NTNU – Trondheim
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Construction Management of Randselva bridge

Assessment between two construction methods: cantilever concrete and steel-box method.

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Abstract:

Purpose of the master thesis is to perform a construction and cost analysis of two proposed solutions for the Randselva bridge on E16 roadway. Project data is based on information obtained from 'Statens Vegvesen', Trondheim. Bridge is built in cooperation with 'Multiconsult' construction company. Construction analysis will be done in 'Sofistik AG' software. Profitability and cost analysis will consist of uncertainty analysis in the 'Projection method' with the 'Successive calculation method'. All data will be then analyzed in cost estimating software 'ANSLAG', NTNU for better insight of project information. The analysis will assess the profitability of both solutions of the bridge with adequate comments in the conclusion.

Keywords:

1. Road bridge
2. Steel-box method
3. Cantilever method
4. Uncertainty analysis

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PREFACE

Cost estimation and analysis has always been one of essential parts of a construction project. Affected by many external and internal influences, it evolved from preliminary stage to most advanced version, finally used in contracting and executing the investment. Throughout the process, uncertainty of costs has also changed and influenced most important parts of a project, mainly the construction itself. The core issue has always been the assessment and reduction of this influence, that is why it is the main element to perform in given master thesis.

Purpose of the master thesis is to perform a construction and cost analysis of two proposed solutions for the Randselva bridge on E16 roadway. Project data is based on information obtained from 'Statens Vegvesen', Trondheim. Bridge is built in cooperation with 'Multiconsult' construction company. Construction analysis will be done in 'Sofistik AG' software. Profitability and cost analysis will consist of uncertainty analysis in the 'Projection method' with the 'Successive calculation method'. All data will be then analyzed in cost estimating software 'ANSLAG', NTNU for better insight of project information. The analysis will assess the profitability of both solutions of the bridge with adequate comments in the conclusion.

Acknowledgments

My special thanks to my supervisor Amund Bruland PhD. for help and support along my project work. It proved most essential, as I have learned many new aspects of cost and uncertainty analysis. I would also like to thank 'Statens Vegvesen' 's coordinator Bjørn Nyquist for providing me with the information and documentation, for the project wouldn't be completed without mentioned materials.

SUMMARY

Purpose of the master thesis is to perform a construction and cost analysis of two proposed solutions for the Randselva bridge on E16 roadway. Project data is based on information data given from 'Statens Vegvesen', Trondheim along with 'MultiConsult' construction company. Information data consist of all aspects of construction: from geotechnical surveys and geological inspections to final construction solutions with drawings, stated in further tables of contents.

Construction analysis will be performed as static system analysis with given cross-sections and materials, without designing the sections. Optimization process will be performed in order to update the further cost estimates. All calculation data will be processed and analyzed in software 'SoFiSTiK AG'.

Profitability and cost analysis will consist of uncertainty analysis in the 'Projection method' along with the 'Successive calculation method'. Both methods are popular in project management and financial analysis of construction enterprises and are based on risk factors and uncertainties values used in cost estimation. The analysis will be performed for both concrete and steel solutions. Results will be presented in tables and charts.

All data will be then analyzed in the computer program 'ANSLAG' provided by the supervisor and NTNU University. Computer analysis will conclude in final uncertainty projection and cost estimations for both construction solutions. Report will conclude then on results' comparison with adequate comments.

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APPENDIX C – EXTENDED COST ESTIMATE AFTER CONSTRUCTION ANALYSIS, STEEL-BOX ALTERNATIVE, 2 pages

ATTACHMENTS

concrete_preliminary.pdf – PDF file of preliminary project of concrete cantilever variant, Norwegian version

steel_preliminary.pdf – PDF file of preliminary project of steel-box variant, Norwegian version

concrete_part1_sofistik.rar – SoFiSTiK program result files for concrete variant, cantilever phase

concrete_part2_sofistik.rar – SoFiSTiK program result files for concrete variant, segment phase

steel_part1_sofistik.rar – SoFiSTiK program result files for steel-box variant, 1st part of longitudinal pull-up

steel_part2_sofistik.rar – SoFiSTiK program result files for steel-box variant, 2nd part of longitudinal pull-up

steel_part3_sofistik.rar – SoFiSTiK program result files for steel-box variant, 3rd part of longitudinal pull-up

concrete_preliminary_anslag.rar – ANSLAG program result files for cantilever variant, preliminary cost estimate

concrete_appA_anslag.rar – ANSLAG program result files for cantilever variant, appendix A

concrete_appB_anslag.rar – ANSLAG program result files for cantilever variant, appendix B

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1. Introduction

Background

Over the years, building construction management has been improved many times. Many methods have been introduced as new, transferred from other industries and developed further. When it comes to bridges and their technology, construction management went further into digital analysis, in order to transfer the risk and responsibility into the machines rather than humans.

Being equipped with strong computational units, we can now model the entire project from scratch. Yet one thing remained unchanged – human factor, involved now in the preliminary design studies and which created and still creates huge amounts of uncertainties in a project. That is why the methods of assessing uncertainties were developed. As a result, the cost estimates of a project have been subjected to this analysis and have become one of core issues before executing the project. The most important thing is if the cost amount will be more exact before enclosing or not. Then, in1970 other method – Projection method developed by Steen Lichtenberg from Technical University of Denmark appeared and submitted the cost amounts to risk factors related to many building industry subjects. Based on successive calculation principle, This has given a powerful tool for project managers to make sure that every problem has been solved before execution and that future problems appearing on building sites are taken into account.

In this paper we are going to assess if this method will apply to given topic of Randselva bridge construction and its issues. Moreover we will analyze the profitability of two of construction variants presented by MulitConsult company. By analyzing the construction itself and comparing cost estimates we will conclude in which scenario is most likely to take place.

History of a project

Preliminary designed and signed in 20.12.2013 by Multiconsult, 'Randselva bridge' project has become a part of large investment of Statens Vegvesen in Oslo region, Norway. As a part of new Eggemoen-Olum roadway (started in 01.07.2008), project introduces the bridge as a first engineering structure on the roadway construction. So far, project remains in preliminary phase due to archeological and further geotechnical studies on the future building site. Project is planned to be revised in first half of this year with further alterations and progress in documentation.

Core issues

In an organizational matter most unfortunate are the time delays, unfortunately existing. As aforementioned, most of the investment will depend on further studies on-site and whether they will be promising or not.

In technical matter most challenging will be the organization of building site, materials and logistics. Dependently on chosen construction type, these issues may influence the entire execution project.

Finally, the financial matter presents most of influence on final cost estimate and this thesis will be focused on reducing the uncertainty influencing the cost amounts. The reduction will be presented through S-Curves and Uncertainty profiles as a part of Projection method.

Methodology

Having the given documentation as a reference to the real conditions, thesis will proceed as follows:

- Presentation of problems in tables and figures,
- Construction analysis in computer designing software SoFiSTiK AG 2014, connected to technical drawing software Autodesk AutoCAD 2014,
- Uncertainty analysis in ANSLAG program, university developed,
- Conclusion based on model comparisons, future predictions and optimization, provided in annexes.

Reasons for taking up the project

One of main reasons for taking up the project is for me to learn more about construction management in bridge industry and develop and provide myself relevant knowledge for future endeavors. As almost every bridge project is unique, this one gives a lot of satisfaction, as its size and complexity are incomparable to any other designed in Norway nowadays. The amount of solutions for the problems seems vast, yet it is remarkable opportunity to test myself in personal engineering experience and selectivity, based on knowledge as well as on a ‘gut feeling’, so present in everyday life of project manager.

The topic is very important to discuss, as in large construction investments it is important to focus on main issues, categorizing and creating hierarchy of other ones. The thesis is based on this theorem, as it will try to clarify most of uncertainties of a project.

Structure of thesis

As given in table of contents, thesis will comprise of:

- Project description
- Construction analysis
- Estimation method
- Calculation of the method
- Final remarks
- Literature reference

Objectives

Q: How will the project description influence the analysis process?

A: Project description section is a vital part of a project when it comes to estimation method. It shows how detailed level we are in and therefore what level of uncertainty to assess in the beginning.

Q: What will the construction analysis cover? How relevant will be its information to the project after this section?

A: Construction analysis will cover most of all the Ultimate Limit State check and tendon optimization. The results of this analysis will prove useful as a source of more precise table of quantities for cost estimates and their further analysis.

Q: What is the relevance of uncertainty factors?

A: Uncertainty factors reflect our level of uncertainty towards project and the information we have gathered about it.

Q: What is expected after the model analysis in estimation method of construction variants?

A: The objective of model analysis in estimation method is to show that when going into more detailed information about the project cost estimates will be more precise in value and amount and decrease in overall price. That is the main expectation of this section.

Q: How will the estimation method results affect the overall project?

A: Depending on the overall prices and whether they will decrease or not, we will have general overview of the effectiveness of the method. In reference to the project's management, lower prices will show us we are going to right direction of cost estimates, the higher ones will indicate cost overrun, which is also likely to happen.

Q: In final assessment, what is more likely to happen in variant comparison: steel alternative will be more profitable or the concrete one?

A: In general, cantilever concrete methods are more costly than steel construction methods, yet in such a big enterprise like 550m long bridge situation may vary. Construction analysis will show more differences in quantities and therefore cost estimates. Most expected to have is the steel alternative which in general comparison is more effective and less material-consuming than concrete one.

Dictionary

Projection method – method developed by Steen Lichtenberg in 1970, based on successive calculation principle, in order to subject cost estimates under uncertainty factors, as a tool to obtain realistic cost estimates in the early stages of projects.

Successive Calculation Principle – principle used in Projection method, used for degradation of the problem from a rough overview at the start to more details as needed (from top to bottom, successively); estimation of uncertain quantities using subjective assessments and triple estimation.

Uncertainty – a measure associated with unknown quantities, which cannot be measured or depend on events that have not yet occurred.

Stochastic cost estimate - cost estimate that is based on uncertain values.

Probability distribution – mathematical function that indicates the relative probability that an uncertain size to be a certain value. Probability distributions can be either discrete or continuous.

S-Curve – cumulative probability distribution

P-Values – probability values of estimate, showing in what probability (%) estimate gives the amount

Most likely value – the peak of a probability distribution and, as the name implies, the single value it is most likely that will happen

Expected value – center of gravity of a probability distribution. It is the sum of all possible outcomes, each of which is weighted by their respective probabilities.

Median – the point of a probability distribution where half the area under the curve lies to the left and the other half of the area is to the right (same as P50).

Variance – expected squared deviation from the expected value.

Standard deviation – square root of the variance. It has the same magnitude as the expected value and therefore the most common measure of uncertainty, either directly or deflected to the relative standard deviation.

Relative standard deviation – standard deviation divided by the expected value and expressed in percent.

Tendon – type of cable used in prestressing technology in bridges. It usually consists of area of smaller steel cables, varying from single-bar cables to multi-bar, used in heavy bridge construction.

Post-tensioned technology – type of prestressing technology when, after concreting the element cables are then place in the prestressing canals and compressed in order to enact compressive stresses in concrete element to minimize the effects of tensile forces.

Quadrilateral elements – also known as Q4 element, is a type of element used in finite element analysis. It is used to give more exact results in a 2D system to a given differential equation for the element. The element combines 2 sets of Lagrange polynomials, each one used to define the variation of a field in each orthogonal direction of the local unit system.

Creep – physical property of concrete, different from creep in metals. Unlike in metals, it occurs at all stress levels and within the Serviceability Limit State is linearly dependent on the stress if the pore pressure is constant.

Truss system – system consisting of 2-force members only, which usually is profiled steel members, e.g. L-profiled or I-profiled. Members are organized in a structure so that the assemblage of whole structure occurs as a single object.

Thin-walled section – type of cross-section, in which one dimension is much smaller than the other ones. Usually used for plate sections for beams, which have higher bending stiffness is much higher than the ones in typical cold- and hot-rolled sections.

Description of symbols

$f_{po,1k}$	–	characteristic yield strength at 0,1% strain
M_{sd}	–	bending moment
N_{sd}	–	uniaxial force
σ_c	–	stresses in concrete
f_{ck}	–	characteristic compressive strength for given concrete type
σ_s	–	stresses in steel
f_{yk}	–	characteristic tensile strength for given steel type
f_{pk}	–	characteristic tensile strength for given prestressing steel type
σ_{cs}	–	stresses due to external loads
σ_{cp}	–	stresses due to prestressing
A_c	–	cross section area
e_0	–	eccentricity of force
y	–	ordinate of calculated stress point
N_{pd}	–	prestressing force
z_{cp}	–	prestressing force eccentricity
η	–	bearing capacity effectiveness
A_y	–	area of y-direction of cross section
A_z	–	area of z-direction of cross section
I_y	–	moment of inertia in y-direction
I_z	–	moment of inertia in z-direction
y_{sc}	–	y coordinate of center of gravity
z_{sc}	–	z coordinate of center of gravity
E	–	Elasticity module
M_{max}, M_{min}	–	maximum, minimum bending moment
N_{xmax}, N_{xmin}	–	maximum, minimum axial force
α_i	–	correlation between one element's elasticity module to the other
A_i	–	area of an 'i' element
a_i	–	distance between 'i' material element and the main axis
$\sigma_{low/high}$	–	fatigue strength of low/high value
$R_{EH,min/max/mean}$	–	yield strength of steel of min/max/mean value

2. Project description

2.1. Overview

The Randselva bridge project is a part of new E16 roadway section between Eggemoen and Olum in Jevnaker and Ringerike municipality. The section is placed southeast of Jevnaker center and will remove traffic in the city downtown. New E16 takes off from existing E16 Eggemoen and put in long bridge over river Rand. From Randselva bridge and east of Kleggerud road goes through a landscape of cultivated lands. At this place there are two planned intersections to access Jevnaker centre. Further eastwards the road is laid through steep woodland.

When going by city of Aslakrud and up to Olum road stretches through hilly rural land before it connects with existing E16. The road is planned as a two-lane road with median barriers, and speed limit of 90 km / h. Road class is determined as H5, two-lane road with median (HB 017).

Constructions

The investment plan contains 6 bridges in the roadside, 5 flyovers, 3 culverts, one railway crossing and one wildlife passage. One of the culverts will also serve as wildlife passage. The lengths of structures are given in Table nr 1.

One of the goals of the new E16 is to create an easy-to-access roadway with continuous elements. It is advised that all types of construction should be similar in shape and materials used. There should not be a contradiction between aesthetics and desired functional features.

All bridges are given a simple design, so that they remain minimally visible in landscape. Most of structures were chosen as slim, plate-bridges n circular columns to create most visual slim and lightweight construction. However, the Randselva bridge has been chosen for another bridge type because of challenging terrain conditions and fragile landscape. Project introduces two construction options for the Randselva bridge: concrete and steel-box cantilever alternative.

Table 1:Description of constructions

Nr	Structure name	Profile nr	Length (m)	Structure type
K01	Randselva bridge	1800-2340	540	In-line bridge
K02	Kistefos bridge	-	36	Crossing concrete bridge
K03	Kleggerud flyover	3350.3385	52	Abutment-free concrete plate-type bridge
K04	Branndalsbekken bridge	4025-4055	ca. 11	Abutment-free concrete plate-type bridge
K05	Moselva bridge	4700-4860	152	Concrete plate-type bridge
K06	Opperud bridge	ca. 5180	ca. 55	Wooden flyover
K07	Svenådalen bridge	6000-6215	205	Concrete plate-type bridge
K08	Søtbakkdalen bridge	6390-6555	151	Concrete plate-type bridge
K09	Søtbakkdalen flyover	ca. 6800	ca. 165	Wooden flyover

Table nr 1 continued

K10	Bekkestua culvert	8330-8370	ca. 15	Cast concrete culvert
K11	Bråtan culvert	9230-9280	ca. 16	Cast concrete culvert
K12	Kanadavegen	ca. 10000	ca. 30	Wooden flyover
K13	Kanadavegen bridge	10920-10980	50	Abutment-free concrete plate-type bridge
K14	Langlia flyover	ca. 11700	ca. 30	Wooden flyover
K15	Olum bridge	12040-12090	39	Concrete plate-type bridge
K16	Olum wildlife crossing	12545-12575	30	Cast concrete culvert/wildlife crossing

Milestones dates:

14-12-2012 – preliminary sketches of bridge
24-05-2013 – revised draft project
12-4-2014 – 11-6-2014 – proposed zoning plan
12-2014 – final archeological surveys
25.02.2015 – proposed zoning plan to municipalities and community
27.03.2015 – adopted and approved zoning plan for the project, starting of land acquisition

2.2. Description of the area

The road starts at the top of Eggemoen plateau from existing road RV35/ E16 and continues over Rand river on a long bridge. Further road stretches on the east side of Jevnaker center in the border of the forest, the valley edge and ends at Olum where the road enters the existing RV35/E16. Randselva bridge is the first bridge on this stretch when coming from the south (Drawing nr 1).

Bridge area consists of varied terrain with Eggemoen plateau that plunges steeply to the westside of Rand river. The east side of the river area consists of flat terrain to Kistefos Museum side. Bridge area extends from Eggemoen plateau over Rand river, the railway and access road to Kistefoss Museum from Kleggerud side (Drawing nr 2).

2.3. Challenges faced when constructing the structure

One of the key challenges faced in construction will be the alum repositories in soils. As mentioned many times in the documentation (Table nr 3), alum repositories would create time delays and transportation issues and is one of the priorities of the investment in given area.

The main challenges are also referred to the construction type. Both concrete and steel types of a bridge will create different boundary conditions, transportation issues, building site usage, but most of all time of construction. Both challenges will be discussed in the separate section of construction analysis.

Depending on the start of investment, weather conditions will affect the works' schedule (time of concreting, time of element transport). Exemplar schedule is presented in next section.

