Managing Temporary Works

A summary of existing problems and solutions

Master's thesis in Master Program Structural Engineering and Building Technology

LARS SCHEIDEGGER

JONATHAN SÖDERQVIST

Department of Architecture and Civil Engineering
Division of Structural Engineering
Lightweight Structures
CHALMERS UNIVERSITY OF TECHNOLOGY

Master's thesis ACEX30-19-69
Gothenburg, Sweden 2019

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Supervisors: Professor Robert Kliger, Department of Architecture and Civil Engineering; Jimmy Lovén, VBK; David Salekärr, Serneke
Examiner: Professor Robert Kliger, Department of Architecture and Civil Engineering

Department of Architecture and Civil Engineering
Division of Structural Engineering
Lightweight Structures
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 10 00

Cover: A figure of a façade scaffolding.

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Abstract

In recent years, a handful of accidents have accrued within the construction industry regarding temporary works. Some of these accidents will be presented in this thesis. Since the rate of these accidents seems to be higher in Sweden compared to other countries, this thesis aimed to investigate the possible reason for this circumstance. To sufficiently cover the broad field of temporary works, the study method was divided into three different sections. First, a literature study was carried out on relevant papers and educational literature as well as standards and code of practices. In addition, some of the more prominent temporary works failures have been studied to investigate if there were similarities between them.

Secondly, an interview study with essential stakeholders within the temporary works industry was carried out. In the decision of choosing the interviewing partners, information from the literature study was a large part. There were interviews conducted with respondents from contractor companies, temporary works engineers, temporary works suppliers and the Swedish Transport Administration. In the Interviews, the respondents were asked to describe their routines regarding temporary works and how they work to uphold a sufficient level of quality regarding their responsibility's.

In a third step, a case study was conducted in order to test the existing design standards and investigate possible flaws and weaknesses. In addition, requirements formulated in the interview study by the respondents were used to select the temporary work used in the case study.

The first conclusion which can be drawn from the thesis regards the lack of coordination between the different stakeholders within the temporary works industry. Guidelines formulated by either an industry organisation or responsible authority is crucial to organise the temporary works field. Secondly, new literature explaining and guiding both engineers and workers through a temporary design erection process, including both governing standards as well as a good practice guide, should be developed. Thirdly an industry organisation focusing on falsework and formwork should be founded. Alternatively, the industry organisation covering falsework could mandate all temporary works. Finally, the industry should work towards homogenise the used stress methods to avoid miscalculations and time loss when designing temporary works.

Keywords: Temporary Work, Falsework, Formwork, Scaffolding, Backpropping, Management, Eurocode, BS 5975, Permanent Work, SS-EN 12812

Acknowledgements

First and foremost, we would like to express our sincere gratitude to our two supervisors Jimmy Lovén at VBK Konsulterande Ingenjörer AB and David Salekärr at Serneke AB. Without both your guidance and David's great interest in temporary works and late night emails, consisting of the Temporary Works Stakeholders Graph for example, this master thesis could not have been completed!

Secondly, we would like to thank our examiner Professor Robert Kliger, for taking his time to answer our questions and guide us within this unexplored subject.

We would also like to thank all the respondents in the interviews, who set aside their time to answer our questions and presented how they are working with temporary works.

Lastly, we would like to thank our opponents, Christoffer Jonsson and Adam Lennell, whom we have had a great collaboration with to improve and refine our both theses with. Occasionally in combination with a "fika".

Lars Scheidegger and Jonathan Söderqvist, Gothenburg, June 2019

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Nomenclature

Greek Letters

α_v	Shear factor
α_b	Bolt factor
$\sigma_{\perp}$	Normal Stress Perpendicular to the Throat
$\sigma_{Ed,1}$	Design stress of the fillet weld
$\sigma_{Ed,2}$	Second design stress of the fillet weld
$\tau_{\parallel}$	Shear Stress Parallel to the Axis of the Weld
$\tau_{\perp}$	Shear Stress Perpendicular to the Axis of the Weld
Ψ_2	Load case factor
$\gamma_{M,1}$	Material safety factor
χ	Reduction factor for relevant buckling mode
β_w	Correlation factor

Roman Upper Case Letters

A	Cross section area
A_{bolt}	Cross section area for bolts
A_v	Shear area
A_s	Tensile stress area of the bolt
F_{Rd}	Design resistance per bolt
$F_{v,Rd}$	Design shear resistance per bolt
$F_{b,Rd}$	Design bearing resistance per bolt
$F_{t,Rd}$	Design tensile force resistance per bolt
$F_{v,Ed}$	Design shear per bolt
$F_{t,Ed}$	Design tensile force per bolt for the ultimate limit state
M_{Rd}	Design values of the resistance to bending moments
M_{Ed}	Design bending moment
$N_{b,Rd}$	Design buckling resistance of the compression member
N_{Ed}	Design value of the compression force to normal
$R_{d,i}$	Design value of resistance
$R_{k,i}$	Characteristic value of resistance
$V_{pl,Rd}$	Design plastic shear resistance
V_{Ed}	Design value of the shear force
W	Section modulus

Roman Lower Case Letters

d_{bolt}	Nominal bolt diameter
f_u	Ultimate strength
f_{ub}	Ultimate tensile strength for bolts
f_y	Yield strength
k_1	Bolt factor
k_2	Bolt factor
t_{plate}	Plate thickness

1
Introduction

Temporary Work (TW) is the structure that is used to support and access the Permanent Works (PWs) during construction or renovation. According to BSI (2008), TWs can be defined as follows: *"Temporary works is an 'Engineered solution' used to support or protect either an existing structure or the permanent works during construction, or to support an item of plant or equipment, or the vertical sides or side-slopes of an excavation during construction operations on site or to provide access."*

In Sweden today, the structural rules and regulations when designing TWs, such as falsework and scaffolding, are primarily regulated in the European Standards (ENs) SS-EN 12810-12813. These ENs are implemented in all countries that are a part of the European Committee for Standardisation (CEN) network (CEN, 2017).

When designing TWs according to the ENs, one has to apply additional documents such as e.g. SS-EN 1992, SS-EN 1993 or SS-EN 1995. This circumstance calls for an experienced engineer who can apply the correct standards in order to design the TWs. Only general advice on how to design TWs is proposed in the ENs (Jones, 2014).

In recent years, numerous incidents have taken place where TWs have been miscalculated or incorrectly installed, resulting in structural failures. Examples of this could be the near structural collapse of a wildlife crossing built over the motorway between Gothenburg and Kungsbacka (Kruse, 2018), or the collapsing of railway bridges in Ludvika and Härnösand during construction (Alexandra Hernandi, 2008).

In the United Kingdom (UK), during the 1960s and 1970s, the construction industry experienced many falsework failures. The accidents resulted in a commission by the UK government to investigate how the handling of TWs could be improved and how fatal accidents could be reduced. The investigation led to what is now known as the Bragg's Report, named after professor Stephen Bragg who was the primary author of the report. The report led to British Standard, BS 5975- - Code of practice for temporary works procedures and the permissible stress design of falsework, that coexist with the ENs. The UK has not experienced any major TW failure since the introduction of the BS 5975 (Hewlett et al., 2014).

1.1 Aim and Objective

The aim of this thesis is to investigate how the regulations and design standards in Sweden related to TWs can be improved. The different control mechanisms, shared responsibilities and way of conduct are of particular interest to understand the industry and the usage of TWs.

The objective will be a study of the current situation in Sweden. The goal will be to identify all the stakeholders in the construction industry and their responsibilities, all the way from the TWs designers, suppliers and to the final end users.

In addition, an evaluation of different options when using other ENs and working papers are performed. In the end, suggestions for different solutions which can be applied in Sweden are presented.

1.2 Method

The methodology is based on the concept of an in-depth literature study, followed by a qualitative interview procedure and case study. The literature study was performed to get a more insightful perspective of the investigated area and a better understanding of the routines and regulations surrounding TWs. The literature study also gave input to identify areas where problems often appear and to choose the right stakeholders for the interviews. In addition, previous failures were studied to identify the involved parties and companies, as well as examine the failure causes. The two processes lead to a list of stakeholders identified as crucial to the thesis. The research process can be described as inductive since the main aim was to capture overall patterns and routines and give general solutions to the aim (Butte.edu, 2013). Furthermore, the interviews resulted in a list of requirements which are used and tested in the case study. To have a visual explanation of how much theoretical and practical knowledge the stakeholders possess, a *Temporary Works Stakeholders Graph* was developed. The graph is used on all stakeholders and interview respondents in order to explain their knowledge levels.

The case study was performed on a specific TW in the Karlatornet, Gothenburg, different requirements were formulated as a result of the interviews, to form the base in the evaluation of two different TWs solutions. The requirements were ranked with an *Analytic Hierarchy Process*, and a weighting factor was calculated for each requirement. The two concepts were then graded with a *Pughs Matrix* together with the weighting factors. The TW solutions aimed to represent the whole field of TWs and were therefore very different in their designs. Moreover, the knowledge which was gathered in the previous literature study and through conversation with experienced respondents in the field helped in the design process.

A preliminary sizing was conducted on the winning solution with the governing ENs. The governing documents have afterwards been discussed and evaluated from a structural engineers point of view. The discussion has been divided into five sections, industry, academy, authority, regulation and responsibility and finally self-reflection of the study.

1.3 Limitations

The thesis does not include ground shoring or excavation supports, e.g. for construction pits. Neither is the impact of geotechnical arrangement for heavy machinery placement included. Consequently, the thesis will only focus on construction parts which are constructed above ground level. In addition, TWs which very much are similar to PWs in terms of calculation and construction, e.g. temporary bridges, have also been excluded.

The main focus of the literature study is on European countries, with Sweden and the UK in particular. The interviewing partners are chosen carefully by the authors to represent a broad perspective of interests in the construction industry.

In the case study, only two solutions to conceptual design have been evaluated and refined to obtain the winning suggestions. The two solutions are chosen to represent the most common TWs designs. The grading of the solutions have been rather subjective, but try to reflect the input gathered in the interviews.

The design of the final truss, presented in Section 6.7, has not been subjected to any types of structural optimisation process during this thesis. The aim has been to present a solution which has the qualities to a sufficient solution.

2

Background and Definitions

To better understand the difficulties when working with Temporary Works (TWs), it is crucial to understand the underlying theory and technical terminology. TWs takes form in many different shapes and configurations and can both be prefabricated and re-used many times or be built explicitly for one purpose only. Different stress design concepts are used throughout the industry with different stakeholders using different concepts.

2.1 Temporary Works

The definition of TWs can be defined as cited by Filip and Pallet (2019) *"Temporary Works means all temporary works of every kind required in or about the construction completion and maintenance of the works"*. 'Work' is then defines as *"Work means the Permanent Works together with the Temporary Works"*.

Already the Romans used falsework to build arches and construct domes, e.g. the Pantheon. Later on, scaffolding and falsework were used to build churches, such as the Notre Dame in Paris (Fazio et al., 2013). TWs have always been used to build bridges, all the way from the Pont du Garde in France, over the Salginatobel bridge in Switzerland to the new Nya Hisingsbron in Gothenburg (Blockley and Blockley, 2010).

The term TWs is a summary for all different types of construction members that are used to support the Permanent Works (PWs), see Section 2.2. Within the definition TWs, one can associate terms like falsework, scaffolding, backpropping, wall forms, lifting equipment, shoring equipment, etc. In addition, the ground is also a TW since it often consists of temporary solutions on the building site. Some key features of TWs can be seen in Figure 2.1.

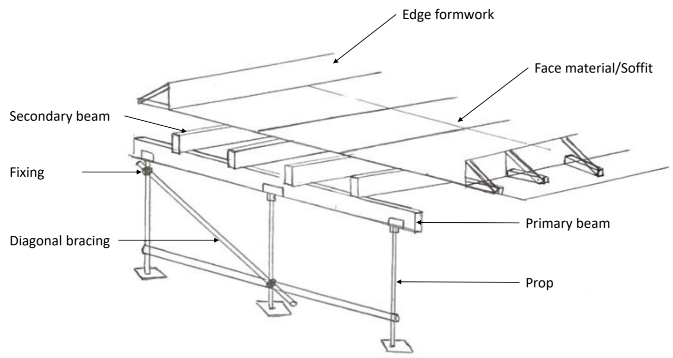


Figure 2.1: *Examples of different element types in a TWs design.*

TW can be of the type where they are built directly on the construction site. In this case, the TW is performed by carpenters with the help of drawings. TWs can also be of the type of prefabricated elements that can be rented for a specific project and the demands it holds (Filip and Pallet, 2019). There are many different suppliers of this type of TW with their own patented solutions (DOKA, 2019). However, they are rather similar to each other as they only vary in joint solutions and element sizes, but all serve the same purpose, which is to support the PW being built and the workers.

2.2 Permanent Work

The PW is the structure that the TW supports until it has enough sufficient capacity to be self-supporting. It usually consists of timber, steel, concrete or composites. The PW usually remains in the same location and position for its entire lifetime, which can be more than 50 years. Examples of permanent works are buildings, roads, bridges, industries, dams, etc. (HSE, 2019).

According to Filip and Pallet (2019), the definitions for PWs are *"Permanent works mean the permanent works to be constructed, completed and maintained in accordance with the contract"*.

2.3 Falsework

Falsework are all structures which temporarily support a PW from underneath. When the PW is self-supporting, the falsework is removed. Typical falsework is scaffolding or back propping for slabs, as seen in Figure 2.2. These can either be standardised and reusable multiple times or made specifically for one purpose. As the construction of falsework is set out to support the PW, the load will only be short term, but very intense with respect to the utilisation of the material, which often can be up to 90% (York and Pallett, 2011).

As the falsework almost always supports a structure in the vertical direction, the main focus of the structural design of falsework is concentrated on vertical stability. The focus on vertical stability can lead to major deficits in the horizontal stability of the structure as it is easily neglected or missed altogether in the design process (Pallett and Bowring, 2011).

Figure 2.2: *Falsework supporting the soffit formwork where the permanent concrete structure is cast (MTA Capital Construction Mega Projects, 2012).*

2.4 Backpropping

Backpropping is used to handle the loads during the construction of the PW. They are often used in multistory buildings constructions were one-floor cannot support the total self-weight of the new floor above. Backprops are used in one or multiple floors downwards which are already completed, to distribute the loads from the newly casted floor above on multiple floors, instead of the floor beneath it. To be able to do so, the concrete slabs have to be activated by dismantling the formwork supporting the slab. Backpropping is especially used when a thicker slab is to be cast over a thinner slab when the thinner slab is not able to carry the imposed loads from the thicker slab above (Filip and Pallet, 2019). An example of a prop can be seen in Figure 2.4a.

2.4.1 Methods of Backpropping

There are multiple techniques for using backpropping. The two main ones are to use the same amount of backpropping on all levels of the building, or the amount of backpropping are reduced with 50% on the secondary backpropping floor, see Figure

2.3 where 50% of the backpropping are reduced on the second floor. Depending on how many floors which are supported by backpropping, there are different standard values describing the load distribution between different slabs and backpropping (Filip and Pallet, 2019).

Figure 2.3: *Backproppinng in one multiple floors.*

Pre-loading or stressing of the props can be used to avoid the elastic deformations of the slab, the pre-loading mechanism can be seen in Figure 2.4b. The pre-loading increases the stiffness of the props and the loads are then re-directed to the back-propping and the supporting slab, see Figure 2.5. The pre-loading is done by turning the props washers, see Figure 2.4b, and tightening it up between the slabs. By doing so, the loads on the upper slab are decreased, and the lower slab increased. The amount of reduced load on the upper slab depends on the amount of pre-loading in the prop (The Concrete Centre, 2004).

(a)

(b)

Figure 2.4: *Usual backpropping from afar on the left in 2.4a and up close with the locking mechanism on the right in 2.4b.*

The load distribution is described with Figure 2.5 and Table 2.1. In Figure 2.5 there are two possible backpropping solutions presented. In both examples, the casted slab is supported by props with the load W_p, which is the total load from the newly casted slab. In the first example with one level of backpropping, the backpropping is loaded with W_{b1}. According to Table 2.5, the props are loaded with 100% (W_p) of the load from the newly casted slab. The supporting slab beneath has a reaction force of 70% (S_{s1}) of the total load and the backpropping, and lower slab (2) have a reaction force of 30% (W_{b1}) from the new slab.

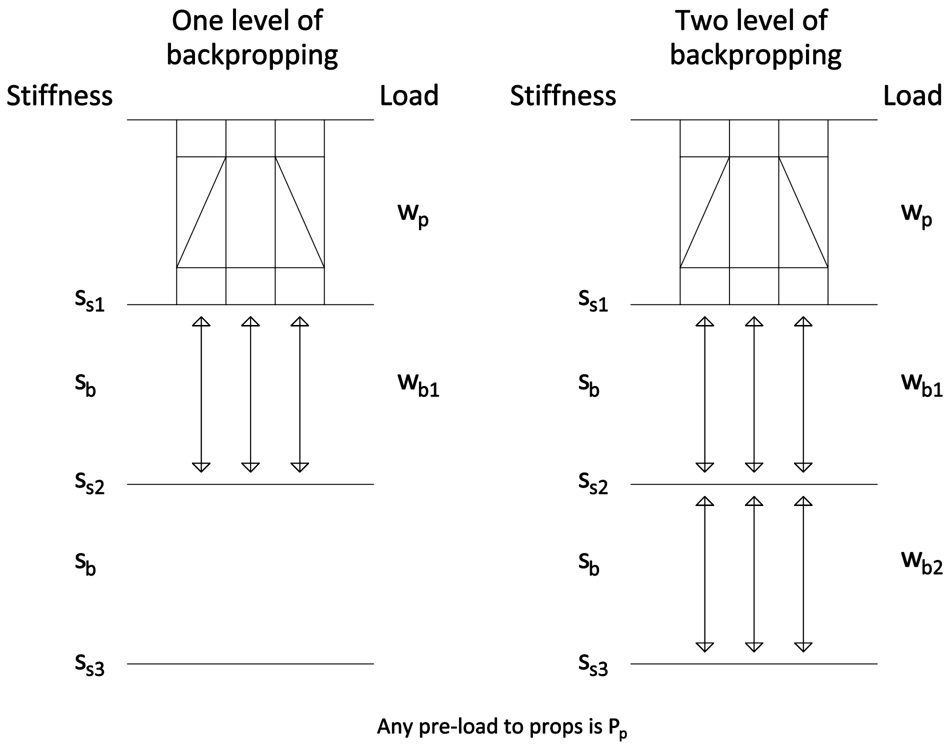


Figure 2.5: *How to backpropping in one and two levels, see Table 2.1 for load distribution.*

In the second example with two levels of backpropping, the props supporting the newly casted slab are also loaded with 100% (W_p) of the load. However, the first supporting slab now has a reaction force of 65%(S_{s1}), the first level of backpropping 35% (W_{b1}), the lower slab (2) 23% (S_{s2}), the second level of backrpopping 12% (W_{b2}) and the lowest slab (3) 12% (S_{s3}). If the backprops are pre-loaded between the slabs, the pre-loading force P_p has to be accounted for in the backprops.

Table 2.1: *Backpropping on one and three floors (Filip and Pallet, 2019).*

Location	Load	No backpropping fitted	One level of backprops		Two levels of backprops	
			On slab	In prop	On slab	In prop
New slab cast on falsework/props	w_p	100%	100%		100%	
		100%		100%		100%
Supporting Slab		100%	70% w_p	-	65% w_p	-
Backrops	w_{b1}	None	-	30% w_p	-	35% w_p
Lower slab (2)		-	30% w_p		23% w_p	-
Backprops	w_{b2}	None		None	-	12% w_p
Lower slab (3)		-	-	-	12% w_p	-

2.5 Scaffolding

Scaffolding has long been used in construction and is still a very common commodity on a construction site today. The purpose of scaffolding is to make spaces accessible, which otherwise would be very hard or impossible to reach in a safe way. Scaffolding can be used to get access to the façade of a building, see Figure 2.6, or as a support of a working platform for casting concrete. Scaffolding is also often used as falsework for bridges or soffit formwork. Scaffolding usually consists of a tubular aluminium or steel system connected by bolts or fixings. In between the "skeleton" lay footpaths of either timber or aluminium. The scaffolds are often sold in packages and are thereby prefabricated which also is mentioned in the EN (SIS, 2019b). There can also be scaffolding built for specific purposes or building sites as long as they follow the regulations given in the SS-EN 12811-1/2 (SIS, 2019b) and regulation by the Swedish Work Environment Authority (SWEA). Before the scaffolding can be used at the construction site, an inspection has to be performed and approved. To clarify that the scaffolding has been approved, a green sign is clearly positioned where one enters the scaffolding. An example of the sign can be seen in Figure 2.7. The inspection is only required by authorities for scaffolding, not for any other types of TWs. As scaffolding can be dismantled and reused, it is by default a TW (Filip and Pallet, 2019).

Figure 2.6: *An example of scaffolding providing working space along the façade (Bernswaelz, 2016).*

Figure 2.7: *An example of a sign which display's an approved inspection of the scaffolding on the entrance of the scaffolding.*

2.6 Formwork

The term formwork describes the form or mould in which the reinforcement is placed and concrete is poured in. The formwork can be modelled in many different ways to achieve the right dimensions and shape of the final PW. There are prefabricated versions from many different suppliers. Formwork can also be made out of construction timber and built directly on site to satisfy the need for unique solutions, this is the traditional way of production. Formwork can be divided into two categories, vertical- and horizontal formwork. The horizontal formwork can also be called soffit formwork (Filip and Pallet, 2019).

2.6.1 Vertical Formwork

If formwork is constructed directly on the working site, the most commonly used material is timber and engineering wood products, also known as EWP. In this design, studs and plywood are assembled into a formwork which supports the concrete structure, see Figure 2.8a and 2.8b. The first step is to erect the studs where the plywood later is going to be screwed onto. These act as a forming surface for the concrete during the casting. When the first side of the form has been constructed, the reinforcement in the mould can be installed accordingly to the drawings. It is important to install spacers that will keep the shape of the mould while casting. When this is done, the other side of the formwork can be constructed in the same manner as the first side (Byggentreprenörerna, 1993).

(a) **(b)**

Figure 2.8: *Examples of formworks constructed by timber products on a construction site.*

There is also formwork from many suppliers that offers solutions like proprietary panels formwork, see Figure 2.9a and 2.9b. These are prefabricated elements that can be assembled and constructed in the dimensions and shapes demanded by the PWs. The systems are well used and tested and come in different lengths, heights and geometries which make it possible to use both lightweight systems and crane-handled panel formworks, the difference being the independence of heavy machinery used for lightweight systems. In these systems, both steel, aluminium, timber, plastic and different composites are used to form the panel system, see Figure 2.9d. The elements are tied together with the help of wedges seen in Figure 2.9c. Generally, the traditional formwork has a high assembly cost and low material cost, compared to the panel system that has a higher material cost but is rather fast to assemble. The cost-efficiency may vary between projects. (The Concrete Society Working Party, 2012)

(a) **(b)** **(c)** **(d)**

Figure 2.9: *Example of formwork assembled by prefabricated and reusable elements.*

2.6.2 Horizontal Formwork

Horizontal formwork, also known as soffit formwork, acts as a form for the underside of horizontal concrete structures, see Figure 2.10. The soffit formwork can both be set with an inclination or right-angled against the ground. Falsework is often used to support the soffit formwork. It is extra important to retain the formwork until the concrete has reached enough capacity to be self-supporting (Filip and Pallet, 2019). Soffit formwork is used for constructing structural parts like slabs, beams and bridge spans etc. As for vertical formwork, soffit formwork come in different types of element systems. The panel system consists of panels which are put together to form the mould. The table formwork looks visually like a table with a plate, which is supported by beams in two directions, see 2.10a, which are supported on props with bracing between them. Table formwork is often not dismantled, instead moved with the help of cranes to reduce the time needed for the montage (Filip and Pallet, 2019).

(a) **(b)**

Figure 2.10: *Example of a soffit formwork supported by props.*

2.7 Limit State Concept

The limit state concept works with different safety factors for the loads ($\gamma_{f,i}$) and partial factors ($\gamma_{M,i}$) for material properties, see Equation 2.1.

$$\gamma_{f,i} \cdot \psi_i \cdot F_k \leq \eta_i \cdot \frac{X_{k,i}}{\gamma_{M,i}} \tag{2.1}$$

The safety factor depends on whether one calculates the Ultimate Limit State (ULS) where the structures failure load is determined or the Serviceability Limit State (SLS) where a structures ability to serve during usage is studied. The overall idea behind the ULS design is to separate the statically smallest possibility of a failure of the structure and material from the highest possible load case, even though highly unlikely to happen. The factor ψ_i takes into account the probability of different loads acting at the same time. The SLS load case, on the other hand, is often limited by allowed deflection and dynamic behaviours of a structure (Al-Emrani et al., 2013).

2.8 Permissible Stress Concept

Permissible stress, also called Working stress, is an older method to secure the design calculation of structures. In contrast to the limit state concept, where partial safety factors are used to increase or decrease capacities and loads in accordance with the probability of defects in the material and load combinations, the permissible stress method only considers one safety factor applied on the resistance of the materials. It basically refers to the failure load of a material with a *safety factor* which can vary as: $working\ load = \frac{failure\ load}{safety\ factor}$ (Pallett and Bowring, 2011).

The equation is based on the theory where the material never reaches the plastic region of the stress-strain curve, thus staying in the linear elastic relation (Arya, 2009). The permissible stress concept is a very simple method to use as it provides a clear magnitude of the allowed load as well as a factor of safety for the whole structure. The disadvantages being that simultaneously and/or contradicting appearing loads are either hard or impossible to account for (Raju and Pranesh, 2013). Furthermore, it does not account for any probabilities if different loads act at the same time since there are no partial factors considering the loads. Also, the structures usually get oversized with a low utilisation ratio since the plastic behaviour of materials is not exploited (Arya, 2009).

2.9 Stakeholders in the Temporary Works Industry

In the construction industry, there are many different types of stakeholders. However, within the field of TWs, seven specific stakeholders can be defined to have a substantial role in legislation, design, resell and use. Therefore, an understanding of the stakeholders is essential to define the relationship between them within a project.

Contractors
The contractors in Sweden has the responsibility to coordinate all the workers and subcontractors on the construction site and to satisfy the requirements detailed in the contract with the client. It is also the contractors' task to ensure that all standards and regulation on TWs are fulfilled.

Manufactures and Suppliers of Temporary Works
There are many manufacturers of TWs solutions, and they are usually selling or rent out the equipment. In addition, some companies have combined both services. When selling their equipment, the suppliers do not take any responsibility for TW design. When offering their equipment for rent, calculation and design of the specific TW are made and the exact amount of equipment delivered. To be able to do so, the needed boundary conditions, such as loads and construction sequences, have to be delivered by the structural engineer of the PW.

Temporary Work Engineers (TWE)
The engineer who has the responsibility to design and size the TW can be found at TW suppliers, construction consultant firms and at consultant companies which have specialised in the field of TW. The engineer can work both with TW and PW or can solely be focused on TW. These TWE often work with both standardised solutions as well as bespoke solutions for one specific construction.

Permanent Work Engineers (PWE)
The engineer responsible for the design and sizing of the PW are usually consultant firms or in-house departments of contractors who have specialised within construction design. The PWE will document the prerequisites so that the TWE can develop a structural design which fulfils the set requirements.

Swedish Transport Administration (STA)
The STA is the authority in Sweden, which has the responsibility of long-term planning of the road, railroad, shipping and air traffic network. The STA also has the responsibility to construct, service and maintain state roads and railways (Trafikverket, 2017b). This commission has resulted in numerous documents which are used when public procurements are carried out. With the help of these documents, terms and regulations for the contractors are established. Since the STA are the largest client for ordering civil engineering projects in Sweden, they also have the responsibility as the client to set up terms for health and safety in their projects.

Swedish Working Environment Authority (SWEA)
The authority for health and safety in the Swedish workplaces has the responsibility to overview the employer and employees and work together with them to achieve a good and safe workplace (Arbetsmiljöverket, 2016). Furthermore, the goal is that no one should get sick or injured in their job. The SWEA provides documentation of how a safe working environment can be reached and employers are legally bound to follow these. Otherwise, penalties and sanctions can be enforced upon the employers by the SWEA.

Swedish Institute for Standards (SIS)
SIS is the Swedish organisation for coordination and development of standardisation. They represent Sweden in the CEN, which is the responsible organisation for publishing Eurocode (EC) and ENs. SIS translates the English versions of the standards into Swedish. SIS also collects all opinions which people in Sweden have on the standards and forwards them to CEN. Finally, SIS is responsible for the Swedish National Annexes of the EC SIS (2019a).

3

Relevant Literature

There is a range of different standards, regulations and working papers surrounding Temporary Works (TWs) both in Sweden and elsewhere. These aim to help engineers and others to safely calculate and asses TW structures and sometimes guide the design process. In Sweden and other European countries, there are both national regulations and European Standards (ENs), published by the European Committee for Standardisation (CEN). An overlook of the relationship between documents and organisations can be seen in Figure 3.1, including the national regulations from the Swedish Transport Authority (STA) and the Swedish Work Environment Authority (SWEA).

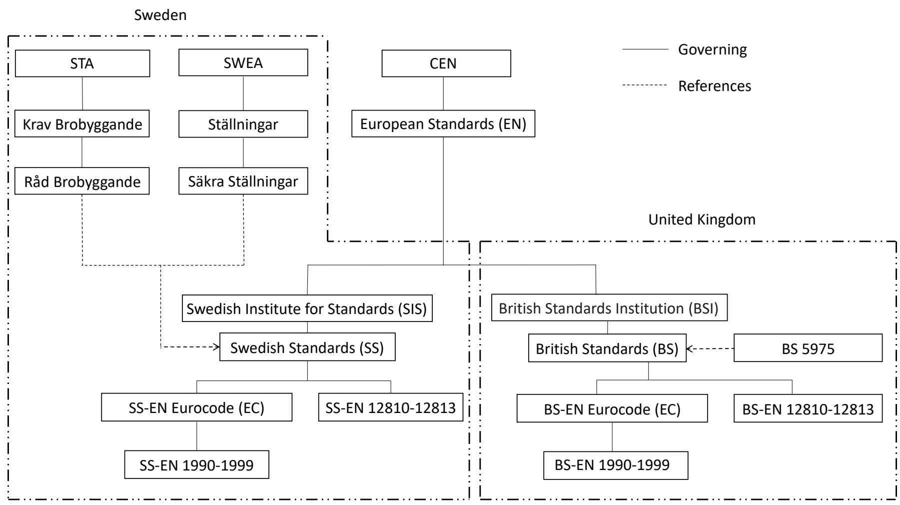


Figure 3.1: *Chart over how different organisations and standards are connected to each other.*

3.1 Swedish Standard and Regulations

TWs, much like permanent works are regulated by the European Codes for Structural Design, Eurocode (EC). These are applicable to almost any civil engineering structure if the basic theoretical knowledge is existing. As all ENs, they work towards homogenising the market in Europe and make it easier for companies to work between countries. For TWs, there are additional ENs which are not part of the EC but work as a complementary regulation (Jones, 2014).

3.1.1 Eurocode

The EC are a collection of different ENs, namely SS-EN 1990 to SS-EN 1999, all related to civil engineering design. They were first published in 1975 and have since then been established in all of the nations in the European Union and other countries, such as Switzerland and Russia (Hewlett et al., 2014). Besides working towards a more homogeneous market place within the European Union, they are also set to establish an equal standard of safety for all the member states (JRC, 2018a).

Since all the participating nations are forced to follow EC, National Annexes (NAs) have been created to make some parts of the EC more suited to the conditions and construction traditions in individual countries. The NAs bring opportunity for different partial factors on the materials and safety factors between the member states since they are free to decide the value of these factors (JRC, 2018b). Unlike previous national standards and regulations in Sweden, the EC based on on the limit state principle and heavily depend on statistical number and probability calculations (JRC, 2018c).

The EC of interest for TWs are for the most part the ones aiming at certain material behaviour such as EC 3 - Design of Steel structure, EC 5 - Design of timber structures and EC 9 - Design of aluminium structures. Of course also the EC 0 - Basis of structural design and EC 1 - Actions on structures, are always to be considered regardless of structure. Apart from these, EC 7 - Geotechnical design and EC 8 - Design of structures for earthquake resistance are used (Jones, 2014).

3.1.2 Temporary Works Standards

As a complement to the EC, there exist numerous additional ENs which are complementary and explain certain details regarding, e.g. materials or building elements. The ones specified for TW are listed below:

SS-EN 12810-1:	Façade scaffolds made of prefabricated components – Part 1: Product specifications
SS-EN 12810-2:	Façade scaffolds made of prefabricated components – Part 2: Particular methods of structural design
SS-EN 12811-1:	Temporary works equipment – Part 1: Scaffolds – Performance requirements and general design
SS-EN 12812:	Falsework – Performance requirements and general design
SS-EN 12813:	Temporary works equipment – Load bearing towers of prefabricated components – Particular methods of structural design

There are also ENs dedicated to specific products and materials which for simplicity are not listed here. All the above governs in Sweden without any NAs. As ENs works in addition to EC, there are many references made to these in them. The EN covering scaffolding are showing a span of minimal or maximal measurements and relying on second-order analysis for the calculation of the internal forces (Jones, 2014). For the calculation of these internal forces, there is a flow chart helping the structural designer through the process (SIS, 2019c). The ENs use the same partial factors as the EC provides for material, but introduce a specific calculation method for the wind forces acting on scaffolding and have some separate working loads.

Whilst the EN covering scaffolding is more or less detailed, the same can not be said for the SS-EN 12812: Falsework – Performance requirements and general design (Hewlett et al., 2014). Most of the text is referring to the EC or other EN and has more overall recommendations, such as *"The structure shall be designed such that all the loads acting on it are carried into the subsoil or into a load-bearing sub-structure"* (SIS, 2012). There are some specific regulations regarding falsework. For example, the PW which will be cast is divided into three different Design classes A, B1 and B2, which have different requirements (SIS, 2012). Design Class A are structures which require minor TWs and are not obligated to undergo any design calculations. Design Class B1 and B2 are larger TWs, which require a detailed design process following the SS-EN 1990, 1991 and 1999 and Chapter 9 in SS-EN 12812. Additionally, B2 is governed by SS-EN 12812 and its regulations on materials, design requirements and actions (SIS, 2012). If conflicts between SS-EN 12812 and any other ENs arise, the regulations in SS-EN 12812 are governing. In SS-EN 12812 Chapter 8, there are recommendations regarding minimum and maximum forces which are to be used. Furthermore, there are also recommendations on four different load combinations during the construction process, these are formulated as followed:

Load case 1:	Unloaded falsework, e.g. before pouring
Load case 2:	Falsework during loading, e.g. pouring
Load case 3:	Loaded falsework
Load case 4:	loaded falsework subjected to seismic effects

In Chapter 9, direction on the resistance and dimensioning stresses are presented. Boundary conditions for TW are also presented in this chapter.

3.1.3 Krav Brobyggande

Krav Brobyggande (Trafikverket, 2018a) is a document published by the STA, stating regulations and recommendations when constructing bridges. The document covers a wide range of topics, from which loads can be assumed, to how the results of the calculations should be presented to the STA. In addition to *Krav Brobyggande*, the STA published a document, *Råd Brobyggande* Trafikverket (2018b), which is a summary of *Krav Brobyggande*. Furthermore, *Råd Brobyggande* explains certain enunciations and gives advice on how to interpret *Krav Brobyggande*. Both documents were re-published in the summer of 2018 with revised content, and its impact has yet to be investigated regarding TWs. When examining the parts concerning TW, there is a desire to clarify which calculations have to be carried out and when a third party check is demanded since that was not always the case in the old document, *TRVR BRO 11* (Trafikverket, 2011). To achieve the goal of clarification, the

STA has worked with the guidelines regarding the design documentation (Personal communication, March 1, 2019). In order to present the demands on documentation more clearly, the STA introduced a new table in *Råd Brobyggande* which is supposed to guide the structural engineers. The largest difference to Permanent Works (PW), is that TW documentation of the initial design does not have to be submitted and that Temporary Works Engineers (TWE) are not required to attend the start meeting of a new project.

There is also a section about how the organisational structure of companies should be certified when working for the STA. Generally, the document demands an ISO 9001 certification which guarantees a certain level of quality throughout the companies management structure. However, *Krav Brobyggande* permits companies without the certification if they can prove enough experience in the required areas and a satisfying structured management (Trafikverket, 2018a).

Moreover, *Krav Brobyggande* consists of a chapter dedicated to TW. However, the chapter focuses on temporary bridges and which exclusions can be made when designing temporary bridges. For falsework and formwork, there are only references to SS-EN 12812 (SIS, 2012) with some additions made regarding loading. These additions are not TW specific and are taken directly from the regulations regarding PW. The structural engineer also has to estimate which loads from SS-EN 12812 and *Krav Brobyggande* generates the most unfavourable load situation on the TW.

3.1.4 Regulations Regarding Scaffolding

The SWEA has released a regulation document, *Ställningar* (Arbetsmiljöverket, 2013), where all the regulations surrounding scaffolding are summarised. Moreover, the document has some requirements which are not regulations but seen as the common working procedure. The document is mandatory to obey if scaffolding is erected in Sweden (Arbetsmiljöverket, 2013). Furthermore, all the erection workers are required to attend training regarding scaffolding (Arbetsmiljöverket, 2014a). Scaffolding for stages, stands and falsework are not covered by these document and explicitly left out. In addition, SWEA has released a working paper, *Säkra ställningar* (Arbetsmiljöverket, 2014b) which explains the more complex regulations in *Ställningar* and provides guidance on how they should be interpreted. The working paper also provides practical suggestions regarding scaffolding in a number of phases of the design and erection process.

3.2 BS 5975 - Code of practice in the United Kingdom

The United Kingdom (UK) has a long tradition of practice codes to help the structural engineers in their work. The former BS 5975: Code of practice for TW procedures and the permissible stress design of falsework (BSI, 2008) is a result of this tradition, paired with lessons learned from fatal falsework accidents in the 1960s and 1970s (Hewlett et al., 2014). During this time period, a report was published 1975 which would become known as the Bragg report. The report detailed the inadequate design and construction process and recommended 27 points to improve the situation (Hewlett et al., 2014).

This report then resulted in the British Standard Institution (BSI) publishing a code of practice, BS 5975, in 1982 where most of the recommendations from the Bragg's report where implemented (Hewlett et al., 2014). Most notable was the introduction of a Falsework Coordinator (FWC), which was mandatory on each construction site. The FWC had the oversight of all the TWs on the construction site site and used in the construction process. The FWC also had the responsibility of controlling the correct erection of the TWs and make sure a safe working environment was established (Hewlett et al., 2014).

In the revision of 2008, the BS 5975 (BSI, 2008) changed from just covering falsework to cover all TWs. In this revision, the titles of BS 5975:2008 changed from *"Code of practice for falsework"* to *"Code of practice for temporary works procedures and the permissible stress design of falsework"*. In this process, the terms FWC changed to Temporary Works Coordinator (TWC) (Hewlett et al., 2014). In BS 5975, there is also a range of suggestions of required checks which have to be performed and documented. These checks are the results of Bragg's investigation and follow the principle of *"check vertical, check horizontal then check horizontal again"* (Pallett and Bowring, 2011)

Furthermore, the British model now contains regulations that for instance, all construction sites using TWs in the UK is required to have a designated TWC. In order to be a TWC there is a certain qualification required, which is acquired during an education from the Construction Industry Training Board (CITB) (CITB, 2019). In these training courses, the attendees learn what to look for in the design process for TW and which failures are common (NHBC, 2019). In addition, the education also contains parts were all the different stakeholders are identified and their responsibilities are outlined (NHBC, 2019).

From 2008, EN 12812 was introduced in the countries connected to the CEN network (Jones, 2014). The introduction resulted in two documents which governed TWs in CEN connected countires. The two documents use different stress methods, limit state design in EN 12812, see Section 2.7 and permissible stress design in BS 5975, see Section 2.8. The two different stress methods are not regarded a problem for the documents to coexist in the UK, since BS 5975 adopted the limit state concept to work alongside with the permissible stress concept (Hewlett et al., 2014).

Accordingly to Hewlett et al. (2014), the reasons for keeping the BS 5975 when the EN 12812 was introduced, is due to the overview and coordination of TWs, which is provided in BS 5975. The definitions of different stakeholders and their role in the design and construction of TW are also of great importance.

4
Learning from Failures

This chapter is an introduction to accidents which occurred in Sweden related to Temporary Works (TWs) in Sweden. Mistakes were identified in the design process, erection and management of TWs. These failures were among the most serious and well-documented accidents in recent years.

