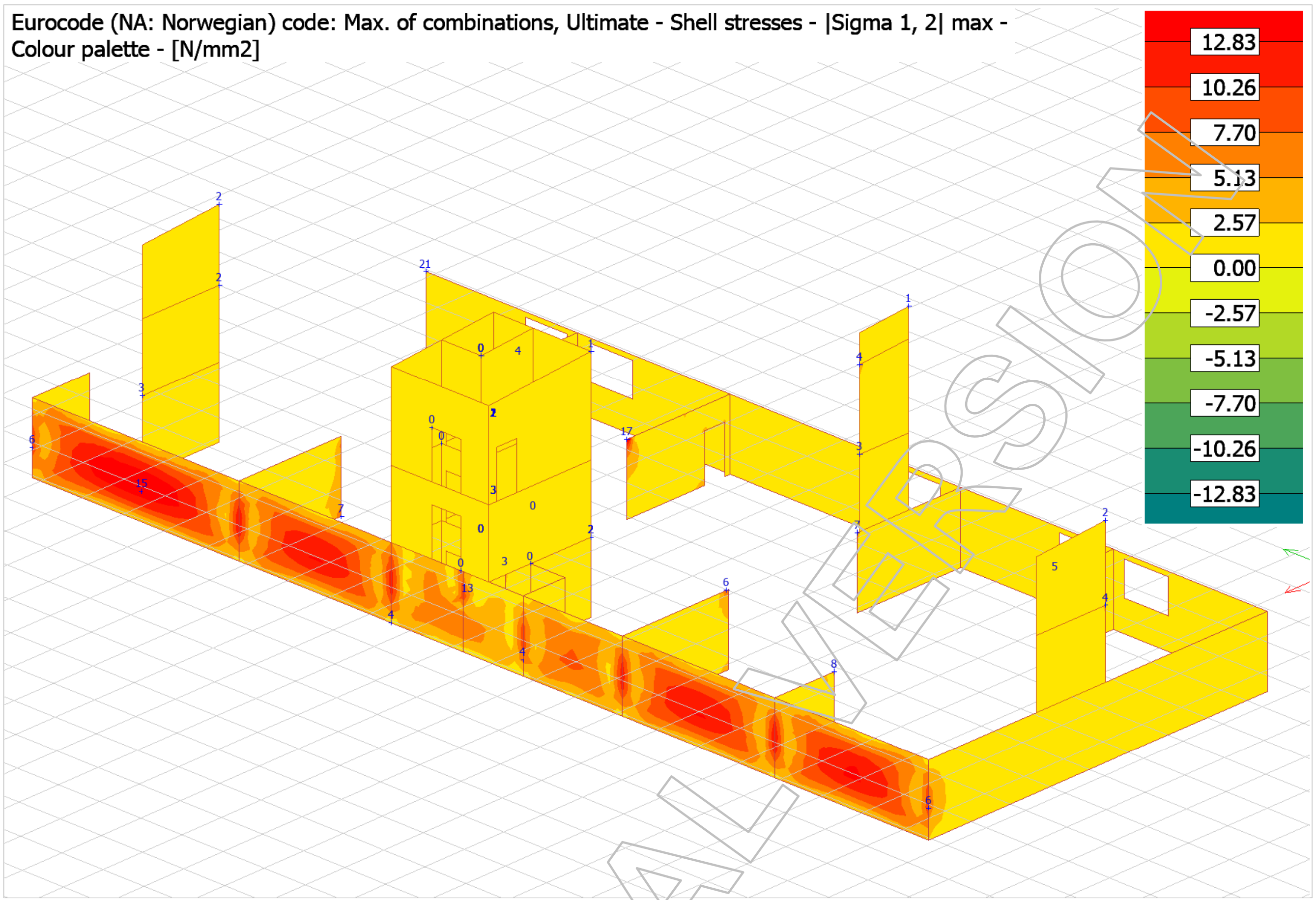
3.2.2 Utilization ration CLT walls

Timber panels

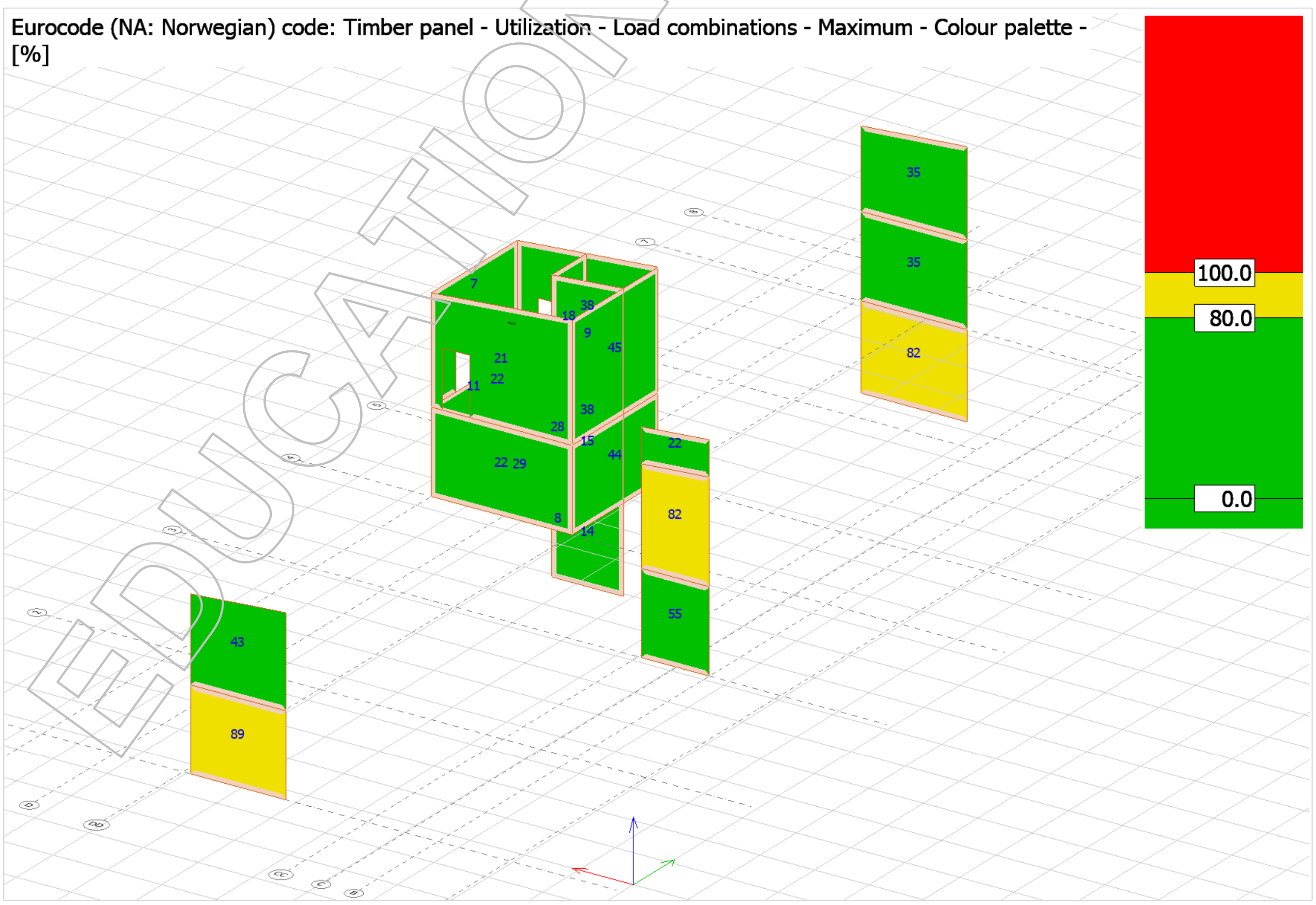
ID	Panel type	Alignment	Gamma M, Ult	Gamma M, Acc./seis	Service class	System factor	Creep factor
[-]	[-]	[-]	[-]	[-]	[-]	[-]	
TP.1	L(T)280-7S	Center	1.300	1.000	2	1.000	0.670
TP.2	L(T)280-7S	Center	1.300	1.000	2	1.000	0.670
TP.3	L(T)280-7S	Center	1.300	1.000	2	1.000	0.670
TP.4	L(T)280-7S	Center	1.300	1.000	2	1.000	0.670
TP.5	L(T)160-5S	Center	1.250	1.000	2	1.000	0.670
TP.6	L(T)160-5S	Center	1.250	1.000	2	1.000	0.670
TP.7	L(T)160-5S	Center	1.250	1.000	2	1.000	0.670
TP.8	L(T)160-5S	Center	1.250	1.000	2	1.000	0.670
TP.9	L(T)160-5S	Center	1.250	1.000	2	1.000	0.670
TP.10	L(T)160-5S	Center	1.250	1.000	2	1.000	0.670
TP.11	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.12	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.13	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.14	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.15	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.16	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.17	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.18	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.19	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.20	L(T)160-5S	Center	1.250	1.000	2	1.000	0.670
TP.21	L(T)160-5S	Center	1.250	1.000	2	1.000	0.670
TP.22	L(T)160-5S	Center	1.250	1.000	2	1.000	0.670
TP.23	L(T)160-5S	Center	1.250	1.000	2	1.000	0.670
TP.24	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.25	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.26	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.27	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.28	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670

ID	Panel type	Alignment	Gamma M, U	Gamma M, Acc./seis	Service class	System factor	Creep factor
[-]	[-]	[-]	[-]	[-]	[-]	[-]	
TP.29	L(T)160-5S	Center	1.250	1.000	2	1.000	0.670
TP.30	L(T)160-5S	Center	1.250	1.000	2	1.000	0.670
TP.31	L(T)160-5S	Center	1.250	1.000	2	1.000	0.670
TP.32	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.33	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.34	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.35	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.36	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.37	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.38	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.39	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.40	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.41	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.42	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.43	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.44	L(T)210-7S	Center	1.250	1.000	2	1.000	0.670
TP.45	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.46	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.47	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.48	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.49	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.50	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.51	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.52	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.53	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.54	L(T)200-5S	Center	1.250	1.000	2	1.000	0.670
TP.55	L(T)280-7S	Center	1.250	1.000	2	1.000	0.670
TP.56	L(T)280-7S	Center	1.300	1.000	2	1.000	0.670
TP.57	L(T)280-7S	Center	1.300	1.000	2	1.000	0.670
TP.58	L(T)280-7S	Center	1.300	1.000	2	1.000	0.670
TP.59	L(T)280-7S	Center	1.300	1.000	2	1.000	0.670
TP.60	L(T)280-7S	Center	1.300	1.000	2	1.000	0.670
TP.61	L(T)160-5S	Center	1.300	1.000	2	1.000	0.670
TP.62	L(T)160-5S	Center	1.300	1.000	2	1.000	0.670

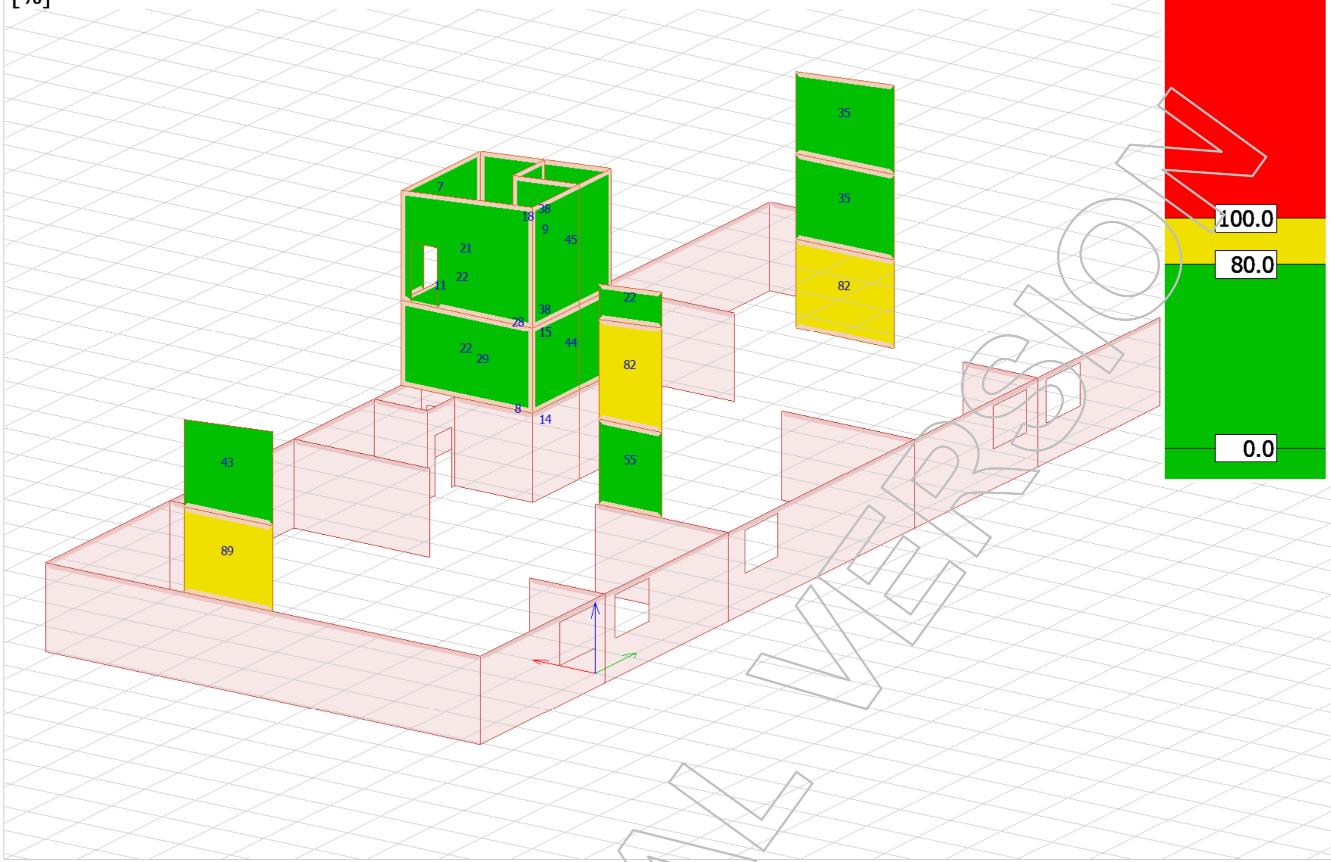
Shell Stresses in walls



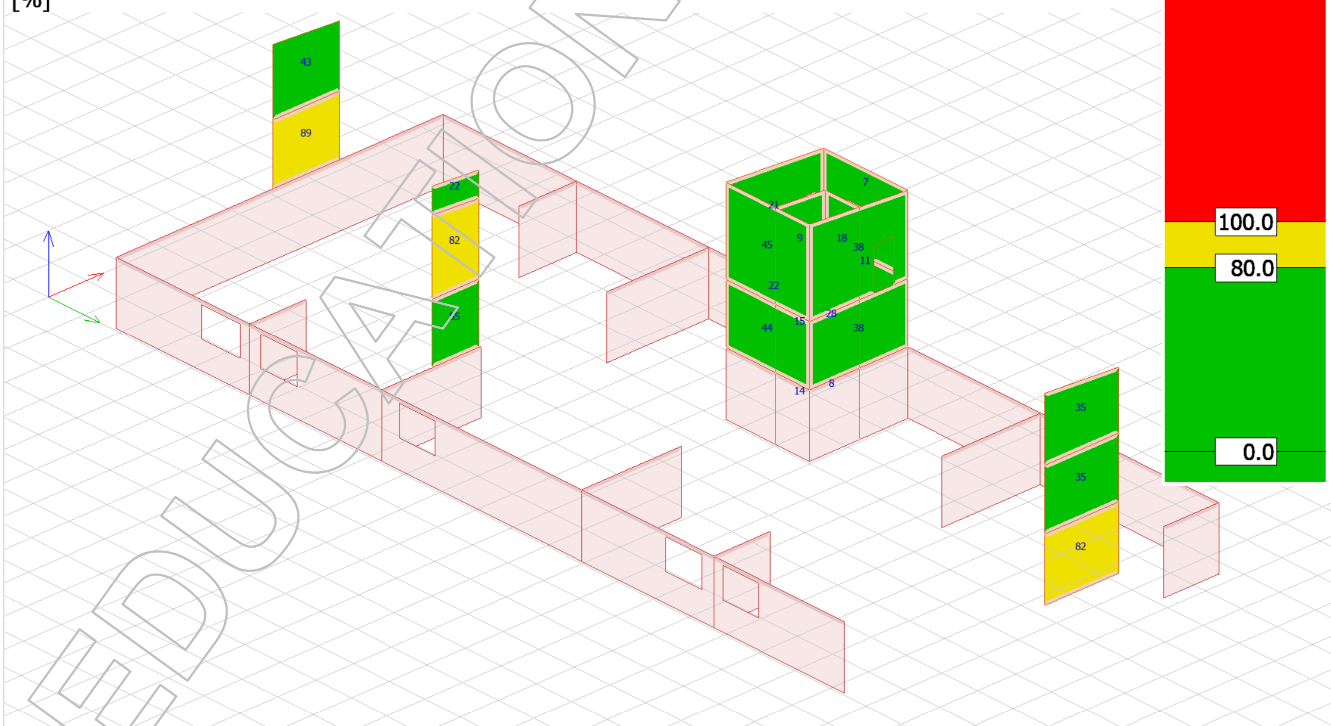
Utilization in CLT walls

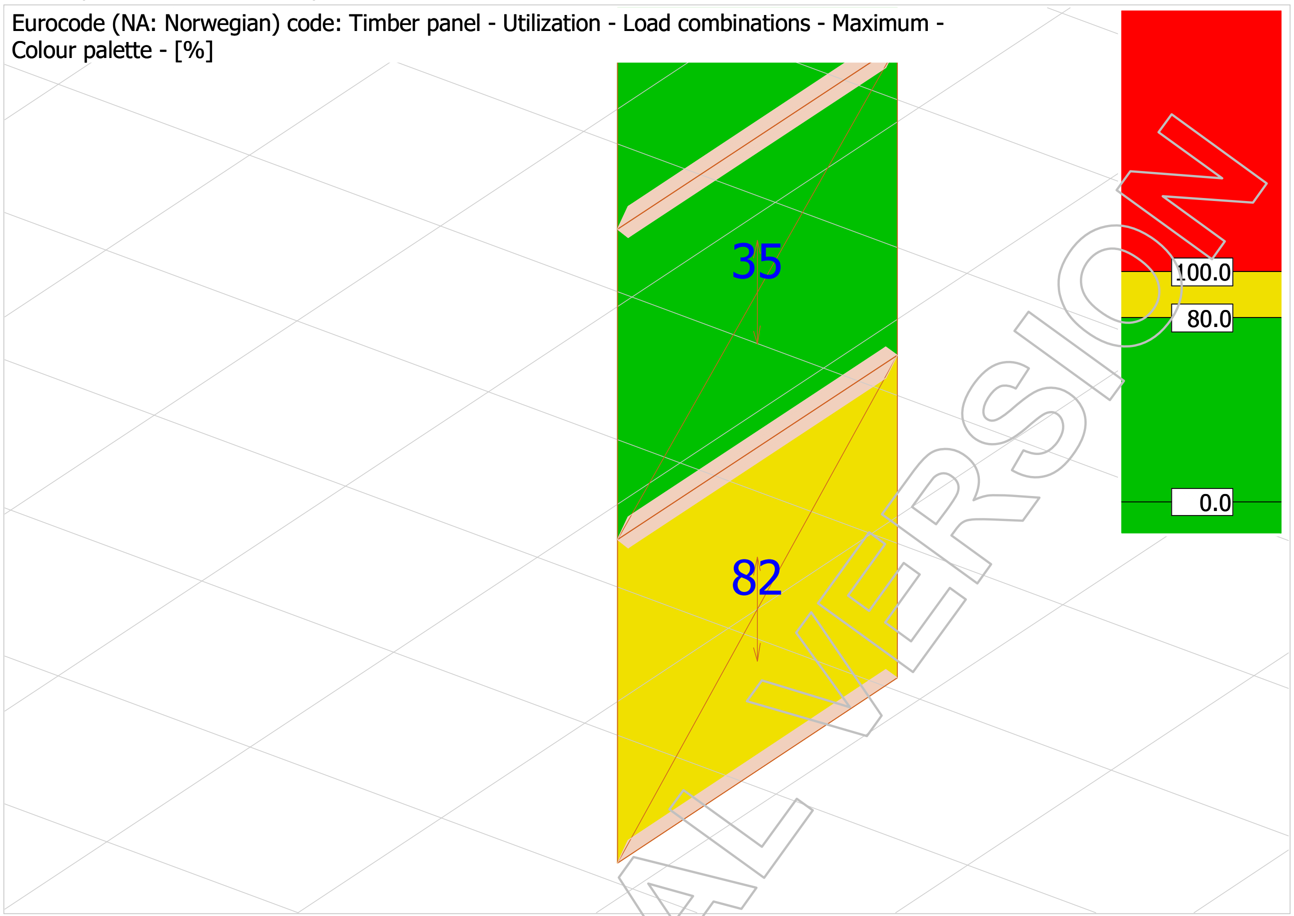


Eurocode (NA: Norwegian) code: Timber panel - Utilization - Load combinations - Maximum - Colour palette - [%]



Eurocode (NA: Norwegian) code: Timber panel - Utilization - Load combinations - Maximum - Colour palette - [%]





Group CLT 200 wall, Maximum of group members
Maximum of load combinations

L(T)200-5S

Service class: 2, $\gamma_{M,ult.}$ = 1.25 , $\gamma_{M,acc./seis.}$ = 1.00 , k_{sys} = 1.00

t	=	200 mm	$f_{m,0,k}$	=	19.00	N/mm^2
$E_{0,mean}$	=	5861.00 N/mm^2	$f_{m,90,k}$	=	2.90	N/mm^2
$E_{90,mean}$	=	978.00 N/mm^2	$f_{t,0,k}$	=	8.40	N/mm^2
$E_{0,t}$	=	4440.00 N/mm^2	$f_{t,90,k}$	=	3.20	N/mm^2
$E_{90,t}$	=	1880.00 N/mm^2	$f_{c,0,k}$	=	12.60	N/mm^2
$E_{0,c}$	=	4440.00 N/mm^2	$f_{c,90,k}$	=	6.40	N/mm^2
$E_{90,c}$	=	1880.00 N/mm^2	$f_{v,k}$	=	1.20	N/mm^2
G_{0}	=	590.00 N/mm^2	$f_{r,0,k}$	=	0.70	N/mm^2
G_{90}	=	100.00 N/mm^2	$f_{r,90,k}$	=	0.70	N/mm^2

Tension and bending, x - 6.2.3

Panel: 'TP.54.1', LC: '0.89*1.35*SW+ 0.89*1.35*dead + 0.89*1.35*soil + 1.50*P + 1.50*0.70*S + 1.50*0.70*W',

$$\frac{|\sigma_{t,0,d}|}{f_{td,x}} + \frac{|\sigma_{m,x}|}{f_{md,x}} = \frac{|1.51|}{7.39} + \frac{|0.00|}{16.72} = 0.20 \le 1.00 \quad (6.17) \text{ - OK}$$

Tension and bending, y - 6.2.3

Panel: 'TP.39.1', LC: 'Stability2 - 0,9G+1,5W+Hi (including misalignment load)', k_{mod} = 1.10 , Coc

$$\frac{|\sigma_{t,90,d}|}{f_{td,y}} + \frac{|\sigma_{m,y}|}{f_{md,y}} = \frac{|0.21|}{2.82} + \frac{|0.00|}{2.55} = 0.07 \leq 1.00 \quad (6.17) \quad \text{- OK}$$

Compression and bending, x - 6.1.4, 6.2.4

Panel: 'TP.45.1', LC: '0.89*1.35*SW+ 0.89*1.35* dead + 0.89*1.35*soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W',

$$\frac{\sigma_{c,0,d}}{f_{cd,x}} = \frac{3.99}{11.09} = 0.36 \leq 1.00 \quad (6.2) \quad \text{- OK}$$

$$\left(\frac{\sigma_{c,0,d}}{f_{cd,x}}\right)^2 + \frac{\sigma_{m,x}}{f_{md,x}} = \left(\frac{3.99}{11.09}\right)^2 + \frac{0.00}{16.72} = 0.13 \leq 1.00 \quad (6.19) \quad \text{- OK}$$

Compression and bending, y - 6.1.4, 6.2.4

Panel: 'TP.45.1', LC: '0.89*1.35*SW+ 0.89*1.35* dead + 0.89*1.35*soil + 1.50*0.70*P + 1.50*S + 1.50*0.70*W',

$$\frac{\sigma_{c,90,d}}{f_{cd,y}} = \frac{0.19}{5.63} = 0.03 \leq 1.00 \quad (6.2) \quad \text{- OK}$$

$$\left(\frac{\sigma_{c,90,d}}{f_{cd,y}}\right)^2 + \frac{\sigma_{m,y}}{f_{md,y}} = \left(\frac{0.19}{5.63}\right)^2 + \frac{0.00}{2.55} = 0.00 \leq 1.00 \quad (6.19) \quad \text{- OK}$$

Shear, xy - 6.1.7

Panel: 'TP.35.1', LC: 'Ultimate - only vertical loads - live dom (1,2G+1,5P+1,05S)', k_{mod} = 0.90 , C

$$\frac{T_{xy}}{1000 \ \text{mm} \cdot t \cdot f_{v,d}} = \frac{142308.05}{1000 \ \text{mm} \cdot 200 \cdot 0.86} = 0.82 \leq 1.00 \quad (6.13) \quad \text{- OK}$$

Shear, xz - 6.1.7

Panel: 'TP.41.1', LC: 'Stability2 - 0,9G+1,5W+Hi (including misalignment load)', k_{mod} = 1.10 , Coc

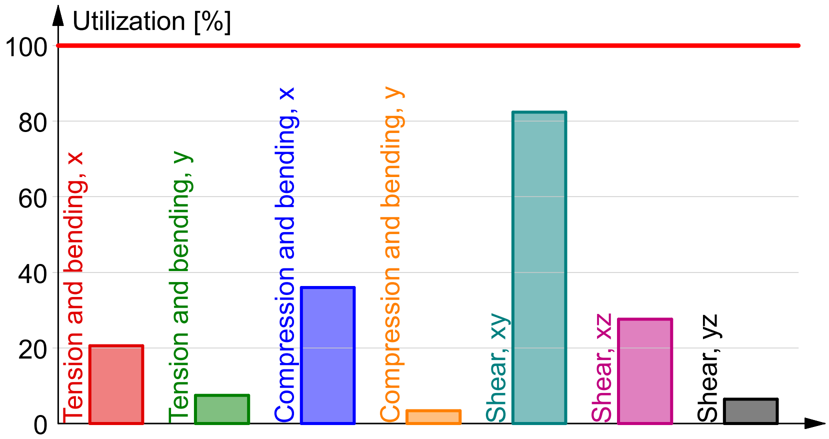
$$\frac{1.50 \cdot T_{xz}}{1000 \ \text{mm} \cdot t \cdot f_{r,d,x}} = \frac{1.50 \cdot 22623.80}{1000 \ \text{mm} \cdot 200 \cdot 0.62} = 0.28 \leq 1.00 \quad (6.13) \quad \text{- OK}$$

Shear, yz - 6.1.7

Panel: 'TP.41.1', LC: 'Stability2 - 0,9G+1,5W+Hi (including misalignment load)', k_{mod} = 1.10 , Coc

$$\frac{1.50 \cdot T_{yz}}{1000 \ \text{mm} \cdot t \cdot f_{r,d,y}} = \frac{1.50 \cdot 5220.09}{1000 \ \text{mm} \cdot 200 \cdot 0.62} = 0.06 \leq 1.00 \quad (6.13) \quad \text{- OK}$$

Summary



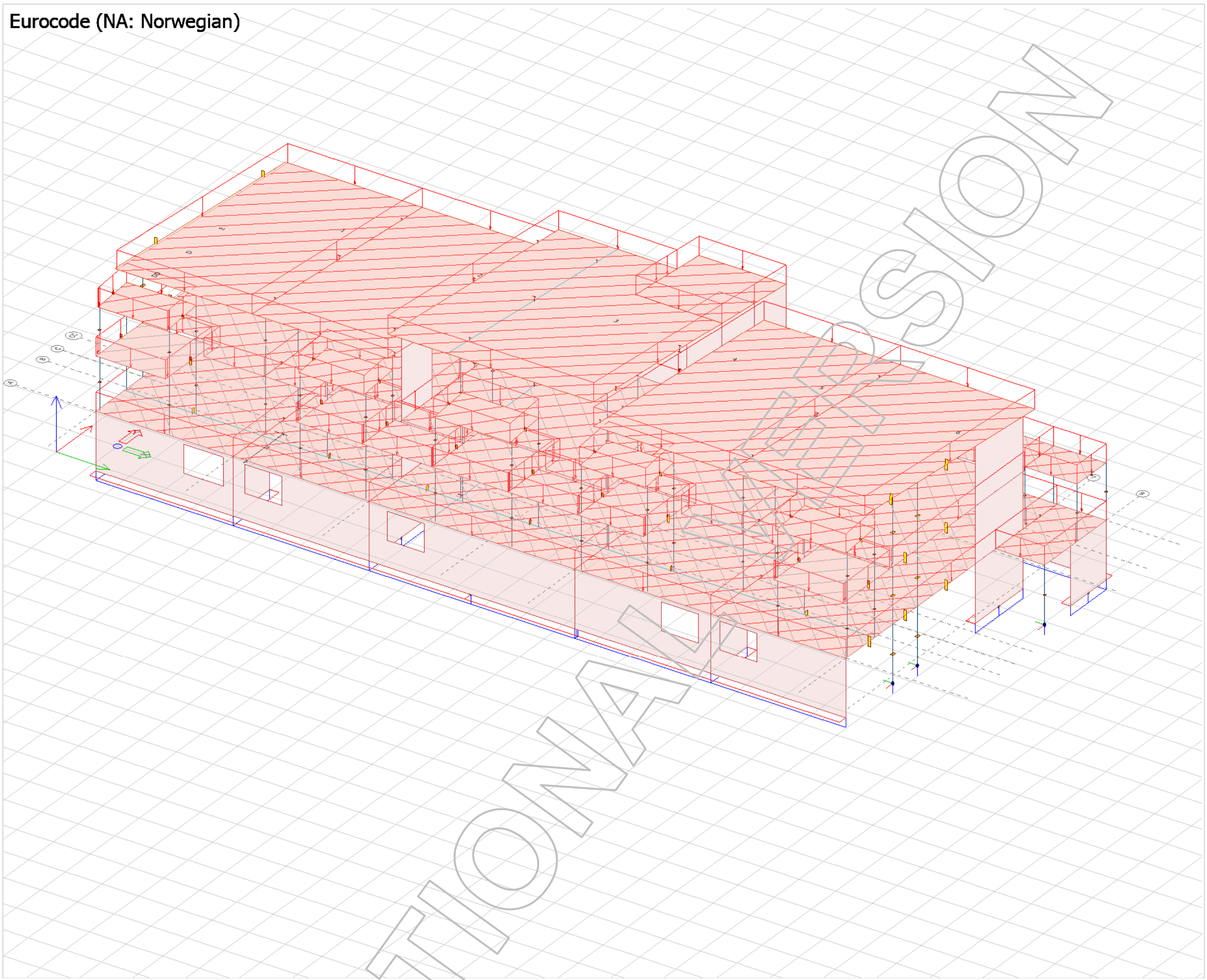
Utilization [%]
100
80
60
40
20
0
Tension and bending, x
Tension and bending, y
Compression and bending, x
Compression and bending, y
Shear, xy
Shear, xz
Shear, yz

Documentation of Steel Fire design in FEM-Design

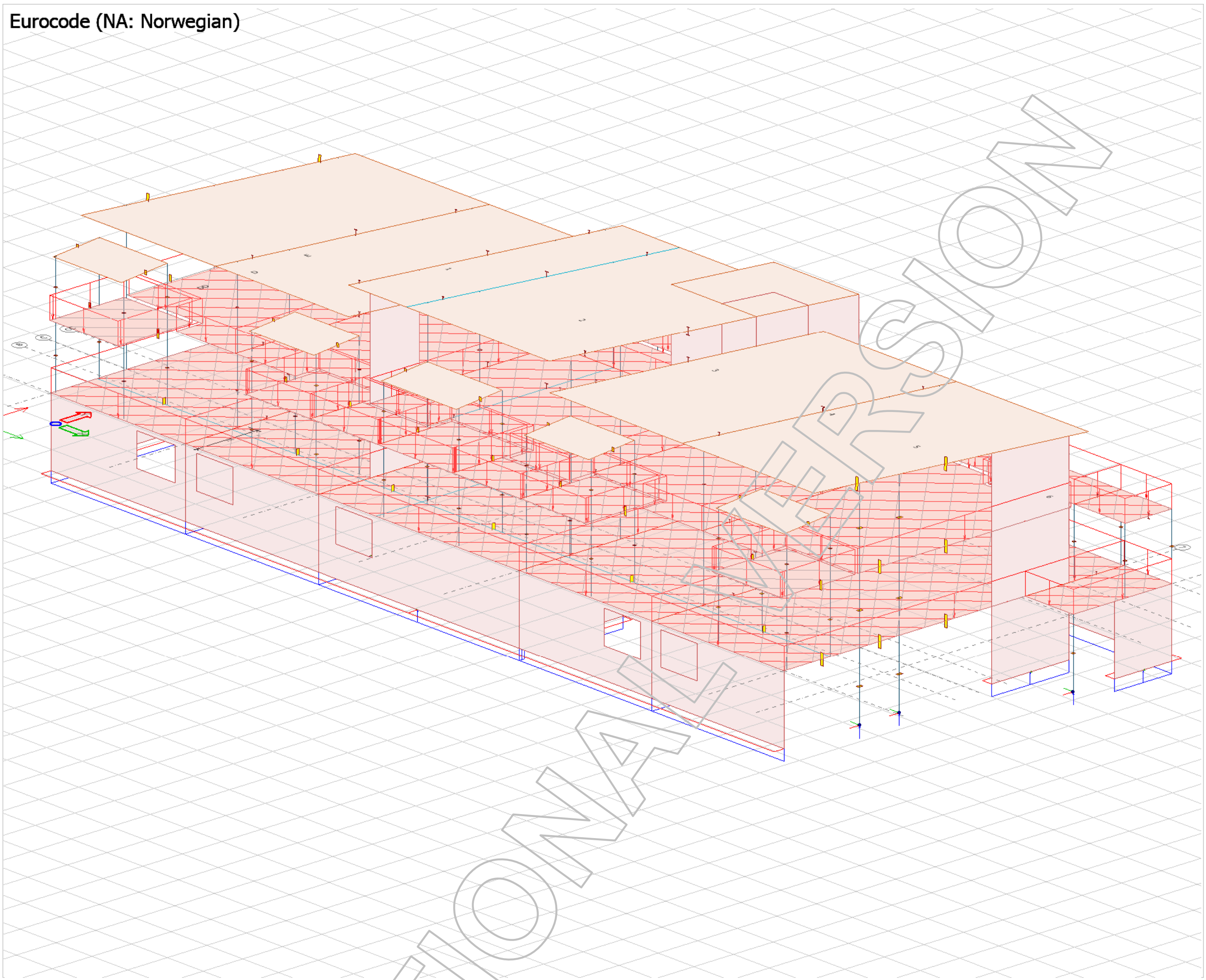
Contents

1.1 Loads applied on the model

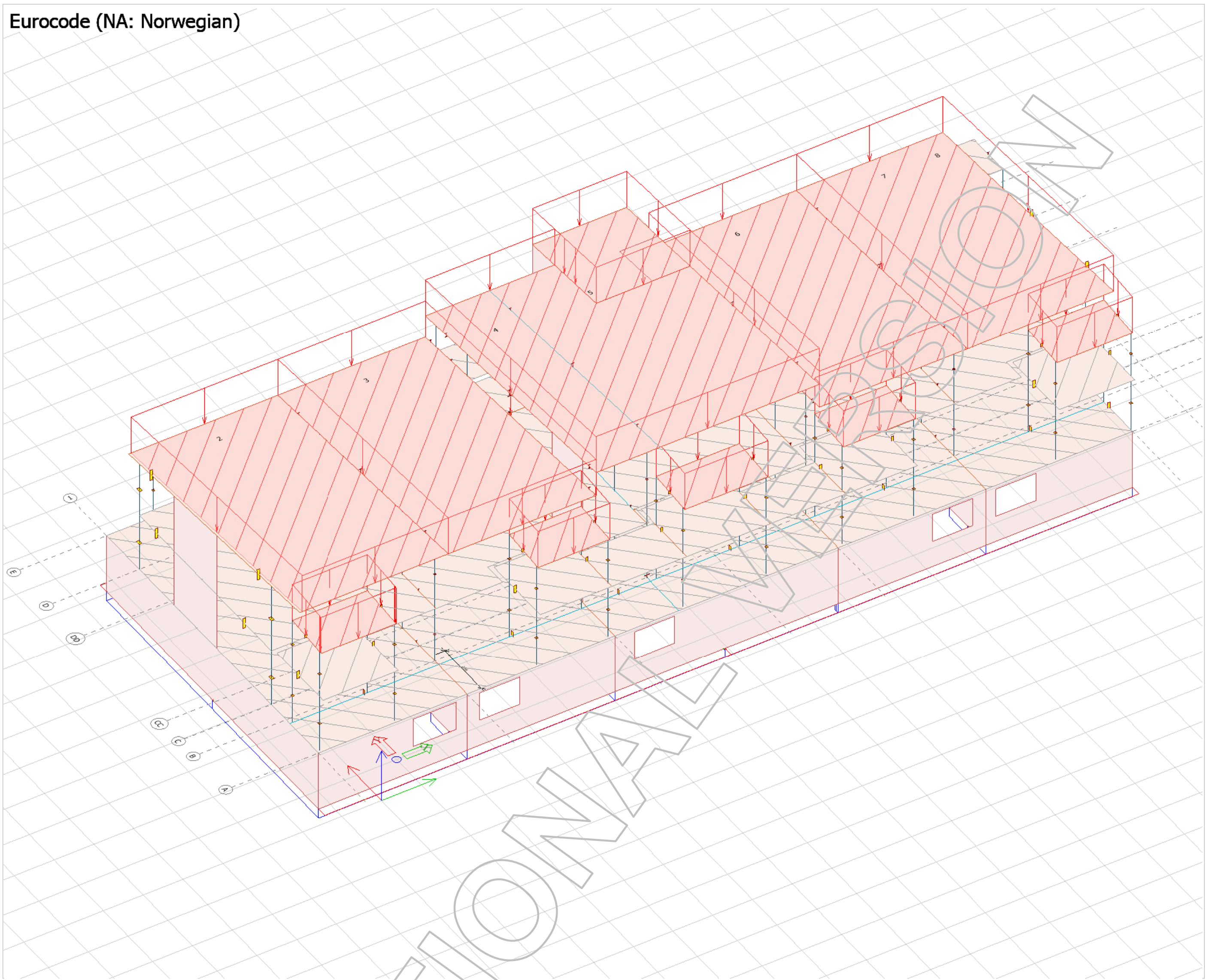
Supperimposed dead



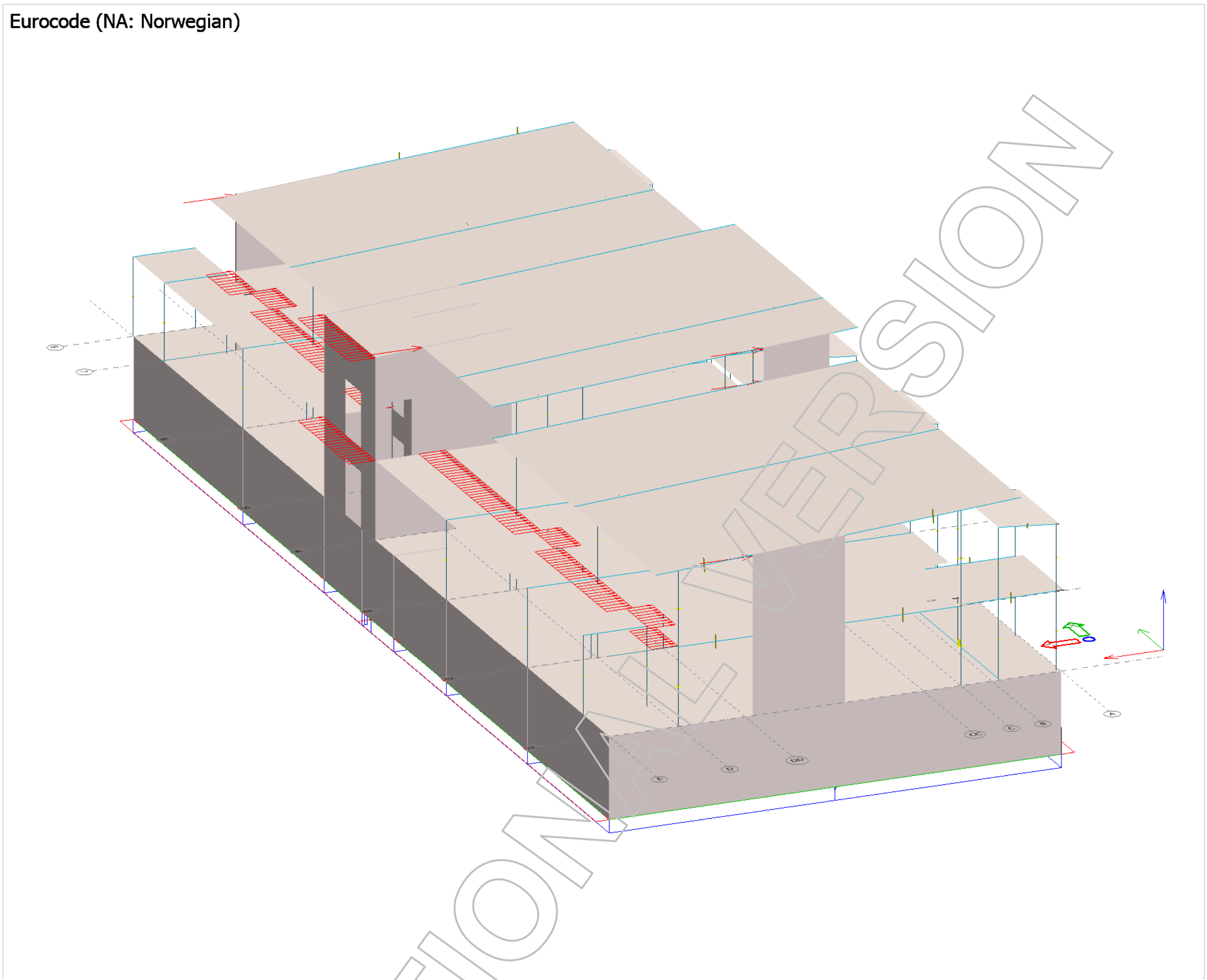
Live load



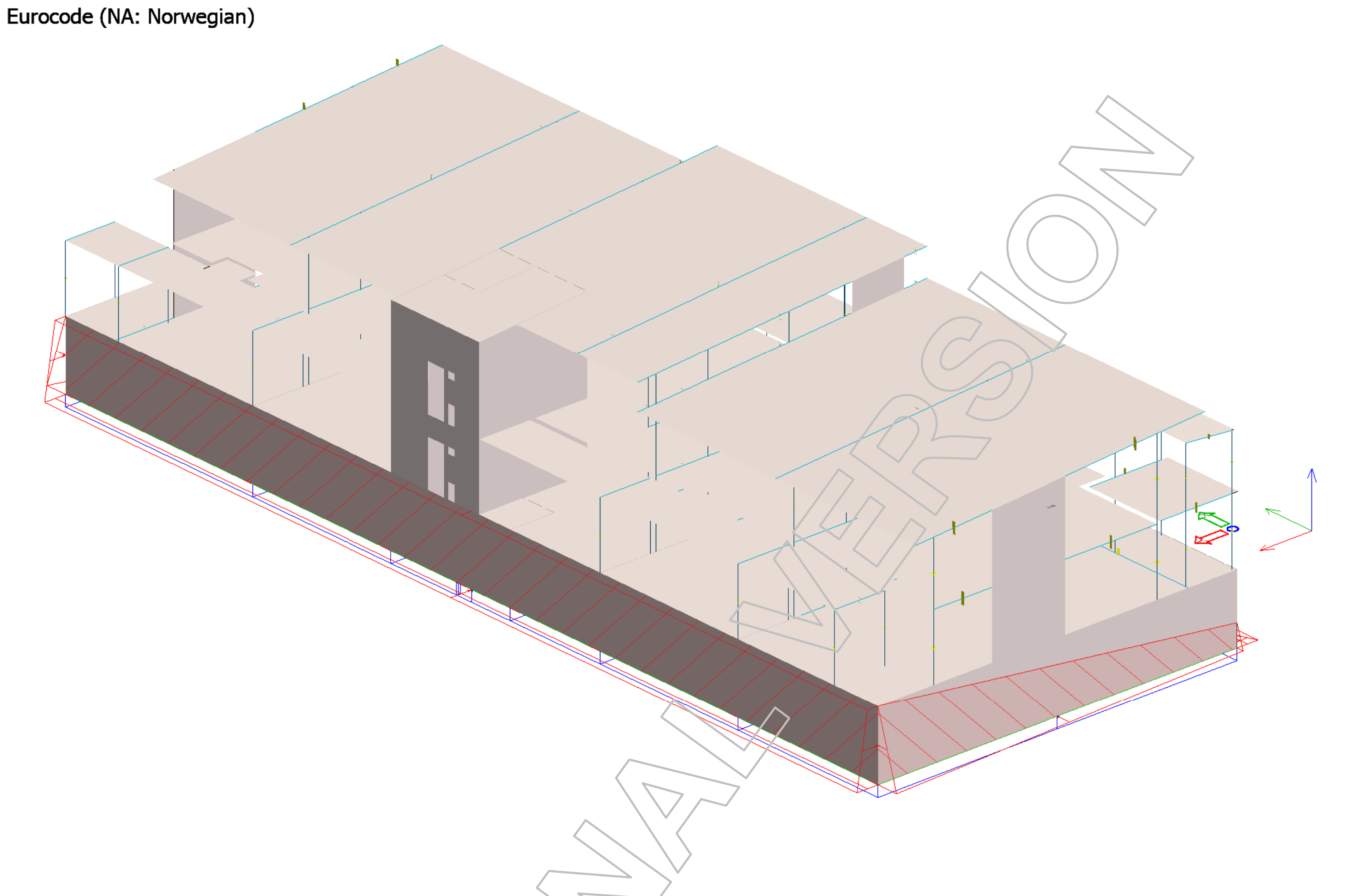
snow load



Wind load Y-



Earth pressure



Surface loads (Ordinary)

No.	q1	q2	q3	Load case	Comment	Applied on Ecc	Assigned	Intensity
[-]	[kN/m2]	[kN/m2]	[kN/m2]	[-]	[-]	[-]	[-]	[-]
1	2.220	2.220	2.220	Supperimposed dead		No	-	Action
2	2.220	2.220	2.220	Supperimposed dead		No	-	Action
3	2.220	2.220	2.220	Supperimposed dead		No	-	Action
4	2.200	2.200	2.200	Supperimposed dead		No	-	Action
5	2.200	2.200	2.200	Supperimposed dead		No	-	Action
6	2.200	2.200	2.200	Supperimposed dead		No	-	Action
7	2.200	2.200	2.200	Supperimposed dead		No	-	Action
8	0.500	0.500	0.500	Supperimposed dead		No	-	Action
9	0.500	0.500	0.500	Supperimposed dead		No	-	Action
10	0.500	0.500	0.500	Supperimposed dead		No	-	Action
11	0.500	0.500	0.500	Supperimposed dead		No	-	Action
12	0.500	0.500	0.500	Supperimposed dead		No	-	Action
13	0.500	0.500	0.500	Supperimposed dead		No	-	Action
14	0.500	0.500	0.500	Supperimposed dead		No	-	Action
15	0.500	0.500	0.500	Supperimposed dead		No	-	Action
16	0.500	0.500	0.500	Supperimposed dead		No	-	Action
17	0.500	0.500	0.500	Supperimposed dead		No	-	Action
18	0.500	0.500	0.500	Supperimposed dead		No	-	Action
19	0.500	0.500	0.500	Supperimposed dead		No	-	Action
20	0.500	0.500	0.500	Supperimposed dead		No	-	Action
21	0.500	0.500	0.500	Supperimposed dead		No	-	Action
22	0.500	0.500	0.500	Supperimposed dead		No	-	Action

No.	q1	q2	q3	Load case	Comment	Applied on Ecc	Assigned	Intensity
[-]	[kN/m2]	[kN/m2]	[kN/m2]	[-]	[-]	[-]	[-]	[-]
23	0.500	0.500	0.500	Supperimposed dead		No	-	Action
24	0.500	0.500	0.500	Supperimposed dead		No	-	Action
25	0.500	0.500	0.500	Supperimposed dead		No	-	Action
26	0.500	0.500	0.500	Supperimposed dead		No	-	Action
27	0.500	0.500	0.500	Supperimposed dead		No	-	Action
28	0.500	0.500	0.500	Supperimposed dead		No	-	Action
29	0.500	0.500	0.500	Supperimposed dead		No	-	Action
30	0.500	0.500	0.500	Supperimposed dead		No	-	Action
31	0.500	0.500	0.500	Supperimposed dead		No	-	Action
32	2.000	2.000	2.000	Live load		No	-	Action
33	2.000	2.000	2.000	Live load		No	-	Action
34	2.000	2.000	2.000	Live load		No	-	Action
35	2.000	2.000	2.000	Live load		No	-	Action
36	2.000	2.000	2.000	Live load		No	-	Action
37	2.000	2.000	2.000	Live load		No	-	Action
38	2.000	2.000	2.000	Live load		No	-	Action
39	2.000	2.000	2.000	Live load		No	-	Action
40	2.000	2.000	2.000	Live load		No	-	Action
41	2.000	2.000	2.000	Live load		No	-	Action
42	2.000	2.000	2.000	Live load		No	-	Action
43	2.000	2.000	2.000	Live load		No	-	Action
44	2.000	2.000	2.000	Live load		No	-	Action
45	2.000	2.000	2.000	Live load		No	-	Action
46	2.000	2.000	2.000	Live load		No	-	Action
47	2.000	2.000	2.000	Live load		No	-	Action
48	2.000	2.000	2.000	Live load		No	-	Action
49	2.000	2.000	2.000	Live load		No	-	Action
50	2.000	2.000	2.000	Live load		No	-	Action
51	2.000	2.000	2.000	Live load		No	-	Action
52	3.200	3.200	3.200	snow load		No	-	Action
53	3.200	3.200	3.200	snow load		No	-	Action
54	3.200	3.200	3.200	snow load		No	-	Action
55	3.200	3.200	3.200	snow load		No	-	Action
56	3.200	3.200	3.200	snow load		No	-	Action
57	3.200	3.200	3.200	snow load		No	-	Action
58	3.200	3.200	3.200	snow load		No	-	Action
59	3.200	3.200	3.200	snow load		No	-	Action
60	3.200	3.200	3.200	snow load		No	-	Action
61	3.200	3.200	3.200	snow load		No	-	Action
62	3.200	3.200	3.200	snow load		No	-	Action
63	2.220	2.220	2.220	Supperimposed dead		No	-	Action
64	2.220	2.220	2.220	Supperimposed dead		No	-	Action
65	2.000	2.000	2.000	Live load		No	-	Action
66	2.000	2.000	2.000	Live load		No	-	Action
67	2.220	2.220	2.220	Supperimposed dead		No	-	Action
68	2.220	2.220	2.220	Supperimposed dead		No	-	Action
69	2.000	2.000	2.000	Live load		No	-	Action
70	2.000	2.000	2.000	Live load		No	-	Action
71	2.000	2.000	2.000	Live load		No	-	Action
72	2.000	2.000	2.000	Live load		No	-	Action
73	2.000	2.000	2.000	Live load		No	-	Action
74	2.220	2.220	2.220	Supperimposed dead		No	-	Action

No.	q1	q2	q3	Load case	Comment	Applied on Ecc	Assigned	Intensity
[-]	[kN/m2]	[kN/m2]	[kN/m2]	[-]	[-]	[-]	[-]	[-]
75	2.220	2.220	2.220	Supperimposed dead		No	-	Action
76	2.000	2.000	2.000	Live load		No	-	Action
77	2.000	2.000	2.000	Live load		No	-	Action
78	2.000	2.000	2.000	Live load		No	-	Action
79	2.220	2.220	2.220	Supperimposed dead		No	-	Action
80	0.000	19.680	6.330	Earth pressure		No	-	Action
81	0.000	0.000	3.160	Earth pressure		No	-	Action
82	0.000	19.680	3.160	Earth pressure		No	-	Action

Surface loads (Soil/Hydrostatic pressure)

No.	z0	q0	qh	qbottom	qtop	Load case	Comment	Applied on Ecc	Assigned	Intensity
[-]	[m]	[kN/m2]	[kN/m2/m]	[kN/m2]	[kN/m2]	[-]	[-]	[-]	[-]	[-]
1	3.100	1.650	21.300	133.923	67.680	Earth pr...		No	-	Action

Load cases

No.	Name	Type	Duration class
1	selfweight	+Struc. dead load	Permanent
2	Supperimposed dead	Ordinary	Permanent
3	Live load	Ordinary	Permanent
4	snow load	Ordinary	Short-term
5	Wind load Y-	Ordinary	Instantaneous
6	Earth pressure	Ordinary	Permanent
7	Misalignement load Hi	Ordinary	Permanent
8	Fire	+Fire	Permanent

Load combinations

No.	Name	Type	Factor	Load cases
1	selfweight + Supperimp...	Accidental	1.000	selfweight (+Struc. dead load)
			1.000	Supperimposed dead
			1.000	Earth pressure
			1.000	Fire (+Fire)
			0.500	Live load
			0.300	snow load
			0.200	Wind load Y-
2	selfweight + Supperimp...	Accidental	1.000	selfweight (+Struc. dead load)
			1.000	Supperimposed dead
			1.000	Earth pressure
			1.000	Fire (+Fire)
			0.300	Live load
			0.500	snow load
			0.200	Wind load Y-
3	selfweight + Supperimp...	Accidental	1.000	selfweight (+Struc. dead load)
			1.000	Supperimposed dead
			1.000	Earth pressure
			1.000	Fire (+Fire)
			0.300	Live load
			0.300	snow load
			0.500	Wind load Y-

1.2 Material properties

Steel materials

No.	Name	fyk(t<16)	fyk(16<=t<=40)	fyk(40<t<=63)	fyk(63<t<=80)
[-]	[-]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]
1	S 355	355.000	355.000	335.000	335.000
2	S 355_1	355.000	355.000	335.000	335.000

fyk(80<t<=100)	fyk(100<t<=150)	fyk(150<t<=200)	fyk(200<t<=250)	fyk(250<t<=400)	fuk(t<3)
[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]
335.000	335.000	335.000	335.000	335.000	510.000
335.000	335.000	335.000	335.000	335.000	510.000

fuk(3<=t<=40)	fuk(40<t<=100)	fuk(100<t<=150)	fuk(150<t<=250)	fuk(250<t<=400)	Gamma M0
[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[N/mm2]	[-]
510.000	470.000	470.000	470.000	470.000	1.000
510.000	470.000	470.000	470.000	470.000	1.050

Gamma M0, Acc	Gamma M1	Gamma M1, Acc	Gamma M2	Gamma M2, Acc	Gamma M5	Gamma M5, Acc	Gamma Mfi	Ek
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[N/mm2]
1.000	1.000	1.000	1.250	1.250	1.000	1.000	1.000	210000.000
1.000	1.050	1.000	1.250	1.000	1.000	1.000	1.000	210000.000

Poisson's ratio	G	Therm. coeff.	Density
[-]	[N/mm2]	[1/°C]	[t/m3]
0.300	80769.000	1.2000e-05	7.850000
0.300	80769.000	1.2000e-05	7.850000

2 Steel design results

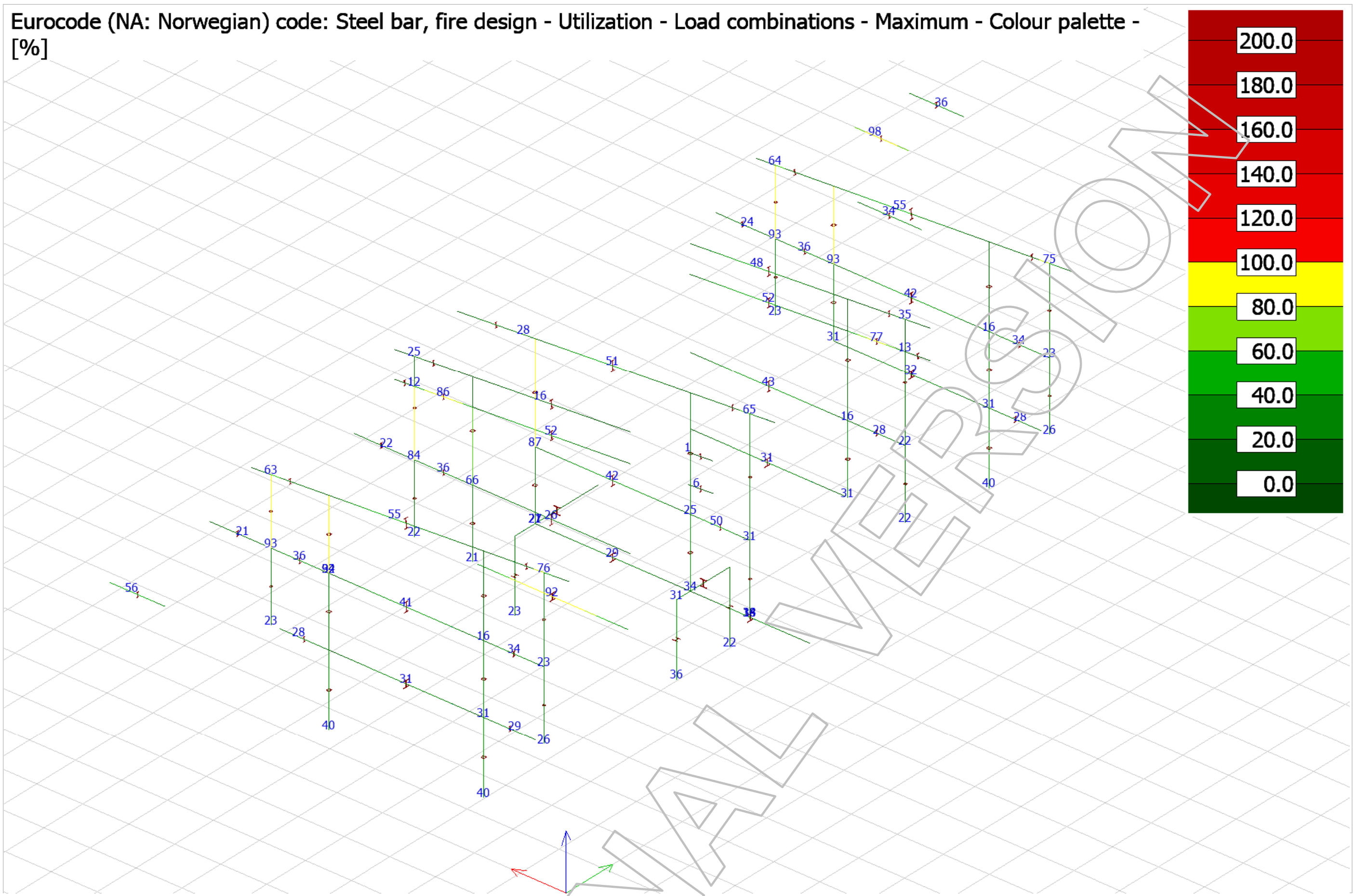
2.1 Utilization ratio

Max. of load combinations, Bar, Fire design, Utilization

Member	Section	Duration	Insulation	Maximum	Combination	RCS
[-]	[-]	[min.]	[-]	[%]	[-]	[%]
B.2.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	63	selfweight ...	16
B.3.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	64	selfweight ...	15
B.4.1	IPE 200	30		28	selfweight ...	14
B.5.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	25	selfweight ...	7
B.6.1	IPE 330	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	48	selfweight ...	20
B.14.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	22	selfweight ...	16
B.16.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	29	selfweight ...	22
B.17.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	28	selfweight ...	20
B.18.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	28	selfweight ...	21
B.19.1	HE-B 280	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	31	selfweight ...	23
B.20.1	HE-B 280	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	34	selfweight ...	25
B.21.1	HE-B 300	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	27	selfweight ...	20
B.22.1	HE-B 280	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	29	selfweight ...	21
B.23.1	HE-B 300	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	31	selfweight ...	31
B.24.1	HE-B 280	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	31	selfweight ...	23
B.25.1	HE-B 280	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	32	selfweight ...	23
B.29.1	HE-B 280	30		92	selfweight ...	55
B.31.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	21	selfweight ...	15
B.32.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	36	selfweight ...	26
B.33.1	IPE 400	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	41	selfweight ...	30
B.34.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	34	selfweight ...	24
B.35.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	36	selfweight ...	26
B.36.1	IPE 400	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	26	selfweight ...	19
B.37.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	50	selfweight ...	21
B.38.1	IPE 400	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	42	selfweight ...	30
B.39.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	28	selfweight ...	20
B.40.1	IPE 400	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	43	selfweight ...	31
B.41.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	34	selfweight ...	25
B.42.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	36	selfweight ...	26
B.43.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	24	selfweight ...	17
B.44.1	IPE 200	30		36	selfweight ...	21
B.45.1	IPE 200	30		98	selfweight ...	58
B.52.1	IPE 200	30		13	selfweight ...	13
B.54.1	IPE 200	30		56	selfweight ...	34
B.55.1	IPE 330	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	52	selfweight ...	21
B.56.1	IPE 200	30		77	selfweight ...	46
B.57.1	IPE 200	30		12	selfweight ...	12
B.58.1	IPE 200	30		86	selfweight ...	51
B.59.1	IPE 330	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	52	selfweight ...	21
B.60.1	IPE 200	30		6	selfweight ...	5
B.62.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	35	selfweight ...	12
B.63.1	IPE 400	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	55	selfweight ...	23
B.64.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	75	selfweight ...	23
B.65.1	IPE 400	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	51	selfweight ...	20
B.66.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	65	selfweight ...	17
B.67.1	IPE 330	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	16	selfweight ...	6
B.68.1	IPE 400	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	55	selfweight ...	23
B.69.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	76	selfweight ...	23

Member	Section	Duration	Insulation	Maximum	Combination	RCS
[-]	[-]	[min.]	[-]	[%]	[-]	[%]
B.70.1	IPE 200	30		1	selfweight ...	1
B.87.1	IPE 400	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	42	selfweight ...	30
B.88.1	IPE 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	34	selfweight ...	25
C.1.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	40	selfweight ...	22
C.2.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	40	selfweight ...	22
C.3.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	40	selfweight ...	22
C.4.1	VKR 140x1...	30		66	selfweight ...	36
C.5.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	25	selfweight ...	8
C.6.1	HE-A 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	36	selfweight ...	2
C.7.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	16	selfweight ...	8
C.8.1	VKR 140x1...	30		94	selfweight ...	51
C.9.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	16	selfweight ...	8
C.10.1	VKR 140x1...	30		93	selfweight ...	51
C.11.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	16	selfweight ...	8
C.12.1	VKR 140x1...	30		87	selfweight ...	33
C.22.1	VKR 100x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	22	selfweight ...	6
C.23.1	VKR 100x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	31	selfweight ...	6
C.24.1	VKR 100x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	23	selfweight ...	7
C.25.1	VKR 100x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	23	selfweight ...	7
C.26.1	VKR 100x1...	30		84	selfweight ...	34
C.27.1	VKR 100x1...	30		93	selfweight ...	38
C.28.1	VKR 100x1...	30		93	selfweight ...	38
C.46.1	HE-A 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	23	selfweight ...	1
C.47.1	HE-A 200	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	22	selfweight ...	1
C.50.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	21	selfweight ...	12
C.51.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	34	selfweight ...	19
C.52.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	31	selfweight ...	17
C.53.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	32	selfweight ...	18
C.54.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	31	selfweight ...	18
C.55.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	31	selfweight ...	18
C.56.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	31	selfweight ...	17
C.57.1	VKR 140x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	21	selfweight ...	12
C.60.1	VKR 100x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	22	selfweight ...	9
C.61.1	VKR 100x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	18	selfweight ...	7
C.62.1	VKR 100x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	26	selfweight ...	10
C.63.1	VKR 100x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	26	selfweight ...	10
C.64.1	VKR 100x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	22	selfweight ...	8
C.65.1	VKR 100x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	23	selfweight ...	9
C.66.1	VKR 100x1...	30	Compressed fibre board - fibre-silicate, mineral wool, stone w...	23	selfweight ...	9

2.2 Detail calculation

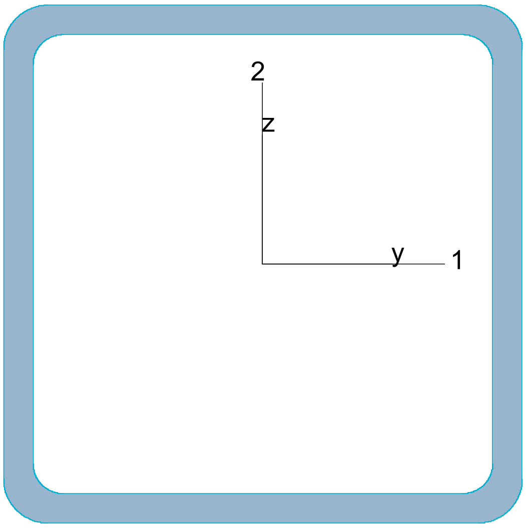


C.8.1 for fire effect
Maximum of load combinations

S 355

E	=	210000	N/mm^2
G	=	80769	N/mm^2
ρ_a	=	7850	kg/m^3
γ_{M0}	=	1.00	
γ_{M1}	=	1.00	
$\gamma_{M,fi}$	=	1.00	

VKR 140x140x8



P	=	539	mm	f_y	=	355	N/mm^2
A	=	4155	mm^2	ε	=	0.69	
I_y	=	1.195e+07	mm^4	λ_1	=	76.40	
I_z	=	1.195e+07	mm^4				
I_1	=	1.195e+07	mm^4				
I_2	=	1.195e+07	mm^4				
$W_{pl,1}$	=	2.043e+05	mm^3				
$W_{pl,2}$	=	2.043e+05	mm^3				
$W_{el,min,1}$	=	1.707e+05	mm^3				
$W_{el,min,2}$	=	1.707e+05	mm^3				
i_1	=	54	mm				
i_2	=	54	mm				
I_t	=	1.928e+07	mm^4				
I_w	=	7.347e+07	mm^6				

Reduction factors at elevated temperature - Part 1-2: 3, 4

t = 30 min, Time-temperature curve: Standard

$\theta_{g,30} = 20 + 345 \log(8 \cdot t + 1) = 20 + 345 \log(8 \cdot 30 + 1) = 842\ °C$

Section exposure: Three sides

Fire protection: Unprotected

$A_m / V = \max\left(\frac{A_m}{V}, 10\right) = \max\left(\frac{0.3994}{4.155e\text{-}03}, 10\right) = 96.12\ 1/m$

$(A_m / V)_b = \frac{A_{m,b}}{V} = \frac{0.4200}{4.155e\text{-}03} = 101.07\ 1/m$

$k_{sh} = \frac{(A_m / V)_b}{A_m / V} = \frac{101.07}{96.12} = 1.05$ (4.26 b)

$\alpha_c = 25\ W/m^2 K$

$\Phi = 1.00$, $\varepsilon_m = 0.70$, $\varepsilon_f = 1.00$

$h_{net,d} =$

$= \alpha_c (\theta_g - \theta_m) + \Phi\ \varepsilon_m \cdot \varepsilon_f \cdot 5.67 \cdot 10^{-8} \left[(\theta_r + 273)^4 - (\theta_m + 273)^4\right]$ (EN1991-1-2 3.1-3.3)

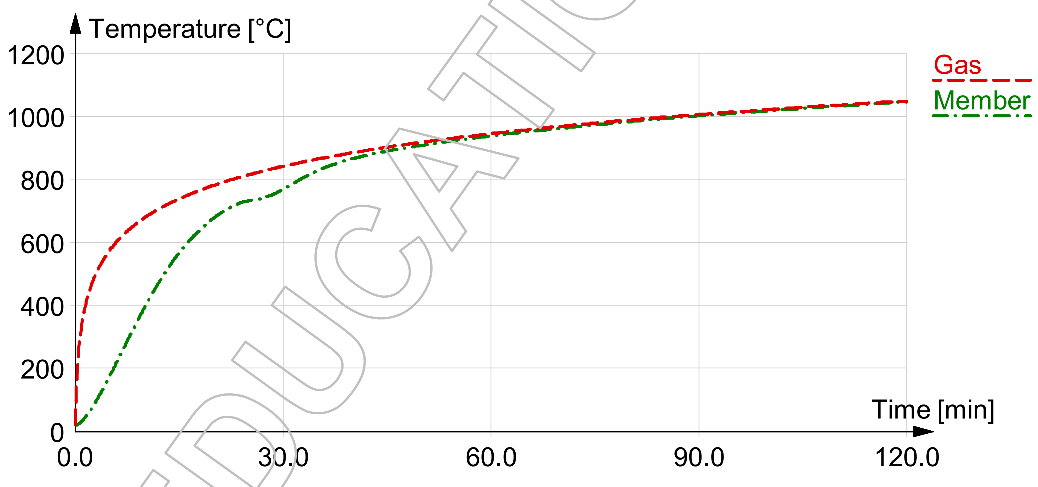
$\Delta t = 5\ s$

c_a is temperature-dependent, calculated according to EN 1993-1-2: 3.4.1.2

$\Delta\theta_{a,t} = k_{sh} \cdot \frac{A_m / V}{c_a \cdot \rho_a} \cdot h_{net,d} \cdot \Delta t$ (4.25)

$\theta_{a,30} = 769\ °C$

$k_{y,\theta} = 0.1473$, $k_{p0.2,\theta} = 0.0886$, $k_{E,\theta} = 0.1024$



Shear resistance, 1-1 - Part 1-1: 6.2.6, 6.2.8, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$V_{1,pl,Rd} = \frac{A_{1,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{2078 \cdot 355}{\sqrt{3} \cdot 1.00} = 425.84 \quad kN \qquad (6.18)$$

$$V_{1,pl,T,Rd} = 1 - \frac{\tau_{t,Ed}}{(f_y / \sqrt{3}) / \gamma_{M0}} \cdot V_{1,pl,Rd} =$$

$$= 1 - \frac{0.00}{(355 / \sqrt{3}) / 1.00} \cdot 425.84 = 425.84 \quad kN \qquad (6.28)$$

$$V_{1,fi,t,pl,T,Rd} = k_{y,\theta} \cdot V_{1,pl,T,Rd} \cdot [\gamma_{M0} / \gamma_{M,fi}] =$$

$$= 0.1473 \cdot 425.84 \cdot [1.00 / 1.00] = 62.72 \quad kN \qquad (4.16)$$

$$\frac{V_{1,Ed}}{V_{1,fi,t,pl,T,Rd}} = \frac{0.00}{62.72} = 0.00 \le 1.00 \qquad (6.25) \quad \text{- OK}$$

Shear resistance, 2-2 - Part 1-1: 6.2.6, 6.2.8, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$V_{2,pl,Rd} = \frac{A_{2,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{2078 \cdot 355}{\sqrt{3} \cdot 1.00} = 425.84 \quad kN \qquad (6.18)$$

$$V_{2,pl,T,Rd} = 1 - \frac{\tau_{t,Ed}}{(f_y / \sqrt{3}) / \gamma_{M0}} \cdot V_{2,pl,Rd} =$$

$$= 1 - \frac{0.00}{(355 / \sqrt{3}) / 1.00} \cdot 425.84 = 425.84 \quad kN \qquad (6.28)$$

$$V_{2,fi,t,pl,T,Rd} = k_{y,\theta} \cdot V_{2,pl,T,Rd} \cdot [\gamma_{M0} / \gamma_{M,fi}] =$$

$$= 0.1473 \cdot 425.84 \cdot [1.00 / 1.00] = 62.72 \quad kN \qquad (4.16)$$

$$\frac{V_{2,Ed}}{V_{2,fi,t,pl,T,Rd}} = \frac{0.00}{62.72} = 0.00 \le 1.00 \qquad (6.25) \quad \text{- OK}$$

Torsional resistance - Part 1-1: 6.2.7, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$\tau_{max,unit} = 4.20 \dfrac{N/mm^2}{kN\,m}$ is calculated by FEM analysis.

$$T_{Rd} = \frac{f_y}{\sqrt{3} \cdot \tau_{max,unit} \cdot \gamma_{M0}} = \frac{355}{\sqrt{3} \cdot 4.20 \cdot 1.00} = 48.77 \quad kN\,m$$

$$T_{fi,t,Rd} = k_{y,\theta} \cdot T_{Rd} \cdot [\gamma_{M0} / \gamma_{M,fi}] = 0.1473 \cdot 48.77 \cdot [1.00 / 1.00] = 7.18 \quad kN\,m$$

$$\frac{T_{Ed}}{T_{fi,t,Rd}} = \frac{0.00}{7.18} = 0.00 \le 1.00 \qquad (6.23) \quad \text{- OK}$$

Shear stress - Part 1-1: 6.2.6, Part 1-2: 4.2.3

Not relevant

Normal stress - Part 1-1: 6.2.1, Part 1-2: 4.2.3

Not relevant

Normal capacity - Part 1-1: 6.2, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.30*Live load + 0.50*snow load + 0.20*Wind load Y-', x =

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$V_{1,Ed} = 0.00 \text{ kN} \leq 0.5 \cdot V_{1,pl,T,Rd} = 0.5 \cdot 425.84 = 212.92 \text{ kN} \rightarrow \rho_1 = 0.00$

$V_{2,Ed} = 0.00 \text{ kN} \leq 0.5 \cdot V_{2,pl,T,Rd} = 0.5 \cdot 425.84 = 212.92 \text{ kN} \rightarrow \rho_1 = 0.00$

$N_{fi,Rd} = k_{y,\theta} \cdot N_{Rd} \cdot [\gamma_{M0} / \gamma_{M,fi}] =$

$= 0.1473 \cdot 1475.16 \cdot [1.00 / 1.00] = 217.26 \text{ kN}$ (4.3)

$M_{fi,1,Rd} = k_{y,\theta} \cdot M_{1,Rd} \cdot [\gamma_{M0} / \gamma_{M,fi}] / \kappa_1 \cdot \kappa_2 =$

$= 0.1473 \cdot 72.54 \cdot [1.00 / 1.00] / 0.70 \cdot 0.85 = 17.96 \text{ kN m}$ (4.10)

$M_{fi,2,Rd} = k_{y,\theta} \cdot M_{2,Rd} \cdot [\gamma_{M0} / \gamma_{M,fi}] / \kappa_1 \cdot \kappa_2 =$

$= 0.1473 \cdot 72.54 \cdot [1.00 / 1.00] / 0.70 \cdot 0.85 = 17.96 \text{ kN m}$ (4.10)

$$\frac{N_{Ed}}{N_{fi,Rd}} + \frac{M_{1,Ed}}{M_{fi,1,Rd}} + \frac{M_{2,Ed}}{M_{fi,2,Rd}} = \frac{111.81}{217.26} + \frac{0.00}{17.96} + \frac{0.00}{17.96} = 0.51 \leq 1.00$$ (6.2) - OK

Flexural buckling, 1-1 - Part 1-1: 6.3.1, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.30*Live load + 0.50*snow load + 0.20*Wind load Y-', x =

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$\bar{\lambda}_1 = \frac{L_{cr,1}}{i_1 \cdot \lambda_1} = \frac{3031}{54 \cdot 76.40} = 0.74$$ (6.50)

$$\alpha_1 = 0.65 \cdot \sqrt{\frac{235}{f_y}} = 0.65 \cdot \sqrt{\frac{235}{355}} = 0.53$$

$$\bar{\lambda}_\theta = \bar{\lambda}_1 \cdot \sqrt{k_{y,\theta} / k_{E,\theta}} = 0.74 \cdot \sqrt{0.1473 / 0.1024} = 0.89$$

$$\varphi_\theta = 0.5 \left(1 + \alpha_1 \cdot \bar{\lambda}_\theta + \bar{\lambda}_\theta^{\,2}\right) = 0.5 \left(1 + 0.53 \cdot 0.89 + 0.89^2\right) = 1.13$$

$$\chi_{fi} = \min\left(\frac{1}{\varphi_\theta + \sqrt{\varphi_\theta^{\,2} - \bar{\lambda}_\theta^{\,2}}}, 1.0\right) =$$

$$= \min\left(\frac{1}{1.13 + \sqrt{1.13^2 - 0.89^2}}, 1.0\right) = 0.55$$ (4.6)

$$N_{b,fi,t,Rd} = \frac{\chi_{fi} \cdot A \cdot k_{y,\theta} \cdot f_y}{\gamma_{M,fi}} = \frac{0.55 \cdot 4155 \cdot 0.1473 \cdot 355}{1.00} = 119.07 \text{ kN}$$ (4.5)

$$\frac{N_{Ed}}{N_{b,fi,t,Rd}} = \frac{111.81}{119.07} = 0.94 \leq 1.00$$ (6.46) - OK

Flexural buckling, 2-2 - Part 1-1: 6.3.1, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.30*Live load + 0.50*snow load + 0.20*Wind load Y-', x =

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$\bar{\lambda}_2 = \frac{L_{cr,2}}{i_2 \cdot \lambda_1} = \frac{3031}{54 \cdot 76.40} = 0.74 \qquad (6.50)$$

$$\alpha_2 = 0.65 \cdot \sqrt{\frac{235}{f_y}} = 0.65 \cdot \sqrt{\frac{235}{355}} = 0.53$$

$$\bar{\lambda}_\theta = \bar{\lambda}_2 \cdot \sqrt{k_{y,\theta} / k_{E,\theta}} = 0.74 \cdot \sqrt{0.1473 / 0.1024} = 0.89$$

$$\varphi_\theta = 0.5 \left(1 + \alpha_2 \cdot \bar{\lambda}_\theta + \bar{\lambda}_\theta^{\,2}\right) = 0.5 \left(1 + 0.53 \cdot 0.89 + 0.89^2\right) = 1.13$$

$$\chi_{fi} = \min\left(\frac{1}{\varphi_\theta + \sqrt{\varphi_\theta^{\,2} - \bar{\lambda}_\theta^{\,2}}}, 1.0\right) =$$

$$= \min\left(\frac{1}{1.13 + \sqrt{1.13^2 - 0.89^2}}, 1.0\right) = 0.55 \qquad (4.6)$$

$$N_{b,fi,t,Rd} = \frac{\chi_{fi} \cdot A \cdot k_{y,\theta} \cdot f_y}{\gamma_{M,fi}} = \frac{0.55 \cdot 4155 \cdot 0.1473 \cdot 355}{1.00} = 119.07 \text{ kN} \qquad (4.5)$$

$$\frac{N_{Ed}}{N_{b,fi,t,Rd}} = \frac{111.81}{119.07} = 0.94 \leq 1.00 \qquad (6.46) \text{ - OK}$$

Torsional-flexural buckling - Part 1-1: 6.3.1, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.30*Live load + 0.50*snow load + 0.20*Wind load Y-', x =

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$i_0 = \sqrt{i_1^2 + i_2^2 + y_0^2 + z_0^2} = \sqrt{54^2 + 54^2 + 0^2 + 0^2} = 76 \text{ mm}$$

$$N_{cr,1} = \frac{\pi^2 \cdot E \cdot I_1}{L_{cr,1}^2} = \frac{\pi^2 \cdot 210000 \cdot 11950231}{3031^2} = 276.23 \text{ kN}$$

$$N_{cr,2} = \frac{\pi^2 \cdot E \cdot I_2}{L_{cr,2}^2} = \frac{\pi^2 \cdot 210000 \cdot 11950231}{3031^2} = 276.23 \text{ kN}$$

$$N_{cr,T,fi} = \frac{1}{i_0^2}\left(G \cdot I_t + \frac{\pi^2 \cdot E \cdot I_w}{L_t^2}\right) \cdot k_{E,\theta} =$$

$$= \frac{1}{76^2}\left(80769 \cdot 1.928e+07 + \frac{\pi^2 \cdot 210000 \cdot 7.347e+07}{3031^2}\right) \cdot 0.1024 =$$

$$= 27733.36 \text{ kN}$$

$$i_0^2 (N - N_{cr,1})(N - N_{cr,2})(N - N_{cr,T,fi}) - N^2 y_0^2 (N - N_{cr,2}) - N^2 z_0^2 (N - N_{cr,1}) =$$

$$= 76^2 (N - 276.23)(N - 276.23)(N - 27733.36) - N^2 0^2 (N - 276.23) - N^2 0^2 (N - 276.23) =$$

$$= 0$$

Smallest root of the above equation related to the torsional-flexural buckling:

$$N_{cr,TF} = 27733.36 \text{ kN}$$

$$N_{cr} = \min(N_{cr,T,fi}, N_{cr,TF}) = \min(27733.36, 27733.36) = 27733.36 \text{ kN}$$

$$\bar{\lambda}_T = \sqrt{\frac{A \cdot f_y}{N_{cr}}} = \sqrt{\frac{4155 \cdot 355}{27733.36}} = 0.23 \quad (6.53)$$

$$\alpha_T = 0.65 \cdot \sqrt{\frac{235}{f_y}} = 0.65 \cdot \sqrt{\frac{235}{355}} = 0.53$$

$$\bar{\lambda}_{T,\theta} = \bar{\lambda}_T \cdot \sqrt{k_{y,\theta} / k_{E,\theta}} = 0.23 \cdot \sqrt{0.1473 / 0.1024} = 0.28$$

$$\varphi_T = 0.5\left(1 + \alpha_T \cdot \bar{\lambda}_{T,\theta} + \bar{\lambda}_{T,\theta}^2\right) =$$

$$= 0.5\left(1 + 0.53 \cdot 0.28 + 0.28^2\right) = 0.61$$

$$\chi_T = \min\left(\frac{1}{\varphi_T + \sqrt{\varphi_T^2 - \bar{\lambda}_{T,\theta}^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{0.61 + \sqrt{0.61^2 - 0.28^2}}, 1.0\right) = 0.86 \quad (4.6)$$

$$N_{b,fi,t,Rd,T} = \frac{\chi_T \cdot A \cdot k_{y,\theta} \cdot f_y}{\gamma_{M,fi}} = \frac{0.86 \cdot 4155 \cdot 0.1473 \cdot 355}{1.00} = 187.85 \text{ kN} \quad (4.5)$$

$$\frac{N_{Ed}}{N_{b,fi,t,Rd,T}} = \frac{111.81}{187.85} = 0.60 \le 1.00 \text{ - OK}$$

Lateral torsional buckling, top flange - Part 1-1: 6.3.2.2, Part 1-2: 4.2.3

Not relevant

Lateral torsional buckling, bottom flange - Part 1-1: 6.3.2.2, Part 1-2: 4.2.3
LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

$\text{Class}_{N} = 1, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$$N_{cr,LT} = \frac{\pi^2 \cdot E \cdot I_z}{(k_z \cdot L_{cr})^2} = \frac{\pi^2 \cdot 2.100e{+}05 \cdot 1.195e{+}07}{(1.00 \cdot 3031)^2} = 2696.81 \quad \text{kN}$$

Loaded on top edge.

$$Z = (C_2 \cdot z_g - C_3 \cdot z_j) = (0.45 \cdot -70 - 0.49 \cdot 0) = -31.50 \quad \text{mm}$$

$$M_{cr} = C_1 \cdot N_{cr,LT} \cdot \left\{\left[\left(\frac{k_z}{k_w}\right)^2 \cdot \frac{I_w}{I_z} + \frac{G \cdot I_t}{N_{cr,LT}} + Z^2\right]^{0.5} - Z\right\} =$$

$$= 1.13 \cdot 2.697e{+}06 \cdot \left\{\left[\left(\frac{1.00}{1.00}\right)^2 \cdot \frac{7.347e{+}07}{1.195e{+}07} + \frac{8.077e{+}04 \cdot 1.928e{+}07}{2.697e{+}06} + -31.50^2\right]^{0.5} - -31.50\right\} =$$

$$= 2413.75 \quad \text{kN m}$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y \cdot f_y}{M_{cr}}} = \sqrt{\frac{204337 \cdot 355}{2.414e{+}09}} = 0.17$$

$$\alpha = 0.65 \cdot \sqrt{\frac{235}{f_y}} = 0.65 \cdot \sqrt{\frac{235}{355}} = 0.53 \qquad (4.14)$$

$$\bar{\lambda}_{LT,\theta} = \bar{\lambda}_{LT} \cdot \sqrt{k_{y,\theta} / k_{E,\theta}} = 0.17 \cdot \sqrt{0.1473 / 0.1024} = 0.21 \qquad (4.15)$$

$$\varphi_{LT,\theta} = 0.5 \left(1 + \alpha + \bar{\lambda}_{LT,\theta} \cdot \bar{\lambda}_{LT,\theta}^2\right) =$$

$$= 0.5 \left(1 + 0.53 + 0.21 \cdot 0.21^2\right) = 0.58 \qquad (4.13)$$

$$\chi_{LT,fi} = \min\left(\frac{1}{\varphi_{LT,\theta} + \sqrt{\varphi_{LT,\theta}^2 - \bar{\lambda}_{LT,\theta}^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{0.58 + \sqrt{0.58^2 - 0.21^2}}, 1.0\right) = 0.90 \qquad (4.12)$$

$$M_{b,fi,t,Rd} = \frac{\chi_{LT,fi} \cdot W_y \cdot k_{y,\theta} \cdot f_y}{\gamma_{M,fi}} = \frac{0.90 \cdot 204337 \cdot 0.1473 \cdot 355}{1.00} = 9.59 \quad \text{kN m} \qquad (4.11)$$

$$\frac{M_{1,Ed}}{M_{b,fi,t,Rd}} = \frac{0.00}{9.59} = 0.00 \leq 1.00 \qquad (6.54) \quad \text{- OK}$$

Interaction between normal force and bending 1. - Part 1-1: 6.3.3, Part 1-2: 4.2.3
Not relevant

Interaction between normal force and bending 2. - Part 1-1: 6.3.3, Part 1-2: 4.2.3
Not relevant

Interaction between normal force and bending, 2nd order - Part 1-1: 6.3.3, Part 1-2: 4.2.3
Not relevant

Shear buckling - Part 1-5: 5, Part 1-2: 4.2.3

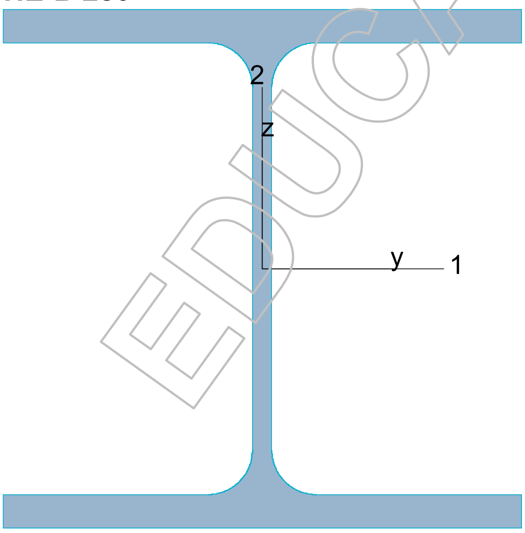
$$\frac{h_w}{t} = \frac{124}{8} = 15.5 \leq \frac{72}{\eta} \cdot \varepsilon = \frac{72}{1.20} \cdot 0.69 = 41.5 \rightarrow$$ Not relevant

B.19.1 for fire effect
Maximum of load combinations

S 355

E	=	210000	N/mm^2
G	=	80769	N/mm^2
ρ_a	=	7850	kg/m^3
γ_{M0}	=	1.00	
γ_{M1}	=	1.00	
$\gamma_{M,fi}$	=	1.00	

HE-B 280



P	=	1618	mm
A	=	13136	mm^2
I_y	=	1.927e+08	mm^4
I_z	=	6.595e+07	mm^4
I_1	=	1.927e+08	mm^4
I_2	=	6.595e+07	mm^4
$W_{pl,1}$	=	1.534e+06	mm^3
$W_{pl,2}$	=	7.177e+05	mm^3
$W_{el,min,1}$	=	1.376e+06	mm^3
$W_{el,min,2}$	=	4.710e+05	mm^3
i_1	=	121	mm
i_2	=	71	mm
I_t	=	1.453e+06	mm^4
I_w	=	1.107e+12	mm^6

f_y	=	355	N/mm^2
ε	=	0.69	
λ_1	=	76.40	

Reduction factors at elevated temperature - Part 1-2: 3, 4

t = 30 min, Time-temperature curve: Standard

$\theta_{g,30} = 20 + 345 \log(8 \cdot t + 1) = 20 + 345 \log(8 \cdot 30 + 1) = 842$ °C

Section exposure: Three sides

Fire protection: Compressed fibre board - fibre-silicate, mineral wool, stone wool, d_p = 10.00 mm

Encasement: Hollow

$$A_p / V = \frac{A_p}{V} = \frac{0.8400}{1.314e\text{-}02} = 63.94 \quad 1/m$$

$\lambda_p = 0.20$ W/mK , $c_p = 1200.00$ J/kgK , $\rho_p = 150.00$ kg/m^3

c_a is temperature-dependent, calculated according to EN 1993-1-2: 3.4.1.2

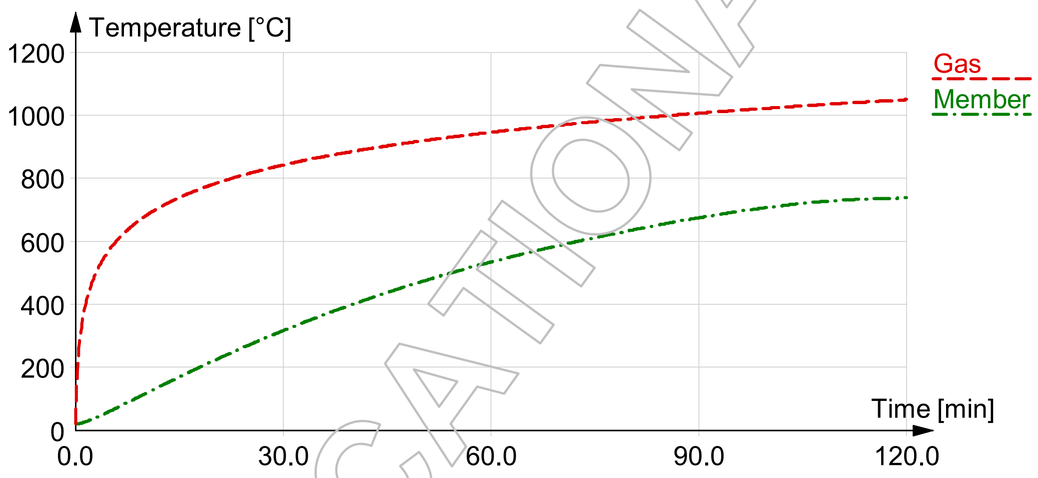
$$\Phi = \frac{c_p \cdot \rho_p}{c_a \cdot \rho_\alpha} d_p \cdot A_p / V$$

$\Delta t = 5$ s

$$\Delta\theta_{a,t} = \frac{\lambda_p \cdot A_p / V \, (\theta_{g,t} - \theta_{a,t})}{d_p \cdot c_a \cdot \rho_a \cdot (1 + \Phi / 3)} \Delta t - \left(e^{\Phi / 10} - 1\right) \Delta\theta_{g,t} \qquad (4.27)$$

$\theta_{a,30} = 316$ °C

$k_{y,\theta} = 1.0000$, $k_{p0,2,\theta} = 0.7588$, $k_{E,\theta} = 0.7837$



Shear resistance, 1-1 - Part 1-1: 6.2.6, 6.2.8, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$V_{1,pl,Rd} = \frac{A_{1,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{10574 \cdot 355}{\sqrt{3} \cdot 1.00} = 2167.33 \quad kN \qquad (6.18)$$

$$V_{1,pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1.25 \left(f_y / \sqrt{3} \right) / \gamma_{M0}}} \cdot V_{1,pl,Rd} =$$

$$= \sqrt{1 - \frac{0.00}{1.25 \left(355 / \sqrt{3} \right) / 1.00}} \cdot 2167.33 = 2167.33 \quad kN \qquad (6.26)$$

$$V_{1,fi,t,pl,T,Rd} = k_{y,\theta} \cdot V_{1,pl,T,Rd} \cdot [\gamma_{M0} / \gamma_{M,fi}] =$$

$$= 1.0000 \cdot 2167.33 \cdot [1.00 / 1.00] = 2167.33 \quad kN \qquad (4.16)$$

$$\frac{V_{1,Ed}}{V_{1,fi,t,pl,T,Rd}} = \frac{0.00}{2167.33} = 0.00 \leq 1.00 \qquad (6.25) \quad \text{- OK}$$