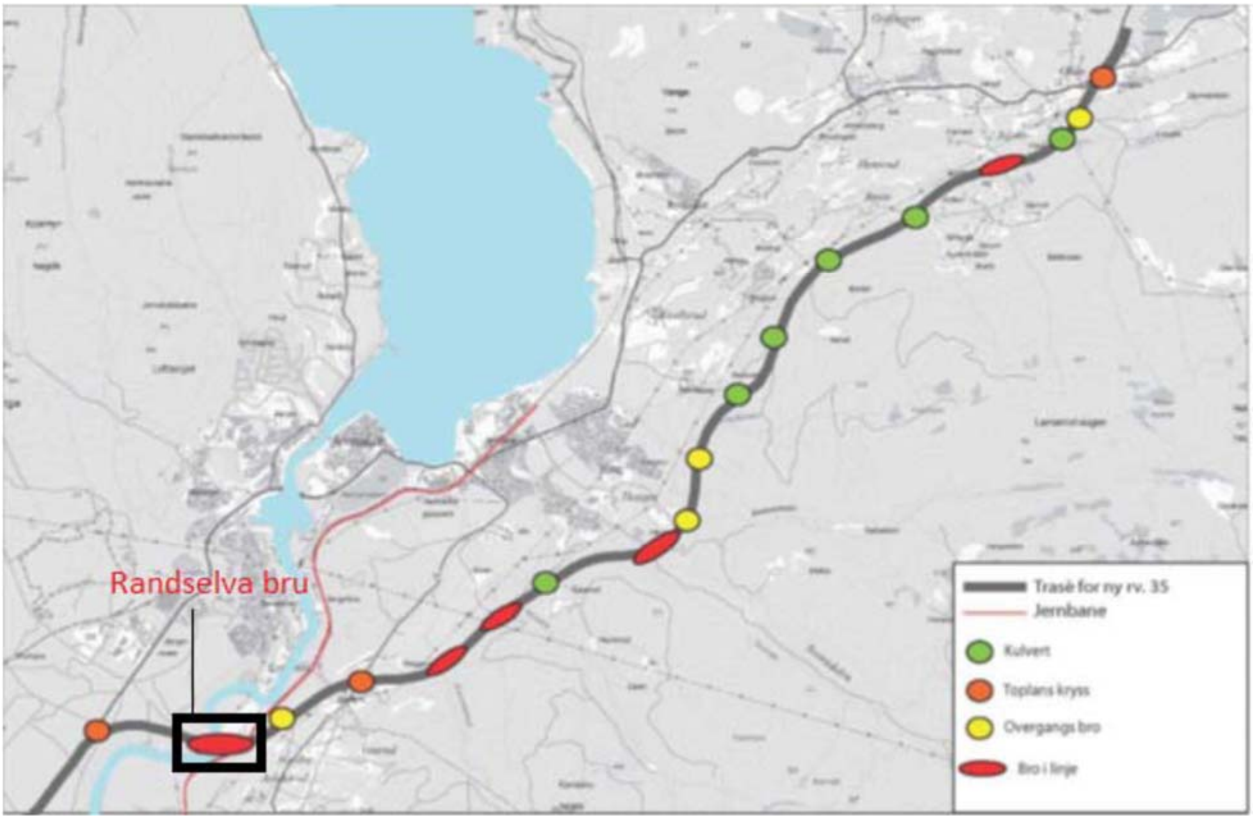


Figure 1: Overview of structures along the new E16 route

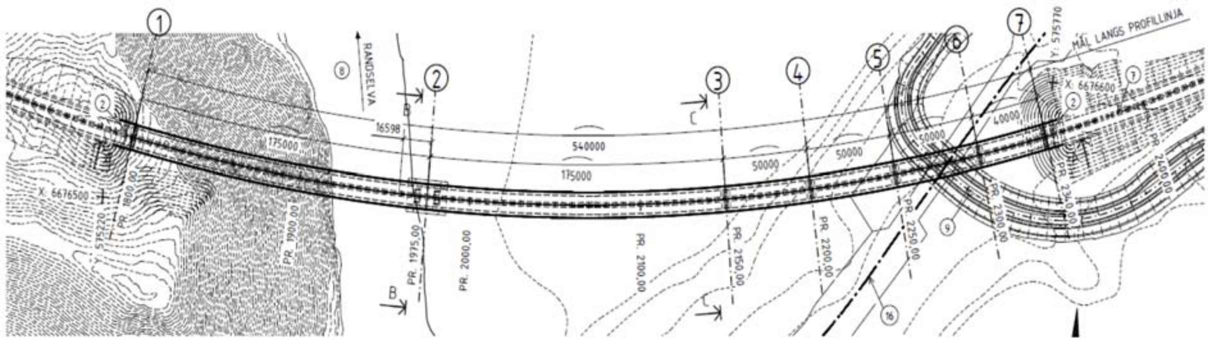


Figure 2: Plan view of road alignment for Randselva bridge

2.4. Geotechnical summary

The area along the river Rand is very hilly, with large differences in terrain heights to the east and west side of the river.
Along bridge stretch there were performed soil investigations east for the profile number 2100 on Kleggerud side and ca. 100 m northwest of slope top of Eggemoen plateau.

On Eggemoen plateau total probing was performed which registered soils consisting of fine sand with some sand / gravel down to 17.1 depth and then moraine, rock and gravel downwards. Drilling was completed at depth 35,7m without detection of the rock level.

2.5. Alum repositories

The bedrock between Rand river and Svenådalen consists mainly of sedimentary (cambrosilurian) rock shale, sandstone and limestone. There is a high risk of encountering alum shale. Instances of alum shale are depicted on both sides or Rand river and p towards Kleggerud junction (geological overview map in documentation “Geological survey report”, Table nr 3).

Alum shale contains sulfates that disintegrate and form sulfuric acid when they come into contact with oxygen. If it happens, formed acid and metal leachates can impose major environmental damage. Pollution Regulations contain therefore provisions for soils that crumble and form acids must be handled as waste. It is possible to transport alum shale to a special deposit in Langøya outside Holmestrand, but this is not desirable due to long transport road. With connection to the construction of Grantunnel in Hadeland, alum shale will serve as landmass replacement in marshland. Peatlands represent chemically stable and oxygen-free environment, therefore masses containing alum shale will not pose a pollution problem. However, no suitable marshland has been found along the landscape, then this solution is not a current one.

The aim is therefore to establish deposits for alum shale in the mountains along the roadway. Such landfills have to be established in stable rock with double insulation, one of natural geological barrier (dense mountain) and second as artificial barrier (membrane). In addition, one must enact strict control regime for runoff from the site. Alum shale may contain some uranium. Covering with landmasses will prevent radiation into the air.

The storage of alum shale in mountain landfill will provide stable conditions so that minerals will not undergo physical and chemical changes. Storage under water and in anaerobic conditions will prevent oxidation and formation of acid (which is the cause for leaching of metals from weathered alum shale). In planning process one will have to relate to pollution regulations, Waste and Radiation Protection regulations and obtain approval form Environment Directorate.

It has not been possible to perform probing of the bedrock around the planned crossing of Kleggerud, so that list of quantities of alum shale has not been obtained. Need for disposal is estimated to be around 70 000 m3 of alum shale. Supplementary drilling is advised for obtaining more detailed results.

3. Construction analysis

3.1. Concrete variant

Bridge is performed as a concrete cantilever bridge between axis 1 and 3 with two spans of 175 m symmetric about the pillar of axis 2. The remaining part of viaduct is performed as box-section of concrete from axis 3 to 7 with a center span of 50 m and the span 40 m (Drawing nr 3).

Description of the method

Cantilever concrete method is one of two methods used in the cantilever bridge construction technology. It was commonly used when constructing steel bridges, but the introduction of prestressed concrete has let to adjust this method to the concrete bridges. Span lengths, for which the method is applied, vary between 70 and 180 meters. The technology is strongly connected with the bridge shape. In order to maintain stability, the height of cross-sections varies: from the support section of 1/15 to 1/25 of a span length to the span section – 1/45 to 1/60 of a span length. Moreover, creating a box cross-section can reduce the segment weight, accelerate construction process and use less formworks when constructing.

Method is based on successive concreting of bridge parts, using a vehicle called ‘traveler’. This is a mobile formworks device which ‘drives’ in span direction from the support with low speed and provides on the way desired formworks shape for concreting. Parts are being concreted with prestressed reinforcement of post-tensioned cables, after completing traveler goes further and connects next parts to the previous ones through reinforcement. The main advantage if this method is that it doesn’t use much space under the construction. Because of the high costs of the montage devices it can only compete with other methods in the high cost investments.

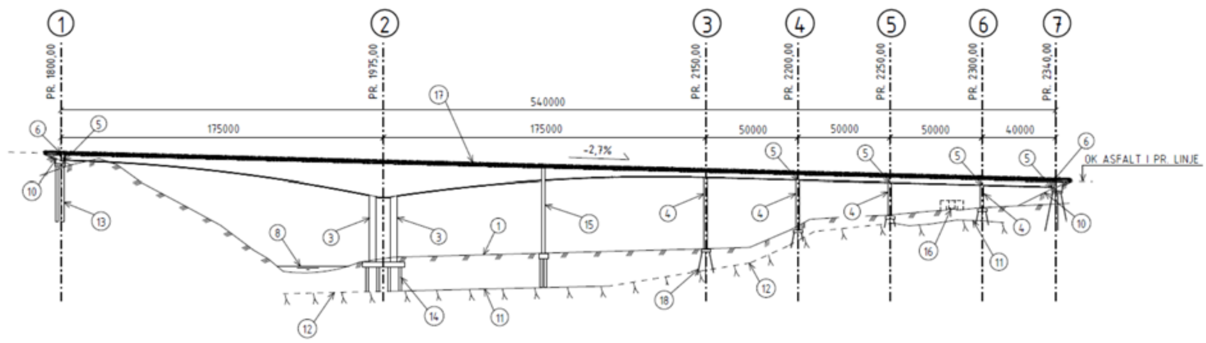


Figure 3: Longitudinal view of concrete bridge construction

Materials used:

- concrete of resistances B45 SV-40, B55 SV-40, B65 SV-40, and LB65 SV-40, detailed specification in NS:EN 1922-1-1:2004 and HB185:2011
- reinforcement steel: medium reinforcement of B500NC, technical class C described in NS-EN 3576:2005, tension reinforcement will consist of post-tensioned cables anchoring of recognized system (characteristic yield strength at 0.1% strain $f_{po,1k} = 1640\ MPa$)

Table 2: Description of cantilever bridge variant

Geometry/function	Description
Recorded width	12,5 m (1,5+3,5+0,75+1,0+0,75+3,5+1,5)
Height	up to ca. 55 m
Length and span	L = 540 m (175+175+50+50+50+40)
Horizontal curvature	R = 1050 m
Vertical curvature	2,7%
Crossfall	6,3%
Bridge type	Cantilever
Height of bridge superstructure	3500 – 19000 mm
Column type	2pcs of box-shaped slab cross section of BxD = 3500x8000 mm. Columns for the viaduct are disc cross section of BxD = 2000x7000 mm. Temporary columns are concrete slab type of BxD = 2000x11000 mm.
Foundations	Axis 1 is founded on drilled piles of diameter ϕ1200 mm. Axis 2 and temporary supports are founded on drilled piles of ϕ1500 into the rock. Axis 3 to 7 is founded on steel core piles of ϕ200 into the rock.

Construction analysis

The purpose of construction analysis is to assess construction resistance to self-weight, pre-stressing and traffic loads with given materials, cross-sections and tendon technology information. Results of analysis will be presented in drawings and tables for reinforcement design, tendon geometry and optimization. Finally, table of quantities will be presented in order to optimize the cost estimate and achieve final step in 3-step estimation process.

Since construction is divided into 2 phases: cantilever and segment phase, analysis will be performed on both of them, separately. Analysis is completed in SoFiSTiK Structural Desktop software, for 'Beam and Slab Bridge' settings. Calculation is performed in respect with Eurocode EC 2 1991-2 part "Road bridges". Calculation data is presented in Table nr 3. Material data is obtained from "Preliminary design – Randselva bridge – concrete cantilever variant" documentation table nr 4.

Table 3: Calculation data, concrete cantilever variant

Geometry	
Total length	L = 540,00 m
Span width	L = 2*175,00+ 50,00+50,00+50,00+40,00 m
Total width including end plates	B = 13,50 m
With between guardrail	B = 12,50 m
Width cross section top	btop = 7,00 m
Width cross section bottom	Bbottom = 7,00 m

Table nr 3 continued

Road width	Broad = 12,5 m
Total cross section height	H = 19,00 m
Structural height	H = 3,50 m
Slenderness ratio	Λ = 25,0
Bridge deck	A1 = 47,72 m2, A2 = 12,01 m2
Material and Pre-stress System	
Concrete	C 60/75
Reinforcing Steel	B 500 C
Prestressing Steel	Y 1960
Building Category	
Design longitudinal direction	Category
Design transverse direction	Category
Boundary conditions	
Exposition class	XC2
Design velocity	120 km/h
Load model	
Tandem axis for global design	Load Model 1
Single axis for local design	Load Model 2
Fatigue load model	Load Model 3

Calculation systems

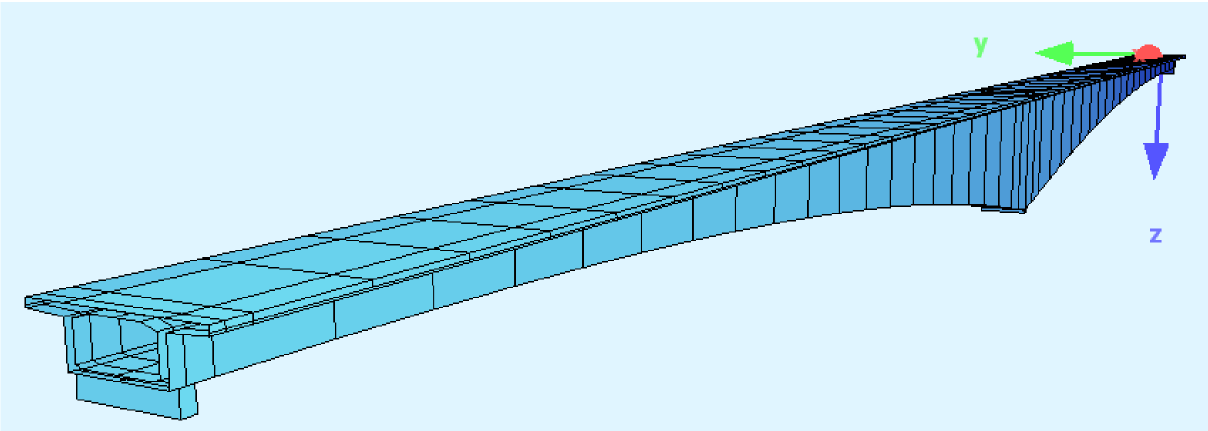


Figure 4: Part 1 - Cantilever phase of concrete variant

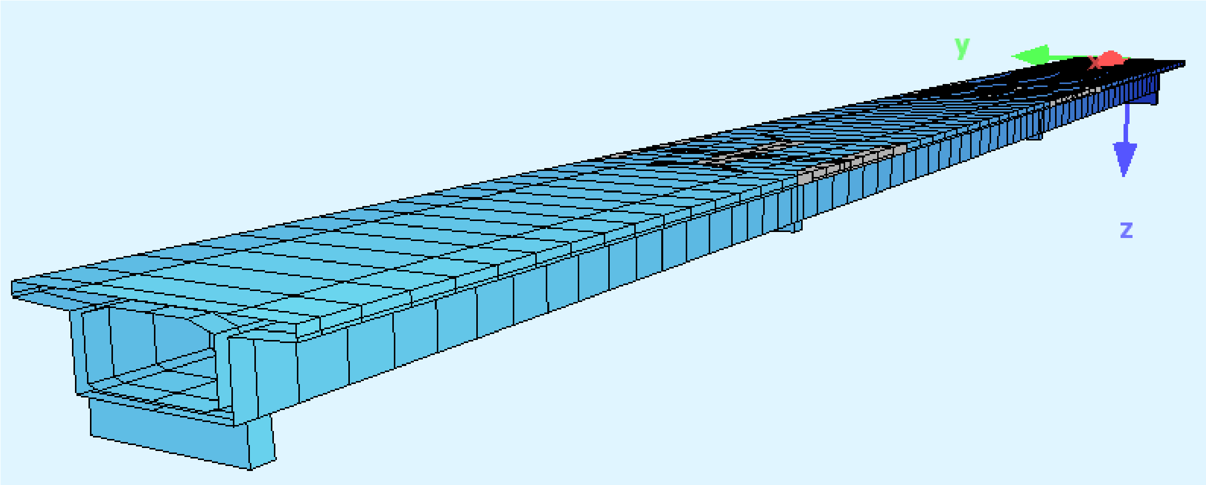


Figure 5: Part 2 - Segment phase of concrete variant

Assumptions regarding construction

- bridge performed in post-tensioned technology of tendons, according to construction phases forces in tendons will be analyzed in CSM (Construction Stages Module),
- static system performed as continuous beam, meshing and results as for beam element,
- beam element consists of quadrilateral elements,
- construction analysis focused only on bridge superstructure, effects of supports and foundation not taken into account in order to simplify the results.

Table 4: Loadcases - cantilever phase

Action	Description	Partition	Superposition	γ-u	γ-f	γ-a	ψ-0	ψ-1	ψ-2	ψ-1'
B	construction stage loading	Q (Variable)	EXCL exclusive	1.00	0.00	1.00	1.00	1.00	1.00	1.00
C	creep + shrinkage	P (Prestress)	PERM always	1.00	1.00	1.00	1.00	1.00	1.00	1.00
G_1	dead load g1	G (Permanent)	PERM always	1.35	1.00	1.00	1.00	1.00	1.00	1.00
G_2	dead load g2	G (Permanent)	PERM always	1.35	1.00	1.00	1.00	1.00	1.00	1.00
L_T	Traffic load TS of EC/DIN...	Q (Variable)	EXCL exclusive	1.35	0.00	1.00	0.75	0.75	0.00	0.80
L_U	Traffic load UDL of EC/DIN-FB	Q (Variable)	EXCL exclusive	1.35	0.00	1.00	0.40	0.40	0.00	0.80
P	prestressing	P (Prestress)	PERM always	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S	snow loading	Q (Variable)	COND conditional	1.50	0.00	1.00	0.50	0.20	0.00	0.20

Model will be analyzed in superpositioned loadcases, worst case scenario (table), i.e.:

- system after constructing whole structure
  - o phases performed in CSM, construction phases from concreting, prestressing, asphalt layers and parapet
- live loads of traffic:
  - o model performed according to Eurocode EN 1991-2 Load Model 1
  - o Live loads of Tandem System and Uniformly Distributed Loads
- post-tensioned tendon system,

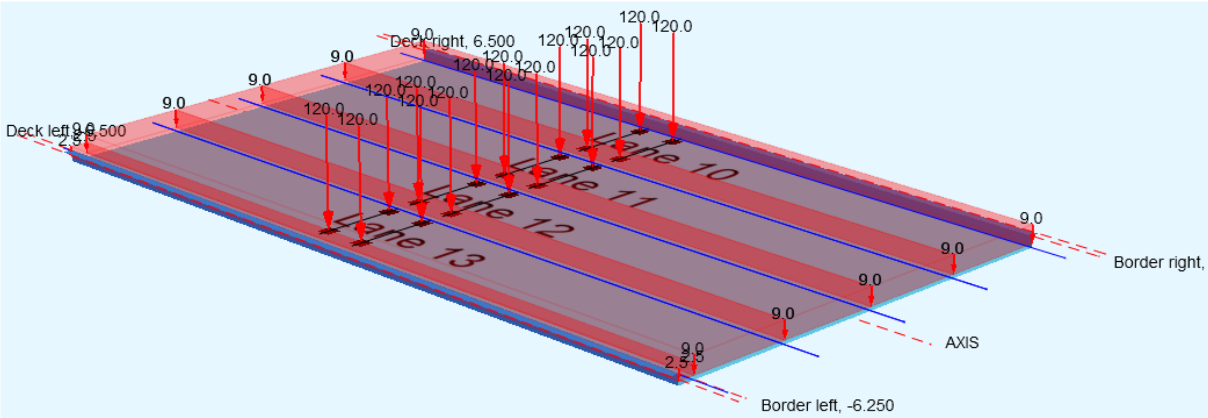


Figure 6: Load model of traffic load

Calculation model – cantilever phase

Due to the fact that static system of cantilever phase is a mirrored view, analysis will simplify to the one of sides of system, as showed in a figure. Model created in SOFIPLUS-X module. Structure undergoes variable heights of cross section, starting from abutment' of 3,5m till 19m on the pier. Cross sections of a model are shown in graphics below. Automatic reinforcement has been installed of #32 diameter rebars of B500C, distance 150mm.