4.1 Bridge Collapse over Älandsfjärden 2008

In May 2008, a new railway bridge was constructed over Älandsfjärden, south of Härnösand. The bridge was going to be 800 meters long and was ordered by the former Swedish Rail Administration (SRA), currently named Swedish Transport Administration (STA). During the casting of the concrete in the first section of the bridge, the formwork failed, and five out of eight workers fell down alongside with the newly casted concrete. Two people were killed while the rest were injured.

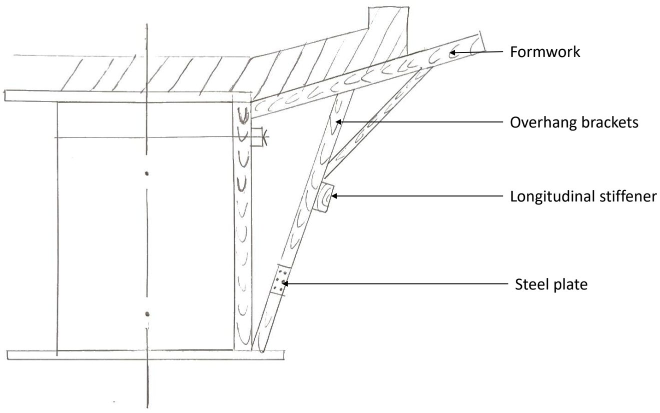
The SRA started an investigation of the accident, as did the contractor. The contractor was involved in a legal process which prohibits them from releasing any documentation from the case. However, an interview was conducted in this thesis, with one of the members in the responsible committee investigating the accident as well as a responsible employee from the contractor.

4.1.1 Reasons Behind the Accident

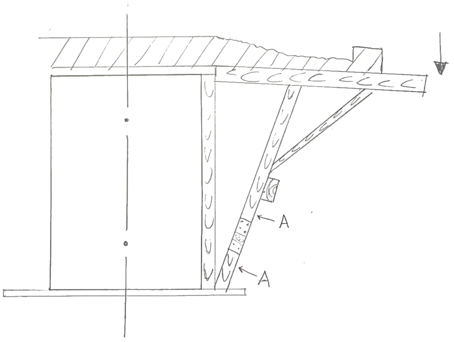
In an internal news memo from the contractor provided to the STA, it was concluded that there were two reasons for the accident. The main reason behind the accident was the design of TWs, which was undersized. The timber overhang brackets that supported the formwork were undersized in the weak direction (longitudinal direction of the bridge), see Figure 4.1. There were also no longitudinal stiffeners supporting the overhang brackets in the weak direction. The overhang bracket also had a joint connected with a nail plate, which further reduced the capacity. In addition, the joints were poorly executed with to much space between the timber studs leaving the nail plate to buckle. These joints were designed by a subcontractor who was specialised in calculating roof trusses. During the construction of the formwork, the question about the overhang brackets strength was questioned. The responsible structural engineer then replied with a suggestion to strengthen the brackets with stiffeners. No specification on how the stiffeners should be carried out was provided.

When the concrete was poured into the formwork, one of the overhang brackets failed in the longitudinal direction. This failure leads to an immediate load redistribution to adjacent overhang brackets, which resulted in a domino effect where all the loaded overhang brackets failed (Skanska Sverige AB, 2008).

The investigation also concluded that the contractor had worked systematically with safety issues during the project and had not failed with their own safety routines despite the accident. Furthermore, it was stated that the contractor did not have any routines regarding TWs in the same manner as for Permanent Works (PWs). Finally, the investigation suggested that new routines for TWs should be implemented in the company (Skanska Sverige AB, 2008).



(a)



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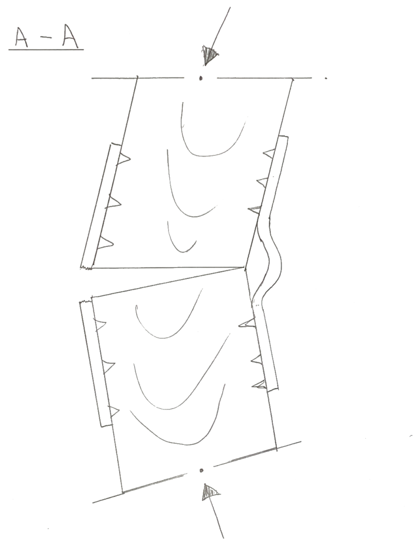


(c)

Figure 4.1: *The over hanging brackets seen in 4.1a were undersized in the longitudinal direction (into the picture). When loaded, see 4.1b, the circumstances lead to the buckling of the bracket and the nail plate, see 4.1c.*

4.2 Near Collapse of Wildlife Crossing in Kungsbacka 2017

In January of 2017, a wildlife crossing was set to be constructed over the highway E6 north of Kungsbacka. During the casting of the concrete, there was a deformation in the falsework leading to the interruption of the casting process and the demolition of the already costed concrete (Kruse, 2018). The STA conducted an investigation after the accident, to evaluate the reasons behind the deformation of the falsework.

During the casting of the first half of the concrete bridge, see Figure 4.2, the workers could hear a ticking noise originate from the falsework. Around midnight, the falsework started to deform, and at the same time, the concrete workers on top of the formwork started evacuating. Afterwards, a large crack could be detected in the casted concrete at support one, see Figure 4.2. The concrete that had been poured into the formwork was estimated to around 1000 m^3 of the total volume of 1300 m^3. The estimated cross-section over support two after the casting was interrupted and estimated to around 50% off its full cross-section (Trafikverket, 2017a).

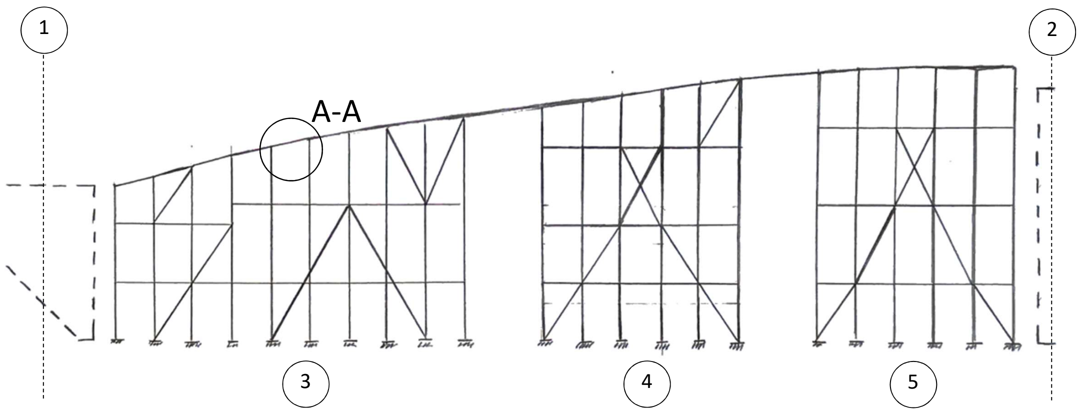


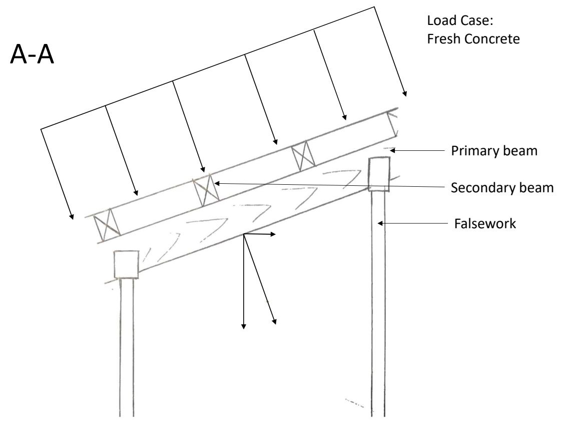
Figure 4.2: *View of the two permanent supports (Number 1 and 2) and the three falsework sections (Number 3,4 and 5).*

The falsework consisted of supporting glued laminated timber beams placed longitudinally to the span of the crossing acting as primary load-bearing beams for the formwork, see Figure 4.4. The falsework was divided up in three separate sections between the two permanent supports at the foot and the outer edge of the casted bridge section (Trafikverket, 2017a).

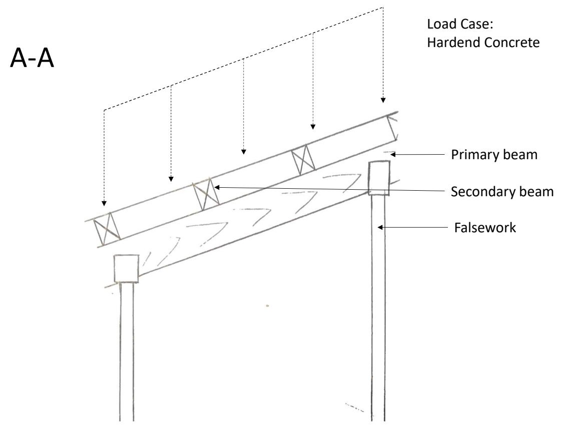
4.2.1 Reasons Behind the Accident

The report clearly states that the most apparent reason for the TW to react this way was too large horizontal loads. After inspection, the calculations were found to be inaccurate, resulting in an undersizing of the falsework in the longitudinal direction. It was established that the primary beams, see Figur 4.4 had been displaced between 100-200 mm in the longitudinal direction against the second permanent support, see Figure 4.2. It could also be stated that in falsework section three, the falsework props had been deformed, and the worst deformations had taken place in the middle of the falsework section five, see Figure 4.2. The responsible engineer had made the assumption that the horizontal loads would be 2.5% of the total vertical loads from the concrete, which was too optimistic. However, it was stated that the calculated vertical loads were correct. The 2.5% of the calculated vertical load resulted in a horizontal load of 6.95kN for every diagonal brace when in reality, the loads were up to approximately 20kN per brace (Trafikverket, 2017a).

The reason for the miscalculated horizontal loads appears to be an error in the assumption of the load behaviour from fresh concrete. When concrete arrives at the construction site and is cast, the concrete is in a liquid state and therefore also behaves like a liquid, see Figure 4.3a. According to hydrodynamics, a liquid acts perpendicular to the surface, and after the concrete has hardened the load behaviour will change to act parallel to the gravity, see Figure 4.3b. The shape of the wildlife passing, see Figure 4.2, is an arc shape. The arc shape resulted in both a horizontal and vertical force couple. The consequence was that the diagonal braces were exposed to a higher load then calculated (Trafikverket, 2017a).



(a)



(b)

Figure 4.3: *On the left the behaviour off fresh concrete can be seen togheter with the resulting force components. On the right the behavour of hardened concrete is shown.*

The shape of the bridge is also varying over the span. From 11% inclination at permanent support one, to 0% at permanent support two, see Figure 4.2. The variation in shape resulted in a horizontal load varying over the longitudinal span (Trafikverket, 2017a).

These assumptions resulted in a miscalculated design of the TW. It was afterwards decided that in the coming parts of the project, the calculations and the installations of the TW had to be reviewed of a third-party. The review was demanded to guarantee that the calculations were done correctly and to avoid further delays and accidents (Trafikverket, 2017a).

4.2.2 Alternative Theories Behind the Accident

During the interview with the experienced Temporary Work Engineer (TWE), see Section 5.4, a different theory regarding the reasons behind the accident was raised and discussed. The TWE is of the opinion that rods were missing between the secondary beams, allowing the beams to fall over in the longitudinal direction of the bridge, see Figure 4.4. The beams fell over due to the inclination of the bridge, which at permanent support one was 11%. These rods were according to the bridge engineer not marked on the drawings for either the falsework or formwork, although, a common practice when designing TWs with an inclination greater than 5%. Also, the primary beams were constructed with a small gap between each other, which allowed deformations to take place before the forces could be transmitted between the beams. All this together led to the introduction of deformations on the falsework, resulting in the accident. The first TW design was performed by an engineer working in Sweden, following the British code of practice. The second design after the accident was performed by an engineer from the United Kingdom (UK), following the same code of practice. As a result, the design then had almost double the amount of horizontal bracing in the falsework.

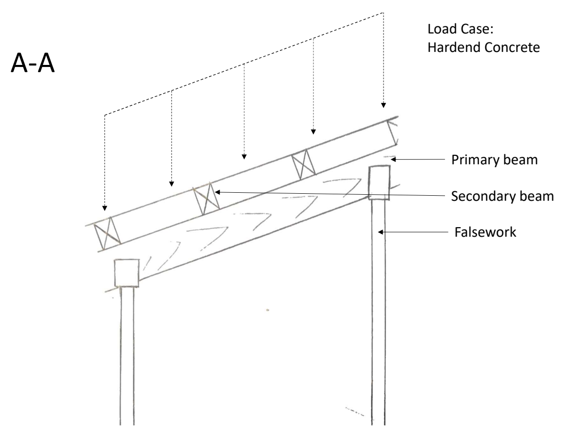


Figure 4.4: *Rods between the secondary beams could have helped prevent the accident (Personal communication, Mars 5, 2019).*

4.3 Bridge Collapse in Ludvika 2017

In July of 2017, a new concrete bridge over the railway tracks in Ludvika, Sweden, was under construction. During the casting of the concrete of the new Kajbron, the falsework failed and collapsed, when approximately 75% of the total concrete volume had been poured. The collapse took place without any indications before the failure. In the accident, twelve workers were injured, and extensive damage was caused on the overhead wire, tracks, and railway signalling system (Trafikverket, 2017c).

4.3.1 Reasons Behind the Accident

After the accident, the STA conducted an investigation to evaluate the reasons behind the collapse. The accident report published by the STA is based on the contractor's investigation of the accident (Trafikverket, 2017c). The contractor's report concluded that the main cause of the failure was undersized designed falsework. The design and calculation of the falsework were not conducted or reviewed by the main contractor, but instead outsourced to another TW company. The construction process was divided between multiple subcontractors. These circumstances resulted in a lack of documentation regarding the completed work and follow-ups made. Another deficit was that no self-control or third-party inspections were carried out on the falsework. The standard procedure for the STA involves successive documentation during the construction process. It was also stated that the contractor did not conduct an inspection with a bridge expert before the start of the concrete casting (Trafikverket, 2017c).

A common routine, but not a demand, in a regular bridge project is to hand over the documentation of the TW design in beforehand to the STA. In this case, the documentation was not handed in by the contractor or its outsourced TW company. It is neither STA's responsibility to demand this documentation, although it is highly recommended by the administration. According to the STA's investigators, the contractor had not reviewed the hired TW company's documents which resulted in no second or third-party review of the design at all.

The decision to change the bridge type from a rigid frame bridge to simply-supported bridge deck by the contractor, lead to further complications in the way of construction. The decision resulted in a new way of production where the bridge had to be cast in an elevated state and afterwards lowered down onto the supports (Trafikverket, 2017c).

After re-visiting their working methodology, the STA took internal actions to avoid future accidents. Three points of interest were established. The first one was to increase the focus on identifying risk factors together with the contractor. TWs should always be regarded as a risk due to the high probability of accidents. The second area of improvement regarded the initiation phase of the planning process where demands, risk analysis, time scheduling and a specific control program for each individual project should be addressed. The third and last point of interest was found in the execution phase, where competent personnel from the contractor in the future should perform a follow-up on the construction site after the erection of the falsework (Trafikverket, 2017c).

According to the STA's accident report, the contractor developed an action plan aiming to improve the methods of production extensively after the accident in Ludvika. The STA's response to this action was to call it a step in the right direction for the industry.

In conclusion, the main reasons behind the accident can be identified as stability problems in the falsework. Mainly because of the miscalculated load case during the casting of the concrete. However, during construction of the TW, no proper inspections discovered the lack of structural integrity.

4.3.2 Alternative Theories Behind the Accident

Accordingly, to the Swedish Working Environment Authority's (SWEA) accident report, the supplier of the falsework aimed suspicions against the contractor which performed the erection of the formwork. Both the execution and design are to be seen as deficient. It is also stated in the report that the casting scheme was changed the same day and this was not communicated and checked with the supplier of the falsework. Instead, the contractor decided to change the direction of the concrete cast front to start from the east side of the bridge instead of the west (Arbetsmiljöverket, 2017).

During the interview with the experienced TWE, see Section 5.4, problems with the foundation of the falsework was raised. The TWE had helped the TW company to investigate the reasons behind the collapse. The TWE was of the opinion that settlements had accrued due to different types of foundations and soils. The settlements of the supports resulted in a new force distribution in the falsework. The redistribution eventually exceeded the resistance capacity of the falsework structure. The STA's and the contractor's accident report does not consider any geotechnical problems (Personal communication, Mars 5, 2019).

4.4 Scaffolding Collapse on Engelbrektsgatan 2018

In February 2018, a façade scaffolding in Gothenburg, Sweden, collapsed, see Figure 4.5. The scaffolding was used during the renovation of a façade. At the time of the collapse, no workers were present due to lunchtime, neither were any civilians close to the scaffolding when it collapsed. No injuries were caused by the accident (Hultman et al., 2018).

Figure 4.5: *The collapse of the façade scaffolding along Engelbrektsgatan in Gothenburg (Hjelmgren, 2018).*

4.4.1 Reasons Behind the Accident

In the inspection report from the SWEA, it is stated that many mistakes were made and procedures were overlooked, leading to the collapse. The scaffold had structural elements from two different manufacturers. If this is the case, an investigation should state that these two brands are compatible together according to Arbetsmiljöverket (2013). However, this had not been concluded according to Arbetsmiljöverket (2018). The sheeting on the scaffolding also influences the wind loads used in the sizing of the structure. According, to Arbetsmiljöverket (2018), the calculations were hard to follow and with obvious shortcomings when calculating the most loaded connection in the façade. Another deficiency was determined regarding the documentation from the scaffolding contractor to the main contractor (Arbetsmiljöverket, 2018). Only one out of five required documents were handed over. The document provided contained the self-checks that had been performed (Arbetsmiljöverket, 2018). The last deficiency specified was the anchorage of the scaffolding in the façade. To achieve the best connection, the anchor should go through the grout and into the bearing stones behind the façade. In this case, the connections were only drilled through the grout. Pull-out tests afterwards showed varying results in capacity regarding these connections. In some cases, the tension capacity was satisfactory, while others failed to reach the minimum capacity required. No capacity tests of the façade anchorage was performed before erection, which is mandatory when constructing a façade scaffolding with wind sheeting (Arbetsmiljöverket, 2018).

4.5 Summary

One major obstacle in the research was the difficulty to access well-documented reports from accidents which had occurred within the building construction division. Unfortunately, accidents during the construction of buildings are often not well-documented, and therefore, it has been hard to investigate the causes and severity of accidents related to TWs within the building construction industry.

One discovery was the lack of independent investigation reviews performed of the accident in Ludvika 2017, where the STA was the client. The STA used the contractor's investigation as the STA's official explanation of the causes behind the accident. However, in the Kungsbacka accident, there was an independent investigation carried out by the STA, although questioned by some experts.

Additionally, the official report from the STA regarding the accident 2008 at Ärlandsfjärden has disappeared in the administration's archives. The incident is to be seen as a severe mishandling of public documents. Instead, the STA has provided the news memo from the contractor at the time, and responsible people of the investigations have been heard to understand the sequences of events.

5
Interviews

The interviews serve a range of different purposes in establishing an overall view of the design and management of Temporary Works (TWs). Seven interviews have been performed with four main types of stakeholders representing: contractors, Temporary Work Engineers (TWE), Permanent Work Engineer (PWE), suppliers and authorities. The questions asked were tried to be as similar as possible with all the respondents, although some changes were made to fit with the respondents' occupations. Even though the respondents and companies are anonymous, it should be noted that all the conclusions and opinions are personal and do not reflect an official statement of the company they work for. As a result of the interviewing structure, the answers are interpreted and reproduced by the authors in the thesis.

5.1 Interviewing Method

To ensure a high enough reliability in the thesis, four bullet points were followed cited in Bryman and Bell (2011). These will be presented individually in the following section.

External reliability
The external reliability essentially points to which degree the thesis can be replicated by other scientists or researchers. It is especially challenging to recognise in this thesis since all the interviewers are selected by some subjective measured. Furthermore, it was hard to follow through with the interview script, since conditions sometimes were more of a presentation type than a regular interview. Despite this, it will be possible to reproduce all of them, provided the interviewing script is the same. Bryman and Bell (2011) also mentions that in some cases it is necessary for the replicating researchers to acquire a similar social role, in this case, master students in the program *Structural Engineering and Building Technology*, to get the same result. A similar education is to recommend since the professional language can be hard to understand for someone not familiar to the studied field.

Internal reliability
In this reliability point, it is ensured that the different members of the research group are in agreement of what is concluded from, e.g. interviews. In this thesis, the agreement of the conclusion is assured since all the interviews were conducted by both authors and thereafter discussed and transcribed. Moreover, all point which has led to discussions have been reassured by the interviewed respondents.

External validity
The external validity of a thesis directs to which degree the findings can be generalised. This generalisation can be a problem since, e.g. the opinions of the interview partners can vary with other stakeholders in the industry. As the approach of the thesis is to find the common errors and misconceptions in the industry today, the overall estimation is that the results and findings will be general enough to use in any further TW projects or studies.

Internal validity
When examining this topic, one compares the observations and findings from the thesis with the ideas developed. According to Bryman and Bell (2011), this is especially true for quality research, since the ideas are directly influenced by the subjects interacting in the researched social structure.

5.1.1 Interviewing Procedure

All the interviews were carried out in a semi-structured style. The semi-structured style means that there was a predetermined set of questions and interview schedule that could be changed and adapted to the respondent's profession. In this interview style, it is also allowed to ask follow-up questions and ask more open-end questions (Bryman and Bell, 2011). The interview schedule for all the interviews can be found in Appendix A. The questions where not sent in beforehand in all but one interview. An exception was made in the interview with the Swedish Transport Administration (STA) since the respondent could not determine if the interview questions could be answered. The questions were not sent in beforehand to the other respondents in order to ensure the sincerity in the answers and retain an open mind, since some questions involved the participation of the respondent in accidents. In all interviews, the two authors to this thesis were present and all but one where recorded to ensure the correction of the answer. It was the interview with the STA which not got recorded due to the respondent's unwillingness. All the interviews were transcribed and sent to the respondents for confirmation of the answers. The confirmation was important to ensure all of the answers were confirmed, and there was no later disagreement about the interview.

5.1.2 Use of the Temporary Works Stakeholders Graph

To visually categorise different stakeholders and interviewing partners within the TW industry, a graph has been developed by David Salekärr to explain the relationship between *Theoretical knowledge–no theoretical knowledge* (x-axis) and *Practical experience–Ignorance or Inexperience* (y-axis), see Figure 5.1. The x–axis represents the theoretical TWs knowledge level and has been marked with different types of theoretical knowledge on the scale, both individual and documented theoretical knowledge. The y-axis represents how much practical knowledge the stakeholder poses, the scale has been marked with a practical experienced structural engineer and a student or person with lack of knowledge, which will give an indication of the scales. The non-linear line in the graph is an indication of how placement in a certain axis has to be supplemented with the other axis to fulfil a safe working procedure with TWs.

The graph *Temporary Works Stakeholders Graph* will be presented along the interviews to explain where the company or respondent can be positioned. It is important to clarify that the positions which have been given are done subjectively by the authors and their understanding of the respondent and the company they represent. In Figure 5.1, four different generic stakeholders been plotted to explain the graph. The *Contractor* placement represent a worker at the construction site. A worker general has good experience from earlier work, which gives them a high grading on the practical experience and knowledge axis. However, the worker does not have the theoretical theory behind why some designs are better and is following rule of thumbs, drawings and instructions manuals. Therefore they would be placed in the upper left corner of the graph. The TW supplier represents an engineer who works at a local office and in general follows the instructions of the TW systems. The engineer has a good practical understanding of the supplier company's offered systems, therefore the intermediate grading in the practical knowledge. With the help of the company's element capacity and simpler software to aid the TWE, the placement on the theoretical knowledge scale is in the middle. The researcher posses a good knowledge in the theoretical aspect and therefore in all the documentation which is published by the scientific society. However, it is likely to believe the researcher may not have the same understanding of practical experience at the construction site, which results in a low placement on the y–axis. Finally, the structural engineer has a good understanding of governing EC and ENs, resulting in the high grading of theoretical knowledge. In the practical knowledge, the engineer possesses a rather good understanding to be able to do a good design of the PW.

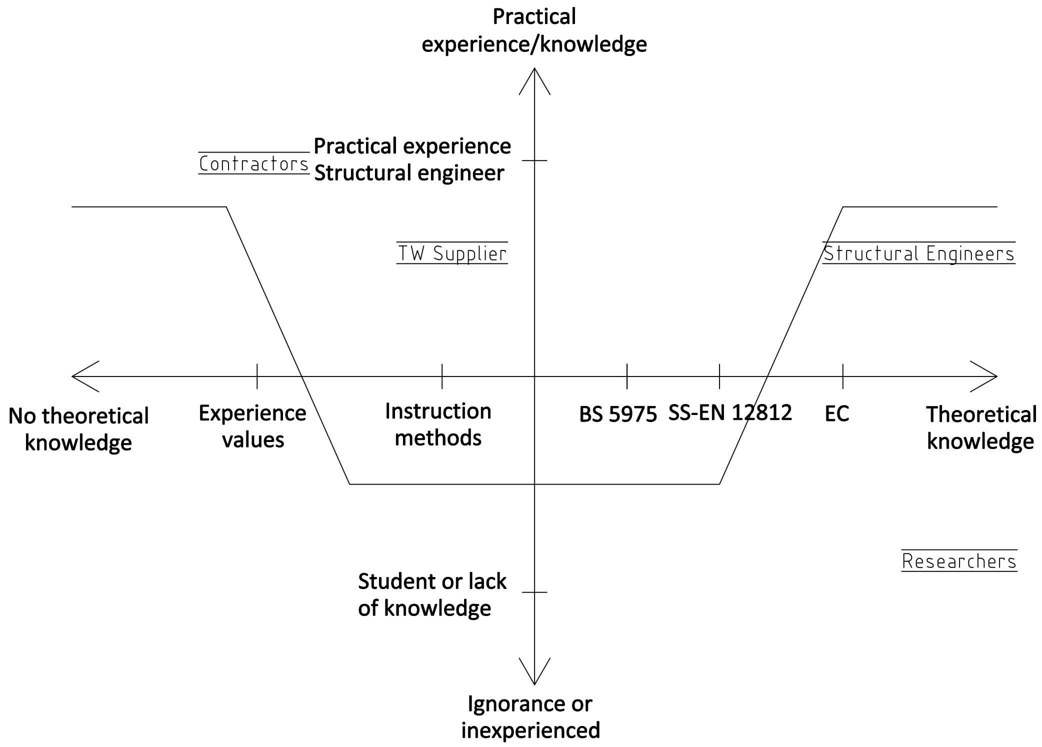


Figure 5.1: *Generic placement of different stakeholders within the industry presented in the Temporary Works Stakeholders Graph.*

5.2 Interview with Swedish Contractor 1

The contractor is one of the largest in Sweden and is active in both the building- and civil engineering industry. They have in recent years developed routines regarding the usage of TWs. These routines were developed after a fatal accident. A committee was established by the contractor to investigate the reasons behind the accident. The committee's aim was to reach conclusions on why the accident took place and what could be learned from it, in order to be able to implement new rules in all divisions to avoid this kind of accidents in the future. The committee used expertise from its subsidiary in the United Kingdom (UK) to developed their new routines in Sweden. The investigation resulted in numerous new routines and documents, and the conclusion that TWs should be managed in the same way as PWs, following ISO 9001 (SIS, 2015).

The contractor uses the following definition for TW: *"A temporary works is needed to be able to perform and complete a permanent structure and are often demolished afterwards or gradually. A TW can also be a PW, for example, an earth retention system"*. The respondent also points out that the ground is a TW. All machinery and TW above the ground rests on the soil or clay and are therefore to be treated as a TW.

5.2.1 Demands on Responsible Engineer and Verification of the Design

After an additional accident a couple of years later, the respondent state that the company decided that too many accidents related to falsework had occurred. The contractor experienced that their subcontractors, which were supposed to be experts on TW, only used standard static calculations and were not able to design advanced TW structures sufficiently. After the second accident, an investigation was carried out, and a decision was made to let all falsework designs for bridges to reviewed by a second opinion. The respondent explained the second opinion as a third-party review, either from their own organisation or by a consultant, as long as the reviewer has the required prerequisites'. In order to regulate this process, the contractor has defined the prerequisite as five years of experience in the industry, especially within TWs. To ensure the prerequisites' are fulfilled, the contractor can demand a CV or other types of confirmation from the consultant. How the review should be done is not specified by the contractor. Instead, it is up to the responsible reviewing engineer to choose the right methodology.

The respondent does not have any knowledge of any attempts to establish an industry-wide national regulation, in the same way as the industry has agreed on the document "*Schakta Säkert*", which explains safe procedures regarding excavation and ground shoring in Sweden. The respondent states that the regulations today can lead to a competitive advantage when disregarding safety issues when handling TWs and in extension, reduce the price offered.

5.2.2 Temporary Work Supervisor

In the routines of the contracting company, it is clearly stated that there should always be a designated Temporary Work Supervisor (TWS) responsible for all TWs on the specific project, no matter the size of the TWs. The TWS should always be on site to overlook the work carried out, with the exception for very small projects where the TWS in the worst case does not have to be present all the time. The TWS's function is to ensure that all TWs are inspected and assembled in a correct way from the instructions and documentation provided. The TWS does not need to be able to assess all parts in TWs, but should be able to estimate if they got enough knowledge to make a correct assessment. If not, the TWS is encouraged to seek help from a more competent person. This person could be a structural engineer in the company or someone else who has the prerequisites of similar work. In the end, the TWS main task is to oversee all parts in the process and make sure they are evaluated and approved, in order to continue with the next step of the production.

To become a TWS within the company, one has to have the right prerequisites and knowledge regarding the usage of TWs. The TWS also has to perform and pass a test on the company's intranet. The test consists of an introduction, lectures and ends with a multiple choice questionnaire. When the test is passed, a certificate is handed out, acknowledging their knowledge in the area. If all this is achieved, it is up to the construction site manager to appoint a TWS.

5.2.3 Verification Document

The verification document is structured to guide the user through all necessary steps while using TWs. For the project to move on, the TWS either needs to sign the verification document or let a responsible person sign the document. The process then follows several control steps until the PW is cast and the TW can be dismantled. The TWS has a large responsibility, sometimes taking place under strict deadlines. The signing momentum should ensure that all steps are performed correctly, resulting in a safe working environment. The TWS is empowered to stop all ongoing work on the construction site if there are any concerns regarding the safety in regard to TWs. The verification document is only to be used if the TWS decides there is danger concerning the workers from the TW.

Inventory
The first step in the verification document is to make an inventory of all boundary conditions and has to include a detailed description of the TW construction. It is also in this stage the TWS decides if there is a risk for workers health and whether it is necessary to proceed with the checks or not of the TW.

Planning
The second step is planning. The prerequisites of the responsible Temporary Work Engineer (TWE) is to be checked and have the right experience. The names of the responsible structural engineer, inspector and independent reviewer of the falsework are noted.

Start-up meeting
The third step is a start-up meeting with the responsible TWE, where the TWs are discussed with the contractor.

Before assembly
The fourth step is taking place before the assembling of the TW. The supervisor has to control all documentation and make sure they are approved, and the latest versions are available on site. An inspection of the delivered TW has to be performed, as well as an inspection of the foundation for the TW. At last, a work preparation document needs to be established and approved.

Before loading
The fifth step is called before loading. A plan for how the loading of the TW will be carried out is established and has to be approved. Thereafter, checks to make sure the erection of the TWs is done correctly are carried out. When all these steps are approved by the TWS, the project can proceed.

During loading

In the sixth step, the TW is loaded according to the previously sett terms. The verification document requires continuous supervision of the whole process to ensure all conditions determined in previous steps are followed.

Dismantling
The seventh and last step is the dismantling of the TW. Before dismantling, a working procedure document has to be established stating how the dismantling is supposed to be carried out. When the working procedure is approved, the project can proceed, and the TW can be dismantled.

5.2.4 Placement in Temporary Works Stakeholders Graph

Due to the extensive work done internally in the company with documentation and the verification document, the employees have guidelines to follow with the help of a TWS. The position is set for the overall company, not the respondent. The position is marked in the graph with a red dot, see Figure 5.2.

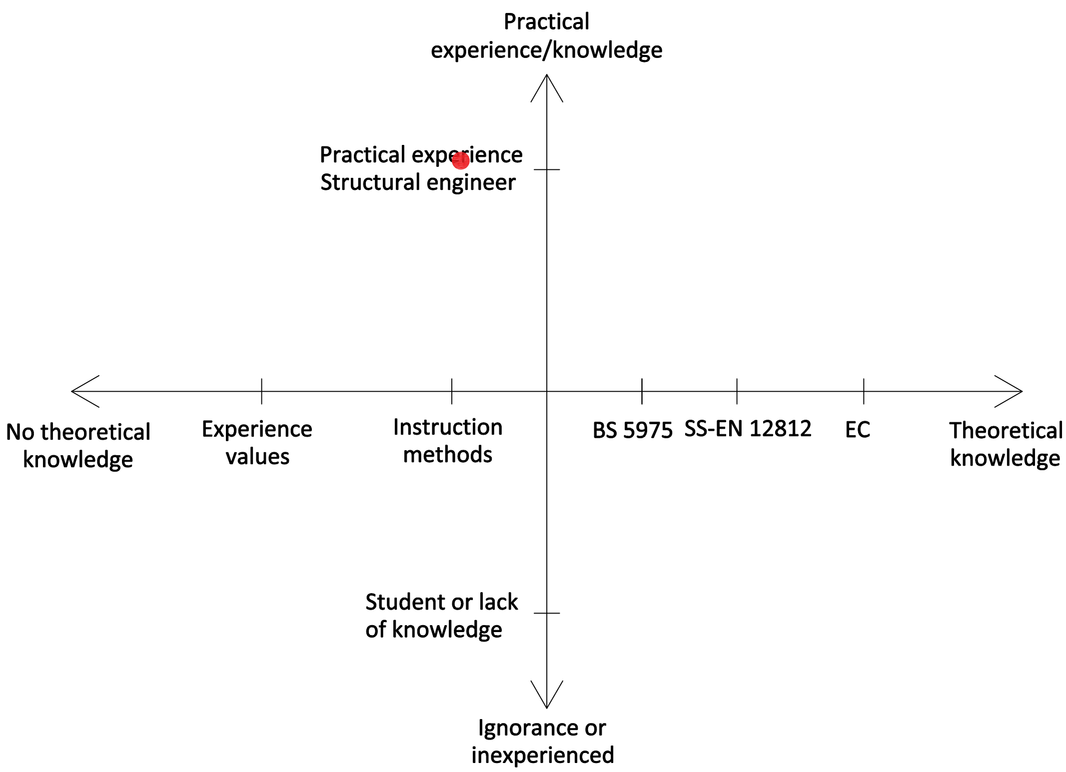


Figure 5.2: *Placement of Contractor 1 in the Temporary Works Stakeholders Graph.*

5.3 Interview with Swedish Contractor 2

The contractor interviewed is one of the largest companies in the Nordic construction industry. They are involved in a wide range of different construction projects such as buildings, bridges and roads etc. The main focus of the company lies on the construction site since they only have a small number of civil engineers working with in-house consulting and then mainly in the geotechnical field. Therefore, the company and its employees are more focused on best practices and experiences from the construction site. The respondent in the interview has a long experience within infrastructure since the mid-’80s from working on the construction site and still directing 20% of his working hours on site.

5.3.1 Demands on Responsible Engineer and Verification of Design

Concerning falsework, the contractor has as a routine to have most of the calculations reviewed by a third-party. The review can either be done by the structural engineer of the permanent structure or one specialised consultant for TWs. In one of the accidents the company was involved in, the routine check carried out by the Swedish Transport Administration (STA) was seen as a third-party review, although the check performed was not as thorough as a standard third-party review according to the respondent. In the respondent’s opinion, the accident was’ therefore’ able to happen since mistakes in the calculations were not detected.

The routine used by the company regarding falsework is based on SS-EN-12812 and states that falsework falling into design class A, does not have to be specifically calculated and is therefore also not required to be third-party reviewed according to the contractor’s routines. Furthermore, the company also requires some kind of review of the erection process and of the finished assembled falsework. The methodology concerning these checks is not clearly described in any internal documentation, and therefore, a large responsibility is on the site manager to have good oversight. The respondent points out that, e.g. that all the falsework drawings on site have to be checked, as there have been incidents where old drawings that not contain the latest updates were circulating on the construction site. The final control of the falsework is performed by the supplier of the falsework. In addition, the contractor performs a review of the erected falsework. The approval usually consists of an inspection protocol provided by the falsework supplier with a signature by the inspector from the supplier and the contractor.

The areas causing continuous problems when constructing falsework for bridges, according to the respondent, are the control of long bearers under the soffit which may have to be extended more than initially calculated in the drawings due to changed ground conditions. Longer bearers lead to a reduced capacity due to the higher risk of buckling. Another critical area which continuously is creating problems is falsework placed in slopes. It is according to the respondent often, very hard to guaranty a safe distribution of the forces into the ground in slopes without the risk of a collapse of the terraces.

Overall, there are no strict guidelines on how to safely manage TWs in the company other than the third-party review. They often rely on the expertise and experience of the site managers and foremen, as well as the overall project manager. There is no continuous knowledge management transfer. After the incident referred to previously, the company concluded not to let the STA make any more third-party reviews of their falsework. The ban is not captured in any document in the company, but more of a broader understanding throughout the organisation.

5.3.2 Placement in Temporary Works Stakeholders Graph

The lack of routines and instructions regarding TWs within the company is the result of the confidence in the workers' and the consultants' experiences to perform and use TWs under safe conditions. This circumstance is why the placement is rather high in practical knowledge, but at a low grade on the theoretical scale. The placement in the graph reflects the position of the company rather than the respondent. The placement can be seen with a red dot in Figure 5.3

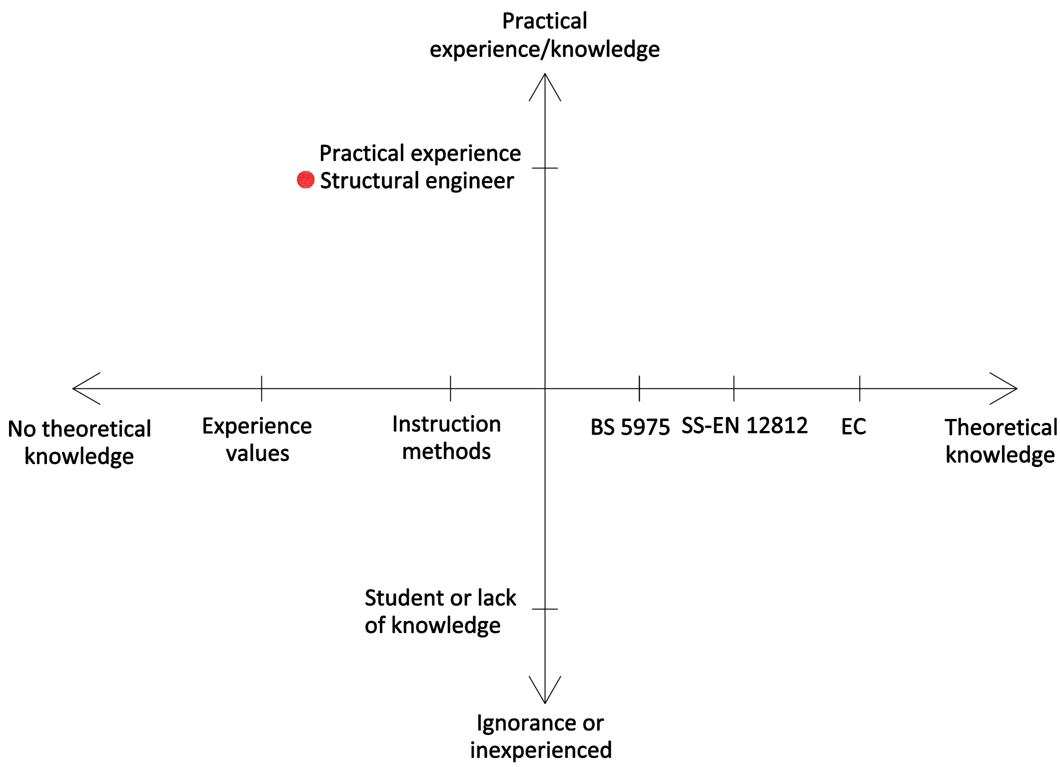


Figure 5.3: *Placement of Contractor 2 in the Temporary Works Stakeholders Graph.*

5.4 Interview with an Experienced Temporary Work Engineer

The respondent in this interview has over 50 years of experience in the field of structural engineering, and TW in particular. The company for which the respondent is working for was, and still is, one of the most known bridge engineering firms in Sweden. Due to this background, the respondent investigated all the previous bridge accidents mentioned in Chapter 4. The respondent only uses conventional calculation methods, such as hand calculation, when designing TWs. According to the respondent, the calculations of the TWs, especially formwork, is not complicated. The problem when designing TWs is rather the basic understanding of structural statics, which often is deficient amongst other structural engineers working with TWs. According to the respondent, one factor leading to this general lack of understanding in statics is the introduction of Finite Element (FE) analysis in the structural engineering field. Although useful in many cases, FE analysis can lead to confusion of the structural system. The absence of education concerning TW in the field of civil engineering at the universities is also something which is pointed out as contributing to the lack of knowledge. Moreover, the engineers at consulting firms rarely come in contact with TWs, which leads to a lack of understanding of TW design.