Shear resistance, 2-2 - Part 1-1: 6.2.6, 6.2.8, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$V_{2,pl,Rd} = \frac{A_{2,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{4109 \cdot 355}{\sqrt{3} \cdot 1.00} = 842.27 \quad kN \qquad (6.18)$$

$$V_{2,pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1.25 \left(f_y / \sqrt{3} \right) / \gamma_{M0}}} \cdot V_{2,pl,Rd} =$$

$$= \sqrt{1 - \frac{0.00}{1.25 \left(355 / \sqrt{3} \right) / 1.00}} \cdot 842.27 = 842.27 \quad kN \qquad (6.26)$$

$$V_{2,fi,t,pl,T,Rd} = k_{y,\theta} \cdot V_{2,pl,T,Rd} \cdot [\gamma_{M0} / \gamma_{M,fi}] =$$

$$= 1.0000 \cdot 842.27 \cdot [1.00 / 1.00] = 842.27 \quad kN \qquad (4.16)$$

$$\frac{V_{2,Ed}}{V_{2,fi,t,pl,T,Rd}} = \frac{105.84}{842.27} = 0.13 \leq 1.00 \qquad (6.25) \quad \text{- OK}$$

Torsional resistance - Part 1-1: 6.2.7, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$\tau_{max,unit} = 19.66 \frac{N/mm^2}{kN\,m}$ is calculated by FEM analysis.

$$T_{Rd} = \frac{f_y}{\sqrt{3} \cdot \tau_{max,unit} \cdot \gamma_{M0}} = \frac{355}{\sqrt{3} \cdot 19.66 \cdot 1.00} = 10.42 \quad kN\,m$$

$$T_{fi,t,Rd} = k_{y,\theta} \cdot T_{Rd} \cdot [\gamma_{M0} / \gamma_{M,fi}] = 1.0000 \cdot 10.42 \cdot [1.00 / 1.00] = 10.42 \quad kN\,m$$

$$\frac{T_{Ed}}{T_{fi,t,Rd}} = \frac{0.00}{10.42} = 0.00 \leq 1.00 \qquad (6.23) \quad \text{- OK}$$

Shear stress - Part 1-1: 6.2.6, Part 1-2: 4.2.3
Not relevant

Normal stress - Part 1-1: 6.2.1, Part 1-2: 4.2.3
Not relevant

Normal capacity - Part 1-1: 6.2, Part 1-2: 4.2.3
LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

$\text{Class}_N = 1, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$V_{1,Ed} = 0.00 \text{ kN} \leq 0.5 \cdot V_{1,pl,T,Rd} = 0.5 \cdot 2167.33 = 1083.67 \text{ kN} \rightarrow \rho_1 = 0.00$

$V_{2,Ed} = 0.11 \text{ kN} \leq 0.5 \cdot V_{2,pl,T,Rd} = 0.5 \cdot 842.27 = 421.13 \text{ kN} \rightarrow \rho_1 = 0.00$

$$N_{fi,Rd} = k_{y,\theta} \cdot N_{Rd} \cdot [\gamma_{M0} / \gamma_{M,fi}] = 1.0000 \cdot 4663.44 \cdot [1.00 / 1.00] = 4663.44 \text{ kN} \quad (4.3)$$

$$M_{fi,1,Rd} = k_{y,\theta} \cdot M_{1,Rd} \cdot [\gamma_{M0} / \gamma_{M,fi}] / \kappa_1 \cdot \kappa_2 = 1.0000 \cdot 544.72 \cdot [1.00 / 1.00] / 0.85 \cdot 0.85 = 753.94 \text{ kN m} \quad (4.10)$$

$$M_{fi,2,Rd} = k_{y,\theta} \cdot M_{2,Rd} \cdot [\gamma_{M0} / \gamma_{M,fi}] / \kappa_1 \cdot \kappa_2 = 1.0000 \cdot 254.77 \cdot [1.00 / 1.00] / 0.85 \cdot 0.85 = 352.63 \text{ kN m} \quad (4.10)$$

$$\frac{N_{Ed}}{N_{fi,Rd}} + \frac{M_{1,Ed}}{M_{fi,1,Rd}} + \frac{M_{2,Ed}}{M_{fi,2,Rd}} = \frac{0.00}{4663.44} + \frac{171.09}{753.94} + \frac{0.00}{352.63} = 0.23 \leq 1.00 \quad (6.2) \text{ - OK}$$

Flexural buckling, 1-1 - Part 1-1: 6.3.1, Part 1-2: 4.2.3
LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

$\text{Class}_N = 1, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$$\bar{\lambda}_1 = \frac{L_{cr,1}}{i_1 \cdot \lambda_1} = \frac{6754}{121 \cdot 76.40} = 0.73 \quad (6.50)$$

$$\alpha_1 = 0.65 \cdot \sqrt{\frac{235}{f_y}} = 0.65 \cdot \sqrt{\frac{235}{355}} = 0.53$$

$$\bar{\lambda}_\theta = \bar{\lambda}_1 \cdot \sqrt{k_{y,\theta} / k_{E,\theta}} = 0.73 \cdot \sqrt{1.0000 / 0.7837} = 0.82$$

$$\varphi_\theta = 0.5 \left(1 + \alpha_1 \cdot \bar{\lambda}_\theta + \bar{\lambda}_\theta^2\right) = 0.5 \left(1 + 0.53 \cdot 0.82 + 0.82^2\right) = 1.06$$

$$\chi_{fi} = \min\left(\frac{1}{\varphi_\theta + \sqrt{\varphi_\theta^2 - \bar{\lambda}_\theta^2}}, 1.0\right) = \min\left(\frac{1}{1.06 + \sqrt{1.06^2 - 0.82^2}}, 1.0\right) = 0.58 \quad (4.6)$$

$$N_{b,fi,t,Rd} = \frac{\chi_{fi} \cdot A \cdot k_{y,\theta} \cdot f_y}{\gamma_{M,fi}} = \frac{0.58 \cdot 13136 \cdot 1.0000 \cdot 355}{1.00} = 2710.05 \text{ kN} \quad (4.5)$$

$$\frac{N_{Ed}}{N_{b,fi,t,Rd}} = \frac{0.00}{2710.05} = 0.00 \leq 1.00 \quad (6.46) \text{ - OK}$$

Flexural buckling, 2-2 - Part 1-1: 6.3.1, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

Class $_N$ = 1, Class $_{M1}$ = 1, Class $_{M2}$ = 1

$$\bar{\lambda}_2 = \frac{L_{cr,2}}{i_2 \cdot \lambda_1} = \frac{6754}{71 \cdot 76.40} = 1.25 \qquad (6.50)$$

$$\alpha_2 = 0.65 \cdot \sqrt{\frac{235}{f_y}} = 0.65 \cdot \sqrt{\frac{235}{355}} = 0.53$$

$$\bar{\lambda}_\theta = \bar{\lambda}_2 \cdot \sqrt{k_{y,\theta} / k_{E,\theta}} = 1.25 \cdot \sqrt{1.0000 / 0.7837} = 1.41$$

$$\varphi_\theta = 0.5 \left(1 + \alpha_2 \cdot \bar{\lambda}_\theta + \bar{\lambda}_\theta^2\right) = 0.5 \left(1 + 0.53 \cdot 1.41 + 1.41^2\right) = 1.87$$

$$\chi_{fi} = \min\left(\frac{1}{\varphi_\theta + \sqrt{\varphi_\theta^2 - \bar{\lambda}_\theta^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{1.87 + \sqrt{1.87^2 - 1.41^2}}, 1.0\right) = 0.32 \qquad (4.6)$$

$$N_{b,fi,t,Rd} = \frac{\chi_{fi} \cdot A \cdot k_{y,\theta} \cdot f_y}{\gamma_{M,fi}} = \frac{0.32 \cdot 13136 \cdot 1.0000 \cdot 355}{1.00} = 1509.82 \text{ kN} \qquad (4.5)$$

$$\frac{N_{Ed}}{N_{b,fi,t,Rd}} = \frac{0.00}{1509.82} = 0.00 \leq 1.00 \qquad (6.46) \text{ - OK}$$

Torsional-flexural buckling - Part 1-1: 6.3.1, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

$Class_{N} = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$i_0 = \sqrt{i_1^2 + i_2^2 + y_0^2 + z_0^2} = \sqrt{121^2 + 71^2 + 0^2 + 0^2} = 140 \text{ mm}$$

$$N_{cr,1} = \frac{\pi^2 \cdot E \cdot I_1}{L_{cr,1}^2} = \frac{\pi^2 \cdot 210000 \cdot 192702776}{6754^2} = 6861.83 \text{ kN}$$

$$N_{cr,2} = \frac{\pi^2 \cdot E \cdot I_2}{L_{cr,2}^2} = \frac{\pi^2 \cdot 210000 \cdot 65945220}{6754^2} = 2348.20 \text{ kN}$$

$$N_{cr,T,fi} = \frac{1}{i_0^2}\left(G \cdot I_t + \frac{\pi^2 \cdot E \cdot I_w}{L_t^2}\right) \cdot k_{E,\theta} =$$

$$= \frac{1}{140^2}\left(80769 \cdot 1.453e{+}06 + \frac{\pi^2 \cdot 210000 \cdot 1.107e{+}12}{6754^2}\right) \cdot 0.7837 =$$

$$= 6672.27 \text{ kN}$$

$$i_0^2 (N - N_{cr,1})(N - N_{cr,2})(N - N_{cr,T,fi}) - N^2 y_0^2 (N - N_{cr,2}) - N^2 z_0^2 (N - N_{cr,1}) =$$

$$= 140^2 (N - 6861.83)(N - 2348.20)(N - 6672.27) - N^2 0^2 (N - 2348.20) - N^2 0^2 (N - 6861.83) =$$

$$= 0$$

Smallest root of the above equation related to the torsional-flexural buckling:

$$N_{cr,TF} = 6672.27 \text{ kN}$$

$$N_{cr} = \min(N_{cr,T,fi}, N_{cr,TF}) = \min(6672.27, 6672.27) = 6672.27 \text{ kN}$$

$$\bar{\lambda}_T = \sqrt{\frac{A \cdot f_y}{N_{cr}}} = \sqrt{\frac{13136 \cdot 355}{6672.27}} = 0.84 \qquad (6.53)$$

$$\alpha_T = 0.65 \cdot \sqrt{\frac{235}{f_y}} = 0.65 \cdot \sqrt{\frac{235}{355}} = 0.53$$

$$\bar{\lambda}_{T,\theta} = \bar{\lambda}_T \cdot \sqrt{k_{y,\theta} / k_{E,\theta}} = 0.84 \cdot \sqrt{1.0000 / 0.7837} = 0.94$$

$$\varphi_T = 0.5\left(1 + \alpha_T \cdot \bar{\lambda}_{T,\theta} + \bar{\lambda}_{T,\theta}^2\right) =$$

$$= 0.5\left(1 + 0.53 \cdot 0.94 + 0.94^2\right) = 1.20$$

$$\chi_T = \min\left(\frac{1}{\varphi_T + \sqrt{\varphi_T^2 - \bar{\lambda}_{T,\theta}^2}}, 1.0\right) =$$

$$= \min\left(\frac{1}{1.20 + \sqrt{1.20^2 - 0.94^2}}, 1.0\right) = 0.52 \qquad (4.6)$$

$$N_{b,fi,t,Rd,T} = \frac{\chi_T \cdot A \cdot k_{y,\theta} \cdot f_y}{\gamma_{M,fi}} = \frac{0.52 \cdot 13136 \cdot 1.0000 \cdot 355}{1.00} = 2417.62 \text{ kN} \qquad (4.5)$$

$$\frac{N_{Ed}}{N_{b,fi,t,Rd,T}} = \frac{0.00}{2417.62} = 0.00 \le 1.00 \text{ - OK}$$

Lateral torsional buckling, top flange - Part 1-1: 6.3.2.2, Part 1-2: 4.2.3

Not relevant

Lateral torsional buckling, bottom flange - Part 1-1: 6.3.2.2, Part 1-2: 4.2.3
LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

Class $_N$ = 1, Class $_{M1}$ = 1, Class $_{M2}$ = 1

$$N_{cr,LT} = \frac{\pi^2 \cdot E \cdot I_z}{(k_z \cdot L_{cr})^2} = \frac{\pi^2 \cdot 2.100e{+}05 \cdot 6.595e{+}07}{(1.00 \cdot 6754)^2} = 2996.37 \quad kN$$

Loaded on top edge.

$$Z = (C_2 \cdot z_g - C_3 \cdot z_j) = (0.45 \cdot 140 - 0.52 \cdot 0) = 63.00 \quad mm$$

$$M_{cr} = C_1 \cdot N_{cr,LT} \cdot \left\{ \left[\left(\frac{k_z}{k_w}\right)^2 \cdot \frac{I_w}{I_z} + \frac{G \cdot I_t}{N_{cr,LT}} + Z^2 \right]^{0.5} - Z \right\} =$$

$$= 1.13 \cdot 2.996e{+}06 \cdot \left\{ \left[\left(\frac{1.00}{1.00}\right)^2 \cdot \frac{1.107e{+}12}{6.595e{+}07} + \frac{8.077e{+}04 \cdot 1.453e{+}06}{2.996e{+}06} + 63.00^2 \right]^{0.5} - 63.00 \right\} =$$

$$= 615.47 \quad kN\,m$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y \cdot f_y}{M_{cr}}} = \sqrt{\frac{1534434 \cdot 355}{6.155e{+}08}} = 0.94$$

$$\alpha = 0.65 \cdot \sqrt{\frac{235}{f_y}} = 0.65 \cdot \sqrt{\frac{235}{355}} = 0.53 \qquad (4.14)$$

$$\bar{\lambda}_{LT,\theta} = \bar{\lambda}_{LT} \cdot \sqrt{k_{y,\theta} / k_{E,\theta}} = 0.94 \cdot \sqrt{1.0000 / 0.7837} = 1.06 \qquad (4.15)$$

$$\bar{\varphi}_{LT,\theta} = 0.5 \left(1 + \alpha + \bar{\lambda}_{LT,\theta} \cdot \bar{\lambda}_{LT,\theta}^{\;2}\right) =$$

$$= 0.5 \left(1 + 0.53 + 1.06 \cdot 1.06^2\right) = 1.35 \qquad (4.13)$$

$$\chi_{LT,fi} = \min\left(\frac{1}{\bar{\varphi}_{LT,\theta} + \sqrt{\bar{\varphi}_{LT,\theta}^{\;2} - \bar{\lambda}_{LT,\theta}^{\;2}}}, 1.0\right) =$$

$$= \min\left(\frac{1}{1.35 + \sqrt{1.35^2 - 1.06^2}}, 1.0\right) = 0.46 \qquad (4.12)$$

$$M_{b,fi,t,Rd} = \frac{\chi_{LT,fi} \cdot W_y \cdot k_{y,\theta} \cdot f_y}{\gamma_{M,fi}} = \frac{0.46 \cdot 1534434 \cdot 1.0000 \cdot 355}{1.00} = 250.88 \quad kN\,m \qquad (4.11)$$

$$\frac{M_{1,Ed}}{M_{b,fi,t,Rd}} = \frac{0.00}{250.88} = 0.00 \leq 1.00 \qquad (6.54) \quad \text{- OK}$$

Interaction between normal force and bending 1. - Part 1-1: 6.3.3, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

$Class_N = 1, \quad Class_{M1} = 1, \quad Class_{M2} = 1$

$$k_y = \min\left(1 - \frac{\min([(2 \cdot \beta_{M,y} - 5) \cdot \lambda_{y\theta} + 0.44 \cdot \beta_{M,y} + 0.29], 0.8) \cdot N^{comp}_{fi,Ed}}{\chi_{y,fi} \cdot A \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}}, 3\right) =$$

$$= \min\left(1 - \frac{\min([(2 \cdot 1.30 - 5) \cdot 0.82 + 0.44 \cdot 1.30 + 0.29], 0.8) \cdot 0}{0.58 \cdot 13136 \cdot 1.0000 \cdot \frac{355}{1.00}}, 3\right) = 1.00$$

$$k_z = \min\left(1 - \frac{\min([(1.2 \cdot \beta_{M,z} - 3) \cdot \lambda_{z\theta} + 0.71 \cdot \beta_{M,z} - 0.29], 0.8) \cdot N^{comp}_{fi,Ed}}{\chi_{z,fi} \cdot A \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}}, 3\right) =$$

$$= \min\left(1 - \frac{\min([(1.2 \cdot 1.10 - 3) \cdot 1.41 + 0.71 \cdot 1.10 - 0.29], 0.8) \cdot 0}{0.32 \cdot 13136 \cdot 1.0000 \cdot \frac{355}{1.00}}, 3\right) = 1.00$$

$$\frac{N^{comp}_{fi,Ed}}{\chi_{min,fi} \cdot A \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} + \frac{k_y \cdot M_{1,fi,Ed}}{W_{pl,1} \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} + \frac{k_z \cdot M_{2,fi,Ed}}{W_{pl,2} \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} =$$

$$= \frac{0}{0.32 \cdot 13136 \cdot 1.0000 \cdot \frac{355}{1.00}} + \frac{1.00 \cdot 171088399}{1534434 \cdot 1.0000 \cdot \frac{355}{1.00}} + \frac{1.00 \cdot 0}{717676 \cdot 1.0000 \cdot \frac{355}{1.00}} =$$

$= 0.31 \leq 1.00 \quad (4.21) \quad$ - OK

Interaction between normal force and bending 2. - Part 1-1: 6.3.3, Part 1-2: 4.2.3

LC: 'selfweight + Supperimposed dead + Earth pressure + Fire + 0.50*Live load + 0.30*snow load + 0.20*Wind load Y-', x =

$\text{Class}_{N} = 1, \quad \text{Class}_{M1} = 1, \quad \text{Class}_{M2} = 1$

$$k_{LT} = \min\left(1 - \frac{\min(0.15 \cdot \lambda_{z\theta} \cdot \beta_{M,LT} - 0.15\ ,\ 0.9) \cdot N_{fi,Ed}^{comp}}{\chi_{z,fi} \cdot A \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}}, 1\right) =$$

$$= \min\left(1 - \frac{\min(0.15 \cdot 1.41 \cdot 1.30 - 0.15\ ,\ 0.9) \cdot 0}{0.32 \cdot 13136 \cdot 1.0000 \cdot \frac{355}{1.00}}, 1\right) = 1.00$$

$$k_z = \min\left(1 - \frac{\min([(1.2 \cdot \beta_{M,z} - 3) \cdot \lambda_{z\theta} + 0.71 \cdot \beta_{M,z} - 0.29], 0.8) \cdot N_{fi,Ed}^{comp}}{\chi_{z,fi} \cdot A \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}}, 3\right) =$$

$$= \min\left(1 - \frac{\min([(1.2 \cdot 1.10 - 3) \cdot 1.41 + 0.71 \cdot 1.10 - 0.29], 0.8) \cdot 0}{0.32 \cdot 13136 \cdot 1.0000 \cdot \frac{355}{1.00}}, 3\right) = 1.00$$

$$\frac{N_{fi,Ed}^{comp}}{\chi_{min,fi} \cdot A \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} + \frac{k_{LT} \cdot M_{1,fi,Ed}}{\chi_{LT,fi} \cdot W_{pl,1} \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} + \frac{k_z \cdot M_{2,fi,Ed}}{W_{pl,2} \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} =$$

$$= \frac{0}{0.32 \cdot 13136 \cdot 1.0000 \cdot \frac{355}{1.00}} + \frac{1.00 \cdot 171088399}{0.00 \cdot 1534434 \cdot 1.0000 \cdot \frac{355}{1.00}} + \frac{1.00 \cdot 0}{717676 \cdot 1.0000 \cdot \frac{355}{1.00}} =$$

$= 0.31 \leq 1.00 \quad (4.21) \quad$ - OK

Interaction between normal force and bending, 2nd order - Part 1-1: 6.3.3, Part 1-2: 4.2.3

Not relevant

Shear buckling - Part 1-5: 5, Part 1-2: 4.2.3

$\frac{h_w}{t} = \frac{244}{10} = 23.2 \leq \frac{72}{\eta} \cdot \varepsilon = \frac{72}{1.20} \cdot 0.69 = 41.5 \rightarrow$ Not relevant

Fire design document

HE200 A column_Basemet floor

HE280 B_Basement floor

HUP-140x140x8 exposed on all sides

IPE300 Beam exposed on 3 sides

Specification for conlit-150

Fire design Requirement for 2-floor Apartment building:

Fire Requirement according to TEK17 (Regulations on Technical Requirements for construction works) is given in the following tables.

The Hazard classes are shown below.

Table: Hazard classes

Hazard classes	Construction works designed for only the sporadic presence of people	People in the construction work are familiar with the opportunities for escape, including escape routes, and can get to safety unassisted	Construction works designed for overnight stays	Intended use of the construction work does not represent a serious fire hazard
1	yes	yes	no	yes
2	yes/no	yes	no	no
3	no	yes	no	yes
4	no	yes	yes	yes
5	no	no	no	yes
6	no	no	yes	yes

From the Norwegian Technical Requirement TEK17 the following tables are used to evaluate buildings. As it can be seen Bo Apartment building (Bolig) is classified under Hazard class 4 which corresponds to Fire class 1 (BKL1) for upto 2 floor buildings.

23 Brannmotstand

231 *Risikoklasser og brannklasser.* Tabell 231 gir en oversikt over risikoklasser og brannklasser i henhold til veiledningen til TEK. Alle de nevnte bygningskategoriene kan oppføres i brannklasse 1 med én etasje, se også [826].

Tabell 231
Risikoklasser og brannklasser for bygg inntil fire etasjer i henhold til veiledningen til TEK

Bygningskategori	Risiko-klasse	Bygningers brannklasse	
		2 etasjer	3 og 4 etasjer
Kontor	2	BKL 1	BKL 2
Undervisning Barnehager	3	BKL 1	BKL 2
Bolig	4	BKL 1	BKL 2[1)]
Forsamlingslokale	5	BKL 2[2)]	uaktuelt
Overnattingssteder	6	BKL 2[3)]	BKL 2
Pleieinstitusjoner Sykehus	6	BKL 2	BKL 2

[1)] Bygning i inntil tre etasjer kan utføres i BKL 1 når hver boenhet har direkte utgang til terreng.
[2)] Bygning som benyttes til forsamlingslokale eller salgslokale som har høyst to etasjer og bruttoareal mindre enn 800 m^2 per etasje, kan oppføres i BKL 1.
[3)] Overnattingssted med mindre bruttoareal enn 300 m^2 i hver etasje kan utføres i BKL 1.

For bolig for BKL1 blir brannmotstad R30 iht TEK 17

Table: Fire classes

Fire class	Impact
1	Slight
2	Moderate
3	Serious
4	Very serious

In the table below from TEK17. Fire class 1 (BKL1) has the requirements marked with red. For structural bearing members the duration time is 30 minutes (R30).

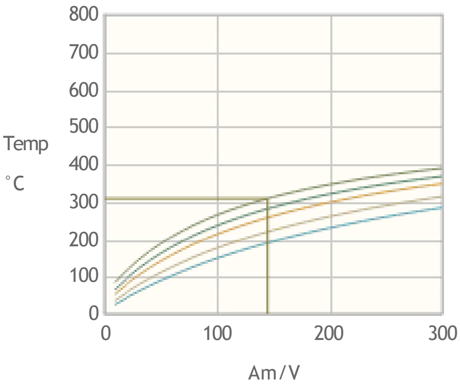
Preaksepterte ytelser

1. Brannmotstanden til bærende bygningsdeler i byggverk må være i samsvar med tabell 1 med unntak som gitt under hvert enkelt ledd.
2. Balkonger, utkragede bygningsdeler og lignende må ha forsvarlig innfesting for å hindre nedfall som kan skade rednings- og slokkemannskapene og deres materiell under førsteinnsatsen. Tyngre bygningsdeler, som for eksempel balkonger, må forankres i byggverkets hovedbæresystem.

§ 11-4 Tabell 1: Bærende bygningsdelers brannmotstand avhengig av brannklasse.

	Brannklasse		
Bygningsdel	**1**	**2**	**3**
Bærende hovedsystem	R 30 [B 30]	R 60 [B 60]	R 90 A2-s1,d0 [A 90]
Sekundære, bærende bygningsdeler, etasjeskillere og takkonstruksjoner som ikke er del av hovedbæresystem eller stabiliserende	R 30 [B 30]	R 60 [B 60]	R 60 A2-s1,d0 [A 60]

Prosjektnavn	Heistad, Porsgrunn
Utarbeidet av	Samsom, Rawand and Mohammad



Conlit 150/150P

Tykkelse: **20 mm**

Ståltemperatur: **309 °**

50mm 40mm 30mm 25mm 20mm

Conlit 300

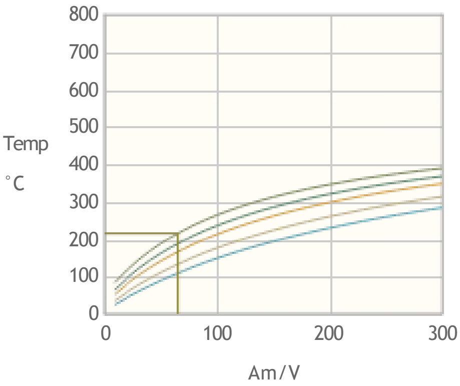
Tykkelse: **10 mm**

Ståltemperatur: **360 °**

30mm 25mm 20mm 15mm 10mm

Festemetode	Sveisemetode (Conlit 150 og 300)
Brannklasse	R30
Maks. ståltemperatur	500
Am/V	145
Profil	HE-A
Dimensjon	200 : 190 x 200
Antall sider	4 sider

Prosjektnavn	Heistad, Porsgrunn
Utarbeidet av	Samsom, Rawand and Mohammad



Conlit 150/150P

Tykkelse: **20 mm**

Ståltemperatur: **216 °**

50mm 40mm 30mm 25mm 20mm

Conlit 300

Tykkelse: **10 mm**

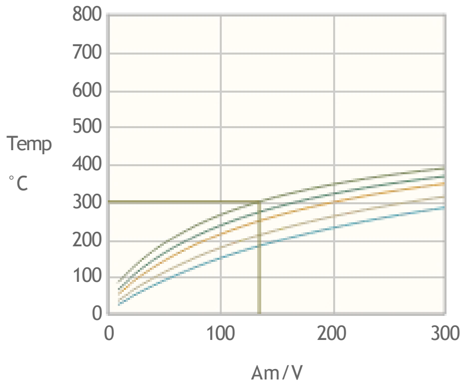
Ståltemperatur: **258 °**

30mm 25mm 20mm 15mm 10mm

Festemetode	Sveisemetode (Conlit 150 og 300)
Brannklasse	R30
Maks. ståltemperatur	500
Am/V	65
Profil	HE-B
Dimensjon	280 : 280 x 280
Antall sider	3 sider

ROCKWOOL
BRANNSIKKER ISOLASJON

Prosjektnavn	Heistad, Porsgrunn
Utarbeidet av	Samsom, Rawand and Mohammad



Conlit 150/150P

Tykkelse: **20 mm**

Ståltemperatur: **301 °**

50mm 40mm 30mm 25mm 20mm

Conlit 300

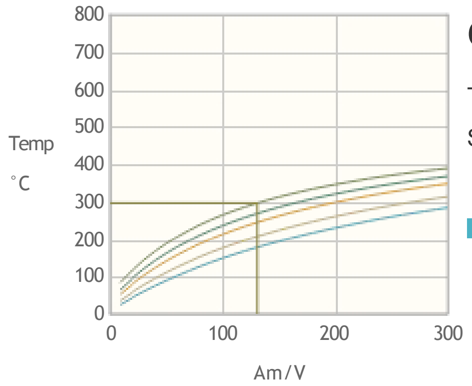
Tykkelse: **10 mm**

Ståltemperatur: **351 °**

30mm 25mm 20mm 15mm 10mm

Festemetode	Sveisemetode (Conlit 150 og 300)
Brannklasse	R30
Maks. ståltemperatur	500
Am/V	135
Profil	HUP Kvadrat
Dimensjon	140 : 140 x 140 x 8
Antall sider	4-sidig

Prosjektnavn	Heistad, Porsgrunn
Utarbeidet av	Samsom, Rawand and Mohammad



Conlit 150/150P

Tykkelse: **20 mm**

Ståltemperatur: **297 °**

50mm 40mm 30mm 25mm 20mm

Conlit 300

Tykkelse: **10 mm**

Ståltemperatur: **347 °**

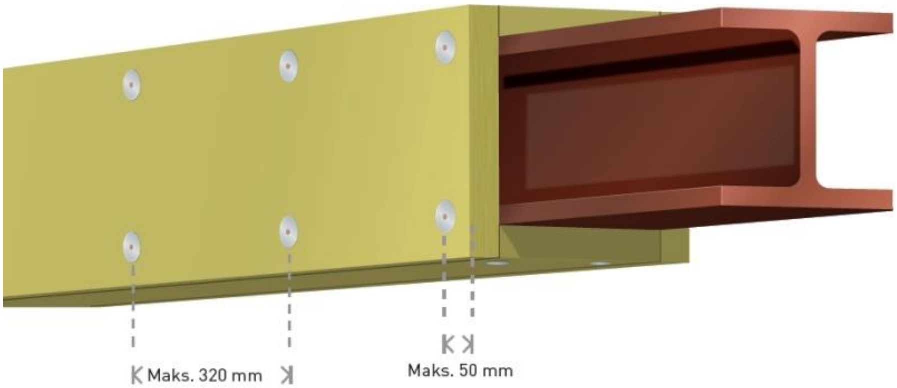
30mm 25mm 20mm 15mm 10mm

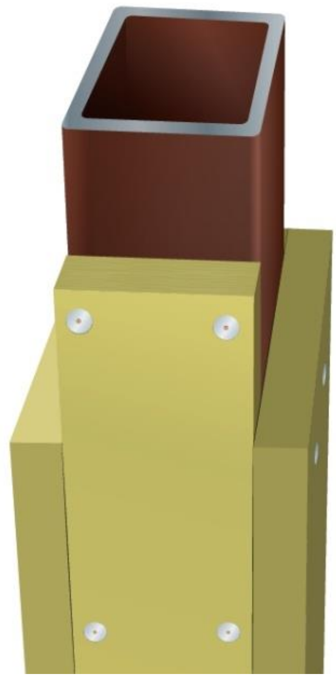
Festemetode	Sveisemetode (Conlit 150 og 300)
Brannklasse	R30
Maks. ståltemperatur	500
Am/V	131
Profil	IPE
Dimensjon	330 : 330 x 160
Antall sider	3 sider

R 30 – R 180 8.52

Brannsikring av bærende stål med Conlit 150

Monteringsanvisning/ Branndokumentasjon





1. Tykkelsen for Conlit-platene dimensjoneres etter tabeller i Sintef produktdokumentasjon 010-0253 eller dimensjoneringsprogram på www.rockwool.no.

2. Stålet skal være rengjort og tørt.

3. Conlit-platen tilskjæres nøyaktig etter stålprofilet som skal isoleres.

4. Platen festes til stålsøylen med sveisestift eller limes med Conlit Kleber.

SVEISESTIFT

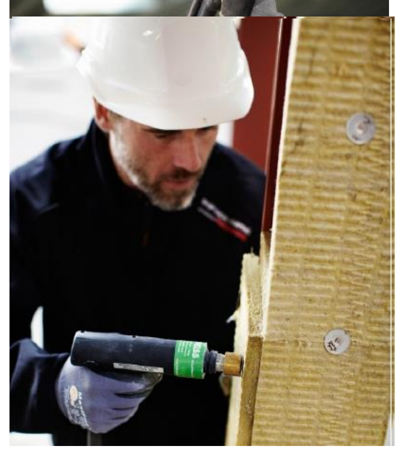
5. Ved bruk av sveisestift skal disse ha en minimumdiameter på 2,7 mm og diameter på skive min. 28 mm. Lengden skal være 2-3 mm større enn isolasjonstykkelsen.

6. Innbyrdes avstand mellom stift skal være maks. 320 mm og maks. avstand til plateskjøt 50 mm.

7. På H-profiler med høyde ≥ 1000 mm settes først en plateremse med bredde min. 200 mm inn i steget bak hver plateskjøte.

8. Sveisestiftene stikkes gjennom isolasjonen og festes til stålprofilen med boltsveis.

9. Platene skal tette godt mot hverandre i alle skjøter.



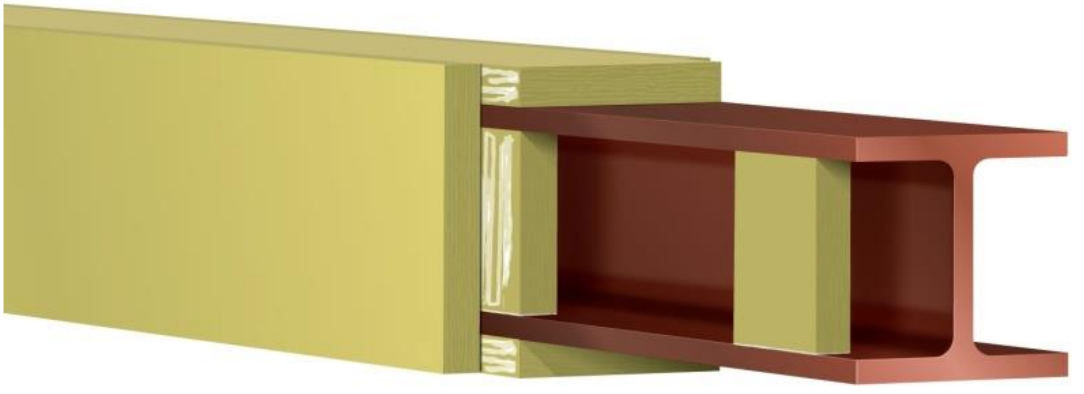
RISEFR 010-0253

ROCKWOOL
BRANNSIKKER ISOLASJON

www.rockwool.no
Rev. nr. 2 – sept. 2015

Arbeid utført:
Dato: ____________________
Sign. ____________________

Firmastempel:



CONLIT KLEBER

10. Ved bruk av lim skal det lages stegplater tilskåret av minimum 20 mm Conlit, limt mellom flensene bak alle plateskjøter.

11. Til liming benyttes Conlit Kleber, forbruk ca. 1 kg/m². Herdetid for kleberen er 1-3 døgn, avhengig av temperatur og luftfuktighet. Ved ekstremt høy luftfuktighet kan herdetiden bli enda lengre. Normal kleber kan benyttes ved montering ned til +5°C, mens type ”Frost” kan benyttes ned til -7°C.

12. Stegplater og alle kontaktflater i.plate- og hjørneskjøter påføres Conlit kleber.

13. Platene settes på plass og festes til stegplater og plate til plate med for eksempel spiker eller kramper. Dette er nødvendig for fastholdelse inntil Conlit Kleberen er herdet. Det er viktig med god heft i alle limskjøter.

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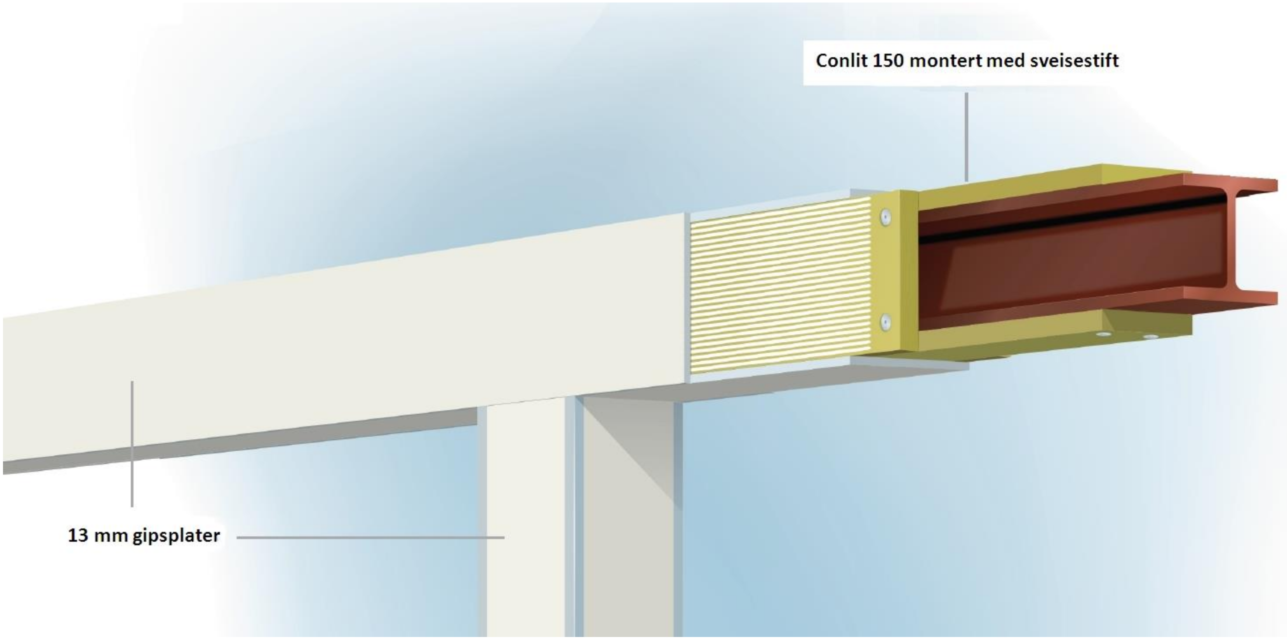


CONLIT GIPS-SYSTEM

14. Tykkelsen for Conlit-platene dimensjoneres etter tabeller i Sintef produktdokumentasjon 010-0253 eller dimensjoneringsprogram på www.rockwool.no.

15. Conlit-platene festes med sveisestift som beskrevet på side 1. (ill. 1)

16. Gipsplatene skjæres til i bredde tilpasset stålprofil med Conlit.

17. Rør ut Conlit Betongkleber med 0,4-0,5 liter rent vann pr. kg pulver til en jevn masse uten klumper. Vent 5 minutter og rør deretter kort om på nytt.

18. Påfør opprørt Conlit Betongkleber med tannsparkel (8x8 mm spor) på gipsplatene. (ill . 2)

    Forbruk av Conlit Betongkleber:
    - ca. 2 kg tørt pulver = 2,8-3,0 kg opprørt kleber pr. m².

19. Sett gipsplaten på plass og trykk over hele flaten så det blir god kontakt mellom gipsplate/kleber og Conlit-platen. (ill. 3)

20. Avslutningsvis kan hjørnebeslag limes eller skrus på i henhold til produsentens anvisning (ill. 4).

PRODUKTDOKUMENTASJON

RISEFR 010-0253

Med henvisning til Plan- og bygningsloven av 27. juni 2008, med Byggeteknisk forskrift av 1. juli 2017 og tilhørende veiledning, bekrefter RISE Fire Research AS, med grunnlag i prøvingsrapporter og vurderinger, at angitt produkt og anvendelse med tilhørende monteringsanvisning imøtekommer norske myndigheters krav til brannteknisk sikkerhet.

Byggevarer: **Conlit 150P/150**

Produktansvarlig: **Rockwool a/s**
Postboks 4215, Nydalen, 0401 Oslo, NORGE

Produktdokumentasjonens gyldighet er betinget av at produktet er i overensstemmelse med spesifikasjonene i vedlegg, at de blir montert og behandlet på en forskriftsmessig måte og at alle viktige detaljer i denne prosessen nøyaktig følger det som er beskrevet i tilhørende monterings- og bruksanvisning som er kontrollert av RISE Fire Research AS. Både anvisning og produktdokumentasjon skal følge produkt eller være lett tilgjengelig for kjøper, bruker, kontrollør og lokal saksbehandler/myndighet.

Produktet skal merkes med **RISEFR 010-0253**, i tillegg til produktnavn og modellbetegnelse, produktansvarlig og/eller produsent og produksjonsinformasjon for sporbarhet. Merkingen skal være lett synlig.

Konstruksjonsdetaljer for produktet er beskrevet i «Standard konstruksjonsdetaljer for **Conlit 150P/150**, tilhørende Produktdokumentasjon **RISEFR 010-0253**.» Den versjonen av detaljsamlingen som til enhver tid er arkivert hos RISE Fire Research AS, utgjør en formell del av godkjenningen.

Produktet skal ha en årlig, ekstern oppfølging av kvaliteten gjennom en tilvirkningskontroll, som er tilpasset produktet. Kontrollen skal overvåke produktenes samsvar med dokumentunderlaget og være spesifisert i skriftlig avtale med RISE Fire Research AS.

Førstegangs utstedelse **2013-05-01.** Fornyelse utstedes på grunnlag av skriftlig søknad. Oppsigelse ved innehaver skal være skriftlig med 6 mnd. varsling. RISE Fire Research AS kan tilbakekalle en produktdokumentasjon ved misligheter eller misbruk, når skriftlig pålegg om endring ikke blir tatt til følge.

Utstedt: 2018-06-07
Gyldig til: 2023-07-01

Asbjørn Østnor
Fagansvarlig dokumentasjon

Jan P. Stensaas
Prosjektleder dokumentasjon

RISE Fire Research AS

Postadresse	*Besøksadresse*	*Telefon*	*E-post / web*	*Foretaksnummer*
Postboks 4767 Sluppen 7465 Trondheim	Tillerbruveien 202 7092 Tiller	464 18 000	post@spfr.no www.spfr.no	NO 982 930 057 MVA

Kompetenzzentrum
holz.bau forschungs gmbh
Inffeldgasse 24, A-8010 Graz
cltdesigner@tugraz.at

CLTdesigner
Version 6.11.1

Summary of results

Project number:	BYG508
Project:	Appartment building G+2
Structural element:	Floor and Roof
Cross section:	User-defined cross section: 7s - 280 mm
Description:	Project for master thesis in UIA
Date:	Apr 23, 2019
Time:	10:32:03 AM
Author:	

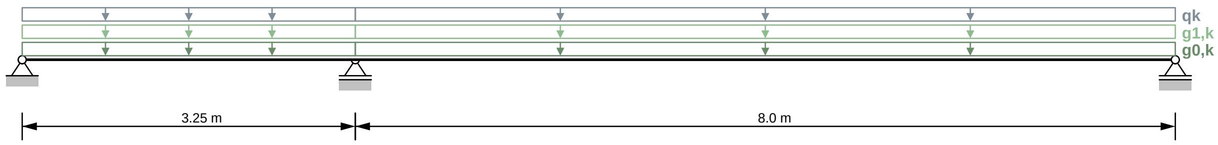
Table of content

1 General

Service class 2

2 Structural system

Continuous beam with 2 spans

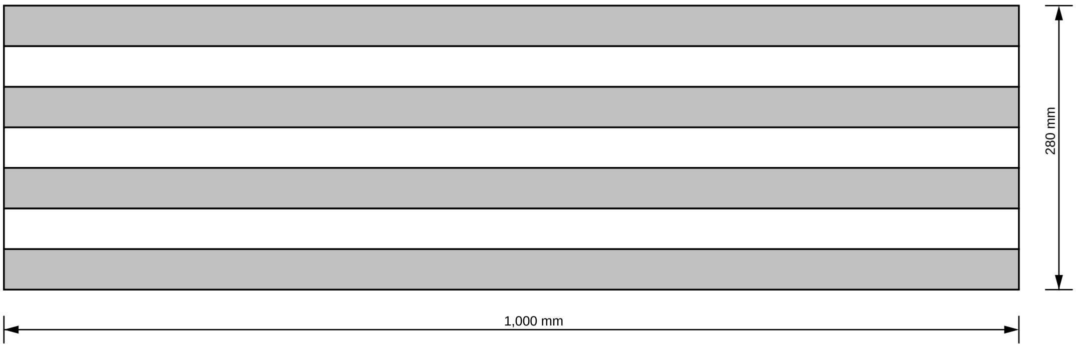


2.1 Supports

Support	x	Width
A	0.0 m	0.1 m
B	3.25 m	0.1 m
C	11.25 m	0.06 m

3 Cross section

User-defined cross section
7 layers (width: 1,000 mm / thickness: 280 mm)



3.1 Layer composition

Layer	Thickness	Orientation	Material
# 1	40 mm	0	C24
# 2	40 mm	90	C24
# 3	40 mm	0	C24
# 4	40 mm	90	C24
# 5	40 mm	0	C24
# 6	40 mm	90	C24
# 7	40 mm	0	C24

Orientation 0 = top layer longitudinal to span; Orientation 90 = top layer perpendicular to span

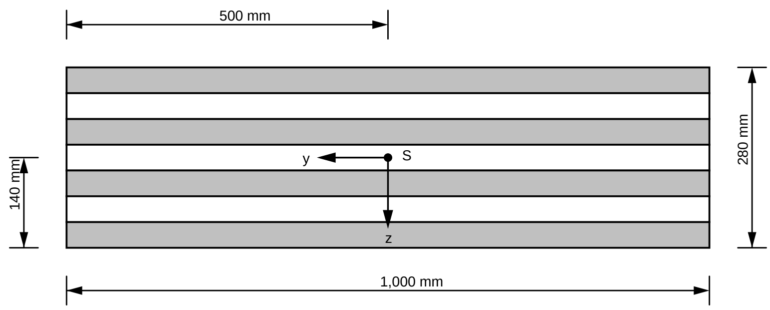
3.2 Material parameters

Partial safety factor γ_M = 1.25

Material parameters for	C24
bending strength [N/mm²]	24.0
tensile strength parallel [N/mm²]	14.0
tensile strength perpendicular [N/mm²]	0.4
compressive strength parallel [N/mm²]	21.0
compressive strength perpendicular [N/mm²]	2.5
shear strength [N/mm²]	2.68
rolling shear strength [N/mm²]	1.0
Youngs modulus parallel [N/mm²]	11,000.0
5%-quantile from Youngs modulus parallel [N/mm²]	7,400.0
Youngs modulus perpendicular [N/mm²]	370.0 (0.0)
shear modulus [N/mm²]	690.0
rolling shear modulus [N/mm²]	69.0
density [kg/m³]	350.0
density mean value [kg/m³]	420.0

3.3 Cross-sectional values

EA_{ef}	1.76E9 N
$EI_{yy,A}$	2.347E11 N·mm²
$EI_{yy,B}$	1.408E13 N·mm²
$GA_{z,A}$	inf N
$GA_{z,B}$	3.011E7 N



4 Loads

Field	$g_{0,k}$	$g_{1,k}$	q_k	Category	s_k	Altitude/Region	w_k
1	1.54 kN/m	2.2 kN/m²	2 kN/m²	A			
2	1.54 kN/m	2.2 kN/m²	2 kN/m²	A			

Partial safety factors:

γ_G = 1.35
γ_Q = 1.5

Load position:

Plate weight: Total
Permanent loads: Total
Imposed loads: Field-by-field
Snow: Field-by-field
Wind: Total

Combinations:

Combination factors: according to NA

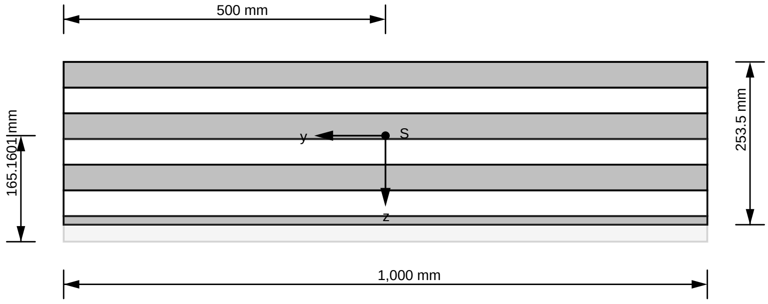
Combinations of distributed and concentrated loads:
q_k and Q_k will be considered as one load group
s_k and S_k will be considered as one load group
w_k and W_k will be considered as one load group

5 Specification concerning structural fire design

Fire duration: 30 minutes
Side exposed to fire: below
falling off of charred layers is considered
Without gaps or with bonded edges
k_{fire} = 1.15
d_0 = 7 mm
Partial safety factor $\gamma_{M,fi}$ = 1.0
Charring rate β_0 = 0.65 mm/min

5.1 Cross-sectional values in case of fire

EA_{ef}	1.468E9 N
$EI_{yy,A}$	1.783E11 N·mm²
$EI_{yy,B}$	8.507E12 N·mm²
$GA_{z,A}$	inf N
$GA_{z,B}$	2.715E7 N



6 Information concerning vibrations

No specifications are available

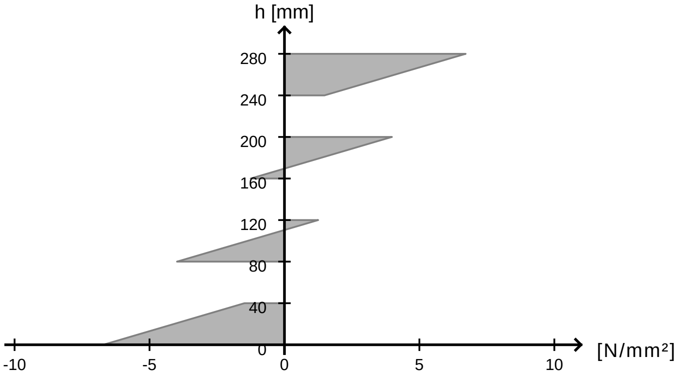
7 Results

Referenced standards: EN 1995-1-1:2009, ON B 1995-1-1/NA:2014-11-15
Underlying calculation method: Shear Analogy Method
Maximum linking distance: 0.28 m

7.1 ULS

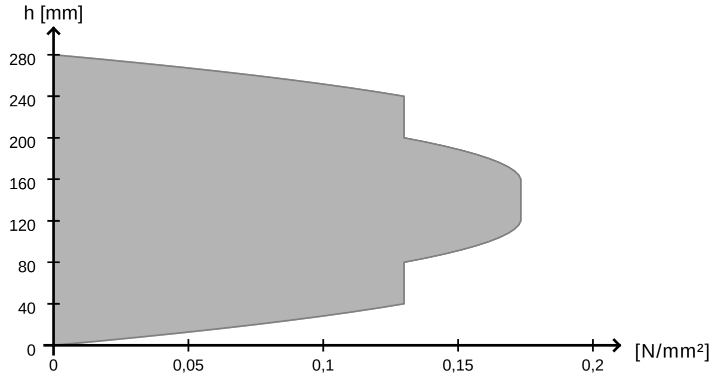
7.1.1 Bending

Utilisation ratio	39.7 %
k_{mod}	0.8
at x	3.25 m
Ek	2
Fundamental combination	$1.35*g_{0,k}$ + $1.35*g_{1,k}$ + $1.50*1.00*q_k$



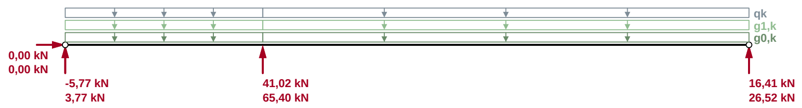
7.1.2 Shear

Utilisation ratio	27.1 %
k_{mod}	0.8
at x	3.536 m
Ek	2
Fundamental combination	$1.35*g_{0,k}$ + $1.35*g_{1,k}$ + $1.50*1.00*q_k$



7.1.3 Bearing pressure

Utilisation ratio	23.9 %
k_{mod}	0.8
at x	3.25 m
Ek	2
Fundamental combination	$1.35 \cdot g_{0,k} + 1.35 \cdot g_{1,k} + 1.50 \cdot 1.00 \cdot q_k$



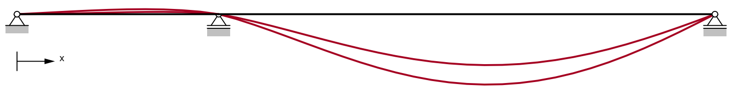
7.2 SLS

7.2.1 Deflection

Limit values according to EN 1995-1-1
Instantaneous deformation w_{inst} t = 0: l/300 (13.9 mm, 52.1 %)
Final deformation $w_{net,fin}$ t = inf: l/250 (24.3 mm, 76.0 %)
Final deformation w_{fin} t = inf: l/150 (24.3 mm, 45.6 %)

Limit values according to ON B 1995-1-1/NA:2014-11-15
Instantaneous deformation w_{inst} t = 0: l/300 (13.9 mm, 52.1 %)
Final deformation $w_{net,fin}$ t = inf: l/250 (20.8 mm, 65.1 %)
Final deformation w_{fin} t = inf: l/150 (24.3 mm, 45.6 %)

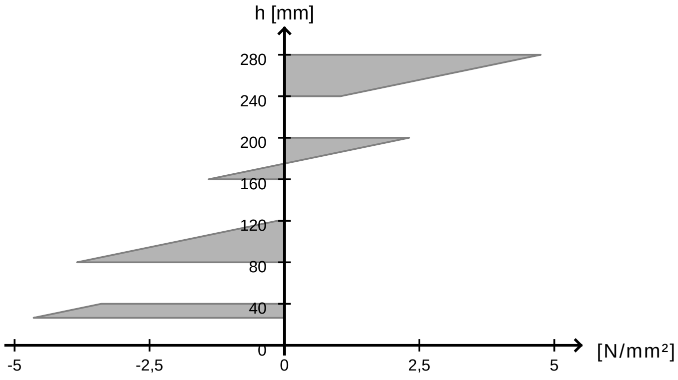
Utilisation ratio	76.0 %
w_{max}	24.3 mm
k_{def}	1.0
at x	7.536 m
Ek	10
Final deformation $w_{net,fin}$ t = inf (l/250)	



7.3 ULS in case of fire

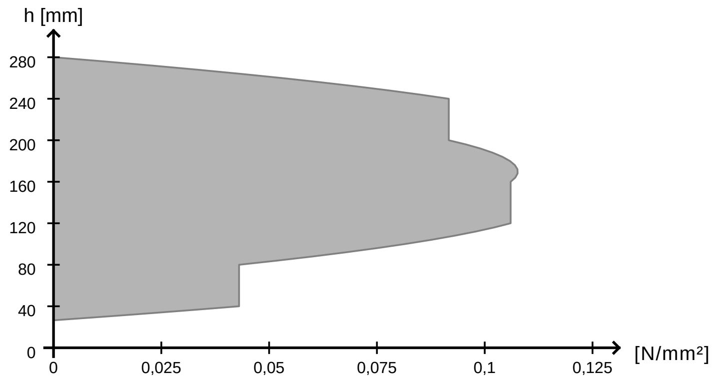
7.3.1 Bending

Utilisation ratio	15.6 %
k_{mod}	1.0
at x	3.25 m
Ek	6
Accidental combination	$g_{0,k} + g_{1,k} + 0.30*q_k$



7.3.2 Shear

Utilisation ratio	9.2 %
k_{mod}	1.0
at x	3.536 m
Ek	6
Accidental combination	$g_{0,k} + g_{1,k} + 0.30*q_k$



8 Appendix

8.1 Combinations

Ek	k_{mod} / k_{def}	Kombination
Fundamental combination		
1	0.6	$1.35*g_{0,k} + 1.35*g_{1,k}$
2	0.8	$1.35*g_{0,k} + 1.35*g_{1,k} + 1.50*1.00*q_k$
3	0.6	$g_{0,k} + g_{1,k}$
4	0.8	$g_{0,k} + g_{1,k} + 1.50*1.00*q_k$
Accidental combination		
5	0.6	$g_{0,k} + g_{1,k}$
6	0.8	$g_{0,k} + g_{1,k} + 0.30*q_k$

Ek	k_{mod} / k_{def}	Kombination
SLS combinations according to EN 1995-1-1		
8	1.0	$g_{0,k} + g_{1,k} + 1.00*q_k$
9	1.0	$g_{0,k} + (g_{0,k})_{creep} + g_{1,k} + (g_{1,k})_{creep} + 1.00*q_k + (0.30*q_k)_{creep}$
10	1.0	$g_{0,k} + (g_{0,k})_{creep} + g_{1,k} + (g_{1,k})_{creep} + 1.00*q_k + (0.30*q_k)_{creep}$
SLS combinations according to EN 1995-1-1:NA		
12	1.0	$g_{0,k} + g_{1,k} + 1.00*q_k$
14	1.0	$g_{0,k} + (g_{0,k})_{creep} + g_{1,k} + (g_{1,k})_{creep} + 1.00*q_k + (0.30*q_k)_{creep}$
15	1.0	$g_{0,k} + (g_{0,k})_{creep} + g_{1,k} + (g_{1,k})_{creep} + 0.30*q_k + (0.30*q_k)_{creep}$

8.2 Internal forces

Field	x	$M_{Ay,d}$	$M_{By,d}$	$V_{Az,d}$	$V_{Bz,d}$
	[m]	[kN·m]	[kN·m]	[kN]	[kN]
Ek 1: $1.35*g_{0,k} + 1.35*g_{1,k}$					
1	0.0	-0.0	-0.0	0.728	-1.499
1	0.295	-0.005	-0.443	0.696	-2.958
1	0.591	-0.02	-1.317	0.672	-4.426
1	0.886	-0.042	-2.625	0.648	-5.894
1	1.182	-0.071	-4.366	0.623	-7.361
1	1.477	-0.107	-6.541	0.599	-8.828
1	1.773	-0.15	-9.149	0.574	-10.295
1	2.068	-0.201	-12.191	0.554	-11.767
1	2.364	-0.258	-15.667	0.483	-13.188
1	2.659	-0.336	-19.564	0.947	-15.143
1	2.955	-0.276	-24.038	-0.545	-15.143
2	3.25	-1.751	-27.419	5.952	17.89
2	3.536	-0.256	-22.307	0.661	21.739
2	3.821	-0.273	-16.096	-0.782	21.739
2	4.107	-0.168	-10.42	-0.354	19.868
2	4.393	-0.081	-5.137	-0.416	18.488
2	4.679	0.0	-0.261	-0.437	17.066
2	4.964	0.075	4.209	-0.461	15.647
2	5.25	0.142	8.275	-0.484	14.228
2	5.536	0.203	11.934	-0.508	12.809
2	5.821	0.258	15.189	-0.531	11.39
2	6.107	0.305	18.038	-0.555	9.972
2	6.393	0.346	20.481	-0.579	8.553
2	6.679	0.38	22.52	-0.602	7.134

Field	x	$M_{Ay,d}$	$M_{By,d}$	$V_{Az,d}$	$V_{Bz,d}$
	[m]	**[kN·m]**	**[kN·m]**	**[kN]**	**[kN]**
2	6.964	0.407	24.152	-0.626	5.715
2	7.25	0.427	25.38	-0.65	4.296
2	7.536	0.441	26.202	-0.673	2.877
2	7.821	0.448	26.618	-0.697	1.458
2	8.107	0.448	26.63	0.698	-1.38
2	8.393	0.442	26.235	0.675	-2.799
2	8.679	0.428	25.436	0.651	-4.218
2	8.964	0.408	24.231	0.627	-5.637
2	9.25	0.381	22.62	0.604	-7.056
2	9.536	0.348	20.604	0.58	-8.474
2	9.821	0.307	18.183	0.556	-9.893
2	10.107	0.26	15.356	0.533	-11.312
2	10.393	0.206	12.124	0.509	-12.731
2	10.679	0.146	8.487	0.487	-14.152
2	10.964	0.079	4.444	0.446	-15.553
2	11.25	-0.0	0.0	-0.997	-15.553
Ek 2: 1.35*$g_{0,k}$ + 1.35*$g_{1,k}$ + 1.50*1.00*q_k					
1	0.0	-0.0	-0.0	1.243	-6.413
1	0.295	-0.029	-1.895	1.191	-7.872
1	0.591	-0.068	-4.221	1.153	-9.34
1	0.886	-0.114	-6.98	1.114	-10.808
1	1.182	-0.168	-10.173	1.075	-12.275
1	1.477	-0.228	-13.8	1.036	-14.074
1	1.773	-0.296	-17.86	0.997	-16.412
1	2.068	-0.371	-22.354	0.963	-18.758
1	2.364	-0.451	-27.283	0.872	-21.024
1	2.659	-0.559	-32.625	1.509	-24.141
1	2.955	-0.463	-38.612	-0.993	-24.141
2	3.25	-2.791	-43.711	9.488	29.016
2	3.536	-0.408	-35.562	1.105	34.656
2	3.821	-0.436	-25.66	-1.247	34.656
2	4.107	-0.269	-16.611	-0.571	31.674
2	4.393	-0.13	-8.19	-0.665	29.473
2	4.679	0.015	-1.146	-0.698	27.206
2	4.964	0.133	7.557	-0.736	24.945
2	5.25	0.24	13.999	-0.774	22.682
2	5.536	0.337	19.795	-0.812	20.42

Field	x	$M_{Ay,d}$	$M_{By,d}$	$V_{Az,d}$	$V_{Bz,d}$
	[m]	[kN·m]	[kN·m]	[kN]	[kN]
2	5.821	0.423	24.945	-0.849	18.158
2	6.107	0.498	29.448	-0.887	15.896
2	6.393	0.562	33.305	-0.925	13.634
2	6.679	0.616	36.516	-0.963	11.372
2	6.964	0.658	39.08	-1.0	9.11
2	7.25	0.69	40.999	-1.038	6.848
2	7.536	0.711	42.271	-1.076	4.586
2	7.821	0.722	42.896	-1.113	2.324
2	8.107	0.722	42.875	1.113	-2.334
2	8.393	0.71	42.209	1.075	-4.596
2	8.679	0.689	40.895	1.038	-6.858
2	8.964	0.656	38.936	1.0	-9.12
2	9.25	0.612	36.33	0.962	-11.382
2	9.536	0.558	33.078	0.925	-13.644
2	9.821	0.493	29.179	0.887	-15.906
2	10.107	0.418	24.635	0.849	-18.168
2	10.393	0.331	19.444	0.811	-20.43
2	10.679	0.234	13.607	0.776	-22.695
2	10.964	0.126	7.122	0.71	-24.928
2	11.25	-0.0	0.0	-1.592	-24.928
Ek 3: $g_{0,k} + g_{1,k}$					
1	0.0	-0.0	-0.0	0.539	-1.11
1	0.295	-0.004	-0.328	0.515	-2.191
1	0.591	-0.015	-0.975	0.498	-3.279
1	0.886	-0.031	-1.944	0.48	-4.366
1	1.182	-0.052	-3.234	0.462	-5.452
1	1.477	-0.079	-4.845	0.444	-6.539
1	1.773	-0.111	-6.777	0.425	-7.626
1	2.068	-0.149	-9.03	0.41	-8.716
1	2.364	-0.191	-11.605	0.358	-9.769
1	2.659	-0.249	-14.492	0.701	-11.217
1	2.955	-0.205	-17.806	-0.404	-11.217
2	3.25	-1.297	-20.31	4.409	13.252
2	3.536	-0.19	-16.524	0.489	16.103
2	3.821	-0.203	-11.923	-0.579	16.103
2	4.107	-0.125	-7.718	-0.262	14.717
2	4.393	-0.06	-3.805	-0.308	13.695

Field	x	$M_{Ay,d}$	$M_{By,d}$	$V_{Az,d}$	$V_{Bz,d}$
	[m]	[kN·m]	[kN·m]	[kN]	[kN]
2	4.679	0.0	-0.194	-0.323	12.641
2	4.964	0.055	3.118	-0.341	11.591
2	5.25	0.105	6.129	-0.359	10.54
2	5.536	0.151	8.84	-0.376	9.488
2	5.821	0.191	11.251	-0.394	8.437
2	6.107	0.226	13.361	-0.411	7.386
2	6.393	0.256	15.171	-0.429	6.335
2	6.679	0.281	16.681	-0.446	5.284
2	6.964	0.301	17.891	-0.464	4.233
2	7.25	0.317	18.8	-0.481	3.182
2	7.536	0.327	19.409	-0.499	2.131
2	7.821	0.332	19.717	-0.516	1.08
2	8.107	0.332	19.726	0.517	-1.022
2	8.393	0.327	19.434	0.5	-2.073
2	8.679	0.317	18.841	0.482	-3.124
2	8.964	0.302	17.949	0.465	-4.175
2	9.25	0.282	16.756	0.447	-5.226
2	9.536	0.258	15.263	0.43	-6.277
2	9.821	0.228	13.469	0.412	-7.328
2	10.107	0.193	11.375	0.395	-8.379
2	10.393	0.153	8.981	0.377	-9.43
2	10.679	0.108	6.287	0.361	-10.483
2	10.964	0.058	3.292	0.33	-11.521
2	11.25	-0.0	0.0	-0.739	-11.521
Ek 4: $g_{0,k} + g_{1,k} + 1.50*1.00*q_k$					
1	0.0	-0.0	-0.0	1.054	-6.024
1	0.295	-0.028	-1.78	1.011	-7.105
1	0.591	-0.063	-3.879	0.979	-8.193
1	0.886	-0.104	-6.3	0.946	-9.28
1	1.182	-0.149	-9.041	0.914	-10.366
1	1.477	-0.2	-12.104	0.881	-11.785
1	1.773	-0.257	-15.488	0.848	-13.743
1	2.068	-0.319	-19.193	0.819	-15.708
1	2.364	-0.384	-23.221	0.747	-17.605
1	2.659	-0.472	-27.553	1.264	-20.215
1	2.955	-0.391	-32.38	-0.852	-20.215
2	3.25	-2.337	-36.602	7.945	24.377

Field	x	$M_{Ay,d}$	$M_{By,d}$	$V_{Az,d}$	$V_{Bz,d}$
	[m]	[kN·m]	[kN·m]	[kN]	[kN]
2	3.536	-0.342	-29.779	0.934	29.02
2	3.821	-0.365	-21.487	-1.044	29.02
2	4.107	-0.225	-13.909	-0.479	26.523
2	4.393	-0.109	-6.858	-0.558	24.68
2	4.679	0.015	-1.078	-0.585	22.782
2	4.964	0.114	6.465	-0.617	20.888
2	5.25	0.203	11.854	-0.649	18.994
2	5.536	0.284	16.701	-0.68	17.1
2	5.821	0.356	21.007	-0.712	15.205
2	6.107	0.419	24.772	-0.743	13.311
2	6.393	0.472	27.995	-0.775	11.417
2	6.679	0.517	30.677	-0.806	9.523
2	6.964	0.553	32.819	-0.838	7.629
2	7.25	0.579	34.419	-0.87	5.735
2	7.536	0.597	35.477	-0.901	3.841
2	7.821	0.606	35.995	-0.933	1.946
2	8.107	0.605	35.972	0.932	-1.977
2	8.393	0.596	35.407	0.901	-3.871
2	8.679	0.578	34.301	0.869	-5.765
2	8.964	0.55	32.654	0.837	-7.659
2	9.25	0.514	30.465	0.806	-9.553
2	9.536	0.468	27.736	0.774	-11.447
2	9.821	0.414	24.465	0.743	-13.341
2	10.107	0.35	20.653	0.711	-15.236
2	10.393	0.277	16.3	0.679	-17.13
2	10.679	0.196	11.406	0.65	-19.026
2	10.964	0.106	5.97	0.595	-20.896
2	11.25	-0.0	0.0	-1.333	-20.896
Ek 5: $g_{0,k} + g_{1,k}$					
1	0.0	-0.0	-0.0	0.539	-1.11
1	0.295	-0.004	-0.328	0.515	-2.191
1	0.591	-0.015	-0.975	0.498	-3.279
1	0.886	-0.031	-1.944	0.48	-4.366
1	1.182	-0.052	-3.234	0.462	-5.452
1	1.477	-0.079	-4.845	0.444	-6.539
1	1.773	-0.111	-6.777	0.425	-7.626
1	2.068	-0.149	-9.03	0.41	-8.716

Field	x	$M_{Ay,d}$	$M_{By,d}$	$V_{Az,d}$	$V_{Bz,d}$
	[m]	[kN·m]	[kN·m]	[kN]	[kN]
1	2.364	-0.191	-11.605	0.358	-9.769
1	2.659	-0.249	-14.492	0.701	-11.217
1	2.955	-0.205	-17.806	-0.404	-11.217
2	3.25	-1.297	-20.31	4.409	13.252
2	3.536	-0.19	-16.524	0.489	16.103
2	3.821	-0.203	-11.923	-0.579	16.103
2	4.107	-0.125	-7.718	-0.262	14.717
2	4.393	-0.06	-3.805	-0.308	13.695
2	4.679	0.0	-0.194	-0.323	12.641
2	4.964	0.055	3.118	-0.341	11.591
2	5.25	0.105	6.129	-0.359	10.54
2	5.536	0.151	8.84	-0.376	9.488
2	5.821	0.191	11.251	-0.394	8.437
2	6.107	0.226	13.361	-0.411	7.386
2	6.393	0.256	15.171	-0.429	6.335
2	6.679	0.281	16.681	-0.446	5.284
2	6.964	0.301	17.891	-0.464	4.233
2	7.25	0.317	18.8	-0.481	3.182
2	7.536	0.327	19.409	-0.499	2.131
2	7.821	0.332	19.717	-0.516	1.08
2	8.107	0.332	19.726	0.517	-1.022
2	8.393	0.327	19.434	0.5	-2.073
2	8.679	0.317	18.841	0.482	-3.124
2	8.964	0.302	17.949	0.465	-4.175
2	9.25	0.282	16.756	0.447	-5.226
2	9.536	0.258	15.263	0.43	-6.277
2	9.821	0.228	13.469	0.412	-7.328
2	10.107	0.193	11.375	0.395	-8.379
2	10.393	0.153	8.981	0.377	-9.43
2	10.679	0.108	6.287	0.361	-10.483
2	10.964	0.058	3.292	0.33	-11.521
2	11.25	-0.0	0.0	-0.739	-11.521
Ek 6: $g_{0,k} + g_{1,k} + 0.30{*}q_k$					
1	0.0	-0.0	-0.0	0.642	-2.093
1	0.295	-0.009	-0.618	0.615	-3.174
1	0.591	-0.024	-1.556	0.594	-4.262
1	0.886	-0.045	-2.815	0.573	-5.348

Field	x	$M_{Ay,d}$	$M_{By,d}$	$V_{Az,d}$	$V_{Bz,d}$
	[m]	[kN·m]	[kN·m]	[kN]	[kN]
1	1.182	-0.072	-4.395	0.552	-6.435
1	1.477	-0.103	-6.297	0.531	-7.588
1	1.773	-0.141	-8.519	0.51	-8.849
1	2.068	-0.183	-11.063	0.492	-10.114
1	2.364	-0.23	-13.928	0.436	-11.336
1	2.659	-0.293	-17.104	0.814	-13.017
1	2.955	-0.242	-20.721	-0.493	-13.017
2	3.25	-1.505	-23.569	5.116	15.477
2	3.536	-0.22	-19.175	0.578	18.686
2	3.821	-0.235	-13.836	-0.672	18.686
2	4.107	-0.145	-8.956	-0.306	17.078
2	4.393	-0.07	-4.416	-0.358	15.892
2	4.679	0.003	-0.371	-0.376	14.669
2	4.964	0.067	3.788	-0.396	13.45
2	5.25	0.125	7.274	-0.417	12.23
2	5.536	0.177	10.412	-0.437	11.011
2	5.821	0.224	13.202	-0.457	9.791
2	6.107	0.264	15.643	-0.478	8.571
2	6.393	0.299	17.736	-0.498	7.352
2	6.679	0.328	19.48	-0.518	6.132
2	6.964	0.352	20.876	-0.539	4.912
2	7.25	0.369	21.924	-0.559	3.693
2	7.536	0.381	22.623	-0.579	2.473
2	7.821	0.387	22.973	-0.6	1.253
2	8.107	0.387	22.975	0.6	-1.213
2	8.393	0.381	22.628	0.58	-2.433
2	8.679	0.369	21.933	0.56	-3.652
2	8.964	0.352	20.89	0.539	-4.872
2	9.25	0.329	19.498	0.519	-6.092
2	9.536	0.3	17.757	0.499	-7.311
2	9.821	0.265	15.668	0.478	-8.531
2	10.107	0.224	13.231	0.458	-9.751
2	10.393	0.178	10.445	0.438	-10.97
2	10.679	0.126	7.311	0.418	-12.191
2	10.964	0.068	3.827	0.383	-13.396
2	11.25	-0.0	0.0	-0.858	-13.396

8.3 Deformations

Field	x	$w_{z,min}$	$w_{z,max}$
	[m]	**[mm]**	**[mm]**
Load case group $g_{0,k}$			
1	0.0	0.00	0.00
1	0.295	-0.03	-0.03
1	0.591	-0.07	-0.07
1	0.886	-0.11	-0.11
1	1.182	-0.15	-0.15
1	1.477	-0.18	-0.18
1	1.773	-0.21	-0.21
1	2.068	-0.22	-0.22
1	2.364	-0.21	-0.21
1	2.659	-0.18	-0.18
1	2.955	-0.12	-0.12
1	3.25	0.00	0.00
2	3.536	0.25	0.25
2	3.821	0.54	0.54
2	4.107	0.86	0.86
2	4.393	1.20	1.20
2	4.679	1.54	1.54
2	4.964	1.88	1.88
2	5.25	2.20	2.20
2	5.536	2.51	2.51
2	5.821	2.79	2.79
2	6.107	3.04	3.04
2	6.393	3.25	3.25
2	6.679	3.43	3.43
2	6.964	3.56	3.56
2	7.25	3.64	3.64
2	7.536	3.68	3.68
2	7.821	3.66	3.66
2	8.107	3.59	3.59
2	8.393	3.48	3.48
2	8.679	3.31	3.31
2	8.964	3.09	3.09
2	9.25	2.83	2.83
2	9.536	2.52	2.52

Field	x	$w_{z,min}$	$w_{z,max}$
	[m]	[mm]	[mm]
2	9.821	2.17	2.17
2	10.107	1.79	1.79
2	10.393	1.37	1.37
2	10.679	0.93	0.93
2	10.964	0.47	0.47
2	11.25	0.00	0.00
Load case group $g_{1,k}$			
1	0.0	0.00	0.00
1	0.295	-0.05	-0.05
1	0.591	-0.10	-0.10
1	0.886	-0.16	-0.16
1	1.182	-0.21	-0.21
1	1.477	-0.26	-0.26
1	1.773	-0.30	-0.30
1	2.068	-0.31	-0.31
1	2.364	-0.30	-0.30
1	2.659	-0.26	-0.26
1	2.955	-0.17	-0.17
1	3.25	0.00	0.00
2	3.536	0.35	0.35
2	3.821	0.78	0.78
2	4.107	1.23	1.23
2	4.393	1.71	1.71
2	4.679	2.20	2.20
2	4.964	2.68	2.68
2	5.25	3.14	3.14
2	5.536	3.58	3.58
2	5.821	3.98	3.98
2	6.107	4.34	4.34
2	6.393	4.65	4.65
2	6.679	4.90	4.90
2	6.964	5.08	5.08
2	7.25	5.20	5.20
2	7.536	5.25	5.25
2	7.821	5.23	5.23
2	8.107	5.13	5.13
2	8.393	4.97	4.97

Field	x	$w_{z,min}$	$w_{z,max}$
	[m]	[mm]	[mm]
2	8.679	4.73	4.73
2	8.964	4.42	4.42
2	9.25	4.04	4.04
2	9.536	3.60	3.60
2	9.821	3.10	3.10
2	10.107	2.55	2.55
2	10.393	1.96	1.96
2	10.679	1.33	1.33
2	10.964	0.67	0.67
2	11.25	0.00	0.00
Load case group q_k			
1	0.0	0.00	0.00
1	0.295	-0.12	0.08
1	0.591	-0.24	0.15
1	0.886	-0.34	0.20
1	1.182	-0.42	0.23
1	1.477	-0.49	0.25
1	1.773	-0.52	0.25
1	2.068	-0.51	0.23
1	2.364	-0.47	0.19
1	2.659	-0.37	0.13
1	2.955	-0.22	0.07
1	3.25	0.00	0.00
2	3.536	-0.04	0.36
2	3.821	-0.07	0.78
2	4.107	-0.10	1.22
2	4.393	-0.13	1.68
2	4.679	-0.15	2.15
2	4.964	-0.17	2.60
2	5.25	-0.18	3.04
2	5.536	-0.19	3.45
2	5.821	-0.20	3.82
2	6.107	-0.21	4.15
2	6.393	-0.21	4.43
2	6.679	-0.21	4.66
2	6.964	-0.21	4.83
2	7.25	-0.21	4.93

Field	x	$w_{z,min}$	$w_{z,max}$
	[m]	[mm]	[mm]
2	7.536	-0.20	4.97
2	7.821	-0.19	4.95
2	8.107	-0.18	4.85
2	8.393	-0.17	4.69
2	8.679	-0.16	4.45
2	8.964	-0.14	4.16
2	9.25	-0.13	3.80
2	9.536	-0.11	3.39
2	9.821	-0.09	2.92
2	10.107	-0.08	2.40
2	10.393	-0.06	1.84
2	10.679	-0.04	1.25
2	10.964	-0.02	0.63
2	11.25	0.00	0.00

8.4 Supporting forces

8.4.1 Characteristic supporting forces

Load case group	Support	x	$F_{z,k,min}$	$F_{z,k,max}$
		[m]	[kN]	[kN]
$g_{0,k}$	A	0.0	-0.235	-0.235
	B	3.25	12.512	12.512
	C	11.25	5.048	5.048
$g_{1,k}$	A	0.0	-0.336	-0.336
	B	3.25	17.875	17.875
	C	11.25	7.211	7.211
q_k	A	0.0	-3.331	3.025
	B	3.25	0.0	16.25
	C	11.25	-0.091	6.647

8.4.2 Design supporting forces

Support	x	$F_{z,d,min}$	Ek	$F_{z,d,max}$	Ek
	[m]	[kN]		[kN]	
A	0.0	-5.767	2	3.967	4

Support	x	$F_{z,d,min}$	Ek	$F_{z,d,max}$	Ek
	[m]	[kN]		[kN]	
B	3.25	30.387	3	65.396	2
C	11.25	12.122	4	26.52	2

8.5 Verification

8.5.1 Bending

Field	x	Ek	k_{mod}	$M_{Ay,d}$	$M_{By,d}$	$\sigma_{max,d}$	$f_{m,d}$	η
	[m]		[-]	[kN·m]	[kN·m]	[N/mm²]	[N/mm²]	[%]
1	0.0	1	0.6	-0.00	-0.00	0.00	12.67	0.0
1	0.295	2	0.8	-0.03	-1.89	0.21	16.90	1.2
1	0.591	2	0.8	-0.07	-4.22	0.46	16.90	2.7
1	0.886	2	0.8	-0.11	-6.98	0.76	16.90	4.5
1	1.182	2	0.8	-0.17	-10.17	1.11	16.90	6.6
1	1.477	2	0.8	-0.23	-13.80	1.51	16.90	8.9
1	1.773	2	0.8	-0.30	-17.86	1.95	16.90	11.6
1	2.068	2	0.8	-0.37	-22.35	2.44	16.90	14.5
1	2.364	2	0.8	-0.45	-27.28	2.98	16.90	17.6
1	2.659	2	0.8	-0.56	-32.63	3.58	16.90	21.2
1	2.955	2	0.8	-0.46	-38.61	4.05	16.90	24.0
2	3.25	2	0.8	-2.79	-43.71	6.71	16.90	39.7
2	3.536	2	0.8	-0.41	-35.56	3.72	16.90	22.0
2	3.821	2	0.8	-0.44	-25.66	2.81	16.90	16.7
2	4.107	2	0.8	-0.27	-16.61	1.81	16.90	10.7
2	4.393	2	0.8	-0.13	-8.19	0.89	16.90	5.3
2	4.679	2	0.8	-0.01	-1.15	0.12	16.90	0.7
2	4.964	2	0.8	0.13	7.56	0.83	16.90	4.9
2	5.25	2	0.8	0.24	14.00	1.54	16.90	9.1
2	5.536	2	0.8	0.34	19.79	2.17	16.90	12.9
2	5.821	2	0.8	0.42	24.94	2.73	16.90	16.2
2	6.107	2	0.8	0.50	29.45	3.23	16.90	19.1
2	6.393	2	0.8	0.56	33.31	3.65	16.90	21.6
2	6.679	2	0.8	0.62	36.52	4.00	16.90	23.7
2	6.964	2	0.8	0.66	39.08	4.28	16.90	25.3
2	7.25	2	0.8	0.69	41.00	4.49	16.90	26.6
2	7.536	2	0.8	0.71	42.27	4.63	16.90	27.4

Field	x	Ek	k_{mod}	$M_{Ay,d}$	$M_{By,d}$	$\sigma_{max,d}$	$f_{m,d}$	η
	[m]		[-]	[kN·m]	[kN·m]	[N/mm²]	[N/mm²]	[%]
2	7.821	2	0.8	0.72	42.90	4.70	16.90	27.8
2	8.107	2	0.8	0.72	42.88	4.70	16.90	27.8
2	8.393	2	0.8	0.71	42.21	4.62	16.90	27.4
2	8.679	2	0.8	0.69	40.90	4.48	16.90	26.5
2	8.964	2	0.8	0.66	38.94	4.27	16.90	25.2
2	9.25	2	0.8	0.61	36.33	3.98	16.90	23.6
2	9.536	2	0.8	0.56	33.08	3.62	16.90	21.5
2	9.821	2	0.8	0.49	29.18	3.20	16.90	18.9
2	10.107	2	0.8	0.42	24.63	2.70	16.90	16.0
2	10.393	2	0.8	0.33	19.44	2.13	16.90	12.6
2	10.679	2	0.8	0.23	13.61	1.49	16.90	8.8
2	10.964	2	0.8	0.13	7.12	0.79	16.90	4.7
2	11.25	1	0.6	-0.00	0.00	0.00	12.67	0.0

8.5.2 Shear

Field	x	Ek	k_{mod}	$V_{Az,d}$	$V_{Bz,d}$	$\tau_{v,d}$	$f_{v,d}$	η
						$\tau_{r,d}$	$f_{r,d}$	
	[m]		[-]	[kN]	[kN]	[N/mm²]	[N/mm²]	[%]
1	0.0	2	0.8	0.65	-6.41	0.03	1.72	1.9
						0.03	0.64	5.0
1	0.295	2	0.8	0.61	-7.87	0.04	1.72	2.3
						0.04	0.64	6.2
1	0.591	2	0.8	0.59	-9.34	0.05	1.72	2.7
						0.05	0.64	7.3
1	0.886	2	0.8	0.57	-10.81	0.05	1.72	3.2
						0.05	0.64	8.4
1	1.182	2	0.8	0.54	-12.27	0.06	1.72	3.6
						0.06	0.64	9.6
1	1.477	2	0.8	0.95	-14.07	0.07	1.72	4.1
						0.07	0.64	11.0
1	1.773	2	0.8	0.91	-16.41	0.08	1.72	4.8
						0.08	0.64	12.8
1	2.068	2	0.8	0.88	-18.76	0.09	1.72	5.5
						0.09	0.64	14.7
1	2.364	2	0.8	0.77	-21.02	0.11	1.72	6.1

Field	x	Ek	k_{mod}	$V_{Az,d}$	$V_{Bz,d}$	$\tau_{v,d}$	$f_{v,d}$	η
						$\tau_{r,d}$	$f_{r,d}$	
	[m]		[-]	[kN]	[kN]	[N/mm²]	[N/mm²]	[%]
						0.11	0.64	16.4
1	2.659	2	0.8	1.51	-24.14	0.12	1.72	7.0
						0.12	0.64	18.9
1	2.955	2	0.8	-0.87	-24.14	0.12	1.72	7.0
						0.12	0.64	18.9
2	3.25	2	0.8	8.86	29.02	0.21	1.72	12.3
						0.15	0.64	22.7
2	3.536	2	0.8	1.05	34.66	0.17	1.72	10.1
						0.17	0.64	27.1
2	3.821	2	0.8	-1.25	34.66	0.17	1.72	10.1
						0.17	0.64	27.1
2	4.107	2	0.8	-0.56	31.67	0.16	1.72	9.2
						0.16	0.64	24.7
2	4.393	2	0.8	-0.66	29.47	0.15	1.72	8.6
						0.15	0.64	23.0
2	4.679	2	0.8	-0.70	27.21	0.14	1.72	7.9
						0.14	0.64	21.3
2	4.964	2	0.8	-0.73	24.94	0.12	1.72	7.3
						0.12	0.64	19.5
2	5.25	2	0.8	-0.77	22.68	0.11	1.72	6.6
						0.11	0.64	17.7
2	5.536	2	0.8	-0.81	20.42	0.10	1.72	6.0
						0.10	0.64	16.0
2	5.821	2	0.8	-0.85	18.16	0.09	1.72	5.3
						0.09	0.64	14.2
2	6.107	2	0.8	-0.88	15.90	0.08	1.72	4.6
						0.08	0.64	12.4
2	6.393	2	0.8	-0.92	13.63	0.07	1.72	4.0
						0.07	0.64	10.7
2	6.679	2	0.8	-0.96	11.37	0.06	1.72	3.3
						0.06	0.64	8.9
2	6.964	2	0.8	-1.00	9.11	0.05	1.72	2.7
						0.05	0.64	7.1
2	7.25	2	0.8	-1.04	6.85	0.03	1.72	2.0
						0.03	0.64	5.4
2	7.536	2	0.8	-1.07	4.59	0.02	1.72	1.3

Field	x	Ek	k_{mod}	$V_{Az,d}$	$V_{Bz,d}$	$\tau_{v,d}$	$f_{v,d}$	η
						$\tau_{r,d}$	$f_{r,d}$	
	[m]		[-]	[kN]	[kN]	[N/mm²]	[N/mm²]	[%]
						0.02	0.64	3.6
2	7.821	2	0.8	-1.11	2.32	0.01	1.72	0.7
						0.01	0.64	1.8
2	8.107	2	0.8	1.11	-2.33	0.01	1.72	0.7
						0.01	0.64	1.8
2	8.393	2	0.8	1.07	-4.60	0.02	1.72	1.3
						0.02	0.64	3.6
2	8.679	2	0.8	1.04	-6.86	0.03	1.72	2.0
						0.03	0.64	5.4
2	8.964	2	0.8	1.00	-9.12	0.05	1.72	2.7
						0.05	0.64	7.1
2	9.25	2	0.8	0.96	-11.38	0.06	1.72	3.3
						0.06	0.64	8.9
2	9.536	2	0.8	0.92	-13.64	0.07	1.72	4.0
						0.07	0.64	10.7
2	9.821	2	0.8	0.88	-15.91	0.08	1.72	4.6
						0.08	0.64	12.4
2	10.107	2	0.8	0.85	-18.17	0.09	1.72	5.3
						0.09	0.64	14.2
2	10.393	2	0.8	0.81	-20.43	0.10	1.72	6.0
						0.10	0.64	16.0
2	10.679	2	0.8	0.77	-22.69	0.11	1.72	6.6
						0.11	0.64	17.7
2	10.964	2	0.8	0.71	-24.93	0.12	1.72	7.3
						0.12	0.64	19.5
2	11.25	2	0.8	-1.59	-24.93	0.13	1.72	7.5
						0.12	0.64	19.5

8.5.3 Bearing pressure

Support	x	Ek	k_{mod}	F_d	A_{sec}	$k_{c,90}$	$\sigma_{c,90,d}$	$f_{c,90,d}$	η
	[m]		[-]	[kN]	[mm²]	[-]	[N/mm²]	[N/mm²]	[%]
B	3.25	2	0.8	65.40	100,000	1.71	0.65	2.73	23.9
C	11.25	2	0.8	26.52	60,000	1.52	0.44	2.44	18.1
A	0.0	4	0.8	3.97	100,000	1.35	0.04	2.17	1.8

8.5.4 Bending in case of fire

Field	x	Ek	k_{mod}	$M_{Ay,d}$	$M_{By,d}$	$\sigma_{max,d}$	$f_{m,d}$	η
	[m]		[-]	[kN·m]	[kN·m]	[N/mm²]	[N/mm²]	[%]
1	0.0	5	1.0	-0.00	-0.00	0.00	26.40	0.0
1	0.295	6	1.0	-0.01	-0.62	0.11	26.40	0.4
1	0.591	6	1.0	-0.02	-1.56	0.28	26.40	0.9
1	0.886	6	1.0	-0.05	-2.82	0.50	26.40	1.6
1	1.182	6	1.0	-0.07	-4.40	0.78	26.40	2.6
1	1.477	6	1.0	-0.10	-6.30	1.12	26.40	3.7
1	1.773	6	1.0	-0.14	-8.52	1.51	26.40	5.0
1	2.068	6	1.0	-0.18	-11.06	1.96	26.40	6.5
1	2.364	6	1.0	-0.23	-13.93	2.47	26.40	8.1
1	2.659	6	1.0	-0.29	-17.10	3.04	26.40	10.0
1	2.955	6	1.0	-0.24	-20.72	3.64	26.40	12.0
2	3.25	6	1.0	-1.50	-23.57	4.75	26.40	15.6
2	3.536	6	1.0	-0.22	-19.17	3.36	26.40	11.1
2	3.821	6	1.0	-0.24	-13.84	2.46	26.40	8.1
2	4.107	6	1.0	-0.14	-8.96	1.59	26.40	5.2
2	4.393	6	1.0	-0.07	-4.42	0.78	26.40	2.6
2	4.679	6	1.0	-0.00	-0.37	0.06	26.40	0.2
2	4.964	6	1.0	0.07	3.79	0.67	26.40	2.2
2	5.25	6	1.0	0.12	7.27	1.29	26.40	4.3
2	5.536	6	1.0	0.18	10.41	1.85	26.40	6.1
2	5.821	6	1.0	0.22	13.20	2.35	26.40	7.7
2	6.107	6	1.0	0.26	15.64	2.78	26.40	9.2
2	6.393	6	1.0	0.30	17.74	3.15	26.40	10.4
2	6.679	6	1.0	0.33	19.48	3.46	26.40	11.4
2	6.964	6	1.0	0.35	20.88	3.71	26.40	12.2
2	7.25	6	1.0	0.37	21.92	3.89	26.40	12.8
2	7.536	6	1.0	0.38	22.62	4.02	26.40	13.2
2	7.821	6	1.0	0.39	22.97	4.08	26.40	13.4
2	8.107	6	1.0	0.39	22.97	4.08	26.40	13.4
2	8.393	6	1.0	0.38	22.63	4.02	26.40	13.2
2	8.679	6	1.0	0.37	21.93	3.90	26.40	12.8
2	8.964	6	1.0	0.35	20.89	3.71	26.40	12.2
2	9.25	6	1.0	0.33	19.50	3.46	26.40	11.4
2	9.536	6	1.0	0.30	17.76	3.15	26.40	10.4
2	9.821	6	1.0	0.26	15.67	2.78	26.40	9.2

Field	x	Ek	k_{mod}	$M_{Ay,d}$	$M_{By,d}$	$\sigma_{max,d}$	$f_{m,d}$	η
	[m]		[-]	[kN·m]	[kN·m]	[N/mm²]	[N/mm²]	[%]
2	10.107	6	1.0	0.22	13.23	2.35	26.40	7.7
2	10.393	6	1.0	0.18	10.44	1.86	26.40	6.1
2	10.679	6	1.0	0.13	7.31	1.30	26.40	4.3
2	10.964	6	1.0	0.07	3.83	0.68	26.40	2.2
2	11.25	5	1.0	-0.00	0.00	0.00	26.40	0.0

8.5.5 Shear in case of fire

Field	x	Ek	k_{mod}	$V_{Az,d}$	$V_{Bz,d}$	$\tau_{v,d}$	$f_{v,d}$	η
						$\tau_{r,d}$	$f_{r,d}$	
	[m]		[-]	[kN]	[kN]	[N/mm²]	[N/mm²]	[%]
1	0.0	6	1.0	0.52	-2.09	0.01	2.68	0.4
						0.01	1.00	1.0
1	0.295	6	1.0	0.50	-3.17	0.02	2.68	0.6
						0.02	1.00	1.6
1	0.591	6	1.0	0.48	-4.26	0.02	2.68	0.8
						0.02	1.00	2.1
1	0.886	6	1.0	0.46	-5.35	0.03	2.68	1.0
						0.03	1.00	2.6
1	1.182	6	1.0	0.45	-6.44	0.03	2.68	1.2
						0.03	1.00	3.2
1	1.477	6	1.0	0.51	-7.59	0.04	2.68	1.4
						0.04	1.00	3.7
1	1.773	6	1.0	0.49	-8.85	0.04	2.68	1.6
						0.04	1.00	4.4
1	2.068	6	1.0	0.48	-10.11	0.05	2.68	1.9
						0.05	1.00	5.0
1	2.364	6	1.0	0.42	-11.34	0.06	2.68	2.1
						0.06	1.00	5.6
1	2.659	6	1.0	0.81	-13.02	0.07	2.68	2.4
						0.07	1.00	6.4
1	2.955	6	1.0	-0.47	-13.02	0.07	2.68	2.5
						0.07	1.00	6.4
2	3.25	6	1.0	4.99	15.48	0.11	2.68	4.7
						0.08	1.00	7.6
2	3.536	6	1.0	0.57	18.69	0.09	2.68	3.5