Prestressing system shown in Tendon function of SOFIPLUS-X, in the drawings below.:

- system of 3 post-tensioned tendons per side is used, prestressing from pier side, then abutment side, jacking procedure – tension+slip.

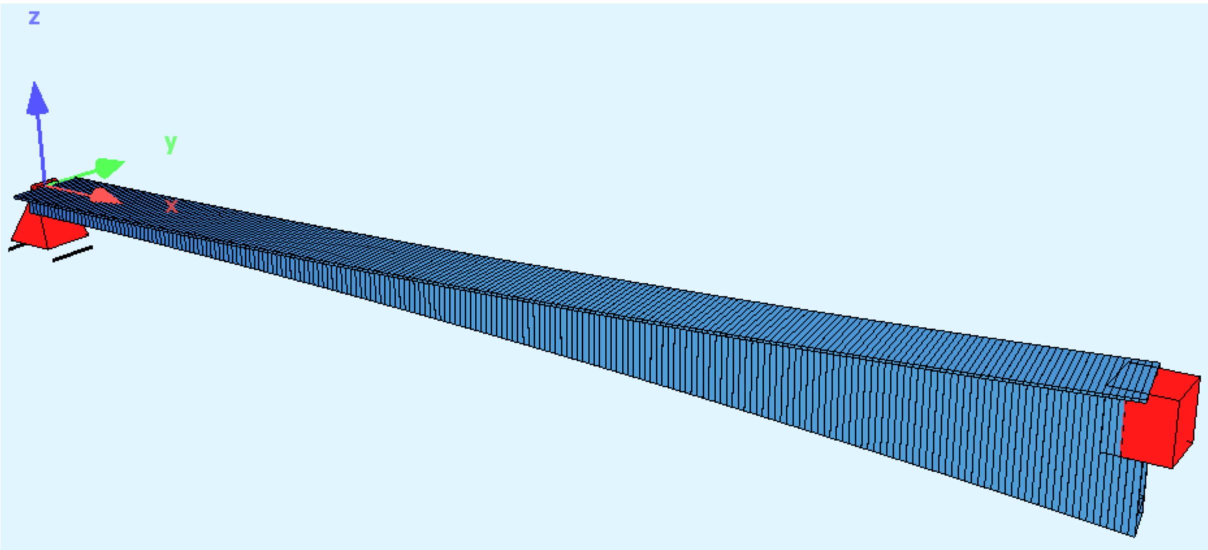


Figure 7: Cantilever phase calculation model, concrete variant

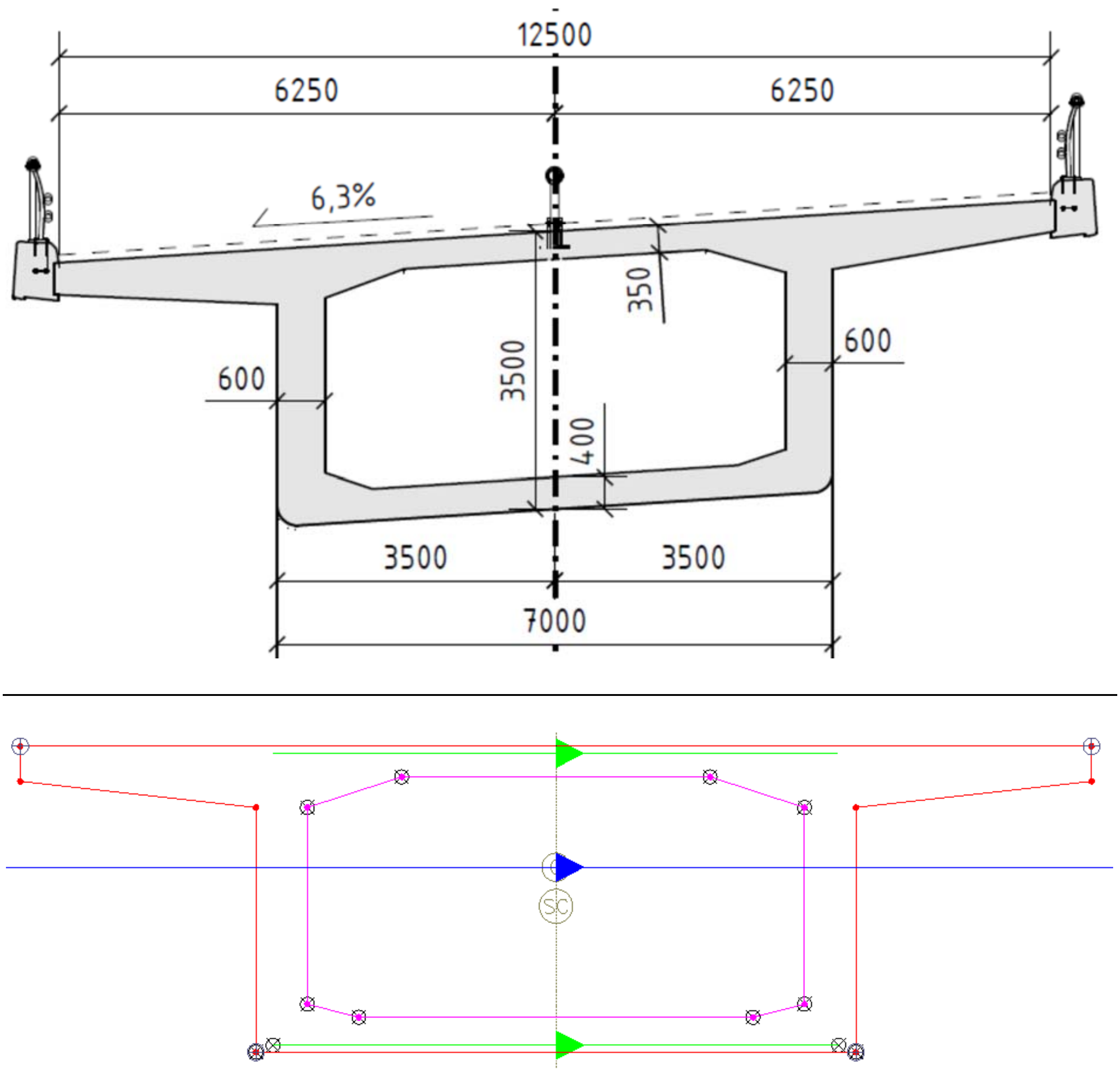


Figure 8: Cross sections of abutment, designed and programmed, cantilever phase, concrete variant

Red lines – contour of cross section, purple lines – contour of opening, green lines – line reinforcement, blue line – shear cut line.

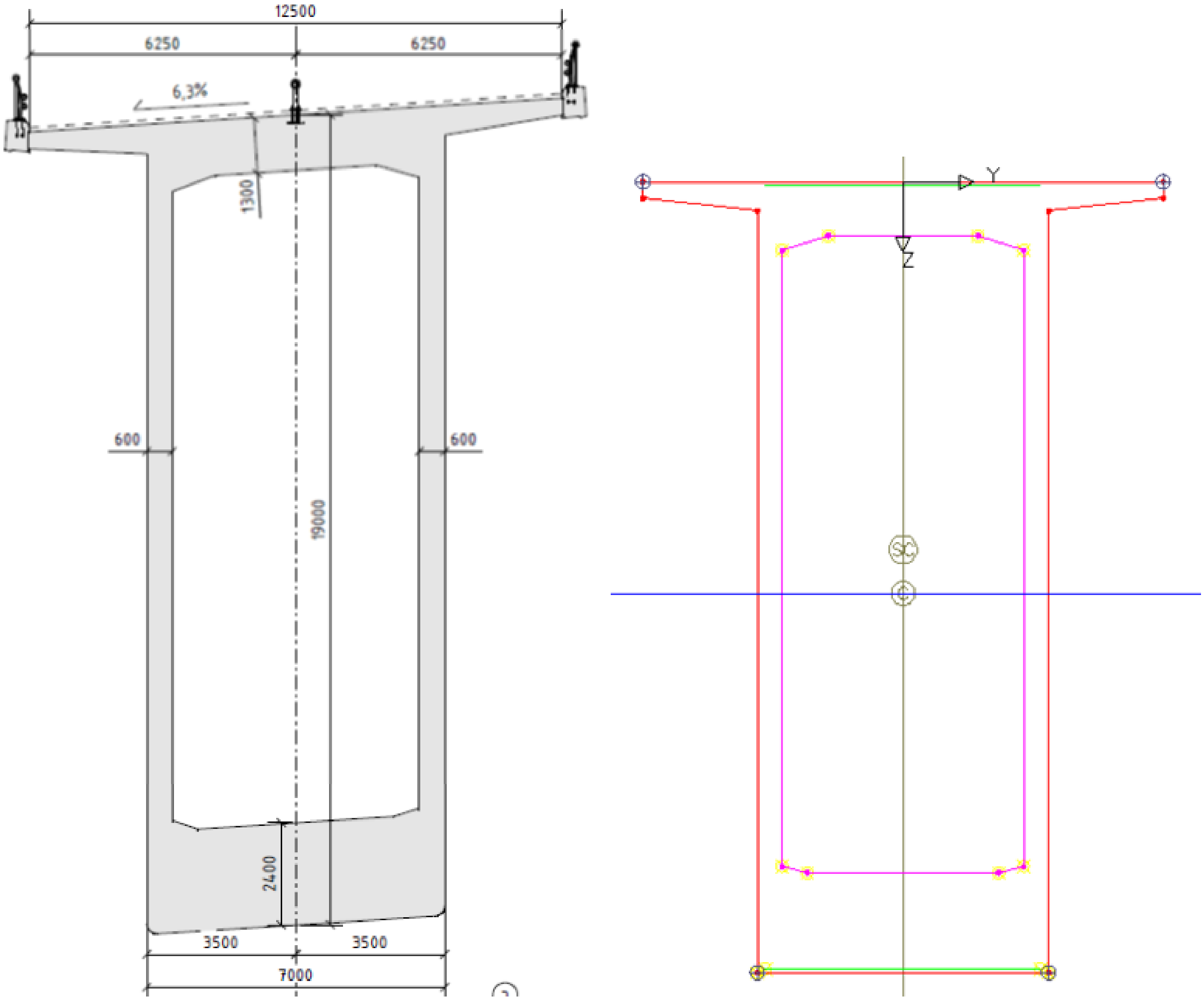


Figure 9: Cross sections of pier section, designed and programmed, cantilever phase, concrete variant

Red lines – contour of cross section, purple lines – contour of opening, green lines – line reinforcement, blue line – shear cut line.

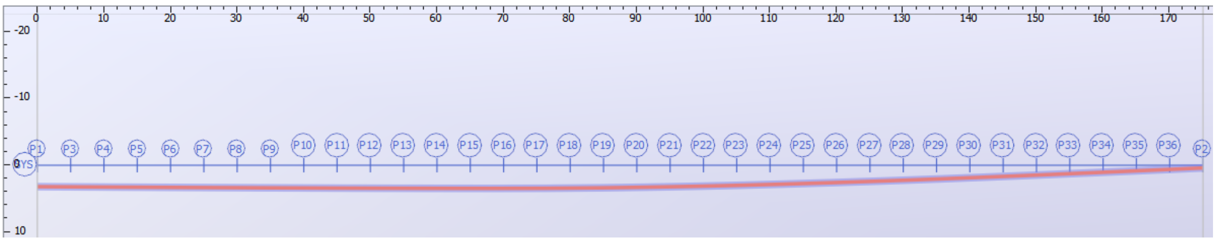


Figure 10: Tendon system of cantilever section, concrete variant

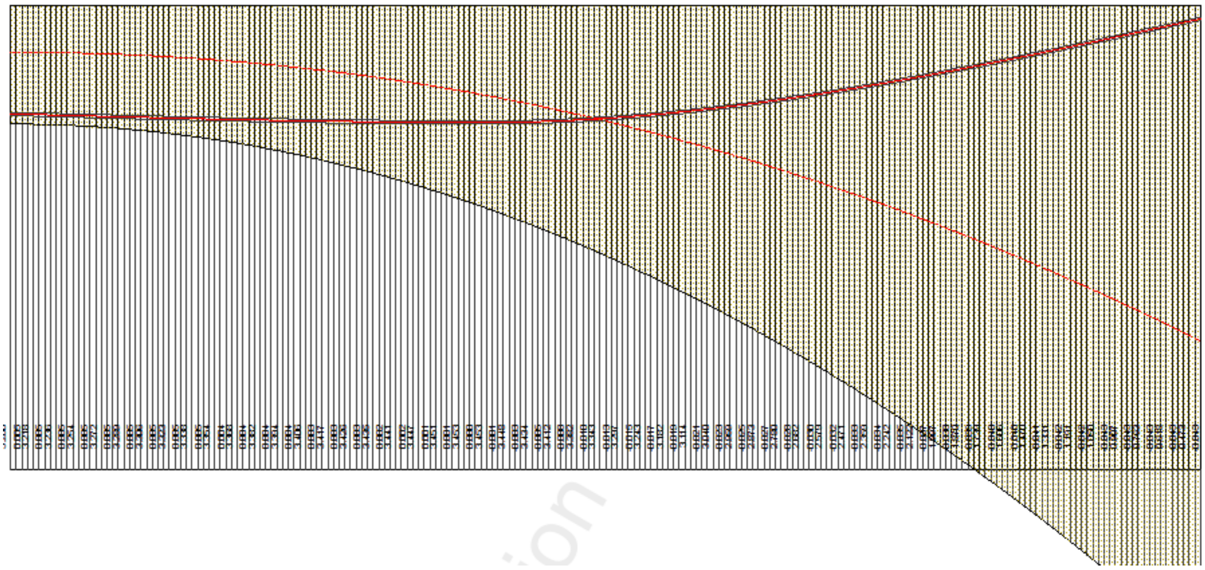


Figure 11: Tendon geometry of cantilever section, concrete variant

Results of analysis

1) Prestressing forces, prestressing force of 1640 kN:

   - FEM analysis, Mises Stresses [MPa]

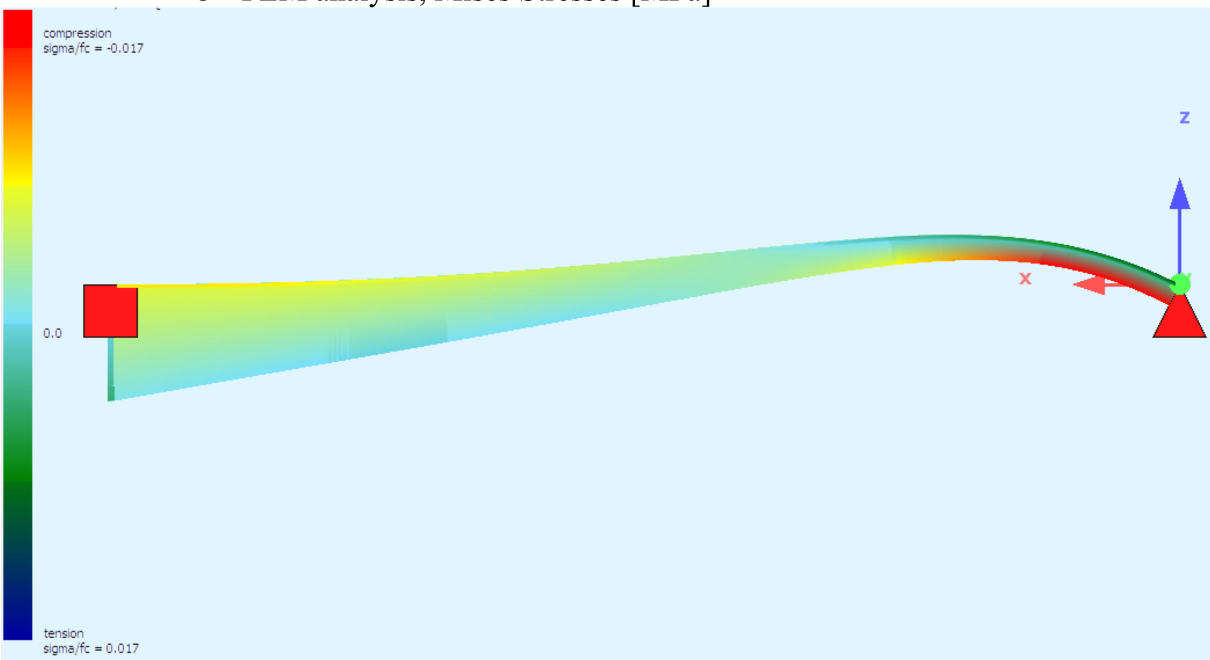


Figure 12: FEM analysis, prestressing forces, cantilever phase, concrete variant

- Prestressing forces figure N_{pd} [kN]

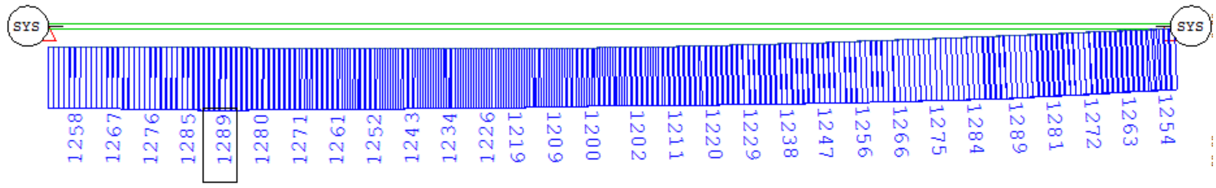


Figure 13: Prestressing forces, cantilever phase, concrete variant

2) Creep after opening, duration 30000days, humidity 70%, temperature 20^{o}:

- FEM analysis, Mises Stresses [MPa]