As the design and calculation of TWs are strongly tied to the on-site production and soil conditions, it is essential to have sufficient knowledge regarding the erection technique of TWs. Overall, the knowledge and craftsmanship at the construction site have, according to the respondent, decreased over the years. As a key factor, the lack of education of foreign workers is mentioned. In earlier years, most of the timber work was performed by trained carpenters, often specialised in formwork and falsework. In recent years, these workers have been substituted by lower skilled and often cheaper workers. In addition to this, the respondent points out the unwillingness by some site-managers and foremen to follow the delivered drawings and dictated terms and insist on applying previous good practice experience. In order to help others working with TWs, the respondent has been educating engineers and other personnel on a contracting company. The main objective was to increase the knowledge within TWs design and make the attendees familiar with TWs.

When conducting a review, the respondent always performs hand calculations continuously, following the original design to compare results. Additionally, and more importantly, all the boundary conditions and structural systems are investigated and tested on their plausibility. In this state, experience and three-dimensional thinking is of outermost importance since flaws in this stage can have catastrophic consequences.

As one last key factor, the respondent cites coordination as crucial. The most important part is the coordination between the responsible engineers of different construction parts, especially between the falsework and the formwork, as well as between the falsework and the supporting ground. When considering the intersection between the formwork and falsework, there is often confusion about where exactly the intersection is and which parts are the responsibility of different structural engineers involved in the design. It can also be hard for the falsework engineer to identify the loads which act on the falsework since the loads are handed over by the formwork engineer. When investigating the intersection between the formwork and the ground, the situation is somewhat different. Here the loads from the formwork are clear, but there can be discoordination between how to transfer the loads into the ground. Either the geotechnical conditions have not been reported correctly, or the foundation of the formwork is poorly executed. Finally, the respondent stresses the importance of experience and routine when designing TWs. However, the respondent states that no knowledge management transfer for the TWs skills the respondents possess take place in the company.

5.4.1 Placement in Temporary Works Stakeholders Graph

The experienced respondent has a good understanding of both practical and theoretical knowledge within TWs. The long experience within design, investigating accidents, reviewing and educating contractors results in a high placement on both scales. The placement is for the individual respondent, not the company which the respondent represents. The placement can be seen in Figure 5.4 as a red dot.

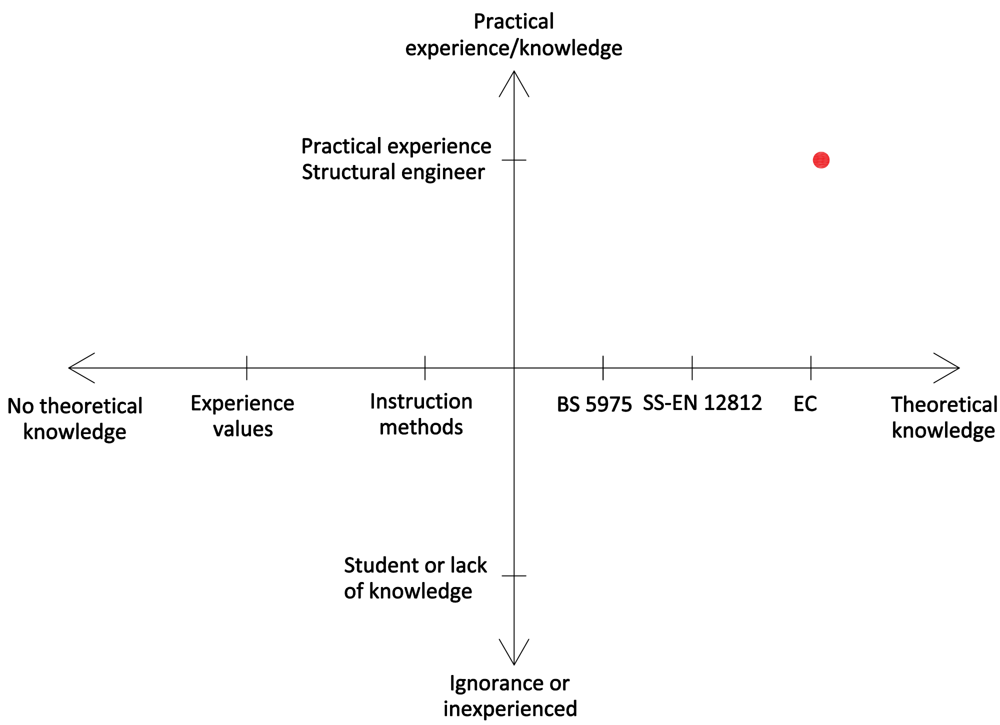


Figure 5.4: *Placement of the Experienced Temporary Work Engineer in the Temporary Stakeholders Works Graph.*

5.5 Interview with a Temporary Work Supplier and Engineering Company

The company interviewed is operating as a supplier of falsework in the production of mainly concrete bridges. The interview was carried out with two persons present, which both are structural engineers. They also provide the construction site with falsework drawings, which are used to assemble the falsework. The company only uses one particular falsework system which they then rent out to contracting companies working with the permanent bridge. The company has also been involved in one of the accident's mentioned in Chapter 4 and has good insight into the strengths and flaws of the TWs sector today.

When designing their own falsework systems, the company is always following SS-EN-12812 and carry out an in-house review, the same applies to the drawings. During design, the supplier also takes guidance from the Swedish formwork and falsework manual "*Handbok i formbyggnad*" (Byggentreprenörerna, 1993) and the British literature *Formwork - A guide to good practice* (The Concrete Society Working Party, 2012). The company claims that although without an ISO 9001 certificate, they have a similarly efficient and safe control system. Out of their perspective, the greatest difficulty when producing calculations is often not the regulations and standards, but rather access to correct information from the contractor hiring them. In their opinion, they often are involved too late in the process, and the boundary conditions do either not correspond to reality or are changed very late in the process. Moreover, the respondents stress the importance of a clear separation in the interfaces within the structure and separation of responsibilities between stakeholders. In addition to the internal reviews, the calculations and drawings are often subject to a third-party review from other structural engineers. The respondents express their mixed feelings about these reviews, on the one hand, they are grateful for the extra check of their own work, which leads to a reduced risk of errors. On the other hand, they often encounter inexperienced reviewers who often focus on unimportant and small details in the calculations rather than on the overall structural integrity and failure capacity.

The respondents also highlight the fact that there is no industry organisation regarding falsework. As a result, the respondents find it noticeable that there are strict regulations surrounding scaffolding but not falsework, e.g. regarding inspection and education of workers. They also stress the importance of an industry organisation when aiming to increase the quality of falsework designs, reviews and erection. The introduction of such an organisation could also result in a fair competition between companies.

A more significant issue, according to the respondents, can be found at the construction site. Although offering an inspection of the erected falsework to all their customers, not all of them take advantage of this. When conducting a review on the construction site, the respondents always follow a similar procedure. Often the control is performed by one individual but if there are complicated or larger structures, there will be two of them performing the review. As they can not check every single detail in the structure, only the important and complicated areas are checked alongside with random samples of common elements. If several errors with the same character are discovered, a more detailed inspection is performed. Errors can be drawn on the documentation papers, so the contractor easily can understand the problem and correct it afterwards.

When entrusted with the control, the respondent often finds a wide range of different shortcomings on the erected falsework. One of the most common errors are not enough secured locks, missing braces or problems in terraced slopes on which the falsework stands on. In some cases, there are more severe problems endangering the structural integrity through incorrectly erected falsework.

During inspections, the respondents also frequently see deficiencies in the geotechnical work and foundations which are poorly executed, in the same way as for the terraced slopes. In order to ensure sufficient foundation for the falsework, the contractor has the responsibility to coordinate different consultants.

The respondents also raise the question about subcontractors performing the erection of the falsework and the lack of knowledge they encounter when visiting the construction site. It is rather common to discover large quantities of unused falsework elements which are not used in the erected falsework. Incorrectly installed elements are especially concerning since the supplier always delivers the necessary amount for the project.

During the design process of TWs, the communication with the main structural engineer are nearly non-existing. Moreover, the respondent also experiences a lack of communication between the contractor and the main structural engineer. The respondents think that the main structural engineer, in most cases, does not consider the process of casting the structure. As a final remark, the respondent stresses that all the adapted third-party reviews and improved internal working methods are ineffective if not the practical knowledge and awareness on the constructions site increases. Interview

5.5.1 Placement in Temporary Works Stakeholders Graph

The Temporary Work Suppliers and Engineers possess a great understanding of the governing codes and regulations. They also use their own system when designing TWs, contributing to their practical knowledge. The structural understanding of PWs are also rather good. The placement in the graph represents both the company and the respondents at the same time. The placement in the graph can be seen in Figure 5.5.

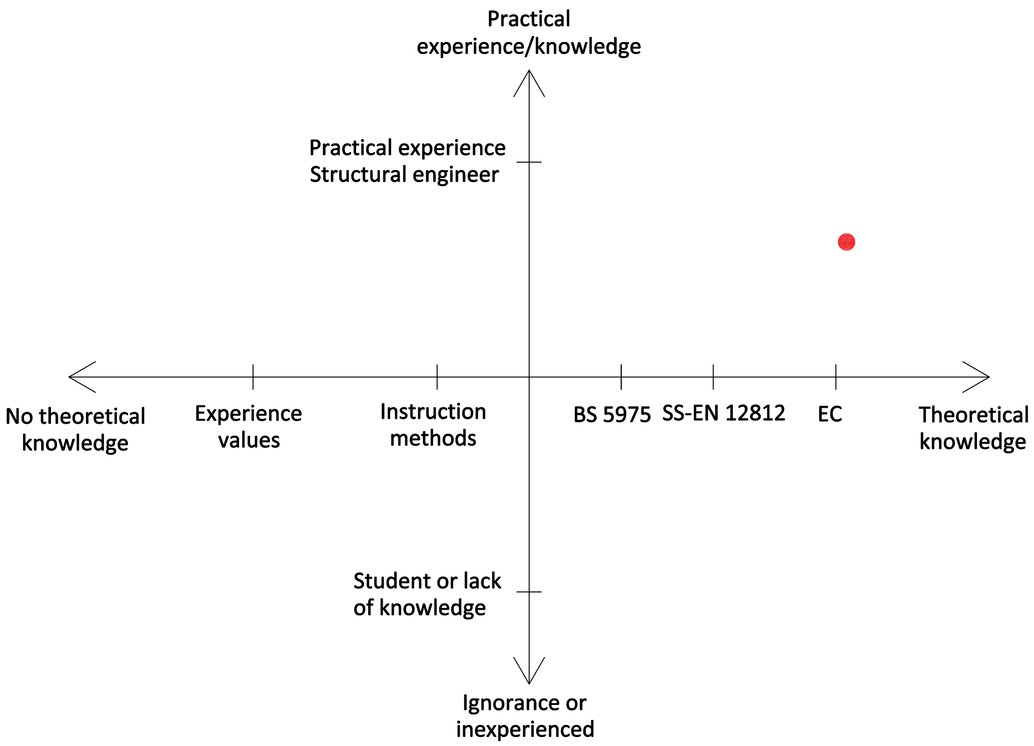


Figure 5.5: *Placement of Temporary Work Suppliers and Engineers in the Temporary Works Stakeholders Graph.*

5.6 Interview with a Temporary Works Supplier

With over 20 years of experience, the respondent has good knowledge of their systems and documentation regarding TW. The company which the respondent represents is one of the major suppliers of TWs in Sweden and abroad. In the interview, it was clearly stated that more oversight and third-party control was to be desired. Furthermore, it transpired a lack of understanding in the industry where the responsibilities lie in the calculation of TWs. The respondent recalled a number of structural designers who asked how to account for different types of loads concerning TWs, and how to make a safe assessment. However, to asses systems for different load types, e.g. a concrete slab on backpropping, is according to the respondent, not the responsibility of the supplying company.

From the supplier's point of view, their responsibility starts with providing safe and operational TW elements which have the right properties demanded by the contractor. According to the respondent, TW products made out of timber have a lifespan of three to four years and elements made out of steel, ten to twelve years. When the boundary conditions for the TWs is formulated by contractors, the supplier can deliver TWs and documentation which meet the demands from the EC, ENs and regulations which governs TWs in the specific country.

The respondent also mentions that only one contractor on the Swedish market has routines that regulate TWs. The calculations which design the sizing of the delivered TWs are usually performed in Sweden, but can be supplied by the main office abroad instead, if the responsible engineer in Sweden does not have sufficient expertise.

Regarding the reviewing of documentation and calculations, the supplier points out that this is rarely done. Their clients often do not have any demands that the documentation should be reviewed, but if stated in the contract, they would be able to offer such a service. When it comes to internal reviews of the supplier, they will soon have an ISO 9001 certificate that proves they have an approved management system in all their operational countries. It should be stated that controls are more often performed for infrastructural projects than for housing projects. Only an extraordinary PW within a housing project which demands a special TW solution would be required to have a TW review.

The respondent is of the opinion that there are almost the same amount of accidents in both housing and infrastructural project. However, there are often different causes behind the accidents. In the infrastructural projects, TWs often have to go outside the standardised solutions, this demands TW structures, which perhaps are not standardised and can lead to accidents. While in housing projects, accidents usually are caused by incorrectly mounted TW systems or accidental overloads on the newly cast floor slab. In this case, it is almost always the case that the supplier's client has given incorrect boundary conditions for the project, or has not ensured the right loading on the slab. According to the respondent, the main reason for the failure of TWs is that no third-party review takes place, especially for infrastructural projects where the loads are larger and structures are more complicated. Reviewing also includes an inspection on site to achieve the desired standards.

Regarding backpropping, there are different understandings between the supplier and the responsible structural engineers. There is a common misconception from structural engineers that the supplier provides the number of props needed to secure a floor soffit, as well as the number of floors which need backpropping. The calculation of loads is not the supplier's responsibility, according to the respondent. The supplier does not have the needed information nor the necessary liability to carry out these calculations. These calculations are the responsibility of the structural engineer in the project, which has the necessary data. The suppliers are for the most part, only interested in line loads as they know the capacity of their elements and can then calculate the amount needed. The supplier uses the permissible stress method when they specify the resistance for their elements. The respondents state that it is easier to specify elements this way.

5.6.1 Placement in Temporary Works Stakeholders Graph

The Temporary Works Suppliers normally use their standard solutions which they know the exact capacity for, but do not have any specific knowledge in the theory behind it. They also possess templates for all their elements, explaining how the elements should be used. All this places them high within practical knowledge, while the theoretical knowledge is somewhere between their manuals and existing standards. The placement can be seen in Figure 5.6.

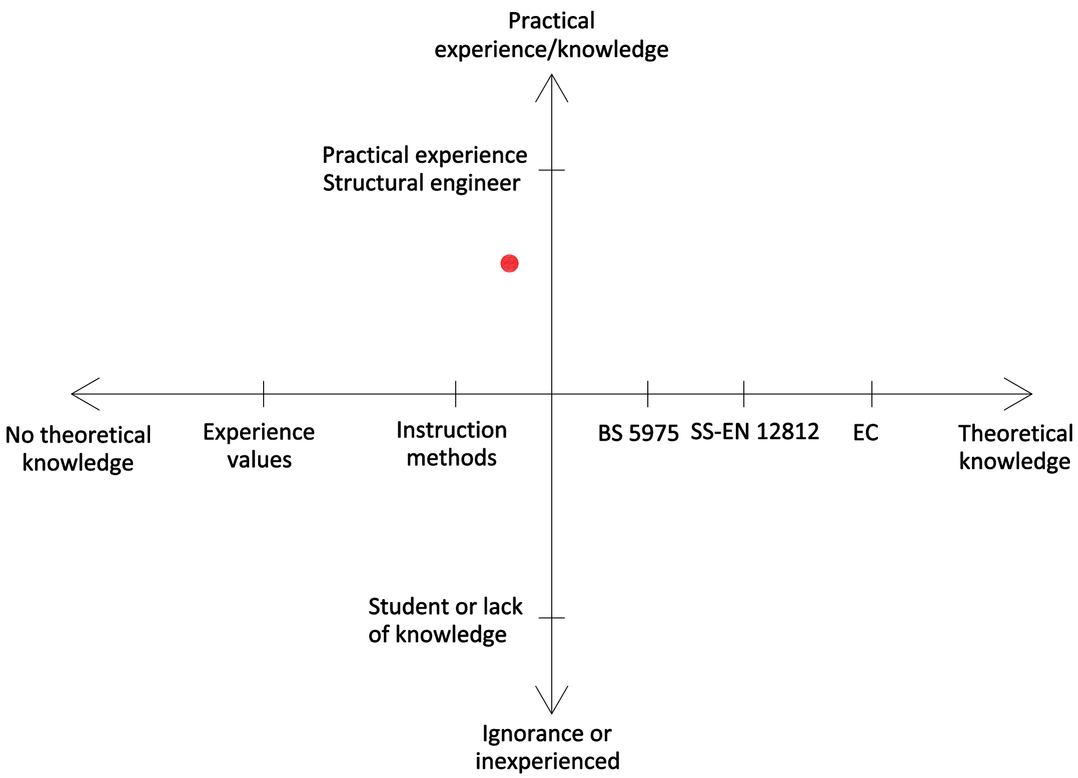


Figure 5.6: *Placement of Temporary Works Suppliers for House Construction in the Temporary Works Stakeholders Graph.*

5.7 Interview with an Scaffolding Supplier

The two respondents in this interview are salesmen and coordinators at a globally operating scaffolding supplier. The company does not erect the scaffolding, but delivers calculations, drawings and material to scaffolding erection companies around Sweden.

Even if the respondents main role in the company is sales, they have previous knowledge of production stages in the construction industry. With this background, they are able to consult on-site and resolve possible questions which can arise. The respondents company does not offer any reviewing service of the erected scaffolding. If a review is demanded, it is up to the client to find a consultant for the job. The company's structural engineers use templates when designing TWs in their computer program. When the design is done, they calculate the structure with the help of EC, ENs and element's user manual. The respondents are of the opinion that accidents most commonly occur if the scaffolding is not erected according to the design instructions.

The industry organisation, which is connecting all scaffolding companies and is working for more dialogue and a level playing field throughout the industry. On the Swedish scaffolding market, this organisation is called *Ställningsentreprenörerna* (STIB). STIB has developed information and guides to establish safe scaffolding and working environment on all levels of the industry. For Example, STIB organises education programs for workers to be permitted to erect scaffolding.

Some contractors also include in the contract that the erection of the scaffolding has to follow STIB's regulations. Although there is an industry association for scaffolding, the respondent stresses the problem of unfit companies on the market. They refer to different construction sites, where they had left an offer, but the contractor went with another company that offered a lower price tag. As a result of a lower price, less safety-related material has been used, leading to a reduced safety on the construction site. In this way, working environment safety becomes part of the negotiation when submitting tenders for projects.

The respondent also addresses concerns regarding SWEA and the lack of knowledge they possess regarding scaffolding. The supplying company educate SWEA inspectors on how to perform professional controls at the construction sites when visiting them during routine visits. The respondents express their concern of an authority that has a poor understanding of the subject but are the enforcers of the law.

5.7.1 Placement in Temporary Works Stakeholders Graph

The Scaffolding Supplier normally uses their standard solutions which they know the exact capacity for, but do not have any specific knowledge in the theory behind it. They also possess templates for all their elements, explaining how the elements should be used. All these circumstances place them high within practical knowledge, while the theoretical knowledge is somewhere between manuals and existing standards. The placement can be seen in Figure 5.7

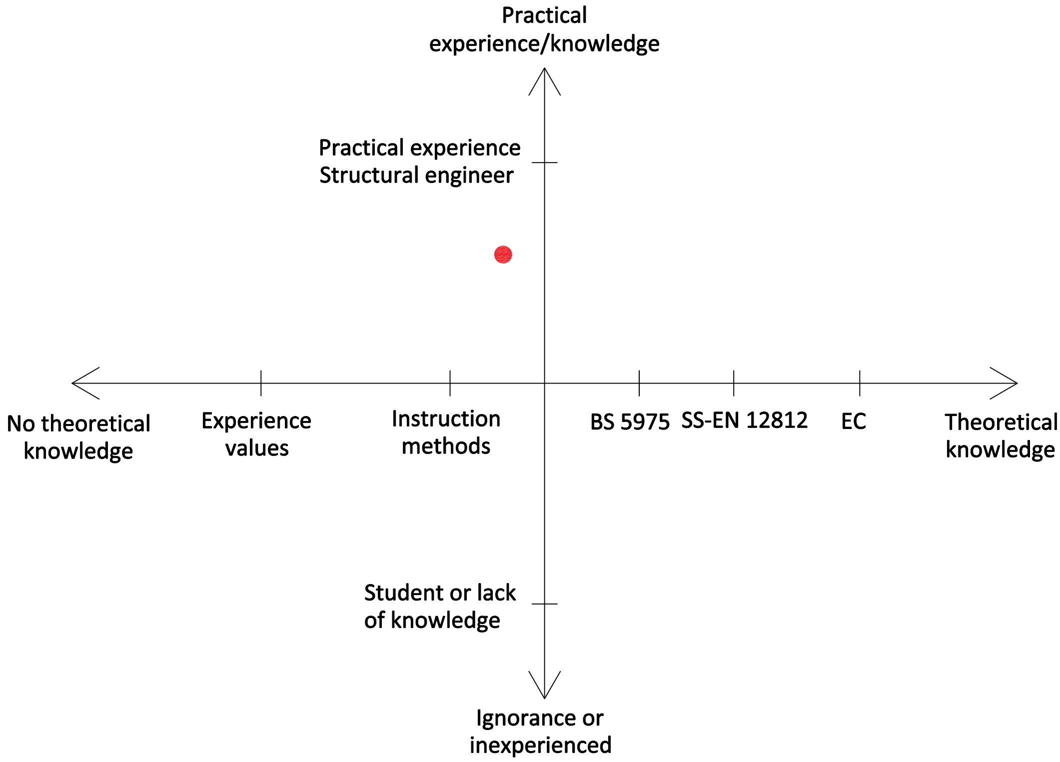


Figure 5.7: *Placement of Scaffolding Supplier in the Temporary Works Stakeholders Graph.*

5.8 Interview with the Swedish Transport Administration

The STA is the largest client for infrastructure investments in Sweden and is therefore very involved in the regulation of construction, planning and execution in the infrastructure industry. The respondent in this interview is employed in the *Technique and Environmental Department* under the *Division of Investment*. Although not an expert within TWs, the respondent has good insight into the newly published document: *Krav Brobyggande*. The questions where sent beforehand because the respondent was unsure if all the questions could be answered. The preliminary preparation gave the respondent time to gather the necessary information.

In principle, the STA distinguishes between two different types of contract forms when hiring contractors. Either the project is defined as an execution contract, or as a turnkey contract. In both cases, TWs are the responsibility of the contractor. In the case of the turnkey contract, the construction company also provides the drawings and calculations for the PWs, which otherwise is provided by a consultant contracted by the STA. To ensure a continuous treatment of TWs, the STA has published a working paper with regulations and recommendations, introduced in Section 3.1. The respondent particularly mentions the beginning of "*Råd Brobyggande*", where the different checkpoints of a construction plan are described. The

TW is in this construction plan excluded from the requirement of having an early fundamental description of its structural system. Also, TWs do not have to be considered at the projects start-up meeting. The reason why TWEs are left out in these meetings is according to the respondent because of the overall simplicity of TWs and costs connected to the engineers providing documentation and participating in meetings. The STA also has a regulation regarding the third-party review. The STA requires a third-party review of TW if there is a danger for any third-party, referring to either people or constructions. There is no definition of when there is a danger for any third-party. According to the respondent, this is often very obvious and is not considered a problem. In instances when this is not the case, the respondent points to the responsibility of the consultants contracted with the assignment.

Overall the respondent often refers to the newly published *Krav Brobyggande* mentioned earlier and stresses the desire of more explicit and clearer demands, both how the calculations are reported and what has to be performed in advance regarding drawings, calculations etc. Furthermore, the respondent highlights the fact that the STA often only has one contracting party, which is the construction company. Therefore, the STA does not have any responsibility in coordinating the different structural engineers, nor be involved in controls and checks regarding TWs. The STA also tries to implement documents guiding its consultants, which are entrusted with the procurement to make them more similar, all over the country as it at the moment can vary between regions. It should be added that there for the moment are no chapters about TWs in those documents. The respondent was furthermore of the opinion that there are relatively few accidents on construction sites compared to the quantity.

5.8.1 Placement in Temporary Works Stakeholders Graph

The STA has extensive knowledge of their own regulations, which often consists of references to EC. In their regulations, they do not give any kind of suggestions for solutions or templates regarding TWs. Instead, the STA lets the consultants decide how the practical issues should be handled in each project. The placements represent STA and can be seen in Figure 5.8.

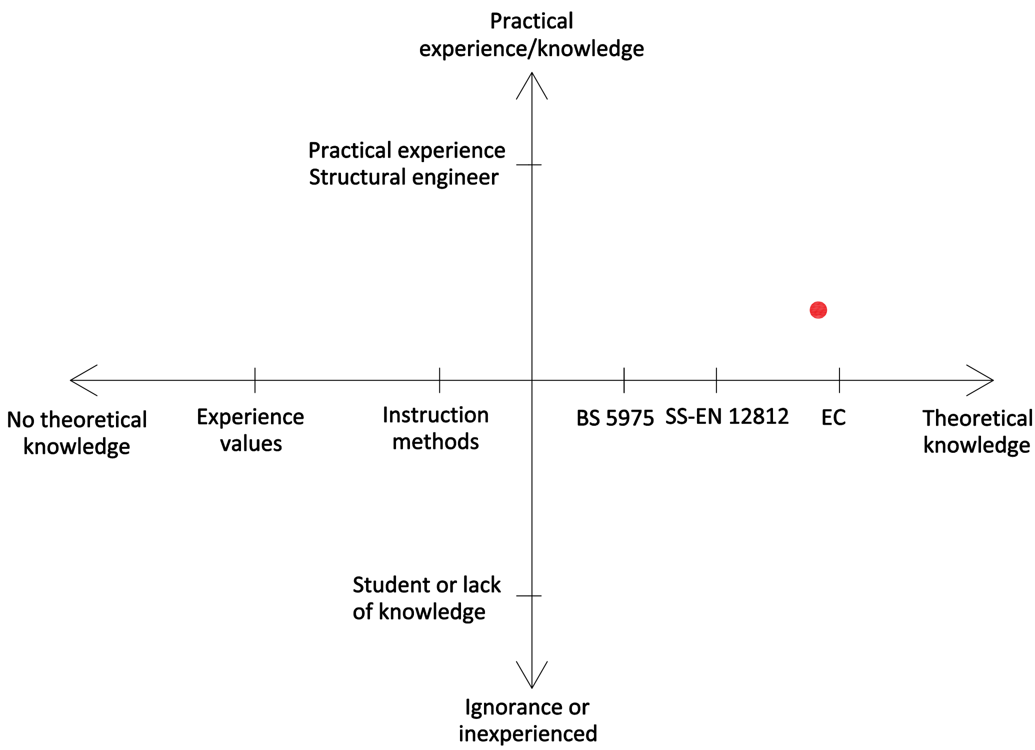


Figure 5.8: *Placement of Swedish Transport Administration in the Temporary Works Stakeholders Graph.*

5.9 Summary of Interviews

Contractors

In the interviews with Contractor 1 in Section 5.2, the respondent was a structural engineer. The respondent has been part of the contractor's investigation of the accidents regarding TWs. Also, the respondent has been involved in the committee developing the verification document, which concerns TWs. The verification document the contractor uses in connection to TWs has seven steps which have to be performed and help the TWS to ensure a safe working environment. The section between ground and falsework or scaffolding seemed to be one of the largest problems according to the respondent.

In the interview with Contractor 2, see Section 5.3, the respondent has worked as a site manager for many years. The respondent was also part of an accident involving TWs. The contractor company in the interview does not have any routines documented regarding TWs and instead relies on the experience of the employees and consultants.

Temporary Work Engineers (TWE)

The TWE in Section 5.4, has worked with TWs surrounding bridges for over 50 years. The respondent has investigated all the bridge accidents covered in Chapter

4, and multiple other accidents which have occurred over the years. The respondent has also held educations for one of the major contractors in Sweden where the respondent lectured about the handling of TW and the importance of performing the design and erection correctly.

The respondents from the second TWE interview, see Section 5.5, represents one of the largest TW designers and renters of falsework systems. The respondents often encounter contractors who do not follow the provided drawings and recommendations when erecting the TWs. Additionally, the ground condition which supports TWs, is according to the respondent the responsibility of a consulting geotechnical engineer. The respondent states that they do not take responsibility to check the ground conditions. However, they often encounter poor ground conditions when performing inspections on site. The respondents would like to see an industry organisation to unify and standardise the design of TW and especially falsework. The organisation would, according to the respondents, lead to better safety and competition on the same terms between companies.

Temporary Work Suppliers
The respondent in Sections 5.6, represents one of the largest TW supplier and has a long experience in the industry. They calculate their equipment based on the loads the Permanent Work Engineer (PWE) provides them with. They rarely encounter a third-party review performed on their designs or their erected TW, but they would prefer some control or check to ensure the quality of their performed design and erected TWs.

The respondents from the second TW supplier, see Section 5.7, mention the industry organisation for scaffolding, STIB. With the industry organisation, the market for scaffolding has been more unified, and fair competition rules have been set. The respondents also discuss the problem regarding SWEA, which the respondents educate on how to inspect a TW properly. To have an authority that has the responsibility to legislate and control, but does not have full control over the situation can lead to complications according to the respondent.

Swedish Transport Administration (STA)
The respondent interviewed at the STA stressed the improvements in the newly published *Krav Brobyggande* see Section 3.1.3. The respondent especially stressed how the document now is more straight forward and easier to understand when presenting TW design. The respondent also highlighted the administration's efforts in order to make the procurement's homogeneous throughout the country.

Swedish Standard Institute (SIS)
The SIS which are responsible for the EN and EC in Sweden has been contacted. The purpose of the interview was to understand SIS thoughts and ideas regarding the different ENs they publish. Specifically, the one named SS-EN-12812 regarding falsework and formwork. However, when contacted, they did not provide any names of representatives from their organisation. Instead, contact with a scaffolding

company was provided. The absence of representatives from SIS is unfortunately significant. It would be valuable to understand how the process and development of the current published ENs and upcoming ENs related to TW are managed.

6
Case Study

To better understand how the design of Temporary Works (TWs) are regulated, a case study was performed on Karlatornet in Gothenburg. The building is set to be 245 meters tall and to be cast in reinforced concrete on site. As a result, multiple unique TWs are required. Some of the TWs will be quite unusual during the erection of the building, and standardised solutions cannot be used. These bespoke solutions can give indicators where there are problems in the design of TWs .

To test the requirements gathered from the interviews, a conceptual design of a TW for the building was performed. This case study will highlight problems with European Standards (ENs) and difficulty in known solutions as well as the compatibility of the requirements from the stakeholders.

6.1 Case Study Methodology

Two different suggested solutions were developed to be compared to each other. The solutions suggested covered both ends of the TW spectrum, reaching from standardised to bespoke solutions. In order to select the final solution, which was more thoroughly calculated and designed, a *Pugh matrix* combined with an *Analytic Hierarchy Process* was used. The *Pugh Matrix* helps engineers and designers to choose between different options, by grading the concepts based on multiple criteria (Burge, 2009). The criteria were gathered from the interviews served as requirements in the case study. Moreover, additional requirements were added after discussion with the client and the supervisors.

In the *Analytic Hierarchy Process*, the different requirements were placed in a vertical line and horizontal line, forming a matrix of *n x n*, where *n* was the number of requirements. Each requirement was then rated against all the other requirements. To determine which requirement was the most important, the grades one, two and three were used. If a requirement achieved a grade of one, it implied that it is recessive, resulting in that the other requirement achieved a grade of three, meaning it was the dominant one. If the requirements were regarded as equally important, they both were graded with a two. Each requirement's grading scores were then summed up in a column at the right. The total score for each requirement was then compared to the total amount of points, and a percentage was calculated. The percentage was the requirement's weighting factor, later to be used in the *Pughs matrix*. It should be pointed out that some requirements can contradict each other, in which case the

Analytic Hierarchy Process shows which one was regarded as more important.

In the *Pughs matris*, the two concepts were placed in separate rows. The different requirements from the *Analytic Hierarchy Process* and their weighting factors were placed in the rows on the left of the concepts. Then each concept was awarded an individual rating of how well they fulfil each requirement on a scale from one to five, where one meant the concept does not correspond to the requirement at all and where five meant it correspond very well to the requirement. The rating for each requirement was then multiplied with the weighting factor. The product reflects how good the concept fulfilled the requirement, as well as how important the requirement was rated in the *Analytic Hierarchy Process*. The concept with the highest summed up score was the one who fulfilled the requirements the best according to the *Pughs matrix*.

As already mentioned, the final solution which was selected was calculated in a conceptual sizing manor and presented with the help of drawings and calculations. The analytic analysis were made in *Pointsketch2D* (Version 1.61), *Mathcad* (Version 15.0), *Frame Analysis* (Version 6.4.032) and by hand while the drawings were made in *Autocad Architecture* (Version 18) and by hand drawings. In order to make the study as realistic and reliable as possible, the same dimensions, loads and construction procedures were used as intended in the real project.

6.2 Dimensions and Structural System

The design of the different TW concepts and the final solution were influenced by both the requirements set by the stakeholders and the boundary conditions given by the building. As already mentioned, Karlatornet will be about 245 meters tall and located in Gothenburg on the north shore of the river Göta älv. The skyscraper is mostly set to be used as an apartment building but will also accommodate a hotel and businesses in the lower parts. The building will, for the most part, be quadratic in its floor plan, but will have a "twisting" rotation a little more than halfway through as seen in Figure 6.1.

Figure 6.1: *Illustration of Karlatornet with its "twisting" part (Serneke AB, 2017).*

The structural system will consist of a concrete core transmitting the horizontal and parts of the vertical loads to the ground. In addition, outrigger walls will be constructed in both directions of each corner from the core at the 12th-13th floors and 67th-68th floors to help stabilise the building in the horizontal direction. As a supplement, the outside walls called belt walls, will help with the horizontal stability, see Figure 6.2. The floors around the core are supported by columns and will be connected to the concrete core constructed on the inside of the curtain wall facade, see Figure 6.2. The floor slabs will transfer horizontal wind-loads through diaphragm action to the core and transfer the vertical loads with the help of plate-theory to the columns and the core. In addition to being reinforced with steel bars, the floors are also post-tensioned to keep the height of the concrete slab low. However, this is not true for the floors connected to the outrigger walls as they will only be reinforced with steel bars. Moreover, the outrigger walls are also going to be post-tensioned, helping them to withstand deflection after the TW is removed. The post-tensioning will be especially important since the outrigger walls are not connected to the belt wall until the end of the construction period, consequently leaving the outrigger wall as a cantilever for a relatively long time. This method is due to the behaviour of concrete after casting. To prevent deformation, shrinkage and creep to have a major effect on the finished building, these are allowed to take place before the whole system is connected together.

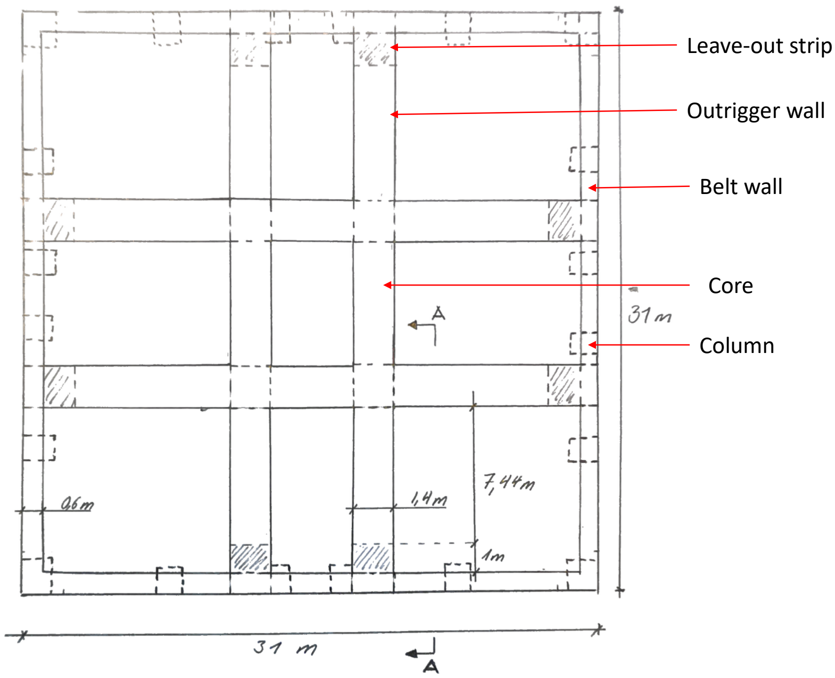


Figure 6.2: *Sketch of the floor plan.*

The TW calculated in the case study aim to support the outrigger walls. The layout of the floor plan can be seen in Figure 6.2. The Outrigger walls have two different lengths since the core is not fully quadratic. The outrigger wall, which was used in the case study, will be about 1.4 meters thick and 8.44 meters long, which will be the longer of the two. The effective length which was used in the calculations was 7.44 meters since one meter will be left as a leave-out strip to be cast at a later stage in the production. The wall is going to stretch continuously over two floor levels and will effectively be 7.04 meters tall, see Figure 6.3.

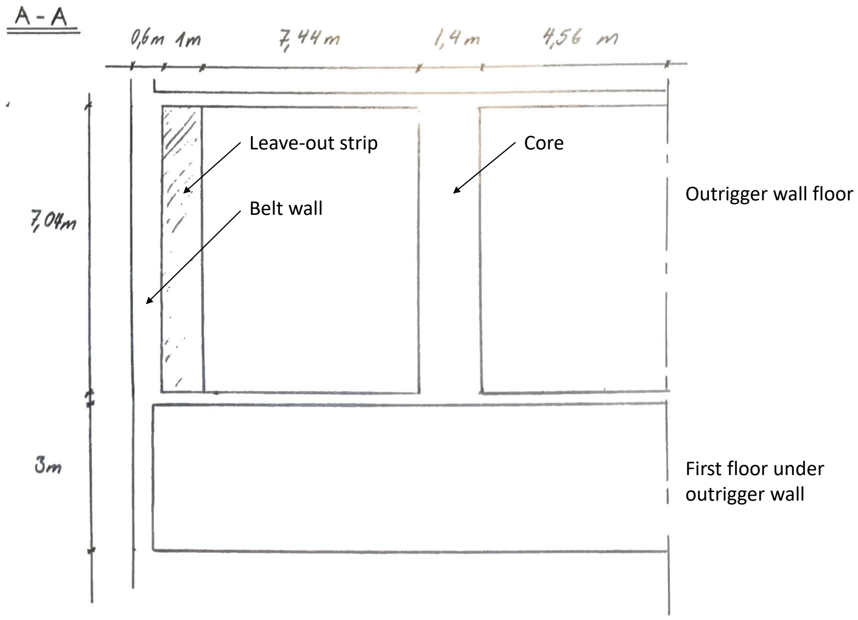


Figure 6.3: *Simple sketch of the outrigger wall floor elevation.*

6.3 Construction Procedure

The whole building will essentially be constructed in reinforced concrete. The core will be established around the elevator shafts and staircases in the middle of the floor plan. These will be constructed with a self-climbing formwork, also known as jump form, where the formwork is lifted continuously from one casted section (usually one storey tall) to the next as they are bolted into the previous part and lifted by a hydraulic system (Filip and Pallet, 2019). The floors and columns will be cast more traditional with the help of propping and formwork. For better safety, health and working conditions, the floors where the cast will be carried out on, are going to be covered by a protection screen which is self-climbing.