Field	x	Ek	k_{mod}	$V_{Az,d}$	$V_{Bz,d}$	$\tau_{v,d}$	$f_{v,d}$	η
						$\tau_{r,d}$	$f_{r,d}$	
	[m]		[-]	[kN]	[kN]	[N/mm²]	[N/mm²]	[%]
						0.09	1.00	9.2
2	3.821	6	1.0	-0.67	18.69	0.09	2.68	3.4
						0.09	1.00	9.2
2	4.107	6	1.0	-0.30	17.08	0.09	2.68	3.1
						0.09	1.00	8.4
2	4.393	6	1.0	-0.36	15.89	0.08	2.68	2.9
						0.08	1.00	7.8
2	4.679	6	1.0	-0.38	14.67	0.07	2.68	2.7
						0.07	1.00	7.2
2	4.964	6	1.0	-0.40	13.45	0.07	2.68	2.5
						0.07	1.00	6.6
2	5.25	6	1.0	-0.42	12.23	0.06	2.68	2.3
						0.06	1.00	6.0
2	5.536	6	1.0	-0.44	11.01	0.06	2.68	2.0
						0.06	1.00	5.4
2	5.821	6	1.0	-0.46	9.79	0.05	2.68	1.8
						0.05	1.00	4.8
2	6.107	6	1.0	-0.48	8.57	0.04	2.68	1.6
						0.04	1.00	4.2
2	6.393	6	1.0	-0.50	7.35	0.04	2.68	1.4
						0.04	1.00	3.6
2	6.679	6	1.0	-0.52	6.13	0.03	2.68	1.1
						0.03	1.00	3.0
2	6.964	6	1.0	-0.54	4.91	0.02	2.68	0.9
						0.02	1.00	2.4
2	7.25	6	1.0	-0.56	3.69	0.02	2.68	0.7
						0.02	1.00	1.8
2	7.536	6	1.0	-0.58	2.47	0.01	2.68	0.5
						0.01	1.00	1.2
2	7.821	6	1.0	-0.60	1.25	0.01	2.68	0.2
						0.01	1.00	0.6
2	8.107	6	1.0	0.60	-1.21	0.01	2.68	0.2
						0.01	1.00	0.6
2	8.393	6	1.0	0.58	-2.43	0.01	2.68	0.4
						0.01	1.00	1.2
2	8.679	6	1.0	0.56	-3.65	0.02	2.68	0.7

Field	x	Ek	k_{mod}	$V_{Az,d}$	$V_{Bz,d}$	$\tau_{v,d}$	$f_{v,d}$	η
						$\tau_{r,d}$	$f_{r,d}$	
	[m]		[-]	[kN]	[kN]	[N/mm²]	[N/mm²]	[%]
						0.02	1.00	1.8
2	8.964	6	1.0	0.54	-4.87	0.02	2.68	0.9
						0.02	1.00	2.4
2	9.25	6	1.0	0.52	-6.09	0.03	2.68	1.1
						0.03	1.00	3.0
2	9.536	6	1.0	0.50	-7.31	0.04	2.68	1.3
						0.04	1.00	3.6
2	9.821	6	1.0	0.48	-8.53	0.04	2.68	1.6
						0.04	1.00	4.2
2	10.107	6	1.0	0.46	-9.75	0.05	2.68	1.8
						0.05	1.00	4.8
2	10.393	6	1.0	0.44	-10.97	0.05	2.68	2.0
						0.05	1.00	5.4
2	10.679	6	1.0	0.42	-12.19	0.06	2.68	2.2
						0.06	1.00	6.0
2	10.964	6	1.0	0.38	-13.40	0.07	2.68	2.5
						0.07	1.00	6.6
2	11.25	6	1.0	-0.86	-13.40	0.07	2.68	2.7
						0.07	1.00	6.6

8.5.6 Deformations

Field	x	Ek	k_{def}	w_{max}	w_{limit}	η
	[m]			[mm]	[mm]	[%]
1	0.0	8	1.0	0.00	10.83	0.0
1	0.295	10	1.0	-0.32	13.00	2.5
1	0.591	10	1.0	-0.65	13.00	5.0
1	0.886	10	1.0	-0.97	13.00	7.5
1	1.182	10	1.0	-1.27	13.00	9.7
1	1.477	10	1.0	-1.51	13.00	11.6
1	1.773	10	1.0	-1.68	13.00	12.9
1	2.068	10	1.0	-1.73	13.00	13.3
1	2.364	10	1.0	-1.64	13.00	12.6
1	2.659	10	1.0	-1.37	13.00	10.5
1	2.955	10	1.0	-0.87	13.00	6.7

Field	x	Ek	k_{def}	w_{max}	w_{limit}	η
	[m]			[mm]	[mm]	[%]
1	3.25	8	1.0	0.00	10.83	0.0
2	3.536	10	1.0	1.67	32.00	5.2
2	3.821	10	1.0	3.65	32.00	11.4
2	4.107	10	1.0	5.79	32.00	18.1
2	4.393	10	1.0	8.01	32.00	25.0
2	4.679	10	1.0	10.26	32.00	32.1
2	4.964	10	1.0	12.49	32.00	39.0
2	5.25	10	1.0	14.64	32.00	45.7
2	5.536	10	1.0	16.66	32.00	52.1
2	5.821	10	1.0	18.51	32.00	57.8
2	6.107	10	1.0	20.16	32.00	63.0
2	6.393	10	1.0	21.56	32.00	67.4
2	6.679	10	1.0	22.70	32.00	71.0
2	6.964	10	1.0	23.56	32.00	73.6
2	7.25	10	1.0	24.10	32.00	75.3
2	7.536	10	1.0	24.32	32.00	76.0
2	7.821	10	1.0	24.21	32.00	75.7
2	8.107	10	1.0	23.76	32.00	74.3
2	8.393	10	1.0	22.98	32.00	71.8
2	8.679	10	1.0	21.86	32.00	68.3
2	8.964	10	1.0	20.42	32.00	63.8
2	9.25	10	1.0	18.68	32.00	58.4
2	9.536	10	1.0	16.64	32.00	52.0
2	9.821	10	1.0	14.34	32.00	44.8
2	10.107	10	1.0	11.80	32.00	36.9
2	10.393	10	1.0	9.06	32.00	28.3
2	10.679	10	1.0	6.15	32.00	19.2
2	10.964	10	1.0	3.11	32.00	9.7
2	11.25	8	1.0	0.00	26.67	0.0

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Summary of results

Project number:	BYG508
Project:	Appartment Building
Structural element:	Floor
Cross section:	User-defined cross section: 7s - 280 mm
Description:	Project for master thesis in UIA
Date:	Apr 23, 2019
Time:	10:45:15 AM
Author:	

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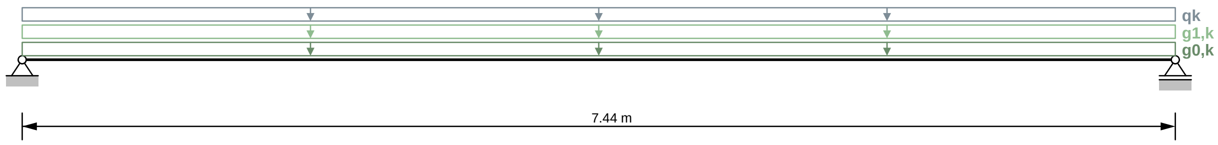
1 General

Service class 2

2 Structural system

Single span girder

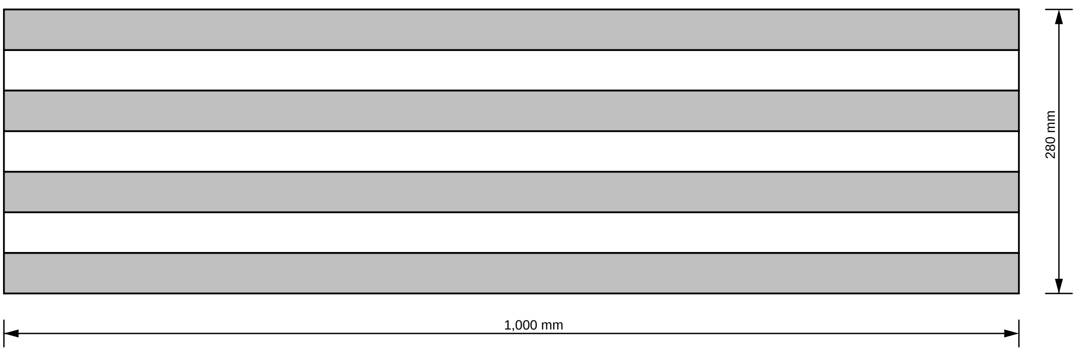


2.1 Supports

Support	x	Width
A	0.0 m	0.1 m
B	7.44 m	0.1 m

3 Cross section

User-defined cross section
7 layers (width: 1,000 mm / thickness: 280 mm)



3.1 Layer composition

Layer	Thickness	Orientation	Material

# 1	40 mm	0	C24
# 2	40 mm	90	C24
# 3	40 mm	0	C24
# 4	40 mm	90	C24
# 5	40 mm	0	C24
# 6	40 mm	90	C24
# 7	40 mm	0	C24

Orientation 0 = top layer longitudinal to span; Orientation 90 = top layer perpendicular to span

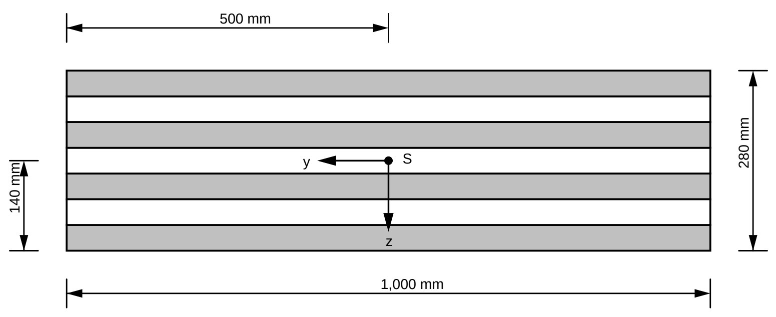
3.2 Material parameters

Partial safety factor γ_M = 1.25

Material parameters for	**C24**
bending strength [N/mm²]	24.0
tensile strength parallel [N/mm²]	14.0
tensile strength perpendicular [N/mm²]	0.4
compressive strength parallel [N/mm²]	21.0
compressive strength perpendicular [N/mm²]	2.5
shear strength [N/mm²]	2.68
rolling shear strength [N/mm²]	1.0
Youngs modulus parallel [N/mm²]	11,000.0
5%-quantile from Youngs modulus parallel [N/mm²]	7,400.0
Youngs modulus perpendicular [N/mm²]	370.0 (0.0)
shear modulus [N/mm²]	690.0
rolling shear modulus [N/mm²]	69.0
density [kg/m³]	350.0
density mean value [kg/m³]	420.0

3.3 Cross-sectional values

EA_{ef}	1.76E9 N
EI_{ef}	1.431E13 N·mm²
GA_{ef}	3.064E7 N



4 Loads

Field	$g_{0,k}$	$g_{1,k}$	q_k	Category	s_k	Altitude/Region	w_k
1	1.54 kN/m	2 kN/m²	2 kN/m²	A			

Partial safety factors:

γ_G = 1.35
γ_Q = 1.5

Load position:

Plate weight: Total
Permanent loads: Total
Imposed loads: Field-by-field
Snow: Field-by-field
Wind: Total

Combinations:

Combination factors: according to NA

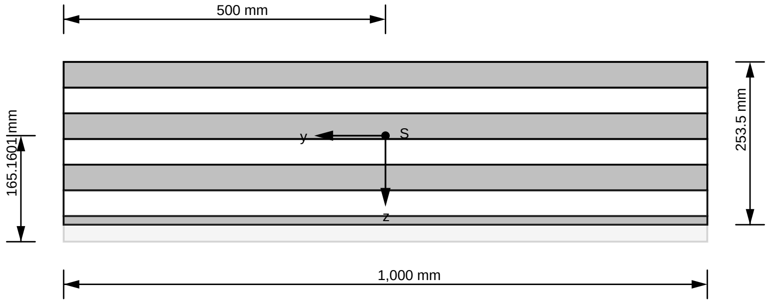
Combinations of distributed and concentrated loads:
q_k and Q_k will be considered as one load group
s_k and S_k will be considered as one load group
w_k and W_k will be considered as one load group

5 Specification concerning structural fire design

Fire duration: 30 minutes
Side exposed to fire: below
falling off of charred layers is considered
Without gaps or with bonded edges
k_{fire} = 1.15
d_0 = 7 mm
Partial safety factor $\gamma_{M,fi}$ = 1.0
Charring rate β_0 = 0.65 mm/min

5.1 Cross-sectional values in case of fire

EA_{ef}	1.468E9 N
EI_{ef}	8.685E12 N·mm²
GA_{ef}	2.671E7 N



6 Information concerning vibrations

No specifications are available

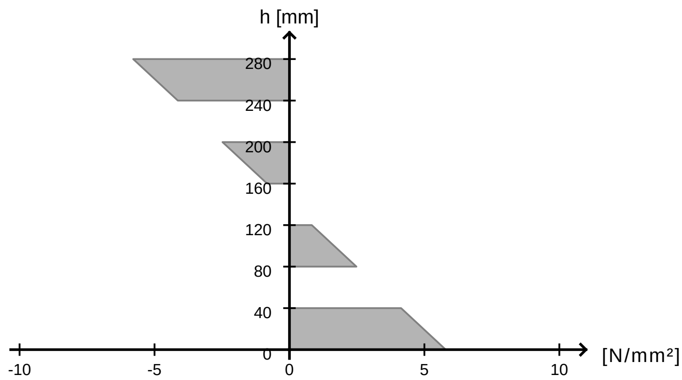
7 Results

Referenced standards: EN 1995-1-1:2009, ON B 1995-1-1/NA:2014-11-15
Underlying calculation method: Timoshenko

7.1 ULS

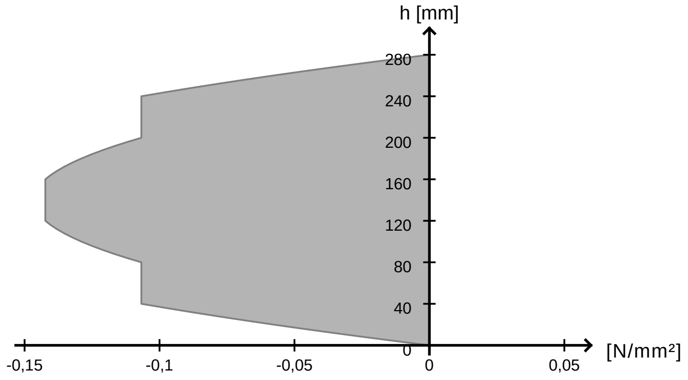
7.1.1 Bending

Utilisation ratio	34.3 %
k_{mod}	0.8
at x	3.72 m
Ek	2
Fundamental combination	$1.35*g_{0,k}$ + $1.35*g_{1,k}$ + $1.50*1.00*q_k$



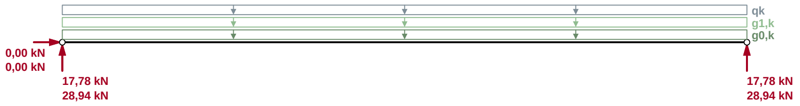
7.1.2 Shear

Utilisation ratio	22.2 %
k_{mod}	0.8
at x	7.44 m
Ek	2
Fundamental combination	$1.35*g_{0,k}$ + $1.35*g_{1,k}$ + $1.50*1.00*q_k$



7.1.3 Bearing pressure

Utilisation ratio	13.4 %
k_{mod}	0.8
at x	7.44 m
Ek	2
Fundamental combination	$1.35*g_{0,k}$ + $1.35*g_{1,k}$ + $1.50*1.00*q_k$



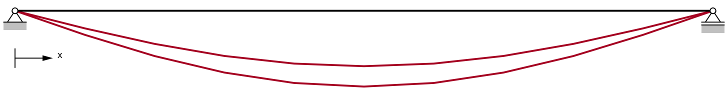
7.2 SLS

7.2.1 Deflection

Limit values according to EN 1995-1-1
Instantaneous deformation w_{inst} t = 0: l/300 (16.7 mm, 67.3 %)
Final deformation $w_{net,fin}$ t = inf: l/250 (29.2 mm, 98.0 %)
Final deformation w_{fin} t = inf: l/150 (29.2 mm, 58.8 %)

Limit values according to ON B 1995-1-1/NA:2014-11-15
Instantaneous deformation w_{inst} t = 0: l/300 (16.7 mm, 67.3 %)
Final deformation $w_{net,fin}$ t = inf: l/250 (24.9 mm, 83.8 %)
Final deformation w_{fin} t = inf: l/150 (29.2 mm, 58.8 %)

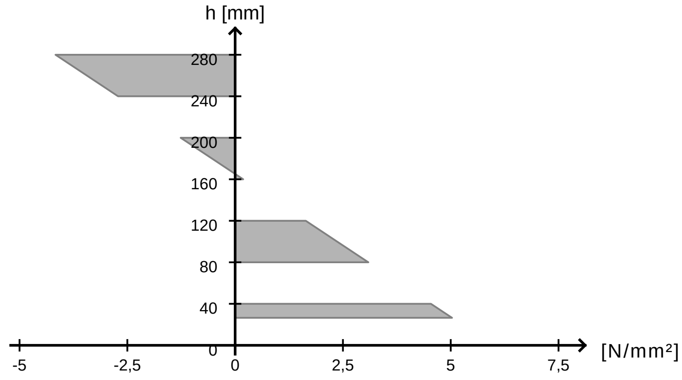
Utilisation ratio	98.0 %
w_{max}	29.2 mm
k_{def}	1.0
at x	3.72 m
Ek	10
Final deformation $w_{net,fin}$ t = inf (l/250)	



7.3 ULS in case of fire

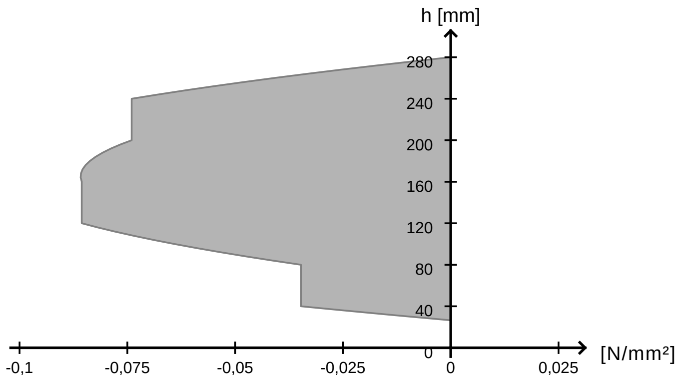
7.3.1 Bending

Utilisation ratio	16.6 %
k_{mod}	1.0
at x	3.72 m
Ek	6
Accidental combination	$g_{0,k} + g_{1,k} + 0.30*q_k$



7.3.2 Shear

Utilisation ratio	7.4 %
k_{mod}	1.0
at x	7.44 m
Ek	6
Accidental combination	$g_{0,k} + g_{1,k} + 0.30*q_k$



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Version 6.11.1

Summary of results

Project number:	BYG508
Project:	Appartment Building
Structural element:	Roof
Cross section:	User-defined cross section: 7s - 280 mm
Description:	Project for master thesis in UIA
Date:	Apr 23, 2019
Time:	10:47:48 AM
Author:	

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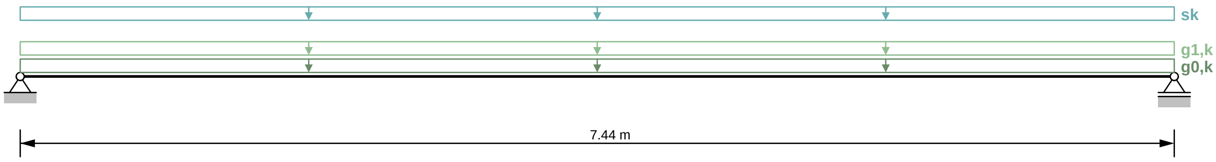
Single span girder

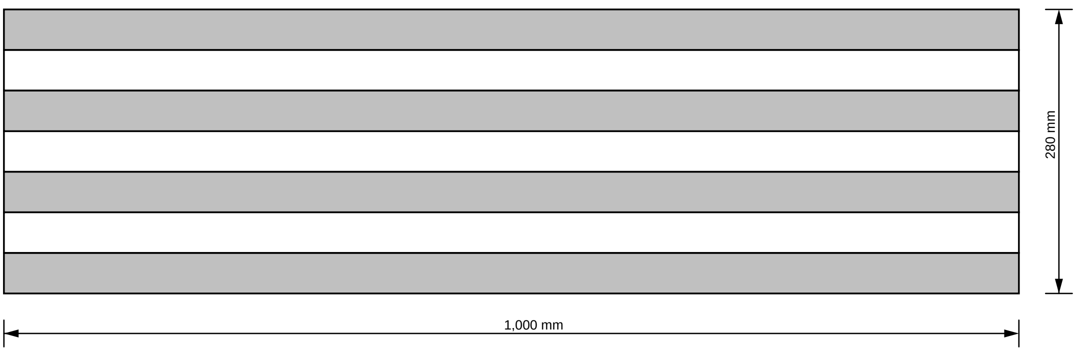


2.1 Supports

Support	x	Width
A	0.0 m	0.1 m
B	7.44 m	0.1 m

3 Cross section

User-defined cross section
7 layers (width: 1,000 mm / thickness: 280 mm)



3.1 Layer composition

Layer	Thickness	Orientation	Material

# 1	40 mm	0	C24
# 2	40 mm	90	C24
# 3	40 mm	0	C24
# 4	40 mm	90	C24
# 5	40 mm	0	C24
# 6	40 mm	90	C24
# 7	40 mm	0	C24

Orientation 0 = top layer longitudinal to span; Orientation 90 = top layer perpendicular to span

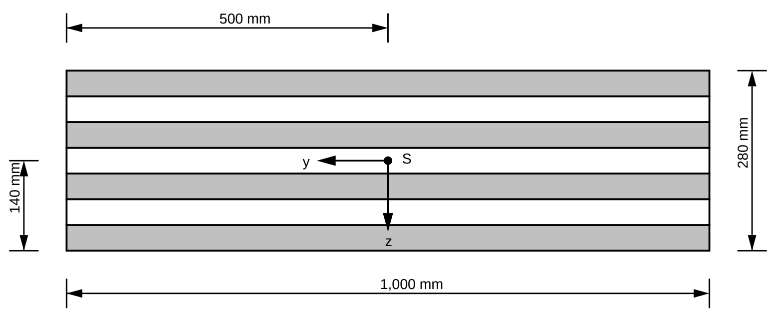
3.2 Material parameters

Partial safety factor $\gamma_M = 1.25$

Material parameters for	**C24**
bending strength [N/mm²]	24.0
tensile strength parallel [N/mm²]	14.0
tensile strength perpendicular [N/mm²]	0.4
compressive strength parallel [N/mm²]	21.0
compressive strength perpendicular [N/mm²]	2.5
shear strength [N/mm²]	2.68
rolling shear strength [N/mm²]	1.0
Youngs modulus parallel [N/mm²]	11,000.0
5%-quantile from Youngs modulus parallel [N/mm²]	7,400.0
Youngs modulus perpendicular [N/mm²]	370.0 (0.0)
shear modulus [N/mm²]	690.0
rolling shear modulus [N/mm²]	69.0
density [kg/m³]	350.0
density mean value [kg/m³]	420.0

3.3 Cross-sectional values

EA_{ef}	1.76E9 N
EI_{ef}	1.431E13 N·mm²
GA_{ef}	3.064E7 N



4 Loads

Field	$g_{0,k}$	$g_{1,k}$	q_k	Category	s_k	Altitude/Region	w_k
1	1.54 kN/m	0.5 kN/m²			3.2kN/m²	FIN, IS, N, S	

Partial safety factors:

γ_G = 1.35
γ_Q = 1.5

Load position:

Plate weight: Total
Permanent loads: Total
Imposed loads: Field-by-field
Snow: Field-by-field
Wind: Total

Combinations:

Combination factors: according to NA

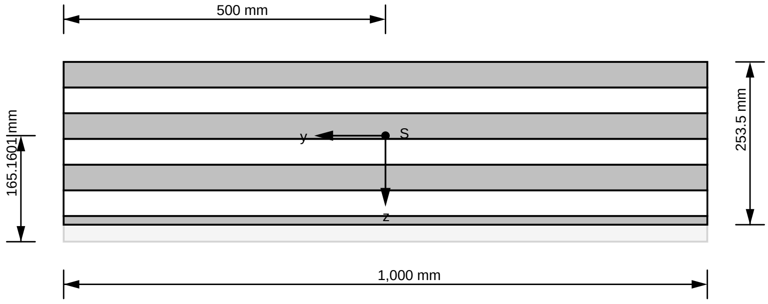
Combinations of distributed and concentrated loads:
q_k and Q_k will be considered as one load group
s_k and S_k will be considered as one load group
w_k and W_k will be considered as one load group

5 Specification concerning structural fire design

Fire duration: 30 minutes
Side exposed to fire: below
falling off of charred layers is considered
Without gaps or with bonded edges
k_{fire} = 1.15
d_0 = 7 mm
Partial safety factor $\gamma_{M,fi}$ = 1.0
Charring rate β_0 = 0.65 mm/min

5.1 Cross-sectional values in case of fire

EA_{ef}	1.468E9 N
EI_{ef}	8.685E12 N·mm²
GA_{ef}	2.671E7 N



6 Information concerning vibrations

No specifications are available

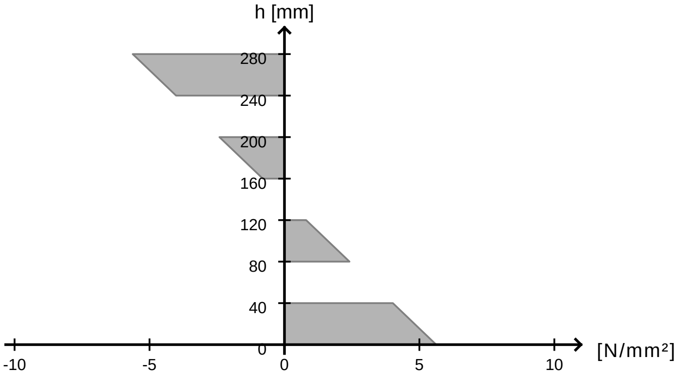
7 Results

Referenced standards: EN 1995-1-1:2009, ON B 1995-1-1/NA:2014-11-15
Underlying calculation method: Timoshenko

7.1 ULS

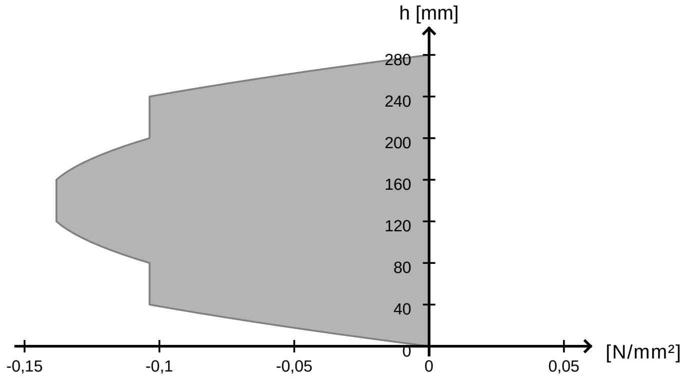
7.1.1 Bending

Utilisation ratio	33.3 %
k_{mod}	0.8
at x	3.72 m
Ek	2
Fundamental combination	$1.35*g_{0,k}$ + $1.35*g_{1,k}$ + $1.50*1.00*s_k$



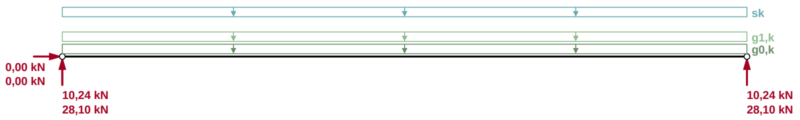
7.1.2 Shear

Utilisation ratio	21.6 %
k_{mod}	0.8
at x	7.44 m
Ek	2
Fundamental combination	$1.35 \cdot g_{0,k}$ + $1.35 \cdot g_{1,k}$ + $1.50 \cdot 1.00 \cdot s_k$



7.1.3 Bearing pressure

Utilisation ratio	13.0 %
k_{mod}	0.8
at x	7.44 m
Ek	2
Fundamental combination	$1.35*g_{0,k}$ + $1.35*g_{1,k}$ + $1.50*1.00*s_k$



7.2 SLS

7.2.1 Deflection

Limit values according to EN 1995-1-1
Instantaneous deformation w_{inst} t = 0: l/300 (15.8 mm, 63.7 %)
Final deformation $w_{net,fin}$ t = inf: l/250 (23.9 mm, 80.2 %)
Final deformation w_{fin} t = inf: l/150 (23.9 mm, 48.1 %)

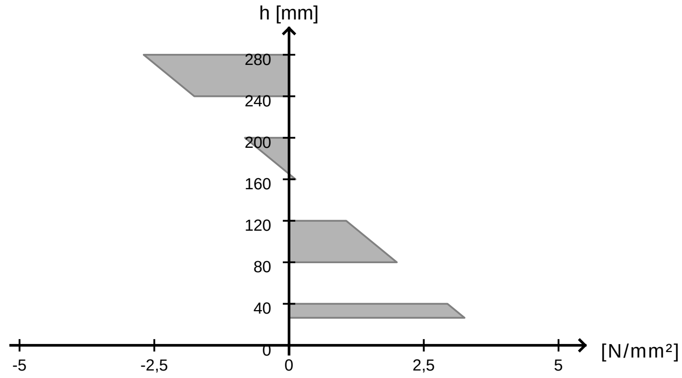
Limit values according to ON B 1995-1-1/NA:2014-11-15
Instantaneous deformation w_{inst} t = 0: l/300 (15.8 mm, 63.7 %)
Final deformation $w_{net,fin}$ t = inf: l/250 (16.1 mm, 54.3 %)
Final deformation w_{fin} t = inf: l/150 (23.9 mm, 48.1 %)

Utilisation ratio	80.2 %
w_{max}	23.9 mm
k_{def}	1.0
at x	3.72 m
Ek	10
Final deformation $w_{net,fin}$ t = inf (l/250)	

7.3 ULS in case of fire

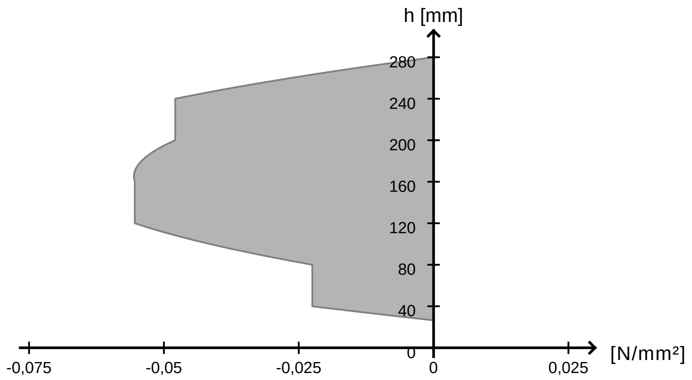
7.3.1 Bending

Utilisation ratio	10.7 %
k_{mod}	1.0
at x	3.72 m
Ek	6
Accidental combination	$g_{0,k} + g_{1,k} + 0.20*s_k$



7.3.2 Shear

Utilisation ratio	4.8 %
k_{mod}	1.0
at x	7.44 m
Ek	6
Accidental combination	$g_{0,k} + g_{1,k} + 0.20*s_k$



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CLTdesigner
Version 6.11.1

Summary of results

Project number:	BYG508
Project:	Appartment building G+2
Structural element:	Floor
Cross section:	User-defined cross section: 5s - 160 mm
Description:	Project for master thesis in UIA
Date:	Apr 23, 2019
Time:	10:39:07 AM
Author:	

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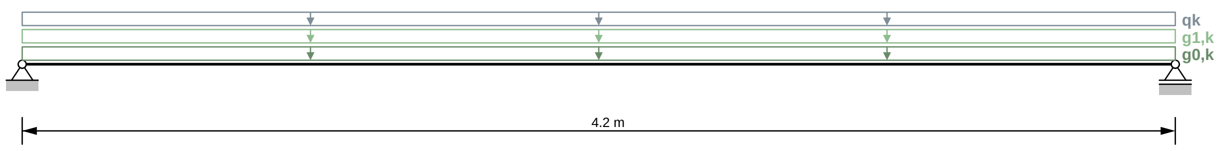
1 General

Service class 2

2 Structural system

Single span girder

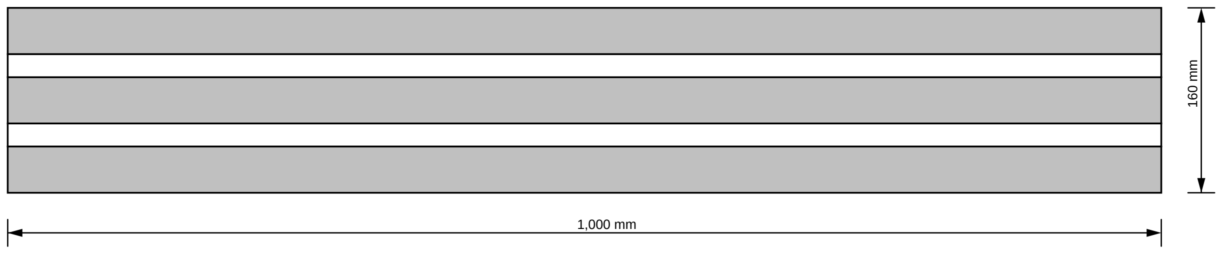


2.1 Supports

Support	x	Width
A	0.0 m	0.1 m
B	4.2 m	0.1 m

3 Cross section

User-defined cross section
5 layers (width: 1,000 mm / thickness: 160 mm)



3.1 Layer composition

Layer	Thickness	Orientation	Material

# 1	40 mm	0	C24
# 2	20 mm	90	C24
# 3	40 mm	0	C24
# 4	20 mm	90	C24
# 5	40 mm	0	C24

Orientation 0 = top layer longitudinal to span; Orientation 90 = top layer perpendicular to span

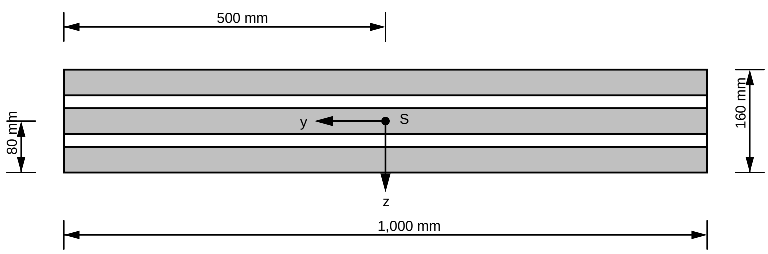
3.2 Material parameters

Partial safety factor γ_M = 1.25

Material parameters for	**C24**
bending strength [N/mm²]	24.0
tensile strength parallel [N/mm²]	14.0
tensile strength perpendicular [N/mm²]	0.4
compressive strength parallel [N/mm²]	21.0
compressive strength perpendicular [N/mm²]	2.5
shear strength [N/mm²]	2.68
rolling shear strength [N/mm²]	1.0
Youngs modulus parallel [N/mm²]	11,000.0
5%-quantile from Youngs modulus parallel [N/mm²]	7,400.0
Youngs modulus perpendicular [N/mm²]	370.0 (0.0)
shear modulus [N/mm²]	690.0
rolling shear modulus [N/mm²]	69.0
density [kg/m³]	350.0
density mean value [kg/m³]	420.0

3.3 Cross-sectional values

EA_{ef}	1.32E9 N
EI_{ef}	3.344E12 N·mm²
GA_{ef}	2.326E7 N



4 Loads

Field	$g_{0,k}$	$g_{1,k}$	q_k	Category	s_k	Altitude/Region	w_k
1	0.88 kN/m	0.5 kN/m²	4 kN/m²	A			

Partial safety factors:

γ_G = 1.35
γ_Q = 1.5

Load position:

Plate weight: Total
Permanent loads: Total
Imposed loads: Field-by-field
Snow: Field-by-field
Wind: Total

Combinations:

Combination factors: according to NA

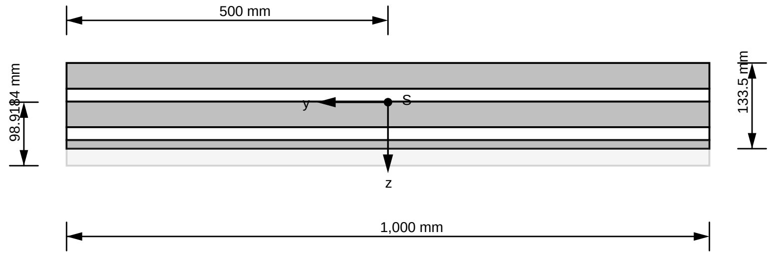
Combinations of distributed and concentrated loads:
q_k and Q_k will be considered as one load group
s_k and S_k will be considered as one load group
w_k and W_k will be considered as one load group

5 Specification concerning structural fire design

Fire duration: 30 minutes
Side exposed to fire: below
falling off of charred layers is considered
Without gaps or with bonded edges
k_{fire} = 1.15
d_0 = 7 mm
Partial safety factor $\gamma_{M,fi}$ = 1.0
Charring rate β_0 = 0.65 mm/min

5.1 Cross-sectional values in case of fire

EA_{ef}	1.028E9 N
EI_{ef}	1.66E12 N·mm²
GA_{ef}	1.901E7 N



6 Information concerning vibrations

No specifications are available

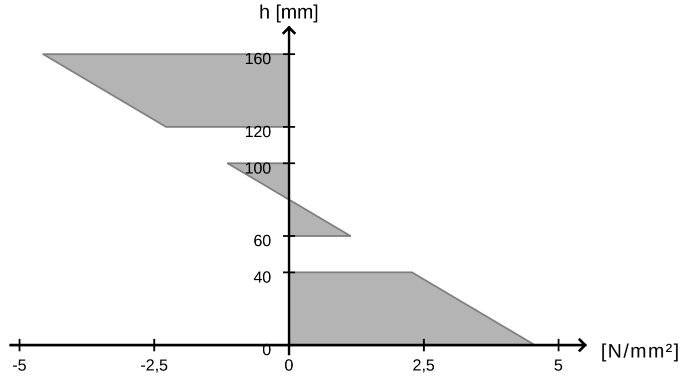
7 Results

Referenced standards: EN 1995-1-1:2009, ON B 1995-1-1/NA:2014-11-15
Underlying calculation method: Timoshenko

7.1 ULS

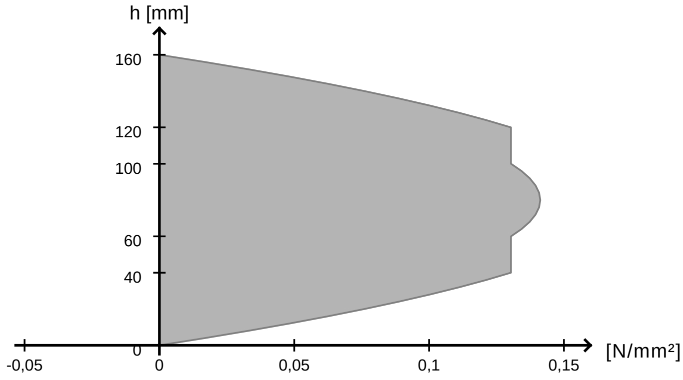
7.1.1 Bending

Utilisation ratio	27.0 %
k_{mod}	0.8
at x	2.1 m
Ek	2
Fundamental combination	$1.35*g_{0,k}$ + $1.35*g_{1,k}$ + $1.50*1.00*q_k$



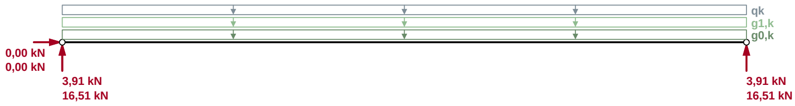
7.1.2 Shear

Utilisation ratio	20.4 %
k_{mod}	0.8
at x	0.0 m
Ek	2
Fundamental combination	$1.35*g_{0,k}$ + $1.35*g_{1,k}$ + $1.50*1.00*q_k$



7.1.3 Bearing pressure

Utilisation ratio	8.2 %
k_{mod}	0.8
at x	0.0 m
Ek	2
Fundamental combination	$1.35*g_{0,k}$ + $1.35*g_{1,k}$ + $1.50*1.00*q_k$



7.2 SLS

7.2.1 Deflection

Limit values according to EN 1995-1-1
Instantaneous deformation w_{inst} t = 0: l/300 (7.0 mm, 50.2 %)
Final deformation $w_{net,fin}$ t = inf: l/250 (10.4 mm, 61.9 %)
Final deformation w_{fin} t = inf: l/150 (10.4 mm, 37.1 %)

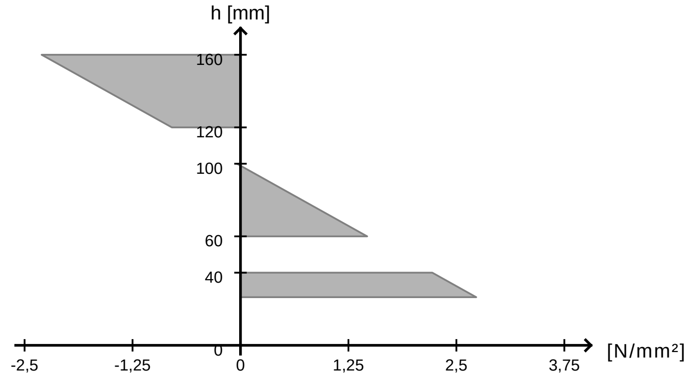
Limit values according to ON B 1995-1-1/NA:2014-11-15
Instantaneous deformation w_{inst} t = 0: l/300 (7.0 mm, 50.2 %)
Final deformation $w_{net,fin}$ t = inf: l/250 (6.7 mm, 40.1 %)
Final deformation w_{fin} t = inf: l/150 (10.4 mm, 37.1 %)

Utilisation ratio	61.9 %
w_{max}	10.4 mm
k_{def}	1.0
at x	2.1 m
Ek	10
Final deformation $w_{net,fin}$ t = inf (l/250)	

7.3 ULS in case of fire

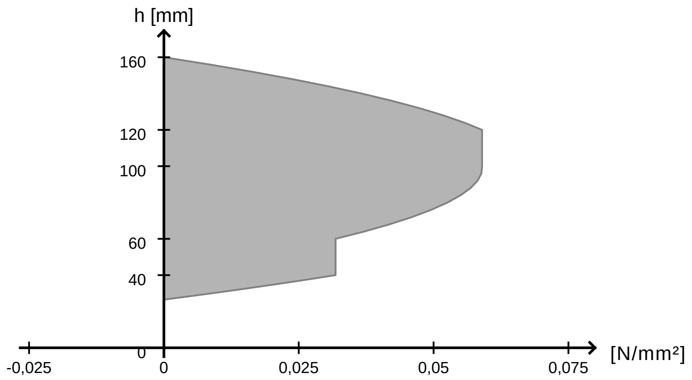
7.3.1 Bending

Utilisation ratio	9.0 %
k_{mod}	1.0
at x	2.1 m
Ek	6
Accidental combination	$g_{0,k} + g_{1,k} + 0.30*q_k$



7.3.2 Shear

Utilisation ratio	5.1 %
k_{mod}	1.0
at x	0.0 m
Ek	6
Accidental combination	$g_{0,k} + g_{1,k} + 0.30*q_k$



8 Appendix

8.1 Combinations

Ek	k_{mod} / k_{def}	Kombination
Fundamental combination		
1	0.6	$1.35*g_{0,k} + 1.35*g_{1,k}$
2	0.8	$1.35*g_{0,k} + 1.35*g_{1,k} + 1.50*1.00*q_k$
3	0.6	$g_{0,k} + g_{1,k}$
4	0.8	$g_{0,k} + g_{1,k} + 1.50*1.00*q_k$
Accidental combination		
5	0.6	$g_{0,k} + g_{1,k}$
6	0.8	$g_{0,k} + g_{1,k} + 0.30*q_k$

Ek	k_{mod} / k_{def}	Kombination
SLS combinations according to EN 1995-1-1		
8	1.0	$g_{0,k} + g_{1,k} + 1.00{*}q_k$
9	1.0	$g_{0,k} + (g_{0,k})_{creep} + g_{1,k} + (g_{1,k})_{creep} + 1.00{*}q_k + (0.30{*}q_k)_{creep}$
10	1.0	$g_{0,k} + (g_{0,k})_{creep} + g_{1,k} + (g_{1,k})_{creep} + 1.00{*}q_k + (0.30{*}q_k)_{creep}$
SLS combinations according to EN 1995-1-1:NA		
12	1.0	$g_{0,k} + g_{1,k} + 1.00{*}q_k$
14	1.0	$g_{0,k} + (g_{0,k})_{creep} + g_{1,k} + (g_{1,k})_{creep} + 1.00{*}q_k + (0.30{*}q_k)_{creep}$
15	1.0	$g_{0,k} + (g_{0,k})_{creep} + g_{1,k} + (g_{1,k})_{creep} + 0.30{*}q_k + (0.30{*}q_k)_{creep}$

8.2 Verification

8.2.1 Bending

Field	x	Ek	k_{mod}	$M_{y,d}$	$\sigma_{max,d}$	$f_{m,d}$	η
	[m]		[-]	[kN·m]	[N/mm²]	[N/mm²]	[%]
1	0.0	2	0.8	0.00	0.00	16.90	0.0
1	0.42	2	0.8	6.24	1.64	16.90	9.7
1	0.84	2	0.8	11.10	2.92	16.90	17.3
1	1.26	2	0.8	14.56	3.83	16.90	22.7
1	1.68	2	0.8	16.64	4.38	16.90	25.9
1	2.1	2	0.8	17.34	4.56	16.90	27.0
1	2.52	2	0.8	16.64	4.38	16.90	25.9
1	2.94	2	0.8	14.56	3.83	16.90	22.7
1	3.36	2	0.8	11.10	2.92	16.90	17.3
1	3.78	2	0.8	6.24	1.64	16.90	9.7
1	4.2	2	0.8	0.00	0.00	16.90	0.0

8.2.2 Shear

Field	x	Ek	k_{mod}	$V_{z,d}$	$\tau_{v,d}$	$f_{v,d}$	η
					$\tau_{r,d}$	$f_{r,d}$	
	[m]		[-]	[kN]	[N/mm²]	[N/mm²]	[%]
1	0.0	2	0.8	16.51	0.14	1.72	8.2
					0.13	0.64	20.4
1	0.42	2	0.8	13.21	0.11	1.72	6.6
					0.10	0.64	16.3
1	0.84	2	0.8	9.91	0.08	1.72	4.9

Field	x	Ek	k_{mod}	$V_{z,d}$	$\tau_{v,d}$ / $\tau_{r,d}$	$f_{v,d}$ / $f_{r,d}$	η
	[m]		[-]	[kN]	[N/mm²]	[N/mm²]	[%]
					0.08	0.64	12.2
1	1.26	2	0.8	6.60	0.06	1.72	3.3
					0.05	0.64	8.1
1	1.68	2	0.8	3.30	0.03	1.72	1.6
					0.03	0.64	4.1
1	2.1	2	0.8	-0.00	0.00	1.72	0.0
					0.00	0.64	0.0
1	2.52	2	0.8	-3.30	0.03	1.72	1.6
					0.03	0.64	4.1
1	2.94	2	0.8	-6.60	0.06	1.72	3.3
					0.05	0.64	8.1
1	3.36	2	0.8	-9.91	0.08	1.72	4.9
					0.08	0.64	12.2
1	3.78	2	0.8	-13.21	0.11	1.72	6.6
					0.10	0.64	16.3
1	4.2	2	0.8	-16.51	0.14	1.72	8.2
					0.13	0.64	20.4

8.2.3 Bearing pressure

Support	x	Ek	k_{mod}	F_d	A_{sec}	$k_{c,90}$	$\sigma_{c,90,d}$	$f_{c,90,d}$	η
	[m]		[-]	[kN]	[mm²]	[-]	[N/mm²]	[N/mm²]	[%]
A	0.0	2	0.8	16.51	100,000	1.26	0.17	2.01	8.2
B	4.2	2	0.8	16.51	100,000	1.26	0.17	2.01	8.2

8.2.4 Bending in case of fire

Field	x	Ek	k_{mod}	$M_{y,d}$	$\sigma_{max,d}$	$f_{m,d}$	η
	[m]		[-]	[kN·m]	[N/mm²]	[N/mm²]	[%]
1	0.0	6	1.0	0.00	0.00	26.40	0.0
1	0.42	6	1.0	2.05	0.98	26.40	3.2
1	0.84	6	1.0	3.64	1.75	26.40	5.8
1	1.26	6	1.0	4.78	2.29	26.40	7.6
1	1.68	6	1.0	5.46	2.62	26.40	8.6
1	2.1	6	1.0	5.69	2.73	26.40	9.0

Field	x	Ek	k_{mod}	$M_{y,d}$	$\sigma_{max,d}$	$f_{m,d}$	η
	[m]		**[-]**	**[kN·m]**	**[N/mm²]**	**[N/mm²]**	**[%]**
1	2.52	6	1.0	5.46	2.62	26.40	8.6
1	2.94	6	1.0	4.78	2.29	26.40	7.6
1	3.36	6	1.0	3.64	1.75	26.40	5.8
1	3.78	6	1.0	2.05	0.98	26.40	3.2
1	4.2	6	1.0	0.00	0.00	26.40	0.0

8.2.5 Shear in case of fire

Field	x	Ek	k_{mod}	$V_{z,d}$	$\tau_{v,d}$	$f_{v,d}$	η
					$\tau_{r,d}$	$f_{r,d}$	
	[m]		**[-]**	**[kN]**	**[N/mm²]**	**[N/mm²]**	**[%]**
1	0.0	6	1.0	5.42	0.06	2.68	1.9
					0.06	1.00	5.1
1	0.42	6	1.0	4.33	0.05	2.68	1.5
					0.05	1.00	4.1
1	0.84	6	1.0	3.25	0.04	2.68	1.1
					0.04	1.00	3.1
1	1.26	6	1.0	2.17	0.02	2.68	0.8
					0.02	1.00	2.1
1	1.68	6	1.0	1.08	0.01	2.68	0.4
					0.01	1.00	1.0
1	2.1	6	1.0	-0.00	0.00	2.68	0.0
					0.00	1.00	0.0
1	2.52	6	1.0	-1.08	0.01	2.68	0.4
					0.01	1.00	1.0
1	2.94	6	1.0	-2.17	0.02	2.68	0.8
					0.02	1.00	2.1
1	3.36	6	1.0	-3.25	0.04	2.68	1.1
					0.04	1.00	3.1
1	3.78	6	1.0	-4.33	0.05	2.68	1.5
					0.05	1.00	4.1
1	4.2	6	1.0	-5.42	0.06	2.68	1.9
					0.06	1.00	5.1

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CLTdesigner
Version 6.11.1

Summary of results

Project number:	BYG508
Project:	Appartment building G+2
Structural element:	Floor
Cross section:	User-defined cross section: 7s - 280 mm
Description:	Project for master thesis in UIA
Date:	Apr 23, 2019
Time:	10:35:21 AM
Author:	

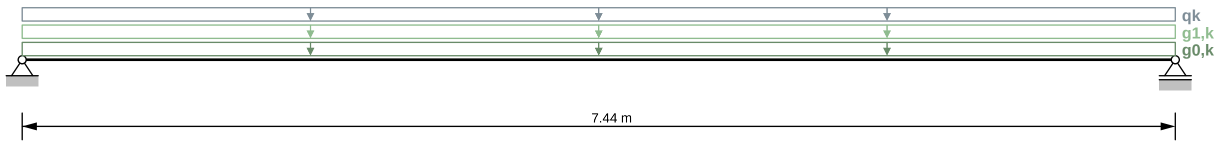
Table of content

1 General

Service class 2

2 Structural system

Single span girder

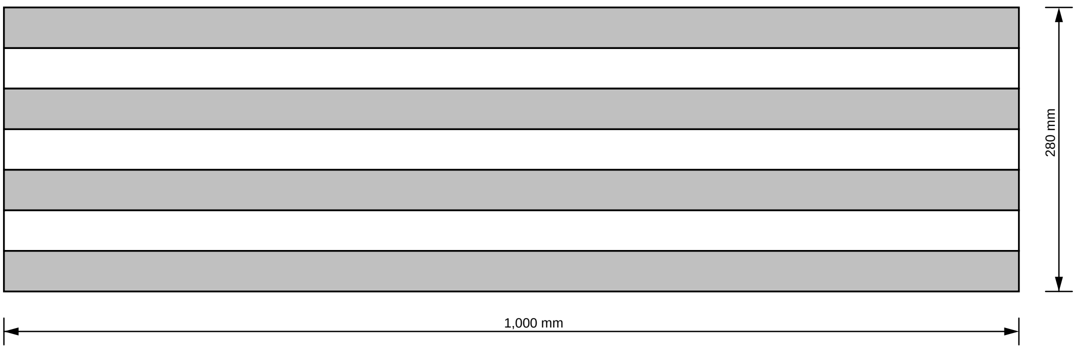


2.1 Supports

Support	x	Width
A	0.0 m	0.1 m
B	7.44 m	0.1 m

3 Cross section

User-defined cross section
7 layers (width: 1,000 mm / thickness: 280 mm)



3.1 Layer composition

Layer	Thickness	Orientation	Material

# 1	40 mm	0	C24
# 2	40 mm	90	C24
# 3	40 mm	0	C24
# 4	40 mm	90	C24
# 5	40 mm	0	C24
# 6	40 mm	90	C24
# 7	40 mm	0	C24

Orientation 0 = top layer longitudinal to span; Orientation 90 = top layer perpendicular to span

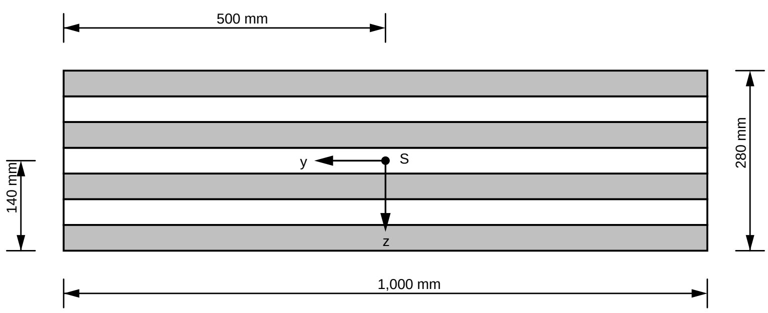
3.2 Material parameters

Partial safety factor γ_M = 1.25

Material parameters for	**C24**
bending strength [N/mm²]	24.0
tensile strength parallel [N/mm²]	14.0
tensile strength perpendicular [N/mm²]	0.4
compressive strength parallel [N/mm²]	21.0
compressive strength perpendicular [N/mm²]	2.5
shear strength [N/mm²]	2.68
rolling shear strength [N/mm²]	1.0
Youngs modulus parallel [N/mm²]	11,000.0
5%-quantile from Youngs modulus parallel [N/mm²]	7,400.0
Youngs modulus perpendicular [N/mm²]	370.0 (0.0)
shear modulus [N/mm²]	690.0
rolling shear modulus [N/mm²]	69.0
density [kg/m³]	350.0
density mean value [kg/m³]	420.0

3.3 Cross-sectional values

EA_{ef}	1.76E9 N
EI_{ef}	1.431E13 N·mm²
GA_{ef}	3.064E7 N



4 Loads

Field	$g_{0,k}$	$g_{1,k}$	q_k	Category	s_k	Altitude/Region	w_k
1	1.54 kN/m	0.5 kN/m²	4 kN/m²	A			

Partial safety factors:

γ_G = 1.35
γ_Q = 1.5

Load position:

Plate weight: Total
Permanent loads: Total
Imposed loads: Field-by-field
Snow: Field-by-field
Wind: Total

Combinations:

Combination factors: according to NA

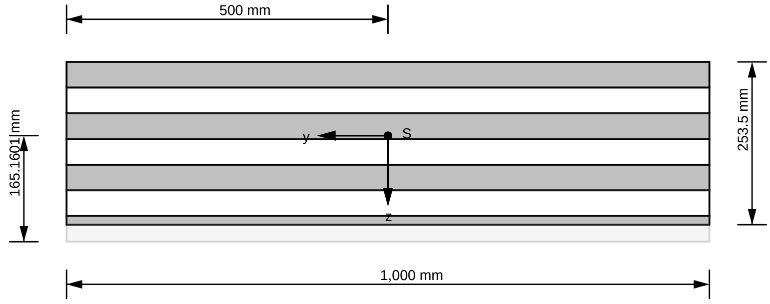
Combinations of distributed and concentrated loads:
q_k and Q_k will be considered as one load group
s_k and S_k will be considered as one load group
w_k and W_k will be considered as one load group

5 Specification concerning structural fire design

Fire duration: 30 minutes
Side exposed to fire: below
falling off of charred layers is considered
Without gaps or with bonded edges
k_{fire} = 1.15
d_0 = 7 mm
Partial safety factor $\gamma_{M,fi}$ = 1.0
Charring rate β_0 = 0.65 mm/min

5.1 Cross-sectional values in case of fire

EA_{ef}	1.468E9 N
EI_{ef}	8.685E12 N·mm²
GA_{ef}	2.671E7 N



6 Information concerning vibrations

No specifications are available

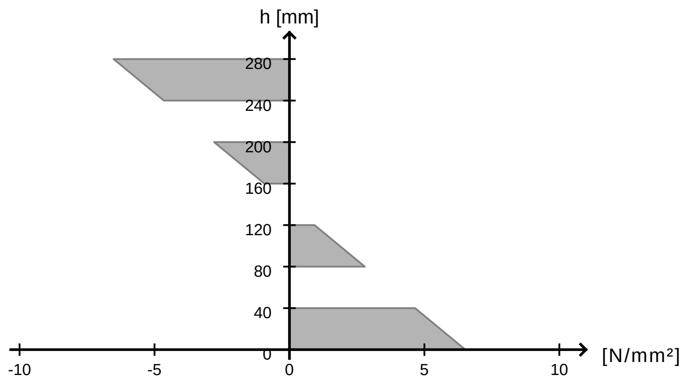
7 Results

Referenced standards: EN 1995-1-1:2009, ON B 1995-1-1/NA:2014-11-15
Underlying calculation method: Timoshenko

7.1 ULS

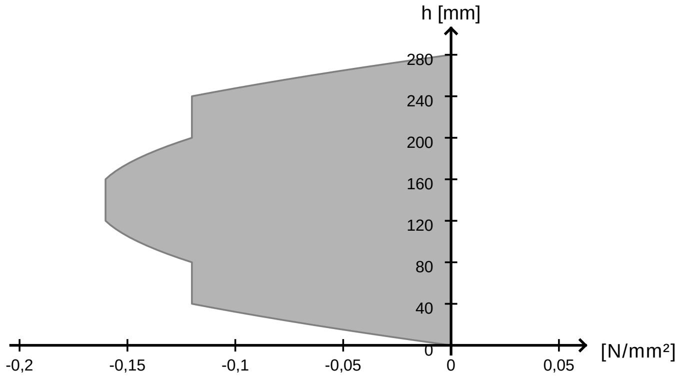
7.1.1 Bending

Utilisation ratio	38.6 %
k_{mod}	0.8
at x	3.72 m
Ek	2
Fundamental combination	$1.35*g_{0,k}$ + $1.35*g_{1,k}$ + $1.50*1.00*q_k$



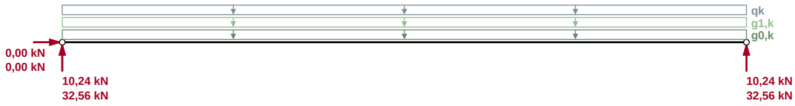
7.1.2 Shear

Utilisation ratio	25.0 %
k_{mod}	0.8
at x	7.44 m
Ek	2
Fundamental combination	$1.35*g_{0,k}$ + $1.35*g_{1,k}$ + $1.50*1.00*q_k$



7.1.3 Bearing pressure

Utilisation ratio	15.0 %
k_{mod}	0.8
at x	7.44 m
Ek	2
Fundamental combination	$1.35*g_{0,k}$ + $1.35*g_{1,k}$ + $1.50*1.00*q_k$



7.2 SLS

7.2.1 Deflection

Limit values according to EN 1995-1-1
Instantaneous deformation w_{inst} t = 0: l/300 (18.2 mm, 73.4 %)
Final deformation $w_{net,fin}$ t = inf: l/250 (28.0 mm, 93.9 %)
Final deformation w_{fin} t = inf: l/150 (28.0 mm, 56.4 %)

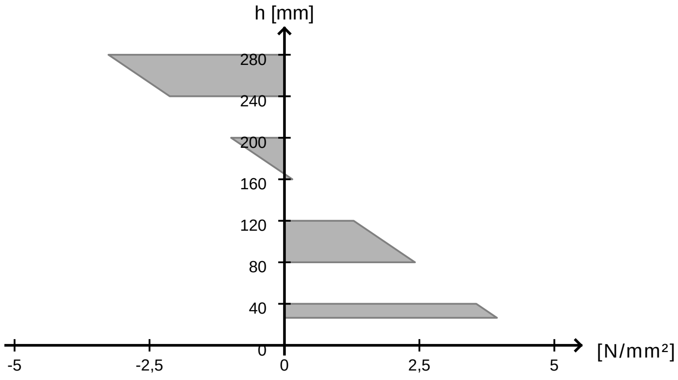
Limit values according to ON B 1995-1-1/NA:2014-11-15
Instantaneous deformation w_{inst} t = 0: l/300 (18.2 mm, 73.4 %)
Final deformation $w_{net,fin}$ t = inf: l/250 (19.5 mm, 65.6 %)
Final deformation w_{fin} t = inf: l/150 (28.0 mm, 56.4 %)

Utilisation ratio	93.9 %
w_{max}	28.0 mm
k_{def}	1.0
at x	3.72 m
Ek	10
Final deformation $w_{net,fin}$ t = inf (l/250)	

7.3 ULS in case of fire

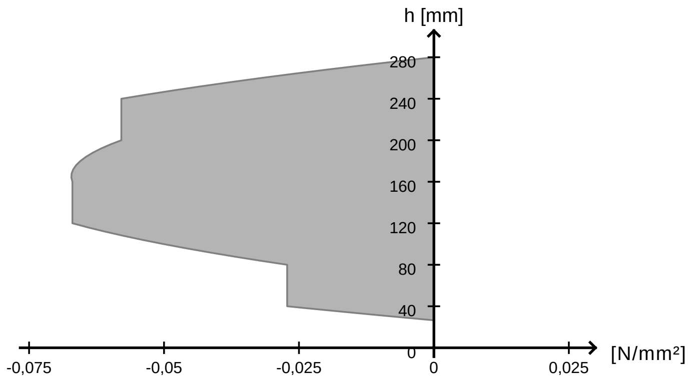
7.3.1 Bending

Utilisation ratio	13.0 %
k_{mod}	1.0
at x	3.72 m
Ek	6
Accidental combination	$g_{0,k} + g_{1,k} + 0.30*q_k$



7.3.2 Shear

Utilisation ratio	5.8 %
k_{mod}	1.0
at x	7.44 m
Ek	6
Accidental combination	$g_{0,k} + g_{1,k} + 0.30*q_k$



Timber column base connection

Beam column dowel connection

Timber Column base design:

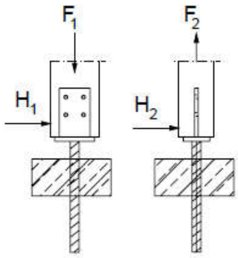
The design is done base on the Simpson Strong-Tie product catalog. In the catalog, load tables are given for different connection types.
The following formula should be applied for the value in the tables.
In the catalog tables the characterstic bearing capasity R_{ik} is given. The design value (load carrying capacity), R_{id}, will be the minimum the design value of steel and timber.

The design value for timber shall be calculated as:

$$R_{id} = \frac{R_{ik} \cdot k_{mod}}{\gamma_M}$$

The design value for steel shall be calculated as:

$$R_{id} = \frac{R_{ik}}{\gamma_M}$$



Force direction in the base of the column

Design check: $\frac{F_{1d}}{R_{1d}} + \frac{H_{2d}}{R_{H2d}} \le 1$

Where:
k_{mod} is a modification factor taking into account the effect of the duration of the laod and moisture content. se table 3.1 from standard.
γ_M is the partial factor for material. In the Simson Strong-Tie the value γ_M = 1,35 for connections. In the Norwegian standard (NS EN 1995) this factor is 1,30 as in the table 2.3 below from the standard.

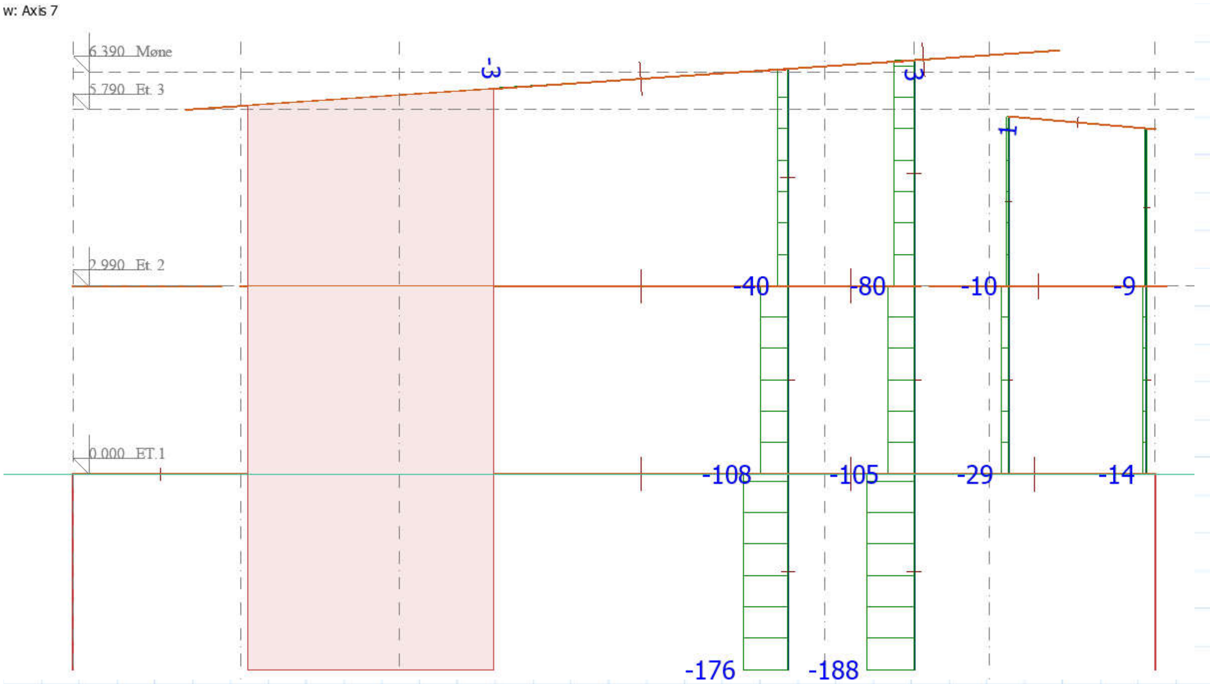
Table 2.3 – Recommended partial factors γ_M for material properties and resistances

Fundamental combinations:	
Solid timber	1,3
Glued laminated timber	1,25
LVL, plywood, OSB,	1,2
Particleboards	1,3
Fibreboards, hard	1,3
Fibreboards, medium	1,3
Fibreboards, MDF	1,3
Fibreboards, soft	1,3
Connections	1,3
Punched metal plate fasteners	1,25
Accidental combinations	1,0

In the project there are timber columns in axis 7.
Table 2 below from the Simpson catalog is used for timber columns in this axis.

The maximum charactersitc force for the columns in axis 7 is 188 kN in downward direction which is equivalent to F_1 in the figure above.

$F_{1d} := 188\ kN$ -------------- > See normal force diagram below



k_{mod} from the Norwegian standard is as in the table below:

Table 2.2 – Examples of load-duration assignment

Load-duration class	Examples of loading
Permanent	self-weight
Long-term	storage
Medium-term	imposed floor load, snow
Short-term	snow, wind
Instantaneous	wind, accidental load

Table 3.1 – Values of k_{mod}

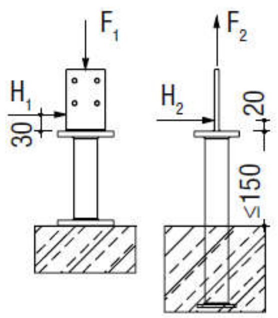
Material	Standard	Service class	Load-duration class				
			Permanent action	Long term action	Medium term action	Short term action	Instanta-neous action
Solid timber	EN 14081-1	1	0,60	0,70	0,80	0,90	1,10
		2	0,60	0,70	0,80	0,90	1,10
		3	0,50	0,55	0,65	0,70	0,90
Glued laminated timber	EN 14080	1	0,60	0,70	0,80	0,90	1,10
		2	0,60	0,70	0,80	0,90	1,10
		3	0,50	0,55	0,65	0,70	0,90
LVL	EN 14374, EN 14279	1	0,60	0,70	0,80	0,90	1,10
		2	0,60	0,70	0,80	0,90	1,10
		3	0,50	0,55	0,65	0,70	0,90

PISMAXI connection type is chosen from Simpson Strong-Tie as in table 2 below

TABEL 2

Kraft-retning	Træ-bredde b [mm]	PIS Træ	PIS Stål	PISB Træ	PISB Stål	Træ-bredde b [mm]	PISMAXI Træ	PISMAXI Stål	PISBMAXI Træ	PISBMAXI Stål
		Karakteristisk bæreevne [kN] min. af [1]					Karakteristisk bæreevne [kN] min. af [1]			
$R_{1,k}$	≥ 80	142,8	101,9	142,8	101,9	≥ 120	272,2	187,9	272,2	256,9
$R_{2,k}$	80	16,0	-	16,0	-	120	34,5	-	34,5	-
	100	18,7	-	18,7	-	140	38,5	-	38,5	-
	120	20,7	-	20,7	-	160	42,1	-	42,1	-
$R_{H1,k}$	80	10,9		10,9		120	22,5		22,5	
	100	12,7	6,7	11,0	6,1	140	25,2	24,0	25,2	14,1
	120			11,0		160	27,5		27,5	
$R_{H2,k}$	80	4,1		4,1		120	7,6	-	7,6	-
	100	5,9	5,1	5,9	5,0	140	9,9	-	9,9	-
	120	7,0	5,7	7,9	5,5	160	12,3	-	12,3	-

Force direction



Reading from the table for timber and steel bearing capacity for PISMAXI

$R_{1kt} := 272.2\ kN$ ....for timber

$k_{mod} := 0.8$ ...... for medium-term action

$\gamma_M := 1.30$

$R_{1ks} := 187.9\ kN$ ...for steel

$$R_{1d} := min\left(\left(\frac{R_{1kt} \cdot k_{mod}}{\gamma_M}\right), \left(\frac{R_{1ks}}{\gamma_M}\right)\right) = 144.538\ kN$$

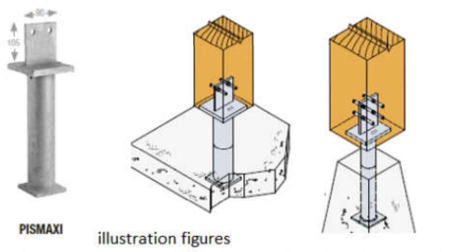


illustration figures

Check:

$$\frac{F_{1d}}{R_{1d}} = 1.301$$ >1 Design not OK!

Since the column size is 140x225 to pieces of PISMAXI will be used.

$$2 \cdot R_{1d} = 289.077\ kN$$

$$\frac{F_{1d}}{2\ R_{1d}} = 0.65$$ < 1 Design is OK!!

Design of dowel connection for beam, Beam-column connection

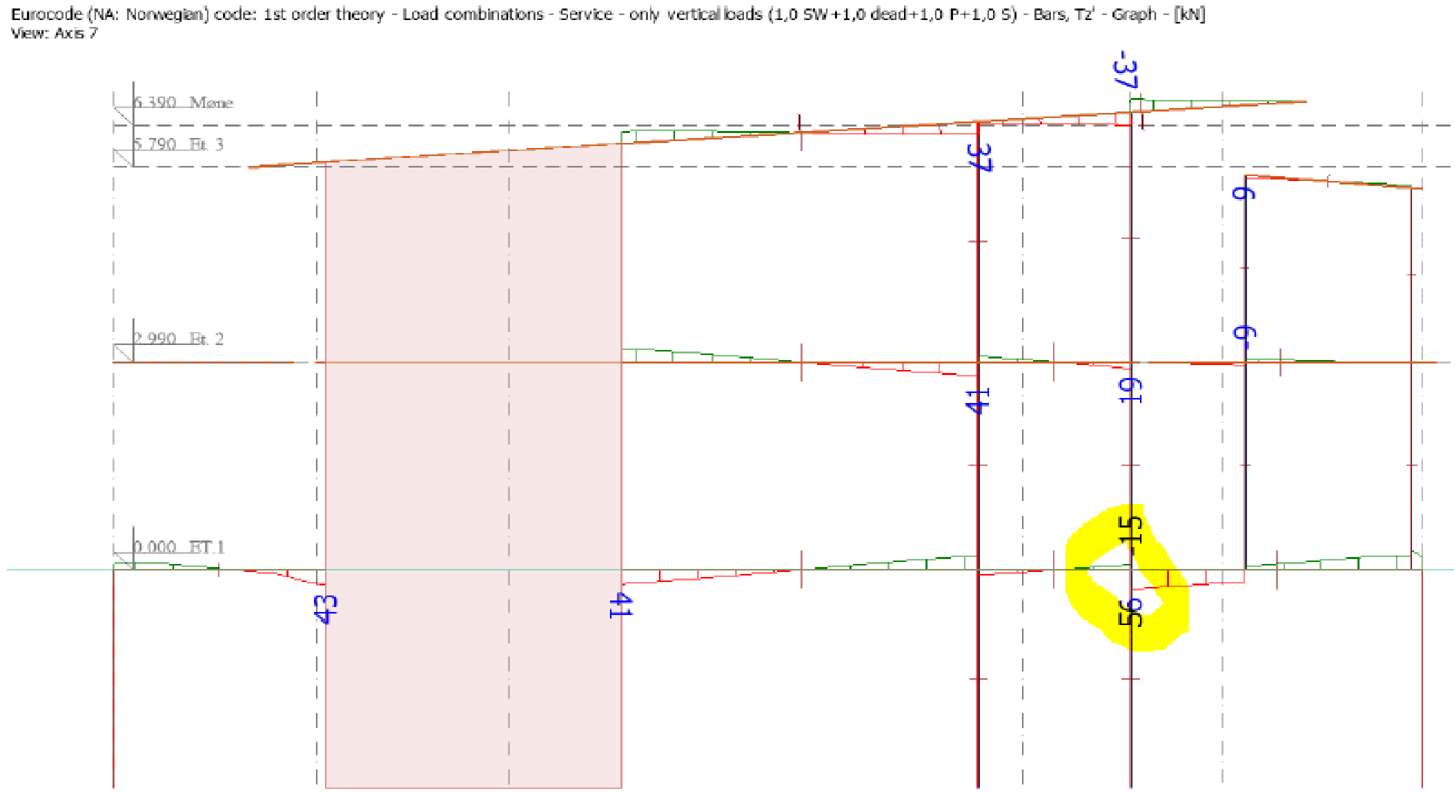


Figure: Shear force diagram

Maximum characterstic shear force at support	56	kN

input data	value	unit
material	GL30C	
Beam width	140	mm
Beam height	540	mm
ρk, is the charactertic density of timber	470	kg/m³
fuk, steel characterstic tensile strength	400	N/mm²
d, diameter of metal dowel or bolt	12	mm
Number of steel plate	1	stk
kmod	0,8	
γm, material factor, connection	1,3	

Minimum spacings and edge and end distance for dowels

	Angle to grain	min spacing, mm	applied
a1, parallel to grain	270	59,6	59,6
a2, perpendicular to grain	270	36	36
a3t, loaded end	-90	84	84
		80	
a3c, unloaded end	90	75,1	75,1
		42	
	270	14,8	
a4t, loaded edge	90	45,5	45,5
		36	
a4c, unloaded edge	270	36	36

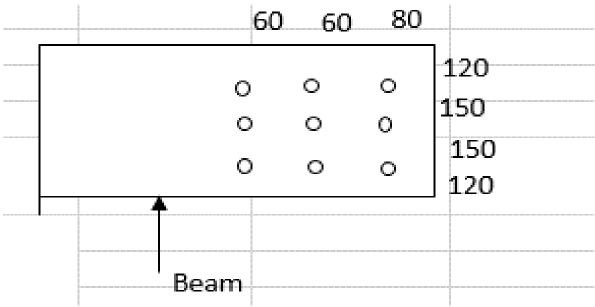
Thick plate: minimum thickenss should be greater or equal to d, mimimum should be 12 mm

Steel to timber connections:

Reference: standard NS EN 1995

Failure modes, with initially single steel plate

k90, for soft woods timber	1,53		(8.33)
fh0k, characterstic embedment strength parallel to the grain N/mm2	33,9152	N/mm²	(8.32)
fh90k, characterstic embedment strength perpendicular (90) to the grain in the timber memberN/mm2	23,82	N/mm²	(8.31)
Myk, characterstic fasteners yield moment	76745,42	Nmm	(8.30)
t1, smaller of thickness of the timber side member or penetration depth	70	mm	(8.11)
Fax, characterstic withdrawal capacity of fastener	0	N	



Beam: choice 9 dowels, 2 steel plate, 3x3.
Distance in x-direction: 100mm - 60mm - 60mm
Distance in y-retning: 120mm - 150mm - 150mm- 120mm

Charactersitc load carrying capacity per shear plane per fastener, Fvrk, For thick steel plate in single shear.

(c) Failure mode, Fvrk	20011,9	N	
(d) Failure mode, Fvrk	9799,4	N	
(e) Failure mode, Fvrk	10773,3	N	(8.11)

Minimum value capacity, Fvrk	9799,4	N	
Design capacity, FvRd per fastener	6030,4	N	
nef, is the effective number of fasteners in line parallel to the grain			
Number of dowels per steel plate	9	pcs	
Number of dowels per 2 steel plate	9	pcs	use 3x3 arrangement

Design of dowel connection for column, Beam-column connection

største opplagskraft	71	kN

input data	value	unit
material	GL30C	
Column width	140	mm
Column height	225	mm
ρk, is the charactertic density of timber	470	kg/m³
fuk, steel characterstic tensile strength	400	N/mm²
d, diameter of metal dowel or bolt	12	mm
Number of steel plate	1	stk
kmod	0,8	
γm, material factor, connection	1,3	

Minimum spacings and edge and end distance for dowels

	Angle to grain	min spacing, mm	applied
a1, parallel to grain	0	60,0	60,0
a2, perpendicular to grain	0	36	36
a3t, loaded end	0	84	84
		80	
a3c, unloaded end	180	67,3	67,3
		42	
	180	67,3	
a4t, loaded edge	0	24,0	36,0
		36	
a4c, unloaded edge	0	36	36

Failure modes, with initial 2 steel plate

k90, for soft woods timber	1,53	
fh0k, characterstic embedment strength parallel to the grain N/mm2	33,9152	N/mm²
fh90k, characterstic embedment strength perpendicular (90) to the grain in the timber memberN/mm2	23,82	N/mm²
Myk, characterstic fasteners yield moment	76745,42	Nmm
t1, smaller of thickness of the timber side member or penetration depth	70	mm
Fax, characterstic withdrawal capacity of fastener	0	N

Charactersitc load carrying capacity per shear plane per fastener, Fvrk, For thick steel plate in single shear

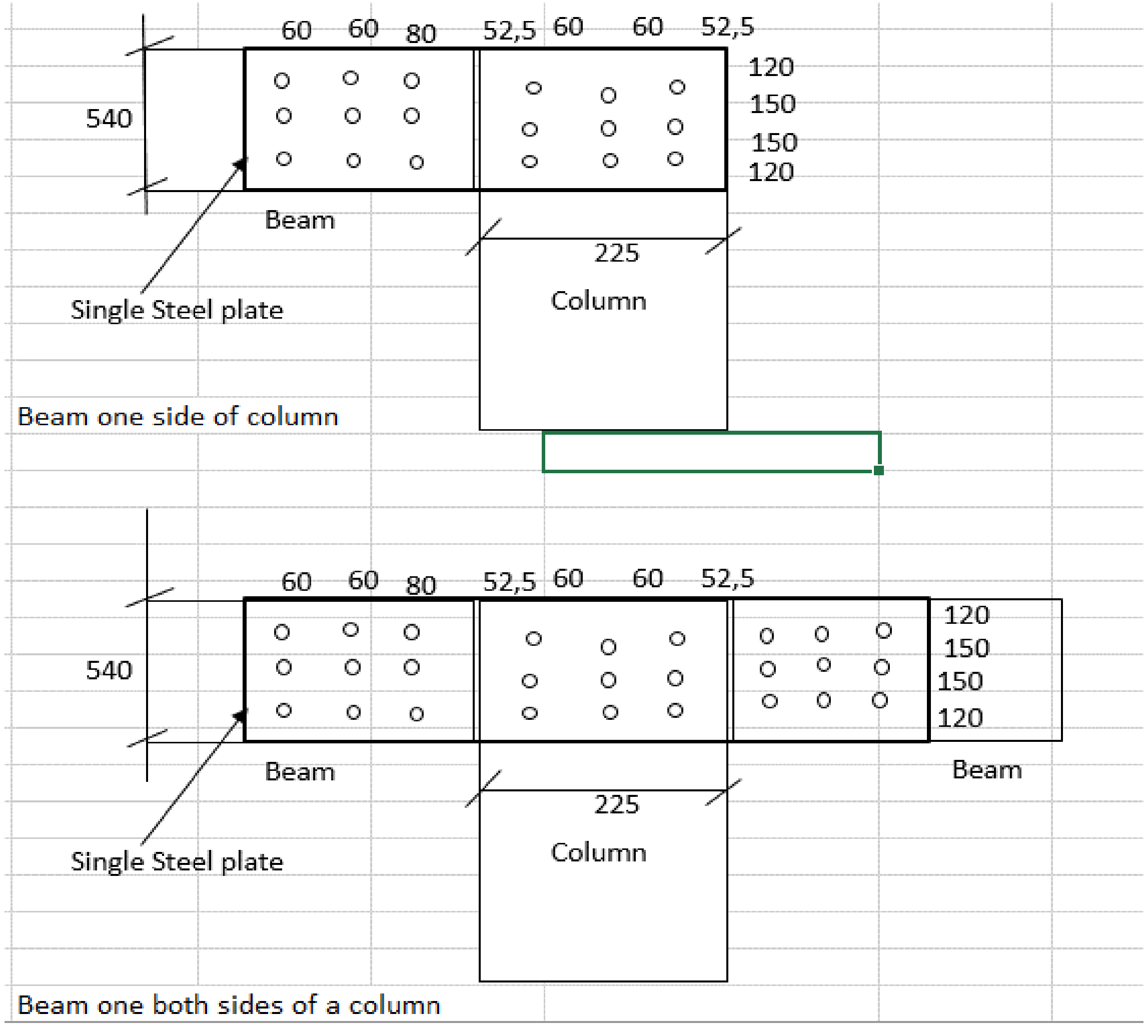
(c) Failure mode, Fvrk	28488,8	N
(d) Failure mode, Fvrk	13322,2	N
(e) Failure mode, Fvrk	12854,1	N
Minimum value capacity, Fvrk	12854,1	N
Design capacity, FvRd per fastener	7910,2	N
Design capacity, FvRd per fastener per section in single	7910,2	N
nef, for 3 dowels per row in line parallel to the grain	2,636	pcs
Number of dowels per row, perpendicular to the grain	3	pcs

(8.34)

arrangement of dowels 3x3

Column: Choose 12 dybler, 2 steel plpate, 4x3
Distance in x-direction: 52,5 mm - 60mm - 60mm - 52,5 mm
Distance in y-direction: 120mm - 150mm - 150mm - 120mm

Arrangement of dowels:



Appendix E.9

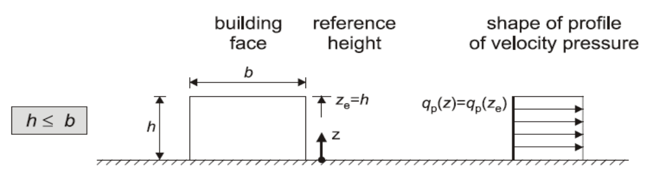
Wind load (W) - NS-EN 1991-1-4:2005+NA:2009

Inputdata:				Reference point in standard
Project location		Porsgrunn		
Fundamental value of the basic wind velocity	$v_{b,0}$	23	m/s	NA.4 (901.1)
Reference height	z	6,39	m	
Level factor	c_{alt}	1		Pkt. NA.4.2(2)P (901.1)
Pobability factor	c_{prob}	1		Pkt. NA.4.2(2)P
Season factor	c_{season}	1		Pkt. NA.4.2(2)P
direction factor	c_{dir}	1		Pkt. NA.4.2(2)P
Terrain category		II		Tabell NA.4.1
terain factor	k_r	0,19		Tabell NA.4.1
Roughness length	z_0	0,05	m	Tabell NA.4.1
Minimum height	z_{min}	4	m	Tabell NA.4.1
Correction legth factor	k_w	1,30		
Density of air	ρ	1,25	kg/m3	
Basic velocity pressure	q_b	0,33	kN/m^2	$q_b = \frac{1}{2} \cdot \rho \cdot v_b^2$
Peak velocity pressure	$q_p(z)$	0,69	kN/m^2	

$$q_p(z) = 0{,}625 \cdot \left[k_r \cdot \ln\left(\frac{z}{z_0}\right)\right]^2 \cdot \left(1 + \frac{7}{\ln(z/z_0)}\right) \cdot v_{b,0}^2 \cdot \left[c_{alt} \cdot c_{prob}\right]^2 = k_w \cdot v_{b,0}^2 \cdot \left[c_{alt} \cdot c_{prob}\right]^2$$

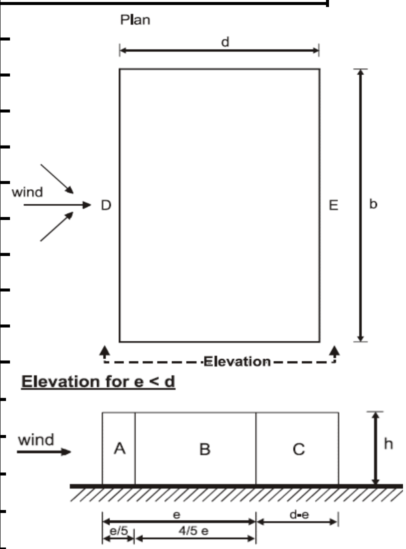
$$k_w = 0{,}625 \cdot \left[k_r \cdot \ln\left(\frac{z}{z_0}\right)\right]^2 \cdot \left(1 + \frac{7}{\ln(z/z_0)}\right)$$

Geometry of building				
width	b	40,86	m	
depth	d	17,25	m	
Total height	h	6,39	m	
Side ratio, elevation / side ratio	h<b	one profile		



Figur 7.4 in standard

Eccentricity of a force, distance to edge	e	12,78	m	e=b or 2h whichever is smaller
Side ratio, height / depth ratio	e<d	Three zones		Figur 7.5
Zone width				
Zone A	e/5	2,556	m	
Zone B	4e/5	14,694	m	
Zone C	d-e	USANN	m	
Zone D	b	40,86	m	
Zone E	b	40,86	m	
Loaded zone area				
Load height for floors		3	m	
Zone A		7,7	m^2	
Zone B		44,1	m^2	
Zone C		0,0	m^2	
Zone D	b	122,6	m^2	
Zone E	b	122,6	m^2	



External pressure coefficient				
	h/d	0,37		Tabell 7.1
Zone A	Interpol	-1,4		
Zone B	Cpe,10	-0,8		
Zone C	Interpol	0		
Zone D	Cpe,10	0,72		
Zone E	Cpe,10	-0,33		

Table 7.1 — Recommended values of external pressure coefficients for vertical walls of rectangular plan buildings

Zone	A		B		C		D		E	
h/*d*	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$
5	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,7	
1	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,5	
≤ 0,25	-1,2	-1,4	-0,8	-1,1	-0,5		+0,7	+1,0	-0,3	

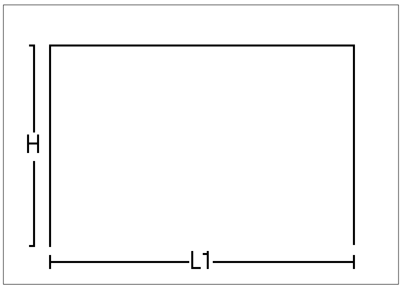
External pressure on the building				
Zone A	$w_{e,sone\ A}$	-0,94	kN/m^2	Pkt. 5.2
Zone B	$w_{e,sone\ B}$	-0,55	kN/m^2	
Zone C	$w_{e,sone\ c}$		kN/m^2	$w_e = q_p(z_e) \cdot c_{pe}$
Zone D	$w_{e,sone\ D}$	0,49	kN/m^2	
Zone E	$w_{e,sone\ E}$	-0,23	kN/m^2	
Total external pressure on the building =		***0,72***		

Wind load on the building

Tittel			Side 1
Prosjekt	Ordre	Sign	Dato 09-03-2019

Dataprogram: LastBeregning versjon 6.2.4 Laget av Sletten Byggdata AS
Standard NS-EN 1991-1-4: Vindlaster
Data er lagret på fil: C:\Users\samsomah\OneDrive - Universitetet i Agder\Forprosjekt til Masteroppgave BYG507\BYG508-G\000________calculations\Wind calculation.sls

1. Geometri



Vertikalsnitt

H	6390	mm
L1	19700	mm

Byggets lengde, L2: 43700 mm
Takvinkel : 2,91 (grader)

2. Vindhastighet

Fylke: Telemark   Kommune: Porsgrunn   Referansevindhastighet: 23 m/s
Byggested, høyde over havet (m): 17   Calt: 1
Returperiode (år):50   Cprob: 1
Årstidsfaktoren, Cseason: 1 hele året
Vindretning (region):Bruker retningsfaktoren C-ret: 1
Basisvindhastighet: 23 m/s
Høyde Z over grunnivået: 6,39 m

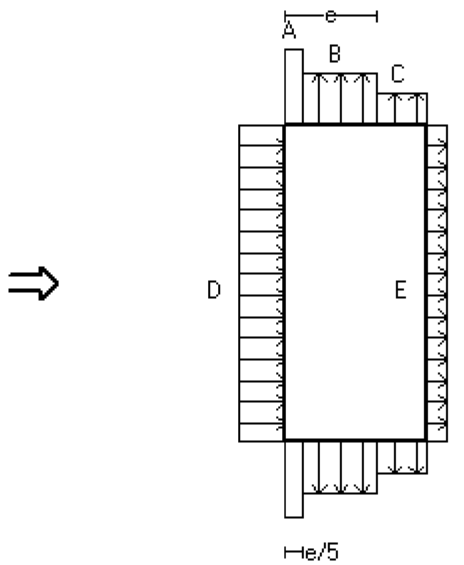
BYGGESTEDETS TERRENGDATA
Terrengruhetskategori II: Landbruksområde, område med spredte små bygninger eller trær.
Terrengruhetsfaktoren Kt: 0,19   Ruhetslengden Zo (m): 0,05   Zmin (m): 4   Vm (m/s): 21,20   Cr: 0,92

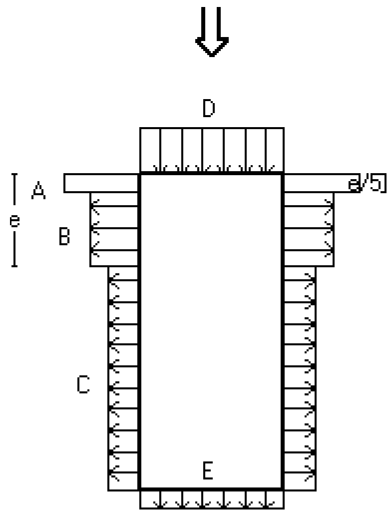
TOPOGRAFI: Ingen topografisk påvirkning.
Terrengformfaktor Co(z): 1   Turbulensfaktor Ki: 1

Vkast: 33,13 m/s
Qkast: 0,686 kN/m2

3. Yttervegger

3.1 Utvendig vindlast





Vindretning 0 grader.   e=12780 mm   *Vindretning 90 grader.   e=12780 mm*

Vindinnfallsretning på 0 grader.