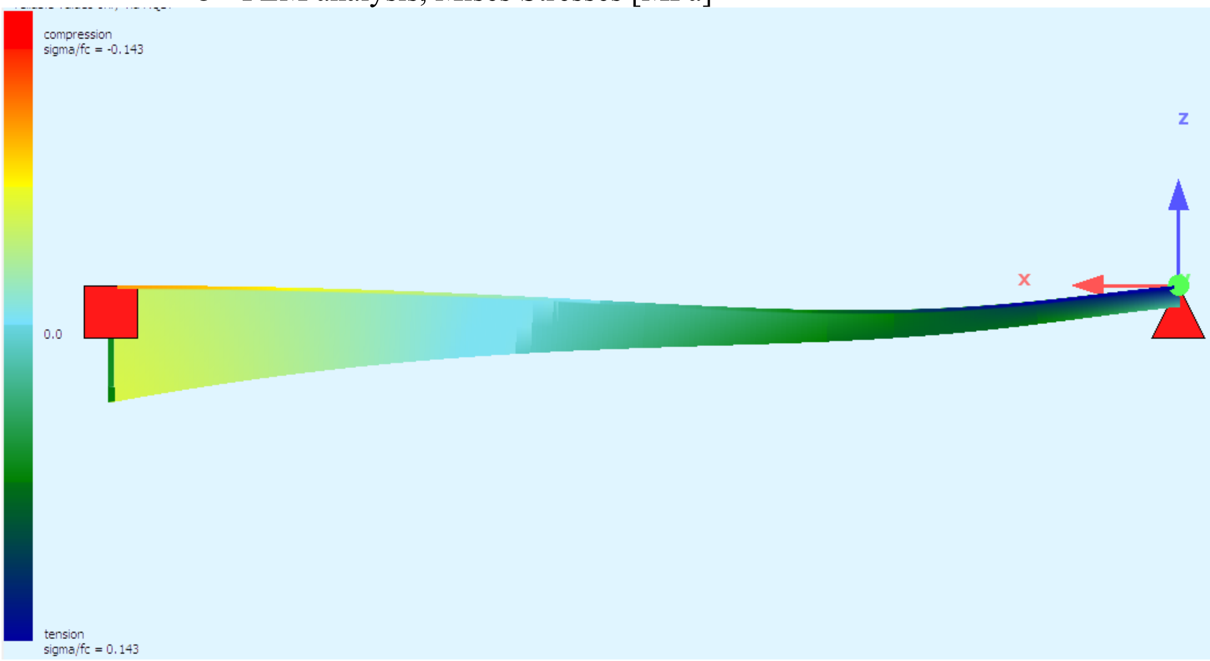


Figure 14: FEM analysis, creep after opening, cantilever phase, concrete variant

- Maximum bending moment M_{sd}, [kNm]

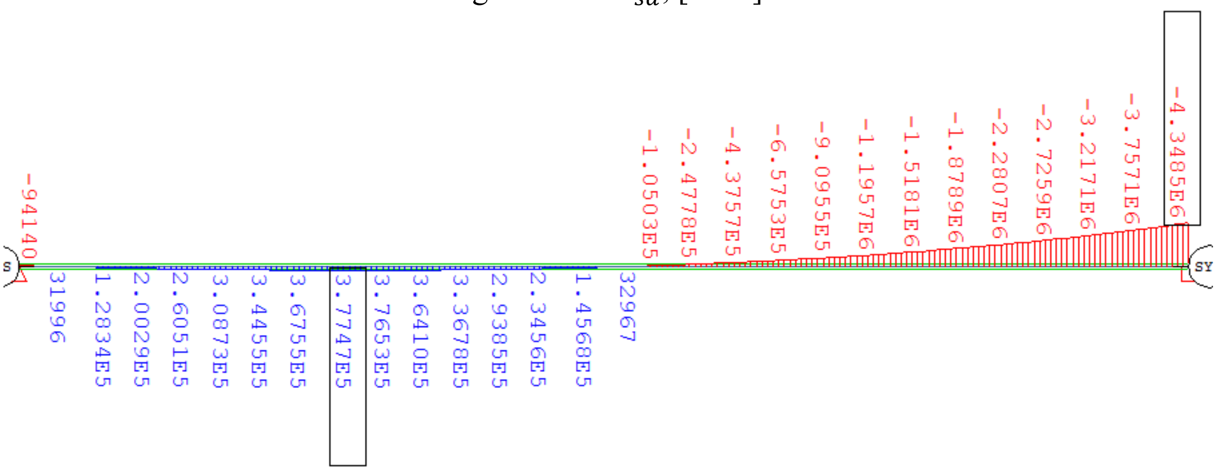


Figure 15: Maximum bending moments, creep after opening, cantilever phase, concrete variant

3) Envelope for Tandem System, Load Model 1:

- Maximum, minimum bending moment M_{sd}, [kNm]

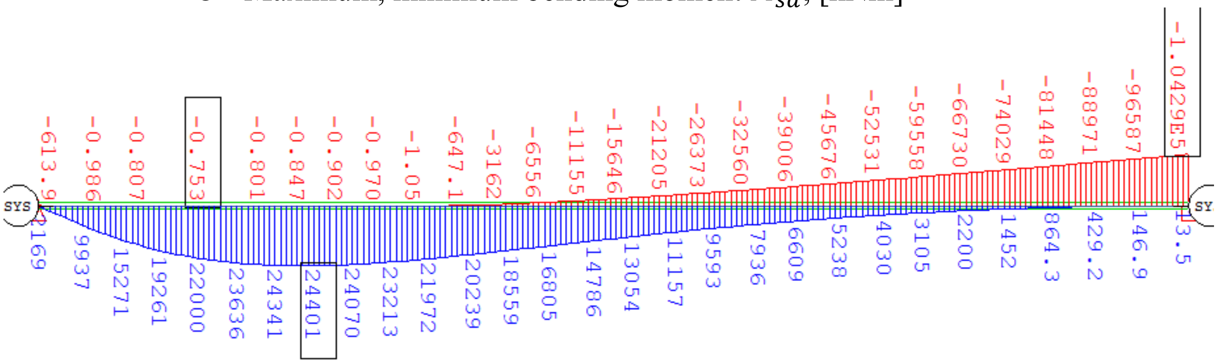


Figure 16: Bending moments envelope for Tandem System, cantilever phase, concrete variant

4) Envelope for Uniformly Distributed Load, Load Model 1:

- Maximum, minimum bending moment M_{sd}, [kNm]

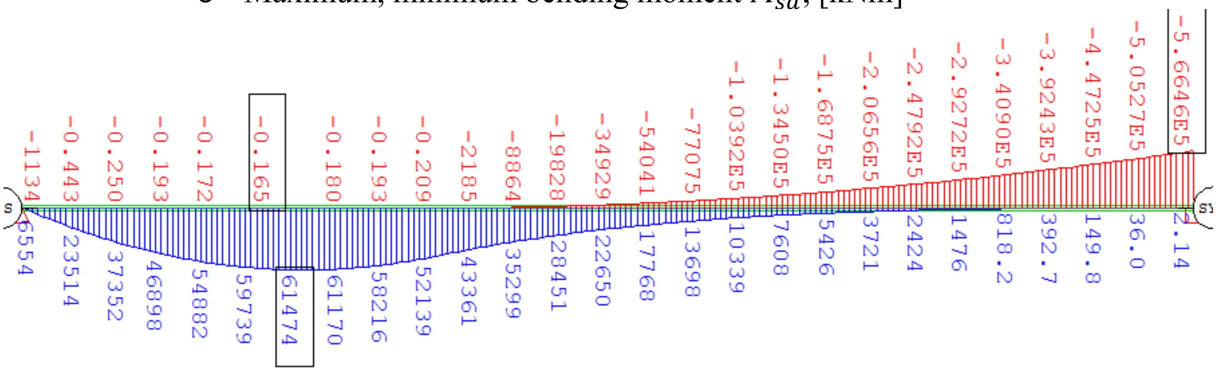


Figure 17: Bending moments envelope for UDL, cantilever phase, concrete variant

5) Superposition of loadcases:

- Maximum, minimum bending moment M_{sd}, [kNm]
  - ULS design for maximum compression stresses

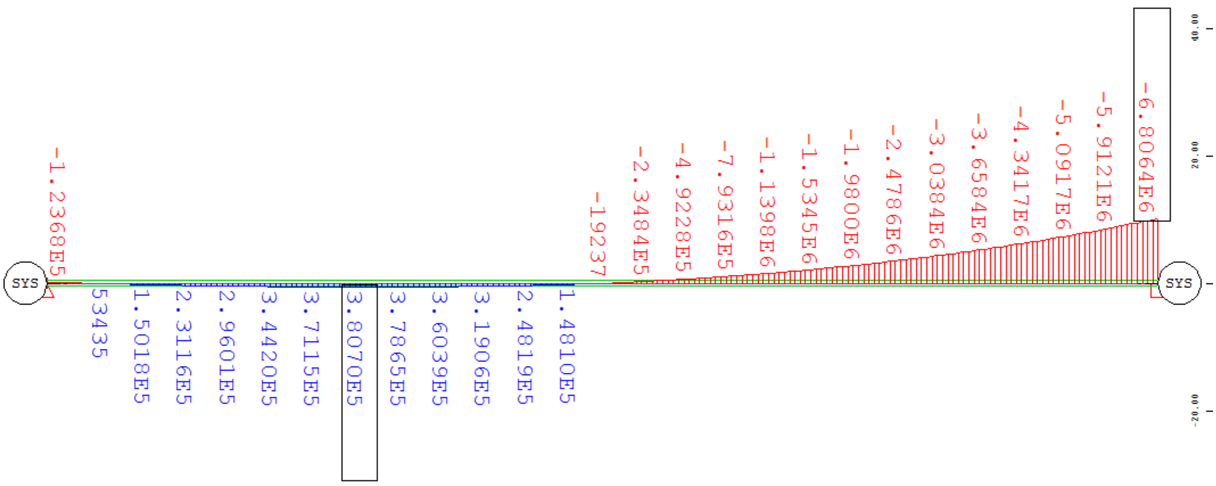


Figure 18: Bending moments for maximum compression stresses, cantilever phase, concrete variant

- ULS design for maximum tension stresses

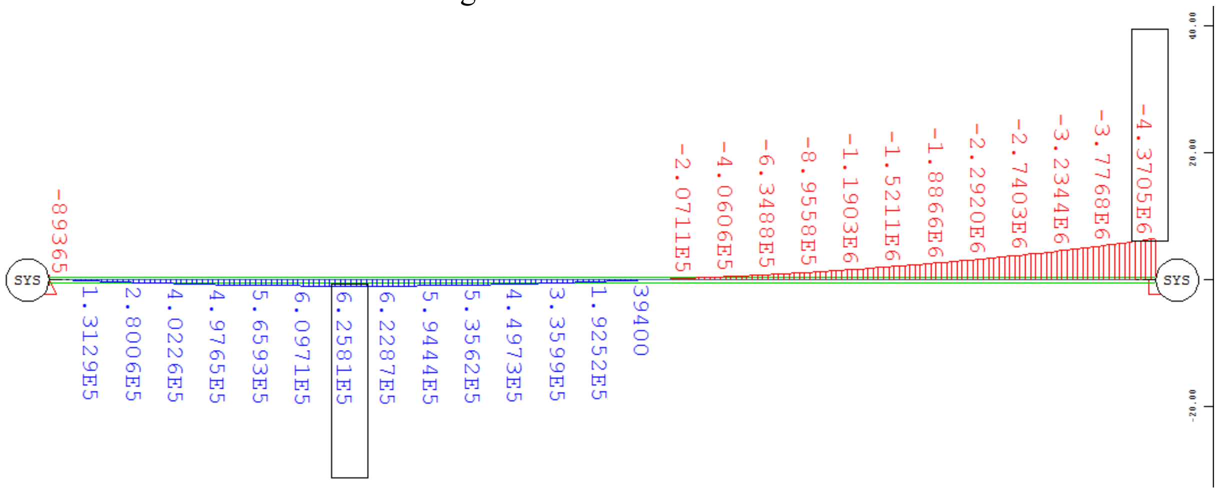


Figure 19: Bending moments for maximum tension stresses, cantilever phase, concrete variant

- Uniaxial force N_{sd}, [kN]
  - ULS design for maximum tension stresses

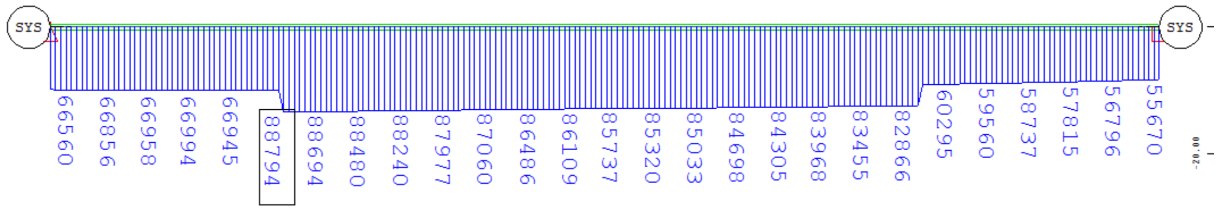


Figure 20: Maximum tension forces for tension stresses, cantilever phase, concrete variant

- ULS design for maximum compression stresses

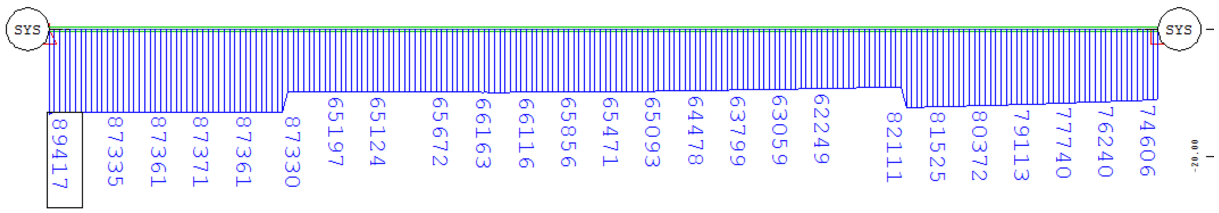


Figure 21: Maximum tension forces for compression stresses, cantilever phase, concrete variant

Serviceability Limit State – Stress check at cross sections

According to EC, stress check in steel and concrete is taken into Serviceability Limit State, not Ultimate Limit State. This compressive stress check is aimed towards avoiding concrete structure deterioration (longitudinal cracks or occurrence of microcracks) and high creep (non-linear creep). In this section we will relate strictly to this requirement.

In order to avoid accelerated construction degradation, compressive stress values in concrete should meet the condition:

$$\sigma_c \leq 0{,}6 * f_{ck} \tag{1}$$

Moreover, to assume linear creep, stresses in concrete equated under almost permanent load combination must not exceed value of:

$$\sigma_c \leq 0{,}45 * f_{ck} \tag{2}$$

We should also narrow the tensile stresses in steel (passive reinforcement), in order to avoid plastic deformation. With assumed characteristic load combination, stresses in steel should meet the condition:

$$\sigma_s \leq f_{yk} \tag{3}$$

In case of prestressing tendons, mean tensile stresses should meet the condition:

$$\sigma_s \leq 0{,}75 * f_{pk} \tag{4}$$

If assumed, that cross section is uncracked, then stress calculation is executed as for linear-elastic material, with assumption of superposition of stresses due to characteristic external loads for given situation and from characteristic value of prestressing force:

$$\sigma_C = \sigma_{cs} + \sigma_{cp} \tag{5}$$

Where:

- Stresses due to external loads:

$$\sigma_{cs} = \frac{N_{sd}}{A_c} + \frac{(N_{sd} * e_0 + M_{sd})}{I_c} * y \tag{6}$$

- Stresses due to prestressing

$$\sigma_{cp} = \frac{N_{pd}}{A_c} + \frac{N_{pd} * z_{cp} * y}{I_c} \tag{7}$$

Based on given results we can now check the Serviceability Limit State of construction of concrete and steel:

$$\sigma_C = \sigma_{cs} + \sigma_{cp} \leq (0{,}6 * f_{ck}; 0{,}45 * f_{ck}) \tag{8}$$

- Cross section at abutment:

Table 5: Abutment cross section calculation data, cantilever phase, concrete variant

Property	Value, unit
N_{sd}	89416,6 kN
A_c	12,05 m^2
e_0	0
M_{sd}	-123680,96 kNm
I_c	20,725 m^4
N_{pd}	1258 kN
z_{cp}	1,816 m
y coordinate:	
- Upper layer	-1,384 m
- Lower layer	2,116 m

Upper layer, equations (6), (7) and (8):

$$\sigma_{cs} = \frac{N_{sd}}{A_c} + \frac{(N_{sd} * e_0 + M_{sd})}{I_c} * y$$
$$= \frac{89416{,}6kN}{12{,}05m^2} + \frac{(89416{,}6kN * 0 - 123680{,}96kNm)}{20{,}725m^4} * -1{,}384m$$
$$= 7420{,}465kPa + 8259{,}322kPa = 15679{,}787\ kPa = 15{,}679MPa$$

$$\sigma_{cp} = \frac{N_{pd}}{A_c} + \frac{N_{pd} * z_{cp} * y}{I_c} = \frac{1258kN}{12{,}05m^2} + \frac{1258kN * 1{,}816m * -1{,}384m}{20{,}725m^4}$$
$$= 104{,}398\ kPa - 152{,}559\ kPa = -48{,}161\ kPa = -0{,}049MPa$$

$$\sigma_C = \sigma_{cs} + \sigma_{cp} = 15{,}679MPa - 0{,}049MPa = \mathbf{15{,}63\ MPa}$$

$\sigma_C \leq 0{,}6 * f_{ck} = 0{,}6 * 55MPa = 33MPa$ – accelerated construction degradation avoided.

$\sigma_C \leq 0{,}45 * f_{ck} = 0{,}6 * 55MPa = 24{,}75MPa$ – linear creep assumed.

All conditions met.

Lower layer, equations (6), (7) and (8):

$$\sigma_{cs} = \frac{N_{sd}}{A_c} + \frac{(N_{sd} * e_0 + M_{sd})}{I_c} * y$$
$$= \frac{89416{,}6kN}{12{,}05m^2} + \frac{(89416{,}6kN * 0 - 123680{,}96kNm)}{20{,}725m^4} * 2{,}116m$$
$$= 7420{,}465kPa - 12627{,}7kPa = -5207{,}227\ kPa = -5{,}207MPa$$

$$\sigma_{cp} = \frac{N_{pd}}{A_c} + \frac{N_{pd} * z_{cp} * y}{I_c} = \frac{1258kN}{12{,}05m^2} + \frac{1258kN * 1{,}816m * 2{,}116m}{20{,}725m^4}$$
$$= 104{,}398\ kPa + 233{,}248\ kPa = 337{,}646\ kPa = 0{,}338MPa$$

$$\sigma_C = \sigma_{cs} + \sigma_{cp} = -5{,}207MPa + 0{,}338MPa = \mathbf{-4{,}869\ MPa} \leq 0{,}6 * f_{ck} = 0{,}6 * 55MPa = 33MPa$$

$\sigma_C \leq 0{,}6 * f_{ck} = 0{,}6 * 55MPa = 33MPa$ – accelerated construction degradation avoided.