6.4 Different Concepts

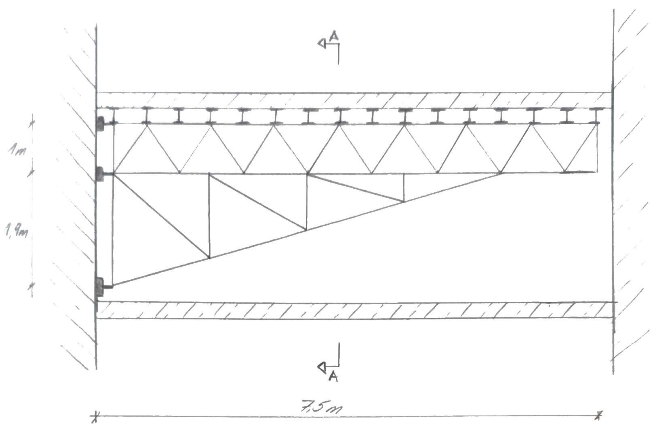
To sufficiently handle the problems described in Section 6.2, two conceptual designs were developed. The two different concepts try to cover most of the possibilities when designing TWs for the outrigger wall. Therefore, concept one was set to be a bespoke designed and built for this project. Concept two, on the other hand, was more of a traditional and standardised TW. When constructing house and industry projects, it is common to use as many standardised elements as possible.

The significant difference between the presented solutions is due to some key factors. First, the aim was to show all the possibilities when working with TW. Second, there was a will to have a comparison between a bespoke concept and a more traditional and standardised concept. The third and last factor was the influences obtained from the interviews in Chapter 5, which resulted in the requirements described in

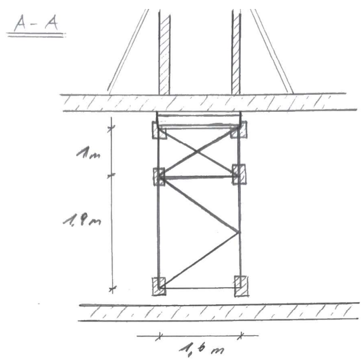
Section 6.5, as well as in the discussions with the contractor and client. The design of the wall formwork was not considered since their dimensions are standardised and will be supported by the surrounding floors.

6.4.1 Concept One: Truss Cantilever

In concept one, all of the forces were set to be supported by two cantilever steel trusses which are connected to each other, see Figure 6.4. This way of executing a cantilever TW can be compared to the way bridges are launched. The beams on the top and the bottom of the truss were set to be the most stressed ones and were therefore designed in larger cross-sections than the other beams in the truss. The emphasis in concept one was to minimise the deflection on the free edge of the cantilever, therefore the global stiffness of the truss was essential.



(a)



(b)

Figure 6.4: *Conceptual sketches of the truss cantilever concept. To the left, the longitudinal section of the cantilever is shown. To the right, the section A-A can be seen.*

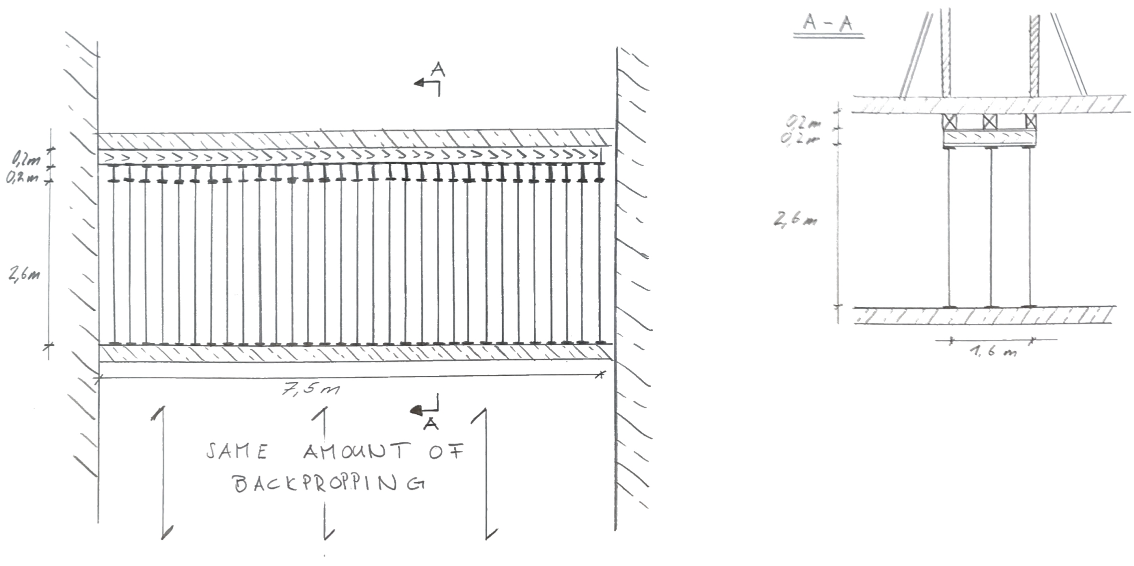
The design of the truss in Figure 6.4, is only conceptual and was redefined after the final selection. The same applies to dimensions and connections displayed in Figure 6.4. To estimate the forces in the truss and the joints, the truss was pre-sized using *pointSketch2D*. The dimensions were defined as a VKR 250x150x8 for the top beam and the diagonal on the bottom side. The other beams were defined as VKR 150x100x5.

The cantilever truss is expected to be mounted onto bolts which would be pre-casted in the core. To help with the mounting steel plates would be welded onto the end of the truss to transfer the loads from the cantilever truss to the core. During the dismantling of the TW, hydraulic presses would be used to lift the slabs above the cantilever just enough to remove the secondary beams. Thereafter, the cantilever itself could be dismounted and re-used.

6.4.2 Concept Two: Propping

The concept was set to be a traditional and standardised concept with soffit, secondary beams, propping and backpropping. The preliminary design, consists of 17 rows with three props each, as can be seen in Figure 6.5. The rows are about 0.44 meters apart, and the props are preliminary designed as EUREX 30 from DOKA with a permissible strength of 30kN. To convert the permissible capacity to the limit state characteristic capacity, Equation 6.1 was used. The safety factor (γ_{M1}) for steel, which is 1.1 and the permissible factor of 1.65 was used. The system could alternatively be constructed in a falsework, usually intended for bridges, with larger load capacity. This falsework could, according to TWEs interviewed reduce the amount of props. After a first brief calculation, see Appendix E, there will presumably be backpropping needed on all the floors down to the ground level.

$$R_k = \frac{R_{\text{k, Permissible stress}} \cdot 1.65}{\gamma_{M1}} \tag{6.1}$$



(a) **(b)**

Figure 6.5: *Conceptual sketches of the propping concept. To the left, a section of the props together with the primary and secondary beam are illustrated. To the right, Section A-A can be seen with a row of props.*

6.5 Requirements from Stakeholders

The requirements were summarised from the interviews, see Chapter 5. For each of the stakeholders relevant in this case study, different requirements have been formulated. Moreover, there are also some requirements chosen by the authors of this thesis, which are more general but not covered in the interviews, see Section 6.5.4. These requirements will be the basis of choosing the final TW solution, which will be investigated further.

6.5.1 Contractor

Redundant system
In the design of TWs, it is important to build in redundancy in the system to prevent the collapse of the whole structure, in case of failure in one specific detail. The redundancy of the system will improve the construction site safety and the working environment. For example, a newly cast floor slab with props should be able to sustain the loads even if a number of props were to fail. If the props still can sustain the loads, it would be regarded as a redundant system.

Inspection and Dismantling
The chosen solution for the TW has to be easy to inspect before and during the

casting of the PW. The TW also needs to have a safe dismantling process which needs to be included in the design process.

Erection time
The erection time of a TW is important to be considered in a construction project since its significant impact on the overall time schedule. Multiple of the respondents in the interviews have stressed that minor delays can influence different aspects of the building process for a substantial amount of time afterwards.

Health and Safety
The contractor has the responsibility for all workers on site. Therefore, it is in the contractor's interest to provide a safe working place for everyone and follow the Ens and current regulations. TWs which take health and safety into consideration could help to reduce accidents on the construction site.

6.5.2 Temporary Work Supplier

Standardised solution
The supplier often delivers a standardised system which is well tested. These standardised systems work well as long as they apply to the boundary conditions corresponding with the TWs method statement. If the boundary conditions, such as loads and support conditions, do not correspond with the TW system, new solutions and elements need to be developed and designed. The more the solution differs from a standardised one, the more uncertainties and room for error will occur.

Need for instructions
More complicated appearing structures often need a more explanatory drawing. Since the communication on the construction site can be difficult due to different languages, misunderstandings can occur. Therefore, a simple and intuitive-to-erect TW, with little or no need of explanatory text is to be preferred.

6.5.3 Temporary Work Engineer (TWE)

Clear structural system
The workers should be able to understand the static relationship and how parts contribute to the structural system. To obtain this understanding, the TWE can reduce the risk of elements being excluded during erection when workers do not see the benefit in them.

Dependency of Permanent Work
When the TW rests on a permanent structure, special requirements are to be fulfilled by the PW. When loads from the TW reach a magnitude where they become the governing load case, they will influence the dimensions of the PW. This scenario is problematic since the structure could be oversized during its following life span. It

is also important to understand how the fixings of the TW will affect the PW and if it will influence the design of the final PW.

6.5.4 General requirements

Material cost
When increasing the material used in a construction process, the overall cost will increase. Therefore, it is important to be as material effective as possible. The material efficiency applies to both more standardised systems, which are rented, and structures built for one particular building process.

Labour cost
Labour contributes to about 24% of the cost on a building project (SCB, 2019). Therefore, if the design of a TW is able to reduce the hours of workers being on site, the overall cost most likely would decrease. This cost decrease applies to all the different stages contributing to a complete TW from production, delivery, assembly to dismantling and reuse of the TW.

Allowed deflection ratio
From the client in the project, there are worries regarding the deflections in the formwork induced by the concrete load during casting and how it will affect bonding between the concrete and the reinforcement. There are concerns bond slip will occur if the concrete deflects to fast while the reinforcement, which is self-supporting from its truss system, does not.

Accessibility on floors
As the building process continues upwards, the need for accessibility to the floors below becomes important. The contractor wants to have access to all the floors all ready cast so that installations such as mechanical, electric and plumbing can proceed and the time schedule does not get interrupted.

6.6 Selection of Final Solution

In order to compare the two solutions presented in Section 6.4, a *Pugh Matrix* in combination with weighting factors obtained in the *Analytic Hierarchy Process*, was used. The procedure is presented in the following section. The grading by the authors is kept as objectively as possible and influenced by the interviews carried out in Chapter 5.

6.6.1 Weighting of Requirements

As mentioned in Section 6.1, the weightings is based on a *Analytic Hierarchy Process*, the result of which, can be seen in Table 6.1.

Table 6.1: *Result after weighting the requirements against each other an Analytic Hierarchy Process, higher percentage indicates greater importance (Appendix B).*

Requirement	**Total**	**Percent** [%]
Redundant System	27	10.3
Clear Structural System	12	4.6
Erection Time	20	7.6
Health and Safety	30	11.4
Standardised Solution	19	7.2
Need for Instruction	15	5.7
Inspection and Dismantling	26	9.9
Dependency of Permanent Work	21	8.0
Material Cost	25	9.5
Labour Cost	19	7.2
Allowed Deflection Ratio	26	9.9
Accessibility on floors	23	8.7
Total	263	100

As can be seen in Table 6.1, *Health and Safety* was rated the most important requirement, with a weighting factor of 11.4%. This high grade was due to the importance the contractor has on the safety of its employees. Since the expressed ambition of the company constructing Karlatornet is to minimise the serious accidents to zero, *Health and Safety* is regarded as more important than all other requirements (Serneke, 2019). One of the requirements scored high as well was *Redundant Systems*. With 10.3%, it also had a very high weighting factor, and similar to *Health and Safety*, is related to keep the workplace safe. In contrast to *Health and Safety*, the requirement *Redundant Systems* focuses on the case when a structural collapse of the TW could take place. Therefore, in some comparisons *Redundant System* fared lower then *Health and Safety*.

Thereafter, the requirements *Inspection and Dismantling* (9.9%), *Allowed deflection ratio* (9.9%) and *Material Cost* (9.5%) follow with almost the same weighting factor. The *Inspection and Dismantling* is, as mentioned in the previous Section 6.5, connected to the well being of the workers. *Material Cost* is related to the overall cost of the project, which naturally is of essential interest for the contractor and the client. Finally, when considering the *Allowed Deflection Ratio*, this requirement is more connected to the demands on the structural integrity of the building. The three requirements were mostly given the same grade when compared to other requirements and were regarded to have the same importance when compared to each other, although *Inspection and Dismantling* dominated over *Allowed Deflection Ratio*. The simpler solution was to be preferred in such a case and somewhat larger deflections would be accepted, as long as the allowed limits are fulfilled.

The next requirement when considering importance is *Accessibility on Floors*. This requirement affects multiple areas of interest, such as cost and safety. Therefore the requirement has been deemed with the same grading on four occasions, leading to its score of 8.7%. In the next places there are four requirements, *Dependency of*

PW (8.0%), *Erection Time* (7.6%), *Standardised Solution* (7.2%), and *Labour Cost* (7.2%), with similar scores. The three are closely associated with one another, and somewhat go hand in hand, explaining their similar weighting factors. A standardised system is often well known by the workforce, resulting in a faster erection time and lower labour costs. As fast erection time not only results in lowered costs in terms of labour but also allows the upcoming constructions and installations to take place earlier, it was regarded slightly higher. The one requirement sticking out from these three was the *Dependency of PW*.

The least important requirements according to the *Analytic Hierarchy Process* are *Need for Instruction* (5.7%) and *Clear Structural System* (4.6%). Both of these are meant to help the workers on site to understand the importance of all the elements in a TW, and also make the installation of the TW as easy as possible. Although an important input, it was in the evaluation face determined that the safety on the construction site can be secured better with the other requirements.

6.6.2 Grading of Concepts

After the weighting of the requirements, the two proposed concepts presented in Section 6.4, were graded from one to five in regard to each requirement, which can be seen in Table 6.2. In this grading system, five stands for *correspond very well*, and one stand for *corresponds not at all*. The grading was made as objectively as possible by the authors with the knowledge gathered from the literature study and the interviews. The objectiveness of the authors can be secured since none of them has a background in the production, supplier or design business. In addition, discussions with the main structural engineer and the contractor of the project have been carried out to achieve the most objectively grading.

Table 6.2: *Grading of the two different solutions with each concept's individual weighted final grade in the bottom row (Appendix B)*

Requirement	**Weighting Factor**	**Cantilever Truss**	**Propping**
Redundant System	10.3	3	4
Clear Structural System	4.6	4	5
Erection Time	7.6	5	3
Health and Safety	11.4	4	3
Standardised Solution	7.2	2	4
Need for Instruction	5.7	3	4
Inspection and Dismantling	9.9	3	4
Dependency of Permanent Work	8.0	1	3
Material Cost	9.5	2	5
Labour Cost	7.2	4	2
Allowed Deflection Ratio	9.9	4	2
Accessibility on floors	8.7	5	1
Total	100	3.33	3.27

Redundant System
As can be seen in Table 6.2, the difference between the two solutions is quite small. The truss cantilever was graded with a passing grade as it is fairly independent of one crucial component. However, the propping system was regarded slightly more redundant since it would consist of multiple props, where the loads can be redistributed if one failed.

Clear Structural System
Both these systems are very clear structured systems where the load distribution is easily comprehended. As the propping almost only would consist of vertical components without any redistribution of forces, it was graded with the highest possible rating while the truss cantilever was awarded one grade lower because the truss can be somewhat confusing for the untrained eye.

Erection Time
The installation of props is usually very fast since the workflow is easy and well known. However, since there are set to be many props which have to be installed (up to 600 props for one outrigger wall) the installation would take a considerable amount of time. The truss cantilever, on the other hand, is expected to directly be lifted and mounted onto pre-in-casted bolts, resulting in a fast erection time.

Health and Safety
In the requirement *Health and Safety*, which has the highest weighting factor, the cantilever was considered somewhat more qualified since it will consist of fewer parts, which can experience unintended impact loads in a dangerous way. In contrary, the truss cantilever will be made as one element. Because of its self-weight, which can

be of danger for the workers, the truss does not reach the highest grade.

Standardised Solution
As the truss cantilever will be a bespoke structure for this project, it is not a standardised solution, although some parts could be made of standard elements which lifted the grade to some degree. On the contrary, the propping solution is a standardised system which almost does not need any project specific changes. The higher standardisation of the props gave the system a two points higher grade in the requirement *Standardised Solution*.

Need for Instruction
Again, the grading was quite similar, with a small advantage for the propping system. This advantage was due to the fact that the workflow is well known in advance, which lowers the need for instruction, resulting in a comparatively high grade. As the truss cantilever will be unique, but predominantly simple, the need for instruction will be foreseeable.

Inspection and Dismantling
Like the erection, the dismantling of the prop system is easy and well known. Moreover, the inspection would be very straight forward, although a little complicated due to a large amount of props. The truss cantilever would be more challenging to dismantle compared to erecting it and would be constructed with a large amount of welded element which could be difficult to inspect.

Dependency of Permanent Work
Since the truss cantilever would be mounted onto the core, the whole system would be depended on the PW. The PW will then almost certainly have to be designed with regard to the forces which arise from the truss joints. Therefore, the grade was low. The propping, on the other hand, is a more independent system. Even more so as it in the initial calculations, see Appendix E, appears that all floors have to be backpropped. In that case, the main concern was how large the loads would be transferred through the concrete slabs. As a result, the grade was slightly lower.

Material Cost
To estimate the material cost of the two concepts, brief and rough calculations were carried out and are presented in Appendix E. As a result, the material cost for the truss cantilever was much higher in comparison to the cost for the propping system all the floors for one month. As can be seen in Table 6.2, the substantial difference was expressed in the grades.

Labour Cost
In order to install the truss cantilevers, there will be either a crane or some other sort of lifting system in place. However, there will not be a large number of workers necessary since the truss gets mounted on to the core with bolts, which resulted in a high grade. In contrast, there will be many labour-hours required to install all the needed props, which the low grade accounted for.

Allowed Deflection
Due to the expected stiffness, the deflection of the truss cantilever is expected to be small, depending on its shape. The propping system was harder to estimate in this regard since the loads will be large and the force distribution uncertain.

Accessibility on floor
The requirement *Accessibility on floors* was the requirement where the grading differed the most. As the truss cantilever only will claim the first floor under the outrigger wall to operate, it got the highest possible grading. The propping system, on the other hand, was after first calculations set to need propping on all floors below, see Appendix E. Because this amount of backpropping would interrupt the building process as a whole and be unpractical, it was awarded the lowest grade.

6.6.3 Final Selection

As can be seen in Table 6.2, the concept with the higher total grade was the truss cantilever with a small margin. Although scoring lower grades in some areas, mostly due to the high cost and the bespoke structure of the cantilever, the accessibility to the floors below and the anticipated stiffness of the structure prevailed. Furthermore, it should be pointed out that the propping system probably would be impossible to use, since it would occupy too many floors for backpropping.

6.7 Final Design

The chosen design was *Concept One: Truss Cantilever*, the main objectives was the compression and tension stresses, as well as the final deflection on the outermost point on the truss. As already mentioned in Section 6.1, the program *Frame Analysis* was used to obtain the forces acting in the truss system. Furthermore, the same program was used to size the final design in order to stay within the maximum deflection demand. The final analytic calculation checks were carried out in *Mathcad*, in order to prove the structural integrity of the truss and to size details, such as welds and bolts.

6.7.1 Final Geometry

The final geometry was changed from the initial design, see Figure 6.4. The final geometry of the truss was found through iterations to fulfil the deflection demand, described in Section 6.7.2. The final arrangement of the truss system can be seen in Figure 6.6.

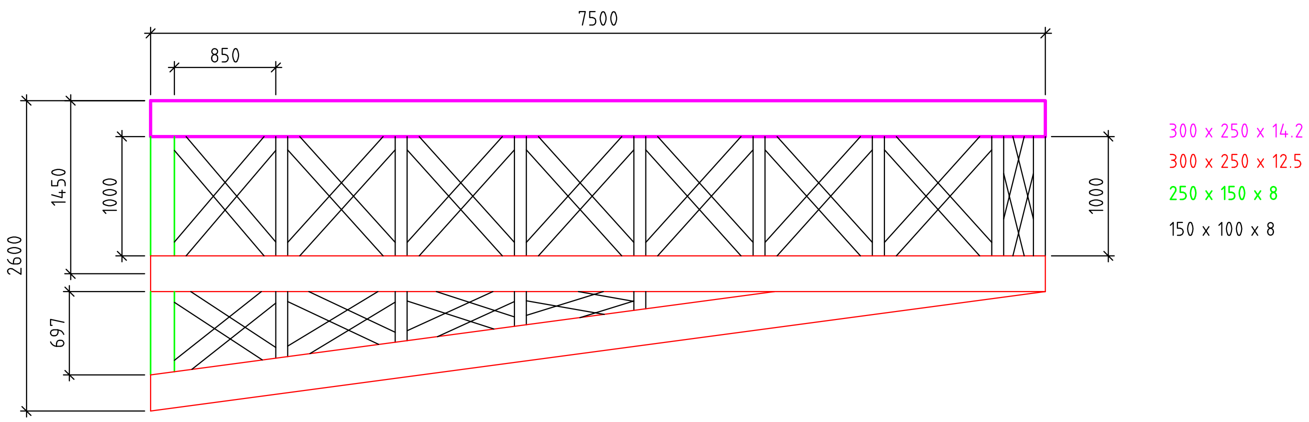


Figure 6.6: *Final truss dimensions.*

The truss was modelled in *Frame Analysis* as a 2D cantilever with continuous beams at the top, middle and bottom, and braces in between, as can be seen in Figure 6.6. The braces were connected with moment free nodes and were either subject to tension or compression. The truss model was simply supported in three Nodes (2, 5 and 36), as can be seen in Figure 6.7.

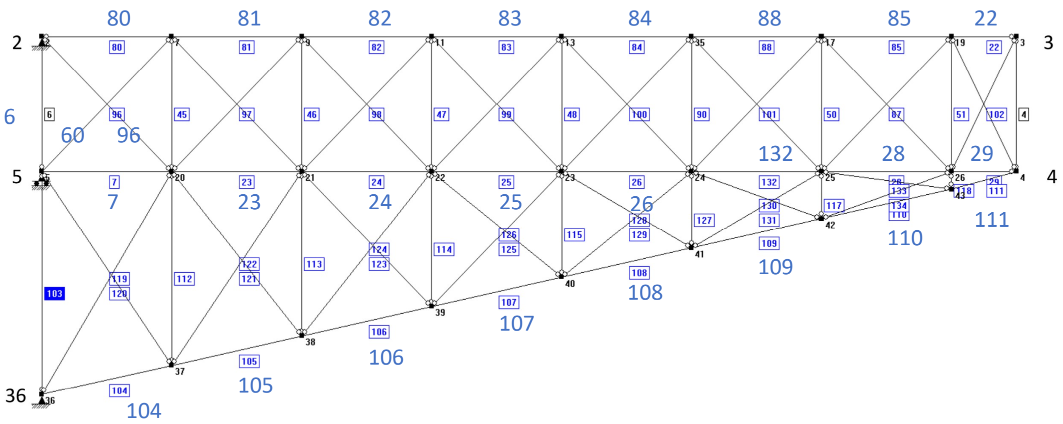


Figure 6.7: *Modell of the truss (Appendix E).*

6.7.2 Material Properties and Partial Factors

To sufficiently conduct the analytic analysis, the necessary information had to be gathered from relevant literature and standards, see Chapters 3. The material properties listed in Table 6.3 were found in Eurocode 3 (SIS, 2011b). Since only steel material was used in the truss system, the decision was made to design the VKR profile and the connection plate in the steel grade S355. The bolts presented in Table 6.4, connect the truss to the concrete core and were designed in the bolt class 10.9 (SIS, 2011c).

Table 6.3: *Material properties for steel*

Steel Material Properties			
Yield strength	(f_{yk})	[MPa]	355
Ultimate strength	(f_{uk})	[MPa]	510
Young's modulus	(E)	[GPa]	210

Table 6.4: *Material properties for steel bolts M16, bolt class 10.9*

M16 10.9			
Yield strength	(f_{yb})	[MPa]	900
Ultimate strength	(f_{ub})	[MPa]	1000
Bolt diameter	(d)	[mm]	16
Hole diameter	(d_0)	[mm]	18
Cross section	(A)	[mm^2]	201
Stress area	(A_s)	[mm^2]	157

The European Standards (ENs) regulating falsework, SS-EN 12812 (SIS, 2012), refers to Eurocode 3 when considering the reduction factors regarding the steel material. Furthermore, SS-EN 12812 states the partial safety factors for both Ultimate Limit State (ULS) and Serviceability Limit State (SLS), see Table 6.5. The load case factor (Ψ_i) in SS-EN 12812 is defined either as 0 or 1.0 in order to take the different stages of the casting procedure into account. As the wind load can be neglected, see Section 6.7.4, load case 2 (falsework during loading, e. g. pouring) in SS-EN 12812 will be the governing load case. Since all the load case factors (Ψ_2) in this load case are equal to 1.0, only one will be shown in Table 6.5 for simplicity.

Table 6.5: *Eurocode Partial and Reduction Factors (SIS, 2012) (Al-Emrani et al., 2013)*

Partial Safety and Reduction Factors	
$\gamma_{g,ULS}$	1.35
$\gamma_{q,ULS}$	1.50
$\gamma_{g,SLS}$	1.00
$\gamma_{q,SLS}$	1.00
Ψ_2	1.00
γ_{M0}	1.00
γ_{M1}	1.00
γ_{M2}	1.25

In the final truss design, four different cross sections were used. These cross sections range from VKR 300x200x14.2 to VKR 150x100x8. The cross-section properties are presented in Appendix C, and were extracted from *Frame Analysis*. Rectangular VKR cross-sections were chosen because of their extra deflection stiffness, and they were considered easier to weld.

As described in Section 3.1, SS-EN 12812 requires to treat the wet concrete as an imposed load. In addition, SS-EN 12812 provides a variable transient action to account for accumulation of concrete during the casting. The maximum value for the variable transient imposed action is 1.75 kN/m^2 over a three square meter area, which was used in the case study. The self-weight of the cross-sections are according to Appendix E. At last, the horizontal load was in accordance to SS-EN 12812 calculated as 2.5% of the vertical load. All the loads can be seen in Table 6.6.

Table 6.6: *Loads used in the calculation*

Loads			
Imposed Load Concrete (Wet)	(q)	[kN/m^3]	27.00
Wet Concrete	(q_k)	[kN/m]	133.00
Variable Transient Imposed Action	(g_P)	[kN/m^2]	1.75
Self-Weight VKR 300x250x14.2	$(g_{300x14.2})$	[kN/m]	1.01
Self-Weight VKR 300x250x12.5	$(g_{300x12.5})$	[kN/m]	0.90
Self-Weight VKR 250x150x8	(g_{250})	[kN/m]	0.47
Self-Weight VKR 150x100x8	(g_{150})	[kN/m]	0.28
Horizontal Load	(Q_k)	[kN]	38.80

The load combinations for ULS and SLS are comparable to the ones in Eurocode 1 (SIS, 2011a) and can be seen in Table 6.7. The exception being that the partial load case factors (Ψ_2) found in Table 6.5 also is applied in ULS. As the governing load case is load case 2 the reduction factor for all load combinations will be 1.0. The partial safety factor γ_{gi} can also be found in Table 6.5.

Table 6.7: *Load combinations in the system*

Load Combinations	
Ultimate Limit State	$\Psi_2 \cdot \gamma_{g.ULS} \cdot g_{tot} + \Psi_2 \cdot \gamma_{q.ULS} \cdot q_k$
Serviceability Limit State	$\Psi_2 * \gamma_{g.SLS} \cdot g_{tot} + \Psi_2 \cdot \gamma_{q.SLS} \cdot q_k$

6.7.3 Analytic Checks Performed on the Truss Cantilever

The requirement which was governing in the final solution was the allowed deflection ratio in Node 3, see Figure 6.7. The deflection was also the governing condition through the process of developing the final solution. To determine the allowed deflection ratio for the truss, the recommended value for launching of bridges was used. According to Eurocode 1-1-6 (SIS, 2010), the allowed ratio is $+/-10$mm in the transverse direction. Since this construction procedure is of the same character, the same value was used as a boundary condition.

In SS-EN 12812 the designed of TWs has to be classified according to the B1 and B2 principle, see Section 3.1. The cantilever truss in the case study fulfils the demands to obtain the classification of B2. To calculate the *Design Resistance* ($R_{d,i,2}$) in B2, an additional reduction of factor of 1.15 has to be multiplied with the *Partial Safety Factor* ($\gamma_{M,i}$) when reducing the *Characteristic Material Properties* ($R_{k,i}$), see Equation 6.2.

$$R_{d,i,B2} = \frac{R_{k,i}}{\gamma_{M,i} \cdot 1.15} \tag{6.2}$$

Slenderness for Euler Buckling
Since the truss mainly will be subjected to axial forces, a control of Euler buckling had to be carried out for all struts experiencing compression, to confirm no elements

fail locally in the system. The check was done according to Eurocode 3. The *Design Buckling Resistance of the Compression Member* ($N_{b,Rd}$) was calculated from the specific element's steel properties, cross section and length, see Equation 6.3. Following, $N_{b,Rd}$ was compared to the *Design Value of the Compression Force* (N_{Ed}) which were extracted from *Frame Analysis*, see Appendix E. The design value has to be lower than the design value resistance, i.e. a utilisation ration below 100% , see Equation 6.4. The control was performed on Element 60 and 96, see Figure 6.7.

$$N_{b,Rd} = \frac{\chi \cdot A \cdot f_y}{\gamma_{M1} \cdot 1.15} \tag{6.3}$$

$$\frac{N_{Ed}}{N_{b,Rd}} \leq 1.0 \tag{6.4}$$

Moment and Shear Capacity

The upper VKR 300x200x14.2 (Element 80-85, 88 and 22), the middle VKR 300x200x12.5 (Element 23-26, 7, 132, 28 and 29) and the diagonal VKR 300x200x12.5 (Element 104-111) act in beam action, since they are continuous beams, see Figure 6.7 and Appendix E. The moment in the upper and middle beam were governing for the system. This required checks for the moment capacity accordingly to Eurocode 3. The *Design Values of the Resistance to Bending Moments* (M_{Rd}) were calculated from the specific element's steel properties and cross section, see Equation 6.5. The *Design Bending Moment* (M_{Ed}) were extracted from *Frame Analysis*, see Appendix E. The design value was controlled not to exceed the design value resistance, see Equation 6.6.

$$M_{Rd} = \frac{W \cdot f_y}{\gamma_{M1} \cdot 1.15} \tag{6.5}$$

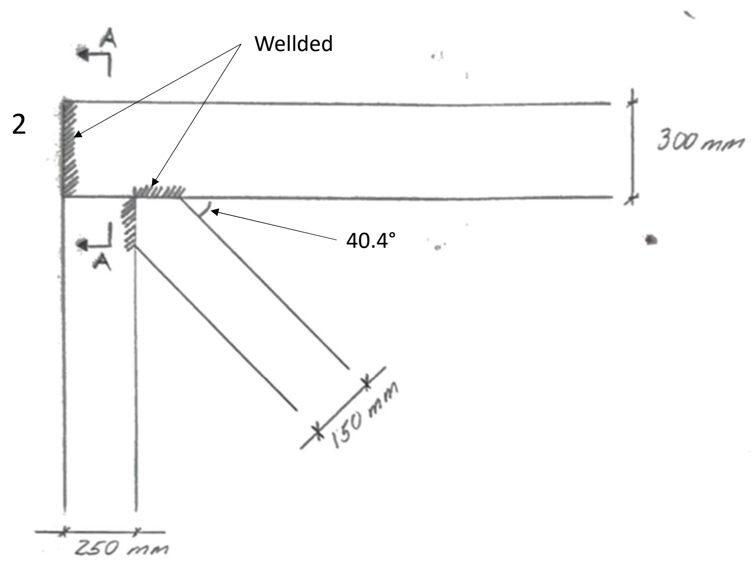
$$\frac{M_{Ed}}{M_{Rd}} \leq 1.0 \tag{6.6}$$

The shear force capacity has also been checked. The *Design Plastic Shear Resistance* ($V_{pl,Rd}$), were calculated from the specific element's steel properties and cross section, see Equation 6.7. The *Design Value of the Shear Force* (V_{Ed}) were extracted from *Frame Analysis*, see Appendix E. The design value was controlled not to exceed the design value resistance, see Equation 6.8. The control was performed on the upper and middle VKR profile.

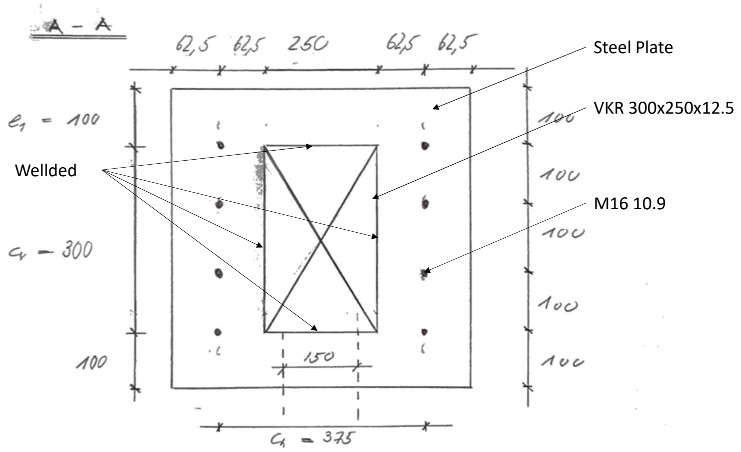
$$V_{pl,Rd} = A_v \cdot \frac{f_y/\sqrt{3}}{\gamma_{M0} \cdot 1.15} \tag{6.7}$$

$$\frac{V_{Ed}}{V_{pl,Rd}} \leq 1.0 \tag{6.8}$$

Weld Capacity
The welds connecting the brace elements have been checked for shear stress parallel and perpendicular to the axial forces and normal stress. Weld checks have also been performed between the connection plate and the vertical VKR 250x150x8 beam, see Section 6.7.1. The steel plate works as a connection plate were bolts will be cast into the concrete core, and the plate can be connected and fastened afterwards, see Figure 6.8. There are four additional plates, one in both node 3 and 36 and the other two will be evenly spread out between them. The shear force is estimated to be carried evenly by the plates. The welds were controlled according to Eurocode 3.



(a)



(b)

Figure 6.8: *Dimensions and placements of the welds in node 2, see Figure 6.7.*

The *Shear Stress (in the plane of the throat) Parallel to the Axis of the Weld* ($\tau_{\parallel}$)

is calculated from Equation 6.9. The *Normal Stress Perpendicular to the Throat* ($\sigma_\perp$) is derived from Equation 6.10. The *Shear Stress (in the plane of the throat) Perpendicular to the Axis of the Weld* ($\tau_\perp$) was calculated in the same manner as $\sigma_\perp$, see Equation 6.11. All these equations were calculated using the force at the end node, the length of the weld and the weld root thickness.

$$\tau_\parallel = \frac{P}{a \cdot L} \tag{6.9}$$

$$\sigma_\perp = \frac{P}{\sqrt{2} \cdot L \cdot a} \tag{6.10}$$

$$\sigma_\perp = \tau_\perp \tag{6.11}$$

The *Design Stress of the Fillet Weld* ($\sigma_{Ed,1}$) was calculated out of $\sigma_\perp$, $\tau_\perp$ and $\tau_\parallel$, see Equation 6.12. The second *Design Stress of the Fillet Weld* ($\sigma_{Ed,2}$) is equal to $\sigma_\perp$. The stresses $\sigma_{Ed,1}$ and $\sigma_{Ed,2}$ have to be controlled against the *Design Resistance of the Fillet Weld* ($\sigma_{Rd,1}$) and ($\sigma_{Rd,2}$), see Equation 6.14 and 6.15. If σ_{Ed} satisfied the demand according to Equation 6.14 and 6.15, the welds have enough capacity to sustain the stresses.

$$\sigma_{Ed,1} = \sqrt{{\sigma_\perp}^2 + 3 \cdot ({\tau_\perp}^2 + {\tau_\parallel}^2)} \tag{6.12}$$

$$\sigma_{Ed,2} = \sigma_\perp \tag{6.13}$$

$$\sigma_{Ed,1} \leq \frac{f_u}{\beta_w * \gamma_{M2} \cdot 1.15} = \sigma_{Rd,1} \tag{6.14}$$

$$\sigma_{Ed,2} \leq 0.9 \cdot \frac{f_u}{\gamma_{M2} \cdot 1.15} = \sigma_{Rd,2} \tag{6.15}$$

Design of Joints

The bolts used to connect the welded connection plate and truss to the concrete core were controlled according to Eurocode 3. The analysis was an iterative process were the minimum dimensions for one bolt out of 16 bolts was calculated from the *Design Shear Resistance Per Bolt* ($F_{v,Rd}$), see Equation 6.16. A larger dimension for the bolt was then chosen to allow a suitable utilisation ratio. The connection plate was afterwards checked against failure between hole-hole and hole-edge. The governing mode was found to be the one between the hole-edge of the plate. The hole-edge mode resulted in the *Design Bearing Resistance per Bolt* ($F_{b,Rd}$) according to Equation 6.17. The governing resistance F_{Rd} between the bolt and the plate was decided according to Equation 6.18. To satisfy the resistance, a check between F_{Rd} and the total shear force divided on the 16 bolts ($F_{v,Ed}$) was performed, see Equation

6.19.

$$F_{v,Rd} = \frac{\alpha_v \cdot f_{ub} \cdot A_{bolt} \cdot n}{\gamma_{M2} \cdot 1.15} \tag{6.16}$$

$$F_{b,Rd} = \frac{k_1 \cdot \alpha_b \cdot f_u \cdot d_{bolt} \cdot t_{plate}}{\gamma_{M2} \cdot 1.15} \tag{6.17}$$

$$F_{Rd} \leq min \begin{cases} F_{v,Rd} \\ F_{b,Rd} \end{cases} \tag{6.18}$$

$$\frac{F_{v,Ed}}{F_{Rd}} \leq 1.0 \tag{6.19}$$

The bolt was then also checked against normal tension in the upper support. The *Design Tension Resistance per Bolt* was calculated according to Equation 6.20 and compared to the *Design Tensile Force per Bolt for the Ultimate Limit State* ($F_{t,Ed}$), see Equation 6.21. Due to interaction between tension stresses and shear stresses in the bolts, an interaction check was carried out in node 2, see Equation 6.22

$$F_{t,Rd} = \frac{k_2 \cdot f_{ub} \cdot A_s}{\gamma_{M2} \cdot 1.15} \tag{6.20}$$

$$\frac{F_{t,Ed}}{F_{t,Rd}} \leq 1.0 \tag{6.21}$$

$$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1.4 \cdot F_{t,Rd}} \leq 1.0 \tag{6.22}$$

6.7.4 Limitations of the Analytic Calculation

In the case study, some analytic checks were neglected due to various reasons. The torsional buckling check of the truss globally has not been carried out. The truss is seen as stabilised in the horizontal direction as there is the possibility of bracing. Furthermore, the impact of the reaction forces acting on the core wall are not checked since they are regarded to be part of the PW design. Wind-loads have been neglected due to the presence of the protection screen described in Section 6.2.

7
Results

The results of the study can be divided into two parts. The first part is a summary of the most important statements made by the respondents in the interview study and the similarities between them. In addition, the stakeholder graph with all the respondent gathered in one will be presented. In the second part, the findings from the case study will be presented. The findings from both the selection and design process will be summarised.

7.1 Interview Results

Through the interviews, there were many areas where the respondents agreed there could be improvements regarding the Temporary Works (TWs) industry. One of the most mentioned areas of problems was the level of inconsistency throughout the industry. Especially when outlining the different routines between contractors.

As a result, the respondents stressed the lack of an industry organisation, which could set up guidelines for all the suppliers, contractors and engineers. Furthermore, the organisation could help organise the education of both workers and designers of TWs. Especially educational programs where the characteristics of TWs is introduced, and guidance is given, not only on how to design but also how to critically and efficiently review a design. Here the Temporary Works Engineers (TWEs) in Section 5.5, saw the potential for improvement of the reviews since they often encounter third-party reviews of unsatisfying quality, where the response of the reviews often focuses on minor details of low importance, instead of the overall structural stability. Moreover, the respondent from the first contractor, in Section 5.2, made the case that third-party reviews would not be necessary if there were better knowledge and understanding amongst the TWEs. Likewise, there is a common understanding that there is an overall lack of practice throughout the structural engineering ranks regarding TWs since the main focus of design and calculation often is on the PW.