	A	**B**	**C**	**D**	**E**
Formfaktor Cpe,10	-1,20	-0,80	-0,50	0,71	-0,32
Utvendig last (kN/m2)	-0,82	-0,55	-0,34	0,49	-0,22
Formfaktor Cpe,1	-1,40	-1,10	-0,50	1,00	-0,32
Utvendig last (kN/m2)	-0,96	-0,75	-0,34	0,69	-0,22
Utstrekning (mm)	2556	10224	6920	43700	43700

Vindinnfallsretning på 90 grader.

	A	**B**	**C**	**D**	**E**
Formfaktor Cpe,10	-1,20	-0,80	-0,50	0,70	-0,30
Utvendig last (kN/m2)	-0,82	-0,55	-0,34	0,48	-0,21
Formfaktor Cpe,1	-1,40	-1,10	-0,50	1,00	-0,30
Utvendig last (kN/m2)	-0,96	-0,75	-0,34	0,69	-0,21
Utstrekning (mm)	2556	10224	30920	19700	19700

Positiv verdi for last gir trykk. Negativ verdi hvis last er sug.

3.2 Innvendig vindlast

Bygning uten dominerende vindfasade

Beregn innvendig vindlast for u=0.2 overtrykk og u=-0.3 (undertrykk)

	Undertrykk	**Overtrykk**
Formfaktor	-0,30	0,20
Innvendig last (kN/m2)	-0,21	0,14

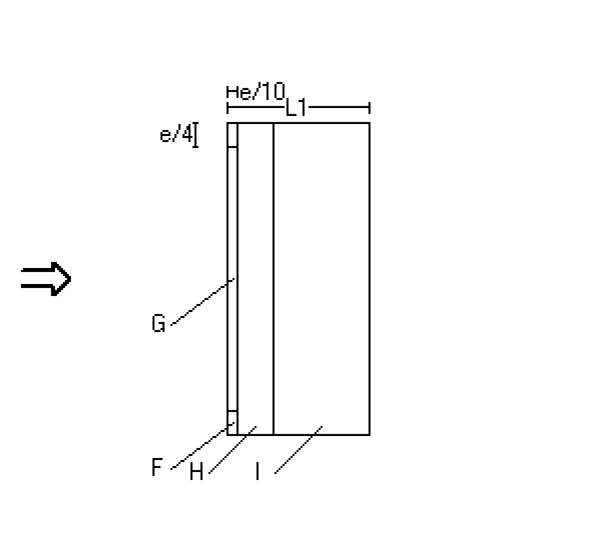
4 Overside av tak

Taktype: Flatt tak

L1=19700 mm L2=43700 mm

Cpe,10 Gjelder for hele bygget. (>=10m2)

Positiv verdi for last gir trykk. Negativ verdi hvis last er sug.



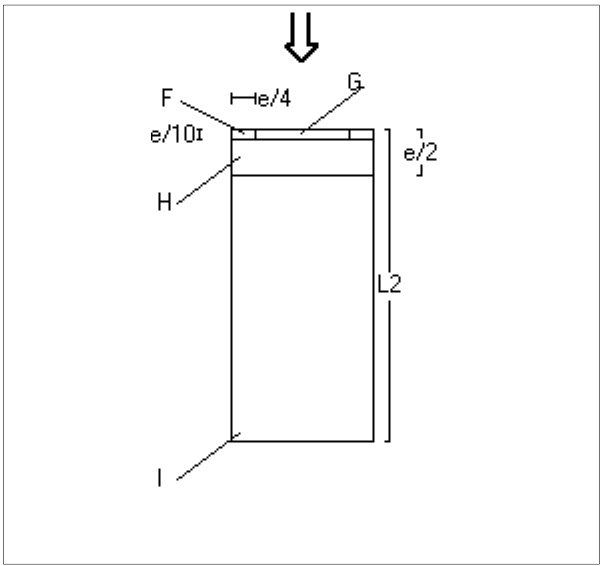
Utstrekning (mm)

e=12780

e/4=3195

e/10=1278

	Cpe,10	Last (kN/m2)	Hor.projeksjon (mm)
F	-1,80	-1,23	3195x1278
G	-1,20	-0,82	37310x1278
H	-0,70	-0,48	43700x5112
I	+/-0,20	+/-0,14	43700x13310



Utstrekning (mm)

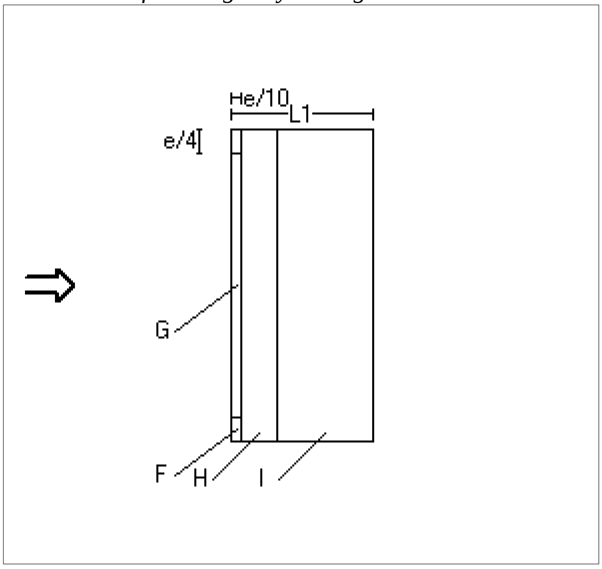
e=12780

e/4=3195

e/10=1278

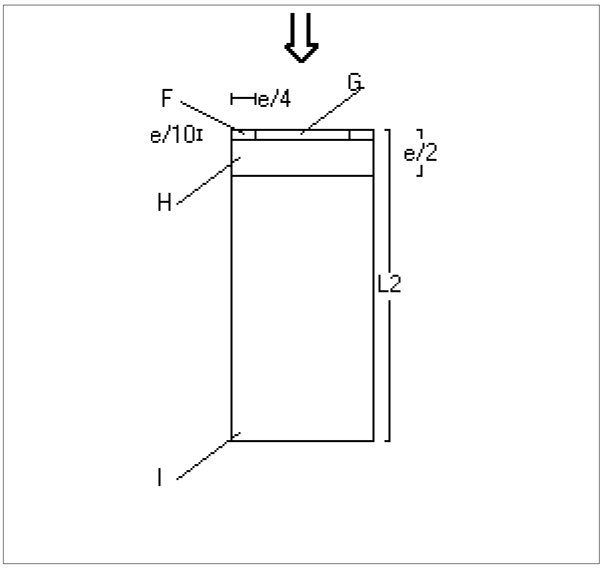
	Cpe,10	Last (kN/m2)	Hor.projeksjon (mm)
F	-1,80	-1,23	3195x1278
G	-1,20	-0,82	13310x1278
H	-0,70	-0,48	19700x5112
I	+/-0,20	+/-0,14	19700x37310

Taktype: Flatt tak
L1=19700 mm L2=43700 mm
Cpe,1 Gjelder for en lokal flate på 1m2. Benyttes ved dimensjonering av limfuger, spikring, båndstål o.l.
*Interpoleringsformel for belastet areal A mellom 1 og 10 m2 : Cpe = Cpe,1 + (Cpe,10 - Cpe,1) * $log_{10}A$*
Positiv verdi for last gir trykk. Negativ verdi hvis last er sug.



Utstrekning (mm)
e=12780
e/4=3195
e/10=1278

	Cpe,1	Last (kN/m2)	Hor.projeksjon(mm)
F	-2,50	-1,72	3195x1278
G	-2,00	-1,37	37310x1278
H	-1,20	-0,82	43700x5112
I	+/-0,20	+/-0,14	43700x13310



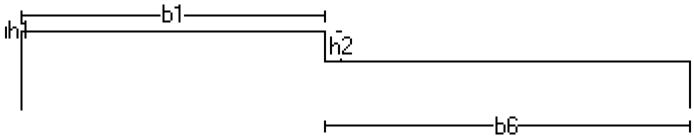
Utstrekning (mm)
e=12780
e/4=3195
e/10=1278

	Cpe,1	Last (kN/m2)	Hor.projeksjon(mm)
F	-2,50	-1,72	3195x1278
G	-2,00	-1,37	13310x1278
H	-1,20	-0,82	19700x5112
I	+/-0,20	+/-0,14	19700x37310

Tittel Snow calculation for roofs at different levels			Side 1
Prosjekt	Ordre	Sign	Dato 26-03-2019

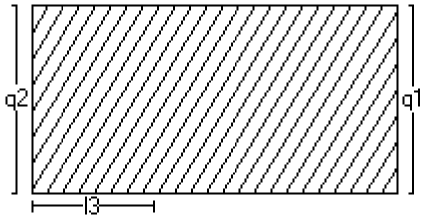
Dataprogram: LastBeregning versjon 6.2.4 Laget av Sletten Byggdata AS
Standard NS-EN 1991-1-3: Snølaster
Data er lagret på fil:

1. Geometri



b1	12432	mm
h1	0	mm
h2	1200	mm
b6	15000	mm

2. Snølast på tak



Last nr.:1

q1	3,20	kN/m2
q2	3,20	kN/m2
l3	5000	mm

3. Snølastdata

Fylke	Telemark
Kommune	Porsgrunn
Sted	Porsgrunn
Byggets plassering (moh)	17 moh
Eksponeringskoeffisient Ce	1
Termisk koeffisient Ct	1
Snølast, S:	4 kN/m2

Foundation loads

basement wall axis E

basement wall_foundation Axis E

Footing F1 1700x1700x400

Footing F2 1300x1300x350

Isolated footing F3 strip footing axis 7

Strip footing axis 2 3 5 and 6

Strip footing axis A

Foundation Design using BT-Sitt (Ove-sletten software)

		Permanent load			Variable load		
Type	location		FZ (kN/m)	Fx (kN/	Fy (kN/m)		FZ (kN/m)	Fx (kN/m)
Strip footing	Axis 2, 3, 5	*Selfweight*	54,5			*Live*	40,5	
		Add. Dead	46			*Snow*	29	
	and 6	*Earth pr.*	180,5	208	6	*Wind*	5,5	4
	Total =		**281**	**208**	**6**		**75**	**4**

Strip footing 1700x400

Type	location		FZ (kN/m)	Fx (kN/	Fy (kN/m)		FZ (kN/m)	Fx (kN/m)
Strip footing	Axis A	*Selfweight*	38			*Live*	16	
		Add. Dead	14			*Snow*	12	
		Earth pr.	50	48		*Wind*	2	
	Total =		**102**	**48**			**30**	

Strip footing 1000x300

		Permanent load			Variable load	
Type	location		FZ (kN)			FZ (kN)
Isolated foot	F1	*Selfweight*	124		*Live*	138
		Add. Dead	169		*Snow*	107
	Total =		**293**			**245**

F1 1700x1700x400

		Permanent load			Variable load	
Type	location		FZ (kN)			FZ (kN)
Isolated foot	F2	*Selfweight*	68		*Live*	69
		Add. Dead	86		*Snow*	57
	Total =		**154**			**126**

F2 1300X1300X350

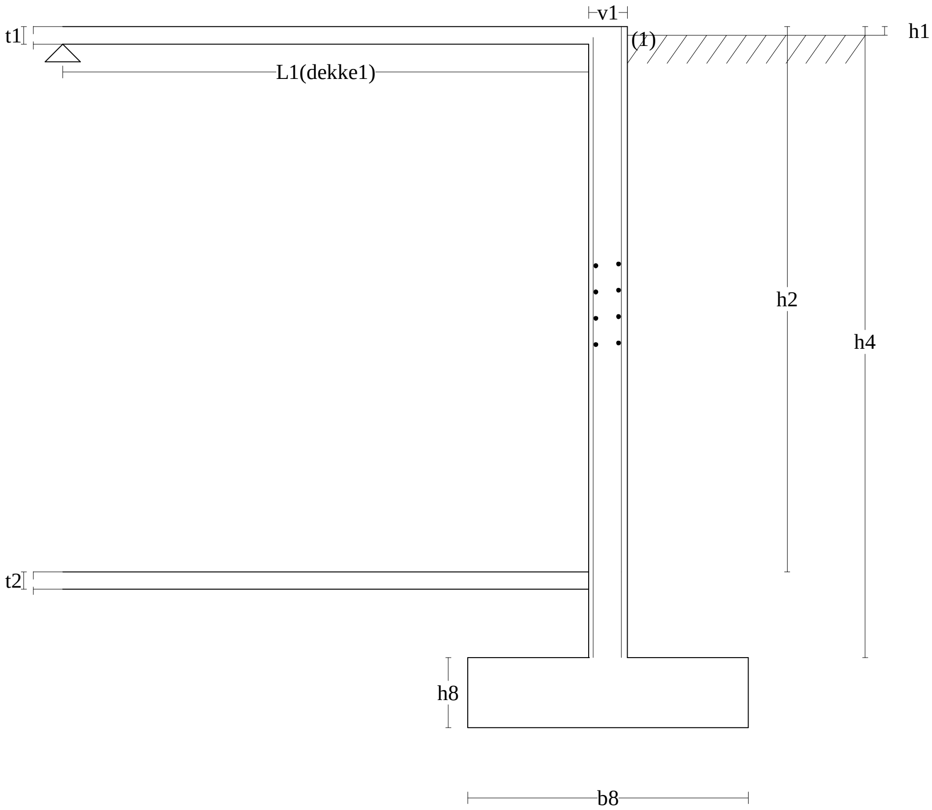
		Permanent load			Variable load	
Type	location		FZ (kN)			FZ (kN)
Isolated foot	F3 axis 7	*Selfweight*	44		*Live*	40
		Add. Dead	45		*Snow*	58
	Total =		**89**			**98**

F3 1000X1000X300 **Strip footing with 1 m width is ok!!**

Tittel			Side 1
Prosjekt	Ordre	Sign	Dato 15-04-2019

Data er lagret på fil: C:\Users\samsomah\OneDrive - Universitetet i Agder\Forprosjekt til Masteroppgave BYG507\BYG508-G\000_
Dataprogram: BTSNITT versjon 6.3.11 Laget av sivilingeniør Ove Sletten
Beregningene er basert på NS-EN 1992-1-1 og NS-EN 1990:2002 + NA:2008

KJELLERVEGG, EN ETASJE.



t1 = 100 mm
t2 = 100 mm
h1 = 50 mm
h2 = 3110 mm
h4 = 3600 mm
h8 = 400 mm

L1 = 3000 mm
v1 = 220 mm
b8 = 1600 mm

Vinkel på terreng mot kjeller:
u = 0 grader

Armering		**Nominell overdekning**	
Veggarmering (ik), vertikalretning	ø 12 c 215	25 mm	Krav til tverrarmering:
Veggarmering (ik), horisontalretning	ø 12 c 265	40 mm	Se NS-EN 1992-1-1 9.6.4
Veggarmering (yk), vertikalretning	ø 12 c 300	35 mm	
Veggarmering (yk), horisontalretning	ø 12 c 265	50 mm	

Armering i bankett og dekke beregnes med egne moduler (ik): innerkant (yk): ytterkant(mot jord)

Materialdata

Materialfaktor betong	1,50
Materialfaktor stål	1,15
Betongkvalitet	B35 (C 35/45)
Armering flytegrense	500
Skjærarmering flytegrense	500
Eksponeringsklasse (ik)	XC1
Eksponeringsklasse (yk)	XC1

Relativ fuktighet 40%
Lite korrosjonsømfintlig armering
Levetid 50 år

Min. overdekning	**(ik)**	**(yk)**
Min. krav	15 mm	15 mm
Toleranse	10 mm	10 mm
Min. nominell overdekning	25 mm	25 mm

Grunnmasse

Jordtype: Sprengstein (Tilført)

Egenvekt av jord:	19,0 kN/m3
Friksjonsvinkel:	30,0 grader

Lastdata og innspenning

Dekke 1: Variabel last	2,0	kN/m2
Dekke 1: Permanent last	3,6	kN/m2

Momentstiv forbindelse: dekke 1 : NEI. eksentr.= 0 mm

Vertikallast i overkant vegg

Variabel last	maks: 0,0	min: 0,0	kN/m
Permanent last	maks: 0,0	min: 0,0	kN/m

Eksentrisk lastplassering (positiv utover) 0,0 mm

Nyttelast på terreng 5,0 kN/m2

Tittel			Side 2
Prosjekt	Ordre	Sign	Dato 15-04-2019

Pålitelighetsklasse: 2					
Lastfaktorer	Bruksgrense	Risskontroll	Bruddgrense B1	Bruddgrense B2	**PSI-Faktor:** Kategori A - Bolig
Permanent last (G)	1,00	1,00	1,35	1,20	**Krav maks.nedbøyning:**
Variabel last (P)	1,00	0,30	1,05	1,50	Nedbøyning fører til skader

Last på terreng	1,00	0,30	1,30
Jordtrykk mot vegg	1,00	1,00	1,00

Materialkoeffisient for jord (for friksjonsvinkel): 1,3

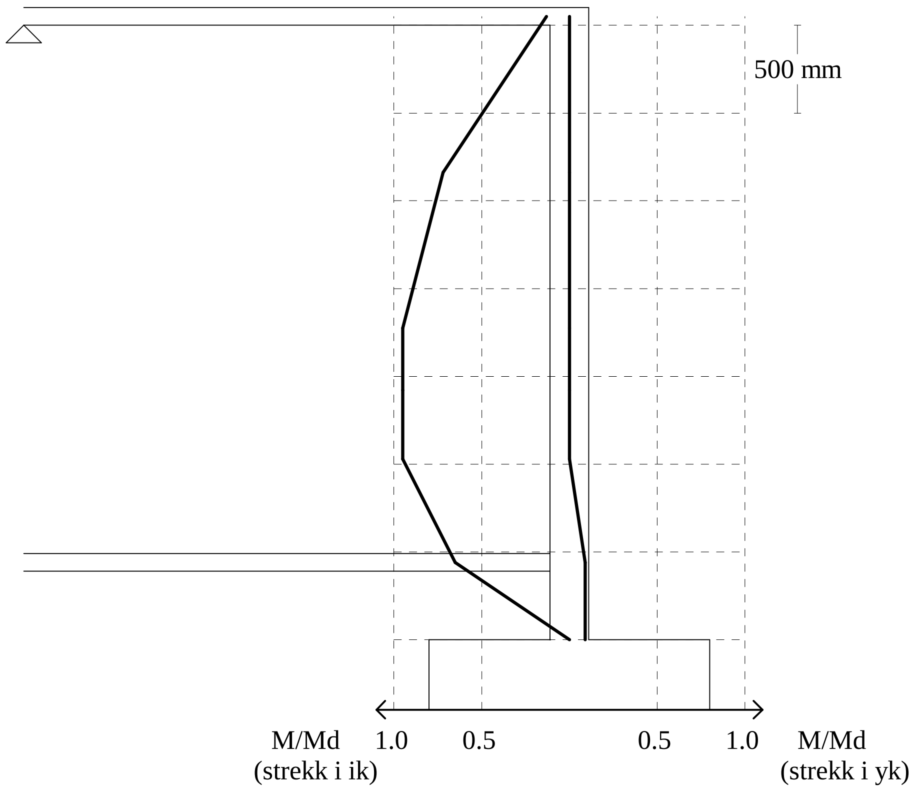
KONTROLL AV KJELLERVEGG

	Momentkapasitet			**Skjærkapasitet**				**Risskontroll**	
				Trykkbrudd		**Skjærstrekkbrudd**			
SNITT	**N (kN)**	**M (kNm)**	**M/Md**	**V (kN)**	**V/Vccd**	**Vred**	**Vred/Vcd**	**w (mm)**	**w/wd**
Vegg 1 ved dekke 1	-9,9	-5,35	0,16	33,0	0,03	32,3	0,33	0,00	0,00
Vegg 1: maks feltmom.	-15,2	-41,85	0,95					0,28	0,70
Vegg 1 ved kjellergulv	-22,5	14,07	0,45	-61,5	0,06	-54,4	0,56	0,14	0,36

Jordtrykkskoeffisient: 0,68

Utbøyning vegg 1: -7 mm
Utbøyningen er basert på samme nyttelastfaktor som for risskontroll, og spennvidden er regnet ned til kjellergulv

Momentkontroll



Last på veggbankett (uten lastfaktorer)
Egenvekt, Ng: -25 kN/m
Nyttelast, Np: -3 kN/m
Moment, Mg_z: -2,07 kNm/m

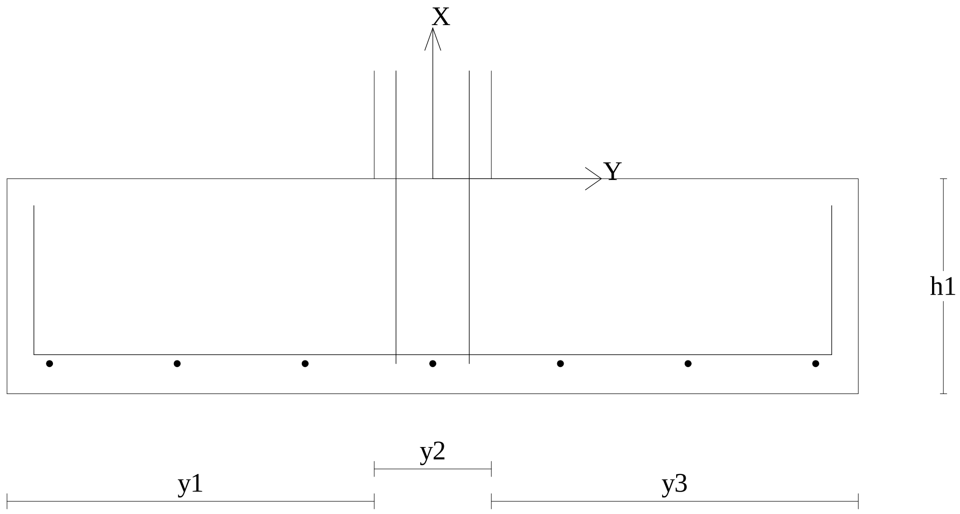
Horisontalkraft kan opptas av bankett eller kjellergulv.
Horisontalkraft, Vg_y: -56 kN/m   MOT BANKETT
Horisontalkraft, Vg_y: -62,9 kN/m   MOT KJELLERGULV

Wall foundation axis E

Tittel			Side 1
Prosjekt	Ordre	Sign	Dato 15-04-2019

Data er lagret på fil: C:\Users\samsomah\OneDrive - Universitetet i Agder\Forprosjekt til Masteroppgave BYG507\BYG508-G\000_
Dataprogram: BTSNITT versjon 6.3.11 Laget av sivilingeniør Ove Sletten
Beregningene er basert på NS-EN 1992-1-1 og NS-EN 1990:2002 + NA:2008

Veggbankett



y1 = 690 mm
y2 = 220 mm
y3 = 690 mm
h1 = 400 mm
h2 = 400 mm
h3 = 400 mm

Armering i tverretning
armering, underkant: d 12 c 205

Armering i lengderetning (ytterst)
*nominell overdekning: 50 mm
armering, uk: 7 d 12 c 240

skjøtarmering til vegg
armering: d 12 c 400
forankringslengde =300 mm
nominell overdekning: 35 mm

(* NS-EN 1992-1-1 4.4.1.3(4) Nominell overdekning bør minst være: 40 mm mot avrettet grunn og 75 mm mot ikke avrettet grunn

Materialdata og jord-data

Korreksjonsfakt. for Emodul pga tilslag	1,00
Materialfaktor betong	1,50
Materialfaktor stål	1,15
Betongkvalitet	B35 (C 35/45)
Densitet kg/m3	2400
Sement i fasthetsklasse	N
Armering flytegrense	500
Skjærarmering flytegrense	500
Eksponeringsklasse	XC1
Lite korrosjonsømfintlig armering	
Levetid 50 år	
Relativ fuktighet	40%

NA.6.2.2(1)Følgende krav til tilslag er oppfyllt
(1.Største tilslag etter NS-EN 12620 D>=16mm. 2.Det grove tilslaget>=50% av total tilslagsmengde.
3.Grovt tilslag skal ikke være av kalkstein eller stein med tilsvarende lav fasthet)

Fundamentnivå under marknivå	600	mm
Grunnvannsnivå over uk fundament	0	mm
Egenvekt av jord	19,0	kN/m3

Uten hensyn til fundamentdybde:

Netto bæreevne	300	kN/m2

Minimum overdekning:
(min.krav + toleranse) = (15 + 10) = 25 mm

Pålitelighetsklasse: 2

Lastfaktorer	Bruksgrense	Grunnbrudd	Bruddgrense B1	Bruddgrense B2
Permanent last (G)	1,00	1,20	1,35	1,20
Variabel last (P)	0,30	1,50	1,05	1,50

PSI-Faktor:
Kategori A - Bolig
Krav maks.nedbøyning:
Nedbøyning fører til skader

Belastning i overkant av fundament. Lasttilfelle nr 1

Permanent last

Mg_z	-2,1 kNm
Vg_y	-56,0 kN
Vg_z	0,0 kN
Ng	-25,0 kN

Variabel last

Mp_z	0,0 kNm
Vp_y	0,0 kN
Vp_z	0,0 kN
Np	-3,0 kN

Kontroll av likevekt (velting)

y-retning: Mvelt/Mstabil =0,83

Vekt av fundament: lastfaktor = 0.9

Vekt av overliggende jord er ikke medregnet

Lastfaktorer

fg=1,2 fp=0,0

Positiv moment-og kraftvektorer i Y og Z-retning. Positiv Ng og Np peker oppover.

Moment -og skjærkontroll i bruddgrensetilstand

Y-retning: Mz = -23,3 kNm Mz/Md_z = 0,30

Skjær-trykkbrudd langs vegg: V/Vd =0,04 Lasttilfelle nr 1

Skjær-strekkbrudd i avstand d fra vegg: V/Vcd =0,17

Dimensjonerende skjærkraft =28,10 kN/m

Kontroll av grunntrykk

Ugunstigste lasttilfelle: 1

Bæreevne 311 kN/m2

tg Ø=0,00 rb =0,00 Nq =0,00 Ny =0,00

Overført grunntrykk 110 kN/m2

Risskontroll

Y-retning: w/wd =0,00

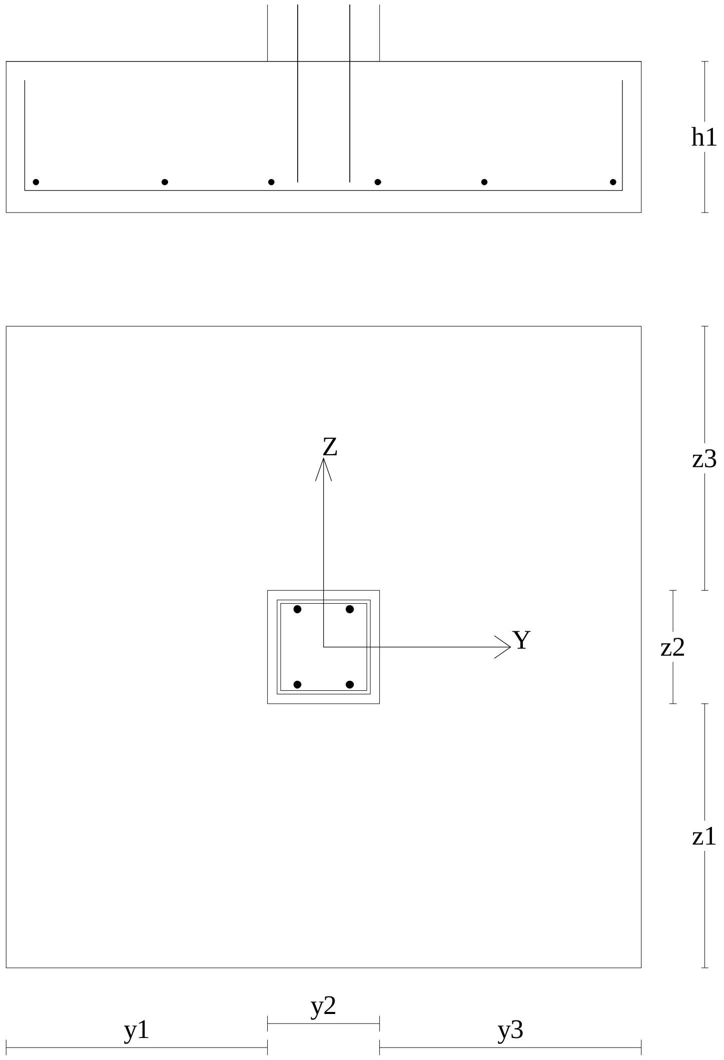
Kontrollsnitt er lagt ved kant av vegg.

Grenseverdi for maks strekkspenning i overkant uten armering : 0,80 ftd

Tittel			Side
Isolated footing F1			1
Prosjekt	Ordre	Sign	Dato
			15-04-2019

Data er lagret på fil: C:\Users\samsomah\OneDrive - Universitetet i Agder\Forprosjekt til Masteroppgave BYG507\BYG508-G\000_
Dataprogram: BTSNITT versjon 6.3.11 Laget av sivilingeniør Ove Sletten
Beregningene er basert på NS-EN 1992-1-1 og NS-EN 1990:2002 + NA:2008

Søylefundament



y1 =	700	mm
y2 =	300	mm
y3 =	700	mm
z1 =	700	mm
z2 =	300	mm
z3 =	700	mm
h1 =	400	mm
h2 =	400	mm

Armering i Y-retning (ligger ytterst)
*nominell overdekning: 50 mm
total armering, underkant: 6 d 16
i midtsone: 4 d 16 c 285
på hver kantsone: 1 d 16 c 320

Armering i Z-retning
total armering. underkant: 6 d 16
i midtsone: 4 d 16 c 285
på hver kantsone: 1 d 16 c 345

skjøtarmering til søyle
4 d 20 , forankringslengde =455 mm
bøyler: 5 d 10 c 200
nominell overdekning: 25 mm

(* NS-EN 1992-1-1 4.4.1.3 Nominell overdekning bør minst være:
40 mm mot avrettet grunn
75 mm mot ikke avrettet grunn)

Materialdata og jord-data

Korreksjonsfakt. for Emodul pga tilslag	1,00
Materialfaktor betong	1,50
Materialfaktor stål	1,15
Betongkvalitet	B35 (C 35/45)
Densitet kg/m3	2400
Sement i fasthetsklasse	N
Armering flytegrense	500
Skjærarmering flytegrense	500
Eksponeringsklasse	XC2
Lite korrosjonsømfintlig armering	
Levetid 50 år	
Relativ fuktighet	40%

NA.6.2.2(1)Følgende krav til tilslag er oppfyllt
(1.Største tilslag etter NS-EN 12620 D>=16mm. 2.Det grove tilslaget>=50% av total tilslagsmengde.
3.Grovt tilslag skal ikke være av kalkstein eller stein med tilsvarende lav fasthet)

Fundamentnivå under marknivå	600	mm
Grunnvannsnivå over uk fundament	0	mm
Egenvekt av jord	19,0	kN/m3

Uten hensyn til fundamentdybde:

Netto bæreevne	300	kN/m2

Minimum overdekning:
(min.krav + toleranse) = (25 + 10) = 35 mm

Pålitelighetsklasse: 2

Lastfaktorer	Bruksgrense	Grunnbrudd	Bruddgrense B1	Bruddgrense B2	**PSI-Faktor:** Kategori A - Bolig
Permanent last (G)	1,00	1,20	1,35	1,20	**Krav maks.nedbøyning:**
Variabel last (P)	0,30	1,50	1,05	1,50	Alminnelige bruks-/estetiske krav

Belastning i overkant av fundament. Lasttilfelle nr 1

Permanent last

Mg_y	0,0 kNm
Mg_z	0,0 kNm
Vg_y	0,0 kN
Vg_z	0,0 kN
Ng	-293,0 kN

Variabel last

Mp_y	0,0 kNm
Mp_z	0,0 kNm
Vp_y	0,0 kN
Vp_z	0,0 kN
Np	-245,0 kN

Kontroll av likevekt (velting) **Lastfaktorer**

z-retning: Mvelt/Mstabil =0,00
y-retning: Mvelt/Mstabil =0,00
Vekt av fundament og overliggende jord: lastfaktor = 0.9
Vekt av overliggende jord er medregnet

Positiv moment-og kraftvektorer i Y og Z-retning. Positiv Ng og Np peker oppover.

Moment -og skjærkontroll i bruddgrensetilstand

Y-retning: Mz = -103,6 kNm Mz/Md_z = 0,60
Z-retning: My = -103,6 kNm My/Md_y = 0,64

Kontroll av gjennomlokking i avstand d fra søylekant
Trykkbruddkontroll langs søylekant: V/Vd =0,44
Skjærkraftkapasitet uten skjæramering Vrd,c=0,98 N/mm2
Største skjærspenning Ved=0,47 N/mm2
Det trengs ikke skjærarmering.

Kontroll av grunntrykk

Ugunstigste lasttilfelle: 1
Bæreevne 311 kN/m2
tg Ø=0,00 rb =0,00 Nq =0,00 Ny =0,00
Overført grunntrykk 265 kN/m2

Risskontroll

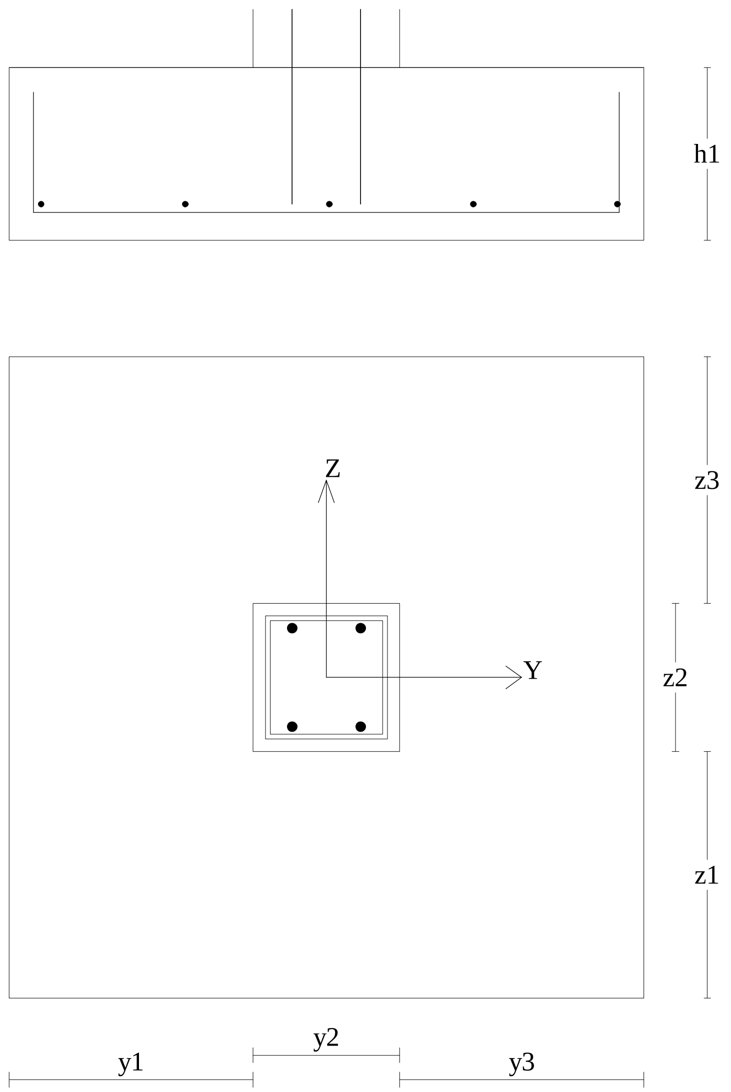
Y-retning: w/wd =0,00
Z-retning: w/wd =0,00

Kontrollsnitt er lagt ved kant av søyle.
Grenseverdi for maks strekkspenning i overkant uten armering : 0,80 ftd

Tittel			Side
Isolated footing F2			1
Prosjekt	Ordre	Sign	Dato
			15-04-2019

Data er lagret på fil: C:\Users\samsomah\OneDrive - Universitetet i Agder\Forprosjekt til Masteroppgave BYG507\BYG508-G\000_
Dataprogram: BTSNITT versjon 6.3.11 Laget av sivilingeniør Ove Sletten
Beregningene er basert på NS-EN 1992-1-1 og NS-EN 1990:2002 + NA:2008

Søylefundament



y1 =	500	mm
y2 =	300	mm
y3 =	500	mm
z1 =	500	mm
z2 =	300	mm
z3 =	500	mm
h1 =	350	mm
h2 =	350	mm

Armering i Y-retning (ligger ytterst)
*nominell overdekning: 50 mm
total armering, underkant: 6 d 12 c 230

Armering i Z-retning
total armering, underkant: 5 d 12 c 295

skjøtarmering til søyle
4 d 20 , forankringslengde =455 mm
bøyler: 4 d 10 c 200
nominell overdekning: 25 mm

(* NS-EN 1992-1-1 4.4.1.3 Nominell overdekning bør minst være:
40 mm mot avrettet grunn
75 mm mot ikke avrettet grunn)

Materialdata og jord-data

Korreksjonsfakt. for Emodul pga tilslag	1,00
Materialfaktor betong	1,50
Materialfaktor stål	1,15
Betongkvalitet	B35 (C 35/45)
Densitet kg/m3	2400
Sement i fasthetsklasse	N
Armering flytegrense	500
Skjærarmering flytegrense	500
Eksponeringsklasse	XC2
Lite korrosjonsømfintlig armering	
Levetid 50 år	
Relativ fuktighet	40%

NA.6.2.2(1)Følgende krav til tilslag er oppfyllt
(1.Største tilslag etter NS-EN 12620 D>=16mm. 2.Det grove tilslaget>=50% av total tilslagsmengde.
3.Grovt tilslag skal ikke være av kalkstein eller stein med tilsvarende lav fasthet)

Fundamentnivå under marknivå	600	mm
Grunnvannsnivå over uk fundament	0	mm
Egenvekt av jord	19,0	kN/m3

Uten hensyn til fundamentdybde:

Netto bæreevne	300	kN/m2

Minimum overdekning:
(min.krav + toleranse) = (25 + 10) = 35 mm

Pålitelighetsklasse: 2					
Lastfaktorer	Bruksgrense	Grunnbrudd	Bruddgrense B1	Bruddgrense B2	**PSI-Faktor:** Kategori A - Bolig
Permanent last (G)	1,00	1,20	1,35	1,20	**Krav maks.nedbøyning:**
Variabel last (P)	0,30	1,50	1,05	1,50	Alminnelige bruks-/estetiske krav

Belastning i overkant av fundament. Lasttilfelle nr 1

Permanent last

Mg_y	0,0 kNm
Mg_z	0,0 kNm
Vg_y	0,0 kN
Vg_z	0,0 kN
Ng	-154,0 kN

Variabel last

Mp_y	0,0 kNm
Mp_z	0,0 kNm
Vp_y	0,0 kN
Vp_z	0,0 kN
Np	-126,0 kN

Kontroll av likevekt (velting) **Lastfaktorer**

z-retning: Mvelt/Mstabil =0,00
y-retning: Mvelt/Mstabil =0,00
Vekt av fundament og overliggende jord: lastfaktor = 0.9
Vekt av overliggende jord er medregnet

Positiv moment-og kraftvektorer i Y og Z-retning. Positiv Ng og Np peker oppover.

Moment -og skjærkontroll i bruddgrensetilstand

Y-retning: Mz = -35,9 kNm Mz/Md_z = 0,43
Z-retning: My = -35,9 kNm My/Md_y = 0,54

Kontroll av gjennomlokking i avstand d fra søylekant
Trykkbruddkontroll langs søylekant: V/Vd =0,27
Skjærkraftkapasitet uten skjæramering Vrd,c=1,03 N/mm2
Største skjærspenning Ved=0,26 N/mm2
Det trengs ikke skjærarmering.

Kontroll av grunntrykk

Ugunstigste lasttilfelle: 1
Bæreevne 311 kN/m2
tg Ø=0,00 rb =0,00 Nq =0,00 Ny =0,00
Overført grunntrykk 237 kN/m2

Risskontroll

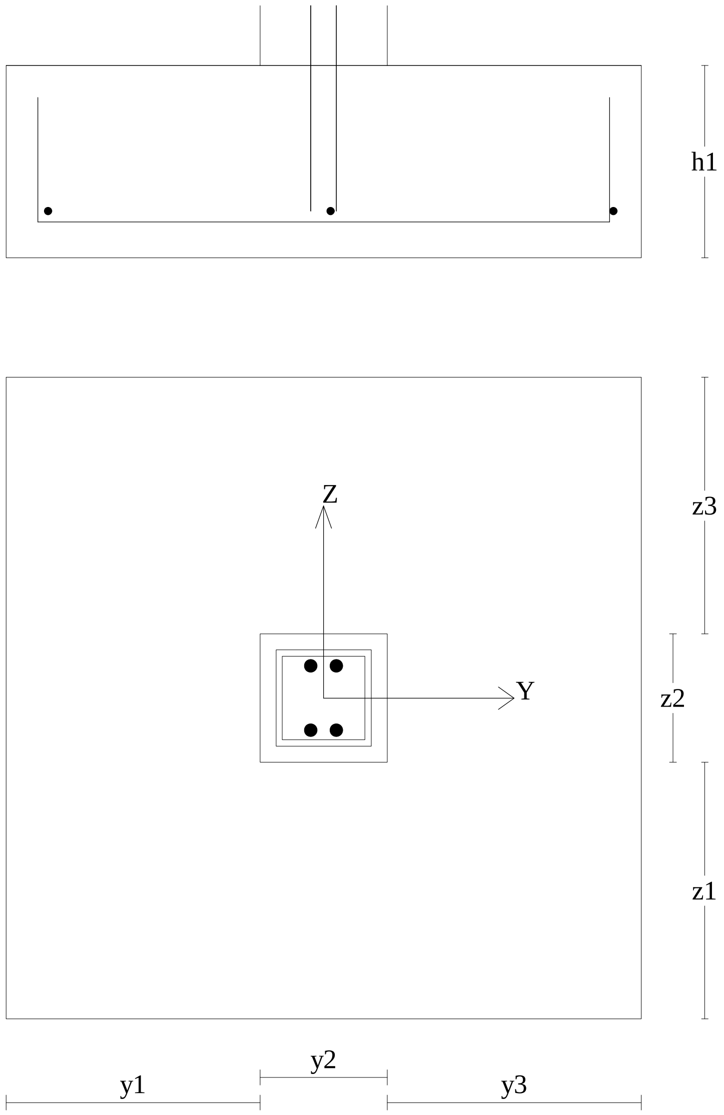
Y-retning: w/wd =0,00
Z-retning: w/wd =0,00

Kontrollsnitt er lagt ved kant av søyle.
Grenseverdi for maks strekkspenning i overkant uten armering : 0,80 ftd

Tittel Isolated footing F3 strip footing axis 7			Side 1
Prosjekt	Ordre	Sign	Dato 15-04-2019

Data er lagret på fil: C:\Users\samsomah\OneDrive - Universitetet i Agder\Forprosjekt til Masteroppgave BYG507\BYG508-G\000_
Dataprogram: BTSNITT versjon 6.3.11 Laget av sivilingeniør Ove Sletten
Beregningene er basert på NS-EN 1992-1-1 og NS-EN 1990:2002 + NA:2008

Søylefundament



y1 = 400 mm
y2 = 200 mm
y3 = 400 mm
z1 = 400 mm
z2 = 200 mm
z3 = 400 mm
h1 = 300 mm
h2 = 300 mm

Armering i Y-retning (ligger ytterst)
*nominell overdekning: 50 mm
total armering, underkant: 4 d 12 c 285

Armering i Z-retning
total armering, underkant: 3 d 12 c 445

skjøtarmering til søyle
4 d 20 , forankringslengde =455 mm
bøyler: 4 d 10 c 200
nominell overdekning: 25 mm

(* NS-EN 1992-1-1 4.4.1.3 Nominell overdekning bør minst være:
40 mm mot avrettet grunn
75 mm mot ikke avrettet grunn)

Materialdata og jord-data

Korreksjonsfakt. for Emodul pga tilslag	1,00	Fundamentnivå under marknivå	600	mm
Materialfaktor betong	1,50	Grunnvannsnivå over uk fundament	0	mm
Materialfaktor stål	1,15	Egenvekt av jord	19,0	kN/m3
Betongkvalitet	B35 (C 35/45)			
Densitet kg/m3	2400	Uten hensyn til fundamentdybde:		
Sement i fasthetsklasse	N	Netto bæreevne	300	kN/m2
Armering flytegrense	500	**Minimum overdekning:**		
Skjærarmering flytegrense	500	(min.krav + toleranse) = (25 + 10) = 35 mm		
Eksponeringsklasse	XC2			
Lite korrosjonsømfintlig armering				
Levetid 50 år				
Relativ fuktighet	40%			

NA.6.2.2(1)Følgende krav til tilslag er oppfyllt
(1.Største tilslag etter NS-EN 12620 D>=16mm. 2.Det grove tilslaget>=50% av total tilslagsmengde.
3.Grovt tilslag skal ikke være av kalkstein eller stein med tilsvarende lav fasthet)

Pålitelighetsklasse: 2

Lastfaktorer	Bruksgrense	Grunnbrudd	Bruddgrense B1	Bruddgrense B2	**PSI-Faktor:** Kategori A - Bolig
Permanent last (G)	1,00	1,20	1,35	1,20	**Krav maks.nedbøyning:**
Variabel last (P)	0,30	1,50	1,05	1,50	Alminnelige bruks-/estetiske krav

Belastning i overkant av fundament. Lasttilfelle nr 1

Permanent last

Mg_y	0,0 kNm
Mg_z	0,0 kNm
Vg_y	0,0 kN
Vg_z	0,0 kN
Ng	-89,0 kN

Variabel last

Mp_y	0,0 kNm
Mp_z	0,0 kNm
Vp_y	0,0 kN
Vp_z	0,0 kN
Np	-98,0 kN

Kontroll av likevekt (velting) **Lastfaktorer**

z-retning: Mvelt/Mstabil =0,00
y-retning: Mvelt/Mstabil =0,00
Vekt av fundament og overliggende jord: lastfaktor = 0.9
Vekt av overliggende jord er medregnet

Positiv moment-og kraftvektorer i Y og Z-retning. Positiv Ng og Np peker oppover.

Moment -og skjærkontroll i bruddgrensetilstand

Y-retning: Mz =	-20,3	kNm	Mz/Md_z =	0,44
Z-retning: My =	-20,3	kNm	My/Md_y =	0,62

Kontroll av gjennomlokking i avstand d fra søylekant
Trykkbruddkontroll langs søylekant: V/Vd =0,33
Skjærkraftkapasitet uten skjæramering Vrd,c=1,10 N/mm2
Største skjærspenning Ved=0,28 N/mm2
Det trengs ikke skjærarmering.

Kontroll av grunntrykk

Ugunstigste lasttilfelle: 1
Bæreevne 311 kN/m2
tg Ø=0,00 rb =0,00 Nq =0,00 Ny =0,00
Overført grunntrykk 269 kN/m2

Risskontroll

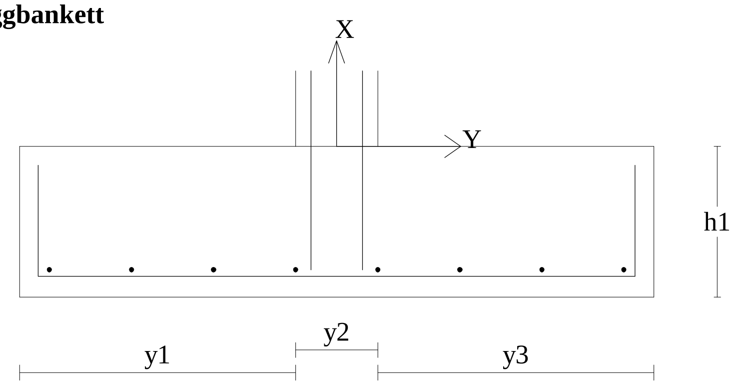
Y-retning: w/wd =0,00
Z-retning: w/wd =0,00

Kontrollsnitt er lagt ved kant av søyle.
Grenseverdi for maks strekkspenning i overkant uten armering : 0,80 ftd

Tittel Strip footing axis 2, 3, 5 and 6			Side 1
Prosjekt	Ordre	Sign	Dato 17-04-2019

Data er lagret på fil: C:\Users\samsomah\OneDrive - Universitetet i Agder\Forprosjekt til Masteroppgave BYG507\BYG508-G\000_
Dataprogram: BTSNITT versjon 6.3.11   Laget av sivilingeniør Ove Sletten
Beregningene er basert på NS-EN 1992-1-1 og NS-EN 1990:2002 + NA:2008

Veggbankett



y1 = 740 mm
y2 = 220 mm
y3 = 740 mm
h1 = 400 mm
h2 = 400 mm
h3 = 400 mm

Armering i tverretning (ytterst)
*nominell overdekning: 50 mm
armering, underkant: d 12 c 175

Armering i lengderetning
armering, uk: 8 d 12 c 220

skjøtarmering til vegg
armering: d 12 c 400
forankringslengde =300 mm
nominell overdekning: 35 mm

(* NS-EN 1992-1-1 4.4.1.3(4) Nominell overdekning bør minst være: 40 mm mot avrettet grunn og 75 mm mot ikke avrettet grunn

Materialdata og jord-data

Korreksjonsfakt. for Emodul pga tilslag	1,00
Materialfaktor betong	1,50
Materialfaktor stål	1,15
Betongkvalitet	B35 (C 35/45)
Densitet kg/m3	2400
Sement i fasthetsklasse	N
Armering flytegrense	500
Skjærarmering flytegrense	500
Eksponeringsklasse	XC2
Lite korrosjonsømfintlig armering	
Levetid 50 år	
Relativ fuktighet	40%

NA.6.2.2(1)Følgende krav til tilslag er oppfyllt
(1.Største tilslag etter NS-EN 12620 D>=16mm. 2.Det grove tilslaget>=50% av total tilslagsmengde.
3.Grovt tilslag skal ikke være av kalkstein eller stein med tilsvarende lav fasthet)

Fundamentnivå under marknivå	600	mm
Grunnvannsnivå over uk fundament	0	mm
Egenvekt av jord	19,0	kN/m3

Uten hensyn til fundamentdybde:
Netto bæreevne 300 kN/m2

Minimum overdekning:
(min.krav + toleranse) = (25 + 10) = 35 mm

Pålitelighetsklasse: 2

Lastfaktorer	Bruksgrense	Grunnbrudd	Bruddgrense B1	Bruddgrense B2
Permanent last (G)	1,00	1,20	1,35	1,20
Variabel last (P)	0,30	1,50	1,05	1,50

PSI-Faktor:
Kategori A - Bolig
Krav maks.nedbøyning:
Nedbøyning fører til skader

Belastning i overkant av fundament. Lasttilfelle nr 1

Permanent last

Mg_z	0,0 kNm
Vg_y	6,0 kN
Vg_z	208,0 kN
Ng	-281,0 kN

Variabel last

Mp_z	0,0 kNm
Vp_y	0,0 kN
Vp_z	4,0 kN
Np	-75,0 kN

Kontroll av likevekt (velting) **Lastfaktorer**
y-retning: Mvelt/Mstabil =0,01 fg=1,2 fp=0,0
Vekt av fundament og overliggende jord: lastfaktor = 0.9
Vekt av overliggende jord er medregnet

Positiv moment-og kraftvektorer i Y og Z-retning. Positiv Ng og Np peker oppover.

Moment -og skjærkontroll i bruddgrensetilstand

Y-retning: Mz = -74,3 kNm Mz/Md_z = 0,80

Skjær-trykkbrudd langs vegg: V/Vd =0,13 Lasttilfelle nr 1
Skjær-strekkbrudd i avstand d fra vegg: V/Vcd =0,65
Dimensjonerende skjærkraft =108,00 kN/m

Kontroll av grunntrykk

Ugunstigste lasttilfelle: 1
Bæreevne 311 kN/m2
tg Ø=0,00 rb =0,00 Nq =0,00 Ny =0,00
Overført grunntrykk 282 kN/m2

Risskontroll

Y-retning: w/wd =0,96

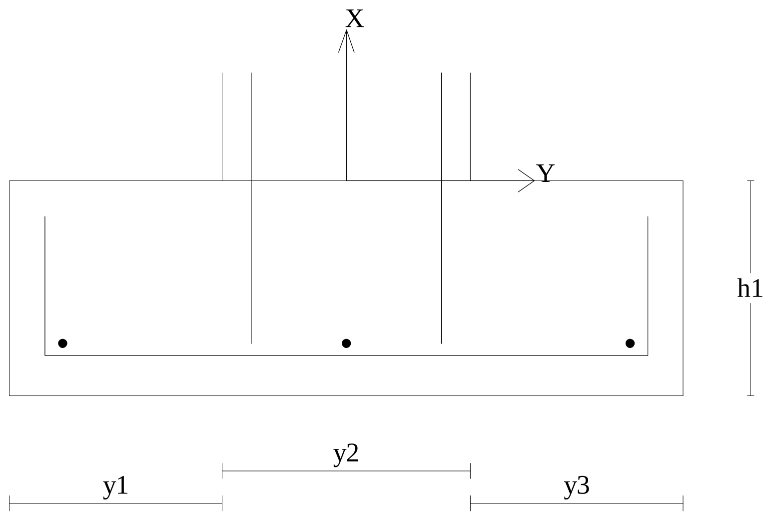
Kontrollsnitt er lagt ved kant av vegg.
Grenseverdi for maks strekkspenning i overkant uten armering : 0,80 ftd

Tittel	Side
Strip footing axis A	1

Prosjekt	Ordre	Sign	Dato
			15-04-2019

Data er lagret på fil: C:\Users\samsomah\OneDrive - Universitetet i Agder\Forprosjekt til Masteroppgave BYG507\BYG508-G\000_
Dataprogram: BTSNITT versjon 6.3.11 Laget av sivilingeniør Ove Sletten
Beregningene er basert på NS-EN 1992-1-1 og NS-EN 1990:2002 + NA:2008

Veggbankett



y1 = 300 mm
y2 = 350 mm
y3 = 300 mm
h1 = 300 mm
h2 = 300 mm
h3 = 300 mm

Armering i tverretning (ytterst)
*nominell overdekning: 50 mm
armering, underkant: d 12 c 280

Armering i lengderetning
armering, uk: 3 d 12 c 400

skjøtarmering til vegg
armering: d 12 c 320
forankringslengde =300 mm
nominell overdekning: 35 mm

(* NS-EN 1992-1-1 4.4.1.3(4) Nominell overdekning bør minst være: 40 mm mot avrettet grunn og 75 mm mot ikke avrettet grunn

Materialdata og jord-data

Korreksjonsfakt. for Emodul pga tilslag	1,00
Materialfaktor betong	1,50
Materialfaktor stål	1,15
Betongkvalitet	B35 (C 35/45)
Densitet kg/m3	2400
Sement i fasthetsklasse	N
Armering flytegrense	500
Skjærarmering flytegrense	500
Eksponeringsklasse	XC2
Lite korrosjonsømfintlig armering	
Levetid 50 år	
Relativ fuktighet	40%

Fundamentnivå under marknivå	600	mm
Grunnvannsnivå over uk fundament	0	mm
Egenvekt av jord	19,0	kN/m3

Uten hensyn til fundamentdybde:
Netto bæreevne 300 kN/m2

Minimum overdekning:
(min.krav + toleranse) = (25 + 10) = 35 mm

NA.6.2.2(1)Følgende krav til tilslag er oppfyllt
(1.Største tilslag etter NS-EN 12620 D>=16mm. 2.Det grove tilslaget>=50% av total tilslagsmengde.
3.Grovt tilslag skal ikke være av kalkstein eller stein med tilsvarende lav fasthet)

Pålitelighetsklasse: 2

Lastfaktorer	Bruksgrense	Grunnbrudd	Bruddgrense B1	Bruddgrense B2
Permanent last (G)	1,00	1,20	1,35	1,20
Variabel last (P)	0,30	1,50	1,05	1,50

PSI-Faktor:
Kategori A - Bolig
Krav maks.nedbøyning:
Nedbøyning fører til skader

Belastning i overkant av fundament. Lasttilfelle nr 1

Permanent last

Mg_z	0,0 kNm
Vg_y	0,0 kN
Vg_z	48,0 kN
Ng	-102,0 kN

Variabel last

Mp_z	0,0 kNm
Vp_y	0,0 kN
Vp_z	0,0 kN
Np	-30,0 kN

Kontroll av likevekt (velting) **Lastfaktorer**

y-retning: Mvelt/Mstabil =0,00
Vekt av fundament og overliggende jord: lastfaktor = 0.9
Vekt av overliggende jord er medregnet

Positiv moment-og kraftvektorer i Y og Z-retning. Positiv Ng og Np peker oppover.

Moment -og skjærkontroll i bruddgrensetilstand

Y-retning: Mz = -7,9 kNm Mz/Md_z = 0,19

Skjær-trykkbrudd langs vegg: V/Vd =0,05 Lasttilfelle nr 1
Skjær-strekkbrudd i avstand d fra vegg: V/Vcd =0,08
Dimensjonerende skjærkraft =10,24 kN/m

Kontroll av grunntrykk

Ugunstigste lasttilfelle: 1
Bæreevne 311 kN/m2
tg Ø=0,00 rb =0,00 Nq =0,00 Ny =0,00
Overført grunntrykk 190 kN/m2

Risskontroll

Y-retning: w/wd =0,00

Kontrollsnitt er lagt ved kant av vegg.
Grenseverdi for maks strekkspenning i overkant uten armering : 0,80 ftd

APPENDIX F

APPENDIX F.1

Network-Characterization(Global warming(kg CO_2 eq)%)-Cut of 5,5%

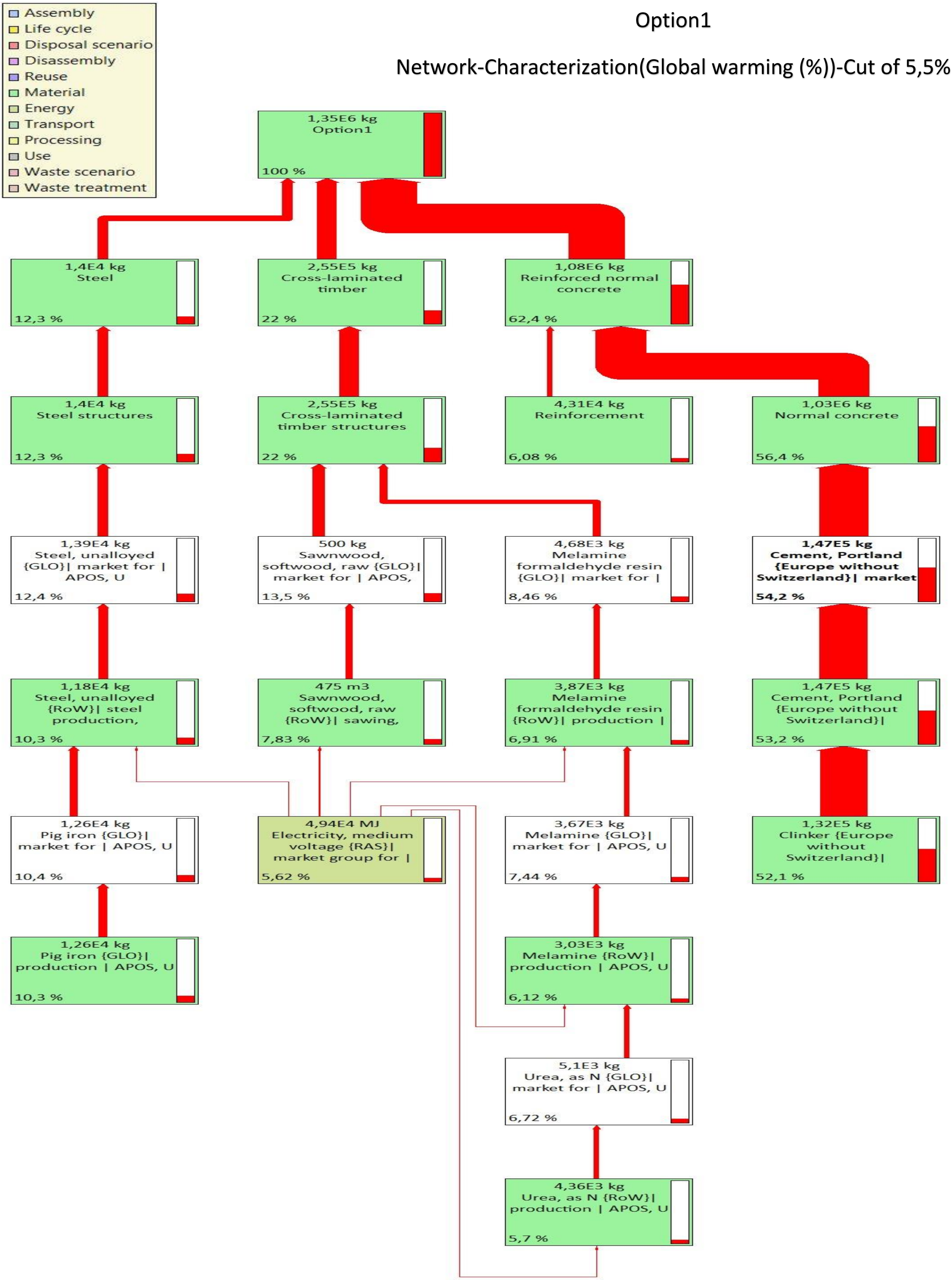
Network-Characterization(Global warming(kg CO_2 eq))-Cut of 5,5%

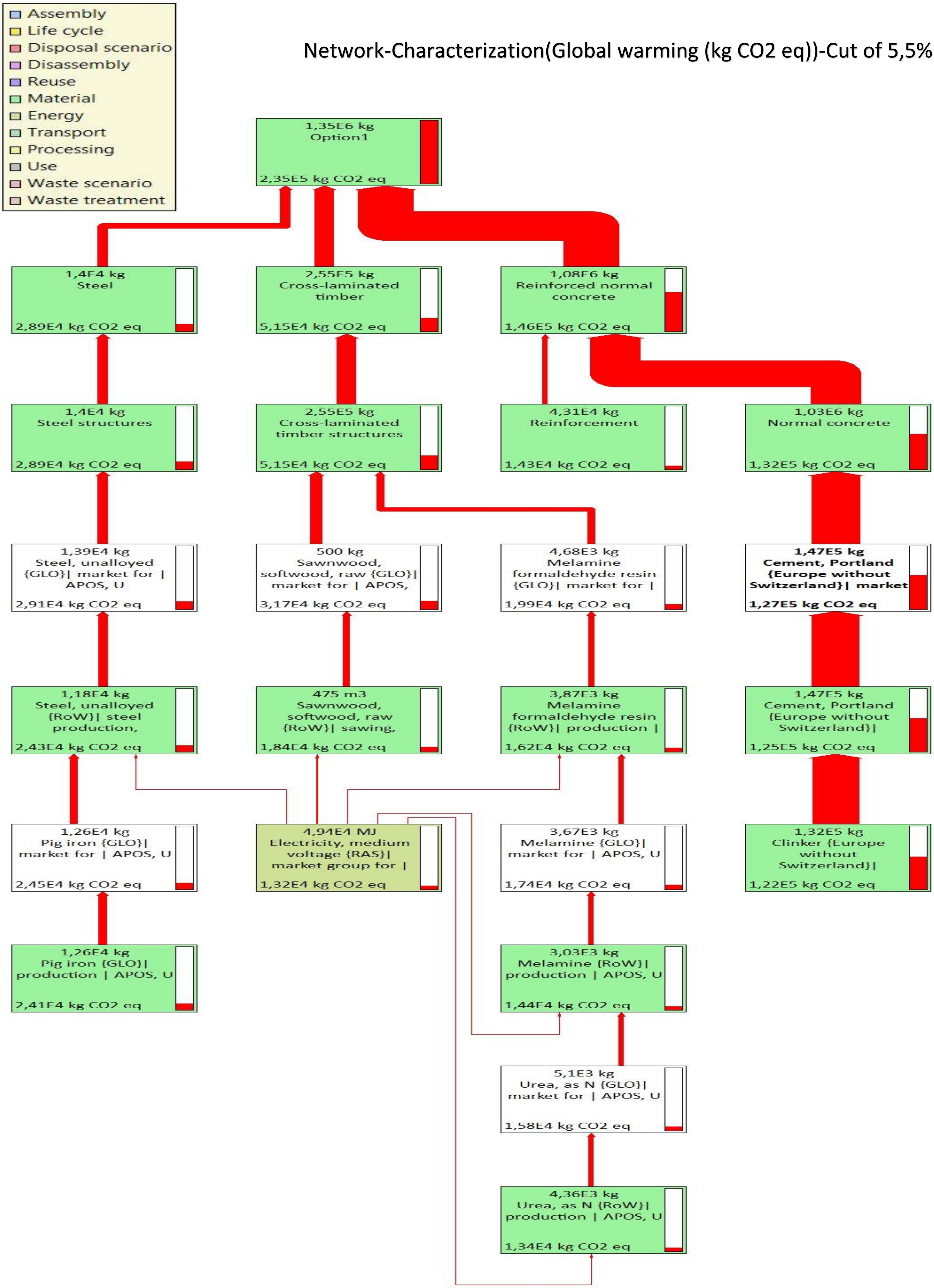
Network-Characterization(Land use(m2a crop eq)%)-Cut of 0,3%

Network-Characterization(Land use(m2a crop eq))-Cut of 0,3%

Option1

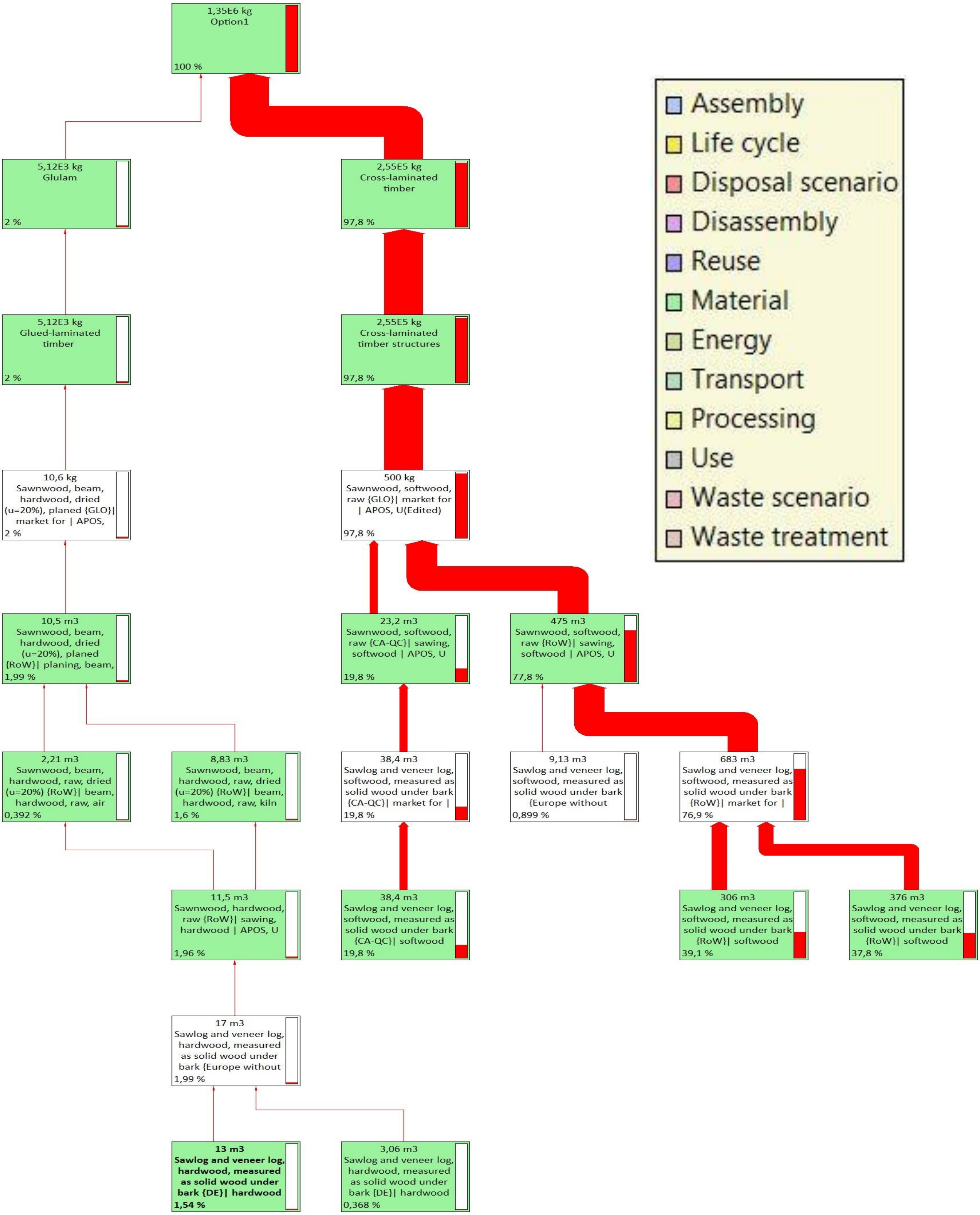
Network-Characterization(Global warming (%))-Cut of 5,5%



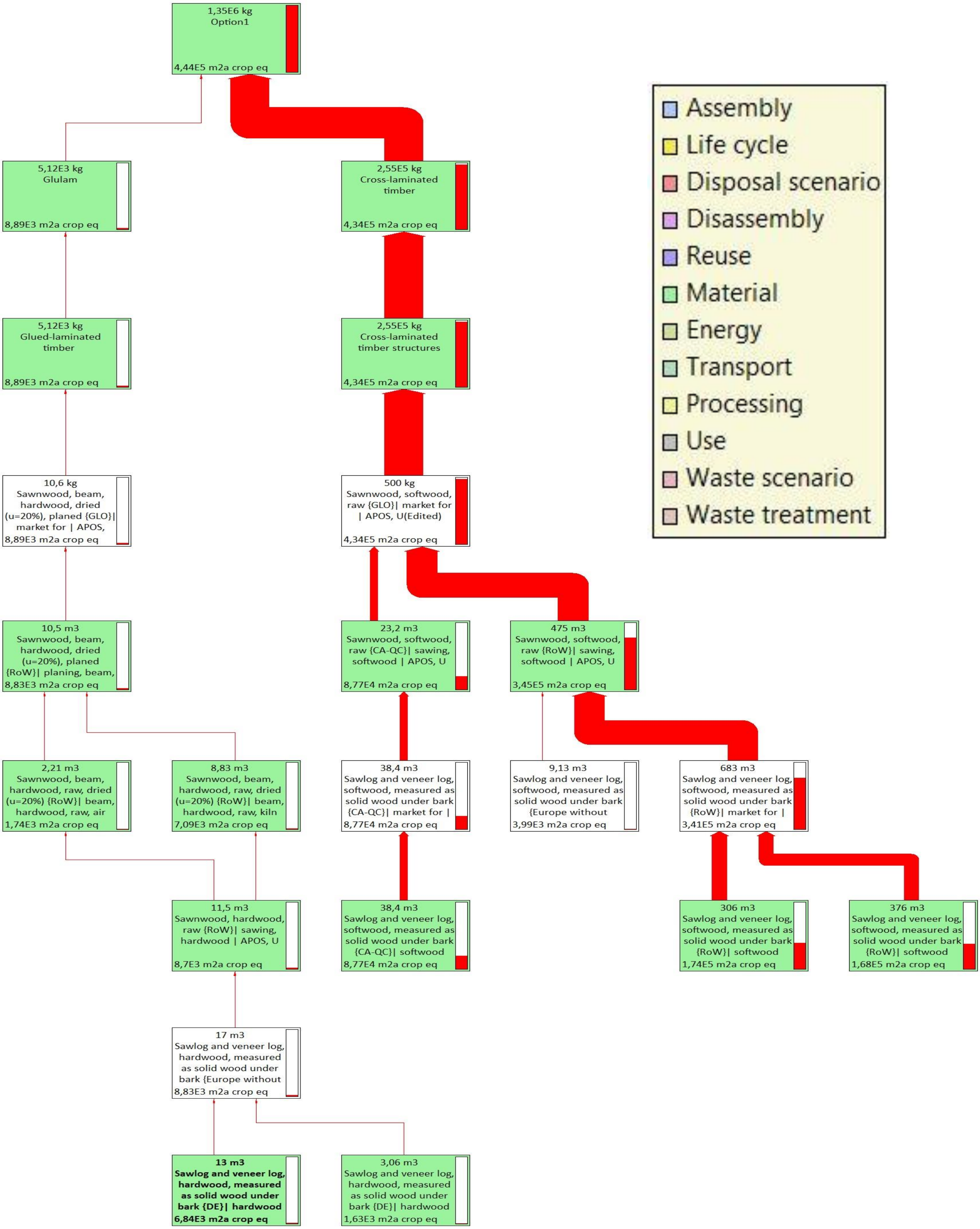


Assembly
Life cycle
Disposal scenario
Disassembly
Reuse
Material
Energy
Transport
Processing
Use
Waste scenario
Waste treatment
Network-Characterization(Global warming (kg CO2 eq))-Cut of 5,5%
1,35E6 kg Option1 2,35E5 kg CO2 eq
1,4E4 kg Steel 2,89E4 kg CO2 eq
2,55E5 kg Cross-laminated timber 5,15E4 kg CO2 eq
1,08E6 kg Reinforced normal concrete 1,46E5 kg CO2 eq
1,4E4 kg Steel structures 2,89E4 kg CO2 eq
2,55E5 kg Cross-laminated timber structures 5,15E4 kg CO2 eq
4,31E4 kg Reinforcement 1,43E4 kg CO2 eq
1,03E6 kg Normal concrete 1,32E5 kg CO2 eq
1,39E4 kg Steel, unalloyed {GLO}| market for | APOS, U 2,91E4 kg CO2 eq
500 kg Sawnwood, softwood, raw {GLO}| market for | APOS, 3,17E4 kg CO2 eq
4,68E3 kg Melamine formaldehyde resin {GLO}| market for | 1,99E4 kg CO2 eq
1,47E5 kg Cement, Portland {Europe without Switzerland}| market 1,27E5 kg CO2 eq
1,18E4 kg Steel, unalloyed {RoW}| steel production, 2,43E4 kg CO2 eq
475 m3 Sawnwood, softwood, raw {RoW}| sawing, 1,84E4 kg CO2 eq
3,87E3 kg Melamine formaldehyde resin {RoW}| production | 1,62E4 kg CO2 eq
1,47E5 kg Cement, Portland {Europe without Switzerland}| 1,25E5 kg CO2 eq
1,26E4 kg Pig iron {GLO}| market for | APOS, U 2,45E4 kg CO2 eq
4,94E4 MJ Electricity, medium voltage {RAS}| market group for | 1,32E4 kg CO2 eq
3,67E3 kg Melamine {GLO}| market for | APOS, U 1,74E4 kg CO2 eq
1,32E5 kg Clinker {Europe without Switzerland}| 1,22E5 kg CO2 eq
1,26E4 kg Pig iron {GLO}| production | APOS, U 2,41E4 kg CO2 eq
3,03E3 kg Melamine {RoW}| production | APOS, U 1,44E4 kg CO2 eq
5,1E3 kg Urea, as N {GLO}| market for | APOS, U 1,58E4 kg CO2 eq
4,36E3 kg Urea, as N {RoW}| production | APOS, U 1,34E4 kg CO2 eq

Network-Characterization(Land use(%))-Cut of 0,3%



Network-Characterization(Land use(m2a crop eq))-Cut of 0,3%



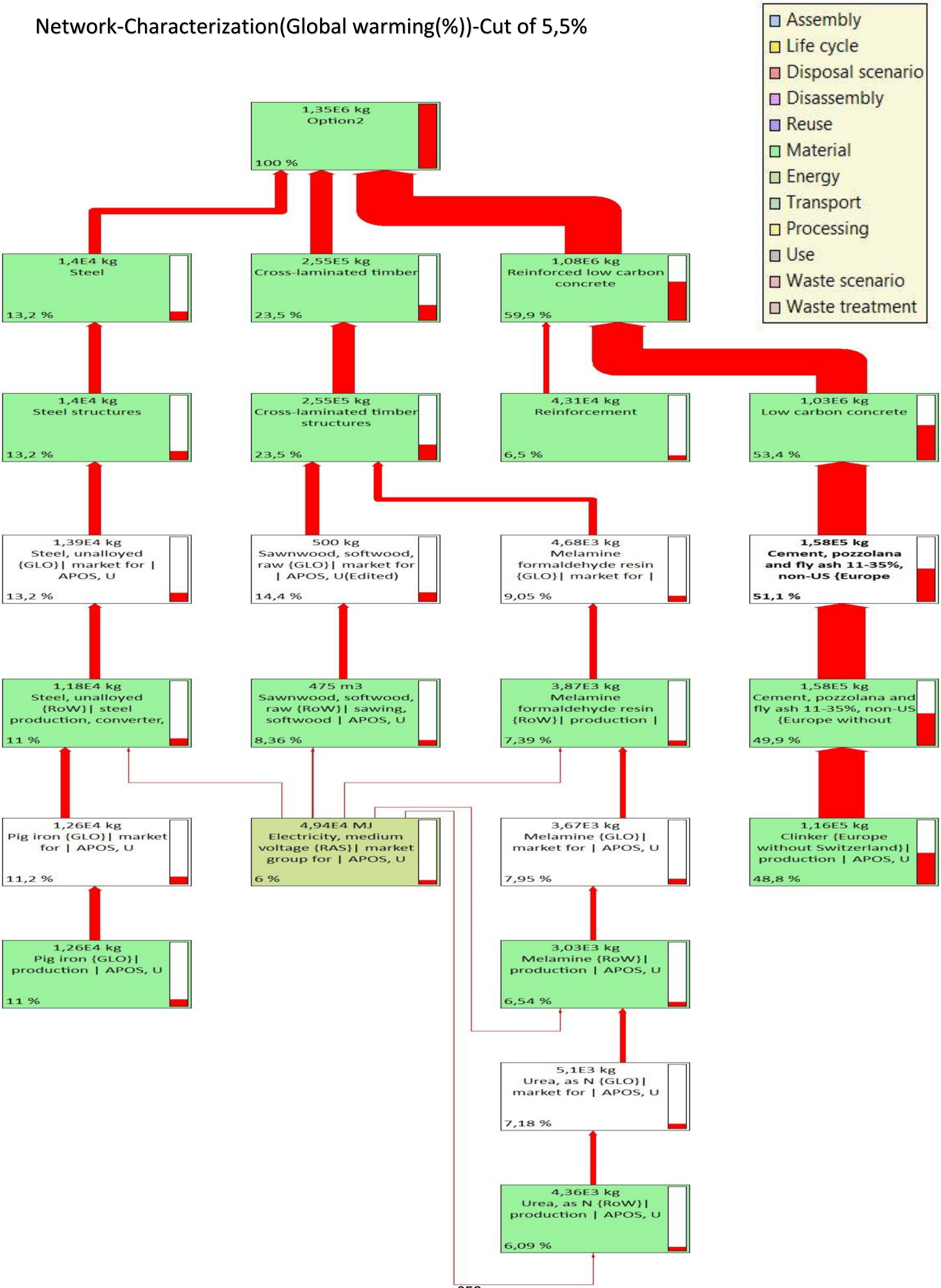
Network-Characterization(Global warming(kg CO2 eq)%)-Cut of 5,5%

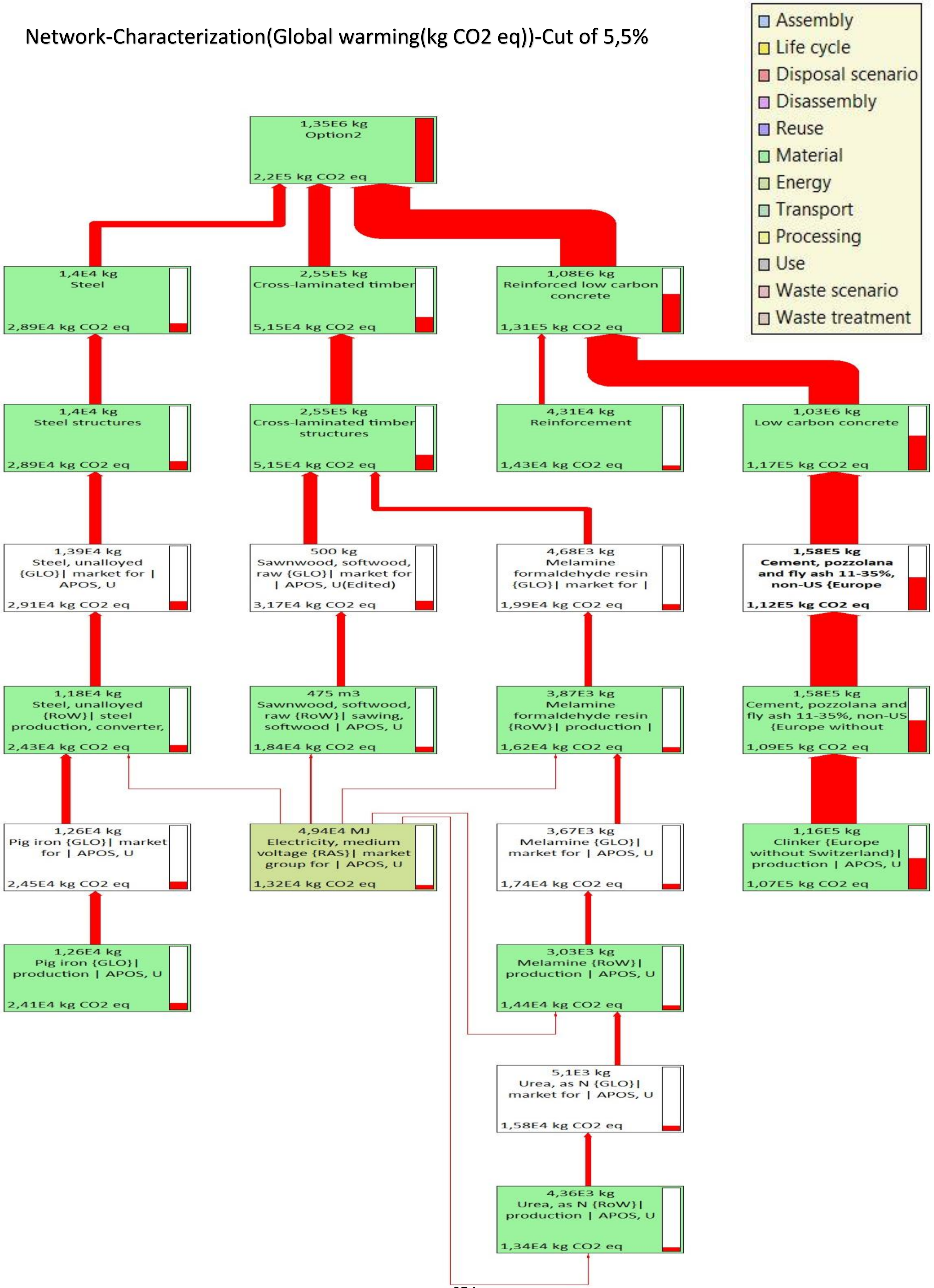
Network-Characterization(Global warming(kg CO2 eq))-Cut of 5,5%

Network-Characterization(Land use(m2a crop eq)%)-Cut of 0,3%

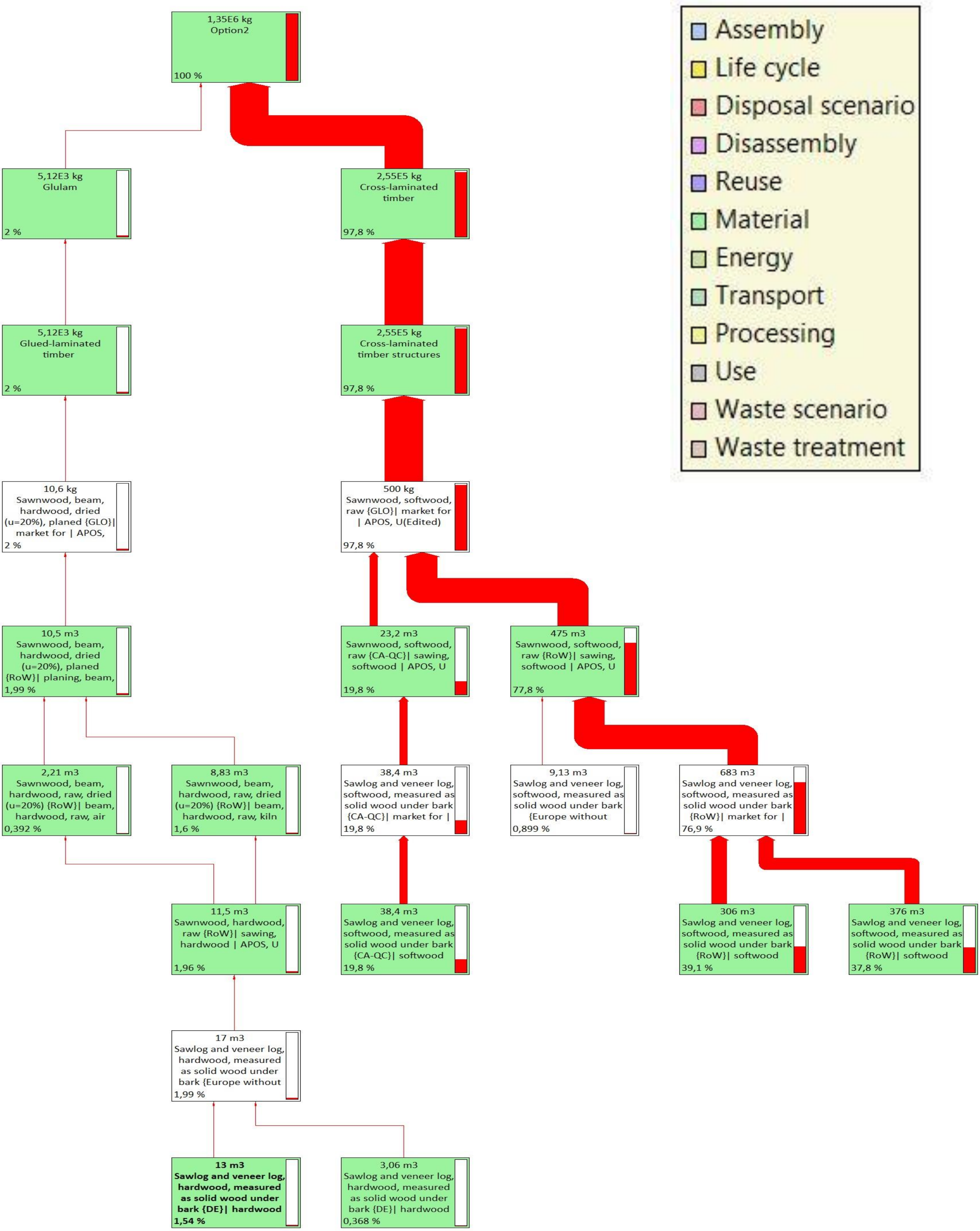
Network-Characterization(Land use(m2a crop eq))-Cut of 0,3%

Network-Characterization(Global warming(%))-Cut of 5,5%

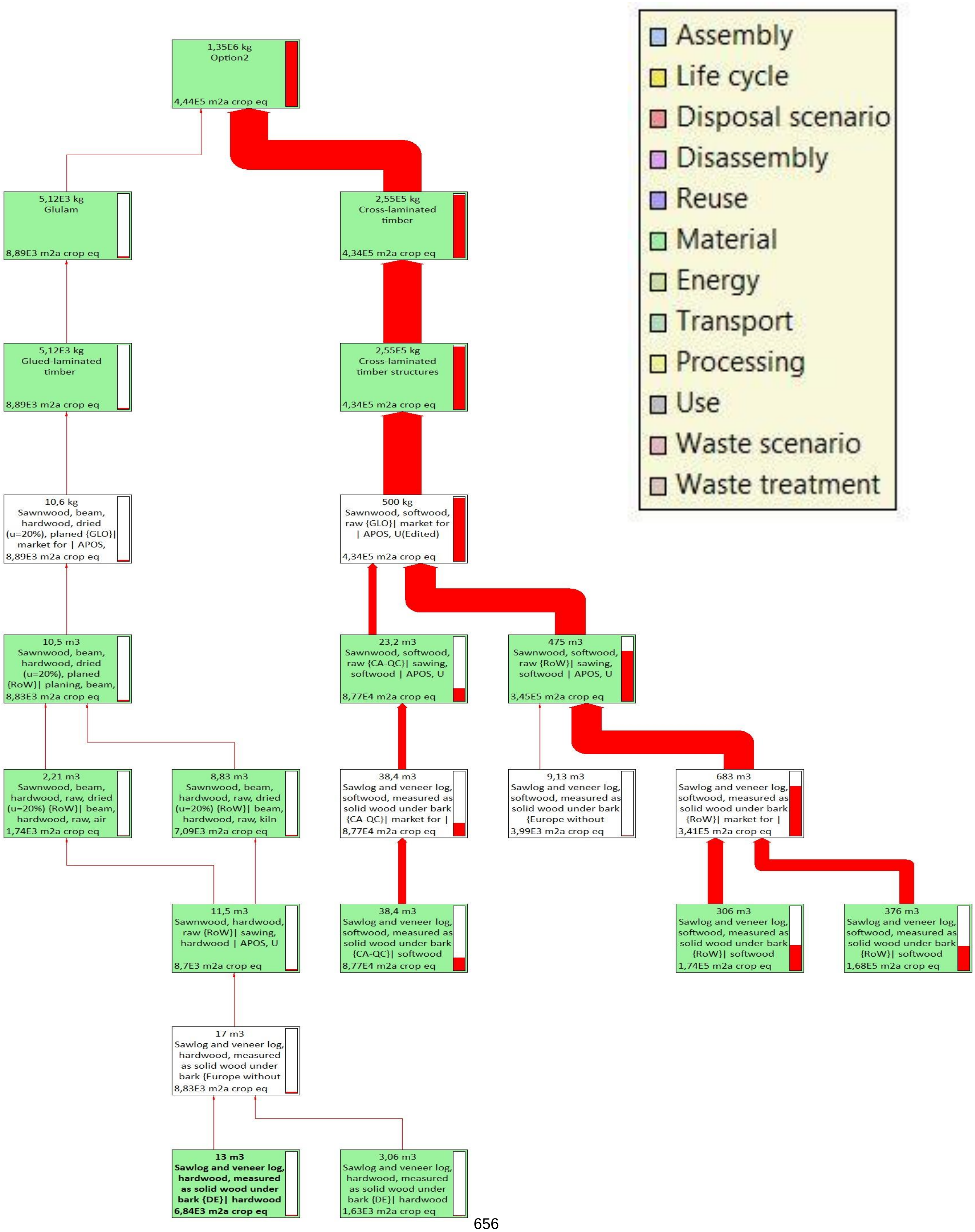



Network-Characterization(Global warming(kg CO2 eq))-Cut of 5,5%
Assembly
Life cycle
Disposal scenario
Disassembly
Reuse
Material
Energy
Transport
Processing
Use
Waste scenario
Waste treatment
1,35E6 kg
Option2
2,2E5 kg CO2 eq
1,4E4 kg
Steel
2,89E4 kg CO2 eq
2,55E5 kg
Cross-laminated timber
5,15E4 kg CO2 eq
1,08E6 kg
Reinforced low carbon concrete
1,31E5 kg CO2 eq
1,4E4 kg
Steel structures
2,89E4 kg CO2 eq
2,55E5 kg
Cross-laminated timber structures
5,15E4 kg CO2 eq
4,31E4 kg
Reinforcement
1,43E4 kg CO2 eq
1,03E6 kg
Low carbon concrete
1,17E5 kg CO2 eq
1,39E4 kg
Steel, unalloyed {GLO}| market for | APOS, U
2,91E4 kg CO2 eq
500 kg
Sawnwood, softwood, raw {GLO}| market for | APOS, U(Edited)
3,17E4 kg CO2 eq
4,68E3 kg
Melamine formaldehyde resin {GLO}| market for |
1,99E4 kg CO2 eq
1,58E5 kg
Cement, pozzolana and fly ash 11-35%, non-US {Europe
1,12E5 kg CO2 eq
1,18E4 kg
Steel, unalloyed {RoW}| steel production, converter,
2,43E4 kg CO2 eq
475 m3
Sawnwood, softwood, raw {RoW}| sawing, softwood | APOS, U
1,84E4 kg CO2 eq
3,87E3 kg
Melamine formaldehyde resin {RoW}| production |
1,62E4 kg CO2 eq
1,58E5 kg
Cement, pozzolana and fly ash 11-35%, non-US {Europe without
1,09E5 kg CO2 eq
1,26E4 kg
Pig iron {GLO}| market for | APOS, U
2,45E4 kg CO2 eq
4,94E4 MJ
Electricity, medium voltage {RAS}| market group for | APOS, U
1,32E4 kg CO2 eq
3,67E3 kg
Melamine {GLO}| market for | APOS, U
1,74E4 kg CO2 eq
1,16E5 kg
Clinker {Europe without Switzerland}| production | APOS, U
1,07E5 kg CO2 eq
1,26E4 kg
Pig iron {GLO}| production | APOS, U
2,41E4 kg CO2 eq
3,03E3 kg
Melamine {RoW}| production | APOS, U
1,44E4 kg CO2 eq
5,1E3 kg
Urea, as N {GLO}| market for | APOS, U
1,58E4 kg CO2 eq
4,36E3 kg
Urea, as N {RoW}| production | APOS, U
1,34E4 kg CO2 eq