$\sigma_C \leq 0{,}45 * f_{ck} = 0{,}6 * 55MPa = 24{,}75MPa$ – linear creep assumed.

All conditions met.

- Cross section at pier:

Table 6: Pier cross section calculation data, cantilever phase, concrete variant

Property	Value, unit
N_{sd}	73817,1 kN
A_c	47,76 m^2
e_0	0
M_{sd}	-6806444,0 kNm
I_c	2522,79 m^4
N_{pd}	1254 kN
z_{cp}	9,486 m
y coordinate:	
- Upper layer	-9,887 m
- Lower layer	9,113 m

Upper layer, equations (6), (7) and (8):

$$\sigma_{cs} = \frac{N_{sd}}{A_c} + \frac{(N_{sd} * e_0 + M_{sd})}{I_c} * y = \frac{73817{,}1kN}{47{,}76m^2} + \frac{(73817{,}1kN * 0 - 6806444kNm)}{2522{,}79m^4} * (-9{,}887m) = 1545{,}584kPa + 26674{,}956kPa = 28220{,}54\ kPa = 28{,}221MPa$$

$$\sigma_{cp} = \frac{N_{pd}}{A_c} + \frac{N_{pd} * z_{cp} * y}{I_c} = \frac{1254kN}{12{,}05m^2} + \frac{1254kN * 9{,}486m * (-9{,}887m)}{2522{,}79m^4} = 26{,}256\ kPa - 46{,}619kPa = -20{,}363\ kPa = -0{,}020MPa$$

$$\sigma_C = \sigma_{cs} + \sigma_{cp} = 28{,}221MPa - 0{,}02MPa = \mathbf{28{,}2\ MPa}$$

$\sigma_C \leq 0{,}6 * f_{ck} = 0{,}6 * 55MPa = 33MPa$ – accelerated construction degradation avoided.

$\sigma_C > 0{,}45 * f_{ck} = 0{,}6 * 55MPa = 24{,}75MPa$ – nonlinear creep assumed.

Lower layer, equations (6), (7) and (8):

$$\sigma_{cs} = \frac{N_{sd}}{A_c} + \frac{(N_{sd} * e_0 + M_{sd})}{I_c} * y$$
$$= \frac{73817{,}1kN}{47{,}76m^2} + \frac{(73817{,}1kN * 0 - 6806444kNm)}{2522{,}79m^4} * (9{,}113m)$$
$$= 1545{,}584kPa - 24586{,}717kPa = -23041{,}13\ kPa = -23{,}041MPa$$

$$\sigma_{cp} = \frac{N_{pd}}{A_c} + \frac{N_{pd} * z_{cp} * y}{I_c} = \frac{1254kN}{12{,}05m^2} + \frac{1254kN * 9{,}486m * (9{,}113m)}{2522{,}79m^4}$$
$$= 26{,}256\ kPa + 42{,}97kPa = 69{,}226\ kPa = 0{,}069MPa$$

$$\sigma_C = \sigma_{cs} + \sigma_{cp} = -23{,}041MPa + 0{,}069MPa = \mathbf{-22{,}972\ MPa}$$

$\sigma_C \leq 0{,}6 * f_{ck} = 0{,}6 * 55MPa = 33MPa$ – accelerated construction degradation avoided.

$\sigma_C \leq 0{,}45 * f_{ck} = 0{,}6 * 55MPa = 24{,}75MPa$ – linear creep assumed.

All conditions met.

In the given cross sections we can also calculate the correlation of stresses in concrete with relation to compressive strength and therefore derive the carrying capacity of section. Values for given cross sections are:

- At abutment:
$$\frac{\sigma_C}{0{,}6 * f_{ck}} = \frac{15{,}63MPa}{33MPa} = 0{,}47 = 47\%$$

- At pier:
$$\frac{\sigma_C}{0{,}6 * f_{ck}} = \frac{28{,}2MPa}{33MPa} = 0{,}85 = 85\%$$

From the values obtained, it is clear we can execute optimization process in order to reduce the materials used and achieve better performance of cross section. Process will be explained further.

Tendon and reinforcement optimization

In this section our main aim will be to optimize cross sections in regard to number of tendons and reinforcement, forces applied in tendons and reinforcement distances. This will prove vital to the final bill of quantities, presented in next section. Optimization will be performed in 3 steps, until we reach 90% of construction carrying capacity. Complete process will be also presented in SOFiSTiK AG program results.

It is important to mention the previous values of tendons and reinforcement used in step 0:

- Nr of tendons = 4
- Areas of longitudinal reinforcement [cm^2], default distance of 150mm:

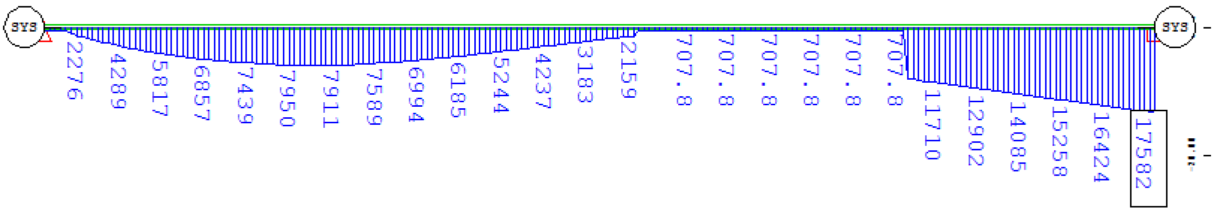


Figure 22: Longitudinal reinforcement for cantilever phase, concrete variant

Table 7: Optimization process for cantilever phase, concrete variant

Assumptions for the optimization process:

- Performed with regard to main stresses, both for compression and tensile forces
- Optimization until 90% of carrying capacity
- Optimization will be performed as for the stress check in previous section, which will prove valid to sections' stresses

Nr of optimization step	Adjustment	Results of optimization							
		M_{sd}, [kNm]		N_{sd}, [kN]		σ_c, [MPa]		$\eta = \frac{\sigma_c}{0,6*f_{ck}}$, [%]	
		Abutment	Pier	Abutment	Pier	Abutment	Pier	Abutment	Pier
1st	-Nr of tendons = 2 -Reinforcement of #32, with distance 200mm -Prestressing force of 1640 kN	-123498,15	-6815700	89284,4	73681,3	15,61	28,234	47,29	85,56
2nd	-Changed upper reinforcement from #32/200 to #28/200 -Changed lower reinforcement from #32/200 to #25/200	-123878,3	-6823335	89559,3	73948,2	15,657	28,269	47,44	85,66
3rd	-Changed lower reinforcement from #25/200 to #20/200	-123784,24	-6824734	89491,3	73880,3	15,645	28,273	47,41	85,68

Process has proved more effective for pier section, yet the changes haven't affected much of carrying capacity. It seems that there is a boundary condition towards reinforcement amounts, most probably through prestressing system.

Bill of quantities – cantilever phase

Based on the optimization results of 3rd step we can now transfer the results to bill of quantities. As these measures influence mostly on superstructure cost estimate, we will take into account:

- Amount of concrete

Interpolated through SOFIPLUS-X module = **4805 m^3 +/- 5m^3** of 175m section.

- Amounts of reinforcement, both active, passive and prestressing system

Amounts derived through designed longitudinal reinforcement profile:

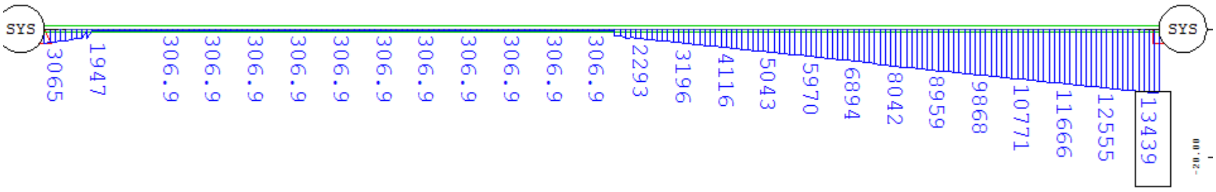


Figure 23: Longitudinal reinforcement after 3rd optimization step, cantilever phase, concrete variant

Stirrup reinforcing:

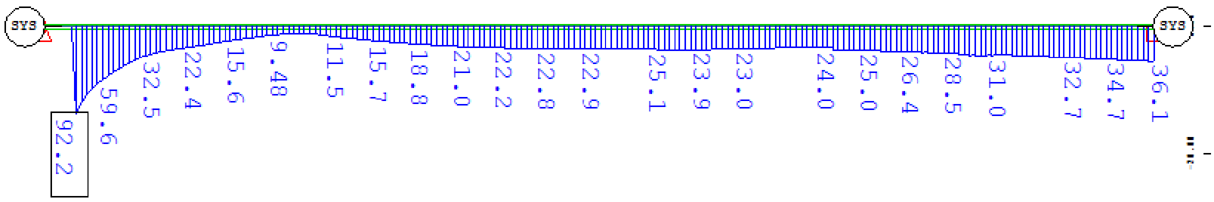


Figure 24: Stirrup reinforcement after 3rd optimization step, cantilever phase, concrete variant

In defined cross section for 3rd optimization, we acquire amounts of reinforcement per line reinforcement:

- Upper reinforcement - #28/200, perpendicular length= 6,6 m

$$nr\ of\ elements = \frac{6600mm}{200mm} = 33elements$$

- Lower reinforcement - #20/200, perpendicular length= 6,6 m

$$nr\ of\ elements = \frac{6600mm}{200mm} = 33elements$$

Reinforcement ratio of upper/bottom layer is 1:1.

Table 8: Longitudinal reinforcement amounts, cantilever phase, concrete variant

Element	Diameter [mm]	Length of section [-]	Nr of elements	Weight per meter [kg/m]	Weight [kg]
Lower reinforcement	20	175	33	2,466	14241,1
Upper reinforcement	28	175	33	4,834	27916,3
				TOTAL	**42157,5**

- Stirrup reinforcement (use of 8-cut stirrup bars, numbering of sections in figure below)

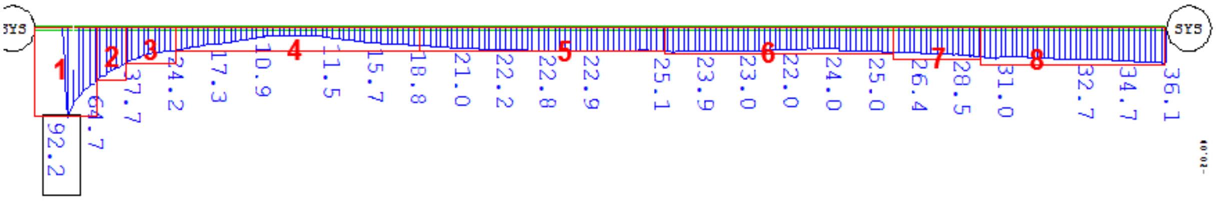


Figure 25: : Division of analyzed stirrup reinforcement, cantilever phase, concrete variant

Table 9: Stirrup reinforcement amounts, cantilever phase, concrete variant

Section nr	1	2	3	4	5	6	7	8
Length [m]	9,5	4,5	7,5	37,5	37,5	35	13,5	30
Diameter [mm]	28	25	18	16	16	16	16	18
Distance [m]	0,15	0,175	0,2	0,3	0,3	0,2	0,175	0,15
Amount n [-]	63	26	38	125	125	175	77	200
Mean perimeter [m]	63,5	63,5	63,5	63,5	63,5	63,5	63,5	63,5
Total perimeter [m]	4021,1	1632,9	2381,3	7937,5	7937,5	11112,5	4898,6	12700
Weight [kg/m]	4,834	3,853	1,998	1,578	1,578	1,578	1,578	1,998
Total weight [kg]	**19440,7**	**6291,4**	**4757,7**	**12525,4**	**12525,4**	**17535,5**	**7729,9**	**25374,6**

Total weight of stirrup reinforcement = **106180,7 kg**.

- Prestressing steel

Prestressing system of Y 1960 (EN 1992):
  - Length of single tendon = 175,054m
  - Area of single tendon = 450 mm2
  - Volume of single tendon = 0,0788 m3
  - Density = 7850kg/m3
  - Weight of single tendon = 618,38 kg
  - TOTAL weight of 2 tendon system = **1236,76 kg**

Bill of quantities

Table below presents the final bill of quantities of cantilever section, in reference to previous cost estimate positions.
Prices taken from Statistisk Sentralbyrå (ssb.no).

Table 10: Bill of quantities, cantilever phase, concrete variant

Element	Amount	Unit	Price per amount [NOK/m^3 or kg]	Price [NOK]
Reinforcement B500C (180kg/m3): - Longitudinal reinforcement (both sides) - Stirrups (both sides)	42 157,5*2 106 180,7*2	kg kg		
TOTAL			78,0	23 140 759,23
Span reinforcement: - Prestressing steel (both sides)	1 236,76*2	kg	6 703,32	16 580 804,76
Concrete B65 SV-40 - Concrete structure (both sides)	4810*2	m^3	1 750,0	16 835 000,00

Calculation model – segment phase

Analysis will be performed on longitudinal beam, as showed in a figure. Model created in SOFIPLUS-X module.
Structure undergoes constant height of cross section, starting from abutment until the pier of 3,5m. Cross sections of a model are shown in graphics below. Automatic reinforcement has been installed of #28 diameter rebars of B500C, distance 150mm.

Prestressing system shown in Tendon function of SOFIPLUS-X, in the drawings below.:

- system of 1 post-tensioned tendon per side is used, prestressing from right abutment side, jacking procedure – tension+slip.