The need for an industry organisation is, as mentioned raised in the interview with the TWE in Section 5.5. When working with different contractors, there are different expectations from each and one of them. An industry organisation could help set the same guidelines for all competing companies and set a standard of what is required for their area of work. In the interview with the scaffolding supplier in Section 5.7, the respondents stated the help their industry organisation (STIB) provided both in setting certain minimum safety requirements and in organising education of the workforce. Although problems also occur in the scaffolding industry, see Section 4.4, they stress that their industry organisation helps to keep non-professional and dishonest companies out of the market.

A significant reason for this lack of knowledge and practice within the TW field can be traced back to the universities and other educational programs where TWs barely are taught to the students according to the respondent in Section 5.4. The respondent also mentions that the lack of education about TWs is the direct cause of the lack of understanding the importance of having a safe procedure and documentation of TWs. The lack of understanding results in a deficiency to fulfil a safe and healthy working environment for everyone at the construction site.

The lack of consistency also influences the way stakeholders work with, and compete against each other. As for almost every project, there are different ways of how responsibilities are distributed. In some cases, there are special Temporary Work Supervisors (TWS), see Section 5.2, in other cases, there is no one designated responsible for TWs, see Section 5.3. Furthermore, several of the respondents often experience confusion regarding the responsibilities between the different structural engineers within TWs and PWs. Also, there is frustration over the lack of communication between TW and PW engineers uttered in the interview with the TWE, see Section 5.5.

The TWE in Section 5.5, raised the importance of holding contractors accountable during the erection process and the contractors' responsibility to follow the delivered drawings and method statements. As a result, they emphasise the need for improved knowledge among the workforce concerning TWs. The respondents argue the fact that third-party reviews only have the desired effect if the TW is erected according to the drawings. Moreover, the respondents argue the responsibility is on the contractors to ensure proper inspections of the TW before usage. In addition, the experienced TWE in Section 5.4, also recalls a decrease in craftsmanship and knowledge among the workforce, supporting the claims of the TWE in Section 5.5.

Another factor emphasised, was the lack of demands on the TWs by the governing institutions, such as the Swedish Transport Administration (STA) and Swedish Working Environment Authority (SWEA). The STA argued in Section 5.8, this circumstance will be covered in the newly published *Krav Brobyggnad* (Trafikverket, 2018a). Furthermore, there was consensus by the involved respondents that the quality of the STA had decreased, due to re-organisations in the last decade. These re-organisations have led to a smaller workforce within the administration, and much of the work previously done by the STA is now outsourced to consultants. In addition, the experienced TWE in Section 5.4, claimed the investigation in Section 4.2, committed by the STA, concluded the wrong reason behind the accident. Moreover, the regulation from the SWEA primarily focus on scaffolding and does not consider, e.g. falsework. There is an existing code of practice and strict regulations for scaffolding, the same can not be said for falsework. In fact, falsework is specifically excluded in the SWEA code of practice for scaffolding.

7.1.1 Results from Temporary Works Stakeholders Graph

In Figure 7.1, all the interviewed respondents and their respective company are presented in the same *Temporary Works Stakeholders Graph*. Two clusters can be recognised in the graph. The first cluster can be found in quadrant one, both the two TWEs, along with the STA, can be found. All three have similar understanding for the Eurocode (EC) and European Standards (ENs), governing TWs according to the graph. However, the three have different types of practices when using the EC and ENs, this is reflected in how well their practical experience and knowledge level is graded. The experienced TWE with the longest experienced is graded the best, compared to the STA which have documentation regulating their contractors' and consultants' use of TWs.

The second cluster can be found in quadrant two, they approximately possess the same practical knowledge, but use different types of theoretical knowledge when working with TW, such as experience or element load resistance.

1: Contractor 1
2: Contractor 2
3: Experienced Temporary Work Engineer
4: Temporary Work Suppliers and Engineers
5: Temporary Works Suppliers for House Construction
6: Scaffolding Supplier
7: Swedish Transport Administration

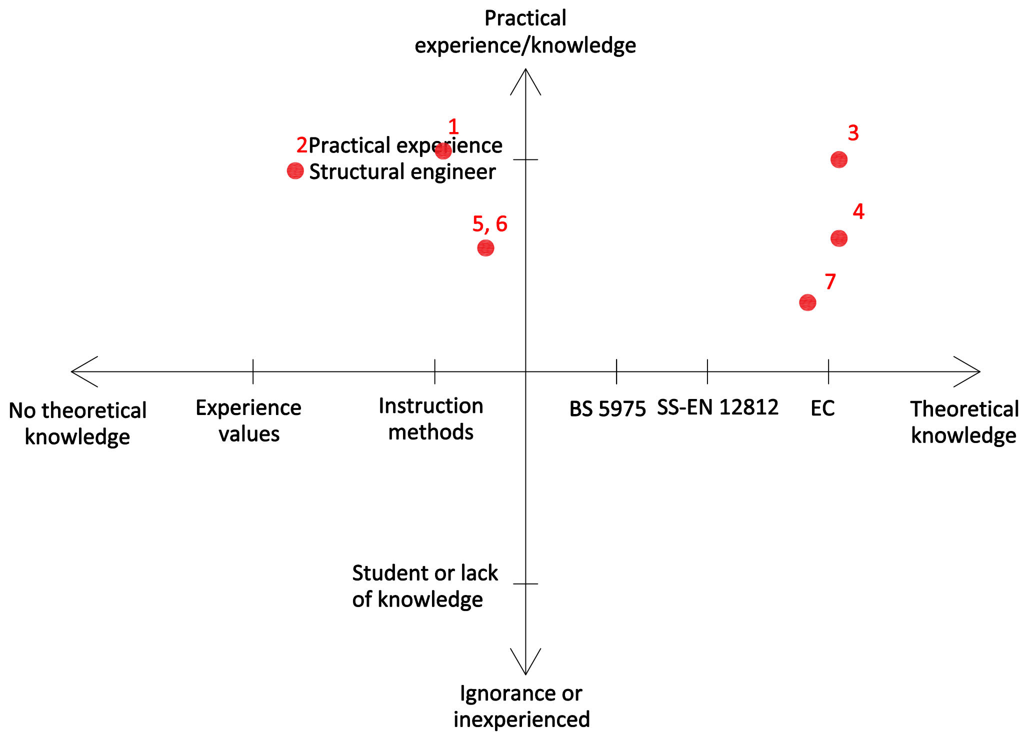


Figure 7.1: *Placement of all the interviewed companies and respondents combined in the graph in the Temporary Works Stakeholders Graph.*

7.2 Results Case Study

In order to select the final TW concepts designed in the case study, the *Pugh Matrix* and an *Analytic Hierarchy Process* were used. In the *Analytic Hierarchy Process*, the requirement *Health and Safety* was obtained as the requirement with the highest importance grading. In addition, the requirements associated with the improvement of the working environment did also score high in the *Analytic Hierarchy Process*. On the other hand, requirements which were dedicated to making the system more easy to understand and explain for the workers scored lower.

In the grading of the two different concepts, it was difficult to estimate certain impacts due to the initial design face of the concepts. The grading indicates that the truss cantilever system is slightly favourable in more requirements then the propping concept, although the scores were almost identical. The cantilever truss scored somewhat lower in most of the requirements but had a firm advantage in the requirement *Accessibility on Floors*. As this requirement was very specific for the project, it achieved a high importance grade in the *Analytic Hierarchy Process*.

The literature used in the case study consists of SS-EN 12812 (SIS, 2012), Eurocode 3 (SIS, 2011b), and the *Handbok i formbyggnad* (Byggentreprenörerna, 1993) for practical design advises.

The final concept design are presented in detail in Section 6.7, but in short, the concept consists of a rectangular truss which rests on a triangular truss acting as a cantilever, supported by the core. The governing boundary condition for the design was the deflection ratio, not allowed to be larger than 10 millimetres (SIS, 2010). Another boundary condition, which strongly influenced the design, was the height of the floor, as the TW had to be fitted accordingly. After consultation with the contractor and the client, it was decided to regard the TW as horizontally stable.

The results from the case study is presented in the tables below. The deflection study can be seen in Table 7.1. The moment and shear capacity of the VKR 300x200x14.2 beam is presented in Table 7.2. The moment, shear and Euler buckling capacity are presented in Table 7.3. The Euler buckling resistance for the diagonal struts in the truss can be seen in Table 7.4. The capacity of the joints in the aspect of shear, tension and the connection plate are presented in Table 7.5. The capacity of the welds required two checks, $\sigma_{Rd,1}$ and $\sigma_{Rd,2}$, this can be seen in Table 7.6 and 7.7. The size of the welds between the struts and ties are designed to 5 millimetres, and the welds between the truss and the connection plate are designed to 9 millimetres.

Table 7.1: *Result of case study deformation (Node 3 in Figure 6.7 (Appendix E).*

Actual deflection [mm]	**Allowed deflection [mm]**	**Utilisation [%]**
9.86	10	99

Table 7.2: *Capacities in VKR 300x200x14.2.*

Performed check		**Design Value**	**Resistance**	**Utilisation [%]**
Moment capacity	[kNm]	28	356	9
Shear capacity	[kN]	125	1410	9

Table 7.3: *Capacities in VKR 300x200x12.5.*

Performed check		**Design Value**	**Resistance**	**Utilisation [%]**
Moment capacity	[kNm]	18	294	6
Shear capacity	[kN]	18	1250	1
Euler buckling	[kN]	2050	3660	56

Table 7.4: *Capacities in VKR 150x100x8.*

Performed check		**Design Value**	**Resistance**	**Utilisation [%]**
Euler buckling	[kN]	382	1060	36

Table 7.5: *Capacities in bolts and the truss's connection plate.*

Performed check		Design Value	Resistance	Utilisation [%]
Shear in bolts	[kN]	112	252	44
Tension in bolts	[kN]	138	221	62
Shear and tension interaction in bolt	-	0.89	1.0	89
Shear in plate	[kN]	310	4060	8

Table 7.6: *Capacities in welds, first control of Design stress ($\sigma_{Ed,1}$) and Design resistance ($\sigma_{Rd,1}$).*

Performed check		$\sigma_{Ed,1}$	$\sigma_{Rd,1}$	Utilisation [%]
Diagonal strut, horizontal weld	[MPa]	341	394	87
Diagonal strut, vertical weld	[MPa]	318	394	81
Upper Column, horizontal weld	[MPa]	254	394	64
Upper Column, vertical welds	[MPa]	364	394	92
Remaining vertical weld (only shear)	[MPa]	150	394	98

Table 7.7: *Capacities in welds, second control of Design stress ($\sigma_{Ed,2}$) and Design resistance ($\sigma_{Rd,2}$).*

Performed check		$\sigma_{Ed,2}$	$\sigma_{Rd,2}$	Utilisation [%]
Diagonal strut, horizontal weld	[MPa]	118	319	37
Diagonal strut, vertical weld	[MPa]	101	319	31
Upper Column, horizontal weld	[MPa]	127	319	40
Upper Column, vertical welds	[MPa]	127	319	40

8

Discussion

The field of Temporary Works (TWs) is a broad subject with many different applications within the construction industry. All working procedures within the construction industry are dependent on TWs to some extent, resulting in the importance to possess an understanding of its limitations and safe working procedures.

8.1 Responsibility of the Industry

The TW industry is today very disorganised. The introduction of a national TW industry organisation could help to implement the mentioned suggestions made in Chapter 5, and raise the level of knowledge within the field of TWs, much like within the scaffolding industry, as mentioned by several respondents in Chapter 5. The TW industry organisation could also help to create a minimum standard regarding, e.g. falsework, as the contractor in Section 5.2 mentioned. The claim is backed from both the Temporary Work Engineer (TWE) in Section 5.5 and the scaffolding suppliers in Section 5.7. The later of the two directly referred to the Scaffolding Industry Organisation (STIB) as a good example of how an industry organisation can help raise safety and awareness. There could be an argument made that the STIB should include falsework to be part of their organisation as well since the two are not that much different. The contractors can also use the organisation's regulations as a benchmark for the security they can demand on their construction site when formulating the procurement. However, it should be pointed out that the scaffolding industry is not immune against failures either, as shown in Section 4.4.

A TW industry organisation could also help enhance the knowledge and craftsmanship amongst workers and provide them with a better understanding of the difficulties surrounding TWs. There could be an education system of Temporary Works Coordinators (TWC) established, similar to the company described in Section 5.2, and the British model in Section 3.2. The introduction and use of a TWC could result in better health and safety procedures on the construction sites and a sufficient TW industry, as the experiences from the United Kingdom show (Hewlett et al., 2014).

Furthermore, the introduction of working papers and/or some type of code of practice could be helpful when designing and reviewing a TW design. The code of practice described in Section 3.2, has been of great support for the secure handling of TWs in Great Britain, according to Hewlett et al. (2014), and the same could hopefully be expected in Sweden. In addition, the education of workers is also a demand that could raise the level of handling TW structures. As mentioned in Section 5.5, drawings and calculations are of little help if the erecting workforce does not know how to erect the TW correctly. The risk of poorly executed TW would most likely decline if only certificated workers would be allowed to erect TW. Especially the contractors should have an interest in correct erected TW, since they heavily rely on the correct erection of, e.g. falsework, often without any regulated control conducted by them internally.

The question of where the boundary section between different structural elements in a TW system ends have in multiple interviews, see Section 5.2, 5.5 and 5.6, been raised. The uncertainty amongst the civil engineering division regarding the boundary section is considered as one significant contributor to many misconceptions and confusion within projects, and many consultants split the responsibilities within one TW. For example, the respondents in Section 5.5, recognise the importance of the ground conditions for the stability of the final TW structures. However, the responsibility to ensure proper ground condition is the responsibility of the contractor. The SS-EN 12812 does not give any value on the stability of the ground more than it should be "sufficient". This example is a good showcase on why the introduction of a TWC should be considered. Such a coordinator could not only be a link between the TWE and the responsible geotechnical engineer but also help to guide which ground assumptions can be made and oversee the construction of the final TW. Another example is the near collapse of a wildlife crossing described in Section 4.2. The alternative theory described by the experienced TWE, pointed at the lack of rods between the secondary beams as one of the main reasons behind the accident. The installation of these rods was not defined in the erection plan, although required for formwork with these inclinations. Here it could be discussed if the rods are the responsibility of the falsework engineering or erection company or of the formwork engineering or erection company. There could also be the argument made that the rods should be installed regardless since it is good practice to do so in situations with inclinations above 5% (Byggentreprenörerna, 1993). However, this seems somewhat unfair if the erection workers have followed the drawings supplied by the TWE. As in the first example, a responsible TWC detecting the missing rods could have made all the difference.

In addition to the answers regarding the overall state of the industry, the respondents also contributed with requirements on how to perform TWs of high quality. These were evaluated and summarised in Section 6.5. When investigating the actual impact of the requirements, it is no surprise that *Health and Safety* is the requirement with the highest impact grading. In a theoretical study like this thesis, the result is somewhat expected since the safety of the workers is considered the most important requirement amongst all the stakeholders within the construction industry. In the interviews, *Health and Safety* was always pointed out as one of the top priorities, but these answers can sometimes be questioned with the studied failures which occurred in the past in mind. Probably there has never been the intention to put the safety of the workers at risk, but actions were simultaneously taken, which suggest that the safety of the workers was not the main focus. For example, the very tight time schedule described in Section 4.3, or the nonchalance shown in Section 4.1 regarding the strengthening of the overhang brackets, indicate a de-prioritisation or lack of knowledge regarding safety. It is welcoming to see that some companies, see Section 5.2, have taken actions to address this problem, and one can only hope these efforts are followed through on the construction site. If the routines are fully implemented can be questioned, since the company has experienced accidents involving TW after the introduction of the new routines. Overall, the introduction of a TWC is a good first step, but improvements can be made, and the support of the workforce for reforms has to be assured.

Also, it has to be pointed out that the second interviewed contractor, see Section 5.3, does not have any such routines in place and has from an outside perspective, had about the same amount of incidents the past five years. Nevertheless, the implementation of a nationwide education for TWC could lead to a positive development within the TW industry, much like the model in place in the United Kingdom, see Section 3.2. The TW industry organisation would probably play a crucial roll in establishing such an educational program and guarantee its quality. Some of the obstacles in establishing such an educational program would be the founding of it, as well as recruiting the necessary educators. Here, the support of the main stakeholders is of great importance to show unity and the desire for change.

8.2 Responsibility of Academics

One of the main problems which can be detected throughout the TW industry is the treatment of TW as lesser important than PW. The treatment originates with the lack of education of TW in the civil engineering and other educational programs, which leads to a knowledge gap later on in the professional ranks. This knowledge gap can both be the result of, and the reason for, the lack of literature regarding TW and research at the universities. The circumstance is somewhat of a catch 22 since the education of engineers in the TW field would require sufficient literature, which only can be produced by experienced engineers in collaboration with the universities. As mentioned in Section 5.4, the experienced TWE had some minor internal education within a contracting company, but these initiatives must be broader and open to the whole construction industry.

More education regarding TW at the universities would be a first step to raise the knowledge amongst structural engineers. Not only would the quality level of design surrounding TW probably increase, but also the standard of the reviews which were criticised by the respondents in Section 5.5. As mentioned by the respondent in Section 5.4, the procedure in how a review has to be carried out and should be structured is not regulated and is often a matter of experience. If there were some education in how TW is designed, the experience level of the graduates would be higher, compared to the current situation. More skilled reviewers would probably also be faster when performing a review, saving both time and money.

8.3 Responsibility of Authorities

When studying the well-documented failures, one can not ignore the fact that several government authorities have been directly involved either as clients or as investigators. As mentioned in the previous section, the requirement *Health and Safety* was identified as the one with the most significant impact in the case study. The Swedish Working Environment Authority (SWEA) is identified as an important stakeholder within the *Health and Safety* field. They have already published documentation on how scaffolding has to be handled, see Section 3.1, but documentation which covers other types of TW are not published by the SWEA. It does, unfortunately, result in a lack of clear regulation from the authority on how the industry should work with TW such as formwork and falsework. As mentioned in Section 5.7, the respondents state that their company educate SWEA inspectors on what to look for during visitations and inspections on the construction sites. These visitations aim to detect errors or missing elements in the TW structures and other risks regarding health and safety. It is essential to state that no interview with a representative from the SWEA has been carried out within this thesis. Instead, only official documentation and protocols from inspection have been studied.

The already mentioned treatment of TW as less critical is also shown in the way it is handled by the Swedish Transport Administration (STA). The STA, which in many other areas is very particular in its demands, has little guidance regarding TW, see Section 3.1.3. Particularly the demands on the company and structural engineer are insufficient as they leave room for interpretation regarding the qualification of the company and structural engineer. There are also no demands on the qualification of the engineer carrying out the third-party review. Some of the respondents expressed their frustration over the inconsistency of contract requirements throughout the STA and differences between regions. Since most of the STA's public procurement are based on documents carried out by external consultants, the requirements on the contractor and engineer can vary, especially with regard to TW. However, according to the respondent in Section 5.8, a plan to make the requirements more cohesive throughout the different regions in the country. Moreover, it is concerning that the STA cannot be trusted with an internal review of drawings and calculations, as mentioned in Section 5.3.

Another confounding result was the fact that the STA based their accident reports on technical investigations carried out by the same company responsible for that same accident. For instance, as mentioned in Section 4.3, the STA chose to adhere to the report conducted by the contractor, although other investigations came to somewhat other conclusions. As this is not an isolated incident, it is concerning that the STA cannot provide an independent investigation of the accidents. When the STA bases their report on the investigation carried out by the responsible contractor could damage the report's credibility due to the conflict of interest.

The responsible authorities in each of the accidents in Chapter 4 have investigated the accident. Even though the investigation reports have determined the direct causes of the accidents, additional theories have been presented during the interviews in Chapter 5 and in other investigations. The fact that the results from the reports can be discussed and be questioned according to some of the respondents' indicates the need to introduce regulations stating how TWs always should be designed and reviewed. To have a united view within the TW industry on how the handling should be performed and how accidents should be investigated could potentially result in a consensus of the underlying causes and how investigations should take all stakeholders perspective into account.

8.4 Regulation and how Responsibilities are addressed

One quickly realised during the case study how the design of TW by structural engineers could be complicated since their main focus is on Permanent Works (PWs). A certain nervousness was associated with the use by SS-EN 12812 (SIS, 2012), since there was an uncertainty on what types of assumptions that can be made and still be on the safe side in the calculations. The uncertainty could be traced back to the lack of education on TW at the universities, as mentioned earlier. In Section 5.4, the respondent agrees to the same premise but simultaneously states there is no knowledge management transfer within the respondent's company. The lack of guidance from codes and standards have also been experienced during the case study. However, this lack of guidance is the case in all ENs, but on the contrary to the EC, there is no explanatory literature surrounding the ENs concerning TW. When assumptions for the truss design were made, the standard of SS-EN 12812 and Eurocode 1 (SIS, 2011a), and Eurocode 3 (SIS, 2011b) served as the base for the calculations. As Eurocode 3 handles the design of PW, it does not take TW specific problems into account, which can lead to difficulties during the designing of TW. The lack of experience can potentially result in misconceptions of understanding the EC and ENs and how assumptions are derived, e.g. that wet concrete during casting should be treated as an imposed load instead of self-weight. This sort of mistakes is easy to commit when the structural engineer does not have the experience concerning the relevant ENs. The same applies if a structural engineer would be appointed with the assignment to review another engineer's TW design. How should an engineer, who does not have the basic understanding of the relevant ENs, be able to do a proper and good review of a design document provided to them for reviewing.

As the case study was performed, the sizing of the props was the background for some problems. The suppliers of TW present their element with working stress, i.e. *Permissible Stress Concept* in their brochures (DOKA, 2019). Countries within the CEN network use the limit state concept to size structural elements. The different concepts require a conversion from the permissible stress to limit state to be able to investigate if the elements have sufficient capacity to sustain the loads from the

PW. To perform this conversion, the engineer needs the partial factors that have been used in the permissible stress resistance declaration. It would be more logical for the suppliers to present their elements capacity in both stress concepts. It would facilitate for the structural engineer who perhaps not have performed this type of sizing before. With the elements presented in the limit state concept with a characteristic capacity resistance, the engineer could easily compare the actual loads from the PW with the resistance and perform the sizing.

As the case study was carried out, one quickly realised the governing demand would be the allowed deflection ratio. The allowed deformation ratio for the cantilever truss has been motivated from the STA's regulation for the launching of bridges (Trafikverket, 2018a), which refers to Eurocode 1. Since no deflection ratios for cantilevering TW or wall elements in vertical direction have been found, the Eurocode 1 regulation was chosen as the governing deformation ratio. In this case study, the outrigger wall had some similarities to a bridge, e.g. the post-tensioned and heavy concrete structure. However, in more normal circumstances, the assumption of the similarities with a bridge may not be valid.

Another notable circumstance is the non-regulation of falsework for, e.g. bridges. Especially with the background that scaffolding is strictly regulated by the SWEA. One can be questioning the reasonableness of the exclusion of falsework in the governing document since scaffolding and falsework are very similar in their design as TW. In particular, when considering the fact that scaffolding often is used in combination with falsework. As an example, one can imagine a complicated bridge falsework which can be constructed by untrained workers and is not required to be inspected before usage. At the same time, the simple scaffolding tower used reach the formwork will be erected by specially trained workers and subject to inspection before release. One can argue that at least education and inspection should be a regulated part by the SWEA when considering falsework.

8.5 Temporary Works Stakeholders Graph

Quadrant One

The three stakeholders in quadrant one are all graded with the same amount of theoretical knowledge. The significant difference between them is to be found in their practical knowledge. They all come in contact with the design and calculation of TW and are therefore also dependent on possessing a high understanding of the theoretical knowledge behind TW. The understanding of how a TW and PW is constructed is the distinction between them.

Depending on how close they are to the construction phase, the better practical experience they possess and therefore, the higher grading in the graph. The experienced TWE are in close contact with the construction site after the design work is finished. While the STA more often have consultants and govern the use of TW through their own regulations.

Quadrant Two
All of the stakeholders use their practical knowledge when working with TW and with the support from material instructions, guidelines from suppliers and internal documentation, which reflect the position between "instruction methods" and "experience values". The two contractors rarely perform any calculations in contrast to the suppliers. The suppliers' TWE use loads from the structural engineer of the PW and apply the sated loads with the defined permissible values for their equipment.

8.6 Self Reflection of the Thesis

There are some constraints in this thesis which should be taken into consideration when evaluating the findings. As the literature study mainly focuses on Sweden and partly on the United Kingdom, the study does not give a collective situation in Europe, which also would be of interest. The input from other countries practices could help in identifying additional areas or solutions of improvement. When the accidents were examined in Chapter 4, one quickly realised the lack of investigations involving the building industry. As described in Chapter 4, there are different reasons for the lack of investigations, but there is no denying that the examination of accident reports within the building industry would have contributed to this thesis. However, the examination of the failures mentioned in Chapter 4, contributed significantly to the understanding of collaboration within the TW industry.

The selection of the different interviewing respondents was founded on multiple criteria described in Section 5.1. Despite this systematic approach, there were some additional stakeholders that could have contributed to the conclusion of the thesis. Interviewing a construction site worker or foreman could have given a brighter insight on the actual construction process on site and possible areas of problems. However, it should be noted that some input in this regard has been given by the supervisor of the thesis. Furthermore, the absence of an interview with the Swedish Institute for standards (SIS) is unfortunate. Although attempts were made to identify a person within the SIS, it was not possible to arrange an interview. The input from SIS would have been of great help while examining the different ENs and EC currently in use and get an insight into the reasoning behind the structure of the ENs and EC. Concerning the credibility of the interviewed respondents, there are a few points to take into consideration. First, all of the respondents had their background from the construction industry, ensuring their credibility in the matter of knowledge within TW. However, it should be taken into consideration that some answers could be framed to fit within the narrative desired by the respondents. Second, all the respondents were very engaged and spoke freely about difficulties and problems which let one believe the answers were sincere.

When developing the two concepts presented in Section 6.4, the idea was to achieve a wide variety between them. First of all, during the *Analytic Hierarchy Process*, the question about access to the floors below and the feasibility in erecting 50 props on each floor all the way down to the bottom slab was raised. In discussion with the contractor and responsible structural engineer, the conclusion was drawn that these many props were unrealistic in practice. Secondly, significant uncertainties on how the forces would be distributed when backpropping took place on so many floors simultaneously arose. However, the propping solution in Table 6.2 achieved a score of 3.27, compared to the winning concept with a score of 3.33. According to the result, the systems should be similar in feasibility, that either one of them would be good enough to perform. However, the fact that the propping solution has so many uncertainties resulted in the decision not to investigate the solution further in the case study.

In Section 6.6, the *Analytic Hierarchy Process* method resulted in the use of a bespoke cantilever truss system. The truss was designed with loads according to SS-EN 1281 and the steel sizing according to Eurocode 3. The use of the two ENs has resulted in a small use in the other ENs related to TW (SS-EN 12810 to 12813). Due to the little use of TW specific ENs and the implementation in the case study, the transparency and understanding of their strengths and weaknesses can have been missed in the discussion. The use of standardised elements could also increase the understanding of how the suppliers document their systems.

As the findings from the interviews were tested in the case study, there were some additional questions which arose. It was especially challenging to determine the impact of different requirements against each other. It can also be discussed if the *Analytic Hierarchy Process* is the right method in this kind of decision making. There is an argument to be made that requirements should not be stacked against each other since some of them, e.g. *Allowed Deflection*, have to be fulfilled regardless. However, the grading of the requirements in the case study was in some cases not set to determine if a requirement can be met, but rather how easy the requirement can be met.

The use of the *Pughs matris* in the comparison between the two concepts in Section 6.6, could perhaps not be the most conventional method used when choosing between two construction methods within an ongoing construction project. The *Pughs matris* is more often used by engineers when new systems or solutions are developed from scratch. The *Analytic Hierarchy Process* can also be hard to use when requirements like *Accessibility on floors below* stands against *Allowed deflection ratio*. The *Accessibility on floors below* requirement is of the character "nice to have", were the *Pughs matris* is useful, since it is easy to grade for each concept. However, the *Allowed deflection ratio* is more of a "minimum allowed" requirement, which the *Pughs matris* is more challenging to take into account for. However, the *Pughs matris* has been introduced and used in many courses at the university when performing conceptual design projects, much like the case study in this thesis.

9 Conclusions

After an intensive study of the current situation regarding the management of Temporary Works (TW), a number of conclusions have been reached. The conclusions drawn from this thesis is to give suggestions on improvements in the industry as a whole, as well as European Standards (EN) and regulations surrounding TW.

- Better coordination between the different stakeholders involved should be considered. Especially the relationship between the structural engineers of the Permanent Work (PW) and the TW should be intensified to ensure a good understanding of the structural system.

- The introduction of educational material and literature at universities and other educations within the industry should be considered. The learning material could help increase the overall knowledge among the engineering and construction ranks and make, e.g. communication between each other easier. Furthermore, the updated literature should be based on modern EN and limit state principles.

- Implementation of TW specific courses or parts in the civil engineering education could help raise the knowledge amongst all structural engineers. The increase of knowledge would especially help PW engineers understand TW and raise the level of awareness.

- Introduction of a national TW industry organisation handling falsework, formwork, and propping in particular. The organisation could help with the improvements mentioned in Section 8.1, as well as unify the overall TW industry.

- Development of the existing ENs regarding TWs. If not on a European level, at least on a national level with the introduction of a National Annex, summarising designing descriptions and custom safety factors for TW.

- There could be a consensus of the stress method (permissible vs limit state) used throughout the industry. The usage of permissible stress can lead to confusion amongst inexperienced structural engineers and should be discarded.

- Introduction of a Temporary Works Coordinator (TWC) with a nationwide accepted work description. The TWC model in the United Kingdom should be taken as a template.

- Stricter demands on the reviewer of the TW designs, especially from the Swedish Transport Administration (STA) regarding bridges.
- Introduce demands to review TWs used in the housing construction industry. since there are no such demands today.
- Impartial investigation of future accidents should be implemented by the STA to ensure repeated problems are identified and erased.
- The Swedish Working Environment Authority (SWEA) should introduce working papers for falsework and formwork, much like their working papers concerning scaffolding.

10 Further Studies

While working with the thesis, multiple questions and areas of interest have been detected, which could be investigated further. These further studies could help raise the awareness and knowledge surrounding Temporary Works (TWs) and hopefully inspire further studies within TWs.

- Investigate the possibility to implement parts regarding management from BS 5975 (BSI, 2008) into the European Standards (ENs). The implementation could result in a better understanding, not only in Sweden but in all countries connected to the European Committee for Standardisation (CEN).

- Investigate if a probabilistic design process could be used on TWs and how the procedure and design would be improved from the one used today.

- Investigate how the tolerances of unintended inclination are affecting the TWs regarding element parts which have been used a long time and are damaged.

- Study how the foundation works is handled as a TW. All the respondents in the interview stressed the importance of a stable foundation on the construction site and the questions regarding how the loads are distributed.

- When calculating TW today, the foundation often is considered as hinged or simple supported, where no vertical movement takes place during the use of TW. However, on the contrary, the foundation behaves more like a spring with movement in the vertical direction depending on the soil and support. In order to perform a more accurate and safe TW design, the engineer should take the spring bed support into consideration. As a result, an investigation regarding foundation support should be performed.

- The use of backpropping today relies on experience and rule of thumb. In BS 5975 there is a suggestion of how the loads are roughly divided between backpropping and floors. The division, however, is not investigated during the TW design process and the understanding of how fresh concrete distributes the loads over slabs are inadequate. The investigation should focus on how the loads actually are distributed in a backpropped, not fully cured slab.

- An interview with the Swedish Work Environment Authority (SWEA) should be carried out. The interview and accommodating investigation should focus on how they work with scaffolding today and if they are planning on including falsework in their regulations in the future.

- Investigation of accidents concerning TW in building construction, preferably in a statistic manner. This investigation could be done in collaboration with SWEA.

- Investigate how the cost ratio between the cost of TWs and total cost of the entire project both within the housing industry and infrastructural projects. The aim would be to investigate how the ratio varies between different contractors and to understand if there is a *lowest recommended cost ratio* that would imply a reduced or increased risk for accidents to take place. In this way, the risk for accidents could be avoided if the cost ratio for a certain type of project is lower then the average ratio.

- Developer the Temporary Works Stakeholder Graph and use a "surface" to explain a company and all its employees in the graph. Additionally to do the grading in a more structured way by investigate knowledge levels further.

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A
Interview Questions

Frågor

Vad är din roll idag?

Hur är era interna rutiner uppbyggda?

- Beräking
- Utförande
- Gjutning
- Rivning
- Management

Vilka dokument är rutinerna baserade på?

Berätta om hur förfarandet kring en typisk dimensionering går till av TW?

Hur går en typisk granskning av TW till?
- Underentreprenör / leverantörer?
- Internet?
- Tredjeparts Granskning?

När ni granskar, vart brukar de största bristerna ligga?

Finns det meningsskillnader i hur man ska designa TW?

I så fall, vart ligger de största skillnaderna i åsikt/verksamhetsområde med tanke på beräkning?

I så fall, vart ligger de största skillnaderna i åsikt/verksamhetsområde med tanke på utförande?

Finns det några motstridigheter mellan det teoretiska och praktiska utformandet?

Hur ser granskningen av TW ut på arbetsplatsen?

När ni granskar TW på plats, vart brukar de största bristerna ligga?

Hur ser ansvarsfördelningen ut på arbetsplatsen?
- Optimalt sett?

- Realistisk sett?

Hur ser relationen ut med leverantören av TW?

Hur vill ni att samarbetet ser ut med dimensionering som aspekt?

Hur vill ni samordna samarbetet med en leverantör (tex skanska maskin?/ doka)?

Hur ser du på kunskapsnivån på säkerhetsansvariga på plats?

Jobbar ni med kunskapsöverföring?

Hur jobbar ni med internutbildningar?

Frågor kring olyckorna?

Berätta om ert arbeta av TW innan olyckan?

Vad anser du är de största skillnaderna mellan arbetsmetoden innan och efter era införda rutiner?

Vad var orsaken till olyckan?
- Berätta gärna händelseförloppet? (så mycket du kan)

Vad var orsaken till olyckan?
- Berätta gärna händelseförloppet? (så mycket du kan)

Vad var din roll i arbetsgruppen som utformade era rutiner efter olyckan?
- Och efter olyckan?

Skilde det något i ert arbetssätt kring uppföljningen av de två olyckorna?

Kan du ge några konkreta exempel kring hur rutinerna förändrades?

Arbetar ni idag kontinuerligt med att utvärdera/revidera era interna rutiner?

Hur ser du kring införandet av regler/standarder som är branschöverskridande med avseende på TW?

Tack!