Network-Characterization(Land use(%))-Cut of 0,3%



Network-Characterization(Land use(m2a crop eq))-Cut of 0,3%

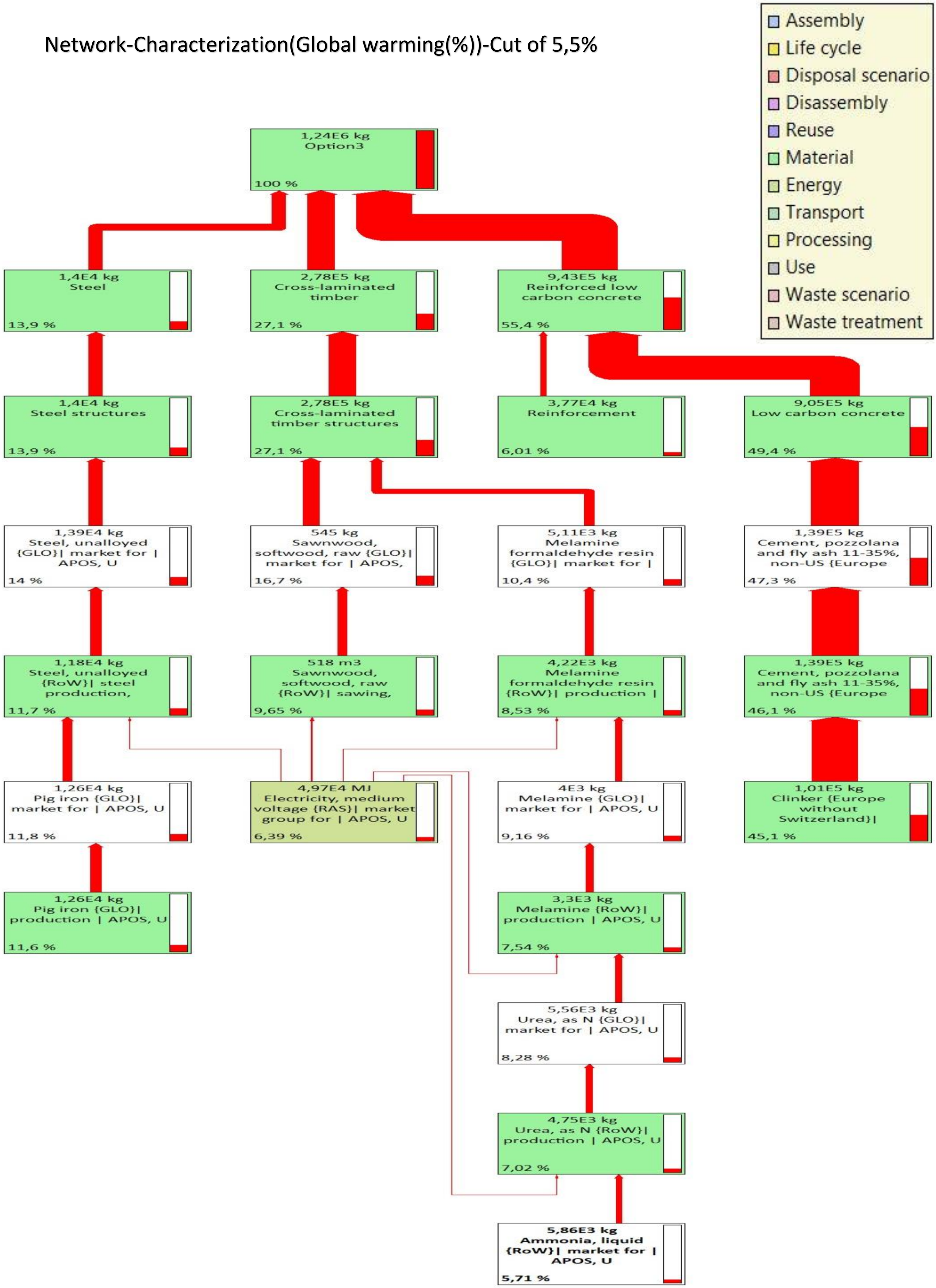


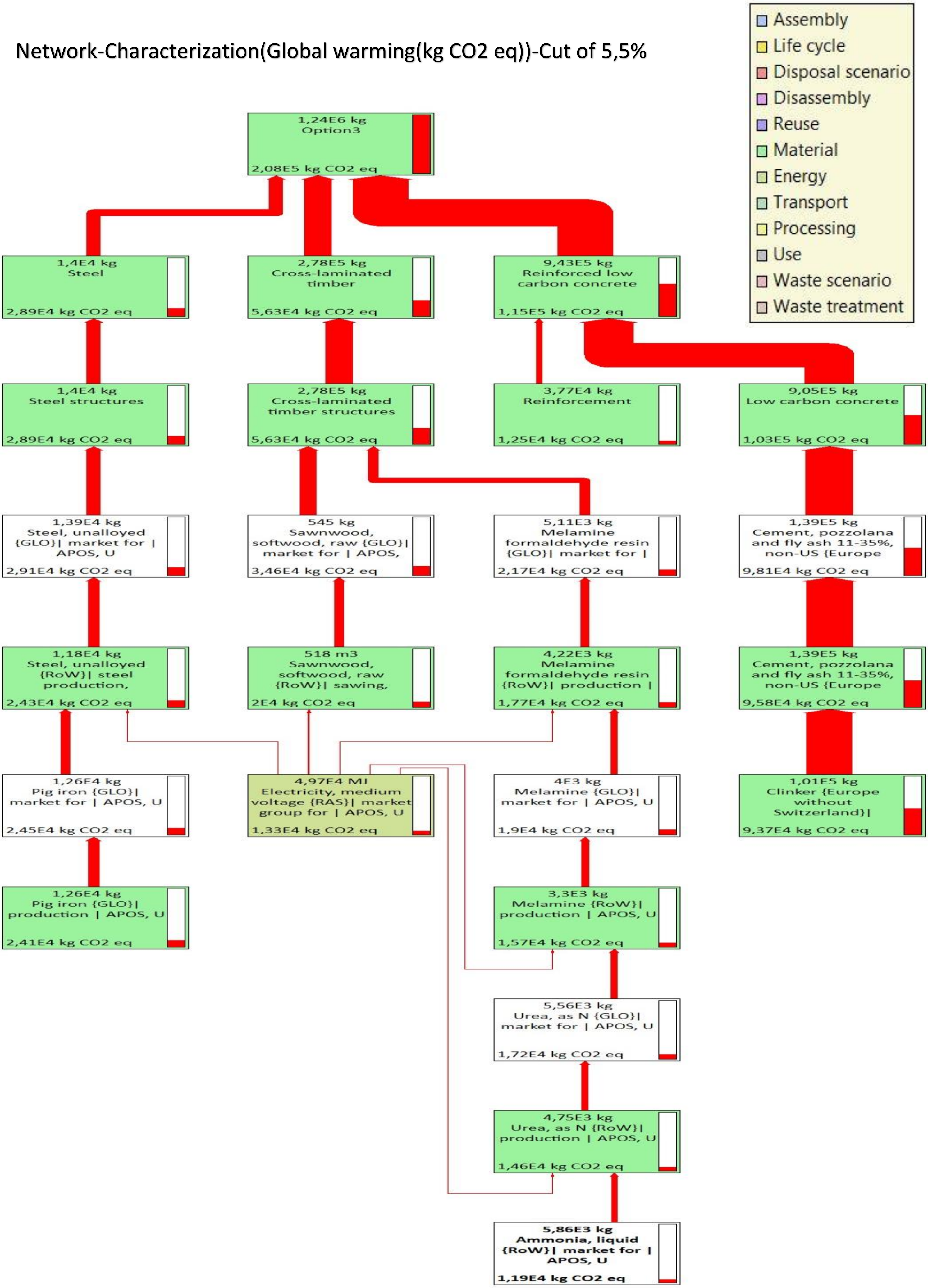
Network-Characterization(Global warming(kg CO2 eq)%)-Cut of 5,5%

Network-Characterization(Global warming(kg CO2 eq))-Cut of 5,5%

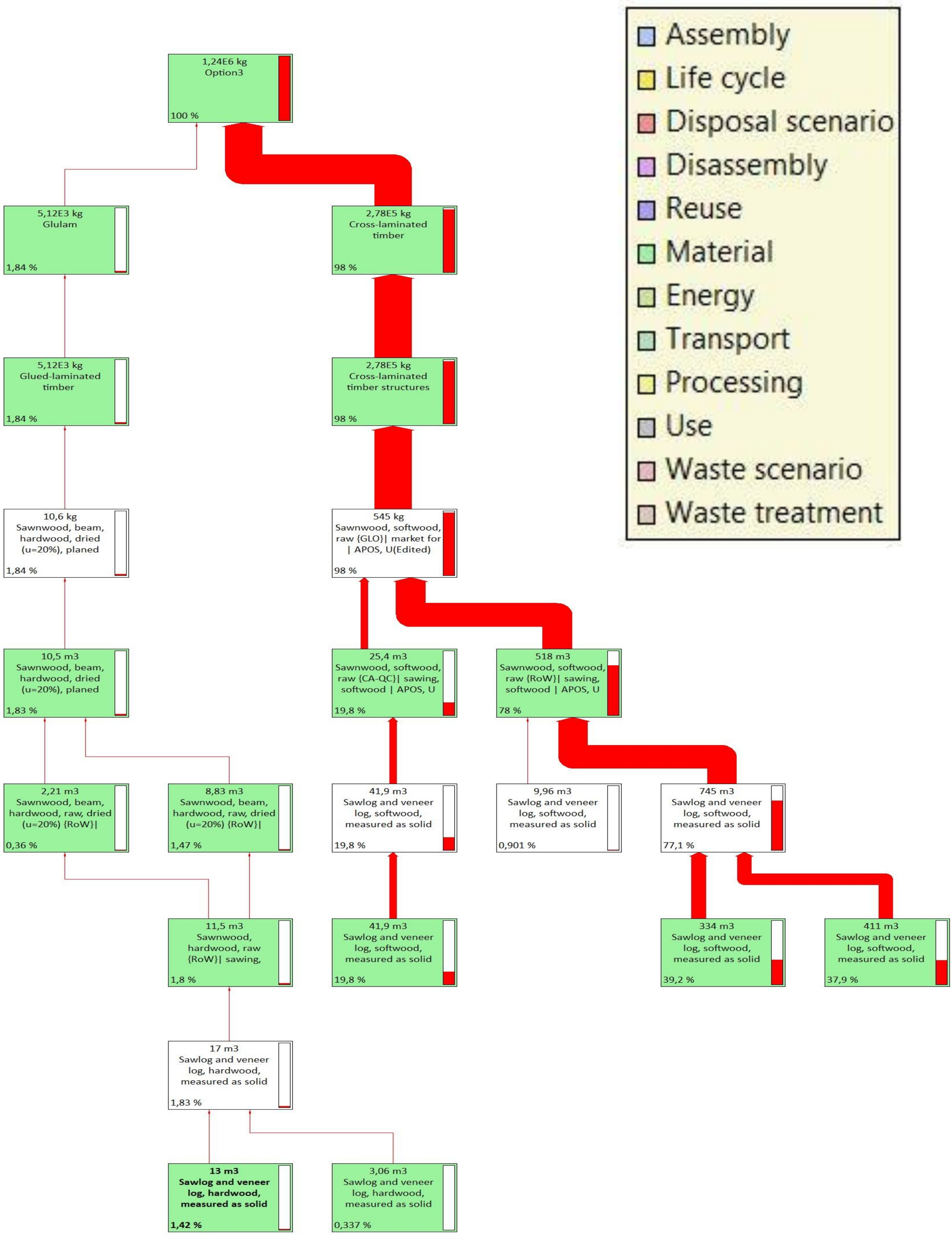
Network-Characterization(Land use(m2a crop eq)%)-Cut of 0,3%

Network-Characterization(Land use(m2a crop eq))-Cut of 0,3%

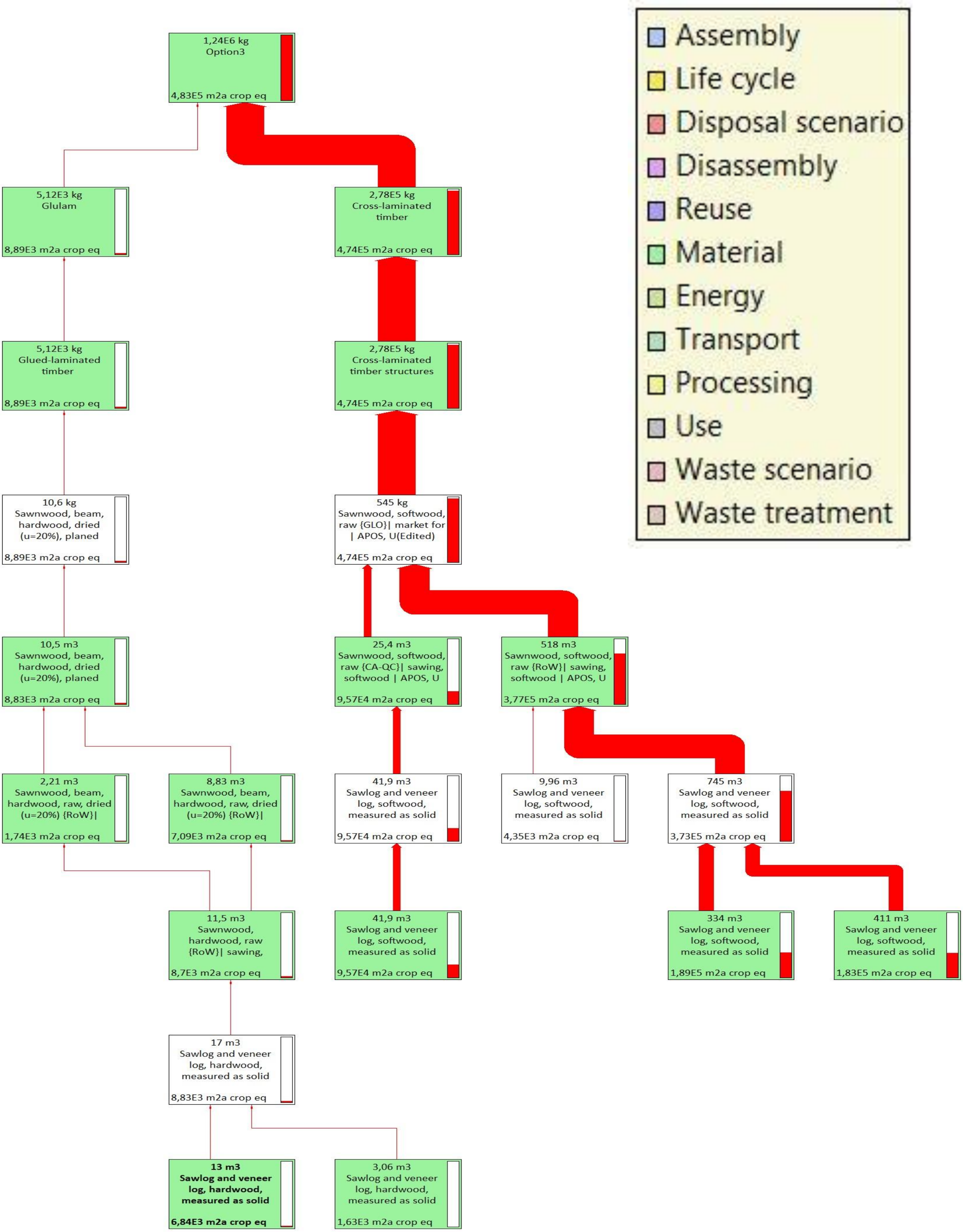

Network-Characterization(Global warming(%))-Cut of 5,5%
Assembly
Life cycle
Disposal scenario
Disassembly
Reuse
Material
Energy
Transport
Processing
Use
Waste scenario
Waste treatment
1,24E6 kg Option3 100 %
1,4E4 kg Steel 13,9 %
2,78E5 kg Cross-laminated timber 27,1 %
9,43E5 kg Reinforced low carbon concrete 55,4 %
1,4E4 kg Steel structures 13,9 %
2,78E5 kg Cross-laminated timber structures 27,1 %
3,77E4 kg Reinforcement 6,01 %
9,05E5 kg Low carbon concrete 49,4 %
1,39E4 kg Steel, unalloyed {GLO}| market for | APOS, U 14 %
545 kg Sawnwood, softwood, raw {GLO}| market for | APOS, 16,7 %
5,11E3 kg Melamine formaldehyde resin {GLO}| market for | 10,4 %
1,39E5 kg Cement, pozzolana and fly ash 11-35%, non-US {Europe 47,3 %
1,18E4 kg Steel, unalloyed {RoW}| steel production, 11,7 %
518 m3 Sawnwood, softwood, raw {RoW}| sawing, 9,65 %
4,22E3 kg Melamine formaldehyde resin {RoW}| production | 8,53 %
1,39E5 kg Cement, pozzolana and fly ash 11-35%, non-US {Europe 46,1 %
1,26E4 kg Pig iron {GLO}| market for | APOS, U 11,8 %
4,97E4 MJ Electricity, medium voltage {RAS}| market group for | APOS, U 6,39 %
4E3 kg Melamine {GLO}| market for | APOS, U 9,16 %
1,01E5 kg Clinker {Europe without Switzerland}| 45,1 %
1,26E4 kg Pig iron {GLO}| production | APOS, U 11,6 %
3,3E3 kg Melamine {RoW}| production | APOS, U 7,54 %
5,56E3 kg Urea, as N {GLO}| market for | APOS, U 8,28 %
4,75E3 kg Urea, as N {RoW}| production | APOS, U 7,02 %
5,86E3 kg Ammonia, liquid {RoW}| market for | APOS, U 5,71 %


Network-Characterization(Global warming(kg CO2 eq))-Cut of 5,5%
Assembly
Life cycle
Disposal scenario
Disassembly
Reuse
Material
Energy
Transport
Processing
Use
Waste scenario
Waste treatment
1,24E6 kg Option3 2,08E5 kg CO2 eq
1,4E4 kg Steel 2,89E4 kg CO2 eq
2,78E5 kg Cross-laminated timber 5,63E4 kg CO2 eq
9,43E5 kg Reinforced low carbon concrete 1,15E5 kg CO2 eq
1,4E4 kg Steel structures 2,89E4 kg CO2 eq
2,78E5 kg Cross-laminated timber structures 5,63E4 kg CO2 eq
3,77E4 kg Reinforcement 1,25E4 kg CO2 eq
9,05E5 kg Low carbon concrete 1,03E5 kg CO2 eq
1,39E4 kg Steel, unalloyed {GLO}| market for | APOS, U 2,91E4 kg CO2 eq
545 kg Sawnwood, softwood, raw {GLO}| market for | APOS, 3,46E4 kg CO2 eq
5,11E3 kg Melamine formaldehyde resin {GLO}| market for | 2,17E4 kg CO2 eq
1,39E5 kg Cement, pozzolana and fly ash 11-35%, non-US {Europe 9,81E4 kg CO2 eq
1,18E4 kg Steel, unalloyed {RoW}| steel production, 2,43E4 kg CO2 eq
518 m3 Sawnwood, softwood, raw {RoW}| sawing, 2E4 kg CO2 eq
4,22E3 kg Melamine formaldehyde resin {RoW}| production | 1,77E4 kg CO2 eq
1,39E5 kg Cement, pozzolana and fly ash 11-35%, non-US {Europe 9,58E4 kg CO2 eq
1,26E4 kg Pig iron {GLO}| market for | APOS, U 2,45E4 kg CO2 eq
4,97E4 MJ Electricity, medium voltage {RAS}| market group for | APOS, U 1,33E4 kg CO2 eq
4E3 kg Melamine {GLO}| market for | APOS, U 1,9E4 kg CO2 eq
1,01E5 kg Clinker {Europe without Switzerland}| 9,37E4 kg CO2 eq
1,26E4 kg Pig iron {GLO}| production | APOS, U 2,41E4 kg CO2 eq
3,3E3 kg Melamine {RoW}| production | APOS, U 1,57E4 kg CO2 eq
5,56E3 kg Urea, as N {GLO}| market for | APOS, U 1,72E4 kg CO2 eq
4,75E3 kg Urea, as N {RoW}| production | APOS, U 1,46E4 kg CO2 eq
5,86E3 kg Ammonia, liquid {RoW}| market for | APOS, U 1,19E4 kg CO2 eq

Network-Characterization(Land use(%))-Cut of 0,3%



Network-Characterization(Land use(m2a crop eq))-Cut of 0,3%



353050 normal concrete

355050035 low carbon class A

epd-massivtre_norsk

NEPD-00131E_rev1_ROCKWOOL-isolering(1)

NEPD-1576-605_Standard-limtrebjelke

NEPD-347-238-EN_Ribbed-reinforcement-bars

NEPD-402-281-EN_Steel-structures

ENVIRONMENTAL PRODUCT DECLARATION

in accordance with ISO 14025 ISO 21930 EN 15804

Eier av deklarasjonen:	NorBetong AS
Programoperatør:	Næringslivets Stiftelse for Miljødeklarasjoner
Utgiver:	Næringslivets Stiftelse for Miljødeklarasjoner
Deklarasjon nummer:	Prosjektspesifikk EPD med ref. til NEPD00283N
Publiserings nummer:	Ikke tildelt
ECO Platform registreringsnummer:	Ikke tildelt
Godkjent dato:	
Gyldig til:	26.11.2019

B35 M45 D16 ANL-FA+S, 353050, Vibrerbar betong, Stor-Oslo

NorBetong AS

www.epd-norge.no

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NORBETONG
HEIDELBERGCEMENTGroup

Generell informasjon

Produkt:

B35 M45 D16 ANL-FA+S, 353050, Vibrerbar betong, Stor-Oslo

Eier av deklarasjonen:

NorBetong AS
Kontaktperson: Magnus Gade
Skjeggerud
Telefon: + 47 22 87 83 00
e-post: mg.skjeggerud@norbetong.no

Programoperatør:

Næringslivets stiftelse for Miljødeklarasjoner
Pb. 5250 Majorstuen, 0303 Oslo
Phone: +47 23 08 80 00
e-post: post@epd-norge.no

Produsent:

NorBetong AS

Deklarasjon nummer:

Prosjektspesifikk EPD med ref. til NEPD00283N

Produksjonssted:

Stor-Oslo

ECO Platform registreringsnummer:

Kvalitet/Miljøsystem:

NorBetongs kvalitets- og miljøsystem er bygget opp iht. NS-EN 206. Det er dessuten supplert med miljømessige momenter iht. NS-EN ISO 14001 samt internkontrollforskriften

Deklarasjonen er basert på PCR:

EN 15804:2012+A1:2013 tjener som kjerne-PCR
PCR for Precast Concrete Products, NPCR 20.2011.

Org. no.:

934 468 740

Erklæringen om ansvar:

Eieren av deklarasjonen skal være ansvarlig for den underliggende informasjon og bevis. EPD Norge skal ikke være ansvarlig med hensyn til produsent informasjon, livsløpsvurdering data og bevis.

Godkjent dato:

Gyldig til:

26.11.2019

Deklarert enhet:

1 m3 B35 M45 D16 ANL-FA+S, 353050, Vibrerbar betong, Stor-Oslo

Årstall for studien:

2017

Deklarert enhet med opsjon:

A1,A2,A3,A4

Sammenlignbarhet:

EPD av byggevarer er nødvendigvis ikke sammenlignbare hvis de ikke samsvarer med NS-EN 15804 og ses i en bygningskontekst.

Funksjonell enhet:

Miljødeklarasjonen er utarbeidet av:

Deklarasjonen er utviklet ved bruk av EPDGen-Version 1.1
Godkjenning:
Bedriftsspesifikke data er

Samlet og registrert av: Thea Vik Nordeide

Kontrollert av: Frode Skåttun

Verifikasjon:

Uavhengig verifikasjon av data, annen miljøinformasjon og EPD er foretatt etter ISO 14025:2010, kapittel 8.1.3 og 8.1.4

Ekstern

Tredjeparts verifikator:

Sign

Anne Rønning

Seniorforsker Anne Rønning

(Uavhengig verifikator godkjent av EPD Norge)

Godkjent:

Sign

(Daglig leder av EPD-Norge)

Produkt

Produktbeskrivelse:

Ferdigbetong produsert iht. NS-EN 206

Produktspesifikasjon:

Miljøindikatorene avviker fra NEPD00283N pga. endret betongsammensetning.

Materials	Percent
Cement	14,16
Aggregate	78,55
Water	6,69
Chemicals	0,16
SCM	0,44

Tekniske data:

B35 M45 D16 ANL-FA+S CL 0,1. Vibrerbar betong med synk opp til 240mm

Markedsområde:

Stor-Oslo

Levetid:

Som for bygninger

LCA: Beregningsregler

Deklarert enhet:

1 m3 B35 M45 D16 ANL-FA+S, 353050, Vibrerbar betong, Stor-Oslo

Cut-off kriterier:

Alle viktige råmaterialer og all viktig energibruk er inkludert. Produksjonsprosessen for råmaterialene og energistrømmer som inngår med veldig små mengder (<1%) er ikke inkludert.

Allokering:

Allokering er gjort ihht bestemmelser i EN 15804
Inngående energi og vann, samt produksjon av avfall i egen produksjon er allokert likt mellom alle produktene gjennom masseallokering. Påvirkning for primærproduksjonen av resirkulerte materialer er allokert til hovedproduktet der materialet ble brukt. Resirkuleringsprosessen og transport av materialet er allokert til denne analysen.

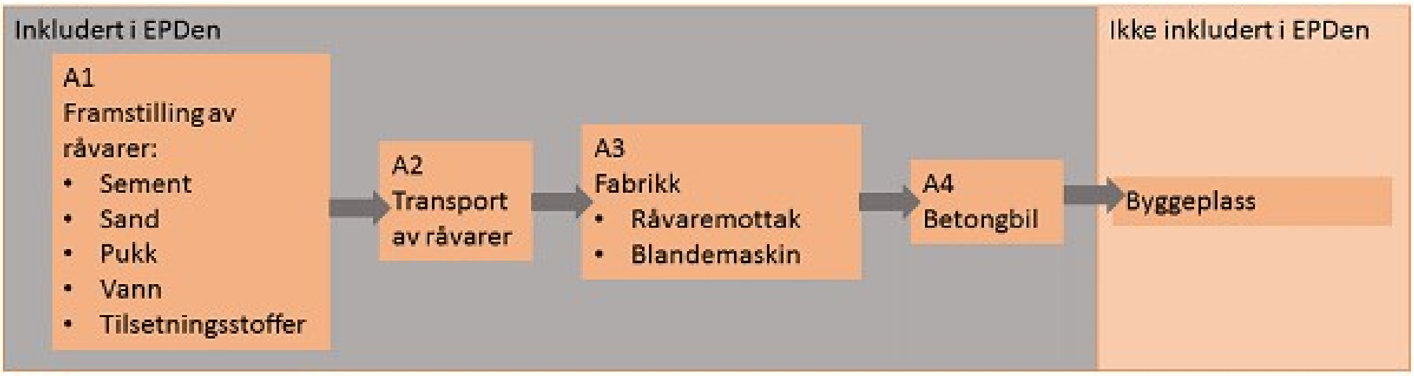
Datakvalitet:

Materials	Data quality	Source	Year
Water	0	0	0
Chemicals	European average	Efca	0
SCM	Waste	0	0
Aggregate	Database	Modified EcoInvent	2012
Aggregate	Database	Østfoldforskning	2012
Cement	EPD	NEPD00024N	2013

Systemgrenser:

Alle prosesser fra råvareuttak til produktet ut fra fabrikkporten er inkludert i analysen.

Flytskjema:



Teknisk tilleggsinformasjon

LCA: Scenarier og annen teknisk informasjon

Følgende informasjonen beskriver scenariene for modulene i EPDen.

Transport fra produksjonssted til bruker (A4)

Type	Kapasitetsutnyttelse inkl retur %	Kjøretøytype	Distanse km	Brennstoff/Energi forbruk	Enhet	Verdi (l/t)
Bil	53,0 %	Concrete truck	7	0,020216	l/tkm	0,14
Jernbane					l/tkm	
Båt					l/tkm	
Annet					l/tkm	

Byggefase A5

.	Enhet	Verdi
Hjelpematerialer	kg	
Vannforbruk	m^3	
Elektrisitetsforbruk	kWh	
Andre energikilder	MJ	
Materialtap	kg	
Materialer fra avfallsbehandling	kg	
Støv i luften	kg	
VOC utslipp	kg	

Monterte produkter i bruk (B1)

.	Unit	Value

Vedlikehold (B2)/Reparasjon (B3)

.	Enhet	Verdi
Vedlikeholdsfrekvens*	.	
Hjelpematerialer	kg	
Andre ressurser	kg	
Vannforbruk	m^3	
Elektrisitetsforbruk	kWh	
Andre energikilder	MJ	
Materialtap	kg	
VOC utslipp	kg	

Utskifting (B4)/Renovering (B5)

.	Enhet	Verdi
Utskiftingsfrekvens*	stk	
Elektrisitetsforbruk	kWh	
Utskifting av slitte deler	0	

* Tall eller referanselevetid

Drifts energi (B6) og vannbruk (B7)

.	Enhet	Verdi
Vannforbruk	m^3	
Elektrisitetsforbruk	kWh	
Andre energikilder	MJ	
Utstyrets varmeeffekt	kW	

Sluttfase (C1,C3,C4)

.	Enhet	Verdi
Farlig avfall	kg	
Blandet avfall	kg	
Gjenbruk	kg	
Resirkulering	kg	
Energigjenvinning	kg	
Til deponi	kg	

Transport avfallsbehandling (C2)

Type	Kapasitetsutnyttelse inkl retur %	Kjøretøytype	Distanse km	Brennstoff/Energi forbruk	Enhet	Verdi (l/t)
Bil					l/tkm	
Jernbane					l/tkm	
Båt					l/tkm	
Annet					l/tkm	

Gevinst og belastninger etter endt levetid (D)

LCA: Resultater

Systemgrenser (X=inkludert, MND=modul ikke deklarert, MNR=modul ikke relevant)

Product stage				Construction installation stage	User stage							End of life stage				.	Beyond the system bondaries
Råmaterialer	Transport	Tilvirkning	Transport	Konstruksjons/ installasjonsfase	Bruk	Vedlikehold	Reparasjon	Utskiftinger	Renovering	Operasjonell energibruk	Operasjonell vannbruk	Demontering	Transport	Avfallsbehandling	Avfall til sluttbehandling		Gjenbruk/gjenvinning/ resirkulering-potensiale
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	.	D
X	X	X	X	MNR	MNR	MNR	MNR	MNR	MNR	MNR	MNR	MNR	MNR	MNR	MNR	.	MNR

Miljøpåvirkning (Environmental impact)

Parameter	Unit	A1	A2	A3	A4	A5	C1	C2
GWP	kg CO_2 -eq	2,19E+002	5,64E+000	2,76E+000	1,36E+000			
ODP	kg CFC11 -eq	3,31E-006	0,00E+000	4,90E-007	0,00E+000			
POCP	kg C_2H_4-eq	3,54E-002	2,92E-003	3,74E-004	2,42E-004			
AP	kg SO_2 -eq	4,96E-001	1,91E-002	7,24E-003	4,80E-003			
EP	kg PO_4^{3-} -eq	1,31E-001	2,66E-002	1,09E-003	9,98E-004			
ADPM	kg Sb -eq	2,09E-004	0,00E+000	2,95E-006	0,00E+000			
ADPE	MJ	1,19E+003	7,92E+001	3,80E+001	2,08E+001			

GWP Global warming potential; ODP Depletion potential of the stratospheric ozone layer; POCP Formation potential of tropospheric photochemical oxidants; AP Acidification potential of land and water; EP Eutrophication potential; ADPM Abiotic depletion potential for non fossil resources; ADPE Abiotic depletion potential for fossil resources

Leseeksempel 9,0 E-03 = 9,0*10 -3 = 0,009

Ressursbruk (Resource use)

Parameter	Unit	A1	A2	A3	A4	A5	C1	C2
RPEE	MJ	2,47E+002	5,74E-001	1,65E+001	3,20E-001			
RPEM	MJ	1,59E+000	1,70E-001	1,41E-001	9,79E-002			
TPE	MJ	2,49E+002	7,44E-001	1,67E+001	4,18E-001			
NRPE	MJ	1,23E+003	7,99E+001	3,94E+001	2,12E+001			
NRPM	MJ	1,47E+001	0,00E+000	0,00E+000	0,00E+000			
TRPE	MJ	1,24E+003	7,99E+001	3,94E+001	2,12E+001			
SM	kg	7,14E+001	0,00E+000	0,00E+000	0,00E+000			
RSF	MJ	0,00E+000	0,00E+000	0,00E+000	0,00E+000			
NRSF	MJ	4,29E+002	0,00E+000	0,00E+000	0,00E+000			
W	m^3	3,74E+002	3,07E-001	2,75E-001	1,89E-002			

RPEE Renewable primary energy resources used as energy carrier; RPEM Renewable primary energy resources used as raw materials; TPE Total use of renewable primary energy resources; NRPE Non renewable primary energy resources used as energy carrier; NRPM Non renewable primary energy resources used as materials; TRPE Total use of non renewable primary energy resources; SM Use of secondary materials; RSF Use of renewable secondary fuels; NRSF Use of non renewable secondary fuels; W Use of net fresh water

Leseeksempel 9,0 E-03 = 9,0*10 -3 = 0,009

Livsløpets slutt - Avfall (End of life - Waste)

Parameter	Unit	A1	A2	A3	A4	A5	C1	C2
HW	kg	1,01E-003	2,30E-005	1,41E-005	1,60E-005			
NHW	kg	3,21E+001	3,13E+000	9,99E+000	2,10E+000			
RW	kg	0,00E+000	0,00E+000	0,00E+000	0,00E+000			

HW Hazardous waste disposed; NHW Non hazardous waste disposed; RW Radioactive waste disposed

Leseeksempel 9,0 E-03 = 9,0*10 -3 = 0,009

Livsløpets slutt - Utgangsfaktorer (End of life - Output flow)

Parameter	Unit	A1	A2	A3	A4	A5	C1	C2
CR	kg	0,00E+000	0,00E+000	0,00E+000	0,00E+000			
MR	kg	0,00E+000	0,00E+000	6,95E+000	0,00E+000			
MER	kg	0,00E+000	0,00E+000	0,00E+000	0,00E+000			
EEE	MJ	0,00E+000	0,00E+000	0,00E+000	0,00E+000			
ETE	MJ	0,00E+000	0,00E+000	0,00E+000	0,00E+000			

CR Components for reuse; MR Materials for recycling; MER Materials for energy recovery; EEE Exported electric energy; ETE Exported thermal energy

Leseeksempel 9,0 E-03 = 9,0*10 -3 = 0,009

Norske tilleggskrav

Klimagassutslipp fra bruk av elektrisitet i produksjonsfasen

Datasett fra databasen ecoinvent v3 (juni 2012) for produksjonsmiks inkludert import, på lavspenning er benyttet; Electricity, low voltage {}| market for | Alloc Def, U. Produksjon av overføringsnett, i tillegg til direkte utslipp og tap ved overføring, er inkludert. Karakteriseringsfaktorer fra EN15804:2012+A1:2013 er benyttet.

Elektrisitetsmiks	Datakilde	Mengde	Enhet
El-mix, Norway [kWh]	Ecoinvent 3	25,30	g CO2-ekv/kWh

Farlige stoffer

Produktet inneholder ingen stoffer fra REACH Kandidatliste eller den norske prioritetslisten

Inneklima

Produktet har ingen påvirkning på inneklima.

Bibliografi

NS-EN ISO 14025:2010 Miljømerker og deklarasjoner - Miljødeklarasjoner type III - Prinsipper og prosedyrer.

NS-EN ISO 14044:2006 Miljøstyring - Livsløpsvurderinger - Krav og retningslinjer

NS-EN 15804:2012+A1:2013 Bærekraftig byggverk - Miljødeklarasjoner - Grunnleggende produktkategoriregler for byggevarer

ISO 21930:2007 Sustainability in building construction - Environmental declaration of building products.

PCR for Precast Concrete Products, NPCR 20.2011, www.epd-norge.no

Vold M. og Edvardsen T. (2014); EPD-generator for betongindustrien, Bakgrunnsinformasjon for verifisering, OR 04.14 Østfoldforskning, Fredrikstad, Januar 2014.

Vold M. og Edvardsen T. (2014); EPD-generator for betongindustrien, Brukerveileding, OR 05.14 Østfoldforskning, Fredrikstad, Januar 2014.

	Programoperatør og utgiver Næringslivets Stiftelse for Miljødeklarasjoner Pb. 5250 Majorstuen 0303 Oslo Norway	Telefon: e-post: web:	+47 23 08 82 92 post@epd-norge.no www.epd-norge.no
	Eier av deklarasjon NorBetong AS Postboks 203 Lilleaker 0216 Oslo	Telefon: Fax: e-post: web:	+ 47 22 87 83 00 mg.skjeggerud@norbetong.no www.norbetong.no
	Forfatter av livsløpsrapporten Østfoldforskning AS Stadion 4 1671 Kråkerøy	Telefon: Fax: e-post: web:	+47 69 35 11 00 +47 69 34 24 94 post@ostfoldforskning.no www.ostfoldforskning.no

ENVIRONMENTAL PRODUCT DECLARATION

in accordance with ISO 14025, ISO 21930 and EN 15804

Eier av deklarasjonen:	NorBetong AS
Programoperatør:	Næringslivets Stiftelse for Miljødeklarasjoner
Utgiver:	Næringslivets Stiftelse for Miljødeklarasjoner
Deklarasjonsnummer:	Prosjektspesifikk EPD med ref. til NEPD00283N
Publiseringsnummer:	Ikke tildelt
ECO Platform registreringsnummer:	Ikke tildelt
Godkjent dato:	23.11.2017
Gyldig til:	26.11.2019

B35 M45 D22 ANL-FA + FA, 355050035, Vibrerbar betong, Stor-Oslo

NorBetong AS

www.epd-norge.no

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Generell informasjon

Produkt:

B35 M45 D22 ANL-FA + FA, 355050035, Vibrerbar betong, Stor-Oslo

Eier av deklarasjonen:

NorBetong AS
Kontaktperson: Magnus Gade
Skjeggerud
Telefon: + 47 22 87 83 00
e-post: mg.skjeggerud@norbetong.no

Programoperatør:

Næringslivets stiftelse for Miljødeklarasjoner
Pb. 5250 Majorstuen, 0303 Oslo
Phone: +47 23 08 80 00
e-post: post@epd-norge.no

Produsent:

NorBetong AS

Deklarasjonsnummer:

Prosjektspesifikk EPD med ref. til NEPD00283N

Produksjonssted:

Stor-Oslo

ECO Platform registreringsnummer:

Kvalitet/Miljøsystem:

NorBetongs kvalitets- og miljøsystem er bygget opp iht. NS-EN 206. Det er dessuten supplert med miljømessige momenter iht. NS-EN ISO 14001 samt internkontrollforskriften

Deklarasjonen er basert på PCR:

EN 15804:2012+A1:2013 tjener som kjerne-PCR
PCR for Precast Concrete Products, NPCR 20.2011.

Org. no.:

934 468 740

Erklæringen om ansvar:

Eieren av deklarasjonen skal være ansvarlig for den underliggende informasjon og bevis. EPD Norge skal ikke være ansvarlig med hensyn til produsent informasjon, livsløpsvurdering data og bevis.

Godkjent dato:

23.11.2017

Gyldig til:

26.11.2019

Deklarert enhet:

1 m3 B35 M45 D22 ANL-FA + FA, 355050035, Vibrerbar betong, Stor-Oslo

Årstall for studien:

2017

Deklarert enhet med opsjon:

A1,A2,A3,A4

Sammenlignbarhet:

EPD av byggevarer er nødvendigvis ikke sammenlignbare hvis de ikke samsvarer med NS-EN 15804 og ses i en bygningskontekst.

Funksjonell enhet:

Miljødeklarasjonen er utarbeidet av:

Deklarasjonen er utviklet ved bruk av EPDGen-Version 2
Godkjenning:
Bedriftsspesifikke data er

Samlet og registrert av: Thea Vik Nordeide

Kontrollert av: Magnus Gade Skjeggerud

Verifikasjon:

Uavhengig verifikasjon av data, annen miljøinformasjon og EPD er foretatt etter ISO 14025:2010, kapittel 8.1.3 og 8.1.4

Ekstern

Tredjeparts verifikator:

Sign

Seniorforsker Anne Rønning

(Uavhengig verifikator godkjent av EPD Norge)

Godkjent:

Sign

(Daglig leder av EPD-Norge)

Produkt

Produktbeskrivelse:

Ferdigbetong produsert iht. NS-EN 206

Produktspesifikasjon:

Miljøindikatorene avviker fra NEPD00283N pga. endret betongsammensetning.

Materials	Percent
Cement	11,91
Aggregate	77,23
Water	6,73
Chemicals	0,16
SCM	3,97

Tekniske data:

B35 M45 D22 ANL-FA + FA CL 0,1. Vibrerbar betong med synk opp til 240mm

Markedsområde:

Stor-Oslo

Levetid, produkt:

Levetid, bygg:

LCA: Beregningsregler

Deklarert enhet:

1 m3 B35 M45 D22 ANL-FA + FA, 355050035, Vibrerbar betong, Stor-Oslo

Cut-off kriterier:

Alle viktige råmaterialer og all viktig energibruk er inkludert. Produksjonsprosessen for råmaterialene og energistrømmer som inngår med veldig små mengder (mindre enn 1%) er ikke inkludert. Disse cut-off kriteriene gjelder ikke for farlige materialer og stoffer.

Alle viktige råmaterialer og all viktig energibruk er inkludert. Produksjonsprosessen for råmaterialene og energistrømmer som inngår med veldig små mengder (<1%) er ikke inkludert.

Allokering:

Allokering er gjort iht. bestemmelser i EN 15804. Inngående energi og vann, samt produksjon av avfall i egen produksjon er allokert likt mellom alle produktene gjennom masseallokering. Miljøpåvirkning og ressursforbruk for primærproduksjonen av resirkulerte materialer er allokert til det opprinnelige produktsystemet. Bearbeidingsprosessen og transport av materialet til produksjonssted er allokert til analysen i denne EPDen.

Allokering er gjort ihht bestemmelser i EN 15804

Inngående energi og vann, samt produksjon av avfall i egen produksjon er allokert likt mellom alle produktene gjennom masseallokering. Påvirkning for primærproduksjonen av resirkulerte materialer er allokert til hovedproduktet der materialet ble brukt. Resirkuleringsprosessen og transport av materialet er allokert til denne analysen.

Datakvalitet:

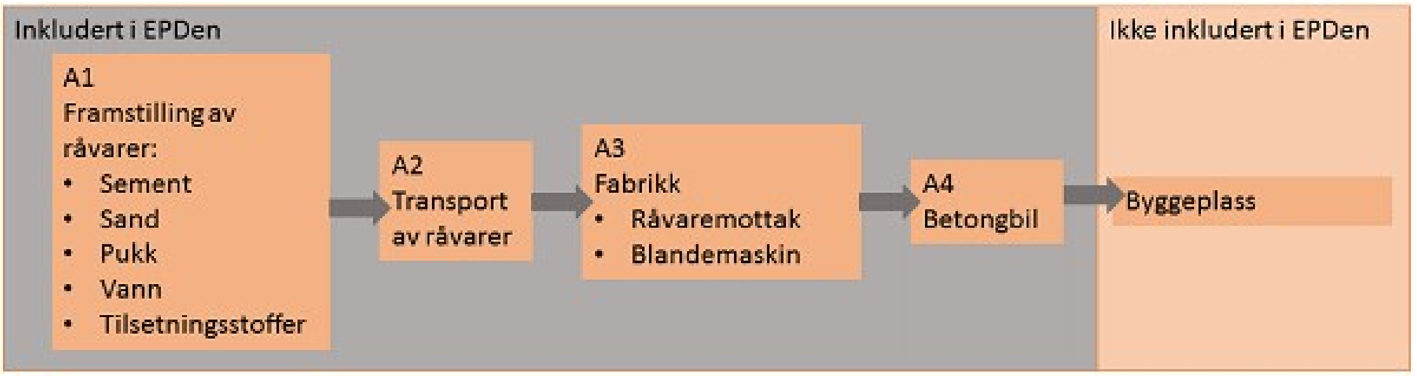
Spesifikke data for produktsammensetningen er fremskaffet av produsenten. De representerer produksjonen av det deklarerte produktet og ble samlet inn for EPD- utvikling i det oppgitte året for studien. Bakgrunnsdata er basert på registrerte EPDer i henhold til EN 15804, Østfoldforskning sine databaser, ecoinvent og andre LCA databaser. Datakvaliteten for råmaterialene i A1 er presentert i tabellen nedenfor.

Materials	Source	Data quality	Year
Water	0	0	0
SCM	0	Waste	0
Aggregate	Modified EcoInvent	Database	2012
Aggregate	Østfoldforskning	Database	2012
SCM	TI, Denmark	EPD	2013
Chemicals	EPD-EFC-20150086-IAG1-EN	EPD	2015
Chemicals	EPD-EFC-20150091-IAG1-EN	EPD	2015
Cement	NEPD-24-201-NO	EPD	2015

Systemgrenser:

Alle prosesser fra råvareuttak til produktet ut fra fabrikkporten er inkludert i analysen.

Flytskjemaet nedenfor illustrerer systemgrensene for analysen:



Teknisk tilleggsinformasjon

LCA: Scenarier og annen teknisk informasjon

Følgende informasjonen beskriver scenariene for modulene i EPDen.

Transport fra produksjonssted til bruker (A4)

Type	Kapasitetsutnyttelse inkl retur %	Kjøretøytype	Distanse km	Brennstoff/Energi forbruk	Enhet	Verdi (l/t)
Bil	53,0 %	Concrete truck	7	0,020216	l/tkm	0,14
Jernbane					l/tkm	
Båt					l/tkm	
Annet					l/tkm	

Byggefase A5

.	Enhet	Verdi
Hjelpematerialer	kg	
Vannforbruk	m^3	
Elektrisitetsforbruk	kWh	
Andre energikilder	MJ	
Materialtap	kg	
Materialer fra avfallsbehandling	kg	
Støv i luften	kg	
VOC utslipp	kg	

Monterte produkter i bruk (B1)

.	Unit	Value

Vedlikehold (B2)/Reparasjon (B3)

.	Enhet	Verdi
Vedlikeholdsfrekvens*	.	
Hjelpematerialer	kg	
Andre ressurser	kg	
Vannforbruk	m^3	
Elektrisitetsforbruk	kWh	
Andre energikilder	MJ	
Materialtap	kg	
VOC utslipp	kg	

Utskifting (B4)/Renovering (B5)

.	Enhet	Verdi
Utskiftingsfrekvens*	stk	
Elektrisitetsforbruk	kWh	
Utskifting av slitte deler	0	

* Tall eller referanselevetid

Driftsenergi (B6) og vannbruk (B7)

.	Enhet	Verdi
Vannforbruk	m^3	
Elektrisitetsforbruk	kWh	
Andre energikilder	MJ	
Utstyrets varmeeffekt	kW	

Sluttfase (C1,C3,C4)

.	Enhet	Verdi
Farlig avfall	kg	
Blandet avfall	kg	
Gjenbruk	kg	
Resirkulering	kg	
Energigjenvinning	kg	
Til deponi	kg	

Transport avfallsbehandling (C2)

Type	Kapasitetsutnyttelse inkl retur %	Kjøretøytype	Distanse km	Brennstoff/Energi forbruk	Enhet	Verdi (l/t)
Bil					l/tkm	
Jernbane					l/tkm	
Båt					l/tkm	
Annet					l/tkm	

Gevinst og belastninger etter endt levetid (D)

LCA: Resultater

Systemgrenser (X=inkludert, MND=modul ikke deklarert, MNR=modul ikke relevant)

Product stage				Construction installation stage	User stage							End of life stage				.	Beyond the system bondaries
Råmaterialer	Transport	Tilvirkning	Transport	Konstruksjons/ installasjonsfase	Bruk	Vedlikehold	Reparasjon	Utskiftinger	Renovering	Operasjonell energibruk	Operasjonell vannbruk	Demontering	Transport	Avfallsbehandling	Avfall til sluttbehandling		Gjenbruk/gjenvinning/ resirkulering-potensiale
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	.	D
X	X	X	X	MNR	MNR	MNR	MNR	MNR	MNR	MNR	MNR	MNR	MNR	MNR	MNR	.	MNR

Miljøpåvirkning (Environmental impact)

Parameter	Unit	A1	A2	A3	A4
GWP	kg CO_2 -eq	1,85E+02	5,40E+00	2,76E+00	1,99E-01
ODP	kg CFC11 -eq	3,32E-06	5,33E-07	4,96E-07	3,76E-08
POCP	kg C_2H_4-eq	3,06E-02	2,74E-03	3,74E-04	3,53E-05
AP	kg SO_2 -eq	4,29E-01	1,80E-02	7,24E-03	7,00E-04
EP	kg PO_4^{3-} -eq	1,13E-01	2,48E-02	1,09E-03	1,46E-04
ADPM	kg Sb -eq	1,83E-04	4,85E-06	2,94E-06	4,39E-07
ADPE	MJ	1,03E+03	7,62E+01	3,80E+01	3,04E+00

GWP Global warming potential; ODP Depletion potential of the stratospheric ozone layer; POCP Formation potential of tropospheric photochemical oxidants; AP Acidification potential of land and water; EP Eutrophication potential; ADPM Abiotic depletion potential for non fossil resources; ADPE Abiotic depletion potential for fossil resources

Leseeksempel 9,0 E-03 = 9,0*10 -3 = 0,009

Ressursbruk (Resource use)

Parameter	Unit	A1	A2	A3	A4
RPEE	MJ	2,09E+02	5,85E-01	1,65E+01	4,67E-02
RPEM	MJ	1,53E+00	1,75E-01	1,41E-01	1,43E-02
TPE	MJ	2,11E+02	7,60E-01	1,67E+01	6,10E-02
NRPE	MJ	1,06E+03	7,69E+01	3,94E+01	3,10E+00
NRPM	MJ	1,23E+01	0,00E+00	0,00E+00	0,00E+00
TRPE	MJ	1,07E+03	7,69E+01	3,94E+01	3,10E+00
SM	MJ	1,40E+02	0,00E+00	0,00E+00	0,00E+00
RSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00
NRSF	MJ	3,59E+02	0,00E+00	0,00E+00	0,00E+00
W	m^3	3,13E+02	2,88E-01	2,75E-01	2,76E-03

RPEE Renewable primary energy resources used as energy carrier; RPEM Renewable primary energy resources used as raw materials; TPE Total use of renewable primary energy resources; NRPE Non renewable primary energy resources used as energy carrier; NRPM Non renewable primary energy resources used as materials; TRPE Total use of non renewable primary energy resources; SM Use of secondary materials; RSF Use of renewable secondary fuels; NRSF Use of non renewable secondary fuels; W Use of net fresh water

Leseeksempel 9,0 E-03 = 9,0*10 -3 = 0,009

Livsløpets slutt - Avfall (End of life - Waste)

Parameter	Unit	A1	A2	A3	A4
HW	kg	9,09E-04	2,47E-05	1,41E-05	2,35E-06
NHW	kg	2,85E+01	3,29E+00	9,99E+00	3,07E-01
RW	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00

HW Hazardous waste disposed; NHW Non hazardous waste disposed; RW Radioactive waste disposed

Leseeksempel 9,0 E-03 = 9,0*10 -3 = 0,009

Livsløpets slutt - Utgangsfaktorer (End of life - Output flow)

Parameter	Unit	A1	A2	A3	A4
CR	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00
MR	kg	0,00E+00	0,00E+00	6,95E+00	0,00E+00
MER	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00
EEE	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00
ETE	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00

CR Components for reuse; MR Materials for recycling; MER Materials for energy recovery; EEE Exported electric energy; ETE Exported thermal energy

Leseeksempel 9,0 E-03 = 9,0*10 -3 = 0,009

Norske tilleggskrav

Klimagassutslipp fra bruk av elektrisitet i produksjonsfasen

Nasjonal produksjonsmiks inkludert import, produksjon av overføringslinjer og tap i nett (lav spenning), er brukt som elektrisitetsmiks. Bakgrunnsdata er presentert i tabellen under. Karakteriseringsfaktorer fra EN15804:2012+A1:2013 er benyttet.

Elektrisitetsmiks	Datakilde	Mengde	Enhet
El-mix, Norway [kWh]	Ecoinvent 3	25,30	g CO2-ekv/kWh

Farlige stoffer

Produktet er ikke tilført stoffer fra REACH kandidatliste eller stoffer på den norske prioritetslisten

Inneklima

Produktet har ingen påvirkning på inneklima.

Bibliografi

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NS-EN 15804:2012+A1:2013 Bærekraftig byggverk - Miljødeklarasjoner - Grunnleggende produktkategoriregler for byggevarer
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Vold M. og Edvardsen T. (2014); EPD-generator for betongindustrien, Brukerveileding, OR 05.14 Østfoldforskning, Fredrikstad, Januar 2014.

	Programoperatør og utgiver	Telefon:	+47 23 08 82 92
	Næringslivets Stiftelse for Miljødeklarasjoner		
	Pb. 5250 Majorstuen	e-post:	post@epd-norge.no
	0303 Oslo Norway	web:	www.epd-norge.no
NORBETONG HEIDELBERGCEMENTGroup	**Eier av deklarasjon**	Telefon:	+ 47 22 87 83 00
	NorBetong AS	Fax:	
	Postboks 203 Lilleaker	e-post:	mg.skjeggerud@norbetong.no
	0216 Oslo	web:	www.norbetong.no
Østfoldforskning	**Forfatter av livsløpsrapporten**	Telefon:	+47 69 35 11 00
	Østfoldforskning AS	Fax:	+47 69 34 24 94
	Stadion 4	e-post:	post@ostfoldforskning.no
	1671 Kråkerøy	web:	www.ostfoldforskning.no

Massivtreelement

MMT Moelven MassivTre AS

NEPD nr: 114N

Godkjent i tråd med ISO 14025, § 8.1.4

Godkjent 01-11-2009

Gyldig til 01-11-2012

Figur 1

Verifikasjon

Uavhengig verifikasjon av underliggende dokumentasjon er foretatt av Anne Rønning (Østfoldforskning), i tråd med ISO 21930, § 9.1

Deklarasjonen er utarbeidet av:

Silje Wærp, SINTEF Byggforsk

PCR

NPCR 015 Solid wood products, godkjent av EPD-stiftelsens Verifikasjonskomité er brukt.

Om EPD

EPDer fra andre programoperatører enn Næringslivets Stiftelse for Miljødeklarasjoner er nødvendigvis ikke sammenlignbare.

Informasjon om produsent

Interesseorganisasjon	Moelven MassivTre AS
Adresse	3535 Krøderen
Kontaktperson	Knut-Arne Johansen, tlf 32 15 08 52, knut-arne.johansen@moelven.no
Organisasjons nr.	986857621
ISO 14001/EMAS:	_____

Informasjon om produktet

Omfang	vugge til grav
Funksjonell enhet (FE)	1m³ massivtreelement, ferdig montert og vedlikeholdt med 60 års forventet gjennomsnittlig levetid. Alle resultater i denne analysen forholder seg til 1 funksjonell enhet (FE).
Antatt levetid	60 år
Årstall for studien	2009, med datagrunnlag fra 2007
Produksjonssted	Norge
Markedsområde	Norge

Produktbeskrivelse

Moelven massivtreelementer er oppbygd av sammenlimte krysslagte lameller lagt i flere sjikt. Lamellene i elementets lengderetning består av fingerskjøtte bord av konstruksjonsvirke, mens lameller tvers på består av bord i hele lengder. Lamellene i elementenes yttersjikt er normalt kantlimt. Limingen gjøres med et MUF lim (Melamin urea formaldehyd) i en høyfrekvent taktpresse. Gjennomsnittlig densitet er 500 kg/m^3. *Denne miljødeklarasjonen gjelder for 1 m^3 massivtreelement.*

Skogsertifisering	95% av tømmer anvendt til produksjon av massivtreelementer er sertifisert iht. Levende Skog standard eller tilsvarende sertifisering (PEFC).

Miljøindikatorer

Global oppvarming	103	kg CO_2-ekv.
Energibruk	5176	MJ
Andel fornybare materialer	98	%
Inneklimaklassifisering (iht. EN 15251:2007)	ikke målt	

Produktspesifikasjon

Tabell 1

Sluttprodukt		Input LCA		
Skurlast	kg	500,0	98,16 %	Spesifikke data
Lim	kg	9,4	1,84 %	Generiske data*
SUM	kg	509,4		

*MUF-lim fra Casco. Moelven massivtre benytter annen leverandør av lim.

Ressursforbruk

Materialressurser

Tabell 2

Materialressurser	Enhet	Råmaterialer	Produksjon	Byggeplass	Bruksfase	Avhending	Transport	Totalt
Nye, fornybare ressurser								
Treråvare inkl bark	kg	641,56	0,02	0	0	0	0	641,58
Vann	kg	555,72	380,45	0,02	0,01	0,02	3,19	939,41
Luft	kg	201,72	100,39	0,01	0,01	0,01	2,98	305,12
Annen fornybar	kg	0,29	0,09	5,2E-06	2,6E-06	5,2E-06	4,6E-03	0,39
Nye, ikke fornybare ressurser								
Stein	kg	2,0E+01	5,2E+00	4,4E-03	2,2E-03	4,4E-03	1,7E+00	2,7E+01
Olje	kg	3,1E+00	8,9E+00	7,6E-05	3,8E-05	7,6E-05	1,2E+01	2,4E+01
Naturgass	kg	9,5E+00	1,4E+00	3,8E-04	1,9E-04	3,8E-04	6,4E-01	1,2E+01
Kalkstein	kg	6,2E-01	1,1E+00	1,1E-03	5,4E-04	1,1E-03	2,6E-02	1,8E+00
Kull	kg	7,1E-01	8,9E-01	6,1E-04	3,1E-04	6,1E-04	5,4E-02	1,7E+00
Lignitt	kg	1,3E+00	2,1E-01	1,7E-04	8,4E-05	1,7E-04	7,2E-02	1,6E+00
Jord	kg	2,7E-01	9,2E-01	9,0E-04	4,5E-04	9,0E-04	3,4E-03	1,2E+00
Natriumklorid	kg	1,9E-01	2,0E-03	8,8E-07	4,4E-07	8,8E-07	1,2E-05	1,9E-01
Malm uten metall	kg	5,6E-02	1,1E-01	1,0E-04	5,2E-05	1,0E-04	7,4E-03	1,7E-01
Tungspat	kg	6,1E-02	1,1E-02	4,6E-07	2,3E-07	4,6E-07	3,1E-02	1,0E-01
Leire	kg	1,5E-02	3,9E-02	3,7E-05	1,9E-05	3,7E-05	3,5E-03	5,8E-02
Jern	kg	2,1E-02	2,8E-02	2,2E-05	1,1E-05	2,2E-05	5,4E-03	5,5E-02
Gips	kg	7,9E-03	2,5E-02	2,5E-05	1,2E-05	2,5E-05	4,7E-04	3,4E-02
Torv	kg	3,0E-02	2,7E-03	5,7E-09	2,8E-09	5,7E-09	1,1E-03	3,4E-02
Kvartssand	kg	1,1E-02	5,0E-03	3,6E-06	1,8E-06	3,6E-06	4,2E-03	2,0E-02
Aluminium	kg	1,8E-03	1,2E-03	1,2E-06	6,0E-07	1,2E-06	5,1E-06	3,0E-03
Sink	kg	3,5E-04	9,9E-04	5,7E-07	2,9E-07	5,7E-07	5,3E-05	1,4E-03
Kopper	kg	2,4E-04	6,6E-04	6,5E-07	3,2E-07	6,5E-07	1,4E-05	9,1E-04
Krom	kg	1,8E-04	6,6E-04	6,5E-07	3,2E-07	6,5E-07	9,6E-07	8,5E-04
Mangan	kg	2,1E-04	4,7E-04	4,5E-07	2,3E-07	4,5E-07	4,4E-05	7,3E-04
Annen ikke fornybar ressurs	kg	1,5E+00	5,1E+00	5,0E-03	2,5E-03	5,0E-03	2,3E-02	6,6E+00
Råmaterialenergi, fornybare ressurser [MJ]								7.200,00
Råmaterialenergi, ikke fornybare ressurser [MJ]								115,89

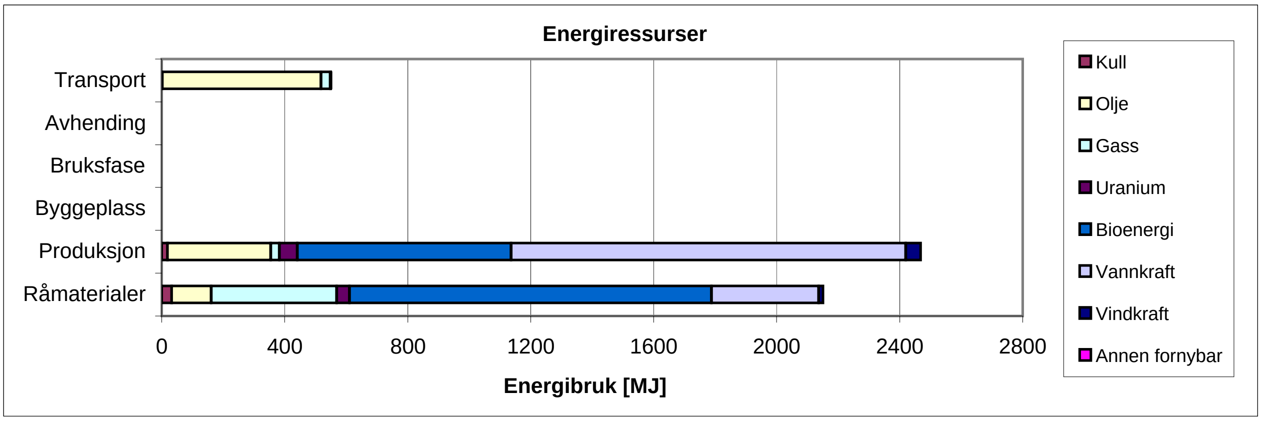
Land og vannressurser

Landareal er ikke kartlagt. Oversikt over vannforbruk finnes i Tabell 2

Energiressurser

Fordeling av energibærere per livsløpsfase

Figur 2



Energiforbruk fordelt på energibærer og livsløpsfaser

Tabell 3

	Enhet	Råmaterialer	Produksjon	Byggeplass	Bruksfase	Avhending	Transport	Totalt
Ikke fornybar energi								
Kull	MJ	31,93	18,51	0,02	0,01	0,02	2,19	52,67
Olje	MJ	129,02	336,17	3,2E-03	1,6E-03	3,2E-03	516,52	981,71
Gass	MJ	408,78	28,43	0,02	0,01	0,02	29,36	466,61
Uranium	MJ	41,47	58,69	0,06	0,03	0,06	2,72	103,03
Fornybar energi								
Bioenergi	MJ	1176,99	694,53	1,4E-05	7,0E-06	1,4E-05	1,5E-04	1871,52
Vannkraft	MJ	348,48	1284,09	1,27	0,63	1,27	0,58	1636,31
Vindkraft	MJ	14,55	49,00	0,05	0,02	0,05	0,07	63,74
Annen fornybar	MJ	0,76	0,05	3,4E-05	1,7E-05	3,4E-05	0,05	0,86
Total	MJ							**5.176,44**

Elektrisitetsforbruk anvendt i Norge er beregnet ut fra Nordel-mixen for Norge i 2007.

Utslipp og miljøpåvirkninger

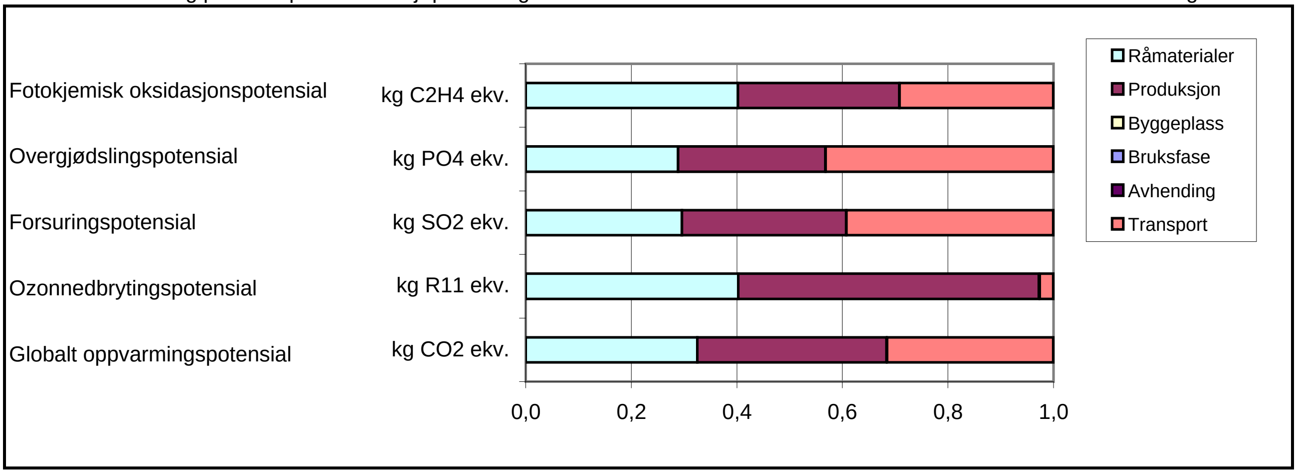
Miljøpåvirkninger

Tabell 4

Indikator	Enhet	Råmaterialer	Produksjon	Byggeplass	Bruksfase	Avhending	Transport	Totalt
Globalt oppvarmingspotensial	kg CO_2 ekv.	33,36	36,83	7,8E-03	3,9E-03	7,8E-03	32,37	102,58
Ozonnedbrytingspotensial	kg R11 ekv.	1,1E-06	1,6E-06	1,5E-09	7,7E-10	1,5E-09	7,2E-08	2,8E-06
Forsuringspotensial	kg SO_2 ekv.	2,0E-01	2,1E-01	6,4E-06	3,2E-06	6,4E-06	2,6E-01	6,7E-01
Overgjødslingspotensial	kg PO_4 ekv.	3,0E-02	2,9E-02	9,1E-07	4,5E-07	9,1E-07	4,5E-02	1,1E-01
Fotokjemisk oksidasjonspotensial	kg C_2H_4 ekv.	2,7E-02	2,0E-02	4,9E-07	2,4E-07	4,9E-07	1,9E-02	6,6E-02

Prosentvis fordeling per livsløpsfase av miljøpåvirkninger

Figur 3



Utslipp og avfall

Tabell 5

	Enhet	Råmaterialer	Produksjon	Byggeplass	Bruksfase	Avhending	Transport	Totalt
Utslipp til luft								
NH_3	g	23,802	13,999	1,3E-05	6,5E-06	1,3E-05	0,203	38,005
CO_2	g	28847,423	34492,844	7,638	3,819	7,638	31269,685	94629,047
CO	g	359,435	234,827	0,002	0,001	0,002	54,123	648,391
HCl	g	0,078	0,172	3,0E-05	1,5E-05	3,0E-05	0,046	0,296
Hg	g	8,6E-05	6,6E-05	4,9E-08	2,5E-08	4,9E-08	3,3E-05	1,9E-04
CH_4	g	107,682	43,123	0,005	0,003	0,005	37,916	188,734
N_2O	g	7,215	3,920	7,1E-05	3,5E-05	7,1E-05	0,515	11,650
NOx	g	114,819	177,813	0,006	0,003	0,006	343,404	636,051
NMVOC	g	27,220	15,770	3,5E-04	1,8E-04	3,5E-04	22,398	65,389
Partikler	g	1,124	3,983	0,001	3,0E-04	0,001	5,980	11,089
Pb	g	0,001	0,002	1,8E-06	8,9E-07	1,8E-06	0,001	0,004
SO_2	g	71,829	56,551	0,002	0,001	0,002	20,183	148,568
Utslipp til vann								
BOD	g	0,348	0,099	8,1E-06	4,0E-06	8,1E-06	0,052	0,499
COD	g	30,879	5,973	0,005	0,002	0,005	1,453	38,316
N	g	12,103	0,187	1,0E-04	5,1E-05	1,0E-04	0,047	12,338
P	g	0,020	0,008	8,5E-07	4,2E-07	8,5E-07	0,013	0,041
Avfall								
Avfall til deponi	kg	19,874	6,919	1,172	0,003	50,005	0,839	79,640
Farlig avfall	kg	21,608	6,471	0,005	0,003	0,011	0,840	29,761

Behandling av avfall fra sluttprodukt

Det er forbud mot deponering av organisk avfall per 01.01.2009. Det er estimert at 10 vekt % av sluttproduktet må behandles på særskilt vis, med dagens avfallsteknologi forbrenning med røykgassrensning.

Energiutnyttelse av sluttprodukt ved endt livsløp tilhører det produktsystemet som nyttiggjør seg av energien, kun råmaterialenergien er synliggjort i denne analysen.

Bruk av kjemikalier

Kjemikalier

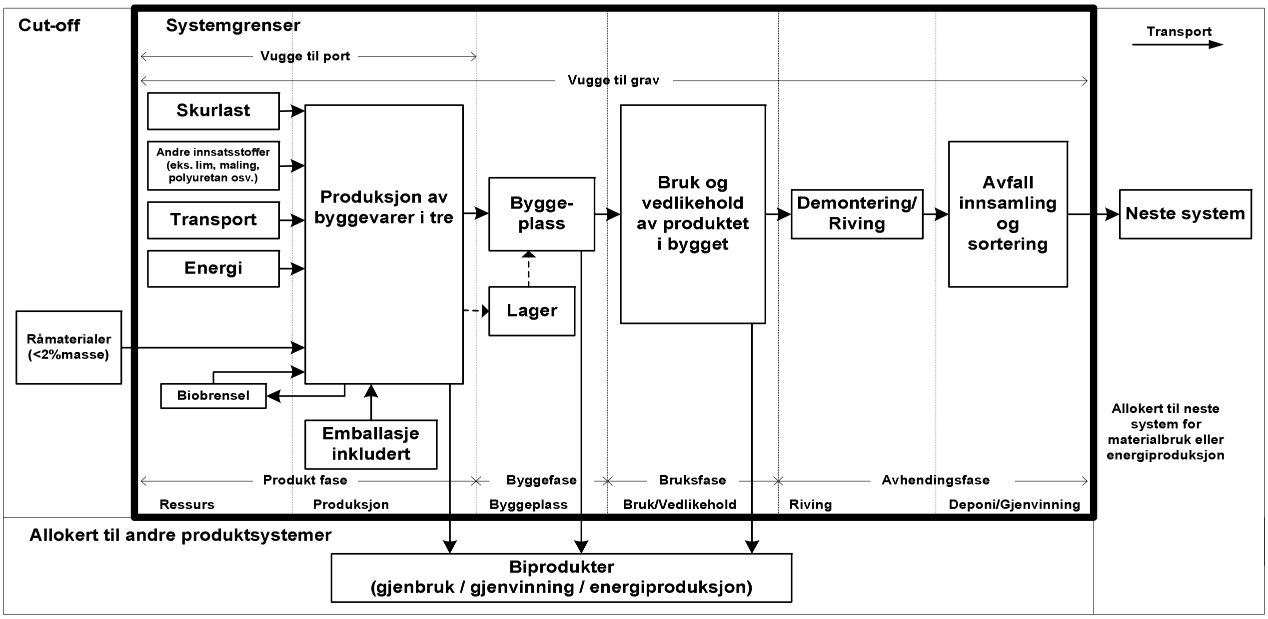
Tabell 6

Betegnelse	Enhet	Totalt	CAS-nr.	R-setninger	Råvare	Helse [4]	Miljø [4]
Lambdacyhalotrin	g	6,52E-03	91465-08-6	R21, R25, R26, R50/53	Tømmer	klasse 2	klasse 2
Imidakloprid	g	4,87E-03	13826-41-3	R22		klasse 4	-
Glyfosat	g	9,71E-02	1071-83-6	R41, R51/53		klasse 4	klasse 3
Formaldehyd	g	4,123	50-00-0	R23/24/25,34,43,40	Lim	klasse 1	-
Metanol	g	16,492	67-56-1	R 11,23/24/25/39/		klasse 2	-
1,4 Butandiol	g	24,737	110-63-4	R 22		klasse 4	-
Epsilon-caprolactam	g	12,369	105-60-2	R 20/22, R 36/37/38		klasse 4	-
Maursyre	g	23,559	64-18-6	R 35		klasse 3	-
Polyvinylacetat	g	0,035	93196-02-2	R22		klasse	-

Metodiske beslutninger

Systemgrenser

Figur 4



Referanser

[1] NS-ISO 14025:2006, Miljømerker og deklarasjoner - Miljødeklarasjoner type III - Prinsipper og prosedyrer

[2] ISO 21930:2007, Sustainability in building construction - Environmental declaration of building products

[3] PCR for preparing an environmental product declaration (EPD) for solid wood products, NPCR 015 2009

[4] Abrahamsen et al. (2008): "EPDs as a tool for documentation/information on chemicals and toxicity in the value chains of products - a pre-study for EPD Norge".

[5] Flæte, Per Otto (2009): "Energiforbruk og utslipp fra skogproduksjonskjeden med utgangspunkt i aktivitetsdata fra 2007 - fra frø til industritomt"

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[7] EN 15251:2007, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

ENVIRONMENTAL PRODUCT DECLARATION

ISO 14025 ISO 21930 EN 15804

epd-norge.no
The Norwegian EPD Foundation

Owner of the declaration	AS ROCKWOOL
Program holder	The Norwegian EPD Foundation
Publisher	The Norwegian EPD Foundation
Declaration number	00131E rev1
Issue date	25.10.2013
Valid to	25.10.2018

ROCKWOOL® isolering

Product

AS ROCKWOOL

Manufacturer

General information

ROCKWOOL® isolering
Product

AS ROCKWOOL
Manufacturer

Program holder:
The Norwegian EPD Foundation
Post Box 5250 Majorstuen, 0303 Oslo
Phone: +4723088000
e-mail: post@epd-norge.no

Owner of the declaration:
AS ROCKWOOL
Contact person: Torkel Wæringsaasen
Phone: 00 47 22 02 40 00
e-mail: Torkel.Weringsaasen@rockwool.com

Declaration number:
00131E rev1

Place of production:
Vamdrup and Doense, Denmark
Trondheim and Moss, Norway

This declaration is based on Product Category Rules:
CEN Standard EN 15804 serve as core PCR
Product Group Insulation materials, NPCR 012rev,

Management system:
ISO 9001, ISO14001, EN13.162, EN13.172, EN14303

Declared unit:
1 m^2 of 37mm thick stone wool insulation product with a density of 29 kg/m^3 and a thermal resistance of R=1 m^2 K/W.

Org. No:
923828583

Declared unit with option:

Issue date:
25.10.2013

Functional unit:

Valid to:
25.10.2018

The environmental product declaration has been worked out by:
Rasmus Nielsen and
Anders Schmidt, Ph.D.,
FORCE Technology,
Lyngby, Denmark

Comparability:
EPD of construction products may not be comparable if they not comply with EN 15804 and seen in a building context.

Year of study:
2013

Verification:
Independent verification of data and other environmental information has been carried out in accordance with ISO14025, 8.1.3.

externally ☑ internally ☐

President Joep Meijer
(IndependentverifierapprovedbyEPDNorway)

Approved according to ISO14025, 8.1.4

Dr. ing. Sverre Fossdal
(ChairmanoftheVerificationGroupofEPD-Norway)

Declared unit:
1 m^2 of 37 mm thick stone wool insulation product with a density of 29 kg/m^3 and a thermal resistance of R=1 m^2 K/W.

Key environmental indicators	Unit	Cradle to gate A1 - A3	Transport Production site - central warehouse Norway
Global warming	kg CO_2 -eqv	1,27	$1{,}19 \cdot 10^{-2}$
Energy use	MJ	13,8	0,17
Dangerous substances	*		

* The product contains no substanses from the REACH Candidate list or the Norwegian priority list

Product

Product description: Stone wool insulation from ROCKWOOL is a firesafe* material for insulation against heat, cold, fire, vibrations and noise. The product is wrapped with PE-foil and placed on wooden pallets for further distribution. Stone wool insulation from ROCKWOOL for the Scandinavian market is supplied by two production sites in Norway (Moss and Trondheim) as well as two sites in Denmark (Doense and Vamdrup), each with two lines. The properties of the ROCKWOOL products from the different production sites are identical. The EPD is based on LCA inventory data from the 4 plants. The reference flow is a weighted average and is calculated using the following distribution of production capacity (2011) on the four production sites: Vamdrup 30,6%, Doense 35,7%, Trondheim 11,9%, Moss 21,7%.
* A1 when tested according to EN 13501-1 (Euroclasses)

Description of manufacturing processes: The furnace used in all four production sites is an oven with coke as the main energy source. The virgin stone raw materials used at all sites are mainly basalt, diabase and dolomite. The Danish sites also use various secondary materials, including internal wool waste, which is mixed with cement into briquettes. The mineral raw materials are melted and spun into fibers at a temperature of about 1500ºC. A synthetic binder and a water-repellant agent are added, whereafter the final curing (polymerisation) and forming takes place at a temperature of about 230ºC. Finally the product is cut into the desired dimensions and packed in PE foil.

Technical data: Scaling factors for ROCKWOOL Insulation materials in this EPD can be seen in the table below. The scaling factors show how much to multiply the environmental burdens by in order to obtain a thermal resistance of R=1 m^2 K/W with other ROCKWOOL products. Product and product variations for the declared product are typically less than 10% when using the scaling factors in the table below. The R-values used for scaling gives a good indication of the amount of materials needed to achieve the desired insulation effect of other product types, but is not an exact measure. Stone wool insulation products marked with an asterix (*) in the table are sold with extra features for special applications e.g. with wire netting, a bitumen membrane or aluminium foil. The extra features are not covered by this LCA. The products covered by the EPD are produced at all production lines in a full year. The variation between production lines has not been determined.

Market: Scandinavia

Reference service life: The service life of the product is >> 60 years and built into a construction and will last the construction lifetime.

Product specification: Material input per functional unit

Material	kg	% of total
Stones	0,902	67,1
Secondary resources mostly slag	0,251	18,7
Cement	0,087	6,46
Formaldehyde (37%)	0,052	3,89
Urea (46%)	0,021	1,57
Phenol	0,016	1,21

Products	Scaling Factor
ALU-BRANDBATTS 80*, 80 VENT*	2.6
A-PLADEBATTS 10	2.0
A-RULLEBATTS M/PAPIR*	1.1
BD-60 FLEXIBATTS	1.2
BETONELEMENTBATTS 35 (80-250 MM)	2.3
BETONELEMENTBATTS 35 (25-79 MM)	2.6
BETONELEMENTBATTS NO: BETONGELEMENTPLATE (30-79 MM)	2.8
BETONELEMENTBATTS NO: BETONGELEMENTPLATE (80-250 MM)	2.4
BJÄLKLAGSSKIVA M/VINDSKYDD*	1.1
BLÅSEULL I HORISONTAL KONSTRUKSJON	2.4
BLÅSEULL I TEGLVEGG	2.2
BLÅSEULL I VERTIKAL KONSTRUKSJON	2.5
B-PLATE	0.9
BRANDBATTS 110	3.7
BRANNPLATE 50	1.7
BRANNSEKSJONERINGSSTAV	4.7
BYGG 100	3.3
BYGG 90	2.9
BYGGRULLE M VINDSKYDD (100-250 MM)*	1.3
BYGGRULLE M VINDSKYDD (50 - 99 MM)*	1.4
CONLIT 150	6.0
CONLIT 300	11.2
CONLIT ALU BRANDMATTE*	2.8
CONLIT ALU BRANNPLATE EI30*	4.0
CONLIT ALU BRANNPLATE EI60*	4.7
DK: HARDKILE (50-85), NO/SE: HARDROCK ENERGY TAKFALL (50-85 MM)	4.7
DK: HARDKILE (5-55), NO/SE: HARDROCK ENERGY TAKFALL (5-55 MM)	6.4
DRENSPLATE*	3.8
FALLRÄNNA TF	6.4
FALLUNDERLAG	3.8
FASADBATTS	3.1
FLEXEKSTREM 33	1.9
FLEXI 35 PLATE	1.2
FLEXI A-PLATE	1.0
FLEXIBATTS	1.1
FLEXIBATTS 35	1.2
FLEXSYSTEM BATTS, REDAIR BATTS	2.2
GRANULAT PRO 28 KG/M3	1.1
GRANULAT PRO 35 KG/M3	1.2
GRANULAT PRO 43 KG/M3	1.5

Products	Scaling Factor
GRANULAT PRO 50 KG/M3	1.7
GULVRENOVERINGSPLADE	4.7
HARDROCK ELEMENTBATTS	2.3
HARDROCK ENERGY 100 MM	3.7
HARDROCK ENERGY 120 MM	3.6
HARDROCK ENERGY 150 MM	3.5
HARDROCK ENERGY 180 MM	3.4
HARDROCK ENERGY 50 MM	4.4
HARDROCK ENERGY 80 MM	3.9
HARDROCK FASADEPLATE (50-79) mm	4.0
HARDROCK FASADEPLATE 100	3.7
HARDROCK FASADEPLATE (120-150 MM)	3.6
HARDROCK FASADEPLATE 200	3.4
HARDROCK FASADEPLATE 80	3.8
IKI-BATTS*	2.1
I-PLATE A	1.0
ISOLERASJÄLV	1.0
LAMELMÅTTE M/ALU*	1.3
LETT-TAK 37	1.0
LYDABSORPSJONSSTAV	1.0
LYDPLATE	1.7
LYDUNDERLAGSPLATE*	3.5
MARKPLATE	4.7
MARKSKIVA INDUSTRI	5.0
MURBATTS 32	1.8
MURBATTS 34	1.3
MURBATTS 37	1.0
MURPLATE	1.4
PLÅTUNDERLAGSSKIVA 80	2.6
RENOVERINGSBOARD	4.8
ROCKORBIT*	1.9
ROCKPROFIL SKIVA 40, 60	1.5
ROCKTORV 100 MM	4.0
ROCKTORV 108 MM	3.8
ROCKTORV 150 MM	3.8
ROCKVEGG 33	2.2
ROXREMSA	1.4
RÄNNDALSKIL 180	6.4
SKALMURSSKIVA	1.7
SKILLEVÆGSBATTS	1.1

Products	Scaling Factor
SKRÅVÆGSATTS 34	1.3
SKRÅVÆGSBATTS 32	1.8
STØPEPLATE PLUSS 100 MM	3.6
STØPEPLATE PLUSS 150 MM	3.4
STØPEPLATE PLUSS 50 MM	4.0
STØPEPLATE PLUSS 80 MM	3.7
STÅLREGELSKIVA 37	1.0
STÅLREGELSKIVA 40	0.9
STÅLSTENDERPLATE	1.0
STÅLUNDERLAG ENERGY 50 MM	3.9
STÅLUNDERLAG ENERGY 60 MM	3.8
STÅLUNDERLAG ENERGY 80 MM	3.4
SUPER VENTI-BATTS	1.7
TAKBOARD FLIES*	6.0
Takkil	5.3
TAKSTOLPLATE*	1.0
TERRÆNBATTS ERHVERV	3.8
TF TAKKILE	6.4
TF-FALLPLATE	5.3
TF-KILE	6.4
TF-PLADE	6.0
TF-PLADE NO: TF-PLATE	6.4
TF-RENNEPLATE	6.4
TOPROCK 230	2.9
TOPROCK 250, 280	2.8
TOPROCK 310, 360	2.7
TOPROCK 430, 530	2.6
TOPROCK CTF System 1, 1B	2.8
TOPROCK CTF System 2, 2B, 3, 3B, 4	2.7
TOPROCK CTF System 5, 6	2.6
TOPROCK CTF System UL	2.4
TP 50	5.0
TRINNLYDPLATE*	5.3
TRÅDVÆVSMÅTTE 80*	2.8
TUNGPLATE 150	4.7
UNDERLAG ENERGY	3.0
UNIVERSALRØRSKÅL*	2.4
VÄGGBOARD*	5.3
VÄSTKUSTSKIVA	2.8

* Products marked with an * are specialty products with extra features such as wire netting, paper facing, aluminium foil, ...
The extra features are not included in the EPD calculations

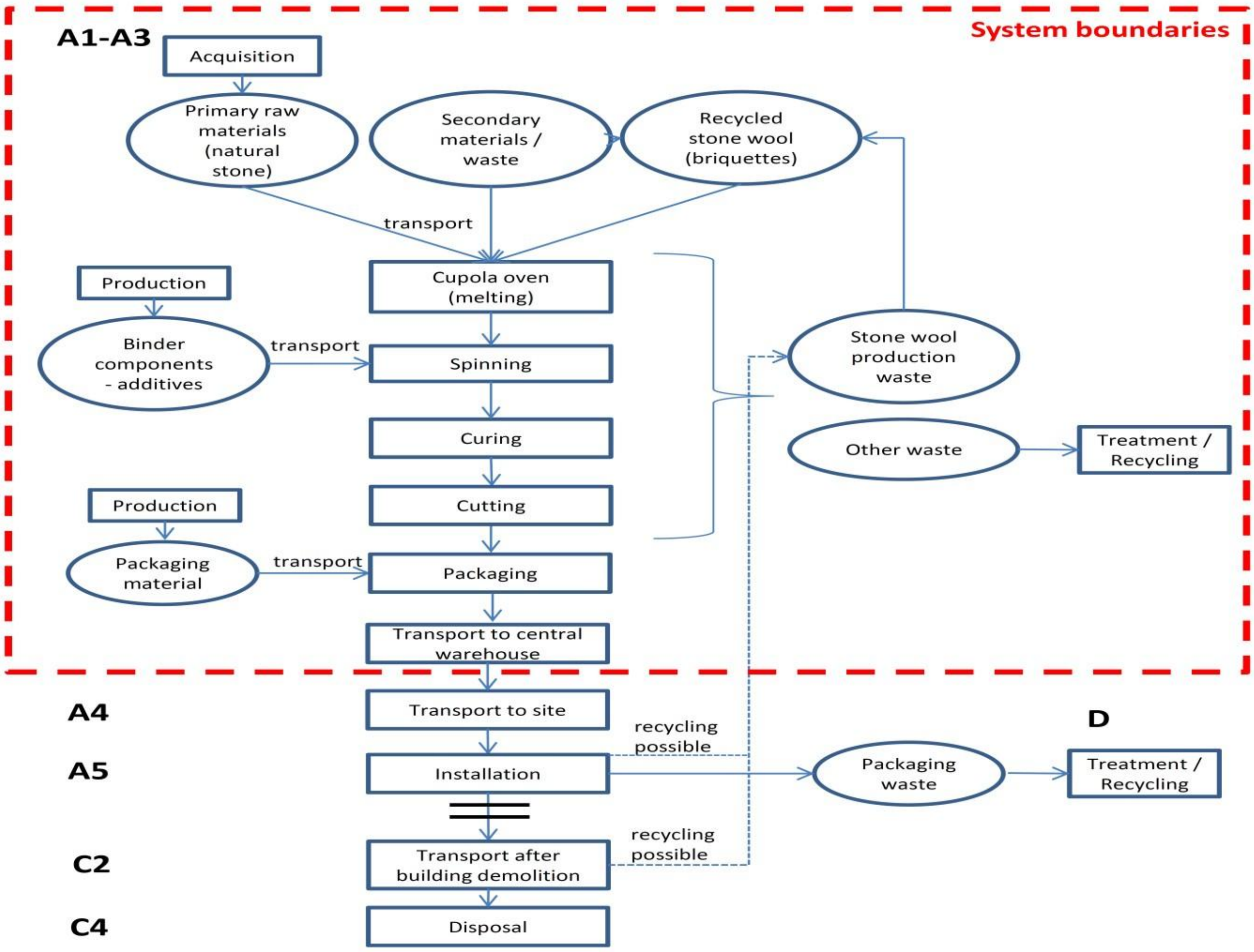
LCA: Calculation rules

Declared unit:

1 m^2 of 37 mm thick stone wool insulation product with a density of 29 kg/m^3 and a thermal resistance of R=1 m^2 K/W.

System boundary:

The overall system boundaries include extraction and transportation of raw materials as well as all manufacturing processes (cradle-to-gate). Transport from all factories to a central storage in Norway has been included.
See Figure below for details



Data quality:

High quality data from GaBi 6 and ecoinvent have been used for acquisition of raw materials and transportation. Legally required information has been used for manufacturing processes at ROCKWOOL. The age of the oldest dataset in the database is 13 years and the vast majority of datasets are under 5 years old. The data collected from the sites are from 2011. Accordingly, the overall quality is judged to be good to very good.

Cut-off criteria:

All inputs of raw materials and energy have been included. Please note that products with special features e.g. wire netting, bitumen membrane or alufoil are not included in the EPD. Please consult ROCKWOOL AS for more information.

Allocation:

Allocation has been made according to the provisions in EN 15804. Impacts from recycled material have been allocated to the primary product, except transportation. ROCKWOOL supply district heating in Denmark. Respectively 7,3% and 9,4% of the energy consumed in the two production sites in Denmark have been allocated to district heating, using the energy content as the allocation key. The emissions associated with energy production have been allocated in the same way. A sensitivity analysis of the results using a different allocation key, such as the economic value, or substitution approach has not been performed.

LCA: Scenarios and additional technical information

The following information describe the scenaries in the different modules of the EPD.

Transport from production site to central warehouse in Norway

Type	Capacity utilisation	Gross density of products	Type of vehicle	Distance km	Fuel/Energy consumption	Value (l/t)
Truck*	30		****	127	$1,7*10^{-2}$ l/tkm	2,16
Truck**	30		****	50	$1,7*10^{-2}$ l/tkm	0,860
Boat***	48		*****	149	$4,6*10^{-3}$ l/tkm	0,685

* Transport by Truck (weighted average). From Danish production sites to Moss in Norway
** Transport byTruck. From Moss and Trondheim to central warehouse in Norway
*** Transport by Boat (weighted average). From Denmark to Norway (Frederikshavn terminal to Oslo)
**** Dataset from GaBi with a Euro class 3 truck-trailer with a payload of 22 tons.
***** Dataset from GaBi with a Bulk commodity carrier with 1,500-20,000 dwt. payload capacity and light fuel oil driven.