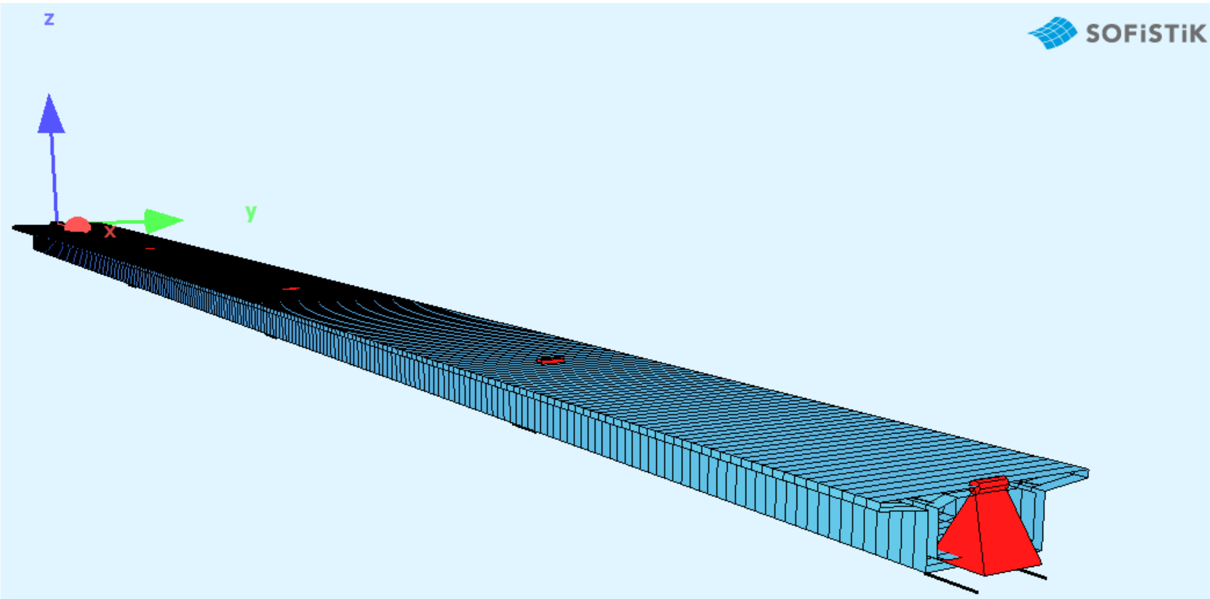


Figure 26: Segment phase calculation model, concrete variant

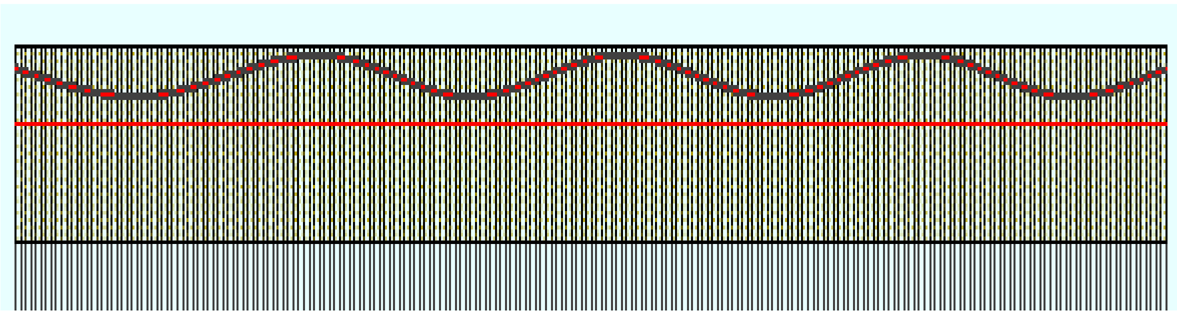


Figure 27: Tendon geometry of segment section, concrete variant

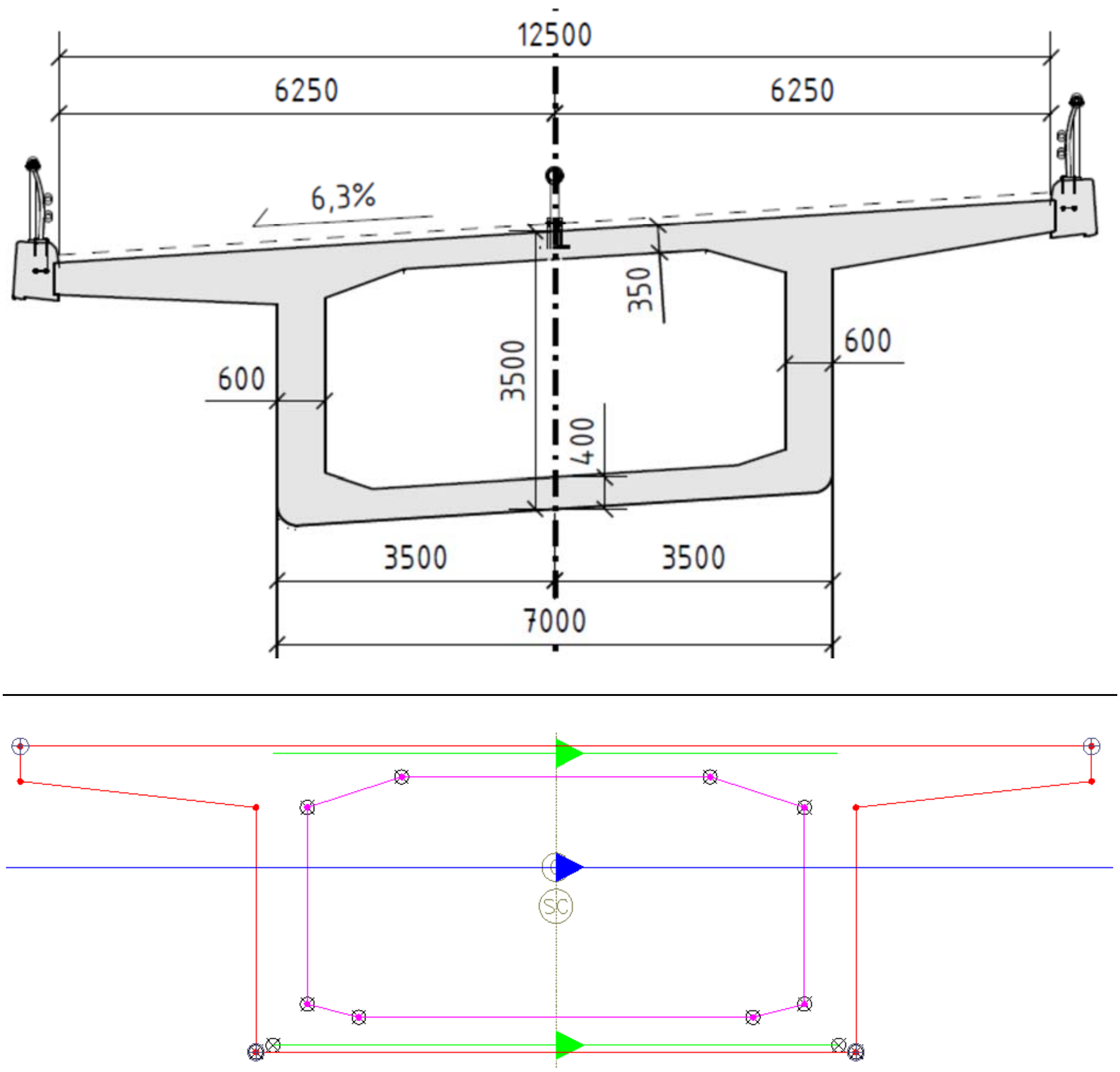


Figure 28: Cross sections of abutment and superstructure section, designed and programmed, segment phase, concrete variant

Red lines – contour of cross section, purple lines – contour of opening, green lines – line reinforcement, blue line – shear cut line.

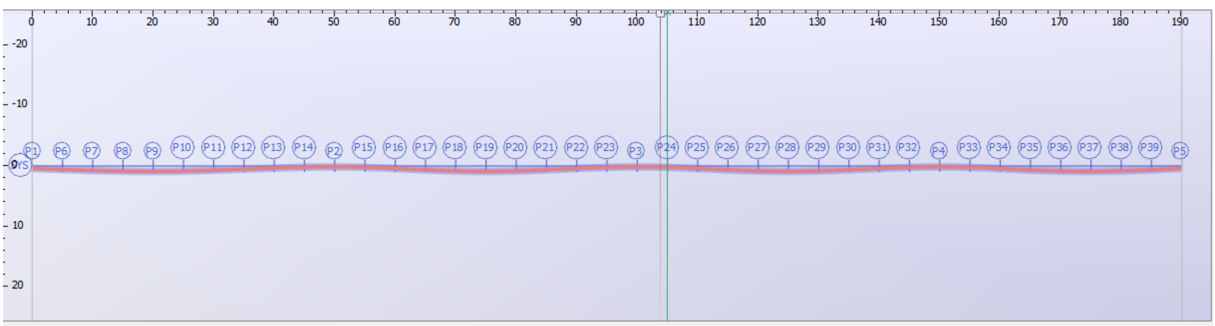


Figure 29: Tendon system of segment phase, concrete variant

Results of analysis

1) Prestressing forces, prestressing force of 1640 kN:

   - FEM analysis, Mises Stresses [MPa]

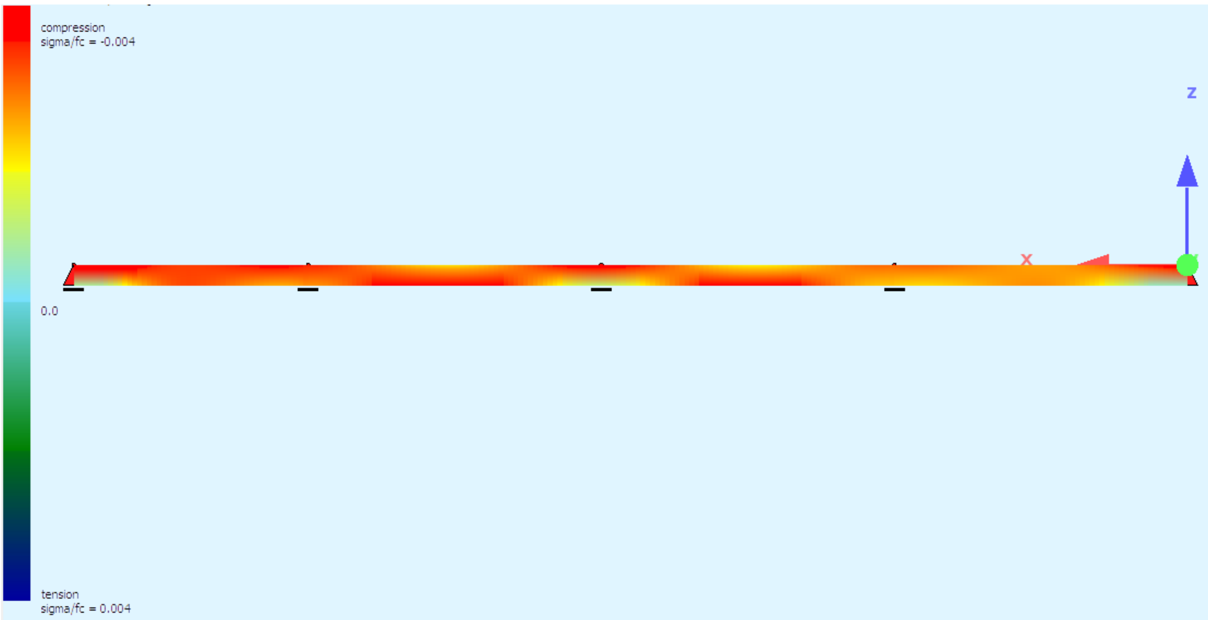


Figure 30: FEM analysis, Mises stresses from prestressing forces, segment phase, concrete variant

   - Prestressing forces figure N_{pd}[kN]

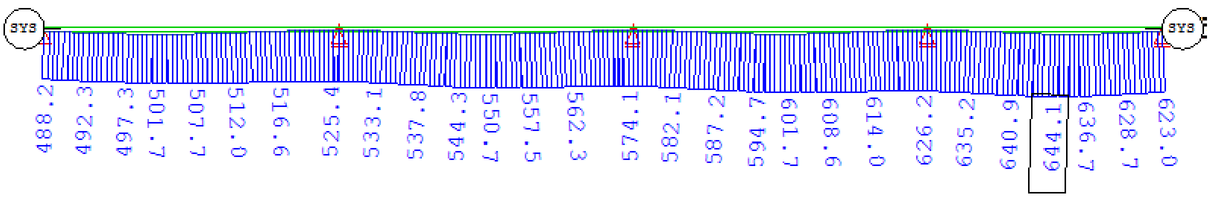


Figure 31: Prestressing forces, segment phase, concrete variant

2) Creep after opening, duration 30000days, humidity 70%, temperature 20º:

- FEM analysis, Mises stresses [MPa]

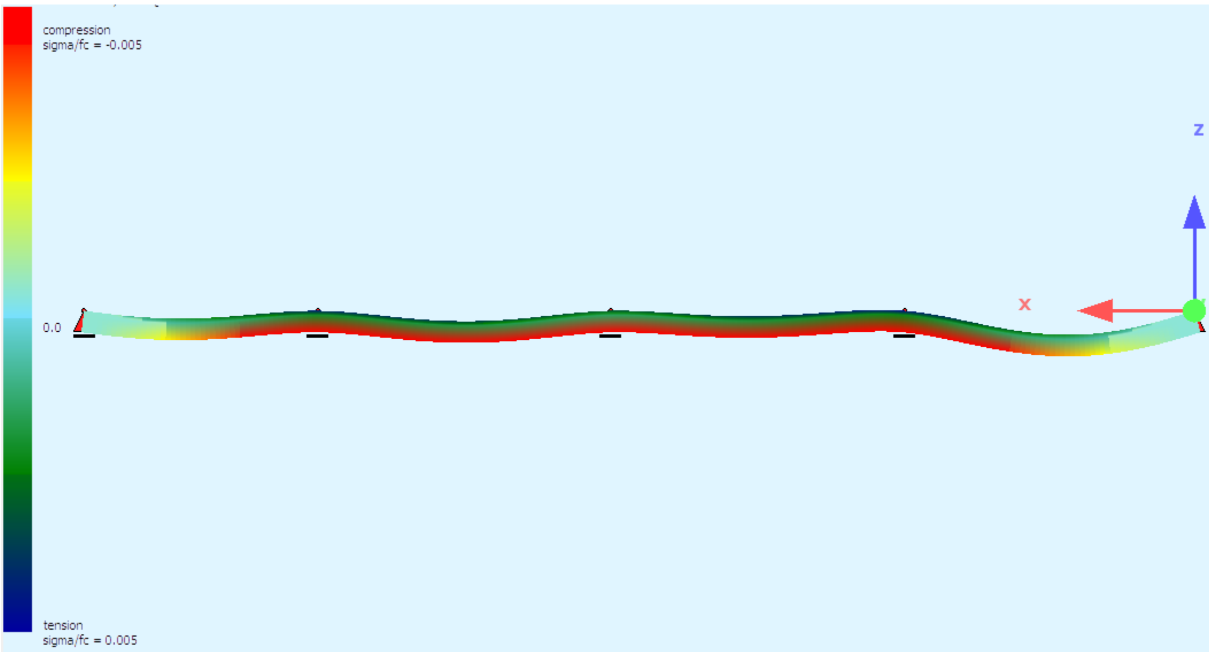


Figure 32: FEM analysis, creep after opening, segment phase, concrete variant

- Maximum bending moment M_{sd}, [kNm]

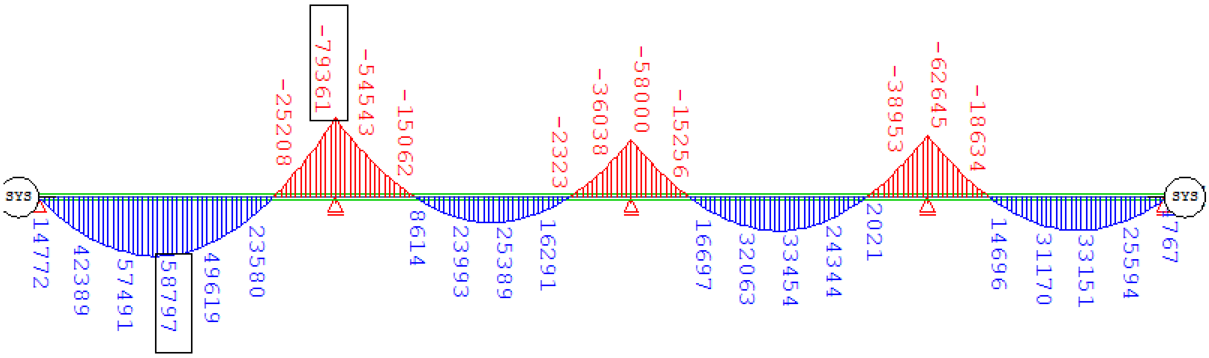


Figure 33: Maximum bending moments, segment phase, concrete variant

3) Envelope for Tandem System, Load Model 1:

- Maximum, minimum bending moment M_{sd}, [kNm]

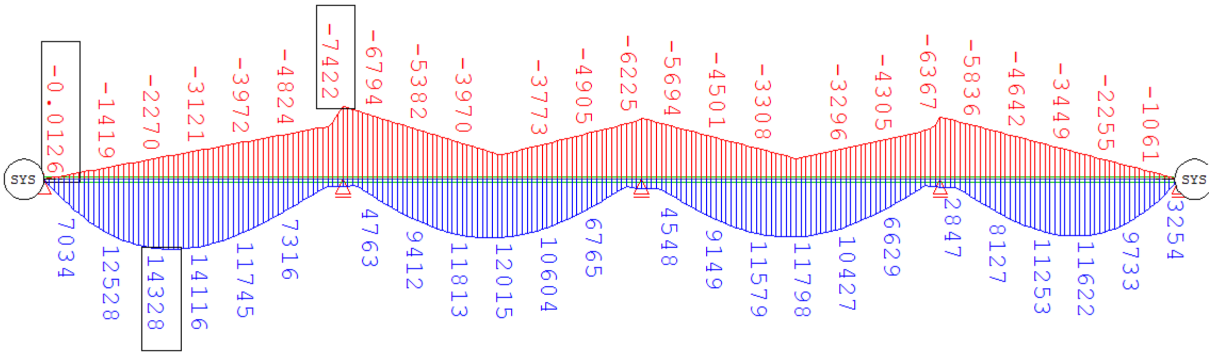


Figure 34: Bending moments envelope for Tandem System, segment phase, concrete variant

4) Envelope for Uniformly Distributed Load, Load Model 1:

- Maximum, minimum bending moment M_{sd}, [kNm]

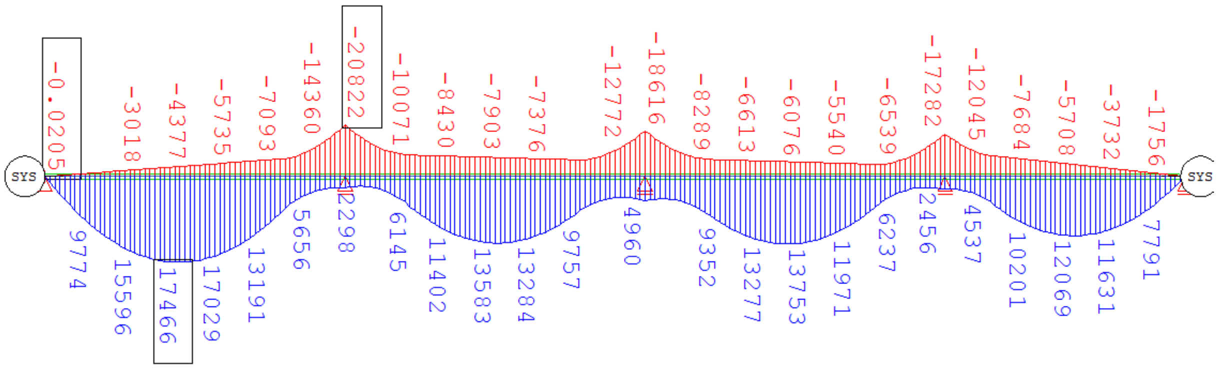


Figure 35: Bending moments envelope for UDL, segment phase, concrete variant

5) Superposition of loadcases:

- Maximum, minimum bending moment M_{sd}, [kNm]
  - ULS design for maximum compression stresses

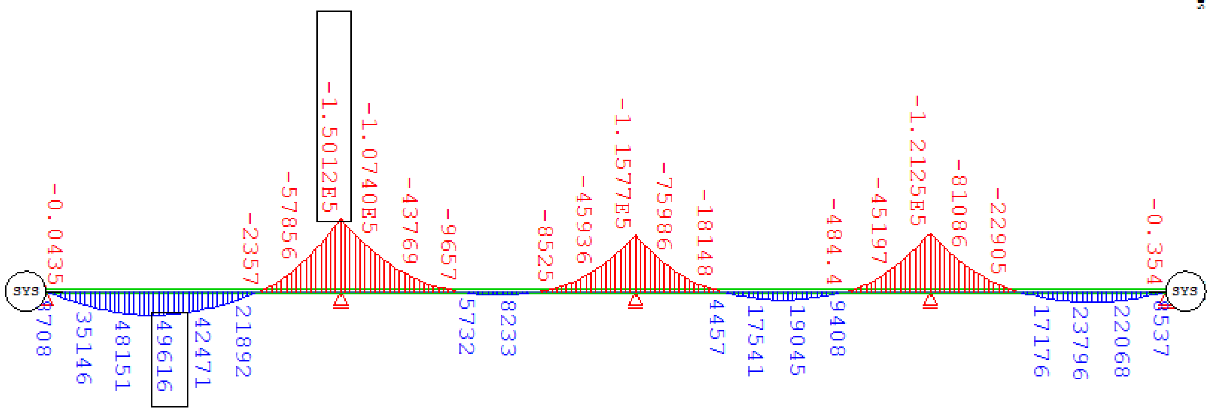


Figure 36: Bending moments for maximum compression stresses, segment phase, concrete variant

- ULS design for maximum tension stresses

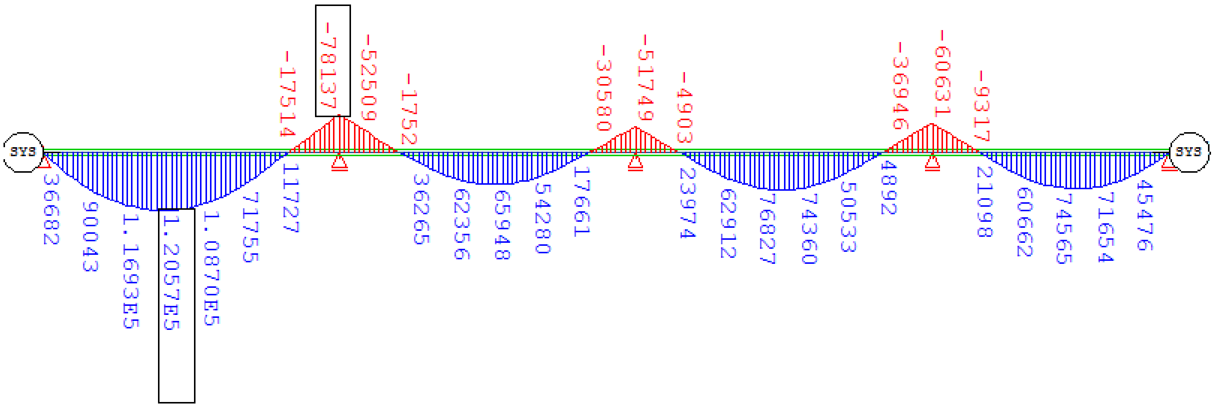


Figure 37: Bending moments for maximum tension stresses, segment phase, concrete variant

- Uniaxial force N_{sd}, [kN]
  - ULS design for maximum compression stresses

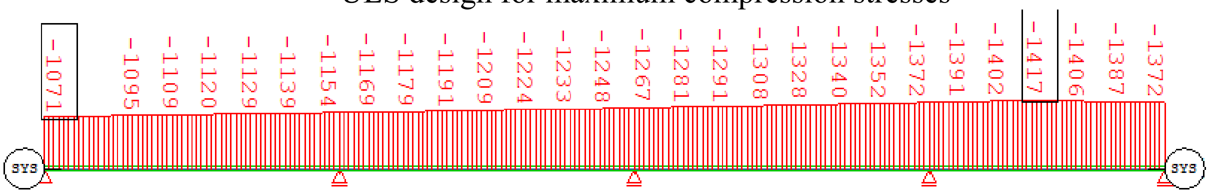


Figure 38: Maximum compression forces for compression stresses, segment phase, concrete variant

Serviceability Limit State – Stress check at cross sections

Stress check performed under the same assumptions as for cantilever phase.