B
Evaluation Matrixes

MATRIX CONTEXTUAL DEMANDS

	Redudant system	Clear structural system	Erection time	Health and safety	Standardised solution	Need for instruction	Inspection and Dismantling	Dependency of Permanent Work	Material cost	Labour cost	Allowed deflection ratio	Accessibility on floors below	Total	Percent	
Redudant system		3	3	2	1	2	1	3	3	3	3	3	27	10.3%	Redudant system
Clear structural system	1		1	1	1	2	1	1	1	1	1	1	12	4.6%	Clear structural system
Erection time	1	3		1	2	3	2	2	1	2	1	2	20	7.6%	Erection time
Health and safety	2	3	3		2	3	2	3	3	3	3	3	30	11.4%	Health and safety
Standardised solution	3	3	2	1		1	1	3	1	1	2	1	19	7.2%	Standardised solution
Need for instruction	2	2	1	1	3		1	1	1	1	1	1	15	5.7%	Need for instruction
Inspection and Dismantling	3	3	2	2	3	3		2	2	3	1	2	26	9.9%	Inspection and Dismantling
Dependency of Permanent Work	1	3	2	1	1	3	2		1	3	2	2	21	8.0%	Dependency of Permanent Work
Material cost	1	3	3	1	3	3	2	3		3	2	1	25	9.5%	Material cost
Labour cost	1	3	2	1	3	3	1	1	1		1	2	19	7.2%	Labour cost
Allowed deflection ratio	1	3	3	1	2	3	3	2	2	3		3	26	9.9%	Allowed deflection ratio
Accessibility on floors below	1	3	2	1	3	3	2	2	3	2	1		23	8.7%	Accessibility on floors below
												Total of the Total:	263		

3	More important
2	Equally important
1	Less important

Temporary works: A permanent problem in Sweden
Master Thesis
Lars Scheidegger, Jonathan Söderqvist

CONCEPT EVALUATION MATRIX

	Weight factor	Truss cantilever	Propping
Redudant system	10.3%	3	4
Clear structural system	4.6%	4	5
Erection time	7.6%	5	3
Health and safety	11.4%	4	3
Standardised solution	7.2%	2	4
Need for instruction	5.7%	3	4
Inspection and Dismantling	9.9%	3	4
Dependency of Permanent Work	8.0%	1	3
Material cost	9.5%	2	5
Labour cost	7.2%	4	2
Allowed deflection ratio	9.9%	4	2
Accessibility on floors	8.7%	5	1
Total		3.33	3.27

Temporary Works: A permanent problem in Sweden

Lars Scheidegger, Jonathan Söderqvist

5	Corresponds very well
4	Corresponds well
3	Neutral
2	Corresponds badly
1	Not corresponding

C

Cross Section Dimensions

Table C.1: *Parameters for steel profile VKR 300x200x14.2.*

VKR 300x200x14.2			
Height	(h)	[mm]	300
Width	(w)	[mm]	200
Thickness	(t)	[mm]	14.3
Area	(A)	[m^2]	$1.32 \cdot 10^{-2}$
Section modulus	(W)	[m^3]	$1.06 \cdot 10^{-4}$
Second moment of area	(I)	[m^4]	$1.58 \cdot 10^{-4}$

Table C.2: *Parameters for steel profile VKR 300x200x12.5.*

VKR 300x200x12.5			
Height	(h)	[mm]	300
Width	(w)	[mm]	200
Thickness	(t)	[mm]	12.5
Area	(A)	[m^2]	$1.17 \cdot 10^{-2}$
Section modulus	(W)	[m^3]	$9.52 \cdot 10^{-4}$
Second moment of area	(I)	[m^4]	$4.43 \cdot 10^{-4}$

Table C.3: *Parameters for steel profile VKR 250x150x8.*

VKR 250x150x8			
Height	(h)	[mm]	250
Width	(w)	[mm]	150
Thickness	(t)	[mm]	8
Area	(A)	[m^2]	$6.08 \cdot 10^{-3}$
Section modulus	(W)	[m^3]	$4.09 \cdot 10^{-3}$
Second moment of area	(I)	[m^4]	$5.11 \cdot 10^{-5}$

Table C.4: *Parameters for steel profile VKR 150x100x8*

VKR 150x100x8			
Height	(h)	[mm]	150
Width	(w)	[mm]	100
Thickness	(t)	[mm]	8
Area	(A)	[m^2]	$3.68 \cdot 10^{-3}$
Section modulus	(W)	[m^3]	$1.45 \cdot 10^{-4}$
Second moment of area	(I)	[m^4]	$1.09 \cdot 10^{-5}$

D

Frame Analysis Results

Project:	Frame2	Date:	2019-06-04
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SUMMARY

26 joints
3 supports
0 springs
95 hinges
71 members
8 sections
83 loads
3 basic loadcase
2 loadcases

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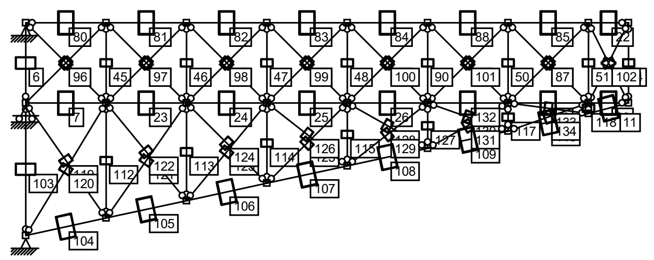
Member



EN 1992-1-1 (standard)

Mould costs

	hour/mÂ²	kr/mÂ²		hour/mÂ²	kr/mÂ²
Beam mould	0.80	50.00	Column mould	0.90	50.00

Work salary: 220kr/hour

Basic loadcase

Name	Des.	Name	Des.	Name	Des.
self-weight steel	B1	Concrete weight	B2	Variable load	B3

Loadcase

	Name	Combination	Limit	Type	Dependency
1	Gjutning ULS	B1*1.35+B2*1.5+B3*1.5	ULS		
2	Gjutning SLS	B1+B2+B3	SLS	Short	

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Results

Max pos. moment - 1. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0	-0.486	Gjutning SLS
6	0	0	-0.316	Gjutning ULS
7	0.063	-17.146	52.093	Gjutning ULS
22	5.472	-1.427	23.338	Gjutning ULS
23	-5.226	6.165	122.818	Gjutning SLS
24	-5.204	0.020	114.555	Gjutning SLS
25	-3.489	1.537	83.267	Gjutning SLS
26	-1.285	1.753	52.724	Gjutning SLS
28	5.548	2.220	51.634	Gjutning ULS
29	5.548	-10.791	61.855	Gjutning ULS
44	0.027	0	-52.185	Gjutning ULS
45	0	0	-143.372	Gjutning SLS
46	0	0	-130.640	Gjutning SLS
47	0	0	-176.839	Gjutning ULS
48	0	0	-158.779	Gjutning ULS
50	0	0	-117.024	Gjutning ULS
51	0	0	-60.122	Gjutning ULS
80	14.298	-4.428	1883.538	Gjutning ULS
81	-0.924	-2.604	990.710	Gjutning SLS
82	-1.073	2.305	763.516	Gjutning SLS
83	1.440	2.601	838.255	Gjutning ULS
84	4.595	3.710	557.853	Gjutning ULS
85	17.955	1.819	119.217	Gjutning ULS
86	0.068	0	-130.298	Gjutning ULS
87	0.068	0	66.463	Gjutning ULS
88	9.017	-5.004	307.355	Gjutning ULS
89	0.068	0	-199.605	Gjutning ULS
90	0	0	-137.202	Gjutning ULS
91	0.068	0	-225.359	Gjutning ULS
92	0.068	0	197.638	Gjutning ULS
93	0.068	0	-231.180	Gjutning ULS
94	0.068	0	279.439	Gjutning ULS
95	0.040	0.006	-289.756	Gjutning ULS
96	0.068	0	453.113	Gjutning ULS
97	0.068	0	-249.418	Gjutning ULS
98	0.068	0	230.828	Gjutning ULS
99	0.068	0	-229.199	Gjutning ULS
100	0.068	0	167.349	Gjutning ULS
101	0.068	0	128.898	Gjutning ULS
102	0	0.071	5.808	Gjutning SLS
103	0	0	-0.386	Gjutning SLS
104	0	-8.175	-1371.401	Gjutning SLS
105	-8.040	0.318	-1123.629	Gjutning SLS
106	-5.754	1.783	-856.669	Gjutning SLS
107	-4.229	1.039	-597.945	Gjutning SLS
108	-2.029	1.700	-366.100	Gjutning SLS
109	2.148	4.444	-275.240	Gjutning ULS
110	5.807	2.968	-114.230	Gjutning ULS
111	5.807	-10.931	-64.950	Gjutning ULS
112	0	0	15.021	Gjutning SLS
113	0	0	-7.835	Gjutning SLS
114	0	0	-17.626	Gjutning SLS
115	0	0	-25.401	Gjutning SLS
117	0	0	-46.613	Gjutning ULS
118	0	0	-17.935	Gjutning SLS
119	0	0.191	267.265	Gjutning ULS
120	0.092	0	-381.956	Gjutning ULS
121	0.084	0	-370.166	Gjutning ULS
122	0	0.142	176.245	Gjutning SLS
123	0.075	0	-351.583	Gjutning ULS
124	0.068	0	228.447	Gjutning ULS
125	0.068	0	-305.471	Gjutning ULS
126	0.061	0	188.848	Gjutning ULS
127	0	0	-32.628	Gjutning SLS
128	0.055	0	147.775	Gjutning ULS
129	0.061	0	-241.387	Gjutning ULS
130	0.051	0	102.623	Gjutning ULS
131	0.055	0	-157.994	Gjutning ULS
132	2.719	4.020	51.314	Gjutning ULS
133	0.048	0	45.791	Gjutning ULS
134	0.051	0	-63.649	Gjutning ULS

Max pos. moment - 2. order

Member	M kNm	V kN	N kN	Loadcase
4	0.004	0	-1.117	Gjutning ULS
6	0	0	-0.234	Gjutning SLS
7	1.388	-18.892	52.895	Gjutning ULS
22	5.478	-1.456	23.362	Gjutning ULS
23	-5.235	6.428	123.278	Gjutning SLS
24	-5.212	-0.017	114.603	Gjutning SLS
25	-3.501	1.528	83.433	Gjutning SLS
26	-1.301	1.750	52.936	Gjutning SLS
28	5.631	2.308	51.690	Gjutning ULS
29	5.631	-10.959	61.880	Gjutning ULS
44	0.221	0	-52.023	Gjutning ULS
45	0.723	0	-215.002	Gjutning ULS
46	0.660	0	-196.499	Gjutning ULS
47	0.595	0	-177.244	Gjutning ULS
48	0.534	0	-159.158	Gjutning ULS
50	0.391	0	-116.780	Gjutning ULS
51	0.201	0	-60.117	Gjutning ULS
80	14.193	-4.552	1885.233	Gjutning ULS
81	-0.962	-2.573	992.475	Gjutning SLS
82	-1.094	2.317	765.189	Gjutning SLS
83	1.413	2.620	840.633	Gjutning ULS
84	4.573	3.713	559.646	Gjutning ULS
85	17.963	1.823	119.516	Gjutning ULS
86	0.690	0	-130.342	Gjutning ULS

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Max pos. moment - 2. order

Member	M kNm	V kN	N kN	Loadcase
87	0.067	0	66.682	Gjutning ULS
88	9.009	-4.971	308.402	Gjutning ULS
89	1.029	0	-199.803	Gjutning ULS
90	0.461	0	-137.561	Gjutning ULS
91	1.155	0	-225.471	Gjutning ULS
92	0.066	0	197.873	Gjutning ULS
93	1.184	0	-231.364	Gjutning ULS
94	0.066	0	279.224	Gjutning ULS
95	0.834	0.169	-288.635	Gjutning ULS
96	0.065	0	452.281	Gjutning ULS
97	1.271	0	-249.051	Gjutning ULS
98	0.066	0	231.019	Gjutning ULS
99	1.173	0	-229.239	Gjutning ULS
100	0.067	0	167.600	Gjutning ULS
101	0.067	0	129.243	Gjutning ULS
102	0	0.096	8.423	Gjutning ULS
103	0	0	0.521	Gjutning ULS
104	0.001	-35.030	-2051.823	Gjutning ULS
105	-5.502	-14.926	-1124.692	Gjutning SLS
106	-4.127	12.651	-857.600	Gjutning SLS
107	-3.148	8.539	-598.655	Gjutning SLS
108	-1.408	6.156	-366.608	Gjutning SLS
109	2.270	7.335	-275.650	Gjutning ULS
110	5.565	1.085	-114.287	Gjutning ULS
111	5.564	-9.595	-64.983	Gjutning ULS
112	0	0	18.748	Gjutning ULS
113	0.001	-0.156	-11.941	Gjutning ULS
114	0	-0.357	-26.931	Gjutning ULS
115	0	-0.511	-38.427	Gjutning ULS
117	0	-0.412	-30.951	Gjutning SLS
118	0.011	0	-26.177	Gjutning ULS
119	0	-0.186	263.402	Gjutning ULS
120	2.721	0	-381.255	Gjutning ULS
121	2.370	0	-371.496	Gjutning ULS
122	0	-0.187	262.599	Gjutning ULS
123	2.000	0	-351.725	Gjutning ULS
124	0.066	0	228.623	Gjutning ULS
125	1.551	0	-305.742	Gjutning ULS
126	0.060	0	189.008	Gjutning ULS
127	0	-0.656	-49.315	Gjutning ULS
128	0.054	0	147.930	Gjutning ULS
129	1.103	0	-241.635	Gjutning ULS
130	0.050	0	102.965	Gjutning ULS
131	0.667	0	-158.301	Gjutning ULS
132	2.715	4.044	51.570	Gjutning ULS
133	0.048	0	45.993	Gjutning ULS
134	0.277	0	-63.790	Gjutning ULS

Max neg. moment - 1. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0	-0.770	Gjutning SLS
6	0	0	0.234	Gjutning SLS
7	-17.692	-18.364	52.093	Gjutning ULS
22	-1.830	54.532	23.338	Gjutning ULS
23	-17.692	10.497	183.755	Gjutning ULS
24	-8.178	-0.983	171.364	Gjutning ULS
25	-8.178	3.581	124.574	Gjutning ULS
26	-5.206	3.904	78.910	Gjutning ULS
28	1.811	2.349	34.493	Gjutning SLS
29	0	-7.644	41.364	Gjutning SLS
44	0	-0.071	-34.732	Gjutning SLS
45	0	0	-143.655	Gjutning SLS
46	0	0	-130.924	Gjutning SLS
47	0	0	-177.222	Gjutning ULS
48	0	0	-159.162	Gjutning ULS
50	0	0	-116.642	Gjutning ULS
51	0	0	-60.505	Gjutning ULS
80	-24.515	-124.947	1883.538	Gjutning ULS
81	-28.417	-104.334	1481.061	Gjutning ULS
82	-28.417	103.881	1141.475	Gjutning ULS
83	-24.969	103.033	838.255	Gjutning ULS
84	-22.368	104.142	557.853	Gjutning ULS
85	-13.823	113.738	119.217	Gjutning ULS
86	0	-0.191	-130.106	Gjutning ULS
87	0	-0.142	44.396	Gjutning SLS
88	-18.986	106.834	307.355	Gjutning ULS
89	0	-0.191	-199.414	Gjutning ULS

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Max neg. moment - 1. order

Member	M kNm	V kN	N kN	Loadcase
90	0	0	-137.584	Gjutning ULS
91	0	-0.191	-225.168	Gjutning ULS
92	0	-0.191	197.446	Gjutning ULS
93	0	-0.191	-230.989	Gjutning ULS
94	0	-0.191	279.247	Gjutning ULS
95	-0.063	0.236	-289.986	Gjutning ULS
96	0	-0.191	452.922	Gjutning ULS
97	0	-0.191	-249.227	Gjutning ULS
98	0	-0.191	230.637	Gjutning ULS
99	0	-0.191	-229.008	Gjutning ULS
100	0	-0.191	167.157	Gjutning ULS
101	0	-0.142	86.162	Gjutning SLS
102	-0.027	0	8.373	Gjutning ULS
103	0	0	0.386	Gjutning SLS
104	-13.193	-13.501	-2049.726	Gjutning ULS
105	-13.193	1.766	-1679.926	Gjutning ULS
106	-12.008	3.948	-1280.861	Gjutning ULS
107	-8.591	2.835	-894.102	Gjutning ULS
108	-6.312	3.824	-547.517	Gjutning ULS
109	-3.022	5.661	-275.504	Gjutning ULS
110	1.430	2.847	-76.613	Gjutning SLS
111	0	-7.736	-43.353	Gjutning SLS
112	0	0	14.615	Gjutning SLS
113	0	0	-8.180	Gjutning SLS
114	0	0	-17.909	Gjutning SLS
115	0	0	-25.623	Gjutning SLS
117	0	0	-31.150	Gjutning SLS
118	0	0	-17.972	Gjutning SLS
119	-0.084	0	266.991	Gjutning ULS
120	0	-0.142	-255.299	Gjutning SLS
121	0	-0.191	-369.892	Gjutning ULS
122	-0.075	0	263.133	Gjutning ULS
123	0	-0.191	-351.351	Gjutning ULS
124	0	-0.191	228.256	Gjutning ULS
125	0	-0.191	-305.280	Gjutning ULS
126	0	0.142	126.467	Gjutning SLS
127	0	0	-32.789	Gjutning SLS
128	0	-0.191	147.667	Gjutning ULS
129	0	0.191	-241.537	Gjutning ULS
130	0	0.142	68.704	Gjutning SLS
131	0	-0.142	-105.599	Gjutning SLS
132	-1.910	5.238	51.314	Gjutning ULS
133	0	0.142	30.647	Gjutning SLS
134	0	-0.191	-63.582	Gjutning ULS

Max neg. moment - 2. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0.015	-1.308	Gjutning ULS
6	0	0	0.234	Gjutning SLS
7	-18.113	-20.110	52.895	Gjutning ULS
22	-1.815	54.503	23.362	Gjutning ULS
23	-18.108	10.895	184.626	Gjutning ULS
24	-8.185	-0.970	171.642	Gjutning ULS
25	-8.186	3.568	124.989	Gjutning ULS

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Max neg. moment - 2. order

Member	M kNm	V kN	N kN	Loadcase
26	-5.228	3.900	79.342	Gjutning ULS
28	1.809	2.407	34.511	Gjutning SLS
29	0	-11.567	61.880	Gjutning ULS
44	0	-0.535	-34.625	Gjutning SLS
45	0	2.889	-215.194	Gjutning ULS
46	-0.001	2.639	-196.690	Gjutning ULS
47	-0.001	2.379	-177.435	Gjutning ULS
48	0	2.135	-159.350	Gjutning ULS
50	0	1.564	-116.971	Gjutning ULS
51	0	0.803	-60.308	Gjutning ULS
80	-24.619	-125.043	1885.233	Gjutning ULS
81	-28.484	-104.530	1484.195	Gjutning ULS
82	-28.484	104.083	1144.472	Gjutning ULS
83	-25.015	103.148	840.633	Gjutning ULS
84	-22.392	104.185	559.646	Gjutning ULS
85	-13.814	113.740	119.516	Gjutning ULS
86	0	1.312	-87.270	Gjutning SLS
87	0	0.141	44.826	Gjutning SLS
88	-19.005	106.863	308.402	Gjutning ULS
89	0	1.942	-133.718	Gjutning SLS
90	0	1.843	-137.753	Gjutning ULS
91	0	2.176	-150.901	Gjutning SLS
92	0	0.189	198.064	Gjutning ULS
93	0	2.230	-154.877	Gjutning SLS
94	0	-0.188	279.032	Gjutning ULS
95	-1.385	5.024	-288.865	Gjutning ULS
96	0	0.185	452.472	Gjutning ULS
97	0	2.392	-166.730	Gjutning SLS
98	0	0.188	231.210	Gjutning ULS
99	0	2.211	-153.438	Gjutning SLS
100	0	0.189	167.792	Gjutning ULS
101	0	-0.141	86.391	Gjutning SLS
102	-0.027	0	8.231	Gjutning ULS
103	0	0	-0.521	Gjutning ULS
104	-11.647	0.095	-2051.651	Gjutning ULS
105	-14.055	-0.331	-1681.248	Gjutning ULS
106	-11.708	0.672	-1282.266	Gjutning ULS
107	-8.396	0.282	-895.145	Gjutning ULS
108	-5.365	-0.158	-548.270	Gjutning ULS
109	-2.096	1.198	-275.914	Gjutning ULS
110	1.513	3.628	-76.634	Gjutning SLS
111	0	-8.001	-43.370	Gjutning SLS
112	0	0	13.045	Gjutning SLS
113	-0.047	0	-11.708	Gjutning ULS
114	-0.089	0	-26.740	Gjutning ULS
115	-0.100	0	-38.277	Gjutning ULS
117	-0.054	0	-46.382	Gjutning ULS
118	0	0.232	-17.444	Gjutning SLS
119	-0.081	0	263.676	Gjutning ULS
120	0	3.671	-255.326	Gjutning SLS
121	0	5.369	-371.770	Gjutning ULS
122	-0.073	0	262.832	Gjutning ULS
123	0	5.043	-351.958	Gjutning ULS
124	0	0.188	228.814	Gjutning ULS

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Max neg. moment - 2. order

Member	M kNm	V kN	N kN	Loadcase
125	0	4.366	-305.934	Gjutning ULS
126	0	0.141	126.571	Gjutning SLS
127	-0.093	0	-49.207	Gjutning ULS
128	0	-0.141	98.879	Gjutning SLS
129	0	3.463	-241.785	Gjutning ULS
130	0	0.141	68.920	Gjutning SLS
131	0	2.320	-158.410	Gjutning ULS
132	-1.937	5.261	51.570	Gjutning ULS
133	0	-0.142	30.737	Gjutning SLS
134	0	1.045	-63.856	Gjutning ULS

Max stresses - 1. order

Member	Sig MPa	Loadcase
4	-0.1	Gjutning SLS
6	0.1	Gjutning ULS
7	23.0	Gjutning ULS
22	7.0	Gjutning ULS
23	34.3	Gjutning ULS
24	23.2	Gjutning ULS
25	19.2	Gjutning ULS
26	12.2	Gjutning ULS
28	10.2	Gjutning ULS
29	11.1	Gjutning ULS
44	-9.3	Gjutning SLS
45	-39.0	Gjutning SLS
46	-35.5	Gjutning SLS
47	-32.1	Gjutning SLS
48	-28.8	Gjutning SLS
50	-21.1	Gjutning SLS
51	-10.9	Gjutning SLS
80	165.9	Gjutning ULS
81	139.1	Gjutning ULS
82	113.4	Gjutning ULS
83	87.2	Gjutning ULS
84	63.5	Gjutning ULS
85	26.0	Gjutning ULS
86	-23.3	Gjutning SLS

Member	Sig MPa	Loadcase
87	18.5	Gjutning ULS
88	46.2	Gjutning ULS
89	-35.9	Gjutning SLS
90	-24.9	Gjutning SLS
91	-40.6	Gjutning SLS
92	54.2	Gjutning ULS
93	-41.7	Gjutning SLS
94	76.4	Gjutning ULS
95	-52.4	Gjutning SLS
96	123.6	Gjutning ULS
97	-45.0	Gjutning SLS
98	63.2	Gjutning ULS
99	-41.3	Gjutning SLS
100	45.9	Gjutning ULS
101	35.5	Gjutning ULS
102	2.5	Gjutning ULS
103	0.1	Gjutning ULS
104	-107.9	Gjutning SLS
105	-86.8	Gjutning SLS
106	-64.8	Gjutning SLS
107	-45.1	Gjutning SLS
108	-26.9	Gjutning SLS
109	-13.6	Gjutning SLS
110	-2.5	Gjutning SLS

Member	Sig MPa	Loadcase
111	0.6	Gjutning ULS
112	6.1	Gjutning ULS
113	-2.1	Gjutning SLS
114	-4.8	Gjutning SLS
115	-6.9	Gjutning SLS
117	-8.4	Gjutning SLS
118	-4.9	Gjutning SLS
119	73.1	Gjutning ULS
120	-69.0	Gjutning SLS
121	-66.9	Gjutning SLS
122	72.0	Gjutning ULS
123	-63.5	Gjutning SLS
124	62.5	Gjutning ULS
125	-55.2	Gjutning SLS
126	51.7	Gjutning ULS
127	-8.9	Gjutning SLS
128	40.5	Gjutning ULS
129	-43.6	Gjutning SLS
130	28.2	Gjutning ULS
131	-28.4	Gjutning SLS
132	7.2	Gjutning ULS
133	12.8	Gjutning ULS
134	-11.3	Gjutning SLS

Max stresses - 2. order

Member	Sig MPa	Loadcase
4	-0.2	Gjutning SLS
6	0.1	Gjutning ULS
7	23.6	Gjutning ULS
22	7.0	Gjutning ULS
23	34.8	Gjutning ULS
24	23.3	Gjutning ULS
25	19.3	Gjutning ULS
26	12.3	Gjutning ULS
28	10.3	Gjutning ULS
29	11.2	Gjutning ULS
44	-8.4	Gjutning SLS
45	-35.7	Gjutning SLS
46	-32.6	Gjutning SLS

Member	Sig MPa	Loadcase
47	-29.4	Gjutning SLS
48	-26.4	Gjutning SLS
50	-19.4	Gjutning SLS
51	-10.0	Gjutning SLS
80	166.1	Gjutning ULS
81	139.4	Gjutning ULS
82	113.7	Gjutning ULS
83	87.4	Gjutning ULS
84	63.6	Gjutning ULS
85	26.1	Gjutning ULS
86	-20.5	Gjutning SLS
87	18.6	Gjutning ULS
88	46.3	Gjutning ULS

Member	Sig MPa	Loadcase
89	-31.5	Gjutning SLS
90	-22.8	Gjutning SLS
91	-35.6	Gjutning SLS
92	54.2	Gjutning ULS
93	-36.6	Gjutning SLS
94	76.3	Gjutning ULS
95	-46.1	Gjutning SLS
96	123.4	Gjutning ULS
97	-39.4	Gjutning SLS
98	63.2	Gjutning ULS
99	-36.2	Gjutning SLS
100	46.0	Gjutning ULS
101	35.6	Gjutning ULS

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Max stresses - 2. order

Member	Sig MPa	Loadcase
102	2.4	Gjutning ULS
103	0.1	Gjutning ULS
104	-109.1	Gjutning SLS
105	-86.3	Gjutning SLS
106	-65.1	Gjutning SLS
107	-45.3	Gjutning SLS
108	-27.6	Gjutning SLS
109	-14.2	Gjutning SLS
110	-2.6	Gjutning SLS
111	0.3	Gjutning ULS
112	5.2	Gjutning ULS
113	-1.9	Gjutning SLS
114	-4.4	Gjutning SLS
115	-6.5	Gjutning SLS
117	-8.1	Gjutning SLS
118	-4.7	Gjutning SLS
119	72.2	Gjutning ULS
120	-57.0	Gjutning SLS
121	-56.7	Gjutning SLS
122	71.9	Gjutning ULS
123	-54.8	Gjutning SLS
124	62.6	Gjutning ULS
125	-48.4	Gjutning SLS
126	51.8	Gjutning ULS
127	-8.5	Gjutning SLS
128	40.6	Gjutning ULS
129	-38.8	Gjutning SLS
130	28.3	Gjutning ULS
131	-25.7	Gjutning SLS
132	7.3	Gjutning ULS
133	12.8	Gjutning ULS
134	-10.3	Gjutning SLS

Equilibrium check - 1. order

Loadcase	X-dir. kN	Y-dir. kN	X-dir. kN	Y-dir. kN
Gjutning ULS	0	-1555.359	0	1555.359
Gjutning SLS	0	-1040.701	0	1040.701

Equilibrium check - 2. order

Loadcase	X-dir. kN	Y-dir. kN	X-dir. kN	Y-dir. kN
Gjutning ULS	0	-1555.359	0	1555.359
Gjutning SLS	0	-1040.701	0	1040.701

Max pos. shear force - 1. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0	-0.770	Gjutning SLS
6	0	0	-0.234	Gjutning SLS
7	0.045	-11.436	34.783	Gjutning SLS
22	-1.830	54.532	23.338	Gjutning ULS
23	-17.692	10.497	183.755	Gjutning ULS
24	-7.803	0.234	171.364	Gjutning ULS
25	-8.178	3.581	124.574	Gjutning ULS
26	-5.206	3.904	78.910	Gjutning ULS
28	2.719	3.437	51.634	Gjutning ULS
29	3.709	-7.193	41.364	Gjutning SLS
44	0	0.096	-52.376	Gjutning ULS
45	0	0	-143.655	Gjutning SLS
46	0	0	-130.924	Gjutning SLS
47	0	0	-177.222	Gjutning ULS
48	0	0	-159.162	Gjutning ULS
50	0	0	-78.093	Gjutning SLS
51	0	0	-60.505	Gjutning ULS
80	0	75.917	1883.538	Gjutning ULS
81	-24.515	96.530	1481.061	Gjutning ULS
82	-28.417	103.881	1141.475	Gjutning ULS
83	-24.969	103.033	838.255	Gjutning ULS
84	-22.368	104.142	557.853	Gjutning ULS
85	-13.823	113.738	119.217	Gjutning ULS
86	0	0.191	-130.489	Gjutning ULS
87	0	0.191	66.654	Gjutning ULS
88	-18.986	106.834	307.355	Gjutning ULS
89	0	0.191	-199.797	Gjutning ULS
90	0	0	-137.584	Gjutning ULS
91	0	0.191	-225.551	Gjutning ULS
92	0	0.191	197.829	Gjutning ULS
93	0	0.191	-231.372	Gjutning ULS
94	0	0.191	279.630	Gjutning ULS
95	-0.063	0.236	-289.986	Gjutning ULS
96	0	0.191	453.305	Gjutning ULS
97	0	0.191	-249.610	Gjutning ULS
98	0	0.191	231.020	Gjutning ULS
99	0	0.191	-229.391	Gjutning ULS
100	0	0.191	167.540	Gjutning ULS
101	0	0.191	129.090	Gjutning ULS
102	0	0.096	8.564	Gjutning ULS
103	0	0	-0.521	Gjutning ULS
104	0	-8.175	-1371.401	Gjutning SLS
105	-13.193	1.766	-1679.926	Gjutning ULS
106	-12.008	3.948	-1280.861	Gjutning ULS
107	-8.591	2.835	-894.102	Gjutning ULS
108	-6.312	3.824	-547.517	Gjutning ULS
109	-3.022	5.661	-275.504	Gjutning ULS
110	2.148	4.185	-114.494	Gjutning ULS
111	3.882	-7.285	-43.471	Gjutning SLS
112	0	0	14.615	Gjutning SLS
113	0	0	-8.180	Gjutning SLS
114	0	0	-17.909	Gjutning SLS
115	0	0	-25.623	Gjutning SLS
117	0	0	-31.150	Gjutning SLS

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Max pos. shear force - 1. order

Member	M kNm	V kN	N kN	Loadcase
118	0	0	-17.972	Gjutning SLS
119	0	0.191	267.265	Gjutning ULS
120	0	0.191	-382.271	Gjutning ULS
121	0	0.191	-370.441	Gjutning ULS
122	0	0.191	263.366	Gjutning ULS
123	0	0.191	-351.816	Gjutning ULS
124	0	0.191	228.638	Gjutning ULS
125	0	0.191	-305.662	Gjutning ULS
126	0	0.191	188.997	Gjutning ULS
127	0	0	-32.789	Gjutning SLS
128	0	0.191	147.883	Gjutning ULS
129	0	0.191	-241.537	Gjutning ULS
130	0	0.191	102.690	Gjutning ULS
131	0	0.191	-158.102	Gjutning ULS
132	-1.910	5.238	51.314	Gjutning ULS
133	0	0.191	45.816	Gjutning ULS
134	0	0.191	-63.716	Gjutning ULS

Max pos. shear force - 2. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0.015	-1.308	Gjutning ULS
6	0	0	-0.316	Gjutning ULS
7	0.927	-12.593	35.255	Gjutning SLS
22	-1.815	54.503	23.362	Gjutning ULS
23	-18.108	10.895	184.626	Gjutning ULS
24	-7.823	0.247	171.642	Gjutning ULS
25	-8.186	3.568	124.989	Gjutning ULS
26	-5.228	3.900	79.342	Gjutning ULS
28	2.714	3.525	51.690	Gjutning ULS
29	3.766	-7.306	41.364	Gjutning SLS
44	0	0.791	-52.214	Gjutning ULS
45	0	2.889	-215.194	Gjutning ULS
46	-0.001	2.639	-196.690	Gjutning ULS
47	-0.001	2.379	-177.435	Gjutning ULS
48	0	2.135	-159.350	Gjutning ULS
50	0	1.564	-116.971	Gjutning ULS
51	0	0.803	-60.308	Gjutning ULS
80	0	75.572	1885.233	Gjutning ULS
81	-24.619	96.771	1484.195	Gjutning ULS
82	-28.484	104.083	1144.472	Gjutning ULS
83	-25.015	103.148	840.633	Gjutning ULS
84	-22.392	104.185	559.646	Gjutning ULS
85	-13.814	113.740	119.516	Gjutning ULS
86	0	1.948	-130.533	Gjutning ULS
87	0	0.190	66.874	Gjutning ULS
88	-19.005	106.863	308.402	Gjutning ULS
89	0	2.898	-199.994	Gjutning ULS
90	0	1.843	-137.753	Gjutning ULS
91	0	3.251	-225.662	Gjutning ULS
92	0	0.189	198.064	Gjutning ULS
93	0.001	3.333	-231.556	Gjutning ULS
94	0	0.188	279.415	Gjutning ULS
95	-1.385	5.024	-288.865	Gjutning ULS
96	0	0.185	452.472	Gjutning ULS
97	0.001	3.577	-249.243	Gjutning ULS
98	0	0.188	231.210	Gjutning ULS
99	0.001	3.303	-229.430	Gjutning ULS
100	0	0.189	167.792	Gjutning ULS
101	0	0.190	129.435	Gjutning ULS
102	0	0.096	8.423	Gjutning ULS
103	0	0	-0.521	Gjutning ULS
104	-8.211	19.075	-2051.559	Gjutning ULS
105	-8.550	21.828	-1681.116	Gjutning ULS
106	-6.153	19.045	-1282.121	Gjutning ULS
107	-4.694	12.861	-895.000	Gjutning ULS
108	-2.095	9.280	-548.086	Gjutning ULS
109	2.270	7.335	-275.650	Gjutning ULS
110	2.271	5.354	-114.551	Gjutning ULS
111	3.720	-6.392	-43.488	Gjutning SLS
112	0	0	12.639	Gjutning SLS
113	0.001	0.156	-11.476	Gjutning ULS
114	0	0.357	-26.548	Gjutning ULS
115	0	0.511	-38.128	Gjutning ULS
117	0	0.618	-46.315	Gjutning ULS
118	0	0.349	-26.202	Gjutning ULS
119	0	0.186	263.950	Gjutning ULS
120	0.001	5.566	-381.571	Gjutning ULS
121	0	5.369	-371.770	Gjutning ULS
122	0	0.187	263.065	Gjutning ULS
123	0	5.043	-351.958	Gjutning ULS
124	0	0.188	228.814	Gjutning ULS
125	0	4.366	-305.934	Gjutning ULS
126	0	0.189	189.157	Gjutning ULS
127	0	0.656	-49.099	Gjutning ULS
128	0	0.190	148.038	Gjutning ULS
129	0	3.463	-241.785	Gjutning ULS
130	0	0.191	103.032	Gjutning ULS
131	0	2.320	-158.410	Gjutning ULS
132	-1.937	5.261	51.570	Gjutning ULS
133	0	0.191	46.018	Gjutning ULS
134	0	1.045	-63.856	Gjutning ULS

Min neg. shear force - 1. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0	-1.133	Gjutning ULS
6	0	0	-0.316	Gjutning ULS

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Min neg. shear force - 1. order

Member	M kNm	V kN	N kN	Loadcase
7	-17.692	-18.364	52.093	Gjutning ULS
22	0	-47.212	23.338	Gjutning ULS
23	-5.226	6.165	122.818	Gjutning SLS
24	-8.178	-0.983	171.364	Gjutning ULS
25	-3.489	1.537	83.267	Gjutning SLS
26	-1.285	1.753	52.724	Gjutning SLS
28	3.709	1.447	34.493	Gjutning SLS
29	0	-11.399	61.855	Gjutning ULS
44	0	-0.096	-51.994	Gjutning ULS
45	0	0	-215.046	Gjutning ULS
46	0	0	-195.994	Gjutning ULS
47	0	0	-118.373	Gjutning SLS
48	0	0	-106.295	Gjutning SLS
50	0	0	-117.024	Gjutning ULS
51	0	0	-40.363	Gjutning SLS
80	-24.515	-124.947	1883.538	Gjutning ULS
81	-28.417	-104.334	1481.061	Gjutning ULS
82	-24.969	-96.983	1141.475	Gjutning ULS
83	-22.368	-97.831	838.255	Gjutning ULS
84	-18.986	-98.035	557.853	Gjutning ULS
85	-1.830	-89.751	119.217	Gjutning ULS
86	0	-0.191	-130.106	Gjutning ULS
87	0	-0.191	66.271	Gjutning ULS
88	-13.823	-96.508	307.355	Gjutning ULS
89	0	-0.191	-199.414	Gjutning ULS
90	0	0	-91.858	Gjutning SLS
91	0	-0.191	-225.168	Gjutning ULS
92	0	-0.191	197.446	Gjutning ULS
93	0	-0.191	-230.989	Gjutning ULS
94	0	-0.191	279.247	Gjutning ULS
95	0	-0.147	-289.603	Gjutning ULS
96	0	-0.191	452.922	Gjutning ULS
97	0	-0.191	-249.227	Gjutning ULS
98	0	-0.191	230.637	Gjutning ULS
99	0	-0.191	-229.008	Gjutning ULS
100	0	-0.191	167.157	Gjutning ULS
101	0	-0.191	128.707	Gjutning ULS
102	0	-0.096	8.182	Gjutning ULS
103	0	0	-0.386	Gjutning SLS
104	-13.193	-13.501	-2049.726	Gjutning ULS
105	-8.040	0.318	-1123.629	Gjutning SLS
106	-5.754	1.783	-856.669	Gjutning SLS
107	-4.229	1.039	-597.945	Gjutning SLS
108	-2.029	1.700	-366.100	Gjutning SLS
109	1.430	2.929	-184.134	Gjutning SLS
110	3.882	1.946	-76.417	Gjutning SLS
111	0	-11.540	-64.790	Gjutning ULS
112	0	0	21.778	Gjutning ULS
113	0	0	-12.330	Gjutning ULS
114	0	0	-26.882	Gjutning ULS
115	0	0	-38.435	Gjutning ULS
117	0	0	-46.746	Gjutning ULS
118	0	0	-26.992	Gjutning ULS
119	0	-0.191	266.716	Gjutning ULS

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Min neg. shear force - 1. order

Member	M kNm	V kN	N kN	Loadcase
120	0	-0.191	-381.640	Gjutning ULS
121	0	-0.191	-369.892	Gjutning ULS
122	0	-0.191	262.900	Gjutning ULS
123	0	-0.191	-351.351	Gjutning ULS
124	0	-0.191	228.256	Gjutning ULS
125	0	-0.191	-305.280	Gjutning ULS
126	0	-0.191	188.698	Gjutning ULS
127	0	0	-49.178	Gjutning ULS
128	0	-0.191	147.667	Gjutning ULS
129	0	-0.191	-241.238	Gjutning ULS
130	0	-0.191	102.557	Gjutning ULS
131	0	-0.191	-157.885	Gjutning ULS
132	1.811	2.646	34.263	Gjutning SLS
133	0	-0.191	45.765	Gjutning ULS
134	0	-0.191	-63.582	Gjutning ULS

Min neg. shear force - 2. order

Member	M kNm	V kN	N kN	Loadcase
4	0	-0.015	-0.925	Gjutning ULS
6	0	0	-0.234	Gjutning SLS
7	-18.113	-20.110	52.895	Gjutning ULS
22	0	-47.241	23.362	Gjutning ULS
23	-5.235	6.428	123.278	Gjutning SLS
24	-8.185	-0.970	171.642	Gjutning ULS
25	-3.501	1.528	83.433	Gjutning SLS
26	-1.301	1.750	52.936	Gjutning SLS
28	3.765	1.505	34.511	Gjutning SLS
29	0	-11.567	61.880	Gjutning ULS
44	0	-0.791	-51.831	Gjutning ULS
45	0	-2.889	-214.811	Gjutning ULS
46	-0.001	-2.639	-196.307	Gjutning ULS
47	-0.001	-2.379	-177.053	Gjutning ULS
48	0	-2.135	-158.967	Gjutning ULS
50	0	-1.564	-116.589	Gjutning ULS
51	0	-0.803	-59.926	Gjutning ULS
80	-24.619	-125.043	1885.233	Gjutning ULS
81	-28.484	-104.530	1484.195	Gjutning ULS
82	-25.015	-97.125	1144.472	Gjutning ULS
83	-22.392	-97.892	840.633	Gjutning ULS
84	-19.005	-98.056	559.646	Gjutning ULS
85	-1.819	-89.749	119.516	Gjutning ULS
86	0	-1.948	-130.151	Gjutning ULS
87	0	-0.190	66.491	Gjutning ULS
88	-13.813	-96.479	308.402	Gjutning ULS
89	0	-2.898	-199.611	Gjutning ULS
90	0	-1.843	-137.370	Gjutning ULS
91	0	-3.251	-225.280	Gjutning ULS
92	0	-0.189	197.682	Gjutning ULS
93	0.001	-3.333	-231.173	Gjutning ULS
94	0	-0.188	279.032	Gjutning ULS
95	0.001	-3.105	-288.482	Gjutning ULS
96	0	-0.185	452.090	Gjutning ULS
97	0.001	-3.577	-248.860	Gjutning ULS
98	0	-0.188	230.827	Gjutning ULS

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Min neg. shear force - 2. order

Member	M kNm	V kN	N kN	Loadcase
99	0.001	-3.303	-229.047	Gjutning ULS
100	0	-0.189	167.409	Gjutning ULS
101	0	-0.190	129.052	Gjutning ULS
102	0	-0.096	8.040	Gjutning ULS
103	0	0	-0.386	Gjutning SLS
104	0.001	-35.030	-2051.823	Gjutning ULS
105	-8.211	-22.486	-1681.380	Gjutning ULS
106	-8.550	-14.378	-1282.385	Gjutning ULS
107	-6.153	-10.017	-895.264	Gjutning ULS
108	-4.695	-4.207	-548.350	Gjutning ULS
109	-1.408	0.846	-184.573	Gjutning SLS
110	3.720	0.686	-76.439	Gjutning SLS
111	0	-11.934	-64.824	Gjutning ULS
112	0	0	18.748	Gjutning ULS
113	0.001	-0.156	-11.941	Gjutning ULS
114	0	-0.357	-26.931	Gjutning ULS
115	0	-0.511	-38.427	Gjutning ULS
117	0	-0.618	-46.448	Gjutning ULS
118	0	-0.349	-26.152	Gjutning ULS
119	0	-0.186	263.402	Gjutning ULS
120	0.001	-5.566	-380.940	Gjutning ULS
121	0	-5.369	-371.221	Gjutning ULS
122	0	-0.187	262.599	Gjutning ULS
123	0	-5.043	-351.493	Gjutning ULS
124	0	-0.188	228.431	Gjutning ULS
125	0	-4.366	-305.551	Gjutning ULS
126	0	-0.189	188.858	Gjutning ULS
127	0	-0.656	-49.315	Gjutning ULS
128	0	-0.190	147.821	Gjutning ULS
129	0	-3.463	-241.485	Gjutning ULS
130	0	-0.191	102.899	Gjutning ULS
131	0	-2.320	-158.193	Gjutning ULS
132	1.810	2.660	34.392	Gjutning SLS
133	0	-0.191	45.968	Gjutning ULS
134	0	-1.045	-63.723	Gjutning ULS

Max pos. axial force - 1. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0	-0.486	Gjutning SLS
6	0	0	0.316	Gjutning ULS
7	0.063	-17.146	52.093	Gjutning ULS
22	5.472	-1.427	23.338	Gjutning ULS
23	-7.803	9.280	183.755	Gjutning ULS
24	-7.781	-0.010	171.364	Gjutning ULS
25	-5.206	2.364	124.574	Gjutning ULS
26	-1.910	2.687	78.910	Gjutning ULS
28	5.548	2.220	51.634	Gjutning ULS
29	5.548	-10.791	61.855	Gjutning ULS
44	0	-0.071	-34.732	Gjutning SLS
45	0	0	-143.372	Gjutning SLS
46	0	0	-130.640	Gjutning SLS
47	0	0	-118.090	Gjutning SLS
48	0	0	-106.011	Gjutning SLS
50	0	0	-77.810	Gjutning SLS
51	0	0	-40.080	Gjutning SLS
80	14.298	-4.428	1883.538	Gjutning ULS
81	-1.358	-3.902	1481.061	Gjutning ULS
82	-1.585	3.449	1141.475	Gjutning ULS
83	1.440	2.601	838.255	Gjutning ULS
84	4.595	3.710	557.853	Gjutning ULS
85	17.955	1.819	119.217	Gjutning ULS
86	0	-0.142	-86.947	Gjutning SLS
87	0	0.191	66.654	Gjutning ULS
88	9.017	-5.004	307.355	Gjutning ULS
89	0	-0.142	-133.282	Gjutning SLS
90	0	0	-91.574	Gjutning SLS
91	0	-0.142	-150.515	Gjutning SLS
92	0	0.191	197.829	Gjutning ULS
93	0	-0.142	-154.432	Gjutning SLS
94	0	0.191	279.630	Gjutning ULS