LCA: Results

System boudaries (X=included, MND=module not declared, MNR=module not relevant)

Product stage			Construction installation stage		Use stage							End of life stage				Beyond the system boundaries
Raw materials	Transport	Manufacturing	Transport	Construction installation stage	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND

Environmental impact

Parameter	A1 - A3								
GWP	1,27								
ODP	$1,48*10^{-9}$								
POCP	$6,92*10^{-4}$								
AP	$8,96*10^{-3}$								
EP	$8.87*10^{-4}$								
ADPM	$2,52*10^{-7}$								
ADPE	12,5								

GWP Global warming potential (kg CO_2-eqv.); **ODP** Depletion potential of the stratospheric ozone layer (kg CFC11-eqv.); **POCP** Formation potential of tropospheric photochemical oxidants (kg C_2H_4-eqv.); **AP** Acidification potential of land and water (kg SO_2-eqv.); **EP** Eutrophication potential (kg PO_4^{-3}-eqv.); **ADPM** Abiotic depletion potential for non fossil resources (kg Sb -eqv.); **ADPE** Abiotic depletion potential for fossil resources (MJ)

Reading example: $9,0*10^{-3} = 0,009$

Resource use

Parameter	A1 - A3							
RPEE	0,543							
RPEM	0,906							
TPE	1,45							
NRPE	12,97							
NRPM	0,00							
TRPE	12,97							
SM	0,281							
RSF	$3{,}89*10^{-2}$							
NRSF	0,202							
W	$3{,}39*10^{-3}$							

RPEE Renewable primary energy resources used as energy carrier (MJ); **RPEM** Renewable primary energy resources used as raw materials (MJ); **TPE** Total use of renewable primary energy resources (MJ); **NRPE** Non renewable primary energy resources used as energy carrier (MJ); **NRPM** Non renewable primary energy resources used as materials (MJ); **TRPE** Total use of non renewable primary energy resources (MJ); **SM** Use of secondary materials (kg); **RSF** Use of renewable secondary fuels (MJ); **NRSF** Use of non renewable secondary fuels (MJ); **W** Use of net fresh water (m^3)

End of life - Waste

Parameter	A1 - A3							
HW	$7{,}22*10^{-3}$							
NHW	0,226							
RW	n/a							

HW Hazardous waste disposed (kg); **NHW** Non hazardous waste disposed (kg), **RW** Radioactive waste disposed (kg)

End of life - Output flow

Parameter	A1 - A3							
CR	0							
MR	$2{,}63*10^{-2}$							
MER	$8{,}29*10^{-4}$							
EEE	0							
ETE	0							

CR Components for reuse (kg); **MR** Materials for recycling (kg); **MER** Materials for energy recovery (kg); **EEE** Exported electric energy (MJ); **ETE** Exported thermal energy (MJ)

Reading example: $9{,}0*10^{-3} = 0{,}009$

Specific Norwegian requirements

Electricity

Electricity used in the manufacturing processes has been accounted for using the process Danish Electricity grid mix (1kV-60kV) from GaBi6 (reference year 2009).

Greenhouse gas emissions 0,139 kg CO_2 eqv/MJ

and the process Norwegian Electricity grid mix (1kV-60kV) from GaBi6 (reference year 2009).

Greenhouse gas emissions 0,011 kg CO_2 eqv/MJ

Dangerous substances

None of the following substances have been added to the product: Substances on the REACH Candidate list of substances of very high concern (of 25.10.2013) substances on the Norwegian Priority list (pr.25.10.2013) and substances that lead to the product being classified as hazardous waste. The chemical content of the product complies with regulatory levels as given in the Norwegian Product Regulations.

Transport

Transport from production site to central warehouse in Norway is 326 km

Indoor environment

In general, ROCKWOOL products have been assessed using the Finnish M1 emission classes for building material. In total 32 specific ROCKWOOL products have been tested representing a wide range of products. To be granted the M1 quality label, an emission test (incl. ammonia, formaldehyde, and carcinogens) and an odour test has to be performed. The time period of testing is 28 days. Criteria: TVOC (Minimum of 70% of the compounds shall be identified): <0,2 mg/m2h, Formaldehyde (HCOH): < 0,05 mg/m2h, Ammonia (NH3): <0,03 mg/m2h, Carcinogenic compounds (belonging to category 1 of IARC monographs): <0,005 m,/m2h, Odour (dissatisfaction with odour shall be below 15%): No Odour. The M1 is the highest achievable best rank in the classification system.
(https www.rakennustieto.fi/index/english/emissionclassificationofbuildingmaterials.html)

Carbon footprint

Carbon footprint has not been worked out for the product.

Bibliography

ISO 14025:2006	*Environmental labels and declarations - Type III environmental declarations - Principles and procedures*
ISO 14044:2006	Environmental management - Life cycle assessment - Requirements and guidelines
EN 15804:2012	*Sustainability of construction works - Environmental product declaration - Core rules for the product category of construction products*
ISO 21930:2007	*Sustainability in building construction - Environmental declaration of building products*
Schmidt A, Nielsen. R, (2013).	*LCA of stone wool insulation on the Scandinavian market from ROCKWOOL, Project report, FORCE Technology, 2013*
PCR 2012	*Product-Category Rules. NPCR 12 rev. Insulation materials, epd-norge.no, 2012*

epd-norge.no The Norwegian EPD Foundation	**Publisher** The Norwegian EPD Foundation Post Box 5250 Majorstuen, 0303 Oslo Norway	Phone: e-mail: web	+4723088000 post@epd-norge.no www.epd-norge.no
epd-norge.no The Norwegian EPD Foundation	**Program holder** The Norwegian EPD Foundation Post Box 5250 Majorstuen, 0303 Oslo Norway	Phone: e-mail: web	+4723088000 post@epd-norge.no www.epd-norge.no
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Ver. 1 2015

epd-norge.no
The Norwegian EPD Foundation

ENVIRONMENTAL PRODUCT DECLARATION

in accordance with ISO 14025, ISO 21930 and EN 15804

Eier av deklarasjonen:	Moelven Limtre AS
Program operatør:	Næringslivets Stiftelse for Miljødeklarasjoner
Utgiver:	Næringslivets Stiftelse for Miljødeklarasjoner
Deklarasjon nummer:	NEPD-1576-605-NO
Publiserings nummer:	NEPD-1576-605-NO
ECO Platform registreringsnummer:	-
Godkjent dato:	02.07.2018
Gyldig til:	02.07.2023

Standard limtrebjelke

Moelven Limtre AS

www.epd-norge.no

Generell informasjon

Produkt:
Standard limtrebjelke

Eier av deklarasjonen:
Moelven Limtre AS
Kontakt person: Kato Sveen
Tlf: +47 908 59 468
e-post: kato.sveen@moelven.no

Program operatør:
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Postboks 5250 Majorstuen, 0303 Oslo
Tlf: +47 977 22 020
e-post: post@epd-norge.no

Produsenter:

Moelven Limtre AS, Moelv	Moelven Limtre AS, Agder
Lundemovegen 1	Stasjonsveien 4
2391 Moelv	4730 Vatnestrøm
Norge	Norge

Deklarasjon nummer:
NEPD-1576-605-NO

Produksjonssted:
Moelv, Norge
Vatnestrøm, Norge

ECO Platform registreringsnummer:
-

Kvalitet/Miljøsystem:
ISO 9001:2015, ISO 14001:2015, PEFC ST 2002:2013

Deklarasjonen er basert på PCR:
CEN Standard EN 15804 tjener som kjerne PCR
NPCR015 Wood and wood-based products for use in construction (08/2013)

Org. no.:
913 711 300

Erklæringen om ansvar:
Eieren av deklarasjonen skal være ansvarlig for den underliggende informasjon og bevis. EPD Norge skal ikke være ansvarlig med hensyn til produsent informasjon, livsløpsvurdering data og bevis.

Godkjent dato:
02.07.2018

Gyldig til:
02.07.2023

Deklarert enhet:
Produksjon av 1 m^3 limtre av gran

Årstall for studien:
2017-2018

Deklarert enhet med opsjon:

Sammenlignbarhet:
EPD av byggevarer er nødvendigvis ikke sammenlignbare hvis de ikke samsvarer med NS-EN 15804 og ses i en bygningskontekst.

Funksjonell enhet:
1 m^3 limtre av gran fra vugge-til-grav med en referanselevetid på 60 år.

Miljødeklarasjonen er utarbeidet av:
Lars G. F. Tellnes

Østfoldforskning

Verifikasjon:
Uavhengig verifikasjon av deklarasjonen og data, i henhold til ISO 14025:2010

☐ internt ☑ eksternt

Tredjeparts verifikator:

Oddbjørn Dahlstrøm, Asplan Viak AS
(Uavhengig verifikator godkjent av EPD Norge)

Godkjent

Håkon Hauan
Daglig leder av EPD-Norge

Produkt

Produktbeskrivelse:
Limtre er oppbygd av trelameller som er sammenbundet med lim. Fiberretningen i lamellene går parallelt med bjelkens lengderetning. Bruksområde er takbjelker, kantbjelker, bjelkelag, og sperrer.

Tekniske data:
GL30c styrkeklasse. Produsert etter EN 14080:2013 og med en fuktighet på 12 %. Limtre har i EN 14080:2013 en densitet på 470 kg/m^3, men gjennomsnittlig er densiteten for limtre av gran cirka 425 kg/m^3.

Produktspesifikasjon:
Lameltykkelsen er 45 mm for standard dimensjoner. Bjelkens høyde er multipel av dette, f.eks. 225, 270, 315 osv. Spesialprodukter og buer med små radier kan/må produseres med andre lamelltykkelser.

Markedsområde:
Norge og Sverige

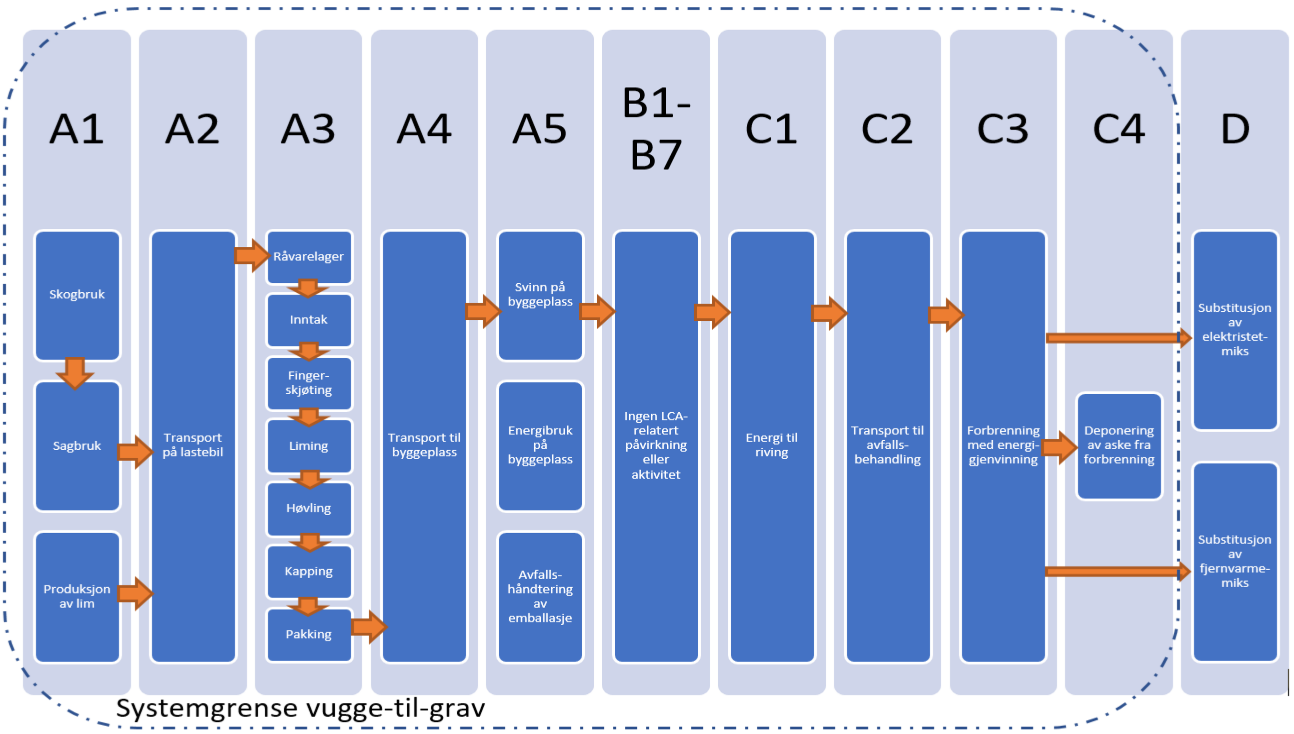
Materialer	kg	%
Trevirke av gran, tørrvekt	375	88,27
Vann, i trevirke	45	10,59
Lim, tørrvekt	4,85	1,14
Totalt for produktet	424,85	100
Plastemballasje	1,46	
Totalt med emballasje	426,31	

Levetid:
Referanselevetid er den samme som for byggverket, som regel settes denne til 60 år.

LCA: Beregningsregler

Deklarert enhet:
Produksjon av 1 m3 limtre av gran

Systemgrenser:
Flytskjema for systemgrensene er vist under for livsløpet til limtre.



Datakvalitet:
Data for produksjonen av limtre ble hentet inn i 2017 og representerer et vektet snitt for de to produksjonsstedene i 2016. Data for skurlast et hentet fra norsk EPD med data representativt for 2013 (NEPD-307-179), men hvor skogbruk og andre oppstrøms generiske data er oppdatert. Skogbruk er basert på norske data fra 2010. Data for produksjon av lim er hentet fra de spesifikke leverandørene og representativ for 2014. Andre data er hentet fra Ecoinvent v3.4 som ble lansert i 2017. Data for fjernvarme er hentet fra Statistisk sentralbyrå og er representative for et gjennomsnitt i 2015.

Cut-off kriterier:
Alle viktige råmaterialer og all viktig energibruk er inkludert. Produksjonsprosessen for råmaterialene og energistrømmer som inngår med veldig små mengder (<1%) er ikke inkludert. Disse cut-off kriteriene gjelder ikke for farlige materialer og stoffer.

Allokering:
Allokering er gjort i henhold til bestemmelser i EN 15804. Inngående energi, vann, avfall og interntransport er allokert etter volum mellom alle produktene. Påvirkning for primærproduksjonen av resirkulerte materialer er allokert til hovedproduktet der materialet ble brukt. For sagbruk er produksjonen delt opp i underprossesser og i hver underprosess er det brukt økonomisk allokering. For skogbruk er det brukt økonomisk allokering mellom sagtømmer og massevirke for skogskjøtsel og avvirkning.

Beregning av biogent karbon:
Opptak og utslipp av karbondioksid fra biologisk opphav er beregnet basert på NS-EN 16485:2014. Denne metoden er basert på modularitetsprinsippet i EN 15804:2012, og hvor utslipp skal telles med i den livsløpsmodulen hvor det faktisk skjer. Mengden karbondioksid er beregnet i henhold til NS-EN 16449:2014. Trevirke kommer fra bærekraftig skogbruk og er sporbarhetssertifisert. Med en tørrvekt på 375 kg/m^3 for limtre, så vil karboninnholdet omregnet til karbondioksid gi 687,5 kg CO_2 per m^3 trevirke.

LCA: Scenarier og annen teknisk informasjon

Følgende informasjonen beskriver scenariene for modulene i EPDen.

Det er forutsatt en transport til byggeplass på 200 km, hvor 100 km skjer på stor lastebil og 100 km på en middels stor lastebil.

Transport fra produksjonssted til bruker (A4)

Type	Kapasitetsutnyttelse inkl. retur (%)	Kjøretøytype	Distanse km	Brennstoff/ Energiforbruk	Enhet
Bil	53	EURO6, >32 tonn	100	0,02	l/tkm
Bil	26	EURO6, 16-32 tonn	100	0,044	l/tkm

I byggefasen er det antatt et behov for 1 MJ elektrisitet og at det blir 1 % svinn av produktet, samt avfallshåndtering av emballasjen.

Byggefase (A5)

	Enhet	Verdi
Hjelpematerialer	kg	0
Vannforbruk	m^3	0
Elektrisitetsforbruk	kWh	0,278
Andre energikilder	MJ	0
Materialtap	kg	4,25
Materialer fra avfallsbehandling	kg	1,46
Støv i luften	kg	0

Produktet har emisjoner til innemiljø deklarert under inneklima, men ingen LCA-relatert miljøpåvirkning i bruk.

Montert produkter i bruk (B1)

	Enhet	Verdi
LCA-relaterte utslipp under bruk	kg	0

Produktet krever normalt ingen vedlikehold eller reparasjon.

Vedlikehold (B2)/Reparasjon (B3)

	Enhet	Verdi
Vedlikeholdsfrekvens*		0
Hjelpematerialer	kg	0
Andre ressurser	kg	0
Vannforbruk	m^3	0
Elektrisitetsforbruk	kWh	0
Andre energikilder	MJ	0
Materialtap	kg	0

Produktet krever normalt ingen utskiftning i byggets levetid.

Utskifting (B4)/Renovering (B5)

	Enhet	Verdi
Utskiftingsfrekvens*		0
Elektrisitetsforbruk	kWh	0
Utskifting av slitte deler	0	0

* Tall eller referanselevetid

Produktet har ingen energi og vannforbruk i drift.

Drifts energi (B6) og vannbruk (B7)

	Enhet	Verdi
Vannforbruk	m^3	0
Elektrisitetsforbruk	kWh	0
Andre energikilder	MJ	0
Utstyrets varmeeffekt	kW	0

Limtre sorteres som blandet treavfall på byggeplass og behandles normalt med energigjenvinning.

Sluttfase (C1, C3, C4)

	Enhet	Verdi
Farlig avfall	kg	0
Blandet avfall	kg	424,85
Gjenbruk	kg	0
Resirkulering	kg	0
Energigjenvinning	kg	424,85
Til deponi	kg	0

Transporten av treavfall er basert på gjennomsnittsavstand for 2007 i Norge og utgjør 85 km (Raadal et al. (2009).

Transport avfallsbehandling (C2)

Type	Kapasitetsutnyttelse inkl. retur (%)	Kjøretøytype	Distanse km	Brennstoff/	Enhet
Bil		Uspesifisert	85	0,045	l/tkm
Jernbane					

Gevinsten av eksportert energi fra energigjenvinning i kommunalt avfallsanlegg er beregnet med erstatning av norsk el-miks og norsk fjernvarmemiks. Data for el-miks er samme som brukt i A1-A3 og fjernvarmemiks er basert på produksjonen i 2015.

Gevinst og belastninger etter endt levetid (D)

	Enhet	Verdi
Substitusjon av elektrisitet	MJ	625
Substitusjon av fjernvarme	MJ	4298

LCA: Resultater

Resultatene for global oppvarming i de ulike module gir stort bidrag fra opptak og utslipp av biogent karbon. Netto bidrag fra biogent karbon i hver modul er vist på side 8.

Systemgrenser (X = inkludert, MID = modul ikke deklarert, MIR = modul ikke relevant)

Produktfase			Konstruksjon installasjon fase		Bruksfase							Sluttfase				Etter endt levetid
Råmaterialer	Transport	Tilvirkning	Transport	Konstruksjon installasjon fase	Bruk	Vedlikehold	Reparasjon	Utskiftinger	Renovering	Operasjonell energibruk	Operasjonell vannbruk	Demontering	Transport	Avfallsbehandling	Avfall til sluttbehandling	Gjenbruk-gjenvinning-resirkulering-potensiale
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Miljøpåvirkning

Parameter	Unit	A1-A3	A4	A5	B1	B2	B3	B4	B5
GWP	kg CO_2 -ekv	-6,08E+02	1,03E+01	1,05E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
ODP	kg CFC11-ekv	1,17E-05	1,99E-06	1,51E-07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
POCP	kg C_2H_4 -ekv	4,49E-02	1,57E-03	5,13E-04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
AP	kg SO_2 -ekv	5,53E-01	2,49E-02	6,97E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
EP	kg PO_4^{3-}-ekv	9,87E-02	3,33E-03	1,32E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
ADPM	kg Sb-ekv	2,37E-04	2,83E-05	2,87E-06	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
ADPE	MJ	1,11E+03	1,71E+02	1,49E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

Miljøpåvirkning

Parameter	Unit	B6	B7	C1	C2	C3	C4		D
GWP	kg CO_2 -ekv	0,00E+00	0,00E+00	8,68E-03	4,64E+00	6,98E+02	5,60E-03		-3,07E+01
ODP	kg CFC11-ekv	0,00E+00	0,00E+00	8,15E-10	8,56E-07	5,00E-07	2,42E-09		-3,46E-06
POCP	kg C_2H_4 -ekv	0,00E+00	0,00E+00	1,93E-06	7,73E-04	4,07E-03	1,73E-06		-1,55E-02
AP	kg SO_2 -ekv	0,00E+00	0,00E+00	4,02E-05	1,81E-02	1,01E-01	3,80E-05		-1,53E-01
EP	kg PO_4^{3-}-ekv	0,00E+00	0,00E+00	9,70E-06	3,18E-03	2,67E-02	6,73E-06		-3,90E-02
ADPM	kg Sb-ekv	0,00E+00	0,00E+00	1,41E-07	1,30E-05	8,84E-06	8,14E-09		-5,95E-05
ADPE	MJ	0,00E+00	0,00E+00	9,54E-02	7,49E+01	1,36E+02	2,16E-01		-4,16E+02

GWP Globalt oppvarmingspotensial; ODP Potensial for nedbryting av stratosfærisk ozon; POCP Potensial for fotokjemisk oksidantdanning; AP Forsurningspotensial for kilder på land og vann; EP Overgjødslingspotensial; ADPM Abiotisk uttømmingspotensial for ikke-fossile ressurser; ADPE Abiotisk uttømmingspotensial for fossile ressurser

Ressursbruk

Parameter	Unit	A1-A3	A4	A5	B1	B2	B3	B4	B5
RPEE	MJ	3,35E+03	2,54E+00	1,05E+02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
RPEM	MJ	7,11E+03	0,00E+00	1,19E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
TPE	MJ	1,05E+04	2,54E+00	1,05E+02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
NRPE	MJ	1,21E+03	1,75E+02	1,59E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
NRPM	MJ	1,38E+02	0,00E+00	5,97E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
TRPE	MJ	1,35E+03	1,75E+02	1,65E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
SM	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
RSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
NRSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
W	m^3	7,07E+00	3,54E-02	7,35E-02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

Ressursbruk

Parameter	Unit	B6	B7	C1	C2	C3	C4		D
RPEE	MJ	0,00E+00	0,00E+00	1,14E+00	9,62E-01	7,12E+03	3,55E-03		-2,50E+03
RPEM	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	-7,11E+03	0,00E+00		0,00E+00
TPE	MJ	0,00E+00	0,00E+00	1,14E+00	9,62E-01	1,59E+00	3,55E-03		-2,50E+03
NRPE	MJ	0,00E+00	0,00E+00	1,58E-01	7,62E+01	1,29E+02	2,22E-01		-5,03E+02
NRPM	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	-7,86E+01	0,00E+00		0,00E+00
TRPE	MJ	0,00E+00	0,00E+00	1,58E-01	7,62E+01	5,07E+01	2,22E-01		-5,03E+02
SM	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00		0,00E+00
RSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00		0,00E+00
NRSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00		0,00E+00
W	m^3	0,00E+00	0,00E+00	8,46E-03	1,49E-02	2,23E-01	2,60E-04		-1,03E+01

RPEE Fornybar primærenergi brukt som energibærer; RPEM Fornybar primærenergi brukt som råmateriale; TPE Total bruk av fornybar primærenergi; NRPE Ikke fornybar primærenergi brukt som energibærer; NRPM Ikke fornybar primærenergi brukt som råmateriale; TRPE Total bruk av ikke fornybar primærenergi; SM Bruk av sekundære materialer; RSF Bruk av fornybart sekundære brensel; NRSF Bruk av ikke fornybart sekundære brensel; W Netto bruk av ferskvann

Livsløpets slutt - Avfall

Parameter	Unit	A1-A3	A4	A5	B1	B2	B3	B4	B5
HW	kg	4,56E+01	1,03E+01	6,58E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
NHW	kg	1,48E-03	9,22E-05	1,75E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
RW	kg	6,76E-03	1,14E-03	8,52E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

Livsløpets slutt - Avfall

Parameter	Unit	B6	B7	C1	C2	C3	C4		D
HW	kg	0,00E+00	0,00E+00	7,28E-03	4,48E+00	4,63E+00	8,16E-01		-1,05E+01
NHW	kg	0,00E+00	0,00E+00	1,93E-07	4,41E-05	1,30E-04	7,36E-08		-5,30E-04
RW	kg	0,00E+00	0,00E+00	9,72E-07	4,84E-04	1,37E-04	1,39E-06		-2,10E-03

HW Avhendet farlig avfall; NHW Avhendet ikke-farlig avfall; RW Avhendet radioaktivt avfall

Livsløpets slutt - Utgangsfaktorer

Parameter	Unit	A1-A3	A4	A5	B1	B2	B3	B4	B5
CR	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
MR	kg	4,42E-01	0,00E+00	1,46E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
MER	kg	7,87E-03	0,00E+00	7,87E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
EEE	MJ	4,93E-01	0,00E+00	6,19E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
ETE	MJ	3,39E+00	0,00E+00	4,26E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

Livsløpets slutt - Utgangsfaktorer

Parameter	Unit	B6	B7	C1	C2	C3	C4		D
CR	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00		0,00E+00
MR	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00		0,00E+00
MER	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00		0,00E+00
EEE	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	6,19E+02	0,00E+00		-6,25E+02
ETE	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,26E+03	0,00E+00		-4,30E+03

CR-komponenter for gjenbruk, MR Materialer for resirkulering, MER Materialer for energigjenvinning, EEE Eksportert elektrisk energi; ETE Eksportert termisk energi

Lese eksempel: 9,0 E-03 = $9{,}0*10^{-3}$ = 0,009

Norske tilleggskrav

Klimagassutslipp fra bruk av elektrisitet i produksjonsfasen

Nasjonal markedsmiks (produksjonsmiks pluss import) på lavspenning er anvendt for elektrisitetsbruk i produksjonprosessen (A3). Markedsmiks inkluderer i tillegg til elektrisitetsproduksjon også livsløpet av overføringslinjer, direkte utslipp fra nettet og tap i nettet.

Data kilde	Mengde	Enhet
Ecoinvent v3.4 (oktober 2017)	0,0312	kg CO_2-ekv/kWh

Farlige stoffer

- ☐ Produktet inneholder ingen stoffer fra REACH Kandidatliste eller den norske prioritetslisten
- ☑ Produktet inneholde stoffer som er under 0,1 vekt% på REACH Kandidatliste
- ☐ Produktet inneholde stoffer fra REACH Kandidatliste eller den norske prioritetslisten, se tabell under Spesifikke norske krav.
- ☐ Produktet inneholder ingen stoffer på REACH Kandidatliste eller den norske prioritetslisten. Produktet kan karakteriseres som farlig avfall (etter Avfallsforskiften, Vedlegg III), se tabell under Spesifikke norske krav.

Navn	CAS no.	Mengde

Transport

Det er ingen transport fra produksjon til sentrallager.

Inneklima

Limtrebjelk av gran har blitt testet for emisjoner av totalt flykte oragniske forbindelser (TVOC), formaldehyd og ammoniakk. Resultatene etter 28 dager viser en emisjonshastighet på 0.04 mg/m^{2}h for TVOC, <0.033 mg/m^{2}h for formaldehyd og <0.005 mg/m^{2}h. I følge den finske innklimaklassifiseringen av byggematerialer fra Rakennustieto, så vil dette ligge i klassen M1. Resultatene har også blitt vurdert til å oppfylle kravene til E1 i NS-EN 717-1:2004 med en beregnet formaldehydemisjon på <0.009 mg/m^3. Dokumentasjon av testresultater kan fås på forespørsel til Moelven limtre AS.

Klimadeklarasjon

For å øke transparensen til beregning av klimapåvirkning og biogent karbon, så er det inkludert flere indikatorer fra livsløpsinventaret og bidragsanalyse for miljøpåvirkning.

Indikatorer for biogent karbon fra livsløpsinventaret er presentert for produktet og emballasjen i tabellen under. Disse er beregnet i henhold til tabell E.4 fra Annex E i ISO 21930:2017.

Livsløpsinventar for biogent karbon i produktet og emballasje

Parameter	Enhet	A1-A3	A4	A5	C1	C2	C3	C4
Opptak og utslipp assosiert med biogent karboninnhold i biobasert produkt	kg CO_2	-6,88E+02	0,00E+00	-2,62E-21	0,00E+00	0,00E+00	6,88E+02	0,00E+00
Opptak og utslipp assosiert med biogent karboninnhold i biobasert emballasje	kg CO_2	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

I beregning av klimapåvirkning, så er indikatoren for GWP blitt delt opp her i underindikatorer i tabellen under. I beregninger som ikke inkluderer hele livsløpet, så skal da indikatoren "GWP - umiddelbar oksidasjon av biogent karbon" anvendes. Denne indikatoren beregner alt utslippet av karbondioksid fra forbrenning av trevirke i modul A1-A3, selv om selve utslippet skjer i andre moduler som A5 og C3.

Underindikatorer for bidraget fra biogent karbon til klimapåvirkning

Parameter	Enhet	A1-A3	A4	A5	C1	C2	C3	C4
GWP - umiddelbar oksidasjon av biogent karbon	kg CO_2 -ekv	7,93E+01	1,03E+01	1,05E+00	8,68E-03	4,64E+00	1,06E+01	5,60E-03
GWP - bidrag fra biogent karbon i materialene	kg CO_2 -ekv	-6,88E+02	0,00E+00	-2,62E-21	0,00E+00	0,00E+00	6,88E+02	0,00E+00
GWP - total	kg CO_2 -ekv	-6,08E+02	1,03E+01	1,05E+00	8,68E-03	4,64E+00	6,98E+02	5,60E-03

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epd-norge.no
The Norwegian EPD Foundation

ENVIRONMENTAL PRODUCT DECLARATION

in accordance with ISO 14025, ISO 21930 and EN 15804

Owner of the declaration:	Norsk Stål AS
Program operator:	The Norwegian EPD Foundation
Publisher:	The Norwegian EPD Foundation
Declaration number:	NEPD-347-238-EN
Issue date:	09.09.2015
Valid to:	09.09.2020

Ribbed reinforcement bars

Norsk Stål AS

NORSK STÅL

www.epd-norge.no

General information

Product:
Ribbed reinforcement bars made from prefabricated steel from European manufacturers, which may be cut and shaped according to the intended use.

Owner of the declaration:
Norsk Stål AS
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Manufacturer:
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Phone: +47 47 81 80 00
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Declaration number:
NEPD-347-238-EN

Place of production:
Norway

ECO Platform reference number:
-

Management system:
NS-EN ISO 14001:2004
NS-EN 10080:2005
NS-EN 1090-1:2009 + A1:2011
Startbank ID: 138341

This declaration is based on Product Category Rules:
CEN Standard EN 15804 serves as core PCR
NPCR 013 Steel as Construction Material Rev 1 (08/2013)

Organisation no:
NO 959493715 MVA

Statement of liability:
The owner of the declaration shall be liable for the underlying information and evidence. EPD Norway shall not be liable with respect to manufacturer information, life cycle assessment data and evidences.

Issue date:
09.09.2015

Valid to:
09.09.2020

Declared unit:
-

Year of study:
2015

Declared unit with option (A1-A3 + A4):
Per kg steel

Comparability:
EPD of construction products may not be comparable if they do not comply with EN 15804 and are seen in a building context.

Functional unit:
-

The EPD has been worked out by:
Annik Magerholm Fet — Michael Myrvold Jenssen

Annik Magerholm Fet — M.M. Jenssen

NTNU – Trondheim
Norwegian University of Science and Technology

Verification:
The CEN Norm EN 15804 serves as the core PCR.
Independent verification of the declaration and data, according to ISO14025:2010

☐ internal ☑ external

Third party verifier:

Helene Sedal

Helene Sedal, Rambøll Norge AS
(Independent verifier approved by EPD Norway)

Approved

Dagfinn Malnes

Dagfinn Malnes
Managing Director of EPD-Norway

700

Product

Product description:

Reinforcement bars *(rebar,* Norwegian: armeringsjern) are steel rods that are used as a tension device in concrete reinforcement. The bars may have protruding features and indentations to better bond with the concrete, commonly in the form of ribs. The picture below shows typical ***ribbed reinforcement bars*** **(Norwegian: kamstål)**. When embedded into concrete, the steel is able to alleviate the tension that is imposed on the concrete by distributing the tension evenly over a large area. Typical applications for reinforcement steel are in the construction of buildings and civil structures.

Technical information:

Steel products may contain many types of alloys, depending on the intended performance characteristic of the steel product. For reinforcement steel, a typical material composition is given the table below.

Scrap content is reported to be 100% [7][8][9]

Product specification:

Materials	kg	%
Fe - Iron	0,98-0,99	98-99
C - Carbon	0,005-0,002	0,05-0,02
Si - Silicon	0,02	0,2
Mn - Manganese	0,03-0,07	0,3-0,7

Market:

Norway

Reference service life, product:

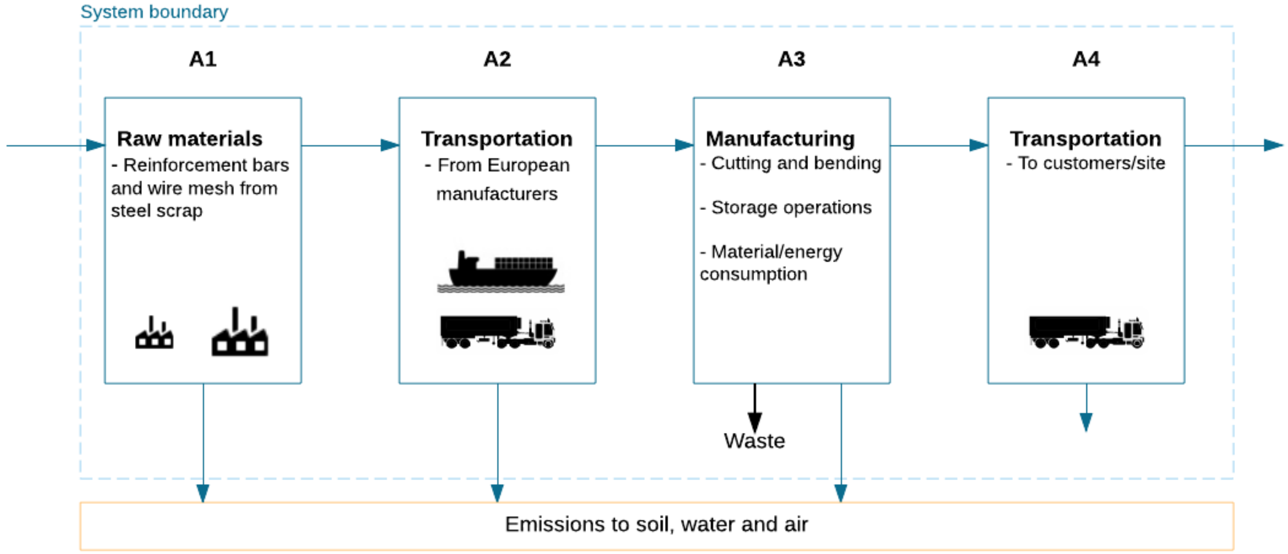
Not relevant.

Typical reinforcement bars with ribbed protrusions.

LCA: Calculation rules

Declared unit:
Per kg steel

System boundary:
Cradle to gate (A1-A3) including transport from manufacturer to customer (A4). System boundaries are shown in the flowchart.



Data quality:
General requirements and guidelines concerning use of generic and specific data and the quality of those are as described in EN 15804: 2012 +A1:2013, clause 6.3.6 and 6.3.7. The data is representative according to temporal, geographical and technological requirements.

Temporal:
Data for use in module A3 is supplied by the manufacturer and consists of the recorded amount of specific material and energy consumption for the product studied. Specific data has been collected for 2014. Generic data has been created or updated within the last 10 years.

Geographical:
The geographic region of the production sites included in the calculation is Norway (A3). Data for A1 represents European manufacturers (Norway included).

Production sites included are in Klepp, Søgne and Skien. Warehouse operations in Larvik and Strømmen are included in the study

Technological:
Data represents technology in use.

Data for module A1 consists of specific data derived from suppliers for reinforcement steel [7][8][9]. All other data are aqcuired from, and calculated in GaBi 7 [10].

Cut-off criteria:
All major raw materials and all the essential energy is included. The production process for raw materials and energy flows that are included with very small amounts (<1%) are not included. This cut-off rule does not apply for hazardous materials and substances.

Allocation:
The allocation is made in accordance with the provisions of EN 15804 + A1:2013. Incoming energy and water and waste production in-house is allocated equally among all products through mass allocation if applicable.

LCA: Scenarios and additional technical information

The following information describe the scenarios in the different modules of the EPD.

The scenarios for transport distances and transportation modes from suppliers to manufacturer represents both recorded and calculated routes and distances from factory gates in Europe to Norway. Transport scenarios for waste handling and transport to sites/customers are based on assumptions and recorded averages respectively.

Transport from suppliers to producer (A2)

Type	Capacity utilisation (incl. return) %	Type of vehicle	Distance km	Fuel/Energy consumption	Value (l/t)
Container vessel	48	27500 DWT	1154	0,005 l/tkm	5,30
River freight ship	65	Downstream barge	700	0,002 l/tkm	1,12
Truck	85	Euro 0-5mix, 27t payl.	175,3	0,044 l/tkm	7,72

Transport in A2 describes the transports of steel products for further manufacturing, expedition or storage at manufacturer.

Waste transportation (A3)

Type	Capacity utilisation (incl. return) %	Type of vehicle	Distance km	Fuel/Energy consumption	Value (l/t)
Truck	85	Euro 6, 27t payl.	50	0,795 l/tkm	0,02

Transport in A3 describes shipping transportation of waste to waste collection points or waste disposal plants.

Transport from production place to user (A4)

Type	Capacity utilisation (incl. return) %	Type of vehicle	Distance km	Fuel/Energy consumption	Value (l/t)
Truck	85	Euro 6, 27t payl.	64	0,016 l/tkm	1,02

Transport in A4 represents an average of actual distances recorded in 2014.

LCA: Results

The results shows that the most significant impacts comes from the production of steel. The steel is shipped from European manufacturers to ports in Norway, giving a moderate impact in A2. Module A3 includes deloading and expediting of goods from a forklift, storage, cutting, bending and office maintenance, and has a relatively low impact. Module A4 gives transport to customers/sites, with a low impact relative to module A1.

System boundaries (X=included, MND= module not declared, MNR=module not relevant)

Product stage			Assemby stage		Use stage							End of life stage				Beyond the system boundaries
Raw materials	Transport	Manufacturing	Transport	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND

Environmental impact

Parameter	Unit	A1-A3	A4						
GWP	kg CO_2 -eqv	3,25E-01	2,51E-03						
ODP	kg CFC11-eqv	5,97E-08	1,69E-14						
POCP	kg C_2H_4 -eqv	9,75E-04	1,10E-07						
AP	kg SO_2 -eqv	6,15E-04	3,04E-06						
EP	kg PO_4^{3-}-eqv	1,70E-04	7,17E-07						
ADPM	kg Sb-eqv	7,47E-08	1,14E-10						
ADPE	MJ	4,76E+00	3,40E-02						

GWP Global warming potential; **ODP** Depletion potential of the stratospheric ozone layer; **POCP** Formation potential of tropospheric photochemical oxidants; **AP** Acidification potential of land and water; **EP** Eutrophication potential; **ADPM** Abiotic depletion potential for non fossil resources; **ADPE** Abiotic depletion potential for fossil resources

Resource use

Parameter	Unit	A1-A3	A4						
RPEE	MJ	2,19E+00	1,92E-03						
RPEM	MJ	3,21E-05	2,67E-15						
TPE	MJ	2,19E+00	1,92E-03						
NRPE	MJ	5,87E+00	3,42E-02						
NRPM	MJ	4,06E-05	9,95E-15						
TRPE	MJ	5,87E+00	3,42E-02						
SM	kg	2,44E-04	INA						
RSF	MJ	2,38E-05	INA						
NRSF	MJ	2,20E-04	INA						
W	m^3	1,90E-01	1,85E-04						

RPEE Renewable primary energy resources used as energy carrier; **RPEM** Renewable primary energy resources used as raw materials; **TPE** Total use of renewable primary energy resources; **NRPE** Non renewable primary energy resources used as energy carrier; **NRPM** Non renewable primary energy resources used as materials; **TRPE** Total use of non renewable primary energy resources; **SM** Use of secondary materials; **RSF** Use of renewable secondary fuels; **NRSF** Use of non renewable secondary fuels; **W** Use of net fresh water
INA = Indicator not assessed

End of life - Waste[1]

Parameter	Unit	A1-A3	A4						
HW	kg	2,86E-02	1,62E-08						
NHW	kg	2,19E-02	INA						
RW	kg	6,48E-04	7,11E-08						

[1] Hazardous and radioactive waste is calculated from deposited goods from background processes. Non-hazardous waste are specific recorded waste from the manufacturer.

HW Hazardous waste disposed; NHW Non hazardous waste disposed; RW Radioactive waste disposed

End of life - Output flow

Parameter	Unit	A1-A3	A4						
CR	kg	INA	INA						
MR	kg	4,09E-02	INA						
MER	kg	1,10E-03	INA						
EEE	MJ	INA	INA						
ETE	MJ	INA	INA						

CR Components for reuse; MR Materials for recycling; MER Materials for energy recovery; EEE Exported electric energy; ETE Exported thermal energy

Reading example: 9,0 E-03 = $9{,}0 \cdot 10^{-3}$ = 0,009

Additional Norwegian requirements

Greenhouse gas emission from the use of electricity in the manufacturing phase

The elecricity mix (NO) represents the average country or region specific electricity supply for final consumers, including electricity own consumption, transmission/distribution losses and electricity imports from neighboring countries.
Reference year: 2011

Data source	Amount	Unit
GaBi 6.4.	0,0465	kg CO_2-eqv/kWh

Dangerous substances

- ☑ The product contains no substances given by the REACH Candidate list or the Norwegian priority list
- ☐ The product contains substances given by the REACH Candidate list or the Norwegian priority list that are less than 0,1 % by weight.
- ☐ The product contain dangerous substances, more then 0,1% by weight, given by the REACH Candidate List or the Norwegian Priority list, see table.
- ☐ The product contains no substances given by the REACH Candidate list or the Norwegian priority list. The product is classified as hazardous waste (Avfallsforskiften, Annex III), see table.

Name	CAS no.	Amount

Indoor environment

No tests have been carried out on the product concerning indoor climate - Not relevant

Carbon footprint

Carbon footprint has not been worked out for the product.

Bibliography

[1] ISO 14025:2010	*Environmental labels and declarations - Type III environmental declarations - Principles and procedures*
[2] ISO 14044:2006	*Environmental management - Life cycle assessment - Requirements and guidelines*
[3] EN 15804:2012+A1:2013	*Sustainability of construction works - Environmental product declaration - Core rules for the product category of construction products*
[4] ISO 21930:2007	*Sustainability in building construction - Environmental declaration of building products*
[5] LCA Report	*Life Cycle Assessment Report:* *Ribbed reinforcement bars and wire mesh reinforcement (NTNU SISVI Report 2015-04)*
[6] NPCR 013-2013	Product Category Rules Steel as Construction Material
[7] Environdec EPD no.: S-P-00306 (2012)	Celsa Steel Service AS: Steel reinforcement products for concrete (Norway)
[8] ift Rosenheim GmbH EPD-BMG-10.1 (2013)	Baustahlgewebe GmbH: Betonstahlmatten und Gitterträger
[9] ift Rosenheim GmbH EPD-BS-10.0 (2013)	Badische Stahlwerke GmbH: Betonstahl zur Bewehrung von Beton
[10] GaBi 7 LCA software DB version 6.110	GaBi database documentation can be viewed at URL: http://www.gabi-software.com/databases/

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The Norwegian EPD Foundation

ENVIRONMENTAL PRODUCT DECLARATION

in accordance with ISO 14025, ISO 21930 and EN 15804

Owner of the declaration:	UPB AS
Program operator:	The Norwegian EPD Foundation
Publisher:	The Norwegian EPD Foundation
Declaration number:	NEPD-402-281-EN
Issue date:	25.01.2016
Valid to:	25.01.2021

Steel structures

UPB AS

www.epd-norge.no

General information

Product:
Steel structures

Owner of the declaration:
UPB AS
Contact person: Liene Klava
Phone: +371 22040585
e-mail: liene.klava@upb.lv

Program operator:
EPD-Norge
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Phone: +47 23088292
e-mail: post@epd-norge.no

Manufacturer:
RK Metals
Lauktehnikas 12, Grobina, Liepaja district, LV-3430
Phone: +371 634 59022
e-mail: rkmetals@rkmetals.lv

Declaration number:
NEPD-402-281-EN

Place of production:
Latvia

ECO Platform reference number:
-

Management system:
ISO 9001 and ISO 14001

This declaration is based on Product Category Rules:
CEN Standard EN 15804 which serves as core PCR and NPCR 013rev1, Steel as construction material (22.08.2013).

Organisation no:
LV42103000187

Statement of liability:
The owner of the declaration shall be liable for the underlying information and evidence. EPD Norway shall not be liable with respect to manufacturer information, life cycle assessment data and evidences.

Issue date:
25.01.2016

Valid to:
25.01.2021

Declared unit:
1 kg steel structure

Year of study:
2015

Declared unit with option:

Comparability:
EPD of construction products may not be comparable if they do not comply with EN 15804 and are seen in a building context.

Functional unit:
1 kg steel structure with a reference service life (RSL) of 100 years.

The EPD has been worked out by:
Helene Sedal, PhD — RAMBØLL

Helene Sedal

Verification:
The CEN Norm EN 15804 serves as the core PCR.
Independent verification of the declaration and data, according to ISO14025:2010

☐ internal ☑ external

Third party verifier:

Christofer Skaar

Christofer Skaar, PhD
(Independent verifier approved by EPD Norway)

Approved

Håkon Hauan

Håkon Hauan
Managing Director of EPD-Norway

Product

Product description:
Steel structures for use in buildings. The steel structures can be columns, beams, bracings, trusses, welded profiles of complicated cross-section.

Technical data:
Steel building structures in accordance with EN 1090-2:2008 +A1:2011 up to execution class EXC4. NACE code 2511.

Product specification:
Product specification per kg product is given below.

Materials	kg	%
Steel	0,986	98,6
Welding consumables	0,01	1
Coating/finish	0,004	0,4
Sum	1	100

Market:
Norway, Sweden and Denmark. The Norwegian market is used for modelling A5 and C1-C4.

Reference service life, product:
100 years

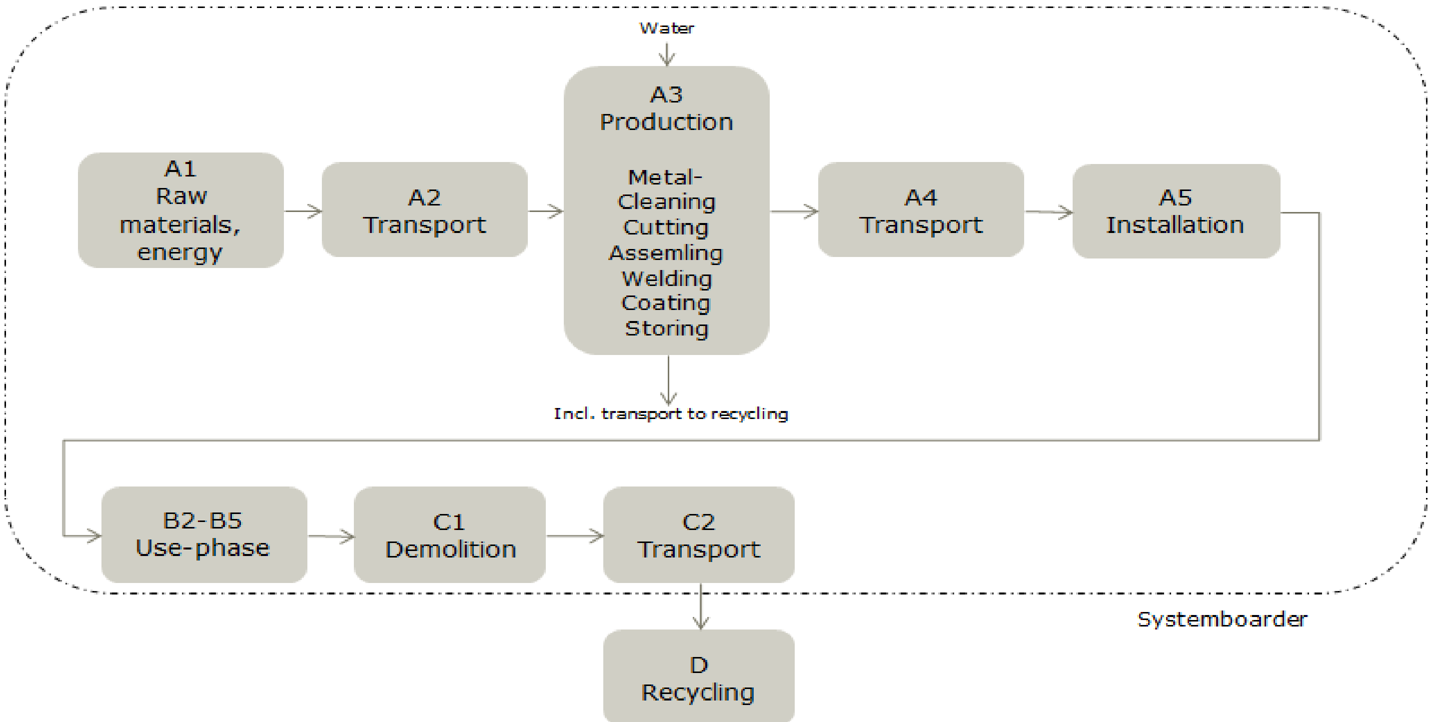
Reference service life, building:
60 years

LCA: Calculation rules

Declared unit:
1 kg steel structure

System boundary:
The system boundaries are given in the flow diagram. There are no environmental impact in B2-B5, and B1, B6 and B7 are not relevant according to PCR.

Figure 1 Flow diagram



Data quality:
Product specific data is from 2014. Generic data is from Simapro v.8.0.5.13 with Ecoinvent 3.1 database from 2014.

Cut-off criteria:
All major raw materials and all the essential energy is included. The production process for raw materials and energy flows that are included with very small amounts (<1%) are not included. This cut-off rule does not apply for hazardous materials and substances.

Allocation:
The allocation is made in accordance with the provisions of EN 15804. Incoming energy and water and waste production in-house is allocated equally among all products through mass allocation. Effects of primary production of recycled materials allocated to the main product in which the material was used. The recycling process and transportation of the material is allocated to this analysis.

LCA: Scenarios and additional technical information

The following information describe the scenarios in the different modules of the EPD.

The transport distance from the production place to consumer is an average distance based on factory location and typical customer location for this product.

Transport from production place to user (A4)

Type	Capacity utilisation (incl. return) %	Type of vehicle	Distance km	Fuel/Energy consumption		Value (l/t)
Truck	58 %	Freight lorry >32t, Euro 4	346	0,014	l/tkm	4,84
Ferry	71 %	Transoceanic ship	294	0,003	l/tkm	0,88

A5 includes energy use in building machines.

Assembly (A5)

	Unit	Value
Auxiliary	kg	
Water consumption	m^3	
Electricity consumption	kWh	
Other energy carriers	MJ	0,02
Material loss	kg	
Output materials from waste treatment	kg	
Dust in the air	kg	

The share of steel sent for material recycling is 100 %.

End of Life (C1, C3, C4)

	Unit	Value
Hazardous waste disposed	kg	
Collected as mixed construction waste	kg	
Reuse	kg	
Recycling	kg	1
Energy recovery	kg	
To landfill	kg	

Steel are transported to material recycling with lorry.

Transport to waste processing (C2)

Type	Capacity utilisation (incl. return) %	Type of vehicle	Distance km	Fuel/Energy consumption		Value (l/t)
Truck	37	Freight lorry, 16-32t, Euro 4	15	0,031	l/tkm	0,47

Benefits and loads beyond the system boundaries (D)

	Unit	Value
Net new steel to recycling	kg	0,66

The share of steel for recycling is 100 % with a share of new steel of 58 %. The recycling efficiency is 96 %. In addition material losses from production is included.

LCA: Results

Results for 1 kg steel structure.

System boundaries (X=included, MND= module not declared, MNR=module not relevant)

Product stage			Assemby stage		Use stage							End of life stage				Beyond the system boundaries
Raw materials	Transport	Manufacturing	Transport	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
x	x	x	x	x	MNR	x	x	x	x	MNR	MNR	x	x	x	x	x

Environmental impact

Parameter	Unit	A1- A3	A4	A5	B2-B5	C1	C2	C3-C4	D
GWP	kg CO_2 -eqv	2,20E+00	5,67E-02	2,54E-03	0	5,90E-02	2,53E-03	0	-1,52E+00
ODP	kg CFC11-eqv	1,71E-07	1,07E-08	4,58E-10	0	1,06E-08	4,64E-10	0	-8,46E-08
POCP	kg C_2H_4 -eqv	1,18E-03	1,17E-05	5,12E-07	0	1,19E-05	4,40E-07	0	-9,88E-04
AP	kg SO_2 -eqv	1,07E-02	2,93E-04	1,92E-05	0	4,45E-04	1,04E-05	0	-7,74E-03
EP	kg PO_4^{3-}-eqv	2,28E-03	4,22E-05	4,07E-06	0	9,43E-05	1,75E-06	0	-1,86E-03
ADPM	kg Sb-eqv	2,82E-05	1,20E-07	8,27E-10	0	1,92E-08	8,21E-09	0	-2,58E-05
ADPE	MJ	2,65E+01	9,35E-01	3,88E-02	0	9,00E-01	4,05E-02	0	-1,61E+01

GWP Global warming potential; ODP Depletion potential of the stratospheric ozone layer; POCP Formation potential of tropospheric photochemical oxidants; AP Acidification potential of land and water; EP Eutrophication potential; ADPM Abiotic depletion potential for non fossil resources; ADPE Abiotic depletion potential for fossil resources

Resource use

Parameter	Unit	A1- A3	A4	A5	B2-B5	C1	C2	C3-C4	D
RPEE	MJ	2,21E+00	1,35E-02	2,00E-04	0	4,64E-03	4,77E-04	0	-1,55E+00
RPEM	MJ	0,00E+00	0,00E+00	0,00E+00	0	0,00E+00	0,00E+00	0	0,00E+00
TPE	MJ	2,21E+00	1,35E-02	2,00E-04	0	4,64E-03	4,77E-04	0	-1,55E+00
NRPE	MJ	2,84E+01	9,53E-01	3,92E-02	0	9,08E-01	4,11E-02	0	-1,69E+01
NRPM	MJ	2,25E-02	0,00E+00	0,00E+00	0	0,00E+00	0,00E+00	0	0,00E+00
TRPE	MJ	2,85E+01	9,53E-01	3,92E-02	0	9,08E-01	4,11E-02	0	-1,69E+01
SM	kg	4,89E-01	INA	INA	0	INA	INA	0	INA
RSF	MJ	INA	INA	INA	0	INA	INA	0	INA
NRSF	MJ	INA	INA	INA	0	INA	INA	0	INA
W	m^3	2,78E-02	1,93E-04	5,56E-06	0	1,29E-04	7,39E-06	0	-1,76E-02

RPEE Renewable primary energy resources used as energy carrier; RPEM Renewable primary energy resources used as raw materials; TPE Total use of renewable primary energy resources; NRPE Non renewable primary energy resources used as energy carrier; NRPM Non renewable primary energy resources used as materials; TRPE Total use of non renewable primary energy resources; SM Use of secondary materials; RSF Use of renewable secondary fuels; NRSF Use of non renewable secondary fuels; W Use of net fresh water

End of life - Waste									
Parameter	**Unit**	**A1- A3**	**A4**	**A5**	**B2-B5**	**C1**	**C2**	**C3-C4**	**D**
HW	kg	1,52E-04	5,08E-07	1,54E-08	0	3,58E-07	2,29E-08	0	-1,13E-04
NHW	kg	1,18E+00	7,74E-02	4,10E-05	0	9,52E-04	1,79E-03	0	-7,25E-01
RW	kg	8,36E-05	6,06E-06	2,58E-07	0	5,98E-06	2,62E-07	0	-3,28E-05

HW Hazardous waste disposed; NHW Non hazardous waste disposed; RW Radioactive waste disposed

End of life - Output flow									
Parameter	**Unit**	**A1- A3**	**A4**	**A5**	**B2-B5**	**C1**	**C2**	**C3-C4**	**D**
CR	kg	INA	INA	INA	INA	INA	INA	INA	INA
MR	kg	1,78E-01	INA	INA	INA	INA	1,00E+00	INA	INA
MER	kg	INA	INA	INA	INA	INA	INA	INA	INA
EEE	MJ	INA	INA	INA	INA	INA	INA	INA	INA
ETE	MJ	INA	INA	INA	INA	INA	INA	INA	INA

CR Components for reuse; MR Materials for recycling; MER Materials for energy recovery; EEE Exported electric energy; ETE Exported thermal energy

Reading example: 9,0 E-03 = $9{,}0 \cdot 10^{-3}$ = 0,009
INA = Indicator not assessed. Indicators are assumed to be zero or close to zero, but as there could be some impact not accounted for in the background system, indicators are marked with INA.

Additional Norwegian requirements

Greenhous gas emission from the use of electricity in the manufacturing phase
The electricity mix for Latvia are calculated based on available statistics from Central Statistical Bureau of Latvia for 2014. The energy sources used are Hydropower (27 %), Natural gas (40 %), Wind power (1%), Import (electricity from Russia) (32 %).

Data source	Amount	Unit
Econinvent v3	0,487	CO_2-eqv/kWh

Dangerous substances

- ☑ The product contains no substances given by the REACH Candidate list or the Norwegian priority list (both checked 02.11.15).
- ☐ The product contains substances given by the REACH Candidate list or the Norwegian priority list that are less than 0,1 % by weight.
- ☐ The product contain dangerous substances, more then 0,1% by weight, given by the REACH Candidate List or the Norwegian Priority list, see table.
- ☐ The product contains no substances given by the REACH Candidate list or the Norwegian priority list. The product is classified as hazardous waste (Avfallsforskiften, Annex III), see table.

Indoor environment
The product has not been tested for emissions to indoor environment.

Carbon footprint
Carbon footprint has not been worked out for the product.

Bibliography

ISO 14025:2010	*Environmental labels and declarations - Type III environmental declarations - Principles and procedures*
ISO 14044:2006	*Environmental management - Life cycle assessment - Requirements and guidelines*
EN 15804:2012+A1:2013	*Sustainability of construction works - Environmental product declaration - Core rules for the product category of construction products*
ISO 21930:2007	*Sustainability in building construction - Environmental declaration of building products*
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Central Statistical Bureau of Latvia, 2015	*http://www.csb.gov.lv/en/statistikas-temas/energy-key-indicators-30736.html (Accessed 31.08.15)*

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BYG 508, Master's Thesis, UIA

Project location: HEISTAD, PORSGRUNN, NORWAY

Options for the structural systems :

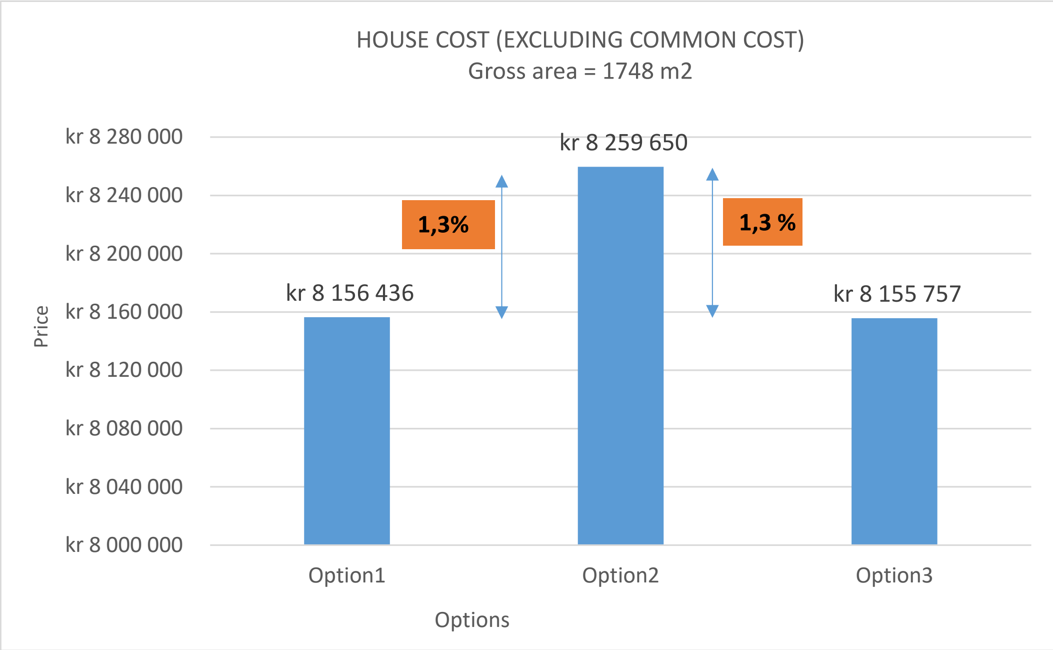
Option1: Timber structural system including walls and foundations made of normal concrete

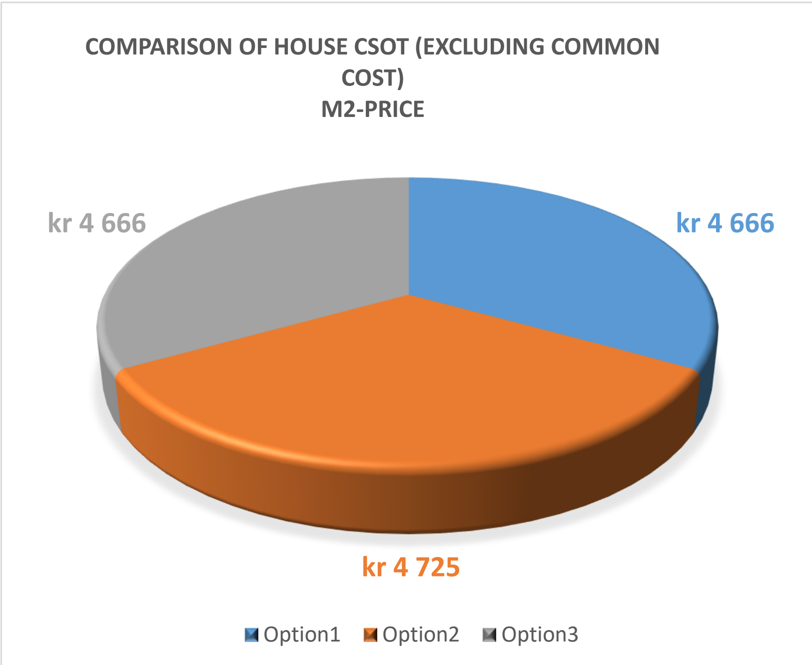
Option2: Timber structural system including walls and foundations made of low carbon concrete.

Option3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.

Assumption for calculation		Calculation include:			House Cost in Kroner		
Project for master thesis		Structural sytems of an apartemnt building			Structural systems options		
Drawing program (CAD): Revit		Gross area… m2		1 748	Option1	Option2	Option3
Unit prices are picked from:				**Sum….**	**kr 8 156 436**	**kr 8 259 650**	**kr 8 155 757**
Holte Kalkulasjonsnøkkel og Norsk Prisbok				**m2-price…..**	**kr 4 666**	**kr 4 725**	**kr 4 666**
Nr.	*Construction member*	*unit*	*Quantity*	*unit price*	*Cost*		
	Concrete work:						
	Option1: *Concrete B35 (C35/45) Ordinary concrete*						
	Option2 and Option3 *: Concrete B35 (C35/45) Low carbon concrete Class A = 3% more expensive than ordinary concrete according to a concrete supplier NORBETONG, Norway.*						
	FOUNDATION						
	Wall (strip) foundation:						
Common	1000x300mm	lm	59,64	1800	107352	110573	110573
Common	1200x400mm	lm	15,00	2760	41400	42642	42642
Common	16000x400mm	lm	64,33	3552	228500	235355	235355
Common	1700x400mm	lm	36,79	3750	137963	142101	142101
			175,76				
	Isolated footing:						
Common	1700x1700x400mm	no.	4	9604	38415	39568	39568
Common	1300x1300x350mm	no.	2	4914	9828	10123	10123
Common	100x1000x300mm	no.	1	2492	2492	2567	2567
			7				
	Structural systems						
	RCC walls						
Option1 and option2	200 mm shear walls	m2	34,9	1620	56538	58234	
Option1 and option2	220 mm basement walls + shear walls	m2	367,71	1655	608560	626817	
Option1 and option2	250 mm basement walls + shear walls	m2	182,1	1710	311391	320733	
Option1 and option2	350 mm basement walls	m2	210,78	1886	397531	409457	
Option1 and option2	200 mm ring wall	m2	10	1620	16200	16686	
Option3	200 mm shear walls	m2	-				
Option3	220 mm basement walls + shear walls	m2	154,81	1655			263897
Option3	250 mm basement walls + shear walls	m2	182,1	1710			320733
Option3	350 mm basement walls	m2	210,78	1886			409457
Option3	200 mm ring wall	m2	10	1620			16686
Option3							
Option3	**Cross-laminated wall**						
Option3	200 mm	m2	247,86	1280			317261
Common	external concrete walls against the terrain.	m2	295,73	190	56189	56189	56189

	Beams:						
Common	Glulam , GL30c						
	GLT 115x180	lm	23,66	527	12459	12459	12459
	GLT 115x405	lm	37,49	1262	47312	47312	47312
	GLT 140x495	lm	40,72	1549	63064	63064	63064
	GLT 140x540	lm	42,16	1690	71229	71229	71229
	Steel, S355						
Common	HE300B	kg	744,66	30	22340	22340	22340
	HE280B	kg	3744,94	30	112348	112348	112348
	IPE 200	kg	1396,59	30	41898	41898	41898
	IPE 330	kg	1258,89	30	37767	37767	37767
	IPE 400	kg	3377,68	30	101330	101330	101330
	Columns:						
common	Concrete B35, Foundation colum						
	300x300 mm	lm	3,6	1821	6556	6752	6752
	Steel, S 355						
common	HE200A	kg	324,6	30	9738	9738	9738
	HUP 100X100X8	kg	1037,27	30	31118	31118	31118
	HUP 140X140X8	kg	1788,06	30	53642	53642	53642
	HUP 140X140X10	kg	330,64	30	9919	9919	9919
	Glulam , GL30c						
common	GLT column 115x115	lm	133,17	760	101209	101209	101209
	GLT column 140x225	lm	28,15	1779	50079	50079	50079
	Floors:						
common	Ground floor slab 120mm concrete + 200mm XPS	m2	689	1810	1247090	1284503	1284503
	50 mm XPS insulation on the ground	m2	67	190	12730	12730	12730
	Cross-laminated floors						
	CLT 280, Et. 01 and Et.02	m2	1224,86	1750	2143505	2143505	2143505
	CLT 160 in balcong, Et.02	m2	93,18	1043	97173	97173	97173
	60 - 80 mm over over CLT 280 for soud requirement, Et. 02 appartments	m2	424	263	111512	114857	114857
	300 mm EPS insulation below CLT	m2	479,83	640	307091	307091	307091
	50 mm EPS insulation over CLT plan 1	m2	423,57	137	58029	58029	58029
	80 mm cast in situ concrete, over CLT plan 1	m2	424	281	119144	122718	122718
	80 mm XPS insulation under Precast concrete elements in balcongs	m2	218,83	350	76591	76591	76591
	50 mm Precast concrete elemnt in balcongs	m2	218,83	220	48143	48143	48143
	Roof:						
Common	CLT 280 main roof	m2	621,9	1750	1088325	1088325	1088325
	CLT 160 roof at balcong	m2	60,15	1043	62736	62736	62736
			Total .... Kr		**8156436**	**8259650**	**8155757**


HOUSE COST (EXCLUDING COMMON COST)
Gross area = 1748 m2
kr 8 280 000
kr 8 240 000
kr 8 200 000
kr 8 160 000
kr 8 120 000
kr 8 080 000
kr 8 040 000
kr 8 000 000
Price
kr 8 156 436
kr 8 259 650
kr 8 155 757
1,3%
1,3 %
Option1
Option2
Option3
Options


COMPARISON OF HOUSE CSOT (EXCLUDING COMMON COST)
M2-PRICE
kr 4 666
kr 4 666
kr 4 725
Option1
Option2
Option3

Summary of preliminary and main project for Master's Thesis

Summary of the six options studied for the project is presented below. The first three options were done in the preliminary project and the second three options were done in final or main project for the master's thesis.

Preliminary Project: (Studied in Autumn 2018)			Main Project (Studied in Spring 2019)			
Preliminary Project for Master's Thesis			Main project for Master's Thesis			
Option1 (Preliminary Project)	Option2 (Preliminary Project)	Option3 (Preliminary Project)	Option1 (Main Project)	Option2 (Main Project)	Option3 (Main Project)	
7 799 640	**6 628 389**	**8 161 548**	**8 156 436**	**8 259 650**	**8 155 757**	**Total (kroner)**
4 462	**3 792**	**4 669**	**4 666**	**4 725**	**4 666**	**M2-price**

Preliminary Project: (Studied in Autumn 2018)

Option1: Concrete structural systems (normal cast in situ concrete)

Option1:Steel frames with hollow core slabs (precast slabs) including walls and foundations made of normal concrete

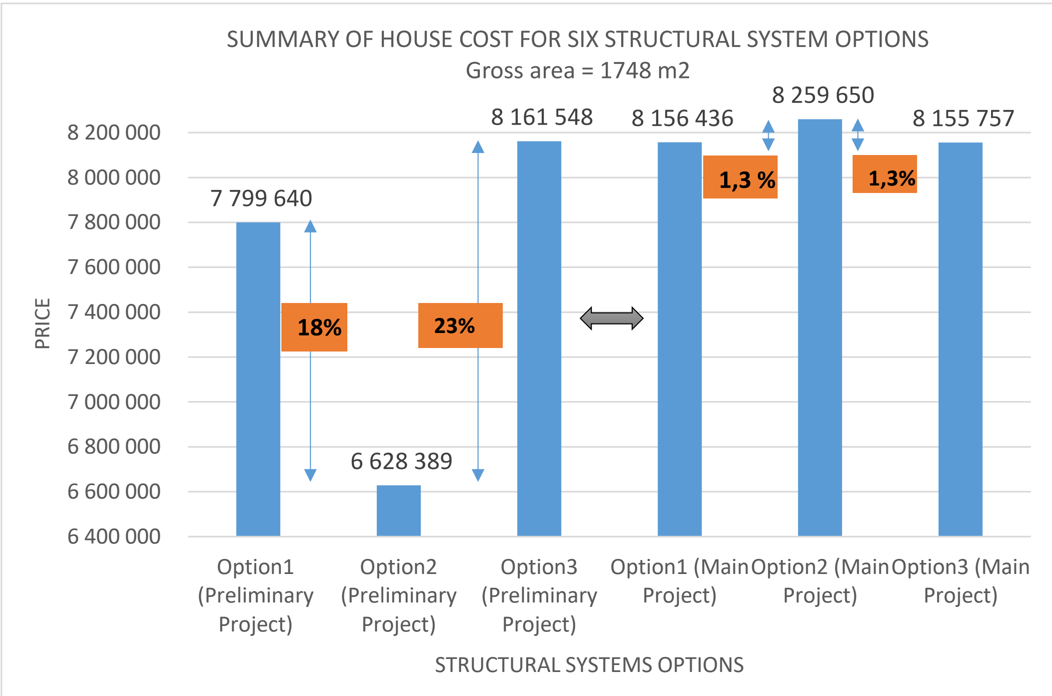
Option3: Timber structural system including walls and foundations made of normal concrete

Main Project (Studied in Spring 2019)

Option1: Timber structural system including walls and foundations made of normal concrete

Option2: Timber structural system including walls and foundations made of low carbon concrete.

Option3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.



From the graph above Option2 (preliminary project) came out cheapest. It is 18% and 23 % cheaper than Option1 (preliminary project) and Option3 (preliminary project) respectively. The cost of Option3 (preliminary project), Option1 and Option3 (main project) are very similar. It can be seen that Option2 (main project) is slightly more expensive than Option1 and Option3 in the main project.

From the economic perspective, Option2 (preliminary project) is more reliable.

APPENDIX H

OPtion1

1st Floor plan

2st Floor plan

Roof

Foundation Plan

Sections and Fire Detail

3D view

Material Quantities

OPtion2

1st Floor plan

2st Floor plan

Roof

Foundation Plan

Sections and Fire Detail

3D view

Material Quantities

OPtion3

1st Floor plan

2st Floor plan

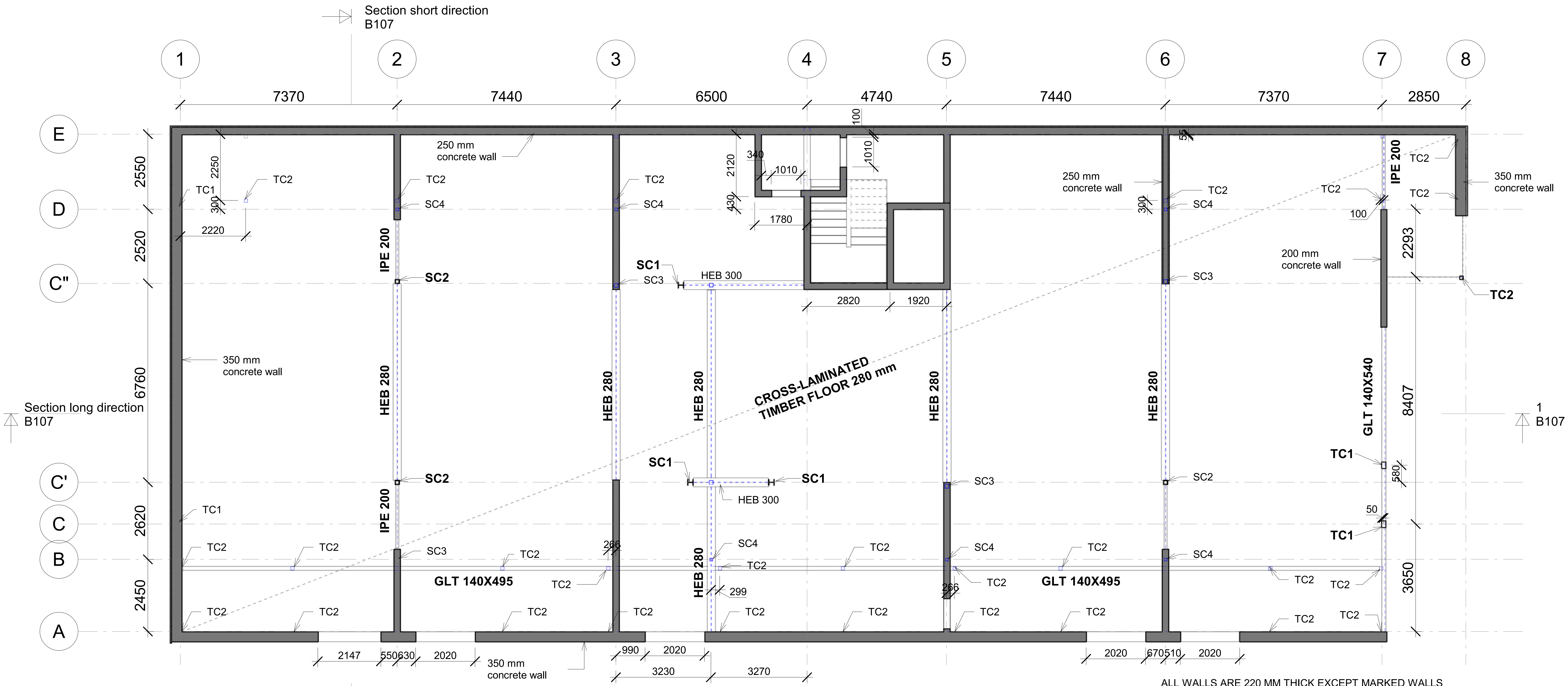
Roof

Foundation Plan

Sections and Fire Detail

3D view

Material Quantities



2
B107

DESIGN NOTES:

Concrete works:

Walls and Foundations

- Strength class B35
- Durability class MF45
- EXposure class XC2

Ground floor slab:

- Strength class B35
- Durability class M60
- EXposure class XC1

- Reiforcement cover:
  1. Cast against and permanently in conctact with the ground: 50mm +/- 10mm
  2. Exposed to weather or in contact with the ground: 25mm +/- 10mm
  3. Not exposed to weather or in conctact with the ground: 15 mm +/- 10mm

Steel works:

- Strength class S355
- Fire protection to all steel columns and Beams and will be applied to all exposed faces:
  20 mm conlit Conlit 150/150P
  Rockwool

Timber works:

- Strength class GL30c

Cross-Laminated Timber (CLT):

- All layers have strength class C24.

ALL WALLS ARE 220 MM THICK EXCEPT MARKED WALLS

Steel column:

SC1 HEA 200
SC2 Square hollow section 140x140x10
SC3 Square hollow section 140x140x8 (columns over plan 1)
SC4 Square hollow section 100x100x8 (columns over plan 1)

Timber column:

TC1 rectangular section 140x225
TC2 square section 115x115 (balcong column over plan 1)

Rev.	Revision description	Designed	Contr.	Date

Project owner
BRYGGEVEGEN 2 - HEISTAD

Scale 1 : 100

Dato 2019-04-24
Designed Author
Contr. Checker

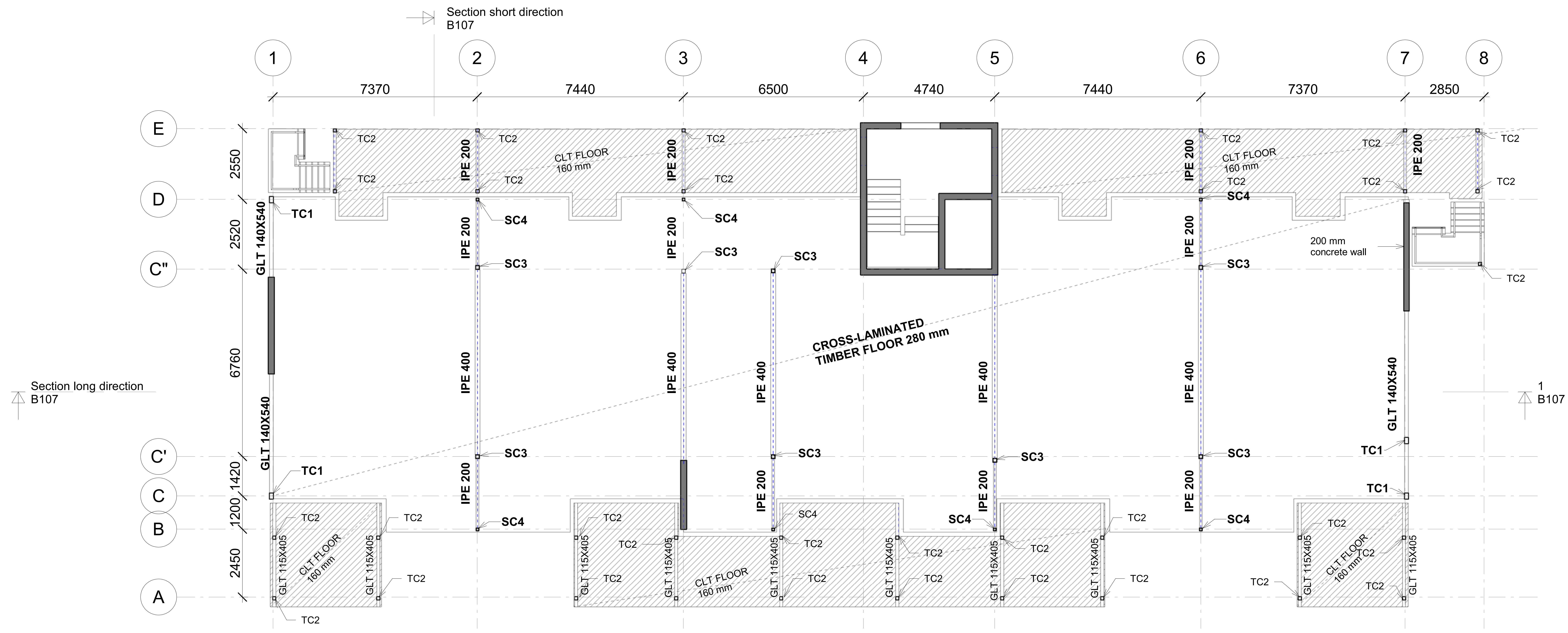
HUSTYPE A
Floor over Basement

Size A2
Projekt nr. Project nr.
Drawing nr. B100
Rev.

Option1: Timber structural system including walls and foundations made of normal concrete

Autodesk Revit

08.05.2019 12.36.15



ALL WALLS ARE 220 MM THICK EXCEPT MARKED WALLS

Steel column:

SC2 Square hollow section 140x140x10
SC3 Square hollow section 140x140x8 (columns over plan 1)
SC4 Square hollow section 100x100x8 (columns over plan 1)

Timber column:

TC1 rectangular section 140x225
TC2 square section 115x115 (balcong column over plan 1)

DESIGN NOTES:

Concrete works:
Walls and Foundations
- Strength class B35
- Durability class MF45
- EXposure class XC2

Ground floor slab:
- Strength class B35
- Durability class M60
- EXposure class XC1

- Reiforcement cover:
  1. Cast against and permanently in conctact with the ground: 50mm +/- 10mm
  2. Exposed to weather or in contact with the ground: 25mm +/- 10mm
  3. Not exposed to weather or in conctact with the ground: 15 mm +/- 10mm

Steel works:
- Strength class S355
- Fire protection to all steel columns and Beams and will be applied to all exposed faces:
  20 mm conlit Conlit 150/150P
  Rockwool

Timber works:
- Strength class GL30c

Cross-Laminated Timber (CLT):
- All layers have strength class C24.

Rev.	Revision description	Designed	Contr.	Date
	Project owner BRYGGEVEGEN 2 - HEISTAD	Scale 1 : 100	Dato	2019-04-24
			Designed	Author
			Contr.	Checker
	HUSTYPE A Floor over plan 1	Size	Projekt nr.	Project nr.
		Drawing nr. B101	Rev.	
	Option1: Timber structural system including walls and foundations made of normal concrete			

Autodesk Revit

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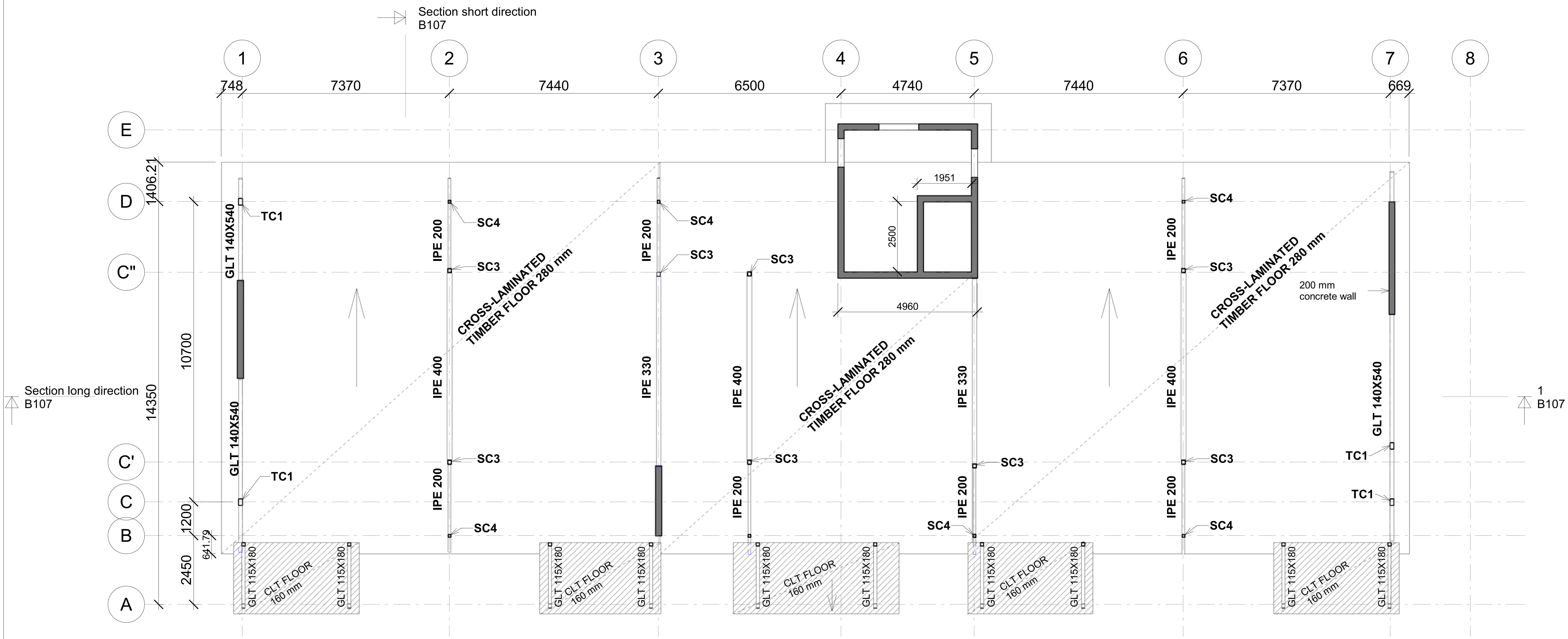


DESIGN NOTES:

Concrete works:

Walls and Foundations

- Strength class B35
- Durability class MF45
- EXposure class XC2

Ground floor slab:

- Strength class B35
- Durability class M60
- EXposure class XC1

- Reiforcement cover:
  1. Cast against and permanently in conctact with the ground: 50mm +/- 10mm
  2. Exposed to weather or in contact with the ground: 25mm +/- 10mm
  3. Not exposed to weather or in conctact with the ground: 15 mm +/- 10mm

Steel works:

- Strength class S355
- Fire protection to all steel columns and Beams and will be applied to all exposed faces:
  20 mm conlit Conlit 150/150P
  Rockwool

Timber works:

- Strength class GL30c

Cross-Laminated Timber (CLT):

- All layers have strength class C24.

ALL WALLS ARE 220 MM THICK EXCEPT MARKED WALLS

Steel column:

SC3 Square hollow section 140x140x8 (columns over plan 1)
SC4 Square hollow section 100x100x8 (columns over plan 1)

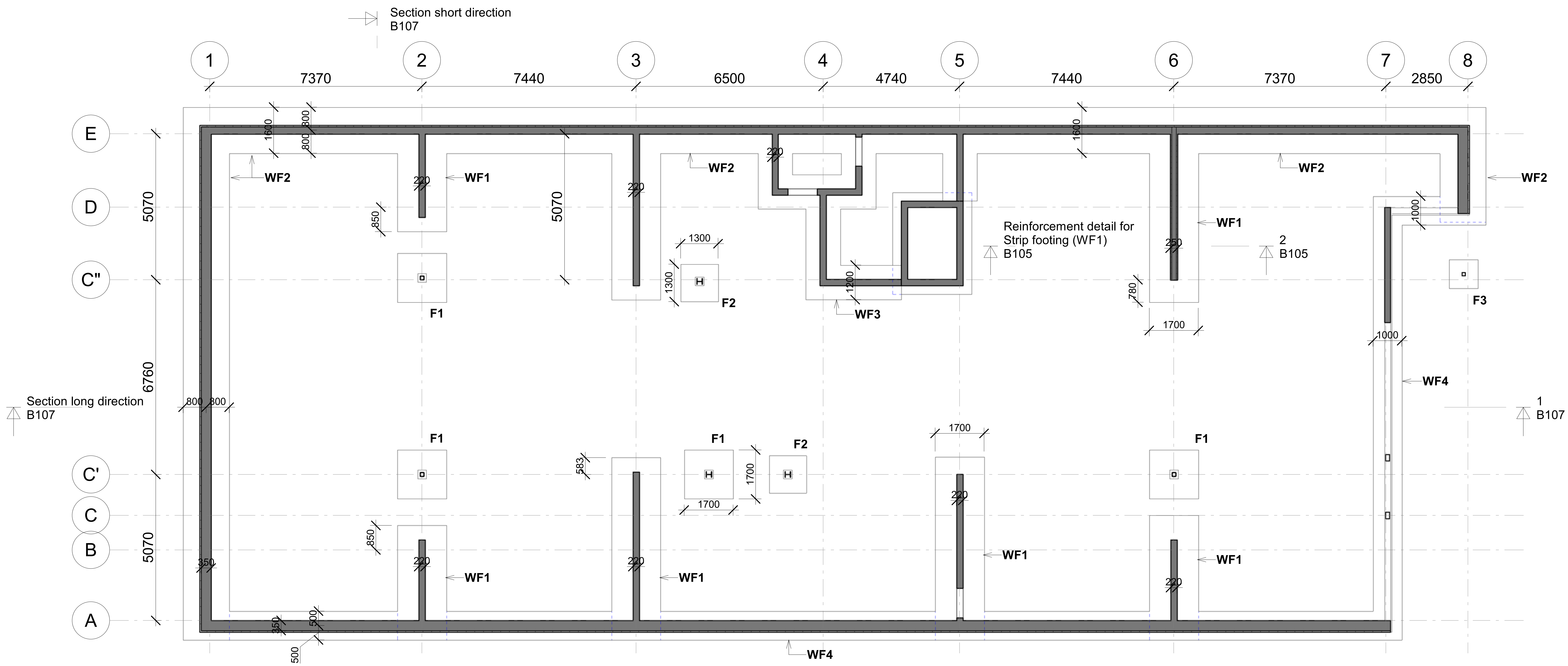
Timber column:

TC1 rectangular section 140x225
TC2 square section 115x115 (balcong column over plan 1)

Rev.	Revision description			Designed	Contr.	Date
Project owner BRYGGEVEGEN 2 - HEISTAD		Scale 1 : 100		Dato	2019-04-24	
				Designed	Author	
				Contr.	Checker	
HUSTYPE A Roof plan		Size A2		Projekt nr.	Project nr.	
		Drawing nr. B102			Rev.	
Option1: Timber structural system including walls and foundations made of normal concrete						

Autodesk Revit

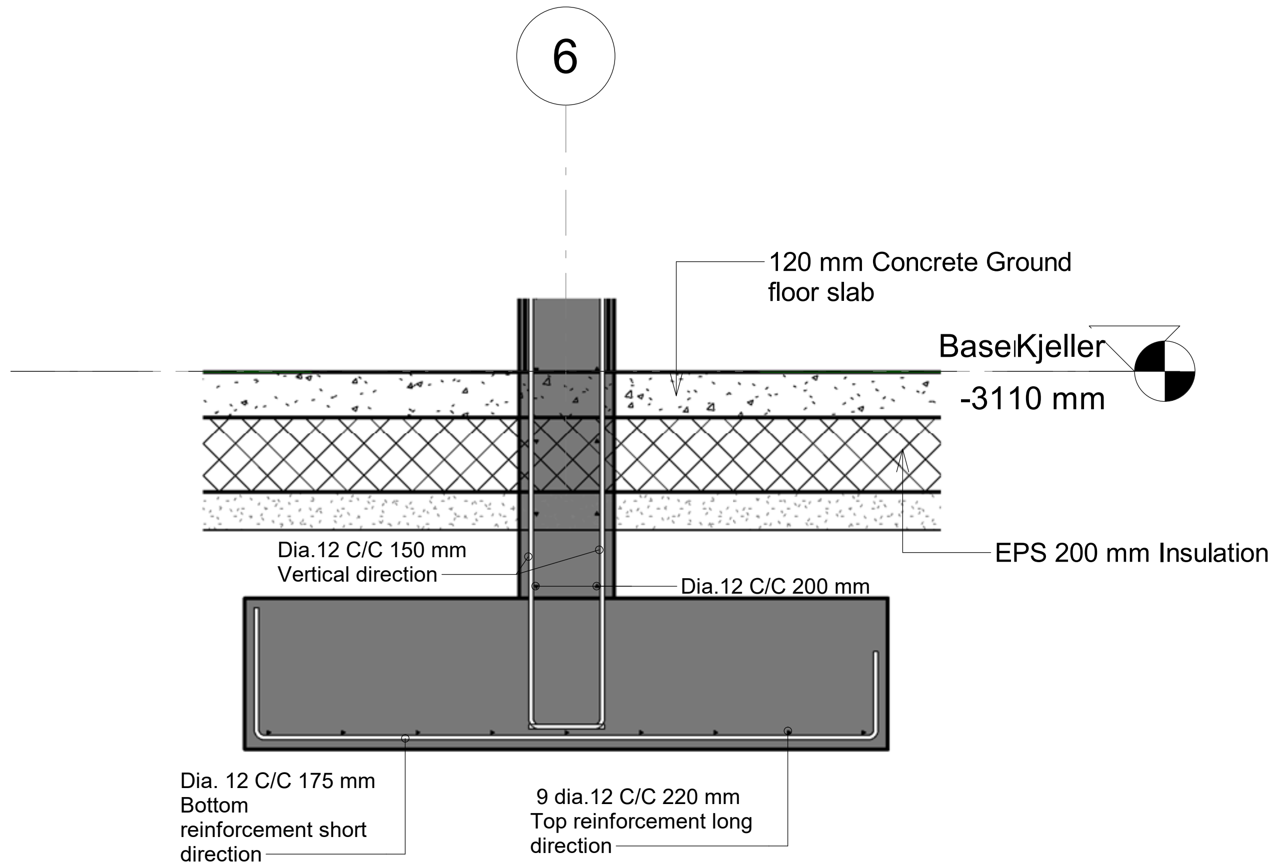
08.05.2019 12.37.25



Foundation plan
1 : 100

Foundation Types:
Isolated footings:
F1: 1700x1700x400
F2: 1300x1300x350
F3: 1000x100x300

Strip footings:
WF1: 1700x400
WF2: 1600x400
WF3: 1200x350
WF4: 1000x300



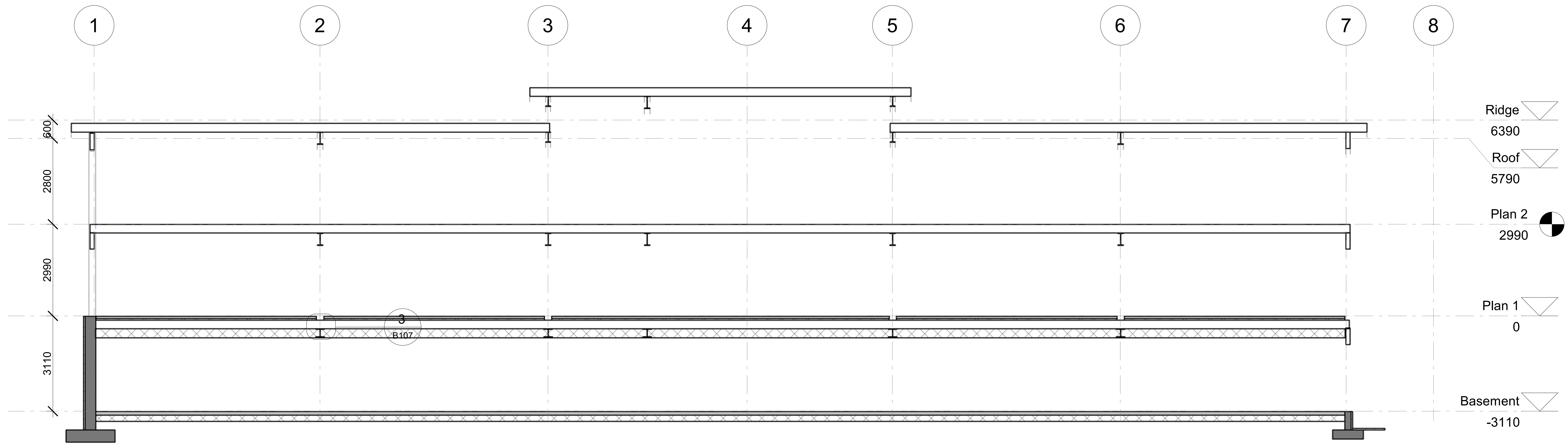
Reinforcement detail for Strip footing (WF1)
1 : 20

Rev.	Revision description	Designed	Contr.	Date
Project owner BRYGGEVEGEN 2 - HEISTAD	Scale: As indicated	Dato: 2019-04-24 Designed: Author Contr.: Checker		
Foundation plan	Size: A2 Drawing nr.: B105	Projekt nr.: Project nr.	Rev.	