- Cross section at support:

Table 11: Support cross section calculation data, segment phase, concrete variant

Property	Value, unit
N_{sd}	-1371,6 kN
A_c	12,05 m^2
e_0	0
M_{sd}	-150124,55 kNm
I_c	20,725 m^4
N_{pd}	525,4 kN
z_{cp}	1,233 m
Y coordinate:	
- Upper layer	-1,384 m
- Lower layer	2,116 m

Upper layer, equations (6), (7) and (8):

$$\sigma_{cs} = \frac{N_{sd}}{A_c} + \frac{(N_{sd} * e_0 + M_{sd})}{I_c} * y$$
$$= \frac{-1371{,}6kN}{12{,}05m^2} + \frac{(-1371{,}6kN * 0 - 150124{,}55kNm)}{20{,}725m^4} * -1{,}384m$$
$$= -113{,}826kPa + 10025{,}205kPa = 9911{,}379\ kPa = 9{,}911\ MPa$$

$$\sigma_{cp} = \frac{N_{pd}}{A_c} + \frac{N_{pd} * z_{cp} * y}{I_c} = \frac{525{,}4kN}{12{,}05m^2} + \frac{525{,}4kN * 1{,}233m * -1{,}384m}{20{,}725m^4}$$
$$= 43{,}602\ kPa - 43{,}261\ kPa = 0{,}341\ kPa = 0{,}0003MPa$$

$$\sigma_C = \sigma_{cs} + \sigma_{cp} = 9{,}911\ MPa + 0{,}0003MPa = \mathbf{9{,}912\ MPa}$$

$\sigma_C \leq 0{,}6 * f_{ck} = 0{,}6 * 55MPa = 33MPa$ – accelerated construction degradation avoided.

$\sigma_C \leq 0{,}45 * f_{ck} = 0{,}6 * 55MPa = 24{,}75MPa$ – linear creep assumed.

All conditions met.

Lower layer, equations (6), (7) and (8):

$$\sigma_{cs} = \frac{N_{sd}}{A_c} + \frac{(N_{sd} * e_0 + M_{sd})}{I_c} * y$$
$$= \frac{-1371{,}6kN}{12{,}05m^2} + \frac{(-1371{,}6kN * 0 - 150124{,}55kNm)}{20{,}725m^4} * 2{,}116m$$
$$= -113{,}826kPa - 15327{,}6kPa = -15441{,}38\ kPa = -15{,}441\ MPa$$

$$\sigma_{cp} = \frac{N_{pd}}{A_c} + \frac{N_{pd} * z_{cp} * y}{I_c} = \frac{525{,}4kN}{12{,}05m^2} + \frac{525{,}4kN * 1{,}233m * 2{,}116m}{20{,}725m^4}$$
$$= 43{,}602\ kPa + 66{,}142\ kPa = 109{,}743\ kPa = 0{,}109MPa$$

$$\sigma_C = \sigma_{cs} + \sigma_{cp} = -15{,}441MPa + 0{,}109MPa = \mathbf{-15{,}332\ MPa}$$

$\sigma_C \leq 0{,}6 * f_{ck} = 0{,}6 * 55MPa = 33MPa$ – accelerated construction degradation avoided.

$\sigma_C \leq 0{,}45 * f_{ck} = 0{,}6 * 55MPa = 24{,}75MPa$ – linear creep assumed.

All conditions met.

- Cross section at mid-span:

Table 12: Mid-span cross section calculation data, segment phase, concrete variant

Property	Value, unit
N_{sd}	-1417,1 kN
A_c	12,05 m^2
e_0	0
M_{sd}	114035,69 kNm
I_c	20,725 m^4
N_{pd}	504,7 kN
z_{cp}	0,483 m
Y coordinate:	
- Upper layer	-1,384 m
- Lower layer	2,116 m

Upper layer, equations (6), (7) and (8):

$$\sigma_{cs} = \frac{N_{sd}}{A_c} + \frac{(N_{sd} * e_0 + M_{sd})}{I_c} * y$$
$$= \frac{-1417{,}1kN}{12{,}05m^2} + \frac{(-1417{,}1kN * 0 + 114035{,}69kNm)}{20{,}725m^4} * -1{,}384m$$
$$= -117{,}602kPa - 7615{,}22kPa = -7732{,}82kPa = -7{,}733\ MPa$$

$$\sigma_{cp} = \frac{N_{pd}}{A_c} + \frac{N_{pd} * z_{cp} * y}{I_c} = \frac{504{,}7kN}{12{,}05m^2} + \frac{504{,}7kN * 0{,}483m * -1{,}384m}{20{,}725m^4}$$
$$= 41{,}884\ kPa - 16{,}279\ kPa = 25{,}605\ kPa = 0{,}026\ MPa$$

$$\sigma_C = \sigma_{cs} + \sigma_{cp} = -7{,}733\ MPa + 0{,}026\ MPa = \mathbf{-7{,}707\ MPa}$$

$\sigma_C \leq 0{,}6 * f_{ck} = 0{,}6 * 55MPa = 33MPa$ – accelerated construction degradation avoided.

$\sigma_C > 0{,}45 * f_{ck} = 0{,}6 * 55MPa = 24{,}75MPa$ – nonlinear creep assumed.

Lower layer, equations (6), (7) and (8):

$$\sigma_{cs} = \frac{N_{sd}}{A_c} + \frac{(N_{sd} * e_0 + M_{sd})}{I_c} * y$$
$$= \frac{-1417{,}1kN}{12{,}05m^2} + \frac{(-1417{,}1kN * 0 + 114035{,}69kNm)}{20{,}725m^4} * 2{,}116m$$
$$= -117{,}602kPa + 11642{,}92kPa = 11525{,}32\ kPa = 11{,}525\ MPa$$

$$\sigma_{cp} = \frac{N_{pd}}{A_c} + \frac{N_{pd} * z_{cp} * y}{I_c} = \frac{504{,}7kN}{12{,}05m^2} + \frac{504{,}7kN * 0{,}483m * 2{,}116m}{20{,}725m^4}$$
$$= 41{,}884\ kPa + 24{,}889\ kPa = 66{,}772\ kPa = 0{,}067\ MPa$$

$$\sigma_C = \sigma_{cs} + \sigma_{cp} = 11{,}525\ MPa + 0{,}067\ MPa = \mathbf{11{,}592\ MPa}$$

$\sigma_C \leq 0,6 * f_{ck} = 0,6 * 55MPa = 33MPa$ – accelerated construction degradation avoided.

$\sigma_C \leq 0,45 * f_{ck} = 0,6 * 55MPa = 24,75MPa$ – linear creep assumed.

All conditions met.

In the given cross sections we can also calculate the correlation of stresses in concrete with relation to compressive strength and therefore derive the carrying capacity of section. Values for given cross sections are:

- At support:

$$\frac{\sigma_C}{0,6 * f_{ck}} = \frac{15,332MPa}{33MPa} = 0,46 = 46\%$$

- At mid-span:

$$\frac{\sigma_C}{0,6 * f_{ck}} = \frac{11,592MPa}{33MPa} = 0,35 = 35\%$$

Tendon and reinforcement optimization

Optimization will be performed similar as cantilever section, in 3 steps, until we reach 90% of construction carrying capacity. Whole process will be also presented in SOFiSTiK AG program results.

Previous values of tendons and reinforcement used in step 0:

- Nr of tendons = 2
- Areas of longitudinal reinforcement #28 [cm^2], default distance of 150mm:

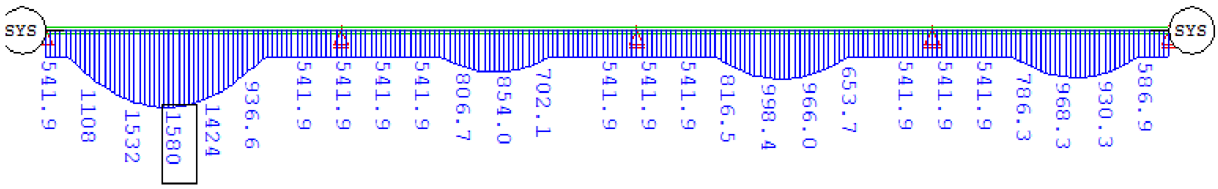


Figure 39: Longitudinal reinforcement for segment phase, concrete variant

Table 13: Optimization process for segment phase, concrete variant

Assumptions for the optimization process:

- Performed with regard to main stresses, both for compression and tensile forces
- Optimization until 90% of carrying capacity
- Optimization will be performed as for the stress check in previous section, which will prove valid to sections' stresses

Nr of optimization step	Adjustment	Results of optimization							
		M_{sd}, [kNm]		N_{sd}, [kN]		σ_c, [MPa]		$\eta = \frac{\sigma_c}{0,6 * f_{ck}}$, [%]	
		Support	Midspan	Support	Midspan	Support	Midspan	Support	Midspan
1st	-upper and lower reinforcement of #25/150	-148240,00	121128,72	-1242,5	-1287,8	15,169	12,327	45,97	37,35
2nd	-upper reinforcement of #12/200 -lower reinforcement of #32/100	-164040,66	116446,09	-1242,5	-1287,8	16,782	11,849	50,85	35,91
3rd	-upper reinforcement of #12/300	-164345,92	116355,62	-1242,5	-1287,8	16,813	11,840	50,95	35,88

As before, process has mostly affected the support cross section, rather less the midspan one. There is also boundary condition for upper reinforcement and due to minimum reinforcement area it will remain for the given last diameter.

Bill of quantities – segment phase

Based on the optimization results of 3rd step we can now transfer the results to bill of quantities. As these measures influence mostly on superstructure cost estimate, we will take into account:

- Amount of concrete

Interpolated through SOFIPLUS-X module = **2289,5 m³** of 190m section.

- Amounts of reinforcement, both active, passive and prestressing system

Amounts derived through designed longitudinal reinforcement profile:

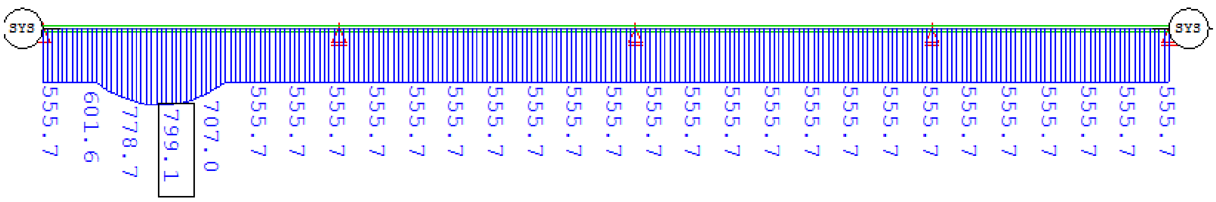


Figure 40: Longitudinal reinforcement after 3rd optimization step, segment phase, concrete variant

Stirrup reinforcing:

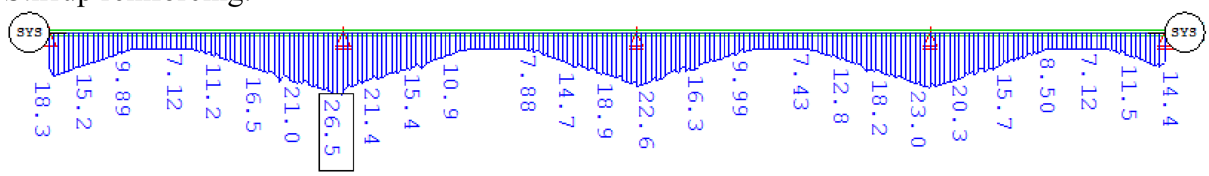


Figure 41: Stirrup reinforcement after 3rd optimization step, segment phase, concrete variant

In defined cross section for 3rd optimization, we acquire amounts of reinforcement per line reinforcement:

- Upper reinforcement - #12/300, perpendicular length= 6,6 m

$$nr\ of\ elements = \frac{6600mm}{300mm} = 22elements$$

- Lower reinforcement - #32/100, perpendicular length= 6,6 m

$$nr\ of\ elements = \frac{6600mm}{100mm} = 66elements$$

Reinforcement ratio of upper/bottom layer is 1:3.

Table 14: Longitudinal reinforcement amounts, segment phase, concrete variant

Element	Diameter [mm]	Length of section [m]	Nr of elements [-]	Weight per meter [kg/m]	Weight [kg]
Lower reinforcement	32	190	66	6,018	75 465,72
Upper reinforcement	12	190	22	0,738	3 084,84
				TOTAL	**78 550,56**

- Stirrup reinforcement (use of 6-cut stirrup bars, numbering of sections in figure below)

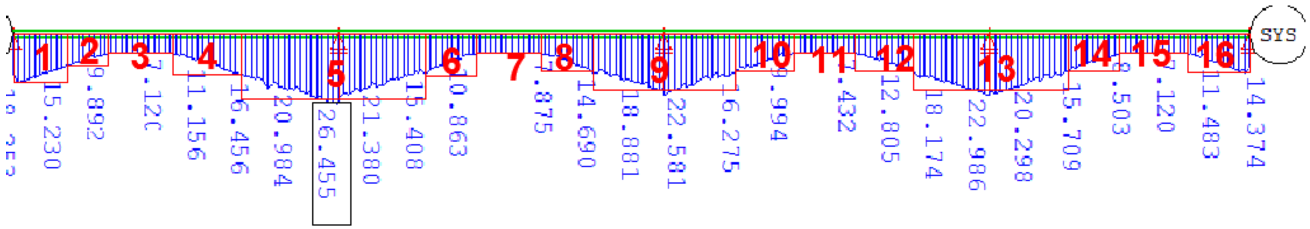


Figure 42: Division of analyzed stirrup reinforcement, segment phase, concrete variant

Table 15: Stirrup reinforcement amounts, segment phase, concrete variant

Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Diameter [mm]	25	25	16	25	32	25	16	25	28	25	16	25	28	25	16	25
Length [m]	8,36	6,18	10	10,52	28,36	7,79	10,06	7,88	21,88	9,08	9,27	9,02	23,86	7,86	10,48	9,4
Distance [m]	0,15	0,2	0,3	0,2	0,15	0,2	0,3	0,2	0,15	0,2	0,3	0,2	0,15	0,2	0,3	0,15
Amount [-]	56	31	33	53	189	39	34	39	146	45	31	45	159	39	35	63
Mean perimeter [m]	63,5	63,5	63,5	63,5	63,5	63,5	63,5	63,5	63,5	63,5	63,5	63,5	63,5	63,5	63,5	63,5
Total perimeter [m]	3539,067	1962,150	2116,667	3340,100	12005,733	2473,325	2129,367	2501,900	9262,533	2882,900	1962,150	2863,850	10100,733	2495,550	2218,267	3979,333
Weight [kg/m]	3,853	3,853	1,578	3,853	6,018	3,853	1,578	3,853	4,834	3,853	1,578	3,853	4,834	3,853	1,578	3,853
Total weight [kg]	13636,024	7560,164	3340,100	12869,405	72250,503	9529,721	3360,141	9639,821	44775,086	11107,814	3096,273	11034,414	48826,945	9615,354	3500,425	15332,371

Total weight of stirrup reinforcement = **279 474,561 kg**.

- Prestressing steel

Prestressing system of Y 1960 (EN 1992):

- Length of single tendon = 190 m
- Area of single tendon = 450 mm2
- Volume of single tendon = 0,0855 m3
- Density = 7850kg/m3
- Weight of single tendon = 671,175 kg
- TOTAL weight of 2 tendon system = **1342,35 kg**

Table below presents the final bill of quantities of cantilever section, in reference to previous cost estimate positions.
Prices taken from Statistisk Sentralbyrå (ssb.no).

Table 16: Bill of quantities, segment phase, concrete variant

Element	Amount	Unit	Price per amount [NOK/m^3 or kg]	Price [NOK]
Reinforcement B500C (180kg/m3): - Longitudinal reinforcement (both sides) - Stirrups (both sides) TOTAL	78 550,56 279 474,56	kg kg	78,0	27 925 959,36
Span reinforcement: - Prestressing steel (both sides)	1 342,35	kg	6 703,32	8 998 201,61
Concrete B65 SV-40 - Concrete structure (all segments)	2289,5	m^3	1 750,0	4 006 625,00

Final bill of quantities

From summing bills of quantities of cantilever and segment phase we can assemble whole cost estimate section of bridge superstructure. The values will then be compared with relation to the ones from Appendix A, attached in the end section of document.

Table 17: Final bill of quantities, concrete variant

Element	Price [NOK]
Reinforcement B500C (180kg/m3): - Cantilever section - Segment phase	 23 140 759,23 27 925 959,36
TOTAL	**51 066 718,59**
Span reinforcement – prestressing steel: - Cantilever phase - Segment phase	 16 580 804,76 8 998 201,61
TOTAL	**25 579 006,37**
Concrete B65 SV-40 - Cantilever phase - Segment phase	 16 835 000,00 4 006 625,00
TOTAL	**20 841 625,00**

Table 18: Comparison of values with regard to cost estimate from Appendix A, concrete variant

6	Bridge concrete superstructure	Values from Appendix A [1000 NOK]	Values from analysis [1000 NOK]	Difference [1000 NOK]
6.1.	Scaffolding	6 000,000	n/a	n/a
6.2.	Formworks	33 600,000	n/a	n/a
6.3.	Addition to edge beams	3 240,000	n/a	n/a
6.4.	Reinforcement B500C (180kg/m3)	32 760,000	51 066,719	18 306,719
6.5.	Span reinforcement	37 125,000	25 579,007	-11 545,993
6.6.	Concrete B65 SV-40	18 180,000	20 841,625	2 661,625
			Overall	**9 422,351**

After complete construction analysis we now have better knowledge of cost items. In this comparison it occurs that analyzed case is more costly from the proposed one in appendix. Nevertheless, it is more accurate within construction elements, which will surely reduce the overestimation risk and prove useful in final 3rd cost estimate of general cost items.