Max pos. axial force - 1. order

Member	M kNm	V kN	N kN	Loadcase
95	0	-0.110	-193.682	Gjutning SLS
96	0	0.191	453.305	Gjutning ULS
97	0	-0.142	-166.646	Gjutning SLS
98	0	0.191	231.020	Gjutning ULS
99	0	-0.142	-153.094	Gjutning SLS
100	0	0.191	167.540	Gjutning ULS
101	0	0.191	129.090	Gjutning ULS
102	0	0.096	8.564	Gjutning ULS
103	0	0	0.521	Gjutning ULS
104	-8.826	-9.076	-1371.205	Gjutning SLS
105	-8.040	0.318	-1123.629	Gjutning SLS
106	-5.754	1.783	-856.669	Gjutning SLS
107	-4.229	1.039	-597.945	Gjutning SLS
108	-2.029	1.700	-366.100	Gjutning SLS
109	1.430	2.929	-184.134	Gjutning SLS
110	3.882	1.946	-76.417	Gjutning SLS
111	0	-7.736	-43.353	Gjutning SLS
112	0	0	22.326	Gjutning ULS
113	0	0	-7.835	Gjutning SLS
114	0	0	-17.626	Gjutning SLS
115	0	0	-25.401	Gjutning SLS
117	0	0	-31.051	Gjutning SLS
118	0	0	-17.935	Gjutning SLS
119	0	0.191	267.265	Gjutning ULS
120	0	-0.142	-255.299	Gjutning SLS
121	0	-0.142	-247.387	Gjutning SLS
122	0	0.191	263.366	Gjutning ULS
123	0	-0.142	-234.981	Gjutning SLS
124	0	0.191	228.638	Gjutning ULS
125	0	-0.142	-204.166	Gjutning SLS
126	0	0.191	188.997	Gjutning ULS
127	0	0	-32.628	Gjutning SLS
128	0	0.191	147.883	Gjutning ULS
129	0	-0.142	-161.334	Gjutning SLS
130	0	0.191	102.690	Gjutning ULS
131	0	-0.142	-105.599	Gjutning SLS
132	2.719	4.020	51.314	Gjutning ULS
133	0	0.191	45.816	Gjutning ULS
134	0	-0.142	-42.534	Gjutning SLS

Max pos. axial force - 2. order

Member	M kNm	V kN	N kN	Loadcase
4	0	-0.010	-0.601	Gjutning SLS
6	0	0	0.316	Gjutning ULS
7	1.388	-18.892	52.895	Gjutning ULS
22	5.478	-1.456	23.362	Gjutning ULS
23	-7.821	9.678	184.626	Gjutning ULS
24	-7.798	0.004	171.642	Gjutning ULS
25	-5.227	2.351	124.989	Gjutning ULS
26	-1.937	2.683	79.342	Gjutning ULS
28	5.631	2.308	51.690	Gjutning ULS
29	5.631	-10.959	61.880	Gjutning ULS
44	0	-0.535	-34.625	Gjutning SLS
45	0	-1.924	-143.434	Gjutning SLS
46	0	-1.757	-131.027	Gjutning SLS
47	0	-1.584	-118.178	Gjutning SLS
48	0	-1.422	-106.105	Gjutning SLS
50	0	-1.042	-77.769	Gjutning SLS
51	0	-0.535	-39.946	Gjutning SLS
80	14.193	-4.552	1885.233	Gjutning ULS
81	-1.412	-3.858	1484.195	Gjutning ULS
82	-1.617	3.464	1144.472	Gjutning ULS
83	1.413	2.620	840.633	Gjutning ULS
84	4.573	3.713	559.646	Gjutning ULS
85	17.963	1.823	119.516	Gjutning ULS
86	0	-1.312	-86.986	Gjutning SLS
87	0	0.190	66.874	Gjutning ULS
88	9.009	-4.971	308.402	Gjutning ULS
89	0	-1.942	-133.435	Gjutning SLS
90	0	-1.228	-91.671	Gjutning SLS
91	0	-2.176	-150.617	Gjutning SLS
92	0	0.189	198.064	Gjutning ULS
93	0	-2.230	-154.593	Gjutning SLS
94	0	0.188	279.415	Gjutning ULS
95	0.001	-2.082	-193.014	Gjutning SLS
96	0	0.185	452.472	Gjutning ULS
97	0	-2.392	-166.446	Gjutning SLS
98	0	0.188	231.210	Gjutning ULS
99	0	-2.211	-153.155	Gjutning SLS
100	0	0.189	167.792	Gjutning ULS
101	0	0.190	129.435	Gjutning ULS
102	0	0.096	8.423	Gjutning ULS
103	0	0	0.521	Gjutning ULS
104	-5.502	12.629	-1372.323	Gjutning SLS
105	-5.734	14.474	-1124.496	Gjutning SLS
106	-4.127	12.651	-857.600	Gjutning SLS
107	-3.148	8.539	-598.655	Gjutning SLS
108	-1.408	6.156	-366.608	Gjutning SLS
109	1.513	4.863	-184.377	Gjutning SLS
110	3.720	0.686	-76.439	Gjutning SLS
111	0	-8.001	-43.370	Gjutning SLS
112	0	0	19.296	Gjutning ULS
113	0	0.103	-7.525	Gjutning SLS
114	0	0.237	-17.624	Gjutning SLS
115	0	0.340	-25.376	Gjutning SLS
117	0	0.412	-30.852	Gjutning SLS
118	0	-0.232	-17.407	Gjutning SLS
119	0	0.186	263.950	Gjutning ULS
120	0	-3.671	-254.859	Gjutning SLS
121	0	-3.554	-248.259	Gjutning SLS
122	0	0.187	263.065	Gjutning ULS
123	0	-3.350	-235.050	Gjutning SLS
124	0	0.188	228.814	Gjutning ULS
125	0	-2.912	-204.330	Gjutning SLS

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Max pos. axial force - 2. order

Member	M kNm	V kN	N kN	Loadcase
126	0	0.189	189.157	Gjutning ULS
127	0	0.437	-32.714	Gjutning SLS
128	0	0.190	148.038	Gjutning ULS
129	0	-2.318	-161.488	Gjutning SLS
130	0	0.191	103.032	Gjutning ULS
131	0	-1.561	-105.795	Gjutning SLS
132	2.715	4.044	51.570	Gjutning ULS
133	0	0.191	46.018	Gjutning ULS
134	0	-0.712	-42.621	Gjutning SLS

Min neg. axial force - 1. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0	-1.133	Gjutning ULS
6	0	0	-0.316	Gjutning ULS
7	-11.842	-12.338	34.783	Gjutning SLS
22	-1.210	36.361	15.596	Gjutning SLS
23	-11.842	7.066	122.818	Gjutning SLS
24	-5.477	-0.701	114.555	Gjutning SLS
25	-5.477	2.439	83.267	Gjutning SLS
26	-3.489	2.655	52.724	Gjutning SLS
28	1.811	2.349	34.493	Gjutning SLS
29	0	-7.644	41.364	Gjutning SLS
44	0	0.096	-52.376	Gjutning ULS
45	0	0	-215.046	Gjutning ULS
46	0	0	-195.994	Gjutning ULS
47	0	0	-177.222	Gjutning ULS
48	0	0	-159.162	Gjutning ULS
50	0	0	-117.024	Gjutning ULS
51	0	0	-60.505	Gjutning ULS
80	-16.373	-83.379	1260.009	Gjutning SLS
81	-18.977	-69.609	990.710	Gjutning SLS
82	-18.977	69.311	763.516	Gjutning SLS
83	-16.672	68.745	560.671	Gjutning SLS
84	-14.932	69.486	373.105	Gjutning SLS
85	-9.217	75.887	79.711	Gjutning SLS
86	0	0.191	-130.489	Gjutning ULS
87	0	-0.142	44.396	Gjutning SLS
88	-12.670	71.278	205.549	Gjutning SLS
89	0	0.191	-199.797	Gjutning ULS
90	0	0	-137.584	Gjutning ULS
91	0	0.191	-225.551	Gjutning ULS
92	0	-0.142	132.150	Gjutning SLS
93	0	0.191	-231.372	Gjutning ULS
94	0	-0.142	186.913	Gjutning SLS
95	-0.063	0.236	-289.986	Gjutning ULS
96	0	-0.142	303.033	Gjutning SLS
97	0	0.191	-249.610	Gjutning ULS
98	0	-0.142	154.370	Gjutning SLS
99	0	0.191	-229.391	Gjutning ULS
100	0	-0.142	111.881	Gjutning SLS
101	0	-0.142	86.162	Gjutning SLS
102	0	-0.071	5.524	Gjutning SLS
103	0	0	-0.521	Gjutning ULS
104	0	-12.284	-2049.990	Gjutning ULS
105	-13.193	1.766	-1679.926	Gjutning ULS
106	-12.008	3.948	-1280.861	Gjutning ULS
107	-8.591	2.835	-894.102	Gjutning ULS
108	-6.312	3.824	-547.517	Gjutning ULS
109	-3.022	5.661	-275.504	Gjutning ULS
110	2.148	4.185	-114.494	Gjutning ULS
111	5.807	-10.931	-64.950	Gjutning ULS
112	0	0	14.615	Gjutning SLS
113	0	0	-12.330	Gjutning ULS
114	0	0	-26.882	Gjutning ULS
115	0	0	-38.435	Gjutning ULS
117	0	0	-46.746	Gjutning ULS
118	0	0	-26.992	Gjutning ULS
119	0	-0.142	178.468	Gjutning SLS
120	0	0.191	-382.271	Gjutning ULS
121	0	0.191	-370.441	Gjutning ULS
122	0	-0.142	175.900	Gjutning SLS
123	0	0.191	-351.816	Gjutning ULS
124	0	-0.142	152.718	Gjutning SLS
125	0	0.191	-305.662	Gjutning ULS
126	0	-0.142	126.245	Gjutning SLS
127	0	0	-49.178	Gjutning ULS
128	0	-0.142	98.788	Gjutning SLS
129	0	0.191	-241.537	Gjutning ULS
130	0	-0.142	68.606	Gjutning SLS
131	0	0.191	-158.102	Gjutning ULS
132	-1.285	3.547	34.263	Gjutning SLS
133	0	-0.142	30.609	Gjutning SLS
134	0	0.191	-63.716	Gjutning ULS

Min neg. axial force - 2. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0.015	-1.308	Gjutning ULS
6	0	0	-0.316	Gjutning ULS
7	-12.117	-13.495	35.255	Gjutning SLS
22	-1.201	36.341	15.592	Gjutning SLS
23	-12.114	7.330	123.278	Gjutning SLS
24	-5.479	-0.693	114.603	Gjutning SLS
25	-5.480	2.429	83.433	Gjutning SLS
26	-3.502	2.651	52.936	Gjutning SLS
28	1.809	2.407	34.511	Gjutning SLS
29	0	-7.757	41.364	Gjutning SLS
44	0	0.791	-52.214	Gjutning ULS
45	0	2.889	-215.194	Gjutning ULS

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Min neg. axial force - 2. order

Member	M kNm	V kN	N kN	Loadcase
46	-0.001	2.639	-196.690	Gjutning ULS
47	-0.001	2.379	-177.435	Gjutning ULS
48	0	2.135	-159.350	Gjutning ULS
50	0	1.564	-116.971	Gjutning ULS
51	0	0.803	-60.308	Gjutning ULS
80	-16.439	-83.441	1260.861	Gjutning SLS
81	-19.016	-69.686	992.475	Gjutning SLS
82	-19.016	69.406	765.189	Gjutning SLS
83	-16.697	68.799	561.962	Gjutning SLS
84	-14.945	69.505	374.061	Gjutning SLS
85	-9.210	75.888	79.830	Gjutning SLS
86	0	1.948	-130.533	Gjutning ULS
87	0	-0.141	44.543	Gjutning SLS
88	-12.680	71.297	206.082	Gjutning SLS
89	0	2.898	-199.994	Gjutning ULS
90	0	1.843	-137.753	Gjutning ULS
91	0	3.251	-225.662	Gjutning ULS
92	0	-0.140	132.327	Gjutning SLS
93	0.001	3.333	-231.556	Gjutning ULS
94	0	-0.140	186.807	Gjutning SLS
95	-1.385	5.024	-288.865	Gjutning ULS
96	0	-0.139	302.527	Gjutning SLS
97	0.001	3.577	-249.243	Gjutning ULS
98	0	-0.140	154.535	Gjutning SLS
99	0.001	3.303	-229.430	Gjutning ULS
100	0	-0.141	112.054	Gjutning SLS
101	0	-0.141	86.391	Gjutning SLS
102	0	-0.071	5.432	Gjutning SLS
103	0	0	-0.521	Gjutning ULS
104	0.001	-35.030	-2051.823	Gjutning ULS
105	-8.211	-22.486	-1681.380	Gjutning ULS
106	-8.550	-14.378	-1282.385	Gjutning ULS
107	-6.153	-10.017	-895.264	Gjutning ULS
108	-4.695	-4.207	-548.350	Gjutning ULS
109	-2.096	1.198	-275.914	Gjutning ULS
110	2.271	5.354	-114.551	Gjutning ULS
111	5.564	-9.595	-64.983	Gjutning ULS
112	0	0	12.639	Gjutning SLS
113	0.001	-0.156	-11.941	Gjutning ULS
114	0	-0.357	-26.931	Gjutning ULS
115	0	-0.511	-38.427	Gjutning ULS
117	0	-0.618	-46.448	Gjutning ULS
118	0	0.349	-26.202	Gjutning ULS
119	0	-0.139	176.329	Gjutning SLS
120	0.001	5.566	-381.571	Gjutning ULS
121	0	5.369	-371.770	Gjutning ULS
122	0	-0.140	175.746	Gjutning SLS
123	0	5.043	-351.958	Gjutning ULS
124	0	-0.140	152.849	Gjutning SLS
125	0	4.366	-305.934	Gjutning ULS
126	0	-0.141	126.349	Gjutning SLS
127	0	-0.656	-49.315	Gjutning ULS
128	0	-0.141	98.879	Gjutning SLS
129	0	3.463	-241.785	Gjutning ULS
130	0	-0.141	68.821	Gjutning SLS
131	0	2.320	-158.410	Gjutning ULS
132	-1.301	3.562	34.392	Gjutning SLS
133	0	-0.142	30.737	Gjutning SLS
134	0	1.045	-63.856	Gjutning ULS

Min neg. stresses - 1. order

Member	Sig MPa	Loadcase
4	-0.3	Gjutning ULS
6	-0.1	Gjutning ULS
7	-14.1	Gjutning ULS
22	-3.4	Gjutning ULS
23	-2.9	Gjutning ULS
24	4.0	Gjutning SLS
25	1.4	Gjutning SLS
26	0.8	Gjutning SLS
28	-1.4	Gjutning ULS
29	-0.5	Gjutning ULS
44	-14.4	Gjutning ULS
45	-58.4	Gjutning ULS
46	-53.3	Gjutning ULS
47	-48.2	Gjutning ULS
48	-43.3	Gjutning ULS
50	-31.8	Gjutning ULS
51	-16.4	Gjutning ULS
80	79.9	Gjutning SLS
81	57.1	Gjutning SLS
82	39.9	Gjutning SLS
83	26.7	Gjutning SLS
84	14.1	Gjutning SLS
85	-8.0	Gjutning ULS
86	-35.9	Gjutning ULS
87	11.8	Gjutning SLS
88	4.3	Gjutning SLS
89	-54.7	Gjutning ULS
90	-37.4	Gjutning ULS
91	-61.7	Gjutning ULS
92	35.6	Gjutning SLS
93	-63.3	Gjutning ULS
94	50.5	Gjutning SLS
95	-79.2	Gjutning ULS
96	82.0	Gjutning SLS
97	-68.2	Gjutning ULS
98	41.6	Gjutning SLS
99	-62.7	Gjutning ULS
100	30.1	Gjutning SLS
101	23.1	Gjutning SLS
102	1.4	Gjutning SLS
103	-0.1	Gjutning ULS
104	-189.1	Gjutning ULS
105	-157.5	Gjutning ULS
106	-122.1	Gjutning ULS
107	-85.4	Gjutning ULS
108	-53.4	Gjutning ULS
109	-26.7	Gjutning ULS
110	-15.9	Gjutning ULS
111	-11.7	Gjutning ULS
112	4.0	Gjutning SLS
113	-3.4	Gjutning ULS
114	-7.3	Gjutning ULS
115	-10.4	Gjutning ULS
117	-12.7	Gjutning ULS
118	-7.3	Gjutning ULS
119	48.1	Gjutning SLS
120	-104.4	Gjutning ULS
121	-101.2	Gjutning ULS
122	47.5	Gjutning SLS
123	-96.1	Gjutning ULS
124	41.2	Gjutning SLS
125	-83.5	Gjutning ULS
126	34.0	Gjutning SLS

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Min neg. stresses - 1. order

Member	Sig MPa	Loadcase	Member	Sig MPa	Loadcase	Member	Sig MPa	Loadcase
127	-13.4	Gjutning ULS	130	18.4	Gjutning SLS	133	8.1	Gjutning SLS
128	26.6	Gjutning SLS	131	-43.3	Gjutning ULS	134	-17.6	Gjutning ULS
129	-66.0	Gjutning ULS	132	1.0	Gjutning SLS			

Min neg. stresses - 2. order

Member	Sig MPa	Loadcase	Member	Sig MPa	Loadcase	Member	Sig MPa	Loadcase
4	-0.4	Gjutning ULS	87	11.8	Gjutning SLS	111	-11.4	Gjutning ULS
6	-0.1	Gjutning ULS	88	4.3	Gjutning SLS	112	3.4	Gjutning SLS
7	-14.5	Gjutning ULS	89	-61.4	Gjutning ULS	113	-3.5	Gjutning ULS
22	-3.4	Gjutning ULS	90	-40.6	Gjutning ULS	114	-7.9	Gjutning ULS
23	-3.3	Gjutning ULS	91	-69.2	Gjutning ULS	115	-11.1	Gjutning ULS
24	4.0	Gjutning SLS	92	35.7	Gjutning SLS	117	-13.0	Gjutning ULS
25	1.4	Gjutning SLS	93	-71.0	Gjutning ULS	118	-7.2	Gjutning ULS
26	0.8	Gjutning SLS	94	50.5	Gjutning SLS	119	47.6	Gjutning SLS
28	-1.5	Gjutning ULS	95	-88.1	Gjutning ULS	120	-122.4	Gjutning ULS
29	-0.6	Gjutning ULS	96	81.9	Gjutning SLS	121	-117.3	Gjutning ULS
44	-15.7	Gjutning ULS	97	-76.4	Gjutning ULS	122	47.4	Gjutning SLS
45	-63.4	Gjutning ULS	98	41.7	Gjutning SLS	123	-109.4	Gjutning ULS
46	-58.0	Gjutning ULS	99	-70.4	Gjutning ULS	124	41.2	Gjutning SLS
47	-52.3	Gjutning ULS	100	30.1	Gjutning SLS	125	-93.8	Gjutning ULS
48	-46.9	Gjutning ULS	101	23.2	Gjutning SLS	126	34.1	Gjutning SLS
50	-34.4	Gjutning ULS	102	1.4	Gjutning SLS	127	-14.0	Gjutning ULS
51	-17.7	Gjutning ULS	103	-0.1	Gjutning ULS	128	26.6	Gjutning SLS
80	79.9	Gjutning SLS	104	-187.6	Gjutning ULS	129	-73.3	Gjutning ULS
81	57.2	Gjutning SLS	105	-158.5	Gjutning ULS	130	18.5	Gjutning SLS
82	40.0	Gjutning SLS	106	-121.9	Gjutning ULS	131	-47.6	Gjutning ULS
83	26.8	Gjutning SLS	107	-85.3	Gjutning ULS	132	1.0	Gjutning SLS
84	14.2	Gjutning SLS	108	-52.5	Gjutning ULS	133	8.1	Gjutning SLS
85	-8.0	Gjutning ULS	109	-25.9	Gjutning ULS	134	-19.2	Gjutning ULS
86	-40.2	Gjutning ULS	110	-15.6	Gjutning ULS			

Max abs. moment - 1. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0	-0.770	Gjutning SLS
6	0	0	-0.316	Gjutning ULS
7	-17.692	-18.364	52.093	Gjutning ULS
22	5.472	-1.427	23.338	Gjutning ULS
23	-17.692	10.497	183.755	Gjutning ULS
24	-8.178	-0.983	171.364	Gjutning ULS
25	-8.178	3.581	124.574	Gjutning ULS
26	-5.206	3.904	78.910	Gjutning ULS
28	5.548	2.220	51.634	Gjutning ULS
29	5.548	-10.791	61.855	Gjutning ULS
44	0.027	0	-52.185	Gjutning ULS
45	0	0	-143.655	Gjutning SLS
46	0	0	-130.924	Gjutning SLS
47	0	0	-177.222	Gjutning ULS
48	0	0	-158.779	Gjutning ULS
50	0	0	-117.024	Gjutning ULS
51	0	0	-60.505	Gjutning ULS
80	-24.515	-124.947	1883.538	Gjutning ULS
81	-28.417	-104.334	1481.061	Gjutning ULS
82	-28.417	103.881	1141.475	Gjutning ULS

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Max abs. moment - 1. order

Member	M kNm	V kN	N kN	Loadcase
83	-24.969	103.033	838.255	Gjutning ULS
84	-22.368	104.142	557.853	Gjutning ULS
85	17.955	1.819	119.217	Gjutning ULS
86	0.068	0	-130.298	Gjutning ULS
87	0.068	0	66.463	Gjutning ULS
88	-18.986	106.834	307.355	Gjutning ULS
89	0.068	0	-199.605	Gjutning ULS
90	0	0	-137.202	Gjutning ULS
91	0.068	0	-225.359	Gjutning ULS
92	0.068	0	197.638	Gjutning ULS
93	0.068	0	-231.180	Gjutning ULS
94	0.068	0	279.439	Gjutning ULS
95	-0.063	0.236	-289.986	Gjutning ULS
96	0.068	0	453.113	Gjutning ULS
97	0.068	0	-249.418	Gjutning ULS
98	0.068	0	230.828	Gjutning ULS
99	0.068	0	-229.199	Gjutning ULS
100	0.068	0	167.349	Gjutning ULS
101	0.068	0	128.898	Gjutning ULS
102	-0.027	0	8.373	Gjutning ULS
103	0	0	-0.386	Gjutning SLS
104	-13.193	-13.501	-2049.726	Gjutning ULS
105	-13.193	1.766	-1679.926	Gjutning ULS
106	-12.008	3.948	-1280.861	Gjutning ULS
107	-8.591	2.835	-894.102	Gjutning ULS
108	-6.312	3.824	-547.517	Gjutning ULS
109	-3.022	5.661	-275.504	Gjutning ULS
110	5.807	2.968	-114.230	Gjutning ULS
111	5.807	-10.931	-64.950	Gjutning ULS
112	0	0	14.615	Gjutning SLS
113	0	0	-7.835	Gjutning SLS
114	0	0	-17.909	Gjutning SLS
115	0	0	-25.623	Gjutning SLS
117	0	0	-46.613	Gjutning ULS
118	0	0	-17.935	Gjutning SLS
119	-0.084	0	266.991	Gjutning ULS
120	0.092	0	-381.956	Gjutning ULS
121	0.084	0	-370.166	Gjutning ULS
122	-0.075	0	263.133	Gjutning ULS
123	0.075	0	-351.583	Gjutning ULS
124	0.068	0	228.447	Gjutning ULS
125	0.068	0	-305.471	Gjutning ULS
126	0.061	0	188.848	Gjutning ULS
127	0	0	-32.789	Gjutning SLS
128	0.055	0	147.775	Gjutning ULS
129	0.061	0	-241.387	Gjutning ULS
130	0.051	0	102.623	Gjutning ULS
131	0.055	0	-157.994	Gjutning ULS
132	2.719	4.020	51.314	Gjutning ULS
133	0.048	0	45.791	Gjutning ULS
134	0.051	0	-63.649	Gjutning ULS

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Max abs. moment - 2. order

Member	M kNm	V kN	N kN	Loadcase
4	0.004	0	-1.117	Gjutning ULS
6	0	0	-0.234	Gjutning SLS
7	-18.113	-20.110	52.895	Gjutning ULS
22	5.478	-1.456	23.362	Gjutning ULS
23	-18.108	10.895	184.626	Gjutning ULS
24	-8.185	-0.970	171.642	Gjutning ULS
25	-8.186	3.568	124.989	Gjutning ULS
26	-5.228	3.900	79.342	Gjutning ULS
28	5.631	2.308	51.690	Gjutning ULS
29	5.631	-10.959	61.880	Gjutning ULS
44	0.221	0	-52.023	Gjutning ULS
45	0.723	0	-215.002	Gjutning ULS
46	0.660	0	-196.499	Gjutning ULS
47	0.595	0	-177.244	Gjutning ULS
48	0.534	0	-159.158	Gjutning ULS
50	0.391	0	-116.780	Gjutning ULS
51	0.201	0	-60.117	Gjutning ULS
80	-24.619	-125.043	1885.233	Gjutning ULS
81	-28.484	-104.530	1484.195	Gjutning ULS
82	-28.484	104.083	1144.472	Gjutning ULS
83	-25.015	103.148	840.633	Gjutning ULS
84	-22.392	104.185	559.646	Gjutning ULS
85	17.963	1.823	119.516	Gjutning ULS
86	0.690	0	-130.342	Gjutning ULS
87	0.067	0	66.682	Gjutning ULS
88	-19.005	106.863	308.402	Gjutning ULS
89	1.029	0	-199.803	Gjutning ULS
90	0.461	0	-137.561	Gjutning ULS
91	1.155	0	-225.471	Gjutning ULS
92	0.066	0	197.873	Gjutning ULS
93	1.184	0	-231.364	Gjutning ULS
94	0.066	0	279.224	Gjutning ULS
95	-1.385	5.024	-288.865	Gjutning ULS
96	0.065	0	452.281	Gjutning ULS
97	1.271	0	-249.051	Gjutning ULS
98	0.066	0	231.019	Gjutning ULS
99	1.173	0	-229.239	Gjutning ULS
100	0.067	0	167.600	Gjutning ULS
101	0.067	0	129.243	Gjutning ULS
102	-0.027	0	8.231	Gjutning ULS
103	0	0	0.521	Gjutning ULS
104	-11.647	0.095	-2051.651	Gjutning ULS
105	-14.055	-0.331	-1681.248	Gjutning ULS
106	-11.708	0.672	-1282.266	Gjutning ULS
107	-8.396	0.282	-895.145	Gjutning ULS
108	-5.365	-0.158	-548.270	Gjutning ULS
109	2.270	7.335	-275.650	Gjutning ULS
110	5.565	1.085	-114.287	Gjutning ULS
111	5.564	-9.595	-64.983	Gjutning ULS
112	0	0	18.748	Gjutning ULS
113	-0.047	0	-11.708	Gjutning ULS
114	-0.089	0	-26.740	Gjutning ULS
115	-0.100	0	-38.277	Gjutning ULS
117	-0.054	0	-46.382	Gjutning ULS

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Max abs. moment - 2. order

Member	M kNm	V kN	N kN	Loadcase
118	0.011	0	-26.177	Gjutning ULS
119	-0.081	0	263.676	Gjutning ULS
120	2.721	0	-381.255	Gjutning ULS
121	2.370	0	-371.496	Gjutning ULS
122	-0.073	0	262.832	Gjutning ULS
123	2.000	0	-351.725	Gjutning ULS
124	0.066	0	228.623	Gjutning ULS
125	1.551	0	-305.742	Gjutning ULS
126	0.060	0	189.008	Gjutning ULS
127	-0.093	0	-49.207	Gjutning ULS
128	0.054	0	147.930	Gjutning ULS
129	1.103	0	-241.635	Gjutning ULS
130	0.050	0	102.965	Gjutning ULS
131	0.667	0	-158.301	Gjutning ULS
132	2.715	4.044	51.570	Gjutning ULS
133	0.048	0	45.993	Gjutning ULS
134	0.277	0	-63.790	Gjutning ULS

Max abs. shear force - 1. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0	-0.770	Gjutning SLS
6	0	0	-0.316	Gjutning ULS
7	-17.692	-18.364	52.093	Gjutning ULS
22	-1.830	54.532	23.338	Gjutning ULS
23	-17.692	10.497	183.755	Gjutning ULS
24	-8.178	-0.983	171.364	Gjutning ULS
25	-8.178	3.581	124.574	Gjutning ULS
26	-5.206	3.904	78.910	Gjutning ULS
28	2.719	3.437	51.634	Gjutning ULS
29	0	-11.399	61.855	Gjutning ULS
44	0	0.096	-52.376	Gjutning ULS
45	0	0	-143.655	Gjutning SLS
46	0	0	-130.924	Gjutning SLS
47	0	0	-177.222	Gjutning ULS
48	0	0	-159.162	Gjutning ULS
50	0	0	-117.024	Gjutning ULS
51	0	0	-60.505	Gjutning ULS
80	-24.515	-124.947	1883.538	Gjutning ULS
81	-28.417	-104.334	1481.061	Gjutning ULS
82	-28.417	103.881	1141.475	Gjutning ULS
83	-24.969	103.033	838.255	Gjutning ULS
84	-22.368	104.142	557.853	Gjutning ULS
85	-13.823	113.738	119.217	Gjutning ULS
86	0	0.191	-130.489	Gjutning ULS
87	0	0.191	66.654	Gjutning ULS
88	-18.986	106.834	307.355	Gjutning ULS
89	0	0.191	-199.797	Gjutning ULS
90	0	0	-137.584	Gjutning ULS
91	0	0.191	-225.551	Gjutning ULS
92	0	0.191	197.829	Gjutning ULS
93	0	0.191	-231.372	Gjutning ULS
94	0	0.191	279.630	Gjutning ULS
95	-0.063	0.236	-289.986	Gjutning ULS
96	0	0.191	453.305	Gjutning ULS

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Max abs. shear force - 1. order

Member	M kNm	V kN	N kN	Loadcase
97	0	0.191	-249.610	Gjutning ULS
98	0	0.191	231.020	Gjutning ULS
99	0	0.191	-229.391	Gjutning ULS
100	0	0.191	167.540	Gjutning ULS
101	0	0.191	129.090	Gjutning ULS
102	0	-0.096	8.182	Gjutning ULS
103	0	0	-0.386	Gjutning SLS
104	-13.193	-13.501	-2049.726	Gjutning ULS
105	-13.193	1.766	-1679.926	Gjutning ULS
106	-12.008	3.948	-1280.861	Gjutning ULS
107	-8.591	2.835	-894.102	Gjutning ULS
108	-6.312	3.824	-547.517	Gjutning ULS
109	-3.022	5.661	-275.504	Gjutning ULS
110	2.148	4.185	-114.494	Gjutning ULS
111	0	-11.540	-64.790	Gjutning ULS
112	0	0	14.615	Gjutning SLS
113	0	0	-8.180	Gjutning SLS
114	0	0	-17.909	Gjutning SLS
115	0	0	-25.623	Gjutning SLS
117	0	0	-31.150	Gjutning SLS
118	0	0	-17.972	Gjutning SLS
119	0	-0.191	266.716	Gjutning ULS
120	0	0.191	-382.271	Gjutning ULS
121	0	0.191	-370.441	Gjutning ULS
122	0	-0.191	262.900	Gjutning ULS
123	0	0.191	-351.816	Gjutning ULS
124	0	0.191	228.638	Gjutning ULS
125	0	0.191	-305.662	Gjutning ULS
126	0	0.191	188.997	Gjutning ULS
127	0	0	-32.789	Gjutning SLS
128	0	0.191	147.883	Gjutning ULS
129	0	0.191	-241.537	Gjutning ULS
130	0	0.191	102.690	Gjutning ULS
131	0	0.191	-158.102	Gjutning ULS
132	-1.910	5.238	51.314	Gjutning ULS
133	0	0.191	45.816	Gjutning ULS
134	0	0.191	-63.716	Gjutning ULS

Max abs. shear force - 2. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0.015	-1.308	Gjutning ULS
6	0	0	-0.234	Gjutning SLS
7	-18.113	-20.110	52.895	Gjutning ULS
22	-1.815	54.503	23.362	Gjutning ULS
23	-18.108	10.895	184.626	Gjutning ULS
24	-8.185	-0.970	171.642	Gjutning ULS
25	-8.186	3.568	124.989	Gjutning ULS
26	-5.228	3.900	79.342	Gjutning ULS
28	2.714	3.525	51.690	Gjutning ULS
29	0	-11.567	61.880	Gjutning ULS
44	0	0.791	-52.214	Gjutning ULS
45	0	2.889	-215.194	Gjutning ULS
46	-0.001	2.639	-196.690	Gjutning ULS
47	-0.001	2.379	-177.435	Gjutning ULS

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Max abs. shear force - 2. order

Member	M kNm	V kN	N kN	Loadcase
48	0	2.135	-159.350	Gjutning ULS
50	0	1.564	-116.971	Gjutning ULS
51	0	0.803	-60.308	Gjutning ULS
80	-24.619	-125.043	1885.233	Gjutning ULS
81	-28.484	-104.530	1484.195	Gjutning ULS
82	-28.484	104.083	1144.472	Gjutning ULS
83	-25.015	103.148	840.633	Gjutning ULS
84	-22.392	104.185	559.646	Gjutning ULS
85	-13.814	113.740	119.516	Gjutning ULS
86	0	1.948	-130.533	Gjutning ULS
87	0	0.190	66.874	Gjutning ULS
88	-19.005	106.863	308.402	Gjutning ULS
89	0	2.898	-199.994	Gjutning ULS
90	0	1.843	-137.753	Gjutning ULS
91	0	3.251	-225.662	Gjutning ULS
92	0	0.189	198.064	Gjutning ULS
93	0.001	3.333	-231.556	Gjutning ULS
94	0	0.188	279.415	Gjutning ULS
95	-1.385	5.024	-288.865	Gjutning ULS
96	0	0.185	452.472	Gjutning ULS
97	0.001	3.577	-249.243	Gjutning ULS
98	0	0.188	231.210	Gjutning ULS
99	0.001	3.303	-229.430	Gjutning ULS
100	0	0.189	167.792	Gjutning ULS
101	0	0.190	129.435	Gjutning ULS
102	0	-0.096	8.040	Gjutning ULS
103	0	0	-0.521	Gjutning ULS
104	0.001	-35.030	-2051.823	Gjutning ULS
105	-8.211	-22.486	-1681.380	Gjutning ULS
106	-6.153	19.045	-1282.121	Gjutning ULS
107	-4.694	12.861	-895.000	Gjutning ULS
108	-2.095	9.280	-548.086	Gjutning ULS
109	2.270	7.335	-275.650	Gjutning ULS
110	2.271	5.354	-114.551	Gjutning ULS
111	0	-11.934	-64.824	Gjutning ULS
112	0	0	18.748	Gjutning ULS
113	0.001	-0.156	-11.941	Gjutning ULS
114	0	-0.357	-26.931	Gjutning ULS
115	0	-0.511	-38.427	Gjutning ULS
117	0	-0.618	-46.448	Gjutning ULS
118	0	0.349	-26.202	Gjutning ULS
119	0	-0.186	263.402	Gjutning ULS
120	0.001	5.566	-381.571	Gjutning ULS
121	0	5.369	-371.770	Gjutning ULS
122	0	-0.187	262.599	Gjutning ULS
123	0	5.043	-351.958	Gjutning ULS
124	0	0.188	228.814	Gjutning ULS
125	0	4.366	-305.934	Gjutning ULS
126	0	0.189	189.157	Gjutning ULS
127	0	-0.656	-49.315	Gjutning ULS
128	0	0.190	148.038	Gjutning ULS
129	0	3.463	-241.785	Gjutning ULS
130	0	0.191	103.032	Gjutning ULS
131	0	2.320	-158.410	Gjutning ULS

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Max abs. shear force - 2. order

Member	M kNm	V kN	N kN	Loadcase
132	-1.937	5.261	51.570	Gjutning ULS
133	0	0.191	46.018	Gjutning ULS
134	0	1.045	-63.856	Gjutning ULS

Max abs. stresses - 1. order

Member	Sig MPa	Loadcase
4	0.3	Gjutning ULS
6	0.1	Gjutning ULS
7	23.0	Gjutning ULS
22	7.0	Gjutning ULS
23	34.3	Gjutning ULS
24	23.2	Gjutning ULS
25	19.2	Gjutning ULS
26	12.2	Gjutning ULS
28	10.2	Gjutning ULS
29	11.1	Gjutning ULS
44	14.4	Gjutning ULS
45	58.4	Gjutning ULS
46	53.3	Gjutning ULS
47	48.2	Gjutning ULS
48	43.3	Gjutning ULS
50	31.8	Gjutning ULS
51	16.4	Gjutning ULS
80	165.9	Gjutning ULS
81	139.1	Gjutning ULS
82	113.4	Gjutning ULS
83	87.2	Gjutning ULS
84	63.5	Gjutning ULS
85	26.0	Gjutning ULS
86	35.9	Gjutning ULS
87	18.5	Gjutning ULS
88	46.2	Gjutning ULS
89	54.7	Gjutning ULS
90	37.4	Gjutning ULS
91	61.7	Gjutning ULS
92	54.2	Gjutning ULS
93	63.3	Gjutning ULS
94	76.4	Gjutning ULS
95	79.2	Gjutning ULS
96	123.6	Gjutning ULS
97	68.2	Gjutning ULS
98	63.2	Gjutning ULS
99	62.7	Gjutning ULS
100	45.9	Gjutning ULS
101	35.5	Gjutning ULS
102	2.5	Gjutning ULS
103	0.1	Gjutning ULS
104	189.1	Gjutning ULS
105	157.5	Gjutning ULS
106	122.1	Gjutning ULS
107	85.4	Gjutning ULS
108	53.4	Gjutning ULS
109	26.7	Gjutning ULS
110	15.9	Gjutning ULS
111	11.7	Gjutning ULS
112	6.1	Gjutning ULS
113	3.4	Gjutning ULS
114	7.3	Gjutning ULS
115	10.4	Gjutning ULS
117	12.7	Gjutning ULS
118	7.3	Gjutning ULS
119	73.1	Gjutning ULS
120	104.4	Gjutning ULS
121	101.2	Gjutning ULS
122	72.0	Gjutning ULS
123	96.1	Gjutning ULS
124	62.5	Gjutning ULS
125	83.5	Gjutning ULS
126	51.7	Gjutning ULS
127	13.4	Gjutning ULS
128	40.5	Gjutning ULS
129	66.0	Gjutning ULS
130	28.2	Gjutning ULS
131	43.3	Gjutning ULS
132	7.2	Gjutning ULS
133	12.8	Gjutning ULS
134	17.6	Gjutning ULS

Max abs. stresses - 2. order

Member	Sig MPa	Loadcase
4	0.4	Gjutning ULS
6	0.1	Gjutning ULS
7	23.6	Gjutning ULS
22	7.0	Gjutning ULS
23	34.8	Gjutning ULS
24	23.3	Gjutning ULS
25	19.3	Gjutning ULS
26	12.3	Gjutning ULS
28	10.3	Gjutning ULS
29	11.2	Gjutning ULS
44	15.7	Gjutning ULS
45	63.4	Gjutning ULS
46	58.0	Gjutning ULS
47	52.3	Gjutning ULS
48	46.9	Gjutning ULS
50	34.4	Gjutning ULS
51	17.7	Gjutning ULS
80	166.1	Gjutning ULS
81	139.4	Gjutning ULS
82	113.7	Gjutning ULS
83	87.4	Gjutning ULS
84	63.6	Gjutning ULS
85	26.1	Gjutning ULS
86	40.2	Gjutning ULS
87	18.6	Gjutning ULS
88	46.3	Gjutning ULS
89	61.4	Gjutning ULS
90	40.6	Gjutning ULS
91	69.2	Gjutning ULS
92	54.2	Gjutning ULS
93	71.0	Gjutning ULS
94	76.3	Gjutning ULS
95	88.1	Gjutning ULS
96	123.4	Gjutning ULS
97	76.4	Gjutning ULS
98	63.2	Gjutning ULS
99	70.4	Gjutning ULS
100	46.0	Gjutning ULS
101	35.6	Gjutning ULS
102	2.4	Gjutning ULS
103	0.1	Gjutning ULS
104	187.6	Gjutning ULS
105	158.5	Gjutning ULS
106	121.9	Gjutning ULS
107	85.3	Gjutning ULS
108	52.5	Gjutning ULS
109	25.9	Gjutning ULS
110	15.6	Gjutning ULS
111	11.4	Gjutning ULS
112	5.2	Gjutning ULS
113	3.5	Gjutning ULS
114	7.9	Gjutning ULS
115	11.1	Gjutning ULS
117	13.0	Gjutning ULS
118	7.2	Gjutning ULS
119	72.2	Gjutning ULS
120	122.4	Gjutning ULS
121	117.3	Gjutning ULS
122	71.9	Gjutning ULS
123	109.4	Gjutning ULS

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Max abs. stresses - 2. order