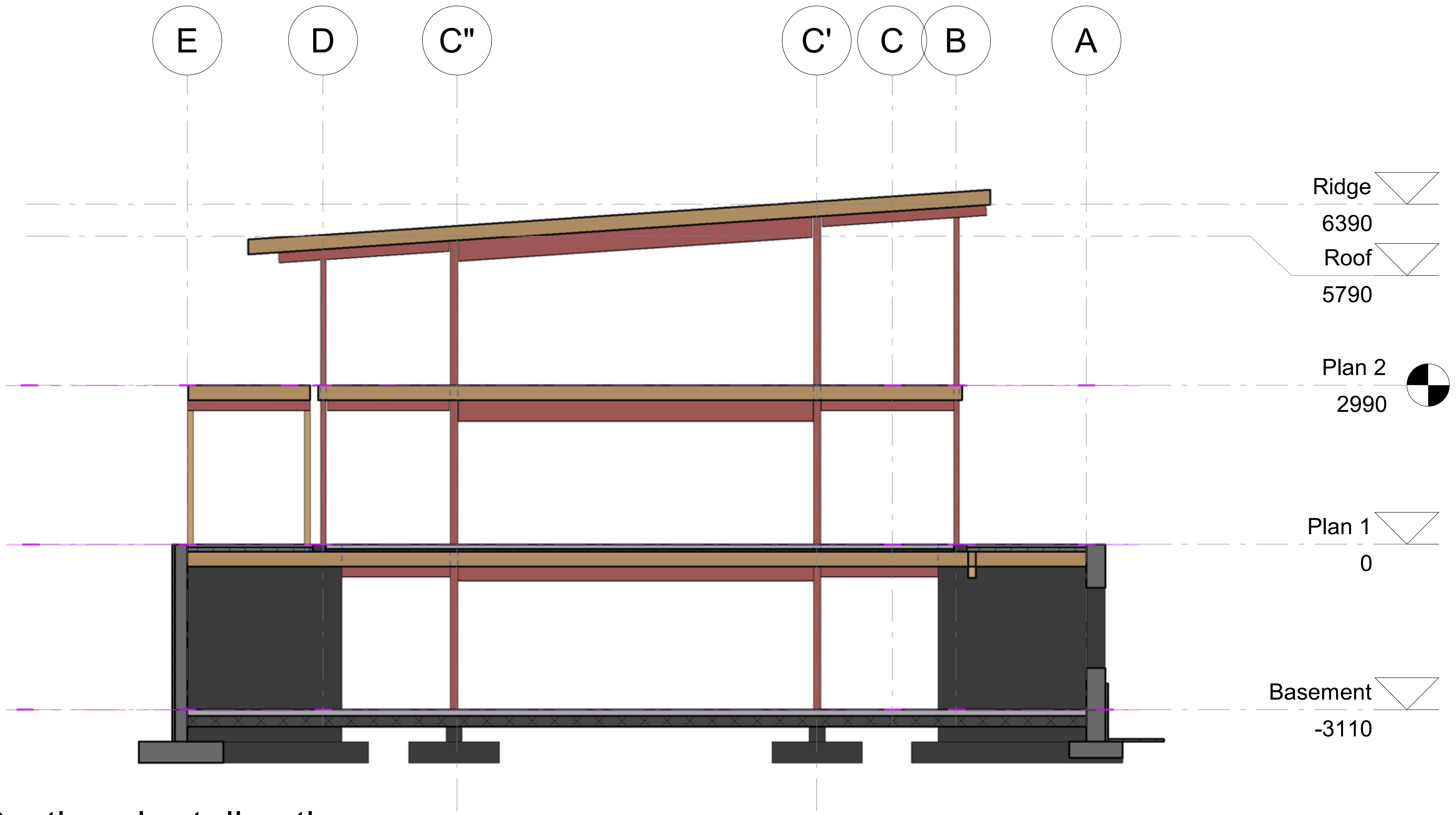
Option1: Timber structural system including walls and foundations made of normal concrete

Autodesk Revit

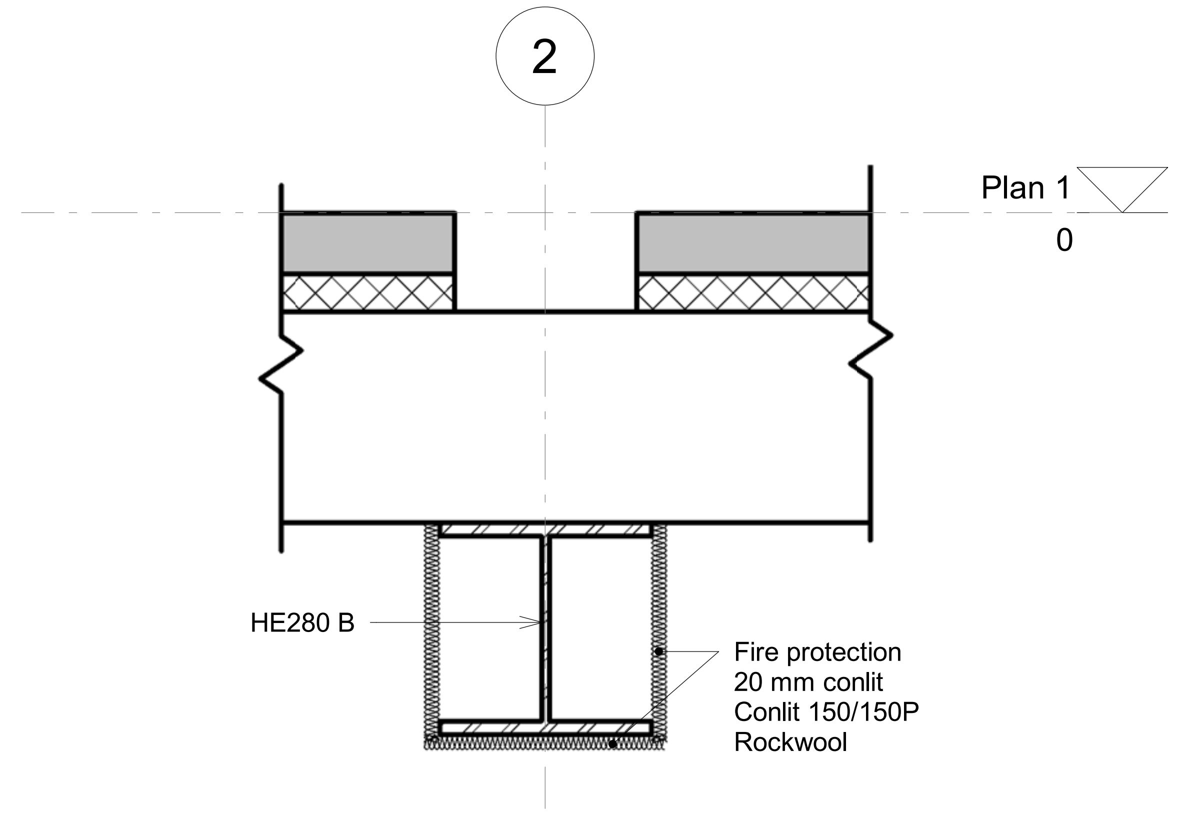
08.05.2019 12.38.46



Section long direction
1 : 100



Section short direction
1 : 100



Fire protection Detail
1 : 10

Rev. | Revision description | Designed | Contr. | Date

Project owner
BRYGGEVEGEN 2 - HEISTAD

Scale: As indicated
Dato: 04/14/19
Designed: Author
Contr.: Checker

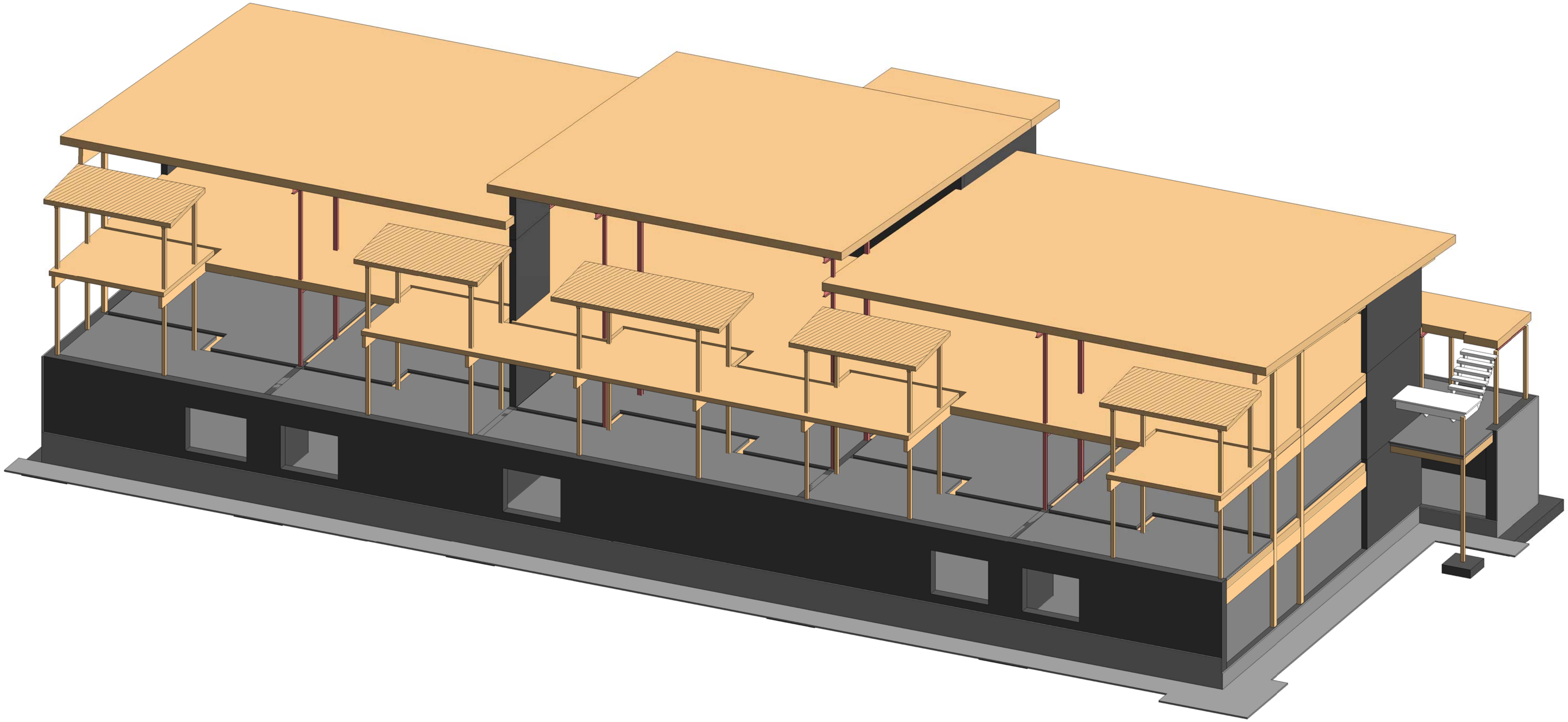
SECTIONS

Size: A2
Projekt nr.: Project nr.
Drawing nr.: B107
Rev.:

Option1: Timber structural system including walls and foundations made of normal concrete

Autodesk Revit

08.05.2019 12.39.11



Rev.	Revision description	Designed	Contr.	Date

Project owner
BRYGGEVEGEN 2 - HEISTAD

Scale

Dato 2019-04-24
Designed Author
Contr. Checker

Size A2

Projekt nr. Project nr.

HUSTPE A
3D View

Drawing nr. B103

Rev.

Option1: Timber structural system including walls and foundations made of normal concrete

Autodesk Revit

08.05.2019 12.37.47

Beams						
Type	Count	Volume	Lengde	Denity	Weight	Structural Material
GLT - GL30c						
GLT Beam 115x180	10	0.48 m³	23659.22	470.00 kg/m³	227.71 kg	GLT - GL30c
GLT Beam 115x405	10	1.75 m³	37490	470.00 kg/m³	820.67 kg	GLT - GL30c
GLT Beam 140x495	1	2.82 m³	40715.5	470.00 kg/m³	1326.14 kg	GLT - GL30c
GLT Beam 140x540	11	3.19 m³	42162.76	470.00 kg/m³	1497.26 kg	GLT - GL30c
		8.24 m³	144027.49		3871.78 kg	
Metal - Steel - S355						
HE280B	6	0.48 m³	37736.3	7850.00 kg/m³	3744.94 kg	Metal - Steel - S355
HE300B	2	0.09 m³	6642	7850.00 kg/m³	744.66 kg	Metal - Steel - S355
IPE200	27	0.18 m³	65442.44	7850.00 kg/m³	1396.59 kg	Metal - Steel - S355
IPE330	4	0.16 m³	26895.35	7850.00 kg/m³	1258.89 kg	Metal - Steel - S355
IPE400	8	0.43 m³	53433.69	7850.00 kg/m³	3377.68 kg	Metal - Steel - S355
		1.34 m³	190149.77		10522.76 kg	
79		9.58 m³	334177.26		14394.54 kg	

Foundations							
Type	Count	Length	Volum	Density	Weight	Structural Material	Comments
Strip Footing WF1 -1700x400	7	36793	21.06 m³	2500.00 kg/m³	52645.60 kg	Concrete, C35/45	Option2: Low carbon
Strip Footing WF2-1600x400	3	64327	41.31 m³	2500.00 kg/m³	103283.20 kg	Concrete, C35/45	Option2: Low carbon
Strip Footing WF3 -1200 x 400	6	15000	5.99 m³	2500.00 kg/m³	14982.00 kg	Concrete, C35/45	Option2: Low carbon
Strip Footing WF4-1000x300	3	59643	16.99 m³	2500.00 kg/m³	42471.00 kg	Concrete, C35/45	Option2: Low carbon
		175763	85.35 m³		213381.80 kg		
F1 1000x1000x300	1	1000	0.3 m³	2500.00 kg/m³	750.00 kg	Concrete, C35/45	Option2: Low carbon
F1 1700x1700x400	4	6800	4.62 m³	2500.00 kg/m³	11560.00 kg	Concrete, C35/45	Option2: Low carbon
F2 1300x1300x350	2	2600	1.18 m³	2500.00 kg/m³	2957.50 kg	Concrete, C35/45	Option2: Low carbon
		10400	6.11 m³		15267.50 kg		
		186163	91.46 m³		228649.30 kg		

Walls							
Type	Count	Area	Volume	Density	Weight	Structural Material	Comments
Concrete, C35/45							
_200 mm shear walls	3	34.9 m²	6.98 m³	2500.00 kg/m³	17452.15 kg	Concrete, C35/45	Option2: Low carbon
IV - 220 mm Concrete	33	367.71 m²	80.88 m³	2500.00 kg/m³	202202.30 kg	Concrete, C35/45	Option2: Low carbon
IV - 250 mm Concrete	1	18.82 m²	4.71 m³	2500.00 kg/m³	11765.34 kg	Concrete, C35/45	Option2: Low carbon
IV - 350 mm Concrete	3	210.78 m²	73.77 m³	2500.00 kg/m³	184434.16 kg	Concrete, C35/45	Option2: Low carbon
Ring wall (Foundation wall) 200 mm	2	10.01 m²	2 m³	2500.00 kg/m³	5004.90 kg	Concrete, C35/45	Option2: Low carbon
YV - 250 mm Concrete	1	163.28 m²	40.82 m³	2500.00 kg/m³	102048.19 kg	Concrete, C35/45	Option2: Low carbon
		805.51 m²	209.16 m³		522907.04 kg		
XPS							
50 mm XPS wall insulation	6	295.73 m²	14.79 m³	30.00 kg/m³	443.60 kg	XPS	
		295.73 m²	14.79 m³		443.60 kg		
		1101.24 m²	223.95 m³		523350.63 kg		

Floors							
Type	Family	Count	Areal	Volum	Density	weight	Structural Material
20.00 kg/m³							
EPS t= 50mm	Floor	5	423.57 m²	21.18 m³	20.00 kg/m³	423.57 kg	EPS
Floor EPS t=300mm	Floor	1	479.82 m²	143.95 m³	20.00 kg/m³	2878.95 kg	EPS
Ground floor insulation 200 mm EPS	Floor	1	689.1 m²	137.82 m³	20.00 kg/m³	2756.39 kg	EPS
		7	1592.5 m²	302.95 m³		6058.91 kg	
30.00 kg/m³							
50 mm XPS insulation on the ground	Floor	1	66.89 m²	3.34 m³	30.00 kg/m³	100.33 kg	XPS
Floor insulation XPS t=80 mm	Floor	3	218.68 m²	17.49 m³	30.00 kg/m³	524.84 kg	XPS
		4	285.57 m²	20.84 m³		625.16 kg	
470.00 kg/m³							
CLT 280 Balcong	Floor	2	88.59 m²	24.81 m³	470.00 kg/m³	11658.97 kg	Heltre - C24(1)
CLT FLOOR 160	Floor	3	93.18 m²	14.91 m³	470.00 kg/m³	7007.10 kg	Heltre - C24(1)
CLT FLOOR 280	Floor	2	1136.27 m²	318.16 m³	470.00 kg/m³	149533.77 kg	Heltre - C24
		7	1318.05 m²	357.87 m³		168199.84 kg	
2500.00 kg/m³							
50 mm Precast concrete element	Floor	3	218.81 m²	10.94 m³	2500.00 kg/m³	27351.47 kg	Concrete, C25/30
80 mm concrete cast in place	Floor	5	424.05 m²	33.92 m³	2500.00 kg/m³	84809.64 kg	Concrete, C25/30
300 mm Foundation slab	Floor	1	9.7 m²	2.91 m³	2500.00 kg/m³	7274.70 kg	Concrete, C35/45
Concrete ground floor slab	Floor	1	689.1 m²	82.69 m³	2500.00 kg/m³	206729.48 kg	Concrete, C25/30
		10	1341.66 m²	130.47 m³		326165.28 kg	
		28	4537.77 m²	812.12 m³		501049.20 kg	

Columns						
Type	Antall	Length	Volume	Density	Weight	Structural Material
470.00 kg/m³						
GLT column 115x115	53	133167.49	1.76 m³	470.00 kg/m³	827.74 kg	GLT - GL30c
GLT column 140x225	4	28154.43	0.89 m³	470.00 kg/m³	416.83 kg	GLT - GL30c
		161321.91	2.65 m³		1244.56 kg	
2500.00 kg/m³						
300x300	6	3600	0.21 m³	2500.00 kg/m³	522.00 kg	Concrete, C35/45
		3600	0.21 m³		522.00 kg	
7850.00 kg/m³						
HE200A	3	8100	0.04 m³	7850.00 kg/m³	324.60 kg	Metal - Steel - S355
RHSS100x100x8	7	44883.09	0.13 m³	7850.00 kg/m³	1037.27 kg	Metal - Steel - S355
RHSS140x140x8	8	53924.77	0.23 m³	7850.00 kg/m³	1788.06 kg	Metal - Steel - S355
RHSS140x140x10	3	8100	0.04 m³	7850.00 kg/m³	330.64 kg	Metal - Steel - S355
		115007.85	0.44 m³		3480.57 kg	
		279929.77	3.3 m³		5247.13 kg	

Roofs					
Type	Count	Area	Volume	Density	Weight
CLT floor 160					
CLT floor 160	1	11.36 m²	1.82 m³	470.00 kg/m³	854.62 kg
CLT floor 160	1	11.02 m²	1.76 m³	470.00 kg/m³	828.84 kg
CLT floor 160	1	15.04 m²	2.41 m³	470.00 kg/m³	1130.81 kg
CLT floor 160	1	11.36 m²	1.82 m³	470.00 kg/m³	854.62 kg
CLT floor 160	1	11.36 m²	1.82 m³	470.00 kg/m³	854.62 kg
		60.15 m²	9.62 m³		4523.51 kg
CLT floor 280					
CLT floor 280	1	218.23 m²	61.11 m³	470.00 kg/m³	28719.52 kg
CLT floor 280	1	217.5 m²	60.9 m³	470.00 kg/m³	28622.83 kg
CLT floor 280	1	173.82 m²	48.67 m³	470.00 kg/m³	22875.37 kg
CLT floor 280	1	12.36 m²	3.46 m³	470.00 kg/m³	1626.07 kg
		621.91 m²	174.14 m³		81843.79 kg
		682.07 m²	183.76 m³		86367.31 kg

Rev.	Revision description	Designed	Contr.	Date

Project owner
BRYGGEVEGEN 2 - HEISTAD

Scale

Dato: 2019-04-24
Designed: Author
Contr.: Checker

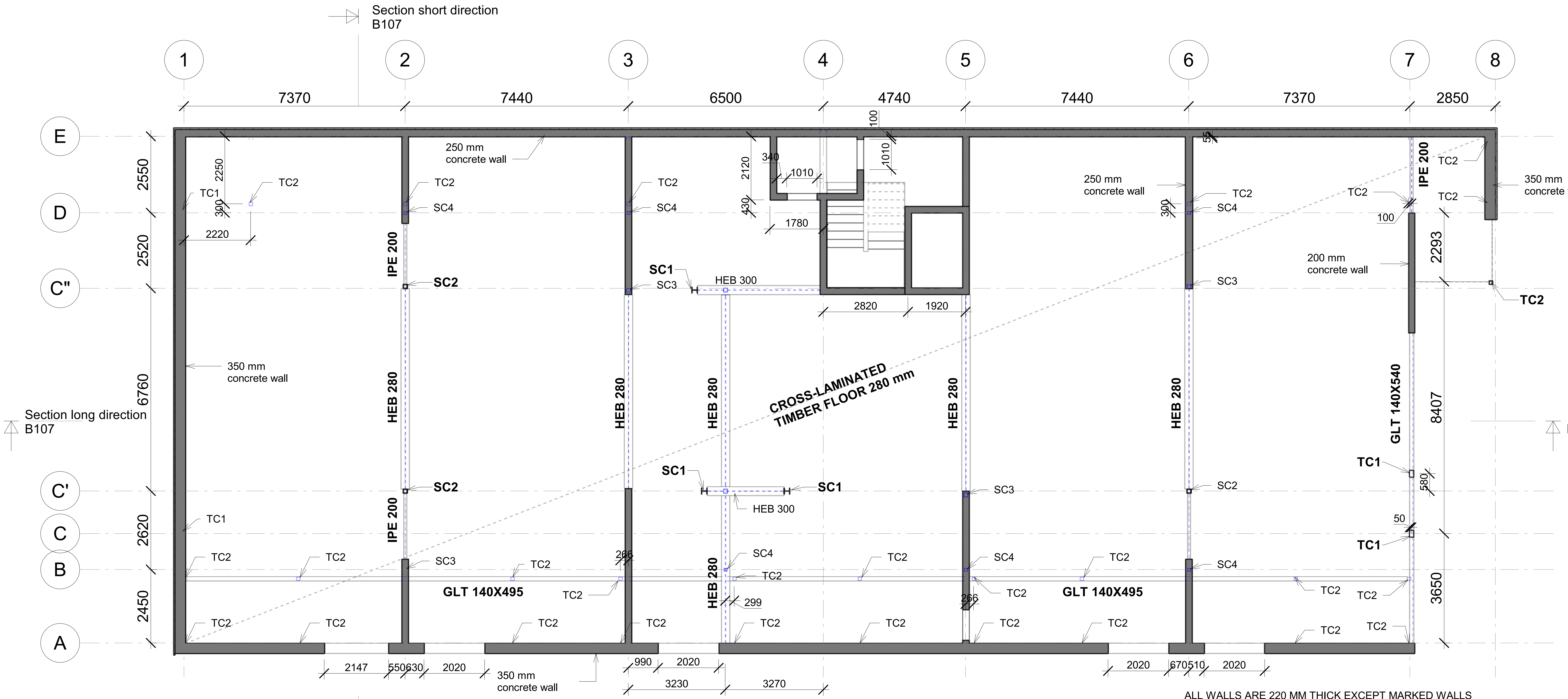
HUSTYPE A
Material Quntities

Size
Projekt nr.: Project nr.
Drawing nr.: B108
Rev.

Option1: Timber structural system including walls and foundations made of normal concrete

Autodesk Revit

08.05.2019 12.39.31



ALL WALLS ARE 220 MM THICK EXCEPT MARKED WALLS

Steel column:
SC1 HEA 200
SC2 Square hollow section 140x140x10
SC3 Square hollow section 140x140x8 (columns over plan 1)
SC4 Square hollow section 100x100x8 (columns over plan 1)

Timber column:
TC1 rectangular section 140x225
TC2 square section 115x115 (balcong column over plan 1)

DESIGN NOTES:

Concrete works:

Walls and Foundations
- Strength class B35, Low carbon Class A
- Durability class MF45
- EXposure class XC2

Ground floor slab:
- Strength class B35, Low carbon Class A
- Durability class M60
- EXposure class XC1

- Reiforcement cover:
  1. Cast against and permanently in conctact with the ground: 50mm +/- 10mm
  2. Exposed to weather or in contact with the ground: 25mm +/- 10mm
  3. Not exposed to weather or in conctact with the ground: 15 mm +/- 10mm
  4.

Steel works:
- Strength class S355
- Fire protection to all steel columns and Beams and will be applied to all exposed faces:
  20 mm conlit Conlit 150/150P
  Rockwool

Timber works:
- Strength class GL30c

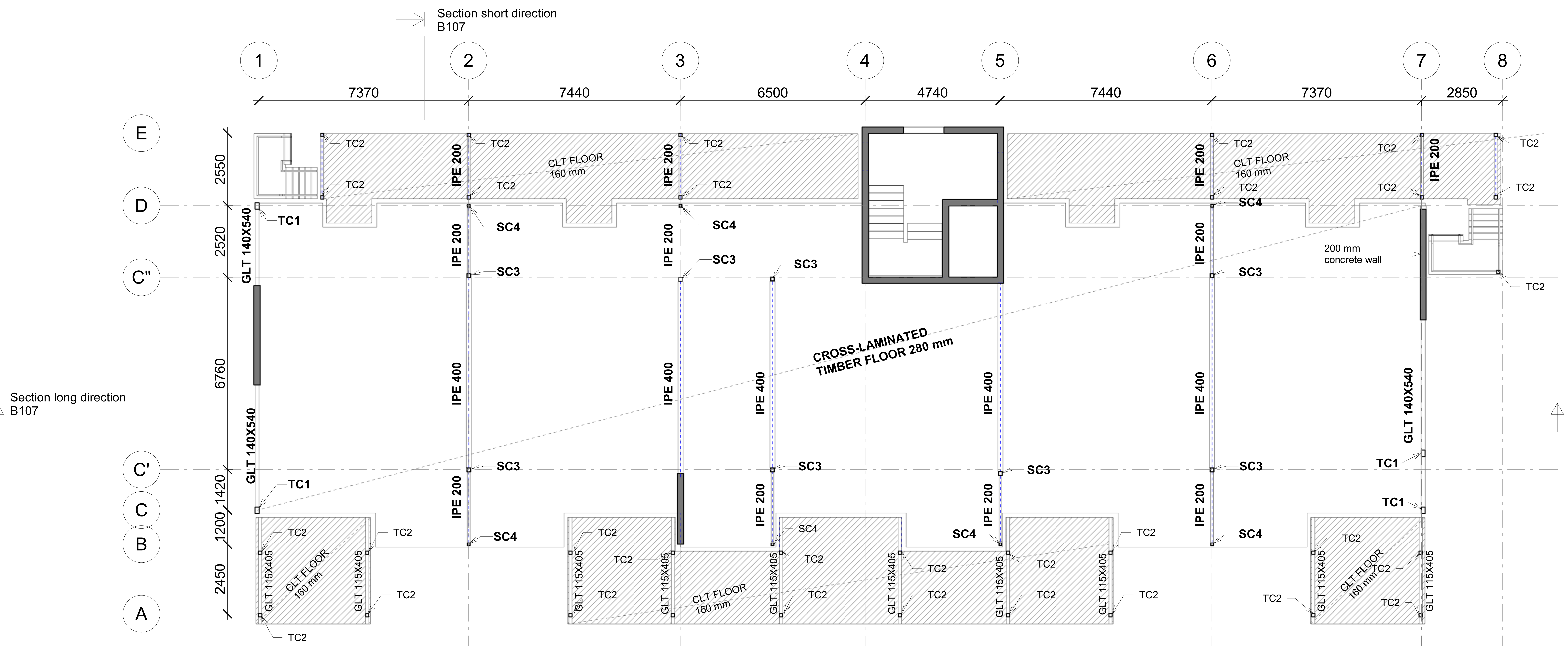
Cross-Laminated Timber (CLT):
- All layers have strength class C24.

Rev.	Revision description	Designed	Contr.	Date
Project owner BRYGGEVEGEN 2 - HEISTAD	Scale 1 : 100	Dato	2019-04-24	
		Designed	Author	
		Contr.	Checker	
HUSTYPE A Floor over Basement	Size A2	Projekt nr.	Project nr.	
	Drawing nr. B100		Rev.	

Option2: Timber structural system including walls and foundations made of low carbon concrete.

Autodesk Revit

08.05.2019 12.40.36



DESIGN NOTES:

Concrete works:

Walls and Foundations
- Strength class B35, Low carbon Class A
- Durability class MF45
- EXposure class XC2

Ground floor slab:
- Strength class B35, Low carbon Class A
- Durability class M60
- EXposure class XC1

- Reiforcement cover:
  1. Cast against and permanently in conctact with the ground: 50mm +/- 10mm
  2. Exposed to weather or in contact with the ground: 25mm +/- 10mm
  3. Not exposed to weather or in conctact with the ground: 15 mm +/- 10mm
  4.

Steel works:
- Strength class S355
- Fire protection to all steel columns and Beams and will be applied to all exposed faces:
  20 mm conlit Conlit 150/150P
  Rockwool

Timber works:
- Strength class GL30c

Cross-Laminated Timber (CLT):
- All layers have strength class C24.

ALL WALLS ARE 220 MM THICK EXCEPT MARKED WALLS

Steel column:

SC2 Square hollow section 140x140x10
SC3 Square hollow section 140x140x8 (columns over plan 1)
SC4 Square hollow section 100x100x8 (columns over plan 1)

Timber column:

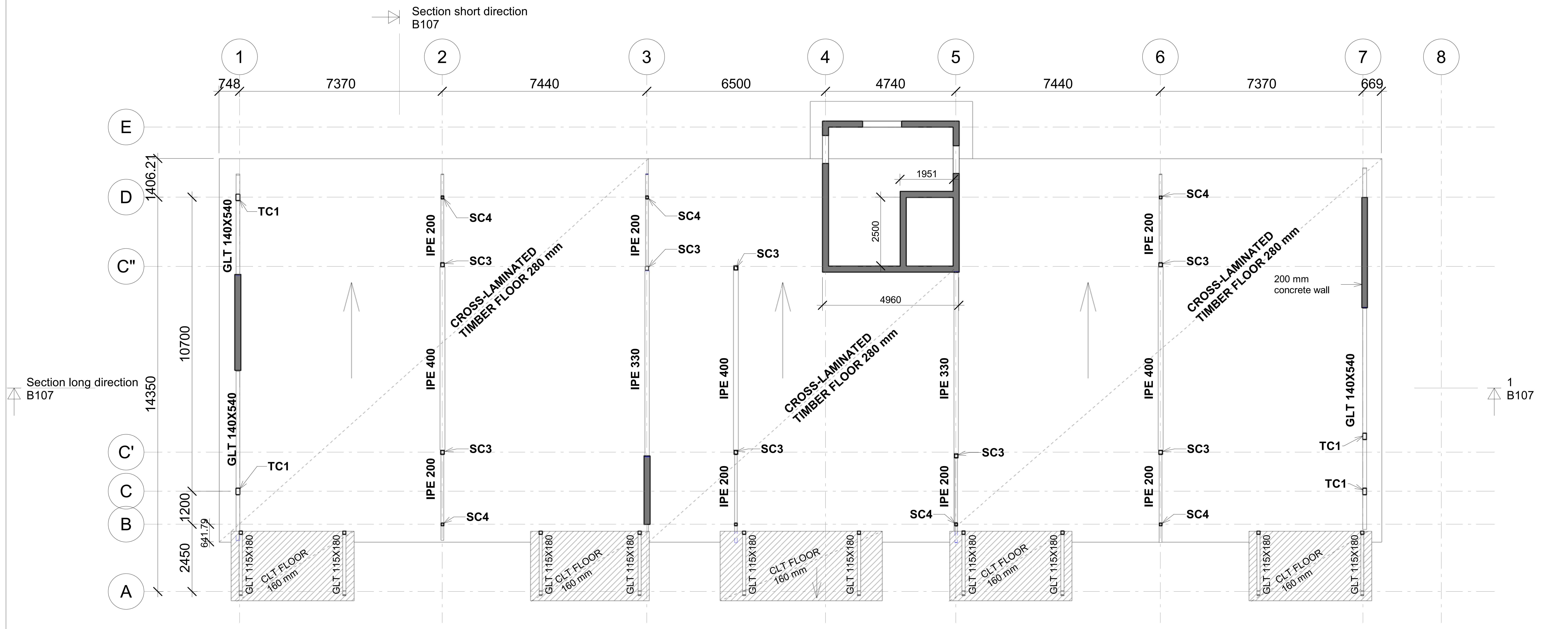
TC1 rectangular section 140x225
TC2 square section 115x115 (balcong column over plan 1)

Rev.	Revision description	Designed	Contr.	Date
Project owner BRYGGEVEGEN 2 - HEISTAD	Scale 1 : 100	Dato	2019-04-24	
		Designed	Author	
		Contr.	Checker	
HUSTYPE A Floor over plan 1	Size	Projekt nr.	Project nr.	
	Drawing nr. B101		Rev.	

Option2: Timber structural system including walls and foundations made of low carbon concrete.

Autodesk Revit

08.05.2019 12.41.01



DESIGN NOTES:

Concrete works:

Walls and Foundations

- Strength class B35, Low carbon Class A
- Durability class MF45
- EXposure class XC2

Ground floor slab:

- Strength class B35, Low carbon Class A
- Durability class M60
- EXposure class XC1

- Reiforcement cover:
  1. Cast against and permanently in conctact with the ground: 50mm +/- 10mm
  2. Exposed to weather or in contact with the ground: 25mm +/- 10mm
  3. Not exposed to weather or in conctact with the ground: 15 mm +/- 10mm

Steel works:

- Strength class S355
- Fire protection to all steel columns and Beams and will be applied to all exposed faces:
  20 mm conlit Conlit 150/150P
  Rockwool

Timber works:

- Strength class GL30c

Cross-Laminated Timber (CLT):

- All layers have strength class C24.

ALL WALLS ARE 220 MM THICK EXCEPT MARKED WALLS

Steel column:

SC3 Square hollow section 140x140x8 (columns over plan 1)
SC4 Square hollow section 100x100x8 (columns over plan 1)

Timber column:

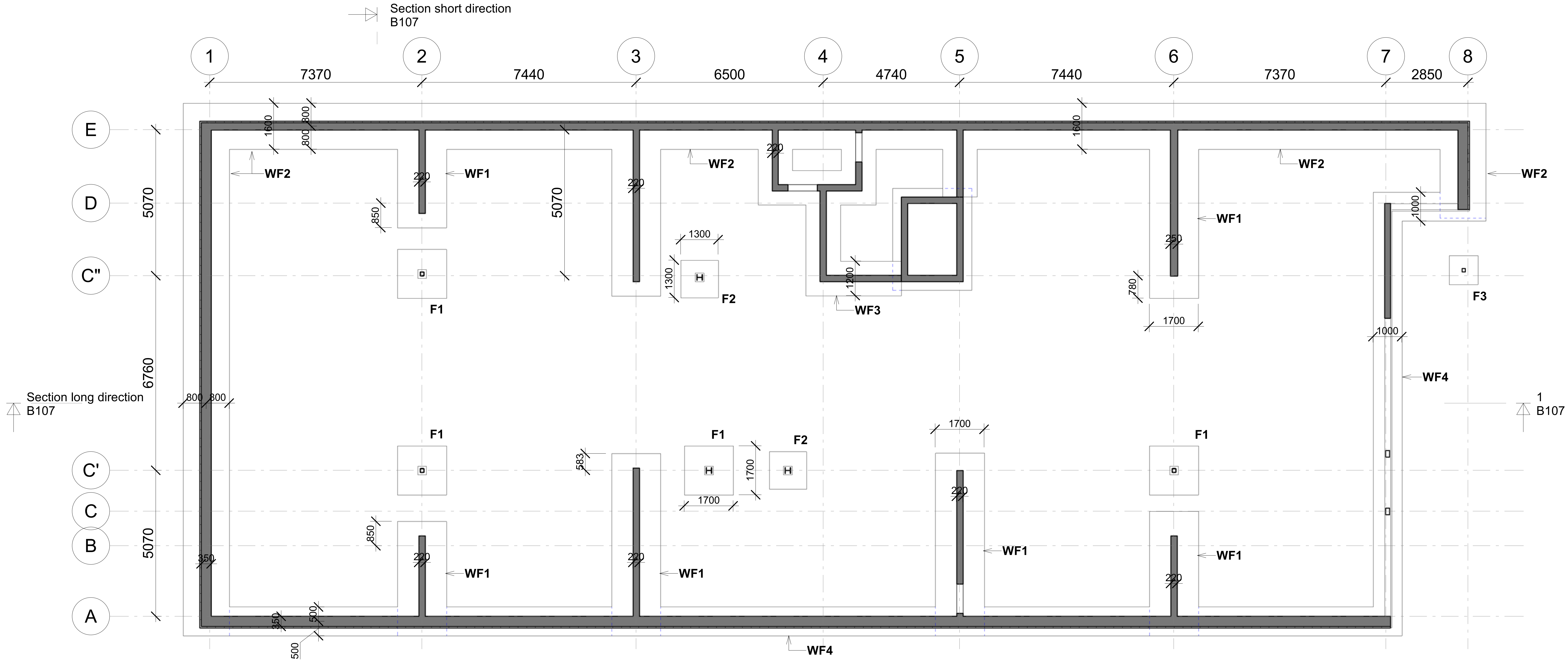
TC1 rectangular section 140x225
TC2 square section 115x115 (balcong column over plan 1)

Rev.	Revision description	Designed	Contr.	Date
Project owner BRYGGEVEGEN 2 - HEISTAD	Scale 1 : 100	Dato	2019-04-24	
		Designed	Author	
		Contr.	Checker	
HUSTYPE A Roof plan	Size A2	Projekt nr.	Project nr.	
	Drawing nr. B102	Rev.		

Option2: Timber structural system including walls and foundations made of low carbon concrete.

Autodesk Revit

08.05.2019 12.41.28



Foundation Types:
Isolated footings:
F1: 1700x1700x400
F2: 1300x1300x350
F3: 1000x100x300

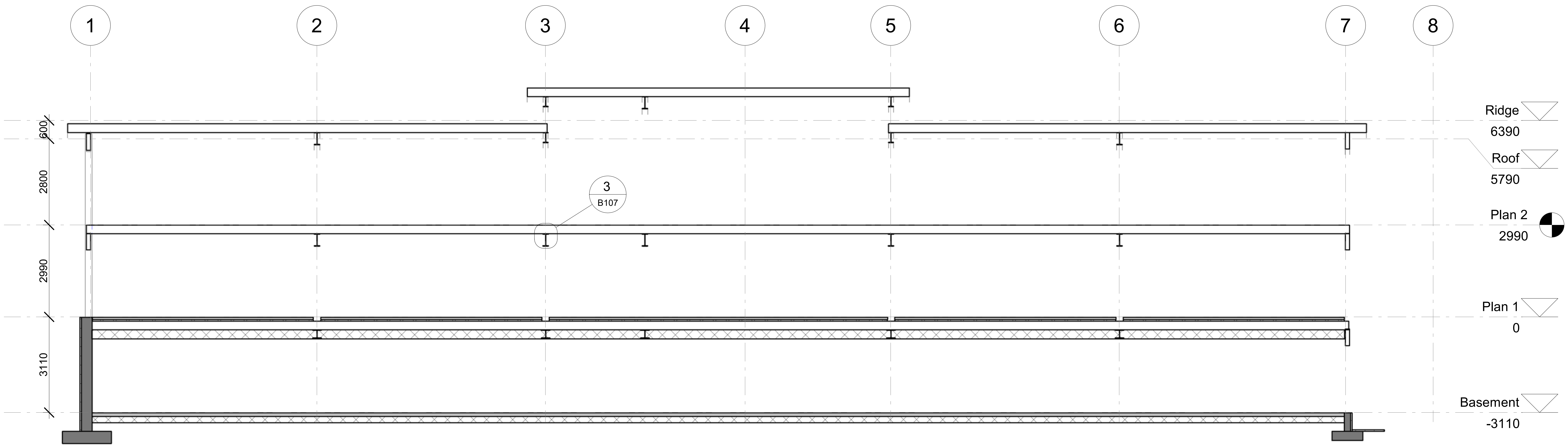
Strip footings:
WF1: 1700x400
WF2: 1600x400
WF3: 1200x350
WF4: 1000x300

Rev.	Revision description	Designed	Contr.	Date
Project owner BRYGGEVEGEN 2 - HEISTAD	Scale 1 : 100	Dato	2019-04-24	
		Designed	Author	
		Contr.	Checker	
Foundation plan	Size A2	Projekt nr.	Project nr.	
	Drawing nr. B105	Rev.		

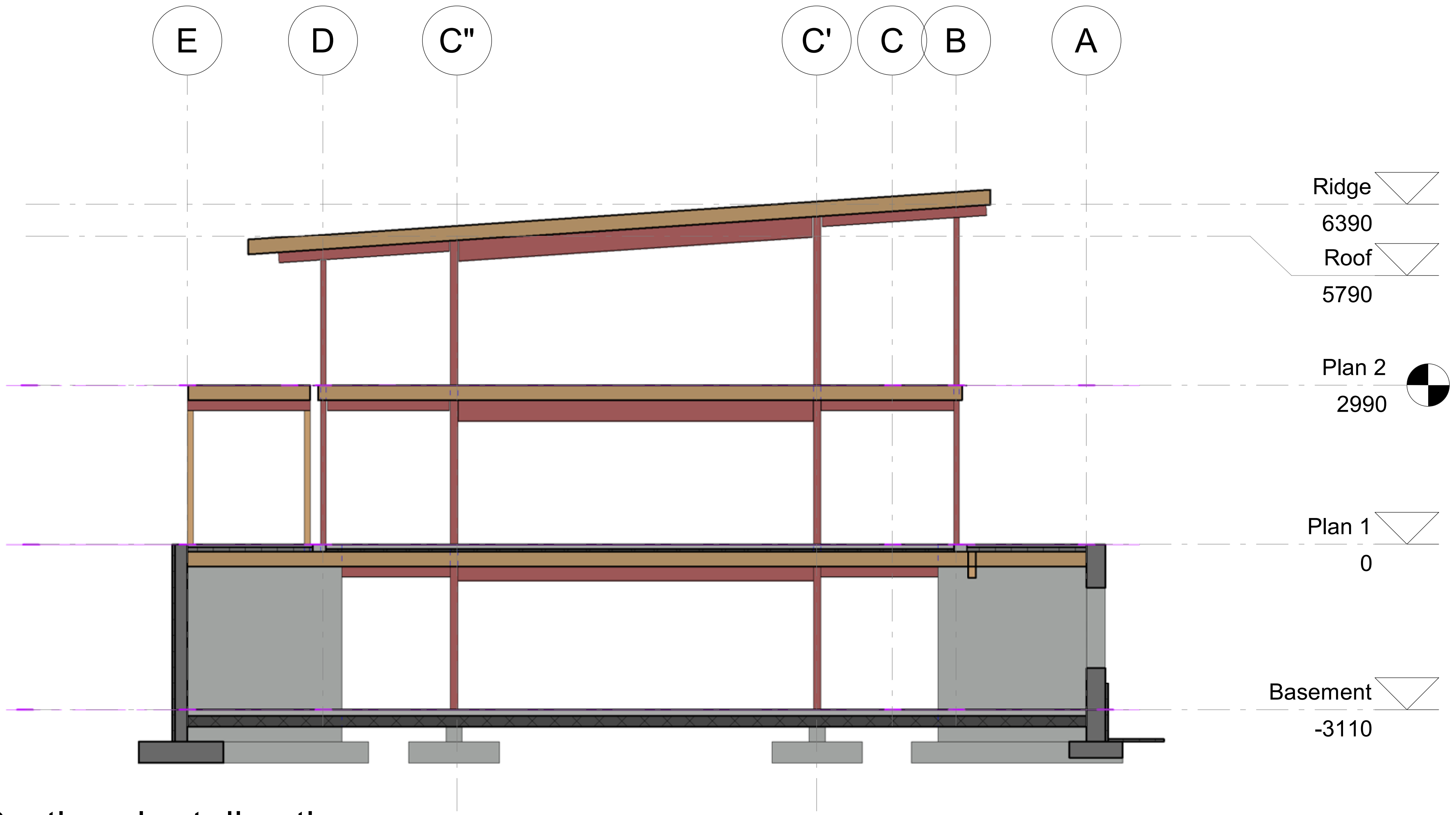
Option2: Timber structural system including walls and foundations made of low carbon concrete.

Autodesk Revit

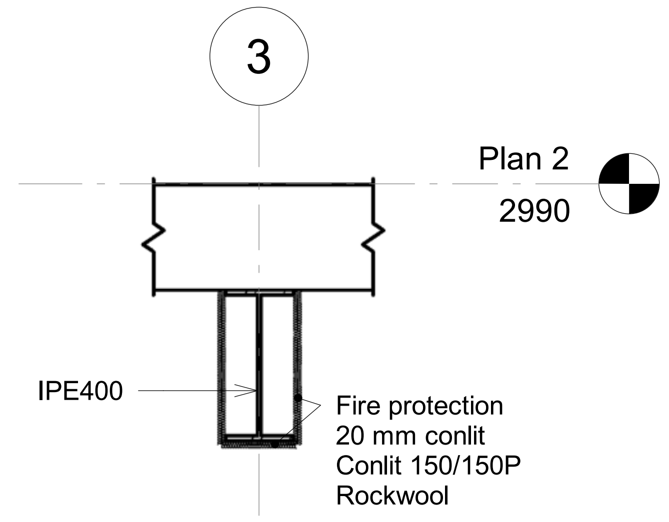
08.05.2019 12.42.14



Section long direction
1 : 100



Section short direction
1 : 100



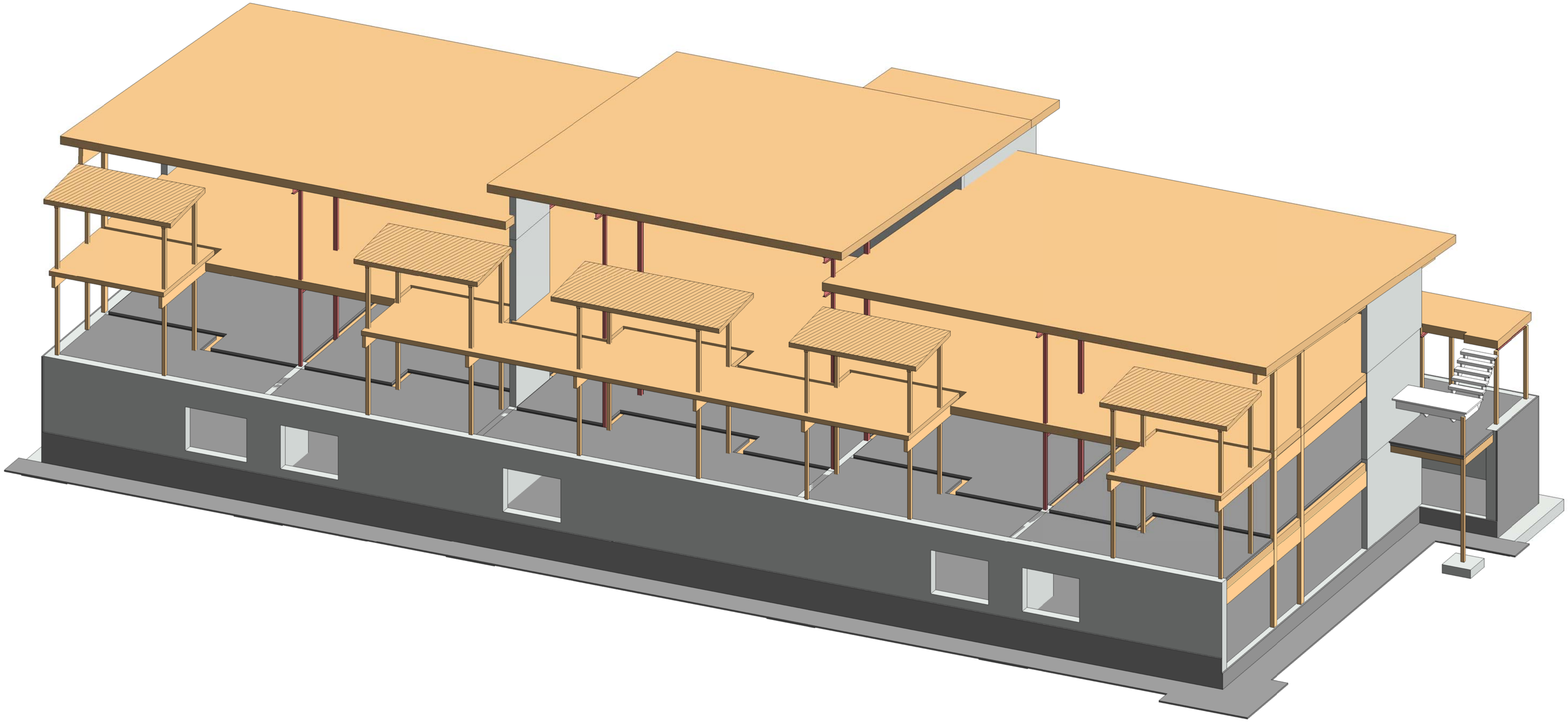
Fire Protection Detail
1 : 20

Rev.	Revision description	Designed	Contr.	Date
Project owner BRYGGEVEGEN 2 - HEISTAD	Scale As indicated	Dato 04/14/19 Designed Author Contr. Checker		
SECTIONS	Size A2 Drawing nr. B107	Projekt nr. Project nr.	Rev.	

Option2: Timber structural system including walls and foundations made of low carbon concrete.

Autodesk Revit

08.05.2019 12.42.35



Rev.	Revision description	Designed	Contr.	Date

Project owner BRYGGEVEGEN 2 - HEISTAD	Scale	Dato 2019-04-24 Designed Author Contr. Checker
HUSTPE A 3D View	Size A2 Drawing nr. B103	Projekt nr. Project nr. Rev.

Option2: Timber structural system including walls and foundations made of low carbon concrete.

Autodesk Revit

08.05.2019 12.41.55

Beams

Type	Count	Volume	Lengde	Denity	Weight	Structural Material
GLT - GL30c						
GLT Beam 115x180	10	0.48 m³	23659.22	470.00 kg/m³	227.71 kg	GLT - GL30c
GLT Beam 115x405	10	1.75 m³	37490	470.00 kg/m³	820.67 kg	GLT - GL30c
GLT Beam 140x495	1	2.82 m³	40715.5	470.00 kg/m³	1326.14 kg	GLT - GL30c
GLT Beam 140x540	11	3.19 m³	42162.76	470.00 kg/m³	1497.26 kg	GLT - GL30c
		8.24 m³	144027.49		3871.78 kg	
Metal - Steel - S355						
HE280B	6	0.48 m³	37736.3	7850.00 kg/m³	3744.94 kg	Metal - Steel - S355
HE300B	2	0.09 m³	6642	7850.00 kg/m³	744.66 kg	Metal - Steel - S355
IPE200	27	0.18 m³	65442.44	7850.00 kg/m³	1396.59 kg	Metal - Steel - S355
IPE330	4	0.16 m³	26895.35	7850.00 kg/m³	1258.89 kg	Metal - Steel - S355
IPE400	8	0.43 m³	53433.69	7850.00 kg/m³	3377.68 kg	Metal - Steel - S355
		1.34 m³	190149.77		10522.76 kg	
79		9.58 m³	334177.26		14394.54 kg	

Foundations

Type	Count	Length	Volum	Density	Weight	Structural Material	Comments
Strip Footing WF1 -1700x400	7	36793	21.06 m³	2500.00 kg/m³	52645.60 kg	Concrete, C35/45	Option2: Low carbon
Strip Footing WF2-1600x400	3	64327	41.31 m³	2500.00 kg/m³	103283.20 kg	Concrete, C35/45	Option2: Low carbon
Strip Footing WF3 -1200 x 400	6	15000	5.99 m³	2500.00 kg/m³	14982.00 kg	Concrete, C35/45	Option2: Low carbon
Strip Footing WF4-1000x300	3	59643	16.99 m³	2500.00 kg/m³	42471.00 kg	Concrete, C35/45	Option2: Low carbon
		175763	85.35 m³		213381.80 kg		
F1 1000x1000x300	1	1000	0.3 m³	2500.00 kg/m³	750.00 kg	Concrete, C35/45	Option2: Low carbon
F1 1700x1700x400	4	6800	4.62 m³	2500.00 kg/m³	11560.00 kg	Concrete, C35/45	Option2: Low carbon
F2 1300x1300x350	2	2600	1.18 m³	2500.00 kg/m³	2957.50 kg	Concrete, C35/45	Option2: Low carbon
		10400	6.11 m³		15267.50 kg		
		186163	91.46 m³		228649.30 kg		

Walls

Type	Count	Area	Volume	Density	Weight	Structural Material	Comments
Concrete, C35/45							
_200 mm shear walls	3	34.9 m²	6.98 m³	2500.00 kg/m³	17452.15 kg	Concrete, C35/45	Option2: Low carbon
IV - 220 mm Concrete	33	367.71 m²	80.88 m³	2500.00 kg/m³	202202.30 kg	Concrete, C35/45	Option2: Low carbon
IV - 250 mm Concrete	1	18.82 m²	4.71 m³	2500.00 kg/m³	11765.34 kg	Concrete, C35/45	Option2: Low carbon
IV - 350 mm Concrete	3	210.78 m²	73.77 m³	2500.00 kg/m³	184434.16 kg	Concrete, C35/45	Option2: Low carbon
Ring wall (Foundation wall) 200 mm	2	10.01 m²	2 m³	2500.00 kg/m³	5004.90 kg	Concrete, C35/45	Option2: Low carbon
YV - 250 mm Concrete	1	163.28 m²	40.82 m³	2500.00 kg/m³	102048.19 kg	Concrete, C35/45	Option2: Low carbon
		805.51 m²	209.16 m³		522907.04 kg		
XPS							
50 mm XPS wall insulation	6	295.73 m²	14.79 m³	30.00 kg/m³	443.60 kg	XPS	
		295.73 m²	14.79 m³		443.60 kg		
		1101.24 m²	223.95 m³		523350.63 kg		

Floors

Type	Family	Count	Areal	Volum	Density	weight	Structural Material
20.00 kg/m³							
EPS t= 50mm	Floor	5	423.57 m²	21.18 m³	20.00 kg/m³	423.57 kg	EPS
Floor EPS t=300mm	Floor	1	479.82 m²	143.95 m³	20.00 kg/m³	2878.95 kg	EPS
Ground floor insulation 200 mm EPS	Floor	1	689.1 m²	137.82 m³	20.00 kg/m³	2756.39 kg	EPS
		7	1592.5 m²	302.95 m³		6058.91 kg	
30.00 kg/m³							
50 mm XPS insulation on the ground	Floor	1	66.89 m²	3.34 m³	30.00 kg/m³	100.33 kg	XPS
Floor insulation XPS t=80 mm	Floor	3	218.68 m²	17.49 m³	30.00 kg/m³	524.84 kg	XPS
		4	285.57 m²	20.84 m³		625.16 kg	
470.00 kg/m³							
CLT 280 Balcong	Floor	2	88.59 m²	24.81 m³	470.00 kg/m³	11658.97 kg	Heltre - C24(1)
CLT FLOOR 160	Floor	3	93.18 m²	14.91 m³	470.00 kg/m³	7007.10 kg	Heltre - C24(1)
CLT FLOOR 280	Floor	2	1136.27 m²	318.16 m³	470.00 kg/m³	149533.77 kg	Heltre - C24
		7	1318.05 m²	357.87 m³		168199.84 kg	
2500.00 kg/m³							
50 mm Precast concrete element	Floor	3	218.81 m²	10.94 m³	2500.00 kg/m³	27351.47 kg	Concrete, C25/30
80 mm concrete cast in place	Floor	5	424.05 m²	33.92 m³	2500.00 kg/m³	84809.64 kg	Concrete, C25/30
300 mm Foundation slab	Floor	1	9.7 m²	2.91 m³	2500.00 kg/m³	7274.70 kg	Concrete, C35/45
Concrete ground floor slab	Floor	1	689.1 m²	82.69 m³	2500.00 kg/m³	206729.48 kg	Concrete, C25/30
		10	1341.66 m²	130.47 m³		326165.28 kg	
		28	4537.77 m²	812.12 m³		501049.20 kg	

Columns

Type	Antall	Length	Volume	Density	Weight	Structural Material
470.00 kg/m³						
GLT column 115x115	53	133167.49	1.76 m³	470.00 kg/m³	827.74 kg	GLT - GL30c
GLT column 140x225	4	28154.43	0.89 m³	470.00 kg/m³	416.83 kg	GLT - GL30c
		161321.91	2.65 m³		1244.56 kg	
2500.00 kg/m³						
300x300	6	3600	0.21 m³	2500.00 kg/m³	522.00 kg	Concrete, C35/45
		3600	0.21 m³		522.00 kg	
7850.00 kg/m³						
HE200A	3	8100	0.04 m³	7850.00 kg/m³	324.60 kg	Metal - Steel - S355
RHSS100x100x8	7	44883.09	0.13 m³	7850.00 kg/m³	1037.27 kg	Metal - Steel - S355
RHSS140x140x8	8	53924.77	0.23 m³	7850.00 kg/m³	1788.06 kg	Metal - Steel - S355
RHSS140x140x10	3	8100	0.04 m³	7850.00 kg/m³	330.64 kg	Metal - Steel - S355
		115007.85	0.44 m³		3480.57 kg	
		279929.77	3.3 m³		5247.13 kg	

Roofs

Type	Count	Area	Volume	Density	Weight
CLT floor 160					
CLT floor 160	1	11.36 m²	1.82 m³	470.00 kg/m³	854.62 kg
CLT floor 160	1	11.02 m²	1.76 m³	470.00 kg/m³	828.84 kg
CLT floor 160	1	15.04 m²	2.41 m³	470.00 kg/m³	1130.81 kg
CLT floor 160	1	11.36 m²	1.82 m³	470.00 kg/m³	854.62 kg
CLT floor 160	1	11.36 m²	1.82 m³	470.00 kg/m³	854.62 kg
		60.15 m²	9.62 m³		4523.51 kg
CLT floor 280					
CLT floor 280	1	218.23 m²	61.11 m³	470.00 kg/m³	28719.52 kg
CLT floor 280	1	217.5 m²	60.9 m³	470.00 kg/m³	28622.83 kg
CLT floor 280	1	173.82 m²	48.67 m³	470.00 kg/m³	22875.37 kg
CLT floor 280	1	12.36 m²	3.46 m³	470.00 kg/m³	1626.07 kg
		621.91 m²	174.14 m³		81843.79 kg
		682.07 m²	183.76 m³		86367.31 kg

Rev.	Revision description	Designed	Contr.	Date

Project owner
BRYGGEVEGEN 2 - HEISTAD

Scale

Dato: 2019-04-24
Designed: Author
Contr.: Checker

Size

Projekt nr.: Project nr.

HUSTYPE A
Material Quntities

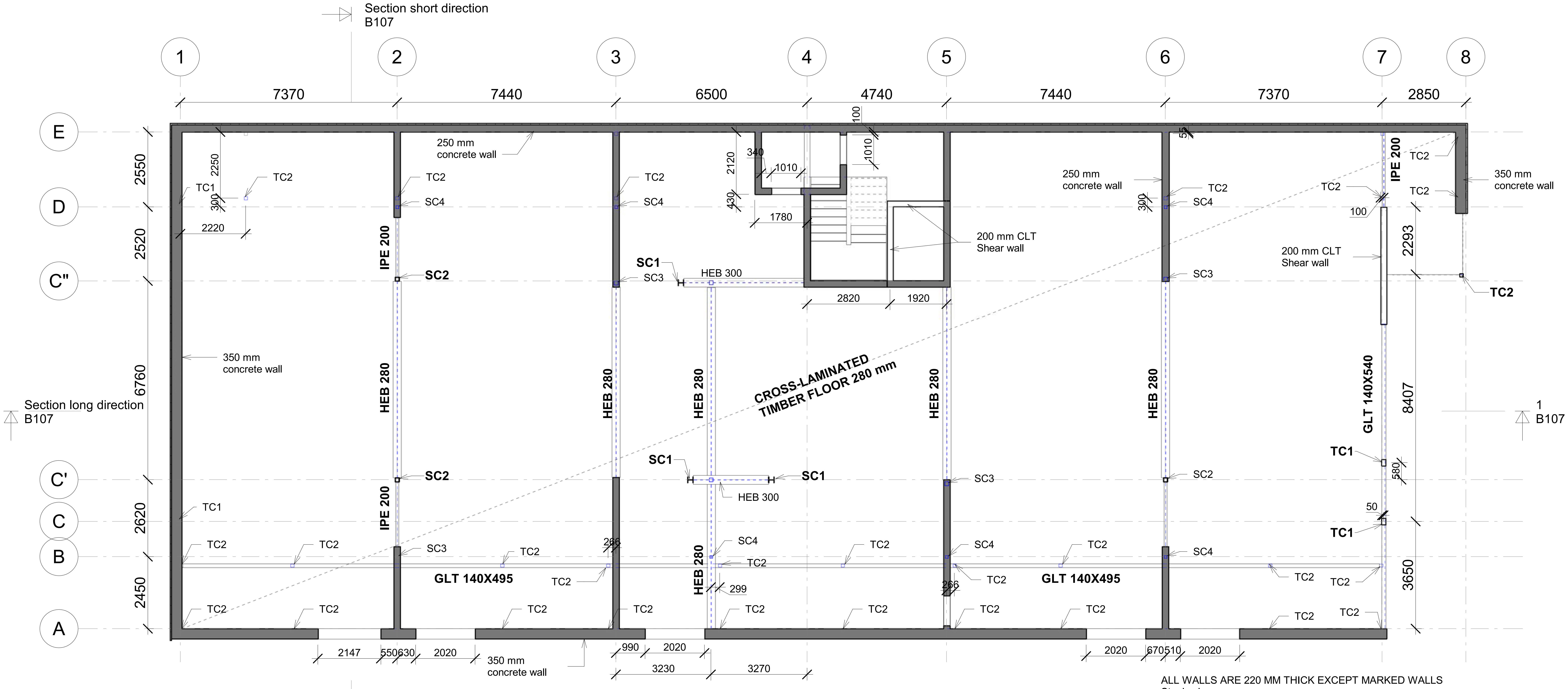
Drawing nr.: B108

Rev.

Option2: Timber structural system including walls and foundations made of low carbon concrete.

Autodesk Revit

08.05.2019 12.42.54



DESIGN NOTES:

Concrete works:

Walls and Foundations

- Strength class B35, Low carbon Class A
- Durability class MF45
- EXposure class XC2

Ground floor slab:

- Strength class B35, Low carbon Class A
- Durability class M60
- EXposure class XC1

- Reinforcement cover:
  1. Cast against and permanently in conctact with the ground: 50mm +/- 10mm
  2. Exposed to weather or in contact with the ground: 25mm +/- 10mm
  3. Not exposed to weather or in conctact with the ground: 15 mm +/- 10mm
  4.

Steel works:

- Strength class S355
- Fire protection to all steel columns and Beams and will be applied to all exposed faces:
  20 mm conlit Conlit 150/150P
  Rockwool

Timber works:

- Strength class GL30c

Cross-Laminated Timber (CLT):

- All layers have strength class C24.

ALL WALLS ARE 220 MM THICK EXCEPT MARKED WALLS

Steel column:

SC1 HEA 200
SC2 Square hollow section 140x140x10
SC3 Square hollow section 140x140x8 (columns over plan 1)
SC4 Square hollow section 100x100x8 (columns over plan 1)

Timber column:

TC1 rectangular section 140x225
TC2 square section 115x115 (balcong column over plan 1)

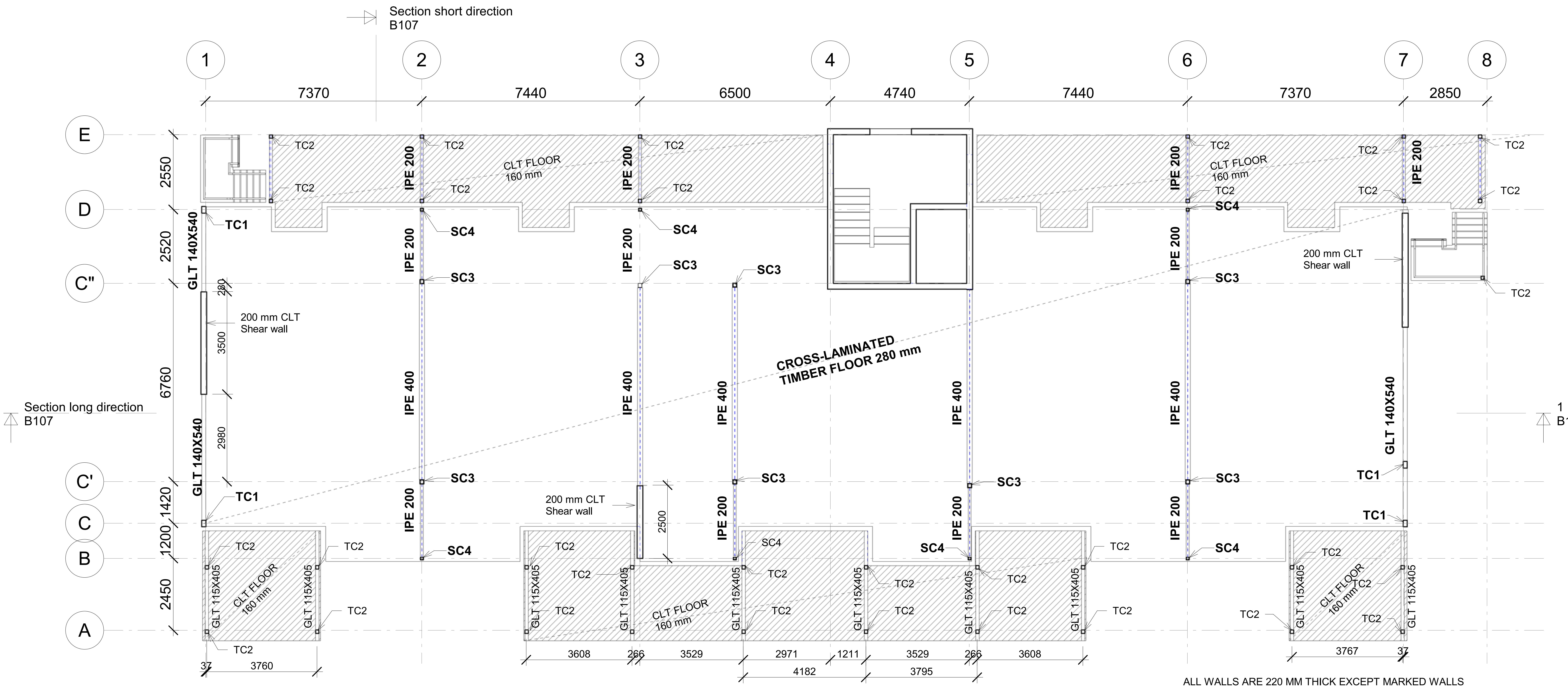
Rev.	Revision description	Designed	Contr.	Date

Project owner BRYGGEVEGEN 2 - HEISTAD	Scale 1 : 100	Dato	2019-04-24
		Designed	Author
		Contr.	Checker
HUSTYPE A Floor over Basement	Size A2	Projekt nr.	Project nr.
	Drawing nr. B100	Rev.	

Option3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.

Autodesk Revit

08.05.2019 12.48.21



ALL WALLS ARE 220 MM THICK EXCEPT MARKED WALLS

Steel column:
SC2 Square hollow section 140x140x10
SC3 Square hollow section 140x140x8 (columns over plan 1)
SC4 Square hollow section 100x100x8 (columns over plan 1)

Timber column:
TC1 rectangular section 140x225
TC2 square section 115x115 (balcong column over plan 1)

DESIGN NOTES:

Concrete works:
Walls and Foundations
- Strength class B35, Low carbon Class A
- Durability class MF45
- EXposure class XC2

Ground floor slab:
- Strength class B35, Low carbon Class A
- Durability class M60
- EXposure class XC1

- Reiforcement cover:
  1. Cast against and permanently in conctact with the ground: 50mm +/- 10mm
  2. Exposed to weather or in contact with the ground: 25mm +/- 10mm
  3. Not exposed to weather or in conctact with the ground: 15 mm +/- 10mm

Steel works:
- Strength class S355
- Fire protection to all steel columns and Beams and will be applied to all exposed faces:
  20 mm conlit Conlit 150/150P
  Rockwool

Timber works:
- Strength class GL30c

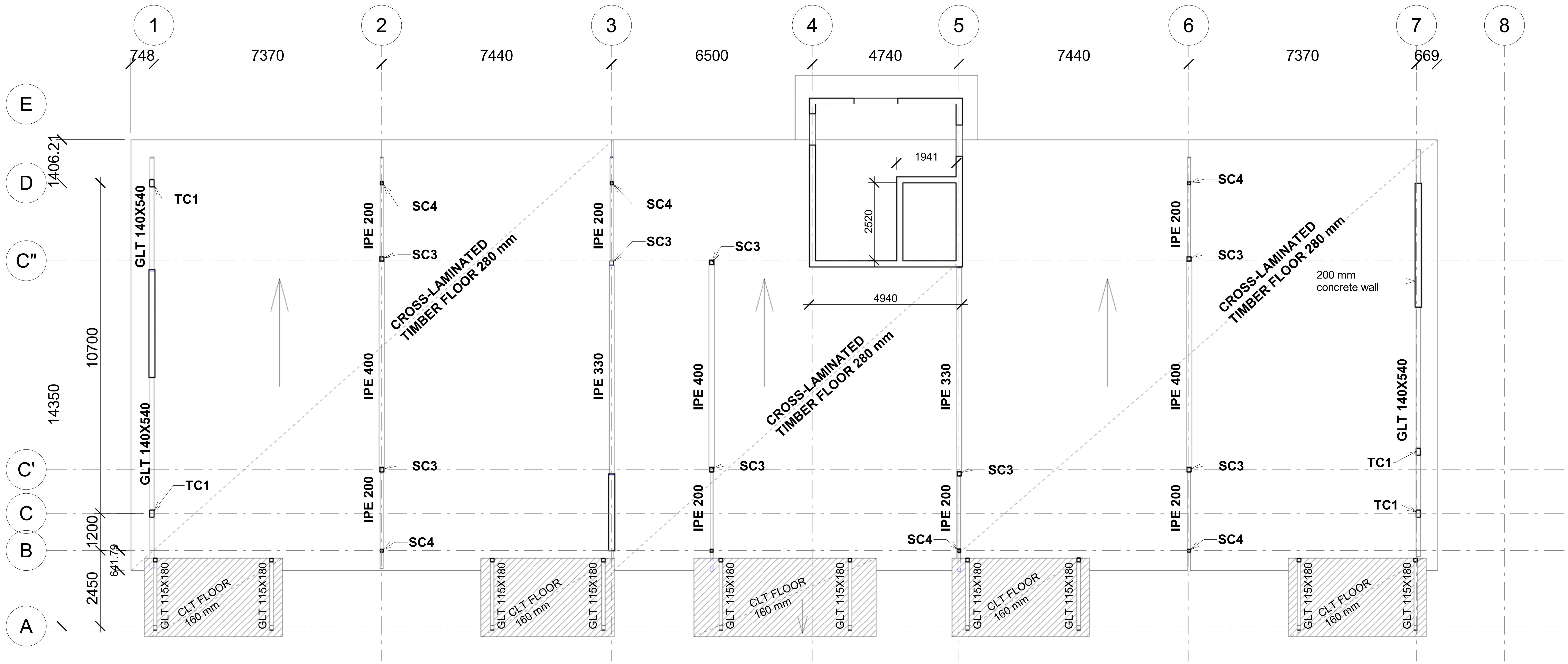
Cross-Laminated Timber (CLT):
- All layers have strength class C24.

Rev.	Revision description	Designed	Contr.	Date
Project owner BRYGGEVEGEN 2 - HEISTAD	Scale 1 : 100	Dato	2019-04-24	
		Designed	Author	
		Contr.	Checker	
HUSTYPE A Floor over plan 1	Size	Projekt nr.	Project nr.	
	Drawing nr. B101	Rev.		

Option3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.

Autodesk Revit

08.05.2019 12.48.43



DESIGN NOTES:

Concrete works:

Walls and Foundations

- Strength class B35, Low carbon Class A
- Durability class MF45
- EXposure class XC2

Ground floor slab:

- Strength class B35, Low carbon Class A
- Durability class M60
- EXposure class XC1

- Reinforcement cover:
  1. Cast against and permanently in conctact with the ground: 50mm +/- 10mm
  2. Exposed to weather or in contact with the ground: 25mm +/- 10mm
  3. Not exposed to weather or in conctact with the ground: 15 mm +/- 10mm

Steel works:

- Strength class S355
- Fire protection to all steel columns and Beams and will be applied to all exposed faces:
  20 mm conlit Conlit 150/150P
  Rockwool

Timber works:

- Strength class GL30c

Cross-Laminated Timber (CLT):

- All layers have strength class C24.

ALL WALLS ARE 220 MM THICK EXCEPT MARKED WALLS

Steel column:

SC3 Square hollow section 140x140x8 (columns over plan 1)
SC4 Square hollow section 100x100x8 (columns over plan 1)

Timber column:

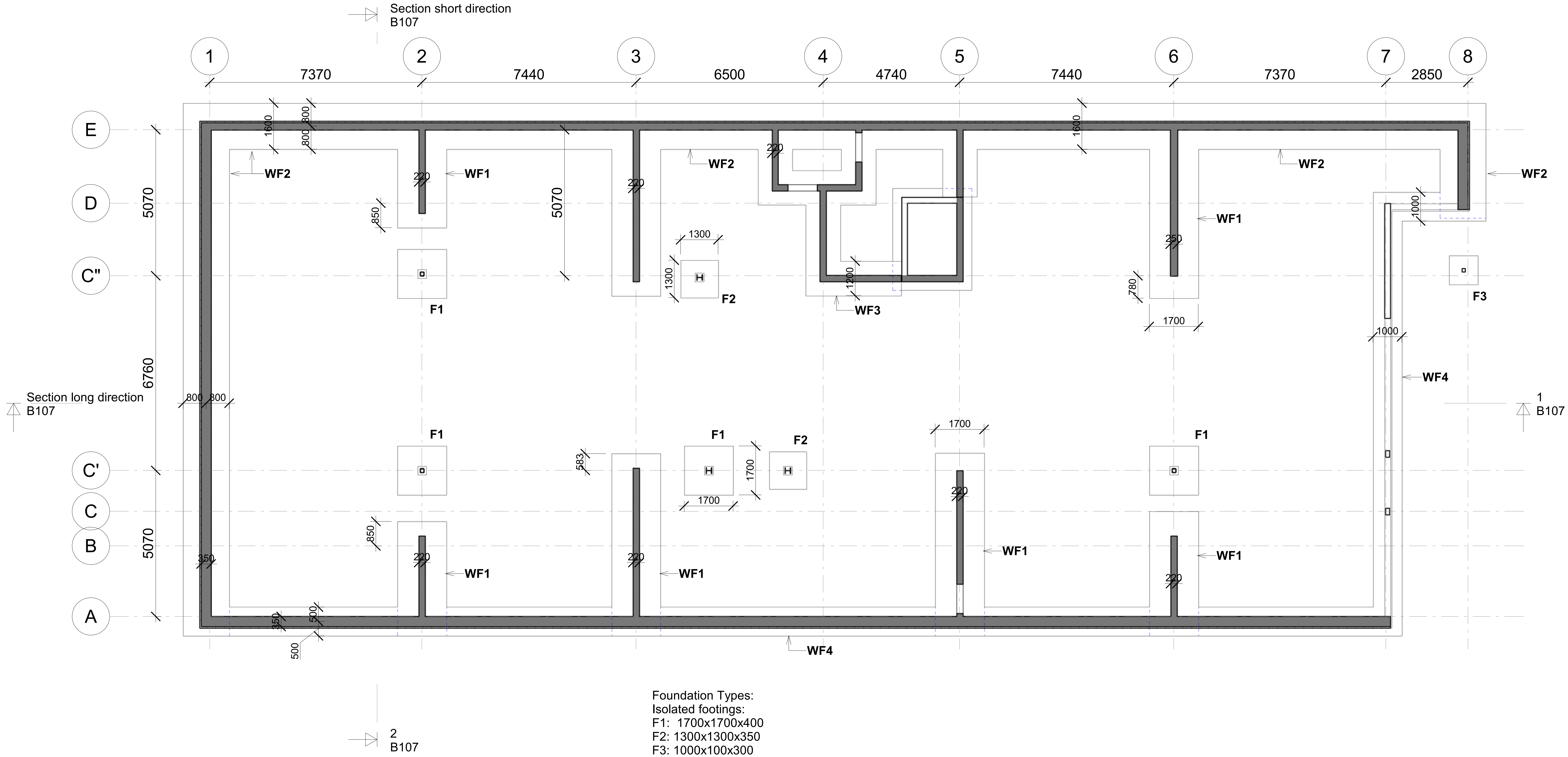
TC1 rectangular section 140x225
TC2 square section 115x115 (balcong column over plan 1)

Rev.	Revision description	Designed	Contr.	Date
Project owner BRYGGEVEGEN 2 - HEISTAD	Scale 1 : 100	Dato	2019-04-24	
		Designed	Author	
		Contr.	Checker	
HUSTYPE A Roof plan	Size A2	Projekt nr.	Project nr.	
	Drawing nr. B102	Rev.		

Option3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.

Autodesk Revit

08.05.2019 12.49.06



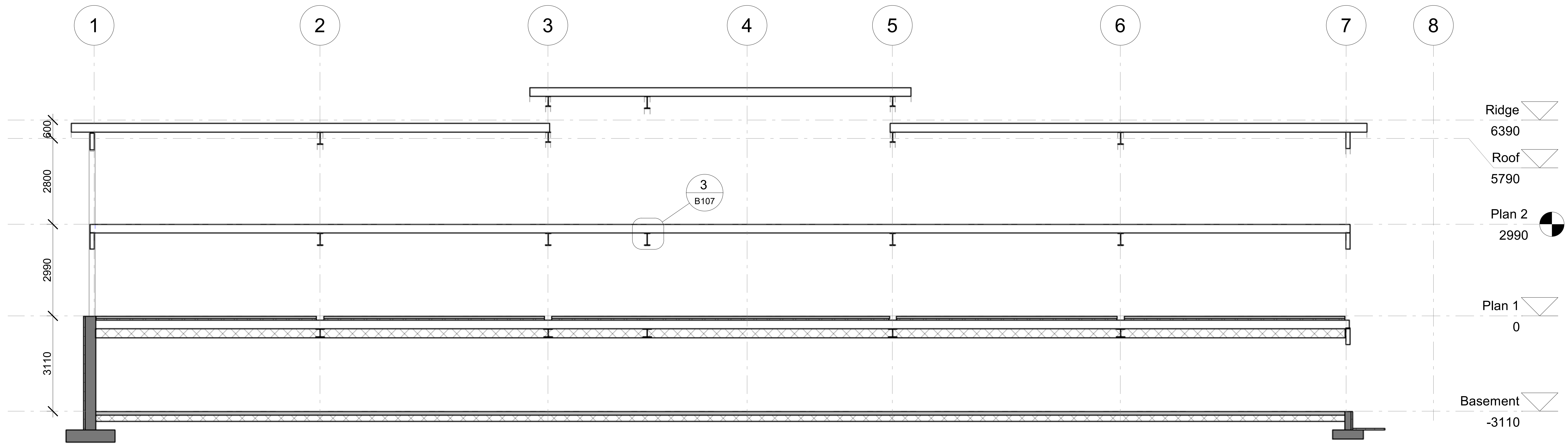
Foundation Types:
Isolated footings:
F1: 1700x1700x400
F2: 1300x1300x350
F3: 1000x100x300

Strip footings:
WF1: 1700x400
WF2: 1600x400
WF3: 1200x350
WF4: 1000x300

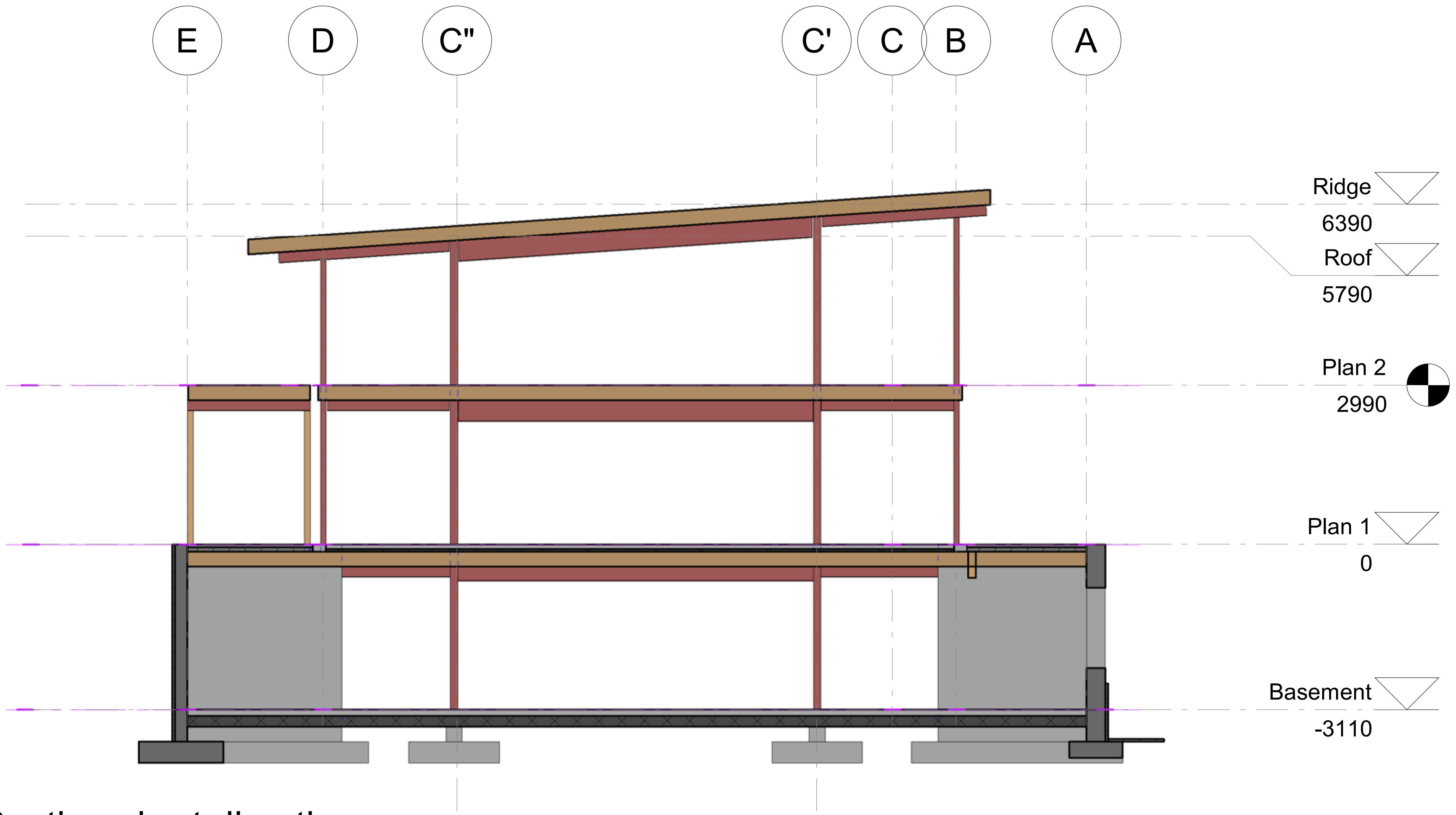
Rev.	Revision description		Designed	Contr.	Date
Project owner BRYGGEVEGEN 2 - HEISTAD		Scale 1 : 100	Dato	2019-04-24	
			Designed	Author	
			Contr.	Checker	
Foundation plan		Size A2	Projekt nr.	Project nr.	
		Drawing nr. B105		Rev.	
Option3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.					

Autodesk Revit

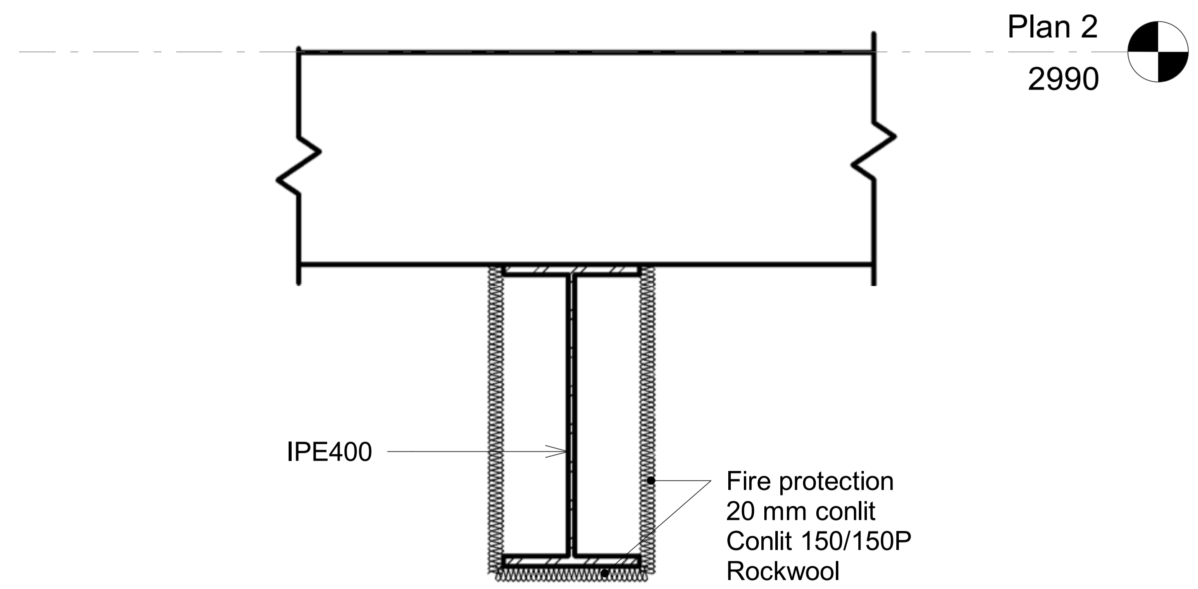
08.05.2019 12.49.48



Section long direction
1 : 100



Section short direction
1 : 100



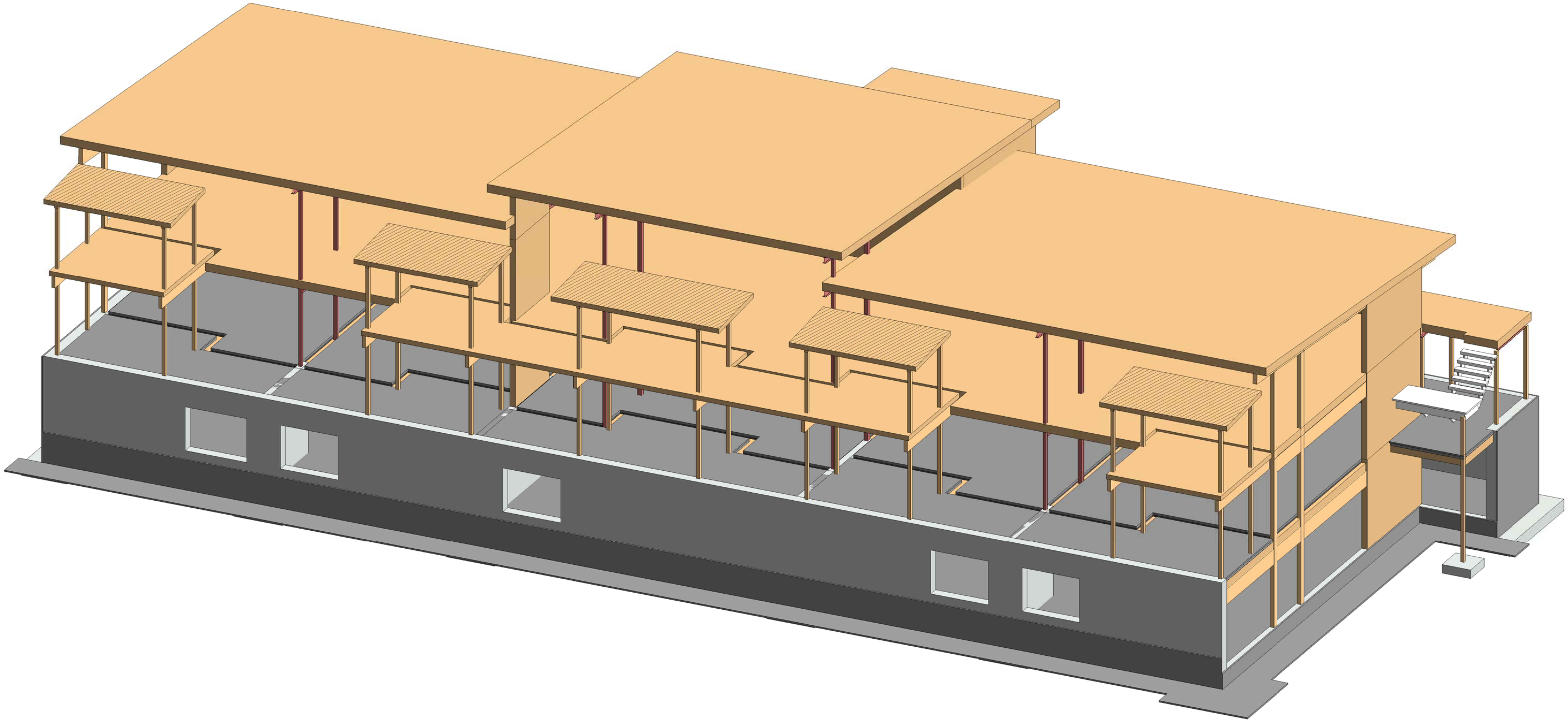
Fire Insulation Detail
1 : 10

Rev.	Revision description	Designed	Contr.	Date
Project owner BRYGGEVEGEN 2 - HEISTAD	Scale: As indicated	Dato	04/14/19	
		Designed	Author	
		Contr.	Checker	
SECTIONS	Size: A2	Projekt nr.	Project nr.	
	Drawing nr.: B107		Rev.	