Member	Sig MPa	Loadcase
124	62.6	Gjutning ULS
125	93.8	Gjutning ULS
126	51.8	Gjutning ULS
127	14.0	Gjutning ULS
128	40.6	Gjutning ULS
129	73.3	Gjutning ULS
130	28.3	Gjutning ULS
131	47.6	Gjutning ULS
132	7.3	Gjutning ULS
133	12.8	Gjutning ULS
134	19.2	Gjutning ULS

Max abs. axial force - 1. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0	-1.133	Gjutning ULS
6	0	0	-0.316	Gjutning ULS
7	-17.692	-18.364	52.093	Gjutning ULS
22	5.472	-1.427	23.338	Gjutning ULS
23	-17.692	10.497	183.755	Gjutning ULS
24	-8.178	-0.983	171.364	Gjutning ULS
25	-8.178	3.581	124.574	Gjutning ULS
26	-5.206	3.904	78.910	Gjutning ULS
28	5.548	2.220	51.634	Gjutning ULS
29	5.548	-10.791	61.855	Gjutning ULS
44	0	0.096	-52.376	Gjutning ULS
45	0	0	-215.046	Gjutning ULS
46	0	0	-195.994	Gjutning ULS
47	0	0	-177.222	Gjutning ULS
48	0	0	-159.162	Gjutning ULS
50	0	0	-117.024	Gjutning ULS
51	0	0	-60.505	Gjutning ULS
80	-24.515	-124.947	1883.538	Gjutning ULS
81	-28.417	-104.334	1481.061	Gjutning ULS
82	-28.417	103.881	1141.475	Gjutning ULS
83	-24.969	103.033	838.255	Gjutning ULS
84	-22.368	104.142	557.853	Gjutning ULS
85	17.955	1.819	119.217	Gjutning ULS
86	0	0.191	-130.489	Gjutning ULS
87	0	0.191	66.654	Gjutning ULS
88	-18.986	106.834	307.355	Gjutning ULS
89	0	0.191	-199.797	Gjutning ULS
90	0	0	-137.584	Gjutning ULS
91	0	0.191	-225.551	Gjutning ULS
92	0	0.191	197.829	Gjutning ULS
93	0	0.191	-231.372	Gjutning ULS
94	0	0.191	279.630	Gjutning ULS
95	-0.063	0.236	-289.986	Gjutning ULS
96	0	0.191	453.305	Gjutning ULS
97	0	0.191	-249.610	Gjutning ULS
98	0	0.191	231.020	Gjutning ULS
99	0	0.191	-229.391	Gjutning ULS
100	0	0.191	167.540	Gjutning ULS
101	0	0.191	129.090	Gjutning ULS
102	0	0.096	8.564	Gjutning ULS
103	0	0	0.521	Gjutning ULS
104	0	-12.284	-2049.990	Gjutning ULS
105	-13.193	1.766	-1679.926	Gjutning ULS
106	-12.008	3.948	-1280.861	Gjutning ULS
107	-8.591	2.835	-894.102	Gjutning ULS
108	-6.312	3.824	-547.517	Gjutning ULS
109	-3.022	5.661	-275.504	Gjutning ULS

Max abs. axial force - 1. order

Member	M kNm	V kN	N kN	Loadcase
110	2.148	4.185	-114.494	Gjutning ULS
111	5.807	-10.931	-64.950	Gjutning ULS
112	0	0	22.326	Gjutning ULS
113	0	0	-12.330	Gjutning ULS
114	0	0	-26.882	Gjutning ULS
115	0	0	-38.435	Gjutning ULS
117	0	0	-46.746	Gjutning ULS
118	0	0	-26.992	Gjutning ULS
119	0	0.191	267.265	Gjutning ULS
120	0	0.191	-382.271	Gjutning ULS
121	0	0.191	-370.441	Gjutning ULS
122	0	0.191	263.366	Gjutning ULS
123	0	0.191	-351.816	Gjutning ULS
124	0	0.191	228.638	Gjutning ULS
125	0	0.191	-305.662	Gjutning ULS
126	0	0.191	188.997	Gjutning ULS
127	0	0	-49.178	Gjutning ULS
128	0	0.191	147.883	Gjutning ULS
129	0	0.191	-241.537	Gjutning ULS
130	0	0.191	102.690	Gjutning ULS
131	0	0.191	-158.102	Gjutning ULS
132	2.719	4.020	51.314	Gjutning ULS
133	0	0.191	45.816	Gjutning ULS
134	0	0.191	-63.716	Gjutning ULS

Max abs. axial force - 2. order

Member	M kNm	V kN	N kN	Loadcase
4	0	0.015	-1.308	Gjutning ULS
6	0	0	-0.316	Gjutning ULS
7	-18.113	-20.110	52.895	Gjutning ULS
22	5.478	-1.456	23.362	Gjutning ULS
23	-18.108	10.895	184.626	Gjutning ULS
24	-8.185	-0.970	171.642	Gjutning ULS
25	-8.186	3.568	124.989	Gjutning ULS
26	-5.228	3.900	79.342	Gjutning ULS
28	5.631	2.308	51.690	Gjutning ULS
29	5.631	-10.959	61.880	Gjutning ULS
44	0	0.791	-52.214	Gjutning ULS
45	0	2.889	-215.194	Gjutning ULS
46	-0.001	2.639	-196.690	Gjutning ULS
47	-0.001	2.379	-177.435	Gjutning ULS
48	0	2.135	-159.350	Gjutning ULS
50	0	1.564	-116.971	Gjutning ULS
51	0	0.803	-60.308	Gjutning ULS
80	-24.619	-125.043	1885.233	Gjutning ULS
81	-28.484	-104.530	1484.195	Gjutning ULS
82	-28.484	104.083	1144.472	Gjutning ULS
83	-25.015	103.148	840.633	Gjutning ULS
84	-22.392	104.185	559.646	Gjutning ULS
85	17.963	1.823	119.516	Gjutning ULS
86	0	1.948	-130.533	Gjutning ULS
87	0	0.190	66.874	Gjutning ULS
88	-19.005	106.863	308.402	Gjutning ULS
89	0	2.898	-199.994	Gjutning ULS

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Max abs. axial force - 2. order

Member	M kNm	V kN	N kN	Loadcase
90	0	1.843	-137.753	Gjutning ULS
91	0	3.251	-225.662	Gjutning ULS
92	0	0.189	198.064	Gjutning ULS
93	0.001	3.333	-231.556	Gjutning ULS
94	0	0.188	279.415	Gjutning ULS
95	-1.385	5.024	-288.865	Gjutning ULS
96	0	0.185	452.472	Gjutning ULS
97	0.001	3.577	-249.243	Gjutning ULS
98	0	0.188	231.210	Gjutning ULS
99	0.001	3.303	-229.430	Gjutning ULS
100	0	0.189	167.792	Gjutning ULS
101	0	0.190	129.435	Gjutning ULS
102	0	0.096	8.423	Gjutning ULS
103	0	0	0.521	Gjutning ULS
104	0.001	-35.030	-2051.823	Gjutning ULS
105	-8.211	-22.486	-1681.380	Gjutning ULS
106	-8.550	-14.378	-1282.385	Gjutning ULS
107	-6.153	-10.017	-895.264	Gjutning ULS
108	-4.695	-4.207	-548.350	Gjutning ULS
109	-2.096	1.198	-275.914	Gjutning ULS
110	2.271	5.354	-114.551	Gjutning ULS
111	5.564	-9.595	-64.983	Gjutning ULS
112	0	0	19.296	Gjutning ULS
113	0.001	-0.156	-11.941	Gjutning ULS
114	0	-0.357	-26.931	Gjutning ULS
115	0	-0.511	-38.427	Gjutning ULS
117	0	-0.618	-46.448	Gjutning ULS
118	0	0.349	-26.202	Gjutning ULS
119	0	0.186	263.950	Gjutning ULS
120	0.001	5.566	-381.571	Gjutning ULS
121	0	5.369	-371.770	Gjutning ULS
122	0	0.187	263.065	Gjutning ULS
123	0	5.043	-351.958	Gjutning ULS
124	0	0.188	228.814	Gjutning ULS
125	0	4.366	-305.934	Gjutning ULS
126	0	0.189	189.157	Gjutning ULS
127	0	-0.656	-49.315	Gjutning ULS
128	0	0.190	148.038	Gjutning ULS
129	0	3.463	-241.785	Gjutning ULS
130	0	0.191	103.032	Gjutning ULS
131	0	2.320	-158.410	Gjutning ULS
132	2.715	4.044	51.570	Gjutning ULS
133	0	0.191	46.018	Gjutning ULS
134	0	1.045	-63.856	Gjutning ULS

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E
Mathcad Analytic Calculations

Dimensioning of Temporary Works
- Conceptual design for construction of outriggerwalls

$k := 1000$

$L_{tot} := 8.44m$

$L_{leavout} := 1m$

$L_{effective} := L_{tot} - L_{leavout} = 7.44\,m$

$H_{tot} := 7.05m$

$H_{slab} := 0.25m$

$t_{outrigger} := 1.4m$

$q_{outrigger\_wet} := 27 \cdot k \cdot \frac{N}{m^3}$

$q_{outrigger\_dry} := 25 \cdot k \cdot \frac{N}{m^3}$

$q_{k\_wet} := H_{tot} \cdot t_{outrigger} \cdot q_{outrigger\_wet} = 266.49 \cdot k \cdot \frac{N}{m}$

$q_{k\_dry} := H_{tot} \cdot t_{outrigger} \cdot q_{outrigger\_dry} = 246.75 \cdot k \cdot \frac{N}{m}$

$q_{d\_wet} := 1.5 \cdot q_{k\_wet} = 399.74 \cdot k \cdot \frac{N}{m}$

$q_{d\_dry} := 1.5 \cdot q_{k\_dry} = 370.12 \cdot k \cdot \frac{N}{m}$

$f_y := 355MPa$ $f_u := 510MPa$ $E := 210GPa$

$\gamma_{M0} := 1.0$ $\gamma_{M1} := 1.0$ $\gamma_{M2} := 1.25$

Steel profiles for the truss
VKR 300 x 200 12.5

$M := 10^6$

$b := 250mm$

$h := 150mm$

$t := 8mm$

$A := 2 \cdot (h + b) \cdot t = 6.4 \times 10^3 \cdot mm^2$

$I := 7.91 \cdot 10^6 mm^4$

$I_x := 132 \cdot 10^3 mm^4$ kolla upp

$f_{Rk} := A \cdot f_y = 2.27 \times 10^3 \cdot kN$

$u := 2.15 \cdot \frac{10^3 \cdot kN}{f_{Rk} \cdot 2} = 0.47$

$p := 26.21 \frac{SEK}{kg}$

Costs

$M_m := 47.7 \frac{kg}{m}$

$g := 9.82 \frac{m}{s^2}$

$w := M_m \cdot g = 0.47 \cdot \frac{kN}{m}$

$l_1 := 7.5m$

$l_2 := 3m$

$l_3 := \sqrt{l_1^2 + l_2^2} = 8.08\,m$

$l_3 := \sqrt{l_1^2 + l_1^2} = 10.61\,m$

$l_{tot} := l_1 + l_3 + l_2$

$kr_{big} := l_{tot} \cdot M_m \cdot p = 26387.83\,SEK$

VKR 150 x 100 x8

$b := 150mm$

$h := 100mm$

$t := 5mm$

$A := 2 \cdot (h + b) \cdot t = 2.5 \times 10^3 \cdot mm^2$

$I := 7.91 \cdot 10^6 mm^4$

$I_v := 132 \cdot 10^3 m^4$ kolla upp

$f_{Rk} := A \cdot f_y = 887.5 \cdot kN$

$u := 1.5 \cdot \frac{10^3 \cdot kN}{f_{Rk} \cdot 2} = 0.85$

$p := 24.59 \frac{SEK}{kg}$

Costs

$M := 28.29 \frac{kg}{m}$

$l_{small.diag} := \sqrt{(1m)^2 + (.5m)^2} = 1.12\,m$ $n_{small.diag} := 16$

$l_{small.diag.tot} := l_{small.diag} \cdot n_{small.diag} = 17.89\,m$

$l_{big.diag.tot} := \sqrt{(1m)^2 + (1.7m)^2} + \sqrt{(1m)^2 + (1.5m)^2} + \sqrt{(1m)^2 + (1.2m)^2} + \sqrt{(1m)^2 + (.9m)^2} + \sqrt{(1m)^2 + (.7m)^2} + \sqrt{(1m)^2 + (.4m)^2} = 8.98\,m$

$l_{vertical} := 1m$ $n_{vertical} := 9$

$l_{vertiacl.tot} := l_{vertical} \cdot n_{vertical} = 9\,m$

$l_{vertical.big.tot} := m \cdot (1.7 + 1.5 + 1.2 + 0.9 + .7 + 0.4) = 6.4\,m$

$l_{thin.tot} := l_{small.diag.tot} + l_{big.diag.tot} + l_{vertiacl.tot} + l_{vertical.big.tot} + 7m = 49.27\,m$

$kr_{thin} := l_{thin.tot} \cdot p \cdot M = 34273.845\,SEK$

$kr_{tot.truss} := 2 \cdot kr_{big} + 2 \cdot kr_{thin} = 121323.355\,SEK$ 121 300 kr (Not representativr for the final design)

With labour costs for weldings and procuvtion the total cost is estimated to 200 000kr á outrigger wall

Backpropping

$m_{tot\_outrigger} := q_{k\_wet} \cdot L_{effective} = 1.98 \times 10^{3} \cdot k \cdot N$ Load from outrigger wall

$R_{primissible} := 30 \cdot k \cdot N$ Doka Eurex 30 - Permissble stress to ultimste limit state accordingly to Doca document

$R_k := \frac{R_{primissible} \cdot 1.65}{1.1} = 45 \cdot k \cdot N$ Resistans per prop

Propping and backpropping

$n_{prop} := \frac{m_{tot\_outrigger}}{R_k} = 44.06$ Minimum amout of proops needed

$n_{prop\_per\_floor} := 51$ Assumed amount from n_propps

$cost_{prop} := 25SEK + 25SEK$ Monthly cost + Starting cost

$n_{floors} := 12$ Number of floor to the gorund slab with backpropping

Supporting beams

$cost_{beam} := 26SEK + 25SEK = 51\,SEK$ Monthly cost + Starting cost

$n_{beam\_primary} := 2 \cdot 3 = 6$ Needed amout of primary beams

$n_{beam\_secondary} := 17$ Needed amount of secondary beams

$cost_{tot\_beam} := (n_{beam\_primary} + n_{beam\_secondary}) \cdot cost_{beam} = 1173\,SEK$ Total cost for bearing beams

$cost_{all\_floors} := n_{prop\_per\_floor} \cdot n_{floors} \cdot cost_{prop} + cost_{tot\_beam} = 31773\,SEK$ Total cost for propping, backpropping and beams for all floors

A total cost of 31 773 SEK for propping all floors down to the ground slab per outrigger wall (Not representativr for the final design)

Controll of how many floors is needed for backpropping

$q_{floor.k} := 3 \frac{kN}{m^2}$ Load resistance from the floor

$q_{floor.d} := \frac{q_{floor.k}}{\gamma_{M0}} = 3 \cdot \frac{kN}{m^2}$

$q_{wet.k} := q_{outrigger\_wet} \cdot H_{tot} = 190.35 \cdot \frac{kN}{m^2}$ Charactiristic load from wet concrete time hight

$q_{wet.d} := 1.5 \cdot q_{wet.k} = 285.52 \cdot \frac{kN}{m^2}$

$n_{floor} := \frac{q_{wet.d}}{q_{floor.d}} = 95.17$ Amount of floors needed to support the loads from the outrigger wal

Calculation of loads on temporary works accordingly to SS-EN 12812

Self-weight Q1

$g_{vkr\_300\_14.2} := 1.01 \frac{kN}{m}$

$g_{vkr\_300\_12.5} := 0.902 \frac{kN}{m}$ VKR 300 x 200 x 12.5 mm^3

$g_{vkr\_250} := 0.468 \frac{kN}{m}$ VKR 250 x 150 x 8 mm^3

$g_{vkr\_150} := 0.182 \frac{kN}{m}$ VKR 150 x 100 x 5 mm^3

Variable imposed actions Q2

1. Supported construction

$q_{k\_wet\_Q2} := \frac{\left(H_{tot} \cdot t_{outrigger} \cdot q_{outrigger\_wet}\right)}{2} = 133.25 \cdot k \cdot \frac{N}{m}$ 27 kN/m see above

2. Storage areas

Neglected due to the reason that no one will be present on the formwork for the wall

3. Construction operation loading - operatives

No platforms will be included on the formwork which relates to the wall

4. Snow and ice

No snow, due to covering

5. Variable persisten horizontal imposed action Q3

1 % of the vertical load

$q_{k\_Q3} := 1\% \cdot q_{k\_wet} = 2.66 \cdot \frac{kN}{m}$

5. Variable transient imposed actions Q4

In-situ concrete loading allowance

10 % of the self-weight of the concrete. Shall not be bellow 0.75kN/m^2 or greater 1.75kN/m*2

$Q_{4k\_10\%} := 10\% \cdot q_{k\_wet} \cdot L_{effective} = 198.27 \cdot kN$

$q_{4.k\_10\%} := \frac{Q_{4k\_10\%}}{3m \cdot 3m} = 22.03 \cdot \frac{kN}{m^2}$ Above 1.75kN/m^2

$q_{4.k} := 1.75 \frac{kN}{m^2}$

6. Wind Q5

Maximum wind

See EN 1991-1-4

$q_{k.w}$

Working wind

$$q_{w.wind} := 0.2\frac{kN}{m^2}$$

7. Flowing water action Q6

Not of concern

8. Seismic effects Q7

Not of concern

Control of axial forces

data from truss in Frame analysis 2019-04-18

Maximum Normal Forces in Truss

$N_{Ed\_vkr\_300\_14.2} := 1884kN$ strut numer 80, second order

$N_{Ed\_vkr\_300\_12.5} := -2050kN$ strut number 60, second order (Compression is negative)

$N_{Ed\_vkr\_150\_tension} := 453kN$ strut number 96, second order

$N_{Ed\_vkr\_150\_compression} := -382kN$ strut number 96, second order

Stresses and utalization stresses

<u>VKR 300 x 200 x 14.2</u>

$h_{300} := 300mm$ $b_{300} := 200mm$ $t_{300} := 14.2mm$

$A_{vkr\_300\_14.2} := 1.320 \cdot 10^{-2} m^2$

$$\sigma_{vkr\_300\_14.2} := \frac{N_{Ed\_vkr\_300\_14.2}}{A_{vkr\_300\_14.2}} = 142.73 \cdot MPa$$

$$utalisation_{vkr\_300\_14.2} := \frac{\left|\sigma_{vkr\_300\_14.2}\right|}{f_y} = 40.2 \cdot \%$$

<u>VKR 300 x 200 x 12,5</u>

$h_{300} := 300mm$ $b_{300} := 200mm$ $t_{300} := 12.5mm$

$A_{vkr\_300\_12.5} := 1.170 \cdot 10^{-2} m^2$

$$\sigma_{vkr\_300\_12.5} := \frac{N_{Ed\_vkr\_300\_12.5}}{A_{vkr\_300\_12.5}} = -175.21 \cdot MPa$$

$$utalisation_{vkr\_300\_12.5} := \frac{\left|\sigma_{vkr\_300\_12.5}\right|}{f_y} = 49.36 \cdot \%$$

<u>VKR 150 x 100 x 8</u>

$h_{150} := 150mm$ $b_{150} := 100mm$ $t_{150} := 8mm$

$A_{vkr\_150} := 3.680 \cdot 10^{-3} \mathbf{m}^2$

$\sigma_{vkr\_150} := \frac{N_{Ed\_vkr\_150\_compression}}{A_{vkr\_150}} = -103.8 \cdot \mathbf{MPa}$

$utalisation_{vkr\_150} := \frac{|\sigma_{vkr\_150}|}{f_y} = 29.24 \cdot \%$

Stresses and utalization normal force

VKR 300 x 200 x 14.2

$A_{vkr\_300\_14.2} = 0.01\, \mathbf{m}^2$

$N_{Rd\_300\_14.2} := f_y \cdot A_{vkr\_300\_14.2} = 4.69 \times 10^3 \cdot \mathbf{kN}$

$utalisation_{vkr\_300\_14.2} := \frac{|N_{Ed\_vkr\_300\_14.2}|}{N_{Rd\_300\_14.2}} = 40.2 \cdot \%$

VKR 300 x 200 x 12,5

$A_{vkr\_300\_12.5} = 0.01\, \mathbf{m}^2$

$N_{Rd\_300\_12.5} := f_y \cdot A_{vkr\_300\_12.5} = 4.15 \times 10^3 \cdot \mathbf{kN}$

$utalisation_{vkr\_300\_12.5} := \frac{|N_{Ed\_vkr\_300\_12.5}|}{N_{Rd\_300\_12.5}} = 49.36 \cdot \%$

VKR 150 x 100 x 8

$A_{vkr\_150} := 3.680 \cdot 10^{-3} \mathbf{m}^2$

$N_{Rd\_150} := f_y \cdot A_{vkr\_150} = 1.31 \times 10^3 \cdot \mathbf{kN}$

$utalisation_{vkr\_150} := \frac{|N_{Ed\_vkr\_150\_tension}|}{N_{Rd\_150}} = 34.68 \cdot \%$

Moments capacity

VKR 300 x 200 x 14.2

$M_{Ed\_max\_300\_14.2} := 28.4 \mathbf{k} \cdot \mathbf{N} \cdot \mathbf{m}$ strut 81

$W_{vkr\_300\_14.2} := 1.055 \cdot 10^{-3} \mathbf{m}^3$

$M_{Rd\_vkr\_300\_14.2} := \frac{W_{vkr\_300\_14.2} \cdot f_y}{\gamma_{M1} \cdot 1.15} = 325.67 \cdot \mathbf{k} \cdot \mathbf{N} \cdot \mathbf{m}$

$utalisation_{M\_vkr\_300\_14.2} := \frac{M_{Ed\_max\_300\_14.2}}{M_{Rd\_vkr\_300\_14.2}} = 8.72 \cdot \%$

VKR 300 x 200 x 12.5

$M_{Ed\_max\_300\_12.5} := 17.7 k \cdot N \cdot m$ strut 7

$W_{vkr\_300\_12.5} := 9.52 \cdot 10^{-4} m^3$

$$M_{Rd\_vkr\_300\_12.5} := \frac{W_{vkr\_300\_12.5} \cdot f_y}{\gamma_{M1} \cdot 1.15} = 293.88 \cdot k \cdot N \cdot m$$

$$utalisation_{M\_vkr\_300\_12.5} := \frac{M_{Ed\_max\_300\_12.5}}{M_{Rd\_vkr\_300\_12.5}} = 6.02 \cdot \%$$

Shear forces

$$\varepsilon := \sqrt{\frac{235MPa}{f_y}} = 0.81$$

VKR 300 x 200 x 14.2

$V_{Ed\_vkr\_300\_14.2} := 125kN$ Strut 80

$t_w := 14.2mm$ $h_w := 300mm - 2 \cdot t_w = 0.27 m$ $\eta := 1.2$

$\frac{h_w}{t_w} = 19.13 < 72 \cdot \frac{\varepsilon}{\eta} = 48.82$ No risk for shear buckling (S5-19)

$$A_v := \frac{A_{vkr\_300\_14.2} \cdot h_{300}}{b_{300} + h_{300}} = 7.92 \times 10^{-3} m^2$$

$$V_{pl\_Rd\_300\_14.2} := A_v \cdot \frac{\frac{f_y}{\sqrt{3}}}{\gamma_{M0} \cdot 1.15} = 1.41 \times 10^3 \cdot kN$$

$$utalisation := \frac{V_{Ed\_vkr\_300\_14.2}}{V_{pl\_Rd\_300\_14.2}} = 8.86 \cdot \%$$

VKR 300 x 200 x 12.5

$V_{Ed\_vkr\_300\_12.5} := 18.4kN$ Strut 7

$t_w := 12.5mm$ $h_w := 300mm - 2 \cdot t_w = 0.28 m$ $\eta := 1.2$

$\frac{h_w}{t_w} = 22 < 72 \cdot \frac{\varepsilon}{\eta} = 48.82$ No risk for shear buckling (S5-19)

$$A_v := \frac{A_{vkr\_300\_12.5} \cdot h_{300}}{b_{300} + h_{300}} = 7.02 \times 10^{-3} m^2$$

$$V_{pl\_Rd\_300\_12.5} := A_v \cdot \frac{\frac{f_y}{\sqrt{3}}}{\gamma_{M0} \cdot 1.15} = 1.25 \times 10^3 \cdot kN$$

$$utalisation := \frac{V_{Ed\_vkr\_300\_12.5}}{V_{pl\_Rd\_300\_12.5}} = 1.47 \cdot \%$$

Slenderness for flexural buckling (knäckning)

VKR 300 x 200 x 12.5

$I_{vkr\_300\_12.5} := 7.537 \cdot 10^{-5} m^4$

$L_{c\_vkr\_300\_12.5}$ $\alpha := 0.21$

$$i_{vkr\_300\_12.5} := \sqrt{\frac{I_{vkr\_300\_12.5}}{A_{vkr\_300\_12.5}}} = 80.26 \cdot mm$$ (S6-11)

$$\lambda_{vkr\_300\_12.5} := \frac{L_{c\_vkr\_300\_12.5}}{i_{vkr\_300\_12.5}} = 10.59$$ (S6-10)

$$\lambda_{1\_vkr\_300\_12.5} := \sqrt{\frac{f_y}{E}} \cdot \frac{\lambda_{vkr\_300\_12.5}}{\pi} = 0.14$$ (S6-9)

$$\phi_{vkr\_300\_12.5} := 0.5 \cdot \left[1 + \alpha \cdot \left(\lambda_{1\_vkr\_300\_12.5} - 0.2\right) + \lambda_{1\_vkr\_300\_12.5}{}^2\right] = 0.5$$ (S6-8)

$$\chi_{vkr\_300.12.5} := \frac{1}{\phi_{vkr\_300\_12.5} + \sqrt{\phi_{vkr\_300\_12.5}{}^2 - \lambda_{1\_vkr\_300\_12.5}{}^2}} = 1.01$$ (S6-7)

$$N_{b.Rd\_vkr\_300\_12.5} := \frac{\chi_{vkr\_300.12.5} \cdot A_{vkr\_300\_12.5} \cdot f_y}{\gamma_{M1} \cdot 1.15} = 3.66 \times 10^3 \cdot kN$$ (S6-6)

$$utalisation_{buckling\_vkr\_300\_12.5} := \frac{\left|N_{Ed\_vkr\_300\_12.5}\right|}{N_{b.Rd\_vkr\_300\_12.5}} = 56.013 \cdot \%$$ (S6-5)

VKR 150 x 100 x 8

$$I_{vkr\_150} := 1.087 \cdot 10^{-5} m^4$$

$$L_{c\_vkr\_150} := 1929mm \qquad \alpha := 0.21$$

Konstruktionsteknik

$$i_{vkr\_150} := \sqrt{\frac{I_{vkr\_150}}{A_{vkr\_150}}} = 54.35 \cdot mm$$ (S6-11)

$$\lambda_{vkr\_150} := \frac{L_{c\_vkr\_150}}{i_{vkr\_150}} = 35.49$$ (S6-10)

$$\lambda_{1\_vkr\_150} := \sqrt{\frac{f_y}{E}} \cdot \frac{\lambda_{vkr\_150}}{\pi} = 0.46$$ (S6-9)

$$\phi_{vkr\_150} := 0.5 \cdot \left[1 + \alpha \cdot \left(\lambda_{1\_vkr\_150} - 0.2\right) + \lambda_{1\_vkr\_150}{}^2\right] = 0.64$$ (S6-8)

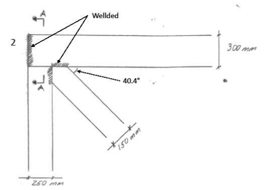
$$\chi_{vkr\_150} := \frac{1}{\phi_{vkr\_150} + \sqrt{\phi_{vkr\_150}{}^2 - \lambda_{1\_vkr\_150}{}^2}} = 0.93$$ (S6-7)

$$N_{b.Rd\_vkr\_150} := \frac{\chi_{vkr\_150} \cdot A_{vkr\_150} \cdot f_y}{\gamma_{M1} \cdot 1.15} = 1.06 \times 10^3 \cdot kN$$ (S6-6)

$$utalisation_{buckling\_vkr\_150} := \frac{\left|N_{Ed\_vkr\_150\_compression}\right|}{N_{b.Rd\_vkr\_150}} = 35.967 \cdot \%$$ (S6-5)

Weld Capacity

Connection 80-2-96



$f_u = 510 \cdot \frac{N}{mm^2}$

$\beta_w := 0.9$

$\alpha_{welled1} := 40.4 \cdot deg$

$b_{150x100} := 150 \cdot mm$

$L_{wH} := b_{150x100} \cdot \sin(\alpha_{welled1}) = 0.1\,m$

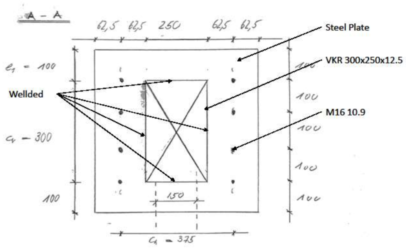
$L_{wV} := b_{150x100} \cdot \cos(\alpha_{welled1}) = 0.11\,m$

$a := 5mm$

$P_{tot} := 426.8kN$

$n := 4$

4 wellded edges



$P_s := \frac{P_{tot}}{n} = 106.7 \cdot kN$

$P_H := \sin(\alpha_{welled1}) \cdot P_s = 69.15 \cdot kN$

$P_V := \cos(\alpha_{welled1}) \cdot P_s = 81.26 \cdot kN$

For welds in horizontal direction

$\tau_{parrallelH} := \frac{P_H}{a \cdot L_{wH}} = 142.27 \cdot MPa$

$\sigma_{perpH} := \frac{P_V}{\sqrt{2} \cdot L_{wH} \cdot a} = 118.2 \cdot MPa$

$\tau_{perpH} := \sigma_{perpH} = 118.2 \cdot MPa$

$\sigma_{Ed1H} := \sqrt{\sigma_{perpH}^2 + 3 \cdot \left(\tau_{perpH}^2 + \tau_{parrallelH}^2\right)} = 341.48 \cdot MPa$

$\sigma_{Rd1H} := \frac{f_u}{\beta_w \cdot \gamma_{M2} \cdot 1.15} = 394.2 \cdot MPa$ **Ok!**

$\sigma_{Ed2H} := \sigma_{perpH} = 118.2 \cdot MPa$

$\sigma_{Rd2H} := 0.9 \frac{f_u}{\gamma_{M2} \cdot 1.15} = 319.3 \cdot MPa$ **Ok!**

For welds in vertical direction

$\tau_{parrallelV} := \frac{P_V}{a \cdot L_{wV}} = 142.27 \cdot MPa$

$\sigma_{perpV} := \frac{P_H}{\sqrt{2} \cdot L_{wH} \cdot a} = 100.6 \cdot MPa$

$\tau_{perpV} := \sigma_{perpV} = 100.6 \cdot MPa$

$\sigma_{Ed1V} := \sqrt{\sigma_{perpV}^2 + 3 \cdot \left(\tau_{perpV}^2 + \tau_{parrallelV}^2\right)} = 318.12 \cdot MPa$

$$\sigma_{Rd1V} := \frac{f_u}{\beta_w \cdot \gamma_{M2} \cdot 1.15} = 394.2 \cdot \mathbf{MPa}$$ **Ok!**

$$\sigma_{Ed2V} := \sigma_{perpV} = 100.6 \cdot \mathbf{MPa}$$

$$\sigma_{Rd2V} := 0.9 \frac{f_u}{\gamma_{M2} \cdot 1.15} = 319.3 \cdot \mathbf{MPa}$$ **Ok!**

<u>Welds wall connection</u>

$$L_{wtH} := 200\mathbf{mm} = 0.2\,\mathbf{m}$$

$$L_{wtV} := 300\mathbf{mm} = 0.3\,\mathbf{m}$$

$$a_{wt} := 9\mathbf{mm}$$

$$T_{upp} := 1940.3\mathbf{kN}$$

$$P_t := \frac{T_{upp}}{4} = 485.07 \cdot \mathbf{kN}$$

$$V_{upp} := \frac{760\mathbf{kN} + 381.5\mathbf{kN} + 406.9\mathbf{kN}}{10} = 154.84 \cdot \mathbf{kN}$$

5 supports for vertikal force (2 wells à 300mm each)

<u>Vertical welds upper Column</u>

$$\sigma_{perp\_t} := \frac{P_t}{\sqrt{2} \cdot L_{wtV} \cdot a_{wt}} = 127.04 \cdot \mathbf{MPa}$$

$$\tau_{perp\_t} := \sigma_{perp\_t} = 127.04 \cdot \mathbf{MPa}$$

$$\tau_{parrallel\_t} := \frac{V_{upp}}{a_{wt} \cdot L_{wV}} = 150.61 \cdot \mathbf{MPa}$$

$$\sigma_{Ed\_t1} := \sqrt{\sigma_{perp\_t}^{2} + 3 \cdot \left(\tau_{perp\_t}^{2} + \tau_{parrallel\_t}^{2}\right)} = 364.15 \cdot \mathbf{MPa}$$

$$\sigma_{Rd\_t1} := \frac{f_u}{\beta_w \cdot \gamma_{M2} \cdot 1.15} = 394.2 \cdot \mathbf{MPa}$$ **Ok!**

$$\sigma_{Ed\_t2} := \sigma_{perp\_t} = 127.04 \cdot \mathbf{MPa}$$

$$\sigma_{Rd\_t2} := 0.9 \cdot \frac{f_u}{\gamma_{M2} \cdot 1.15} = 319.3 \cdot \mathbf{MPa}$$ **Ok!**

<u>Horizontal welds upper Column</u>

$$\sigma_{perp\_t2} := \frac{P_t}{\sqrt{2} \cdot L_{wtV} \cdot a_{wt}} = 127.04 \cdot \mathbf{MPa}$$

$$\tau_{perp\_t2} := \sigma_{perp\_t2} = 127.04 \cdot \mathbf{MPa}$$

$$\sigma_{Ed\_tH2} := \sqrt{\sigma_{perp\_t2}^{2} + 3 \cdot \left(\tau_{perp\_t2}^{2}\right)} = 254.07 \cdot \mathbf{MPa}$$

$\sigma_{Rd\_tH2} := \frac{f_u}{\beta_w \cdot \gamma_{M2} \cdot 1.15} = 394.2 \cdot MPa$ Ok!

$\sigma_{Ed\_tH2} := \sigma_{perp\_t} = 127.04 \cdot MPa$

$\sigma_{Rd\_tH2} := 0.9 \cdot \frac{f_u}{\gamma_{M2} \cdot 1.15} = 319.3 \cdot MPa$ Ok!

Rest of vertical welds

$\tau_{parrallel\_H} := \frac{V_{upp}}{a_{wt} \cdot L_{wV}} = 150.61 \cdot MPa$

$\sigma_{Ed\_H} := \tau_{parrallel\_H} = 150.61 \cdot MPa$

$\sigma_{Rd\_H} := \frac{f_u}{\beta_w \cdot \gamma_{M2} \cdot 1.15} = 394.2 \cdot MPa$ Ok!

Design of joints

$f_{yb} := 900 \frac{N}{mm^2}$ $\quad f_{ub} := 1000 \frac{N}{mm^2}$ 10.9 - tabell 8.1 skruvhållfasthetsklasser

$l_p := 500mm$ $\quad b_p := 500mm$

$V_{tot} := V_{upp} \cdot 2 = 309.68 \cdot kN$ total shear (1500kN) dived on 5 plates

$H_{wind} := 2.5\% \cdot V_{tot} = 7.74 \cdot kN$

$D := \sqrt{V_{tot}^2 + H_{wind}^2} = 309.78 \cdot kN$

$e_1 := 100mm$ $\quad c_v := 100mm$ $\quad c_h := 350mm$ $\quad t_{pl} := 15mm$

Assume that the joints only takes shear respektive tension

$x := \begin{pmatrix} -187.5 \\ 187.5 \\ -187.5 \\ 187.5 \\ -187.5 \\ 187.5 \\ -187.5 \\ 187.5 \end{pmatrix} mm \quad y := \begin{pmatrix} 150 \\ 150 \\ 50 \\ 50 \\ -50 \\ -50 \\ -150 \\ -150 \end{pmatrix} mm$ (S8-23)

$n_{bolts} := 16$

$M_1 := D \cdot \sqrt{(x_1)^2 + (y_1)^2} = 74.38 \cdot kN \cdot m$

$I_p := \sum \left[(x)^2 + (y)^2 \right] = 0.38 \, m^2$

$N_{2x} := \frac{H_{wind}}{n} - \frac{M_1 \cdot y_1}{I_p} = -27.33 \cdot kN$

$N_{2y} := \frac{V_{tot}}{n} + \frac{M_1 \cdot y_1}{I_p} = 1.07 \times 10^5 \, N$

$R_2 := \sqrt{N_{2x}^2 + N_{2y}^2} = 110.13 \cdot kN$ $\quad d := 22mm$

$n_{skär} := 3$ $\quad A_{bolt} := \pi \frac{d^2}{4}$

$R_2 \cdot n_{bolts} = 1.76 \times 10^6 N$

$\alpha_v := 0.6$ Page S112

$F_{v\_Rd} := R_2 = 110.13 \cdot kN$

$A_{tot} := \frac{F_{v\_Rd} \cdot \gamma_{M2}}{\alpha_v \cdot f_{ub} \cdot n_{skär}} = 76.48 \cdot mm^2$ Cross section area for one bolt

$d_{needed} := \sqrt{\frac{A_{tot} \cdot 4}{\pi}} = 9.87 \cdot mm$ Needed diameter for one bolt

$utalisation_{minimum\_area} := \frac{R_2}{F_{v\_Rd}} = 100 \cdot \%$

Assume new bolt diameter

$d_{new} := 16mm$ Diamter of bolt

$d_{0\_new} := 18mm$ Diamterer of hole (S8.2.5)

$A_{bolt\_new} := \pi \frac{d_{new}^2}{4} = 2.01 \times 10^{-4} m^2$

$F_{v\_Rd\_new} := \frac{\alpha_v \cdot f_{ub} \cdot A_{bolt\_new} \cdot n_{skär}}{\gamma_{M2} \cdot 1.15} = 251.76 \cdot kN$

$F_{v\_Rd\_tot\_new} := \frac{\alpha_v \cdot f_{ub} \cdot A_{bolt\_new} \cdot n_{skär} \cdot n_{bolts}}{\gamma_{M2} \cdot 1.15} = 4.03 \times 10^3 \cdot kN$ (S8-20)

$utalisation_{bolt} := \frac{R_2}{F_{v\_Rd\_new}} = 43.74 \cdot \%$

Control of the plate

$\alpha_{d\_1} := \min\left(1, \frac{e_1}{3 \cdot d_{0\_new}}, \frac{f_{ub}}{f_u}\right) = 1$ Failure between hole and edge of plate

$\alpha_{d\_2} := \frac{c_v}{3 \cdot d_{0\_new}} = 1.85$ Failure between two holes

$\alpha_b := \min(\alpha_{d\_1}, \alpha_{d\_2}) = 1$ Governing failure mode

$e_2 := e_1$

$k_1 := \min\left[\left(2.8 \cdot \frac{e_2}{d_{0\_new}} - 1.7\right) 2.5\right] = 34.64$

$F_{b\_Rd} := \frac{k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t_{pl}}{\gamma_{M2} \cdot 1.15} = 4.06 \times 10^3 \cdot kN$

$D = 309.78 \cdot kN$

$Utalisation := \frac{D}{F_{b\_Rd}} = 7.64 \cdot \%$

$$\alpha_{d1} := \frac{e_1}{3 \cdot d_{0\_new}}$$

Tension in bolts

$k_2 := 0.9 \qquad A_s := 353\,mm^2 \qquad F_{t\_Ed} := 2205\,kN$

$$F_{t\_Rd} := \frac{k_2 \cdot f_{ub} \cdot A_s}{\gamma_{M2} \cdot 1.15} = 221.01 \cdot kN$$

$$Utalisation_{bolt} := \frac{F_{t\_Ed}}{F_{t\_Rd} \cdot n_{bolts}} = 62.36 \cdot \%$$

Shear and tension interaction

$F_{v\_Ed} := R_2$

$$\frac{F_{v\_Ed}}{F_{v\_Rd\_new}} + \frac{F_{t\_Ed}}{1.4 \cdot n_{bolts} \cdot F_{t\_Rd}} = 0.88$$ <1 OK