Option3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.

Autodesk Revit

08.05.2019 12.50.09



Rev.	Revision description	Designed	Contr.	Date

Project owner BRYGGEVEGEN 2 - HEISTAD	Scale	Dato: 2019-04-24 Designed: Author Contr.: Checker
HUSTPE A 3D View	Size: A2	Projekt nr.: Project nr.
	Drawing nr.: B103	Rev.

Option3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.

Autodesk Revit

08.05.2019 12.49.27

Beams						
Type	Count	Volume	Length	Denity	Weight	Structural Material
GLT - GL30c						
GLT Beam 115x180	10	0.48 m³	23659.22	470.00 kg/m³	227.71 kg	GLT - GL30c
GLT Beam 115x405	10	1.75 m³	37490	470.00 kg/m³	820.67 kg	GLT - GL30c
GLT Beam 140x495	1	2.82 m³	40715.5	470.00 kg/m³	1326.14 kg	GLT - GL30c
GLT Beam 140x540	11	3.19 m³	42162.76	470.00 kg/m³	1497.26 kg	GLT - GL30c
		8.24 m³	144027.49		3871.78 kg	
Metal - Steel - S355						
HE280B	6	0.48 m³	37736.3	7850.00 kg/m³	3744.94 kg	Metal - Steel - S355
HE300B	2	0.09 m³	6642	7850.00 kg/m³	744.66 kg	Metal - Steel - S355
IPE200	27	0.18 m³	65442.44	7850.00 kg/m³	1396.59 kg	Metal - Steel - S355
IPE330	4	0.16 m³	26895.35	7850.00 kg/m³	1258.89 kg	Metal - Steel - S355
IPE400	8	0.43 m³	53433.69	7850.00 kg/m³	3377.68 kg	Metal - Steel - S355
		1.34 m³	190149.77		10522.76 kg	
79		9.58 m³	334177.26		14394.54 kg	

Foundations							
Type	Count	Length	Volum	Density	Weight	Structural Material	Comments
Strip Footing WF1 -1700x400	7	36793	21.06 m³	2500.00 kg/m³	52645.60 kg	Concrete, C35/45	Low carbon
Strip Footing WF2-1600x400	3	64327	41.31 m³	2500.00 kg/m³	103283.20 kg	Concrete, C35/45	Low carbon
Strip Footing WF3 -1200 x 400	6	15000	5.99 m³	2500.00 kg/m³	14982.00 kg	Concrete, C35/45	Low carbon
Strip Footing WF4-1000x300	3	59643	16.99 m³	2500.00 kg/m³	42471.00 kg	Concrete, C35/45	Low carbon
		175763	85.35 m³		213381.80 kg		
F1 1000x1000x300	1	1000	0.3 m³	2500.00 kg/m³	750.00 kg	Concrete, C35/45	Low carbon
F1 1700x1700x400	4	6800	4.62 m³	2500.00 kg/m³	11560.00 kg	Concrete, C35/45	Low carbon
F2 1300x1300x350	2	2600	1.18 m³	2500.00 kg/m³	2957.50 kg	Concrete, C35/45	Low carbon
		10400	6.11 m³		15267.50 kg		
		186163	91.46 m³		228649.30 kg		

Floors							
Type	Family	Count	Areal	Volum	Density	weight	Structural Material
20.00 kg/m³							
EPS t= 50mm	Floor	5	423.57 m²	21.18 m³	20.00 kg/m³	423.57 kg	EPS
Floor EPS t=300mm	Floor	1	479.83 m²	143.95 m³	20.00 kg/m³	2878.96 kg	EPS
Ground floor insulation 200 mm EPS	Floor	1	689.13 m²	137.83 m³	20.00 kg/m³	2756.51 kg	EPS
		7	1592.53 m²	302.95 m³		6059.05 kg	
30.00 kg/m³							
50 mm XPS insulation on the ground	Floor	1	66.89 m²	3.34 m³	30.00 kg/m³	100.33 kg	XPS
Floor insulation XPS t=80 mm	Floor	3	218.7 m²	17.5 m³	30.00 kg/m³	524.87 kg	XPS
		4	285.58 m²	20.84 m³		625.20 kg	
470.00 kg/m³							
CLT 280 Balcong	Floor	2	88.59 m²	24.81 m³	470.00 kg/m³	11658.97 kg	Heltre - C24(1)
CLT FLOOR 160	Floor	3	93.18 m²	14.91 m³	470.00 kg/m³	7007.10 kg	Heltre - C24(1)
CLT FLOOR 280	Floor	2	1136.31 m²	318.17 m³	470.00 kg/m³	149538.37 kg	Heltre - C24
		7	1318.08 m²	357.88 m³		168204.45 kg	
2500.00 kg/m³							
50 mm Precast concrete element	Floor	3	218.83 m²	10.94 m³	2500.00 kg/m³	27353.38 kg	Concrete, C25/30
80 mm concrete cast in place	Floor	5	424.14 m²	33.93 m³	2500.00 kg/m³	84827.90 kg	Concrete, C25/30
300 mm Foundation slab	Floor	1	9.7 m²	2.91 m³	2500.00 kg/m³	7274.70 kg	Concrete, C35/45
Concrete ground floor slab	Floor	1	689.13 m²	82.7 m³	2500.00 kg/m³	206738.30 kg	Concrete, C25/30
		10	1341.79 m²	130.48 m³		326194.28 kg	
		28	4537.99 m²	812.15 m³		501082.97 kg	

Columns						
Type	Antall	Lengde	Volume	Density	Weight	Structural Material
470.00 kg/m³						
GLT column 115x115	53	133167.49	1.76 m³	470.00 kg/m³	827.74 kg	GLT - GL30c
GLT column 140x225	4	28154.43	0.89 m³	470.00 kg/m³	416.83 kg	GLT - GL30c
		161321.91	2.65 m³		1244.56 kg	
2500.00 kg/m³						
300x300	6	3600	0.21 m³	2500.00 kg/m³	522.00 kg	Concrete, C35/45
		3600	0.21 m³		522.00 kg	
7850.00 kg/m³						
HE200A	3	8100	0.04 m³	7850.00 kg/m³	324.60 kg	Metal - Steel - S355
RHSS100x100x8	7	44883.09	0.13 m³	7850.00 kg/m³	1037.27 kg	Metal - Steel - S355
RHSS140x140x8	8	53924.77	0.23 m³	7850.00 kg/m³	1788.06 kg	Metal - Steel - S355
RHSS140x140x10	3	8100	0.04 m³	7850.00 kg/m³	330.64 kg	Metal - Steel - S355
		115007.85	0.44 m³		3480.57 kg	
		279929.77	3.3 m³		5247.13 kg	

Walls							
Type	Count	Area	Volume	Density	Weight	Structural Material	Comments
Concrete, C35/45							
IV - 220 mm Concrete	14	154.81 m²	34.06 m³	2500.00 kg/m³	85147.61 kg	Concrete, C35/45	low carbon
IV - 250 mm Concrete	1	18.82 m²	4.71 m³	2500.00 kg/m³	11765.34 kg	Concrete, C35/45	low carbon
IV - 350 mm Concrete	3	210.78 m²	73.77 m³	2500.00 kg/m³	184434.16 kg	Concrete, C35/45	low carbon
Ring wall (Foundation wall) 200 mm	2	10.01 m²	2 m³	2500.00 kg/m³	5004.90 kg	Concrete, C35/45	low carbon
YV - 250 mm Concrete	1	163.28 m²	40.82 m³	2500.00 kg/m³	102048.19 kg	Concrete, C35/45	low carbon
		557.71 m²	155.36 m³		388400.19 kg		
Heltre - C24							
200 mm CLT walls	22	247.86 m²	49.56 m³	470.00 kg/m³	23292.50 kg	Heltre - C24	Shear wall
		247.86 m²	49.56 m³		23292.50 kg		
XPS							
50 mm XPS wall insulation	6	295.73 m²	14.79 m³	30.00 kg/m³	443.60 kg	XPS	
		295.73 m²	14.79 m³		443.60 kg		
		1101.3 m²	219.71 m³		412136.29 kg		

Roofs					
Type	Count	Area	Volume	Density	Weight
CLT floor 160					
CLT floor 160	1	11.36 m²	1.82 m³	470.00 kg/m³	854.62 kg
CLT floor 160	1	11.02 m²	1.76 m³	470.00 kg/m³	828.84 kg
CLT floor 160	1	15.04 m²	2.41 m³	470.00 kg/m³	1130.81 kg
CLT floor 160	1	11.36 m²	1.82 m³	470.00 kg/m³	854.62 kg
CLT floor 160	1	11.36 m²	1.82 m³	470.00 kg/m³	854.62 kg
		60.15 m²	9.62 m³		4523.51 kg
CLT floor 280					
CLT floor 280	1	218.23 m²	61.11 m³	470.00 kg/m³	28719.52 kg
CLT floor 280	1	217.5 m²	60.9 m³	470.00 kg/m³	28622.83 kg
CLT floor 280	1	173.82 m²	48.67 m³	470.00 kg/m³	22875.37 kg
CLT floor 280	1	12.36 m²	3.46 m³	470.00 kg/m³	1626.07 kg
		621.91 m²	174.14 m³		81843.79 kg
		682.07 m²	183.76 m³		86367.31 kg

Rev.	Revision description	Designed	Contr.	Date
	Project owner BRYGGEVEGEN 2 - HEISTAD	Scale	Dato	2019-04-24
			Designed	Author
			Contr.	Checker
	HUSTYPE A Material Quntities	Size	Projekt nr.	Project nr.
		Drawing nr. B108		Rev.

Option3: Timber structural system including walls made of cross-laminated timber (CLT) and low-carbon concrete foundations.

Autodesk Revit

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APPENDIX I

4.5 Expressions for the resistance of a single dowel

Tables 4.1 – 4.7 express the resistance per fastener per shear plane. If for example two shear planes are present, the calculated value must be multiplied by 2. $\beta = f_{h,2,k}/f_{h,1,k}$. The presentation can also be found in Eurocode 5, Chapter 8.

Table 4.1 Single shear timber-to-timber joint.

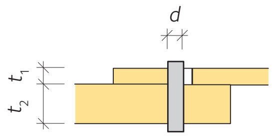
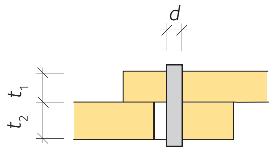
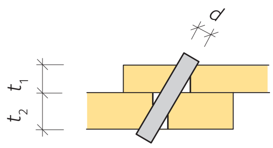
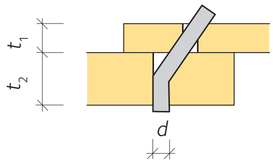
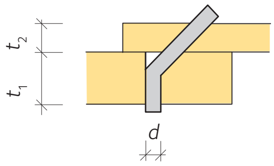
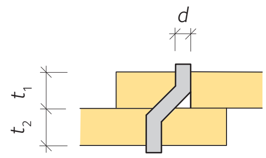
$F_{v,Rk} = f_{h,1,k} t_1 d$	
$F_{v,Rk} = f_{h,2,k} t_2 d$	
$F_{v,Rk} = \frac{f_{h,1,k} t_1 d}{1+\beta}\left(\sqrt{\beta + 2\beta^2\left(1+\frac{t_2}{t_1}+\left(\frac{t_2}{t_1}\right)^2\right)+\beta^3\left(\frac{t_2}{t_1}\right)^2} - \beta\left(1+\frac{t_2}{t_1}\right)\right) + \frac{F_{ax,Rk}}{4}$	
* $F_{v,Rk} = 1{,}05\frac{f_{h,1,k} t_1 d}{2+\beta}\left(\sqrt{2\beta(1+\beta)+\frac{4\beta(2+\beta)M_{y,Rk}}{f_{h,1,k} d t_1^2}} - \beta\right) + \frac{F_{ax,Rk}}{4}$	
* $F_{v,Rk} = 1{,}05\frac{f_{h,1,k} t_2 d}{1+2\beta}\left(\sqrt{2\beta^2(1+\beta)+\frac{4\beta(1+2\beta)M_{y,Rk}}{f_{h,1,k} d t_2^2}} - \beta\right) + \frac{F_{ax,Rk}}{4}$	
* $F_{v,Rk} = 1{,}15\sqrt{\frac{2\beta}{1+\beta}}\sqrt{2M_{y,Rk} f_{h,1,k} d} + \frac{F_{ax,Rk}}{4}$	

Table 4.2 Double shear timber-to-timber joints.

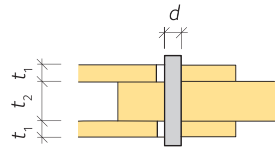
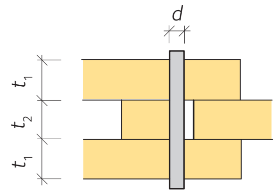
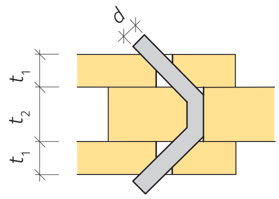
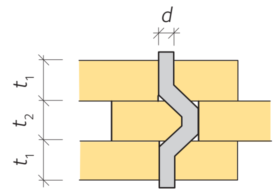
$F_{v,Rk} = f_{h,1,k} t_1 d$	
$F_{v,Rk} = 0{,}5 f_{h,2,k} t_2 d$	
* $F_{v,Rk} = 1{,}05 \frac{f_{h,1,k} t_1 d}{2+\beta}\left(\sqrt{2\beta(1+\beta)+\frac{4\beta(2+\beta)M_{y,Rk}}{f_{h,1,k} d t_1^2}}-\beta\right)+\frac{F_{ax,Rk}}{4}$	
* $F_{v,Rk} = 1{,}15\sqrt{\frac{2\beta}{1+\beta}}\sqrt{2M_{y,Rk} f_{h,1,k} d}+\frac{F_{ax,Rk}}{4}$	

Table 4.3 Single shear steel-to-timber joints, where $t_{steel} \geq d$ (thick steel plate).

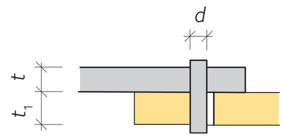
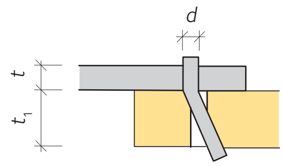
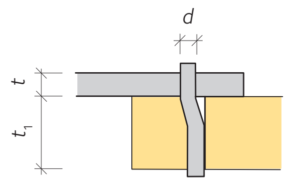
$F_{v,Rk} = f_{h,k} t_1 d$	
* $F_{v,Rk} = f_{h,k} t_1 d\left(\sqrt{2+\frac{4M_{y,Rk}}{f_{h,k} d t_1^2}}-1\right)+\frac{F_{ax,Rk}}{4}$	
* $F_{v,Rk} = 2{,}3\sqrt{M_{y,Rk} f_{h,k} d}+\frac{F_{ax,Rk}}{4}$	

Table 4.4 Single shear steel-to-timber joints, where $t_{steel} \leq 0{,}5d$ (thin steel plate).

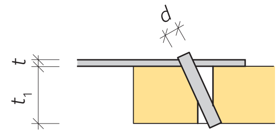
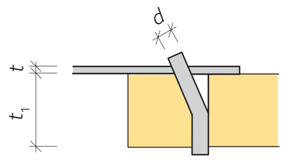
$F_{v,Rk} = 0{,}4\, f_{h,k} t_1 d$	
* $F_{v,Rk} = 1{,}15\sqrt{2M_{y,Rk}\, f_{h,k} d} + \frac{F_{ax,Rk}}{4}$	

Table 4.5 Slotted-in steel plates.

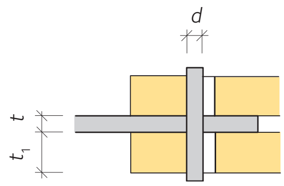
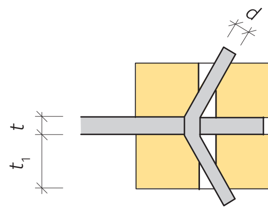
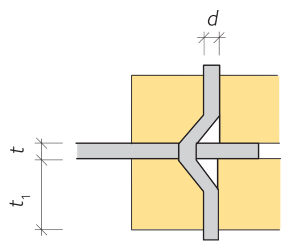
$F_{v,Rk} = f_{h,1,k} t_1 d$	
* $F_{v,Rk} = f_{h,1,k} t_1 d\left(\sqrt{2 + \frac{4M_{y,Rk}}{f_{h,1,k} d t_1^2}} - 1\right) + \frac{F_{ax,Rk}}{4}$	
* $F_{v,Rk} = 2{,}3\sqrt{M_{y,Rk}\, f_{h,1,k} d} + \frac{F_{ax,Rk}}{4}$	

Table 4.6 Double shear steel-to-timber joints where $t_{steel} \geq d$ (thick steel plates).

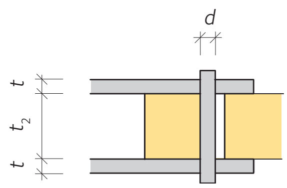
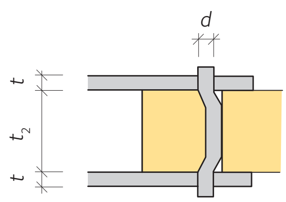
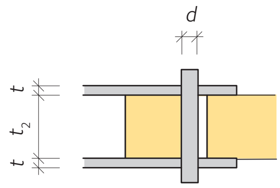
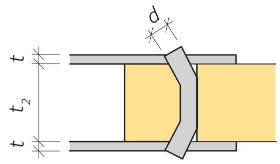
$F_{v,Rk} = 0{,}5\, f_{h,2,k} t_2 d$	
* $F_{v,Rk} = 2{,}3\sqrt{M_{y,Rk}\, f_{h,2,k} d} + \frac{F_{ax,Rk}}{4}$	

Table 4.7 Double shear steel-to-timber joints where $t_{steel} \leq 0{,}5d$ (thin steel plates).

$F_{v,Rk} = 0{,}5 f_{h,2,k} t_2 d$	
$* \quad F_{v,Rk} = 1{,}15\sqrt{2M_{y,Rk} f_{h,2,k} d} + \frac{F_{ax,Rk}}{4}$	

4.6 Tensile capacity of single dowels – rope effect

In all failure modes in shear where the dowel is bent (marked with * in Tables 4.1 – 4.7), some part of the load uptake also occurs in tension. Depending on the surface and end anchorage of the dowel, the part carried in tension can be larger or smaller. The surface of the dowel can have a higher anchorage resistance F_{ax} due to:

- twisted dowels
- annular rings
- threading (the dowel is then a screw or a bolt).

The anchorage of the dowel can be enhanced by:

- washers and nuts on the headside
- washers and nuts on the pointside.

The contribution of tension to the shear capacity of a single dowel can be substantial. Kuipers and Van Der Put (1982) showed that threading can increase the resistance of a joint by as much as 2,6 times the shear capacity calculated through Tables 4.1 – 4.7, omitting the second term in the right part of the formulas. The effect of tensile action can be determined either by empirical formulas or by testing. Since the empirical expressions are derived for a multitude of cases, testing is suggested if a particular joint is to be used repeatedly.

4.6.1 Eurocode 5 application

In Eurocode 5, the rope effect is taken into account by adding the term $F_{ax,Rk}/4$ to the expression for the shear capacity of a single dowel according to Section 4.4. The contribution from the rope effect is limited to given percentages of the shear capacity (Tables 4.1 – 4.7) as presented in Table 4.8.

Table 4.8 Maximum contribution from rope effect in relation to the shear capacity of a single dowel-type fastener.

Fastener type	Percentage
Round nails	15 %
Square and grooved nails	25 %
Other nails	50 %
Screws	100 %
Bolts	25 %
Dowels	0 %

Table 8.3 – Minimum spacings and edge and end distances for staples

Spacing and edge/end distances (see Figure 8.7)	Angle	Minimum spacing or edge/end distance
a_1 (parallel to grain) for $\theta \geq 30°$ for $\theta < 30°$	$0° \leq \alpha \leq 360°$	 $(10 + 5\|\cos\alpha\|)\,d$ $(15 + 5\|\cos\alpha\|)\,d$
a_2 (perpendicular to grain)	$0° \leq \alpha \leq 360°$	$15\,d$
$a_{3,t}$ (loaded end)	$-90° \leq \alpha \leq 90°$	$(15 + 5\|\cos\alpha\|)\,d$
$a_{3,c}$ (unloaded end)	$90° \leq \alpha \leq 270°$	$15\,d$
$a_{4,t}$ (loaded edge)	$0° \leq \alpha \leq 180°$	$(15 + 5\|\sin\alpha\|)\,d$
$a_{4,c}$ (unloaded edge)	$180° \leq \alpha \leq 360°$	$10\,d$

8.5 Bolted connections

8.5.1 Laterally loaded bolts

8.5.1.1 General and bolted timber-to-timber connections

(1) For bolts the following characteristic value for the yield moment should be used:

$$M_{y,Rk} = 0{,}3\, f_{u,k}\, d^{2{,}6} \qquad (8.30)$$

where:

$M_{y,Rk}$ is the characteristic value for the yield moment, in Nmm;

$f_{u,k}$ is the characteristic tensile strength, in N/mm²;

d is the bolt diameter, in mm.

(2) For bolts up to 30 mm diameter, the following characteristic embedment strength values in timber and LVL should be used, at an angle α to the grain:

$$f_{h,\alpha,k} = \frac{f_{h,0,k}}{k_{90}\sin^2\alpha + \cos^2\alpha} \qquad (8.31)$$

$$f_{h,0,k} = 0{,}082\,(1 - 0{,}01\,d)\,\rho_k \qquad (8.32)$$

where:

$$k_{90} = \begin{cases} 1{,}35 + 0{,}015\,d & \text{for softwoods} \\ 1{,}30 + 0{,}015\,d & \text{for LVL} \\ 0{,}90 + 0{,}015\,d & \text{for hardwoods} \end{cases} \qquad (8.33)$$

and:

$f_{h,0,k}$ is the characteristc embedment strength parallel to grain, in N/mm^2;

ρ_k is the characteristic timber density, in kg/m³;

α is the angle of the load to the grain;

d is the bolt diameter, in mm.

(3) Minimum spacings and edge and end distances should be taken from Table 8.4, with symbols illustrated in Figure 8.7.

Table 8.4 – Minimum values of spacing and edge and end distances for bolts

Spacing and end/edge distances (see Figure 8.7)	Angle	Minimum spacing or distance
a_1 (parallel to grain)	$0^\circ \leq \alpha \leq 360^\circ$	$(4 + \lvert\cos \alpha\rvert)\, d$
a_2 (perpendicular to grain)	$0^\circ \leq \alpha \leq 360^\circ$	$4\, d$
$a_{3,t}$ (loaded end)	$-90^\circ \leq \alpha \leq 90^\circ$	max (7 d; 80 mm)
$a_{3,c}$ (unloaded end)	$90^\circ \leq \alpha < 150^\circ$ $150^\circ \leq \alpha < 210^\circ$ $210^\circ \leq \alpha \leq 270^\circ$	[A1⟩ $(1 + 6 \sin \alpha)\, d$ $4\, d$ $(1 + 6 \lvert\sin \alpha\rvert)\, d$ ⟨A1]
$a_{4,t}$ (loaded edge)	$0^\circ \leq \alpha \leq 180^\circ$	max [$(2 + 2 \sin \alpha)\, d$; $3d$]
$a_{4,c}$ (unloaded edge)	$180^\circ \leq \alpha \leq 360^\circ$	$3\, d$

(4) For one row of n bolts parallel to the grain direction, the load-carrying capacity parallel to grain, see 8.1.2(4), should be calculated using the effective number of bolts n_{ef} where:

$$n_{ef} = \min \begin{cases} n \\ n^{0,9} \sqrt[4]{\dfrac{a_1}{13d}} \end{cases} \tag{8.34}$$

where:

a_1 is the spacing between bolts in the grain direction;

d is the bolt diameter

n is the number of bolts in the row.

For loads perpendicular to grain, the effective number of fasteners should be taken as

$$n_{ef} = n \tag{8.35}$$

For angles $0° < \alpha < 90°$ between load and grain direction, n_{ef} may be determined by linear interpolation between expressions (8.34) and (8.35).

(5) Requirements for minimum washer dimensions and thickness in relation to bolt diameter are given in 10.4.3

8.5.1.2 Bolted panel-to-timber connections

(1) For plywood the following embedment strength, in N/mm^2, should be used at all angles to the face grain:

$$f_{h,k} = 0{,}11\,(1 - 0{,}01\,d)\,\rho_k \tag{8.36}$$

where:

ρ_k is the characteristic plywood density, in kg/m³;

d is the bolt diameter, in mm.

(2) For particleboard and OSB the following embedment strength value, in N/mm^2, should be used at all angles to the face grain:

$$f_{h,k} = 50\, d^{-0,6}\, t^{0,2} \tag{8.37}$$

where:

d is the bolt diameter, in mm;

t is the panel thickness, in mm.

8.5.1.3 Bolted steel-to-timber connections

(1) The rules given in 8.2.3 apply.

8.5.2 Axially loaded bolts

(1) The axial load-bearing capacity and withdrawal capacity of a bolt should be taken as the lower value of:

- the bolt tensile capacity;
- the load-bearing capacity of either the washer or (for steel-to-timber connections) the steel plate.

(2) The bearing capacity of a washer should be calculated assuming a characteristic compressive strength on the contact area of $3{,}0 f_{c,90,k}$.

(3) The bearing capacity per bolt of a steel plate should not exceed that of a circular washer with a diameter which is the minimum of:

- $12t$, where t is the plate thickness;
- $4d$, where d is the bolt diameter.

8.6 Dowelled connections

(1) The rules given in 8.5.1 except 8.5.1.1(3) apply.

(2) The dowel diameter should be greater than 6 mm and less than 30 mm.

(3) Minimum spacing and edge and end distances are given in Table 8.5, with symbols illustrated in Figure 8.7.

Table 8.5 – Minimum spacings and edge and end distances for dowels

Spacing and edge/end distances (see Figure 8.7)	Angle	Minimum spacing or edge/end distance
a_1 (parallel to grain)	$0^\circ \le \alpha \le 360^\circ$	$(3 + 2\lvert\cos\alpha\rvert)\,d$
a_2 (perpendicular to grain)	$0^\circ \le \alpha \le 360^\circ$	$3\,d$
$a_{3,t}$ (loaded end)	$-90^\circ \le \alpha \le 90^{0^\circ}$	max $(7\,d;\ 80\ \text{mm})$
$a_{3,c}$ (unloaded end)	$90^{0^\circ} \le \alpha < 150^\circ$ $150^\circ \le \alpha < 210^\circ$ $210^\circ \le \alpha \le 270^\circ$	$\max(a_{3,t}\lvert\sin\alpha\rvert)\,d;\ 3d)$ $3\,d$ $\max(a_{3,t}\lvert\sin\alpha\rvert)\,d;\ 3d)$
$a_{4,t}$ (loaded edge)	$0^\circ \le \alpha \le 180^\circ$	$\max([2 + 2\sin\alpha)\,d;\ 3d)$
$a_{4,c}$ (unloaded edge)	$180^\circ \le \alpha \le 360^\circ$	$3\,d$

(4) Requirements for dowel hole tolerances are given in 10.4.4.

(5)P It shall be taken into account that the load-carrying capacity of steel-to-timber connections with a loaded end may be reduced by failure along the perimeter of the fastener group.

NOTE: A method of determining the strength of the fastener group is given in Annex A (informative).

8.3 Nailed connections

8.3.1 Laterally loaded nails

8.3.1.1 General

(1) The symbols for the thicknesses in single and double shear connections (see Figure 8.4) are defined as follows:
t_1 is:

the headside thickness in a single shear connection;

the minimum of the head side timber thickness and the pointside penetration in a double shear connection;
t_2 is:

the pointside penetration in a single shear connection;

the central member thickness in a double shear connection.

[A1) (2) Timber should be pre-drilled when:
- the characteristic density of the timber is greater than 500 kg/m³;
- the diameter d of the nail exceeds 6 mm. (A1]

(3) For square and grooved nails, the nail diameter d should be taken as the side dimension.

(4) For smooth nails produced from wire with a minimum tensile strength of 600 N/mm², the following characteristic values for yield moment should be used:

$$M_{y,Rk} = \begin{cases} 0{,}3\, f_u\, d^{2{,}6} & \text{for round nails} \\ 0{,}45\, f_u\, d^{2{,}6} & \text{for square and grooved nails} \end{cases} \qquad (8.14)$$

where:

$M_{y,Rk}$ is the characteristic value for the yield moment, in Nmm;

d is the nail diameter as defined in EN 14592, in mm;

f_u is the tensile strength of the wire, in N/mm².

(5) For nails with diameters up to 8 mm, the following characteristic embedment strengths in timber and LVL apply:
- without predrilled holes

$$f_{h,k} = 0{,}082\, \rho_k\, d^{-0{,}3} \quad \text{N/mm}^2 \qquad (8.15)$$

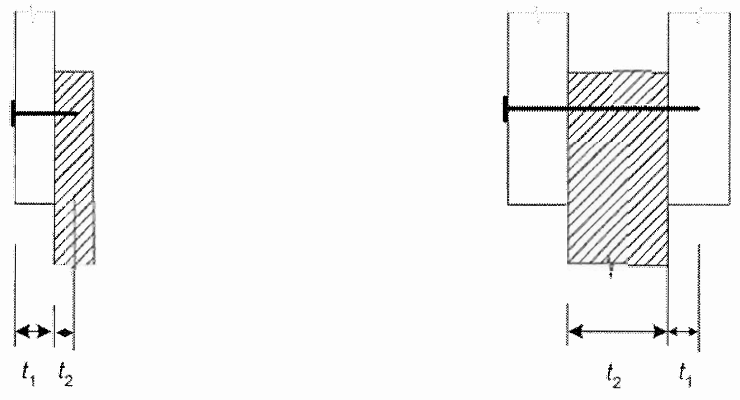
- with predrilled holes

$$f_{h,k} = 0{,}082\,(1-0{,}01\,d)\, \rho_k \quad \text{N/mm}^2 \qquad (8.16)$$

where:

ρ_k is the characteristic timber density, in kg/m³;

d is the nail diameter, in mm.



(a) **(b)**

Figure 8.4 – Definitions of t_1 and t_2 (a) single shear connection, (b) double shear connection

(6) For nails with diameters greater than 8 mm the characteristic embedment strength values for bolts according to 8.5.1 apply.

(7) In a three-member connection, nails may overlap in the central member provided (t - t_2) is greater than $4d$ (see Figure 8.5).

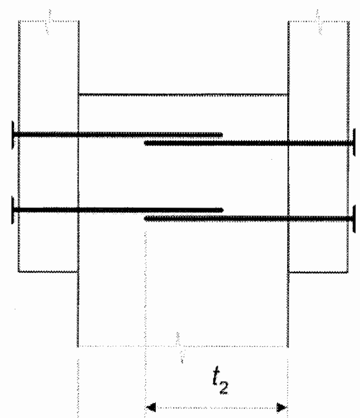


Figure 8.5 – Overlapping nails

(8) For one row of n nails parallel to the grain, unless the nails of that row are staggered perpendicular to grain by at least $1d$ (see figure 8.6), the load-carrying capacity parallel to the grain (see 8.1.2(4)) should be calculated using the effective number of fasteners n_{ef}, where:

$$n_{ef} = n^{k_{ef}} \tag{8.17}$$

where:

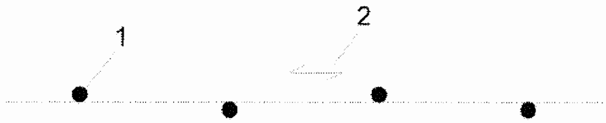
n_{ef} is the effective number of nails in the row;

n is the number of nails in a row;

k_{ef} is given in Table 8.1.

Table 8.1 – Values of k_{ef}

Spacing[a]	k_{ef}	
	Not predrilled	Predrilled
$a_1 \geq 14d$	1,0	1,0
$a_1 = 10d$	0,85	0,85
$a_1 = 7d$	0,7	0,7
$a_1 = 4d$	-	0,5
[a] For intermediate spacings, linear interpolation of k_{ef} is permitted		



Key:
1 Nail
2 Grain direction

Figure 8.6 – Nails in a row parallel to grain staggered perpendicular to grain by *d*

(9) There should be at least two nails in a connection.

(10) Requirements for structural detailing and control of nailed connections are given in 10.4.2.

8.3.1.2 Nailed timber-to-timber connections

(1) For smooth nails the pointside penetration length should be at least $8d$.

(2) For nails other than smooth nails, as defined in EN 14592, the pointside penetration length should be at least $6d$.

(3) Nails in end grain should not be considered capable of transmitting lateral forces.

(4) As an alternative to 8.3.1.2(3), for nails in end grain the following rules apply:

- In secondary structures smooth nails may be used. The design values of the load-carrying capacity should be taken as 1/3 of the values for nails installed at right angles to the grain;
- Nails other than smooth nails, as defined in EN 14592, may be used in structures other than secondary structures. The design values of the load-carrying capacity should be taken as 1/3 of the values for smooth nails of equivalent diameter installed at right angles to the grain, provided that:
  - the nails are only laterally loaded;
  - there are at least three nails per connection;
  - the pointside penetration is at least $10d$;
  - the connection is not exposed to service class 3 conditions;
  - the prescribed spacings and edge distances given in Table 8.2 are satisfied.

Note 1: An example of a secondary structure is a fascia board nailed to rafters.

Note 2: The recommended application rule is given in 8.3.1.2(3). The National choice may be specified in the National annex.

(5) Minimum spacings and edge and end distances are given in Table 8.2, where (see Figure 8.7):

a_1 is the spacing of nails within one row parallel to grain;

a_2 is the spacing of rows of nails perpendicular to grain;

$a_{3,c}$ is the distance between nail and unloaded end;

$a_{3,t}$ is the distance between nail and loaded end;

$a_{4,c}$ is the distance between nail and unloaded edge;

$a_{4,t}$ is the distance between nail and loaded edge;

α is the angle between the force and the grain direction.

Table 8.2 – Minimum spacings and edge and end distances for nails

Spacing or distance (see Figure 8.7)	Angle α	Minimum spacing or end/edge distance		
		without predrilled holes		with predrilled holes
		$\rho_k \leq 420$ kg/m^3	420 kg/m^3 < $\rho_k \leq 500$ kg/m^3	
Spacing a_1 (parallel to grain)	$0^\circ \leq \alpha \leq 360^\circ$	$d < 5$ mm: $(5+5\vert\cos\alpha\vert)\,d$ $d \geq 5$ mm: $(5+7\vert\cos\alpha\vert)\,d$	$(7+8\vert\cos\alpha\vert)\,d$	$(4+\vert\cos\alpha\vert)\,d$
Spacing a_2 (perpendicular to grain)	$0^\circ \leq \alpha \leq 360^\circ$	$5d$	$7d$	$(3+\vert\sin\alpha\vert)\,d$
Distance $a_{3,t}$ (loaded end)	$-90^\circ \leq \alpha \leq 90^\circ$	$(10+5\cos\alpha)\,d$	$(15+5\cos\alpha)\,d$	$(7+5\cos\alpha)\,d$
Distance $a_{3,c}$ (unloaded end)	$90^\circ \leq \alpha \leq 270^\circ$	$10d$	$15d$	$7d$
Distance $a_{4,t}$ (loaded edge)	$0^\circ \leq \alpha \leq 180^\circ$	$d < 5$ mm: $(5+2\sin\alpha)\,d$ $d \geq 5$ mm: $(5+5\sin\alpha)\,d$	$d < 5$ mm: $(7+2\sin\alpha)\,d$ $d \geq 5$ mm: $(7+5\sin\alpha)\,d$	$d < 5$ mm: $(3+2\sin\alpha)\,d$ $d \geq 5$ mm: $(3+4\sin\alpha)\,d$
Distance $a_{4,c}$ (unloaded edge)	$180^\circ \leq \alpha \leq 360^\circ$	$5d$	$7d$	$3d$

(6) Timber should be pre-drilled when the thickness of the timber members is smaller than

$$t = \max \begin{cases} 7d \\ (13d - 30)\dfrac{\rho_k}{400} \end{cases} \tag{8.18}$$

where:

t is the minimum thickness of timber member to avoid pre-drilling, in mm;

ρ_k is the characteristic timber density in kg/m³;

d is the nail diameter, in mm.

(7) Timber of species especially sensitive to splitting should be pre-drilled when the thickness of the timber members is smaller than

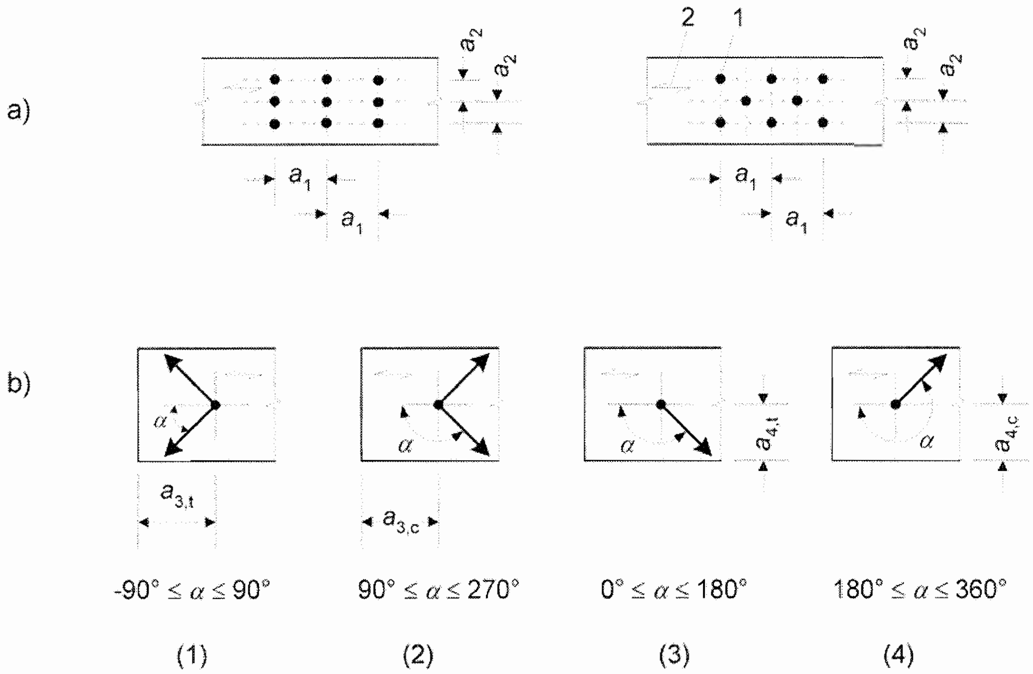
$$t = \max \begin{cases} 14d \\ (13d - 30)\dfrac{\rho_k}{200} \end{cases} \qquad (8.19)$$

Expression (8.19) may be replaced by expression (8.18) for edge distances given by:

$a_4 \geq 10\ d$ for $\rho_k \leq 420$ kg/m^3

$a_4 \geq 14\ d$ for 420 kg/m$^3 \leq \rho_k \leq 500$ kg/ m^3.

Note: Examples of species sensitive to splitting are fir (abies alba), Douglas fir (pseudotsuga menziesii) and spruce (picea abies). It is recommended to apply 8.3.1.2(7) for species fir (abies alba) and Douglas fir (pseudotsuga menziesii). The National choice may be specified in the National annex.



Key:
(1) Loaded end
(2) Unloaded end
(3) Loaded edge
(4) Unloaded edge
1 Fastener
2 Grain direction

Figure 8.7 – Spacings and end and edge distances
(a) Spacing parallel to grain in a row and perpendicular to grain between rows, (b) Edge and end distances

8.3.1.3 Nailed panel-to-timber connections

(1) Minimum nail spacings for all nailed panel-to-timber connections are those given in Table 8.2, multiplied by a factor of 0,85. The end/edge distances for nails remain unchanged unless otherwise stated below.

(2) Minimum edge and end distances in plywood members should be taken as $3d$ for an unloaded edge (or end) and $(3 + 4 \sin \alpha)d$ for a loaded edge (or end), where α is the angle between the direction of the load and the loaded edge (or end).

(3) For nails with a head diameter of at least $2d$, the characteristic embedment strengths are as follows:

- for plywood:

$$f_{\mathrm{h,k}} = 0{,}11\,\rho_{\mathrm{k}}\, d^{-0,3} \qquad (8.20)$$

where:

$f_{\mathrm{h,k}}$ is the characteristic embedment strength, in N/mm^2;

ρ_{k} is the characteristic plywood density in kg/m^3;

d is the nail diameter, in mm;

- for hardboard in accordance with EN 622-2:

$$f_{\mathrm{h,k}} = 30\, d^{-0,3} t^{0,6} \qquad (8.21)$$

where:

$f_{\mathrm{h,k}}$ is the characteristic embedment strength, in N/mm^2;

d is the nail diameter, in mm;

t is the panel thickness, in mm.

- for particleboard and OSB:

$$f_{\mathrm{h,k}} = 65\, d^{-0,7}\, t^{0,1} \qquad (8.22)$$

where:

$f_{\mathrm{h,k}}$ is the characteristic embedment strength, in N/mm^2;

d is the nail diameter, in mm;

t is the panel thickness, in mm.

8.3.1.4 Nailed steel-to-timber connections

(1) The minimum edge and end distances for nails given in Table 8.2 apply. Minimum nail spacings are those given in Table 8.2, multiplied by a factor of 0,7.

8.3.2 Axially loaded nails

[A1⟩ (1)P Nails used to resist permanent or long-term axial loading shall be threaded.

NOTE: The following definition of threaded nails is given in EN 14592: Nail that has its shank profiled or deformed over a part of its length of minimum 4,5 d (4,5 times the nominal diameter) and that has a characteristic withdrawal parameter $f_{\mathrm{ax,k}}$ greater than or equal to 6 N/mm^2 when measured on timber with a characteristic density of 350 kg/m^3 when conditioned to constant mass at 20 °C and 65 % relative humidity. ⟨A1]

(2) For threaded nails, only the threaded part should be considered capable of transmitting axial load.

(3) Nails in end grain should be considered incapable of transmitting axial load.

(4) The characteristic withdrawal capacity of nails, $F_{ax,Rk}$, for nailing perpendicular to the grain (Figure 8.8 (a) and for slant nailing (Figure 8.8 (b)), should be taken as the smaller of the values

found from the following expressions:

- For nails other than smooth nails, as defined in EN 14592:

$$F_{ax,Rk} = \begin{cases} f_{ax,k}\, d\, t_{pen} & \text{(a)} \\ f_{head,k}\, d_h^2 & \text{(b)} \end{cases} \qquad (8.23)$$

- For smooth nails:

$$F_{ax,Rk} = \begin{cases} f_{ax,k}\, d\, t_{pen} & \text{(a)} \\ f_{ax,k}\, d\, t + f_{head,k}\, d_h^2 & \text{(b)} \end{cases} \qquad (8.24)$$

where:

$f_{ax,k}$ is the characteristic pointside withdrawal strength;

$f_{head,k}$ is the characteristic headside pull-through strength;

d is the nail diameter according to 8.3.1.1;

t_{pen} is the pointside penetration length or the length of the threaded part in the pointside member;

t is the thickness of the headside member;

d_h is the nail head diameter.

(5) The characteristic strengths $f_{ax,k}$ and $f_{head,k}$ should be determined by tests in accordance with EN 1382, EN 1383 and EN 14358 unless specified in the following.

(6) For smooth nails with a pointside penetration of at least $12d$, the characteristic values of the withdrawal and pull-through strengths should be found from the following expressions:

$$f_{ax,k} = 20 \times 10^{-6}\, \rho_k^2 \qquad (8.25)$$

$$f_{head,k} = 70 \times 10^{-6}\, \rho_k^2 \qquad (8.26)$$

where:

ρ_k is the characteristic timber density in kg/m³;

(7) For smooth nails, the pointside penetration t_{pen} should be at least $8d$. For nails with a pointside penetration smaller than $12d$ the withdrawal capacity should be multiplied by $(t_{pen}/4d - 2)$. For threaded nails, the pointside penetration should be at least $6d$. For nails with a pointside penetration smaller than $8d$ the withdrawal capacity should be multiplied by $(t_{pen}/2d - 3)$.

(8) For structural timber which is installed at or near fibre saturation point, and which is likely to dry out under load, the values of $f_{ax,k}$ and $f_{head,k}$ should be multiplied by 2/3.

(9) The spacings, end and edge distances for laterally loaded nails apply to axially loaded nails.

[A1) (10) For slant nailing the distance to the loaded end should be at least $10d$ (see Figure 8.8(b)). There should be at least two slant nails in a connection. (A1]

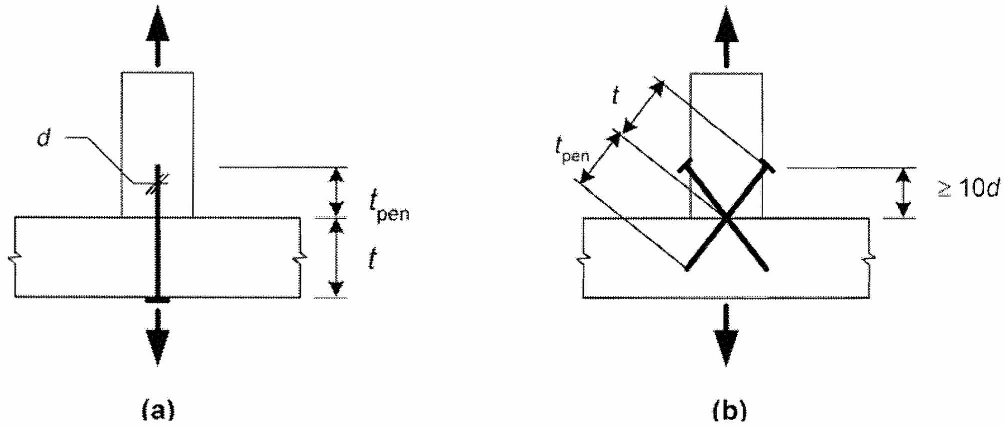


Figure 8.8 – (a) Nailing perpendicular to grain and (b) slant nailing

8.3.3 Combined laterally and axially loaded nails

(1) For connections subjected to a combination of axial load ($F_{ax,Ed}$) and lateral load ($F_{v,Ed}$) the following expressions should be satisfied:

- for smooth nails:

$$\frac{F_{ax,Ed}}{F_{ax,Rd}} + \frac{F_{v,Ed}}{F_{v,Rd}} \leq 1 \tag{8.27}$$

- for nails other than smooth nails, as defined in EN 14592:

$$\left(\frac{F_{ax,Ed}}{F_{ax,Rd}}\right)^2 + \left(\frac{F_{v,Ed}}{F_{v,Rd}}\right)^2 \leq 1 \tag{8.28}$$

where:

$F_{ax,Rd}$ and $F_{v,Rd}$ are the design load-carrying capacities of the connection loaded with axial load or lateral load respectively.

8.4 Stapled connections

[A1⟩ (1) The rules given in 8.3, except for 8.3.1.1(4) and (6) and 8.3.1.2(7), apply for round or nearly round or rectangular staples with bevelled or symmetrical pointed legs. ⟨A1]

(2) For staples with rectangular cross-sections the diameter d should be taken as the square root of the product of both dimensions.

(3) The width b of the staple crown should be at least $6d$, and the pointside penetration length t_2 should be at least $14d$, see Figure 8.9.

(4) There should be at least two staples in a connection.

(5) The lateral design load-carrying capacity per staple per shear plane should be considered as equivalent to that of two nails with the staple diameter, provided that the angle between the crown and the direction of the grain of the timber under the crown is greater than 30°, see Figure 8.10. If the angle between the crown and the direction of the grain under the crown is equal to or less than 30°, then the lateral design load-carrying capacity should be multiplied by a factor of 0,7.

(6) For staples produced from wire with a minimum tensile strength of 800 N/mm², the following characteristic yield moment per leg should be used:

Annex A (Informative): Block shear and plug shear failure at multiple dowel-type steel-to-timber connections

(1) For steel-to-timber connections comprising multiple dowel-type fasteners subjected to a force component parallel to grain near the end of the timber member, the characteristic load-carrying capacity of fracture along the perimeter of the fastener area, as shown in Figure A.1 (block shear failure) and Figure A.2 (plug shear failure), should be taken as:

$$F_{bs,Rk} = \max \begin{cases} 1{,}5\, A_{net,t} f_{t,0,k} \\ 0{,}7\, A_{net,v} f_{v,k} \end{cases} \tag{A.1}$$

with

$$A_{net,t} = L_{net,t}\, t_1 \tag{A.2}$$

[A1⟩

$$A_{net,v} = \begin{cases} L_{net,v}\, t_1 & \text{failure modes (c, f, j/l, k, m)} \\ \dfrac{L_{net,v}}{2}\left(L_{net,t} + 2t_{ef}\right) & \text{all other failure modes} \end{cases} \tag{A.3}$$

⟨A1]

and

$$L_{net,v} = \sum_i l_{v,i} \tag{A.4}$$

$$L_{net,t} = \sum_i l_{t,i} \tag{A.5}$$

– for thin steel plates (for failure modes given in brackets)

$$t_{ef} = \begin{cases} 0{,}4\, t_1 & \text{(a)} \\ 1{,}4\sqrt{\dfrac{M_{y,Rk}}{f_{h,k}\, d}} & \text{(b)} \end{cases} \tag{A.6}$$

– for thick steel plates (for failure modes given in brackets)

[A1⟩

$$t_{ef} = \begin{cases} 2\sqrt{\dfrac{M_{y,Rk}}{f_{h,k}\, d}} & \text{(e)(h)} \\ t_1\left[\sqrt{2 + \dfrac{M_{y,Rk}}{f_{h,k}\, d\, t_1^2}} - 1\right] & \text{(d)(g)} \end{cases} \tag{A.7}$$

⟨A1]

where

$F_{bs,Rk}$ is the characteristic block shear or plug shear capacity;

$A_{net,t}$ is the net cross-sectional area perpendicular to the grain;

$A_{net,v}$ is the net shear area in the parallel to grain direction;

$L_{net,t}$ is the net width of the cross-section perpendicular to the grain;

$L_{net,v}$ is the total net length of the shear fracture area;

$\ell_{v,i}$, $\ell_{t,i}$ are defined in figure A.1;

t_{ef} is the effective depth depending of the failure mode of the fastener, see Figure 8.3;

t_1 is the timber member thickness or penetration depth of the fastener;

$M_{y,Rk}$ is the characteristic yield moment of the fastener;

Section 8 Connections with metal fasteners

8.1 General

8.1.1 Fastener requirements

(1)P Unless rules are given in this section, the characteristic load-carrying capacity, and the stiffness of the connections shall be determined from tests according to EN 1075, EN 1380, EN 1381, EN 26891 and EN 28970. If the relevant standards describe tension and compression tests, the tests for the determination of the characteristic load-carrying capacity shall be performed in tension.

8.1.2 Multiple fastener connections

(1)P The arrangement and sizes of the fasteners in a connection, and the fastener spacings, edge and end distances shall be chosen so that the expected strength and stiffness can be obtained.

(2)P It shall be taken into account that the load-carrying capacity of a multiple fastener connection, consisting of fasteners of the same type and dimension, may be lower than the summation of the individual load-carrying capacities for each fastener.

(3) When a connection comprises different types of fasteners, or when the stiffness of the connections in respective shear planes of a multiple shear plane connection is different, their compatibility should be verified.

(4) For one row of fasteners parallel to the grain direction, the effective characteristic load-carrying capacity parallel to the row, $F_{v,ef,Rk}$, should be taken as:

$$F_{v,ef,Rk} = n_{ef} F_{v,Rk} \tag{8.1}$$

where:

$F_{v,ef,Rk}$ is the effective characteristic load-carrying capacity of one row of fasteners parallel to the grain;

n_{ef} is the effective number of fasteners in line parallel to the grain;

$F_{v,Rk}$ is the characteristic load-carrying capacity of each fastener parallel to the grain.

NOTE: Values of n_{ef} for rows parallel to grain are given in 8.3.1.1(8) and 8.5.1.1(4).

(5) For a force acting at an angle to the direction of the row, it should be verified that the force component parallel to the row is less than or equal to the load-carrying capacity calculated according to expression (8.1).

8.1.3 Multiple shear plane connections

(1) In multiple shear plane connections the resistance of each shear plane should be determined by assuming that each shear plane is part of a series of three-member connections.

[A1⟩ (2) To be able to combine the resistance from individual shear planes in a multiple shear plane connection, the governing failure mode of the fasteners in the respective shear planes should be compatible with each other and should not consist of a combination of failure modes (a), (b), (g) and (h) from Figure 8.2 or modes (c), (f) and (j/l) from Figure 8.3 with the other failure modes. ⟨A1]

8.1.4 Connection forces at an angle to the grain

(1)P When a force in a connection acts at an angle to the grain, (see Figure 8.1), the possibility of splitting caused by the tension force component, $F_{Ed} \sin \alpha$, perpendicular to the grain, shall be taken into account.

(2)P To take account of the possibility of splitting caused by the tension force component, $F_{Ed} \sin \alpha$, perpendicular to the grain, the following shall be satisfied:

$$F_{v,Ed} \leq F_{90,Rd} \tag{8.2}$$

with

$$F_{v,Ed} = \max \begin{cases} F_{v,Ed,1} \\ F_{v,Ed,2} \end{cases} \tag{8.3}$$

where:

$F_{90,Rd}$ is the design splitting capacity, calculated from the characteristic splitting capacity $F_{90,Rk}$ according to 2.4.3;

$F_{v,Ed,1}$, $F_{v,Ed,2}$ are the design shear forces on either side of the connection. (see Figure 8.1).

(3) For softwoods, the characteristic splitting capacity for the arrangement shown in Figure 8.1 should be taken as:

$$F_{90,Rk} = 14 b w \sqrt{\frac{h_e}{\left(1 - \frac{h_e}{h}\right)}} \tag{8.4}$$

where:

$$w = \begin{cases} \max \begin{cases} \left(\frac{w_{pl}}{100}\right)^{0,35} \\ 1 \end{cases} & \text{for punched metal plate fasteners} \\ 1 & \text{for all other fasteners} \end{cases} \tag{8.5}$$

and:

$F_{90,Rk}$ is the characteristic splitting capacity, in N;

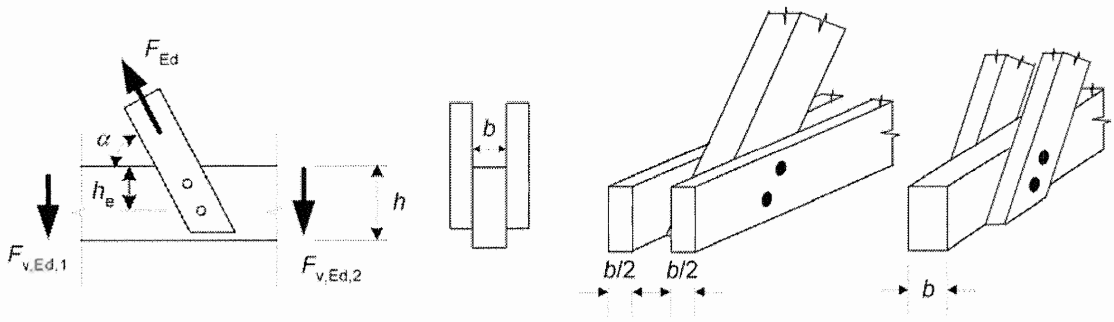
w is a modification factor;

h_e is the loaded edge distance to the centre of the most distant fastener or to the edge of the punched metal plate fastener, in mm;

h is the timber member height, in mm;

b is the member thickness, in mm;

w_{pl} is the width of the punched metal plate fastener parallel to the grain, in mm.



a) b)

Figure 8.1 – Inclined force transmitted by a connection

8.1.5 Alternating connection forces

(1)P The characteristic load-carrying capacity of a connection shall be reduced if the connection is subject to alternating internal forces due to long-term or medium-term actions.

(2)The effect on connection strength of long-term or medium-term actions alternating between a tensile design force $F_{t,Ed}$ and a compressive design force $F_{c,Ed}$ should be taken into account by designing the connection for ($F_{t,Ed}$ + 0,5$F_{c,Ed}$) and ($F_{c,Ed}$ + 0,5$F_{t,Ed}$).

8.2 Lateral load-carrying capacity of metal dowel-type fasteners

8.2.1 General

(1)P For the determination of the characteristic load-carrying capacity of connections with metal dowel-type fasteners the contributions of the yield strength, the embedment strength, and the withdrawal strength of the fastener shall be considered.

8.2.2 Timber-to-timber and panel-to-timber connections

(1) The characteristic load-carrying capacity for nails, staples, bolts, dowels and screws per shear plane per fastener, should be taken as the minimum value found from the following expressions:

– For fasteners in single shear

$$F_{v,Rk} = \min \begin{cases} f_{h,1,k} t_1 d & \text{(a)} \\ f_{h,2,k} t_2 d & \text{(b)} \\ \dfrac{f_{h,1,k} t_1 d}{1+\beta}\left[\sqrt{\beta + 2\beta^2\left[1+\dfrac{t_2}{t_1}+\left(\dfrac{t_2}{t_1}\right)^2\right]+\beta^3\left(\dfrac{t_2}{t_1}\right)^2} - \beta\left(1+\dfrac{t_2}{t_1}\right)\right] + \dfrac{F_{ax,Rk}}{4} & \text{(c)} \\ 1{,}05\dfrac{f_{h,1,k} t_1 d}{2+\beta}\left[\sqrt{2\beta(1+\beta)+\dfrac{4\beta(2+\beta)M_{y,Rk}}{f_{h,1,k}\, d\, t_1^2}} - \beta\right] + \dfrac{F_{ax,Rk}}{4} & \text{(d)} \\ 1{,}05\dfrac{f_{h,1,k} t_2 d}{1+2\beta}\left[\sqrt{2\beta^2(1+\beta)+\dfrac{4\beta(1+2\beta)M_{y,Rk}}{f_{h,1,k}\, d\, t_2^2}} - \beta\right] + \dfrac{F_{ax,Rk}}{4} & \text{(e)} \\ 1{,}15\sqrt{\dfrac{2\beta}{1+\beta}}\sqrt{2M_{y,Rk} f_{h,1,k} d} + \dfrac{F_{ax,Rk}}{4} & \text{(f)} \end{cases} \tag{8.6}$$

APPENDIX J

Appendix J.1

Appendix J.2

Annex A [informative] – Method 1: Interaction factors k_{ij} for interaction formula in 6.3.3(4)

Table A.1: Interaction factors k_{ij} (6.3.3(4))

Interaction factors	Design assumptions: elastic cross-sectional properties class 3, class 4	Design assumptions: plastic cross-sectional properties class 1, class 2
k_{yy}	$C_{my} C_{mLT} \dfrac{\mu_y}{1 - \dfrac{N_{Ed}}{N_{cr,y}}}$	$C_{my} C_{mLT} \dfrac{\mu_y}{1 - \dfrac{N_{Ed}}{N_{cr,y}}} \dfrac{1}{C_{yy}}$
k_{yz}	$C_{mz} \dfrac{\mu_y}{1 - \dfrac{N_{Ed}}{N_{cr,z}}}$	$C_{mz} \dfrac{\mu_y}{1 - \dfrac{N_{Ed}}{N_{cr,z}}} \dfrac{1}{C_{yz}} 0{,}6 \sqrt{\dfrac{w_z}{w_y}}$
k_{zy}	$C_{my} C_{mLT} \dfrac{\mu_z}{1 - \dfrac{N_{Ed}}{N_{cr,y}}}$	$C_{my} C_{mLT} \dfrac{\mu_z}{1 - \dfrac{N_{Ed}}{N_{cr,y}}} \dfrac{1}{C_{zy}} 0{,}6 \sqrt{\dfrac{w_y}{w_z}}$
k_{zz}	$C_{mz} \dfrac{\mu_z}{1 - \dfrac{N_{Ed}}{N_{cr,z}}}$	$C_{mz} \dfrac{\mu_z}{1 - \dfrac{N_{Ed}}{N_{cr,z}}} \dfrac{1}{C_{zz}}$

Auxiliary terms:

$\mu_y = \dfrac{1 - \dfrac{N_{Ed}}{N_{cr,y}}}{1 - \chi_y \dfrac{N_{Ed}}{N_{cr,y}}}$	$C_{yy} = 1 + (w_y - 1)\left[\left(2 - \dfrac{1{,}6}{w_y} C_{my}^2 \bar{\lambda}_{max} - \dfrac{1{,}6}{w_y} C_{my}^2 \bar{\lambda}_{max}^2\right) n_{pl} - b_{LT}\right] \geq \dfrac{W_{el,y}}{W_{pl,y}}$ with $b_{LT} = 0{,}5\, a_{LT}\, \bar{\lambda}_0^2 \dfrac{M_{y,Ed}}{\chi_{LT} M_{pl,y,Rd}} \dfrac{M_{z,Ed}}{M_{pl,z,Rd}}$
$\mu_z = \dfrac{1 - \dfrac{N_{Ed}}{N_{cr,z}}}{1 - \chi_z \dfrac{N_{Ed}}{N_{cr,z}}}$	$C_{yz} = 1 + (w_z - 1)\left[\left(2 - 14 \dfrac{C_{mz}^2 \bar{\lambda}_{max}^2}{w_z^5}\right) n_{pl} - c_{LT}\right] \geq 0{,}6 \sqrt{\dfrac{w_z}{w_y}} \dfrac{W_{el,z}}{W_{pl,z}}$
$w_y = \dfrac{W_{pl,y}}{W_{el,y}} \leq 1{,}5$	with $c_{LT} = 10\, a_{LT} \dfrac{\bar{\lambda}_0^2}{5 + \bar{\lambda}_z^4} \dfrac{M_{y,Ed}}{C_{my}\, \chi_{LT}\, M_{pl,y,Rd}}$
$w_z = \dfrac{W_{pl,z}}{W_{el,z}} \leq 1{,}5$	$C_{zy} = 1 + (w_y - 1)\left[\left(2 - 14 \dfrac{C_{my}^2 \bar{\lambda}_{max}^2}{w_y^5}\right) n_{pl} - d_{LT}\right] \geq 0{,}6 \sqrt{\dfrac{w_y}{w_z}} \dfrac{W_{el,y}}{W_{pl,y}}$
AC2 $n_{pl} = \dfrac{N_{Ed}}{N_{Rk} / \gamma_{M0}}$ AC2	with $d_{LT} = 2\, a_{LT} \dfrac{\bar{\lambda}_0}{0{,}1 + \bar{\lambda}_z^4} \dfrac{M_{y,Ed}}{C_{my}\, \chi_{LT}\, M_{pl,y,Rd}} \dfrac{M_{z,Ed}}{C_{mz}\, M_{pl,z,Rd}}$
C_{my} see Table A.2 $a_{LT} = 1 - \dfrac{I_T}{I_y} \geq 0$	AC2 $C_{zz} = 1 + (w_z - 1)\left[2 - \dfrac{1{,}6}{w_z} \cdot C_{mz}^2 \bar{\lambda}_{max} - \dfrac{1{,}6}{w_z} \cdot C_{mz}^2 \bar{\lambda}_{max}^2 - e_{LT}\right] n_{pl} \geq \dfrac{W_{el,z}}{W_{pl,z}}$ AC2 with $e_{LT} = 1{,}7\, a_{LT} \dfrac{\bar{\lambda}_0}{0{,}1 + \bar{\lambda}_z^4} \dfrac{M_{y,Ed}}{C_{my}\, \chi_{LT}\, M_{pl,y,Rd}}$

Table A.1 (continued)

$$\bar{\lambda}_{max} = \max\begin{cases}\bar{\lambda}_y \\ \bar{\lambda}_z\end{cases}$$

$\bar{\lambda}_0$ = non-dimensional slenderness for lateral-torsional buckling due to uniform bending moment, i.e. $\psi_y = 1{,}0$ in Table A.2

$\bar{\lambda}_{LT}$ = non-dimensional slenderness for lateral-torsional buckling

If $\bar{\lambda}_0 \le 0{,}2\sqrt{C_1}\sqrt[4]{\left(1-\frac{N_{Ed}}{N_{cr,z}}\right)\left(1-\frac{N_{Ed}}{N_{cr,TF}}\right)}$:

$$C_{my} = C_{my,0}$$

$$C_{mz} = C_{mz,0}$$

$$C_{mLT} = 1{,}0$$

If $\bar{\lambda}_0 > 0{,}2\sqrt{C_1}\sqrt[4]{\left(1-\frac{N_{Ed}}{N_{cr,z}}\right)\left(1-\frac{N_{Ed}}{N_{cr,TF}}\right)}$:

$$C_{my} = C_{my,0} + \left(1 - C_{my,0}\right)\frac{\sqrt{\varepsilon_y}\,a_{LT}}{1+\sqrt{\varepsilon_y}\,a_{LT}}$$

$$C_{mz} = C_{mz,0}$$

$$C_{mLT} = C_{my}^2 \frac{a_{LT}}{\sqrt{\left(1-\frac{N_{Ed}}{N_{cr,z}}\right)\left(1-\frac{N_{Ed}}{N_{cr,T}}\right)}} \ge 1$$

[AC2) $C_{mi,0}$ see Table A.2 (AC2]

$\varepsilon_y = \frac{M_{y,Ed}}{N_{Ed}}\frac{A}{W_{el,y}}$ for class 1, 2 and 3 cross-sections

$\varepsilon_y = \frac{M_{y,Ed}}{N_{Ed}}\frac{A_{eff}}{W_{eff,y}}$ for class 4 cross-sections

[AC2) C_1 is a factor depending on the loading and end conditions and may be taken as $C_1 = k_c^{-2}$ where k_c is to be taken from Table 6.6. (AC2]

$N_{cr,y}$ = elastic flexural buckling force about the y-y axis

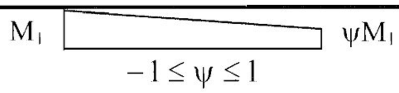
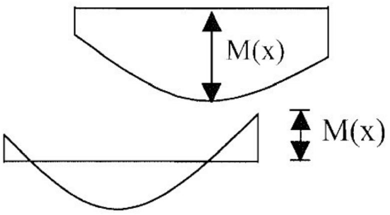
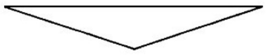
$N_{cr,z}$ = elastic flexural buckling force about the z-z axis

$N_{cr,T}$ = elastic torsional buckling force

I_T = St. Venant torsional constant

I_y = second moment of area about y-y axis

Table A.2: Equivalent uniform moment factors $C_{mi,0}$

Moment diagram	$C_{mi,0}$
	$C_{mi,0} = 0{,}79 + 0{,}21\psi_i + 0{,}36(\psi_i - 0{,}33)\frac{N_{Ed}}{N_{cr,i}}$
	$C_{mi,0} = 1 + \left(\frac{\pi^2 EI_i \lvert\delta_x\rvert}{L^2 \lvert M_{i,Ed}(x)\rvert} - 1\right)\frac{N_{Ed}}{N_{cr,i}}$ $M_{i,Ed}(x)$ is the maximum moment $M_{y,Ed}$ or $M_{z,Ed}$ [AC2⟩ according to the first order analyses ⟨AC2] $\lvert\delta_x\rvert$ is the maximum member [AC2⟩ deflection ⟨AC2] along the member
	$C_{mi,0} = 1 - 0{,}18\frac{N_{Ed}}{N_{cr,i}}$
	$C_{mi,0} = 1 + 0{,}03\frac{N_{Ed}}{N_{cr,i}}$

Annex B [informative] – Method 2: Interaction factors k_{ij} for interaction formula in 6.3.3(4)

Table B.1: Interaction factors k_{ij} for members not susceptible to torsional deformations

<table>
<tr><th rowspan="2">Interaction factors</th><th rowspan="2">Type of sections</th><th colspan="2">Design assumptions</th></tr>
<tr><th>elastic cross-sectional properties
class 3, class 4</th><th>plastic cross-sectional properties
class 1, class 2</th></tr>
<tr><td>k_{yy}</td><td>I-sections
RHS-sections</td><td>$C_{my}\left(1+0,6\bar{\lambda}_y\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right)$
$\leq C_{my}\left(1+0,6\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right)$</td><td>$C_{my}\left(1+\left(\bar{\lambda}_y-0,2\right)\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right)$
$\leq C_{my}\left(1+0,8\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right)$</td></tr>
<tr><td>k_{yz}</td><td>I-sections
RHS-sections</td><td>k_{zz}</td><td>$0,6\ k_{zz}$</td></tr>
<tr><td>k_{zy}</td><td>I-sections
RHS-sections</td><td>$0,8\ k_{yy}$</td><td>$0,6\ k_{yy}$</td></tr>
<tr><td rowspan="2">k_{zz}</td><td>I-sections</td><td rowspan="2">$C_{mz}\left(1+0,6\bar{\lambda}_z\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$
$\leq C_{mz}\left(1+0,6\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$</td><td>$C_{mz}\left(1+\left(2\bar{\lambda}_z-0,6\right)\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$
$\leq C_{mz}\left(1+1,4\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$</td></tr>
<tr><td>RHS-sections</td><td>$C_{mz}\left(1+\left(\bar{\lambda}_z-0,2\right)\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$
$\leq C_{mz}\left(1+0,8\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$</td></tr>
<tr><td colspan="4">For I- and H-sections and rectangular hollow sections under axial compression and uniaxial bending $M_{y,Ed}$ the coefficient k_{zy} may be $k_{zy} = 0$.</td></tr>
</table>

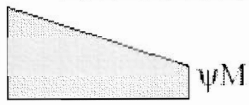
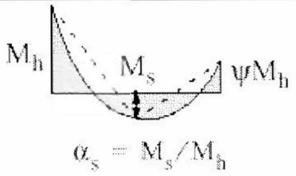
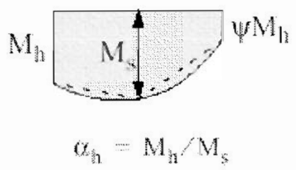
Table B.2: Interaction factors k_{ij} for members susceptible to torsional deformations

<table>
<tr><th rowspan="2">Interaction factors</th><th colspan="2">Design assumptions</th></tr>
<tr><th>elastic cross-sectional properties
class 3, class 4</th><th>plastic cross-sectional properties
class 1, class 2</th></tr>
<tr><td>k_{yy}</td><td>k_{yy} from Table B.1</td><td>k_{yy} from Table B.1</td></tr>
<tr><td>k_{yz}</td><td>k_{yz} from Table B.1</td><td>k_{yz} from Table B.1</td></tr>
<tr><td>k_{zy}</td><td>$\left[1-\frac{0,05\bar{\lambda}_z}{\left(C_{mLT}-0,25\right)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right]$
$\geq\left[1-\frac{0,05}{\left(C_{mLT}-0,25\right)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right]$</td><td>$\left[1-\frac{0,1\bar{\lambda}_z}{\left(C_{mLT}-0,25\right)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right]$
$\geq\left[1-\frac{0,1}{\left(C_{mLT}-0,25\right)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right]$

for $\bar{\lambda}_z < 0,4$:
$k_{zy}=0,6+\bar{\lambda}_z \leq 1-\frac{0,1\bar{\lambda}_z}{\left(C_{mLT}-0,25\right)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}$</td></tr>
</table>

k_{zz}	k_{zz} from Table B.1	k_{zz} from Table B.1

Table B.3: Equivalent uniform moment factors C_m in Tables B.1 and B.2

Moment diagram	range		C_{my} and C_{mz} and C_{mLT}	
			uniform loading	concentrated load
	$-1 \le \psi \le 1$		$0{,}6 + 0{,}4\psi \ge 0{,}4$	
	$0 \le \alpha_s \le 1$	$-1 \le \psi \le 1$	$0{,}2 + 0{,}8\alpha_s \ge 0{,}4$	$0{,}2 + 0{,}8\alpha_s \ge 0{,}4$
	$-1 \le \alpha_s < 0$	$0 \le \psi \le 1$	$0{,}1 - 0{,}8\alpha_s \ge 0{,}4$	$-0{,}8\alpha_s \ge 0{,}4$
		$-1 \le \psi < 0$	$0{,}1(1-\psi) - 0{,}8\alpha_s \ge 0{,}4$	$0{,}2(-\psi) - 0{,}8\alpha_s \ge 0{,}4$
	$0 \le \alpha_h \le 1$	$-1 \le \psi \le 1$	$0{,}95 + 0{,}05\alpha_h$	$0{,}90 + 0{,}10\alpha_h$
	$-1 \le \alpha_h < 0$	$0 \le \psi \le 1$	$0{,}95 + 0{,}05\alpha_h$	$0{,}90 + 0{,}10\alpha_h$
		$-1 \le \psi < 0$	$0{,}95 + 0{,}05\alpha_h(1+2\psi)$	AC2⟩ $0{,}90 + 0{,}10\alpha_h(1+2\psi)$ ⟨AC2

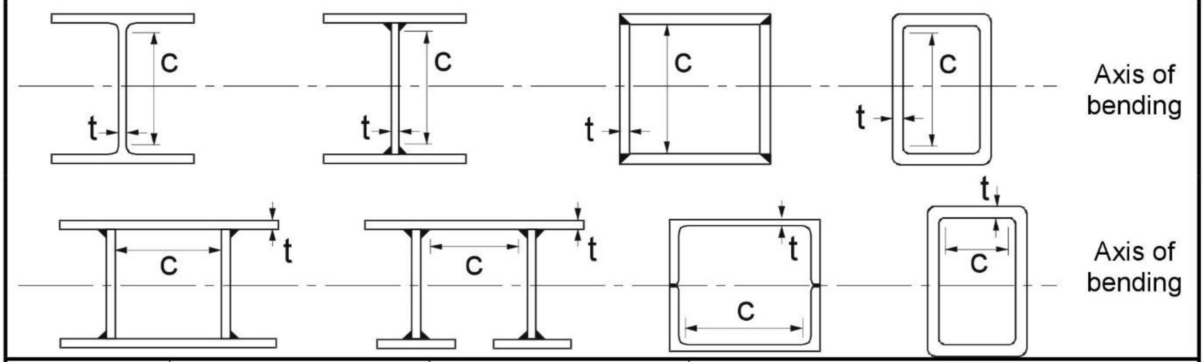
For members with sway buckling mode the equivalent uniform moment factor should be taken $C_{my} = 0{,}9$ or AC2⟩ C_{mz} ⟨AC2 = 0,9 respectively.

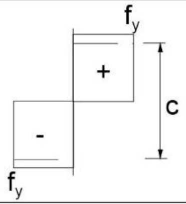
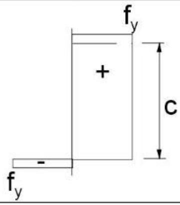
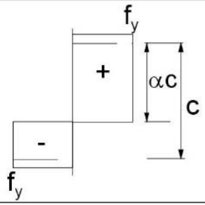
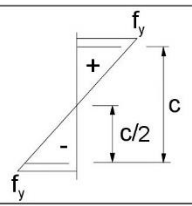
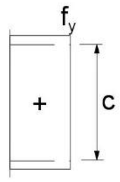
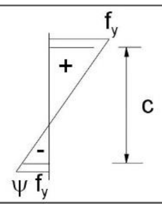
C_{my}, C_{mz} and C_{mLT} should be obtained according to the bending moment diagram between the relevant braced points as follows:

moment factor	bending axis	points braced in direction
C_{my}	y-y	z-z
C_{mz}	z-z	y-y
C_{mLT}	y-y	y-y

765

Internal compression parts



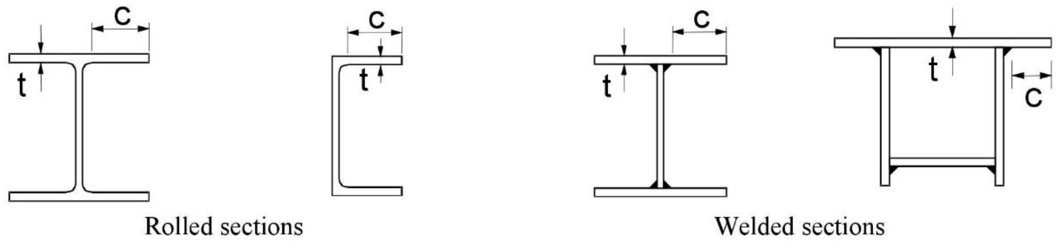
Class	Part subject to bending	Part subject to compression	Part subject to bending and compression
Stress distribution in parts (compression positive)			
1	$c/t \leq 72\varepsilon$	$c/t \leq 33\varepsilon$	when $\alpha > 0{,}5$: $c/t \leq \frac{396\varepsilon}{13\alpha - 1}$ when $\alpha \leq 0{,}5$: $c/t \leq \frac{36\varepsilon}{\alpha}$
2	$c/t \leq 83\varepsilon$	$c/t \leq 38\varepsilon$	when $\alpha > 0{,}5$: $c/t \leq \frac{456\varepsilon}{13\alpha - 1}$ when $\alpha \leq 0{,}5$: $c/t \leq \frac{41{,}5\varepsilon}{\alpha}$
Stress distribution in parts (compression positive)			
3	$c/t \leq 124\varepsilon$	$c/t \leq 42\varepsilon$	when $\psi > -1$: $c/t \leq \frac{42\varepsilon}{0{,}67 + 0{,}33\psi}$ when $\psi \leq -1^{*)}$: $c/t \leq 62\varepsilon(1-\psi)\sqrt{(-\psi)}$

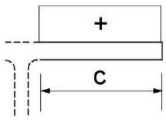
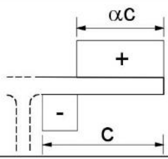
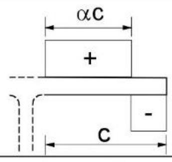
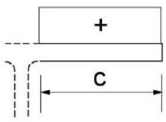
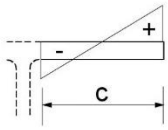
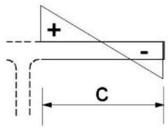
$\varepsilon = \sqrt{235/f_y}$	f_y	235	275	355	420	460
	ε	1,00	0,92	0,81	0,75	0,71

*) $\psi \leq -1$ applies where either the compression stress $\sigma \leq f_y$ or the tensile strain $\varepsilon_y > f_y/E$

Table 2. (sheet 1 of 3): Maximum width-to-thickness ratios for compression parts

Outstand flanges

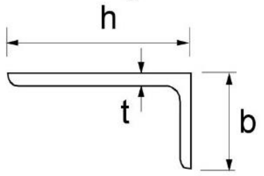


Class	Part subject to compression	Part subject to bending and compression: Tip in compression	Part subject to bending and compression: Tip in tension
Stress distribution in parts (compression positive)			
1	$c/t \le 9\varepsilon$	$c/t \le \frac{9\varepsilon}{\alpha}$	$c/t \le \frac{9\varepsilon}{\alpha\sqrt{\alpha}}$
2	$c/t \le 10\varepsilon$	$c/t \le \frac{10\varepsilon}{\alpha}$	$c/t \le \frac{10\varepsilon}{\alpha\sqrt{\alpha}}$
Stress distribution in parts (compression positive)			
3	$c/t \le 14\varepsilon$	$c/t \le 21\varepsilon\sqrt{k_\sigma}$ For k_σ see EN 1993-1-5	

$\varepsilon = \sqrt{235/f_y}$	f_y	235	275	355	420	460
	ε	1,00	0,92	0,81	0,75	0,71

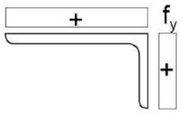
Table 2. (sheet 2 of 3): Maximum width-to-thickness ratios for compression parts

Angles

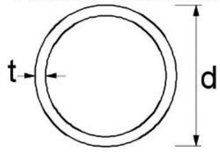


Refer also to "Outstand flanges" (see sheet 2 of 3)

Does not apply to angles in continuous contact with other components

Class	Section in compression
Stress distribution across section (compression positive)	
3	$h/t \le 15\varepsilon : \dfrac{b+h}{2t} \le 11{,}5\varepsilon$

Tubular sections



Class	Section in bending and/or compression
1	$d/t \le 50\varepsilon^2$
2	$d/t \le 70\varepsilon^2$
3	$d/t \le 90\varepsilon^2$ **NOTE** For $d/t > 90\varepsilon^2$ see EN 1993-1-6.

$\varepsilon = \sqrt{235/f_y}$						
	f_y	235	275	355	420	460
	ε	1,00	0,92	0,81	0,75	0,71
	ε^2	1,00	0,85	0,66	0,56	0,51

Table 2. (sheet 3 of 3): Maximum width-to-thickness ratios for compression parts

APPENDIX K

SimaPro 8.5.2.0	Impact assessment Date:	08.11.2018 Time:	15:00
Project	LCA-FORPROSJEKT-UIA-HØST-2018		

Calculation:	Compare
Results:	Impact assessment
Product 1:	2455611,67 kg (Apartment building)Option 1P (of project LCA-FORPROSJEKT-UIA-HØST-2018)
Product 2:	1784825,2 kg (Apartment building)Option 2P (of project LCA-FORPROSJEKT-UIA-HØST-2018)
Product 3:	1269156,25 kg (Apartment building)Option 3P (of project LCA-FORPROSJEKT-UIA-HØST-2018)
Method:	ReCiPe 2016 Midpoint (H) V1.02
Indicator:	Characterization
Skip categories:	With result = 0
Exclude infrastructure processes:	No
Exclude long-term emissions:	No
Sorted on item:	Impact category
Sort order:	Ascending

Impact category	Unit	Option 1P	Option 2P	Option 3p
Global warming	kg CO2 eq	545032,1543	318530,3538	307564,8745
Stratospheric ozone depletion	kg CFC11 eq	0,094708488	0,130746424	0,074909318
Ionizing radiation	kBq Co-60 eq	21159,40068	11361,00796	12117,81337
Ozone formation, Human health	kg NOx eq	1110,500708	699,1367515	783,5299918
Fine particulate matter formation	kg PM2.5 eq	698,0987862	439,5297282	449,7637121
Ozone formation, Terrestrial ecosystems	kg NOx eq	1141,755895	719,8346583	809,8477333
Terrestrial acidification	kg SO2 eq	1292,730339	833,0152244	837,6654933
Freshwater eutrophication	kg P eq	127,3836299	84,72780221	81,84903611
Marine eutrophication	kg N eq	7,620533178	4,897696778	4,850361239
Terrestrial ecotoxicity	kg 1,4-DCB	1603338,472	990235,7738	1043869,853
Freshwater ecotoxicity	kg 1,4-DCB	17216,64212	10101,81014	9878,654123
Marine ecotoxicity	kg 1,4-DCB	24941,43563	14577,55101	14293,8332
Human carcinogenic toxicity	kg 1,4-DCB	376922,8201	170680,6856	166333,785
Human non-carcinogenic toxicity	kg 1,4-DCB	334163,6611	225224,4031	221551,8049
Land use	m2a crop eq	6918,774226	5445,886068	482391,1234
Mineral resource scarcity	kg Cu eq	8461,426716	5266,837535	4967,661849
Fossil resource scarcity	kg oil eq	79131,26869	50573,5649	58514,09911
Water consumption	m3	3054,927311	3018,698116	1854,977

Byggekostnad

BYG 507, Forprosjekt til masteroppgave, UIA

Byggetsted:

HEISTAD, PORSGRUNN KOMMUNE

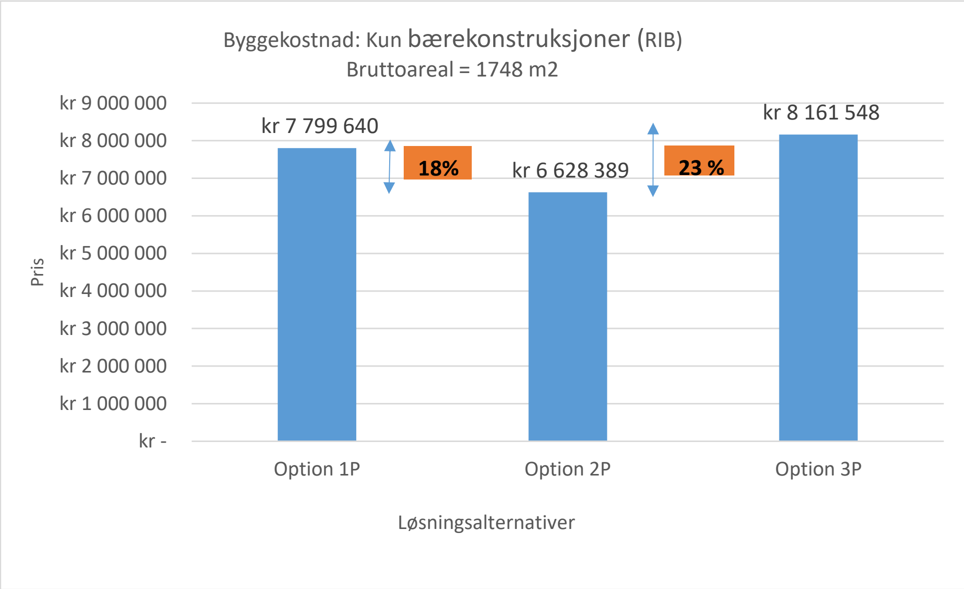
Option 1P: Bæresystem i plasstøpt betong
Option 2P: Bæresystem i stål og prefabrikrte betong
Option 3P: Bæresystem i tre

Høst 2018

FORUTSETNINGER FOR KALKYLE:	KALKYLEN OMFATTER:		Byggekostnad for hvert alternativ		
Forprosjekt til masteroppgave	Boligblokk bærekonstruksjoner		Løsningsalternativer		
Tegningsprogram: Revit	Bruttoareal… m2	1 748	Option 1P	Option 2P	Option 3P
Enhetsprisene er hentet fra:		**Sum….**	**kr 7 799 640**	**kr 6 628 389**	**kr 8 161 548**
Holte Kalkulasjonsnøkkel og Norsk Prisbok		**m2-pris…..**	**kr 4 462**	**kr 3 792**	**kr 4 669**

Nr.	*Konstuskjontype*	*enhet*	*mengde*	*enhetspris*	*pris*		
	FUNDAMENTER						
	Betong B30						
	Fundament:						
Felles	Såle kjeller 1200x400mm	lm	152,77	3037	463962	463962	463962
	Såle kjeller ringmur 800x300mm	lm	17,183	1650	28352	28352	28352
for alle	Punktfundament 1000x1000x300mm	stk	1	2492	2492	2492	2492
Alt 1	Punktfundament 1700x1700x400mm	stk	3	9604	28811		
	Punktfundament 2500x2500x500mm	stk	3	18720	56160		
Alt 2	Punktfundament 2000x2000x400mm	stk	3	10400		31200	
Alt 3	Punktfundament 1700x1700x400mm	stk	6	8400			50400
	BÆRESYSTEMER						
	Yttervegger:						
Alt 1	200 mm betong kjellervegg… avstivning	m2	55,76	1620	90331		
Felles	220 mm betong kjellervegg	m2	488,86	1655	809063	809063	809063
	350 mm betong kjellervegg	m2	191,75	1886	361641	361641	361641
	200 mm ringmur	m2	10	1620	16200	16200	16200
for alle	50 mm xps på utsiden av yttervegger	m2	386,12	190	73363	73363	73363
	Bjelker:						
Alt 1	Bjelke, betong plasstøpt, 200x500 mm	lm	130,12	1842	239681		
	Bjelke, betong plasstøpt,300x500 mm	lm	14,56	2195	31959		
Alt 2	Prefab betongbjelker, dobbel hylle, DLB	lm	33,94	2831		96084	
	IPE 180	kg	684,12	30		20524	
	IPE 220	kg	320,11	30		9603	
	IPE 240	kg	1840	30		55200	
	IPE 360	kg	4003	30		120090	
	IPE 400	kg	1609,33	30		48280	
	IPE 450	kg	1519,64	30		45589	
	IPE 160	kg	351,32	30		10540	
	Vindkryss Flattstål 100x20	kg	714,65	30		21440	
Alt 3	Limtre , GL30c						
	Limtrebjelke 115x180	lm	23	527			12121
	Limtrebjelke 115x360	lm	37,49	1053			39477
	Limtrebjelke 140x540	lm	63,68	1690			107619
	Stål, S355						
	HE300B	kg	5830,11	30			174903
	IPE 200	kg	281,66	30			8450
	IPE 330	kg	3886,41	30			116592
	IPE 400	kg	3309,55	30			99287
	Vindkryss Flattstål 100x20	kg	667,13	30			20014
	Søyler:						
Alt 1	Søyle, betong plasstøpt, 200x300 mm	lm	84,8	1467	124402		
	Søyle, betong plasstøpt, 300x300 mm	lm	9,24	1821	16826		
	Søyle, betong plasstøpt, 200x400 mm	lm	60,65	1620	98253		
	Søyle, betong plasstøpt, dia 450 mm	lm	10,08	2552	25724		

	Søyle, betong plasstøpt, dia 150 mm	lm	149,25	900	134325		
Alt 2	Søyle, betong plasstøpt, dia 300 mm	lm	9,79	1521		14891	
	HUP 150X150X10	kg	1907	30		57210	
	HUP 150X100X10	kg	3630	30		108900	
	HUP 80X 80 6,3	kg	2147	30		64410	
Alt 3	Betong B30, Pilaster						
	Søyle, betong plasstøpt, 300x300 mm	lm	3,6	1821			6556
	Stål, S 355						
	HUP 140X140X6,3	kg	2969,62	30			89089
	HE200A	kg	649,2	30			19476
	Limtre , GL30c						
	Limtresøyle 115x115	lm	125,08	760			95061
	Limtresøyle 140x180	lm	32,96	1423			46902
	Limtresøyle 140x225	lm	44,41	1779			79005
	DEKKER						
Felles for alle	Gulv på grunn 120mm betong, 200mm XPS	m2	1810	689	1247090	1247090	1247090
	50 mm XPS Isolasjon på mark	m2	67	190	12730	12730	12730
Alt 1	280 mm plasstøptdekke, Et.01 og Et.02	m2	1176,5	1640	1929460		
	200 mm plasstøptdekke, Et.02	m2	182	1500	273000		
Alt 2	Hulldekke 200 mm og 15 mm sparkel, Et.02	m2	93,18	1143		106505	
	Hulldekke 265 mm og 15 mm sparkel, Et .01 og Et. 02	m2	1252,5	1227		1536818	
Alt 3	Massivtre 280, Et. 01 og Et.02	m2	1251,4	1750			2189950
	Massivtre 160 på balkong, Et.02	m2	93,18	1050			97839
	60 - 80 mm plasstøpt over massivtre 280 for og tilfredstille lydkrav, Et. 02 leiligheter	m2	450	263			118350
Felles for alle	300 mm EPS Isolasjon under dekke plan 1	m2	480	640	307200	307200	307200
	50 mm EPS isolasjon over dekke plan 1	m2	424	137	58088	58088	58088
	80 mm plasstøpt over dekke plan 1	m2	424	281	119144	119144	119144
	80 mm XPS isolasjon under betongelementer på balkong	m2	245	350	85750	85750	85750
	50 mm Betongelementer balkong	m2	245	220	53900	53900	53900
	YTTERTAK						
Alt 1	Dekke over plan 2 280 mm plasstøptdekke hovedtak	m2	622,87	1640	1021507		
	200 mm plasstøptdekke på balkong	m2	60,15	1500	90225		
Alt 2	Hulldekke 200 mm på balkong tak	m2	60,15	867		52150	
	Hulldekke 265 mm hovedtak	m2	620,38	951		589981	
Alt 3	Massivtre 280 hovedtak	m2	621,9	1750			1088325
	Massivtre 160 på balkong tak	m2	60,15	1050			63158
			Totalt .... Kr		**7799640**	**6628389**	**8161548**


Byggekostnad: Kun bærekonstruksjoner (RIB)
Bruttoareal = 1748 m2
kr 9 000 000
kr 8 000 000
kr 7 000 000
kr 6 000 000
kr 5 000 000
kr 4 000 000
kr 3 000 000
kr 2 000 000
kr 1 000 000
kr -
Pris
kr 7 799 640
18%
kr 6 628 389
23 %
kr 8 161 548
Option 1P
Option 2P
Option 3P
Løsningsalternativer