3.2. Steel-box variant

Bridge is performed as a continuous steel-box bridge cooperating with the concrete deck (upper flange) with the largest span of 125m. It is performed with a monolithic connection between the V-supports and bridge superstructure in axis 2 and 3, resting on abutments (bearings). Horizontal forces in longitudinal direction are transmitted via V-shaped pillars to the foundation (Figure nr 44).

Description of the method

Selected steel-box method is based on a longitudinal pulling of sections, prepared next to the pulling station. Before pulling, the upper horizontal section of support is being constructed out of 6 steel sections, welded after put in place (see figure 43). Sections are lifted by 600t crane.

After support assembly, crane is transported to the eastern abutment. An area of 110 meters is organized, where span will be prepared, section after section, welded and pulled towards the support (so called incremental launching). To prepare a span of 134,5m (125m + 9,5m) a temporary reinforced superstructure crane will be assembled. Steel sections will be pulled 5 times for 100-110 meters.

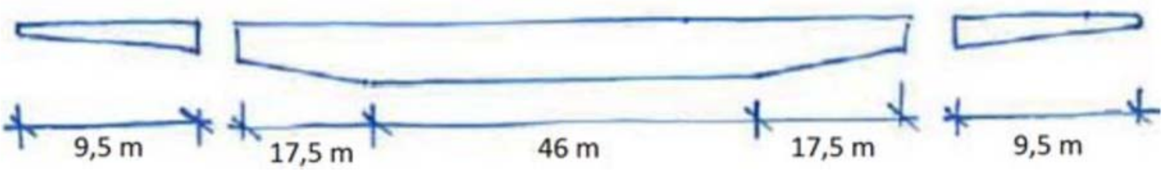


Figure 43: Horizontal support section overview

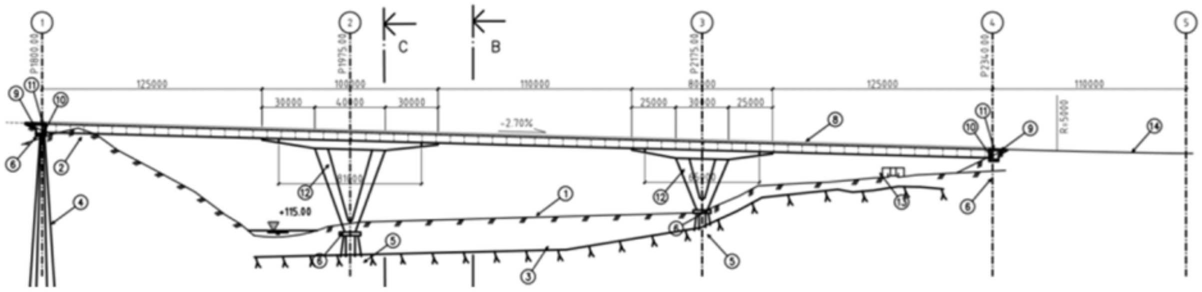


Figure 44: Longitudinal view of steel-box bridge construction

Materials used:

- Steel: for the superstructure steel type S355NL, S460NL, specification in NS-EN 10025-1:2004, NS-EN 1993-2:2006+NA:2009; for the medium pillars reinforcement B500NC
- Concrete: for the pavement and supports concrete class B45 SV-40, specification in NS-EN 1992-1-1:2004, technical class C described in NS-EN 3576:2005.

Table 19: Steel-box variant description

Geometry/function	Description
Recorded width	12,5 m (1,5+3,5+0,75+1,0+0,75+3,5+1,5)
Height	up to ca. 55 m
Length and span	L = 540 m (125+30+40+30+110+25+30+25+125)
Horizontal curvature	R = 1050 m
Vertical curvature	2,7%
Crossfall	6,3%
Bridge type	Steel-box
Height of bridge superstructure	5000 – 10000 mm
Column type	2pcs of V-shaped concrete support columns (in profile) of rectangular box section BxD = 7000x4000-7000 (variable) (thickness t=500 and 1000mm)
Foundations	Axis 1 is founded on drilled piles of diameter ϕ1200 mm. Axis 2 and 3 are founded on drilled piles of ϕ1500 into the rock. Axis 4 is founded on steel core piles of ϕ200 into the rock.

Construction analysis

The purpose of construction analysis is to assess construction resistance to self-weight, construction phases and traffic loads with given materials of both steel and concrete profiles. Results of analysis will be presented in drawings and tables for reinforcement design and optimization of only given steel profiles. Finally, table of quantities will be presented in order to optimize the cost estimate and achieve final step in 2-step estimation process.

Since construction comprises of both concrete cross-section with vast amount of steel truss elements and a steel box, analysis will be divided into 3 parts as for 3 spans of a bridge.

Composite cross-section comprises of concrete reinforced slab connected rigidly to thin-walled steel section of welded plates. Plate thickness of 10mm welded with a standard fillet weld. The inner part of cross section is also reinforced by transverse truss system of L-profiles, shown in figures (Figure 49-51).

Due to amounts of data analyzed and difficulty in modelling the whole structure, process will simplify with meshing and element division into one-element generation for both beam and truss elements. After calculating the superstructure model, steel support section will be calculated to obtain more accurate information about steel material used in superstructure generally.

Analysis is completed in SoFiSTiK Structural Desktop software, for 'Beam and Slab Bridge' settings. Calculation is performed in respect with Eurocode EC 2 1991-2 part "Road bridges". Calculation data is presented in Table nr 20. Material data is obtained from "Preliminary design – Randselva bridge – steel-box variant" documentation table nr 4.

Table 20: Calculation data, steel-box variant

Geometry	
Total length	L = 540,00 m
Span width	L = 180+180+180 m
Total width including end plates	B = 13,50 m
With between guardrail	B = 12,50 m
Width cross section top	b_{top} = 8,00 m
Width cross section bottom	b_{bottom} = 7,00 m
Road width	b_{road} = 12,5 m
Total cross section height	H = 10,00 m
Structural height	H = 5,00 m
Slenderness ratio	Λ = 25,0
Bridge deck area	$A_{1concrete}$ = 5,00 m2, $A_{1steelbox}$ = 0,2755 m2
Material and Pre-stress System	
Concrete	C 45/55
Reinforcing Steel	B 500 C
Profiles' Steel	S355NL, S460NL
Building Category	
Design longitudinal direction	Category 1
Design transverse direction	Category 2
Boundary conditions	
Exposition class	XC2
Design velocity	120 km/h
Load model	
Tandem axis for global design	Load Model 1

Calculation systems

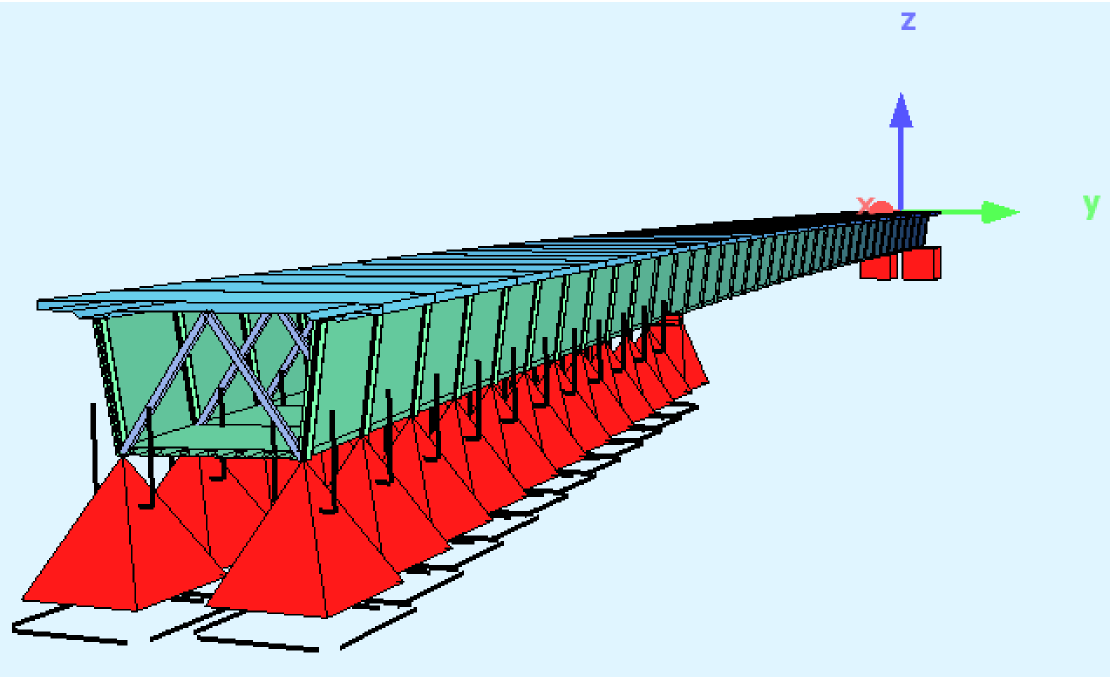


Figure 45: 1st longitudinal pull-up static system

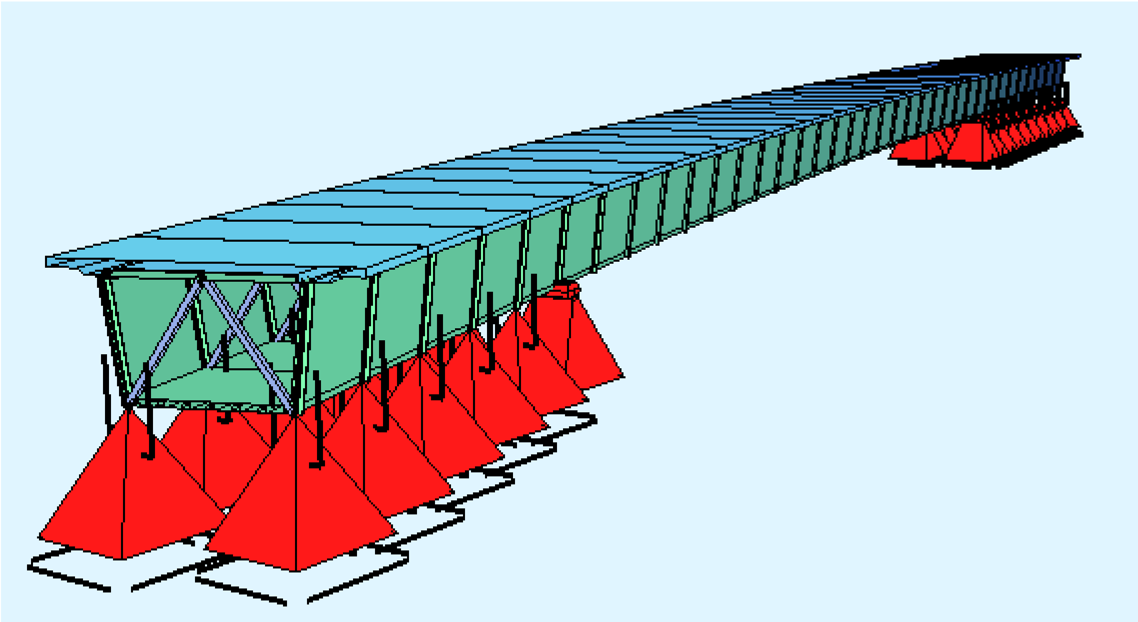


Figure 46: 2nd longitudinal pull-up static system

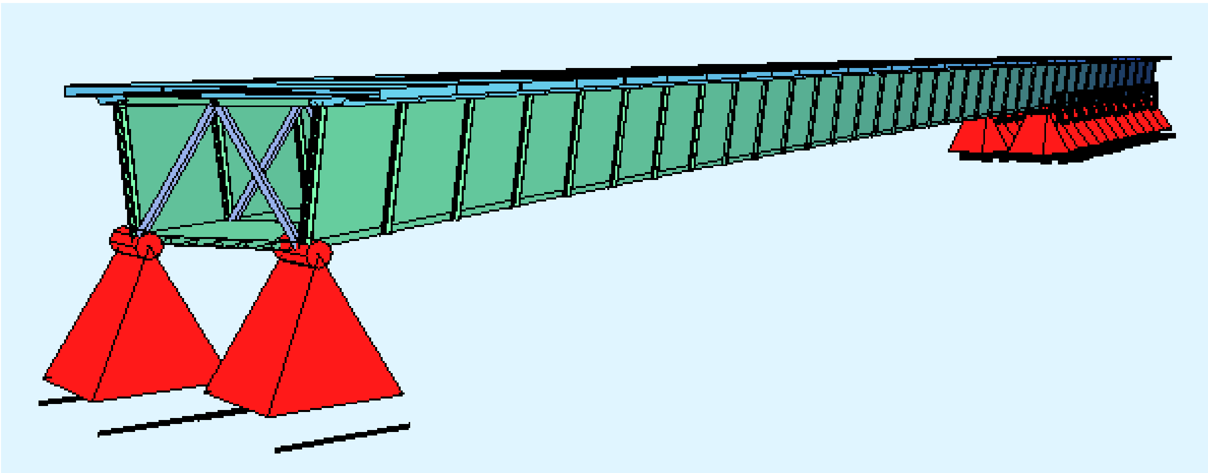


Figure 47: 3rd longitudinal pull-up static system

Assumptions regarding construction

- bridge performed in longitudinal pull-up technology, phases will be analyzed in CSM (Construction Stages Module),
- static system performed as continuous beam, meshing and results as for beam element,
- beam element consists of quadrilateral elements, truss elements of one-element generated, hinged for normal forces,
- construction analysis focused only on bridge superstructure, effects of supports and foundation not taken into account in order to simplify the results.

Table 21: Loadcases – steel-box variant

Action	Description	Partition	Superposition	γ-u	γ-f	γ-a	ψ-0	ψ-1	ψ-2	ψ-1'
B	construction stage loading	Q (Variable)	EXCL exclusive	1.00	0.00	1.00	1.00	1.00	1.00	1.00
C	creep + shrinkage	P (Prestress)	PERM always	1.00	1.00	1.00	1.00	1.00	1.00	1.00
G_1	dead load g1	G (Permanent)	PERM always	1.35	1.00	1.00	1.00	1.00	1.00	1.00
G_2	dead load g2	G (Permanent)	PERM always	1.35	1.00	1.00	1.00	1.00	1.00	1.00
L	live loading	Q (Variable)	EXCL exclusive	1.50	0.00	1.00	0.75	0.75	0.75	0.80
L_T	Traffic load TS of EC/DIN...	Q (Variable)	EXCL exclusive	1.35	0.00	1.00	0.75	0.75	0.00	0.80
L_U	Traffic load UDL of EC/DIN-FB	Q (Variable)	EXCL exclusive	1.35	0.00	1.00	0.40	0.40	0.00	0.80

Model will be analyzed in superpositioned loadcases, worst case scenario (table), i.e.:

- system after constructing whole structure
  - phases performed in CSM, construction phases from setting truss system, concreting, asphalt layers and parapet
- live loads of traffic:
  - model performed according to Eurocode EN 1991-2 Load Model 1
  - Live loads of Tandem System and Uniformly Distributed Loads

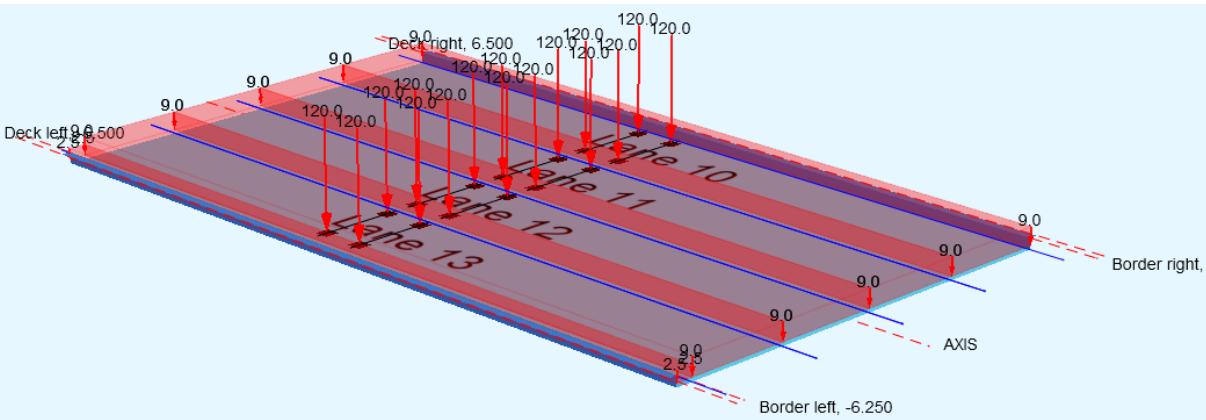


Figure 48: Load model of traffic load, steel-box variant

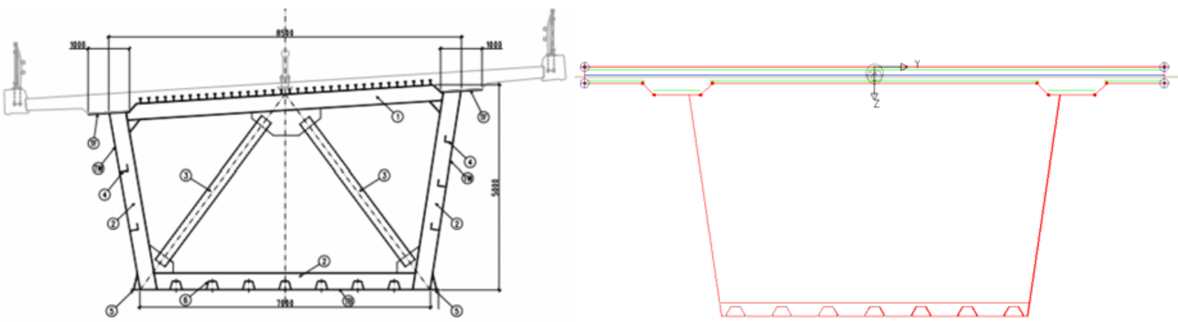


Figure 49: Cross sections of superstructure, designed and modelled

Truss member cross-sections

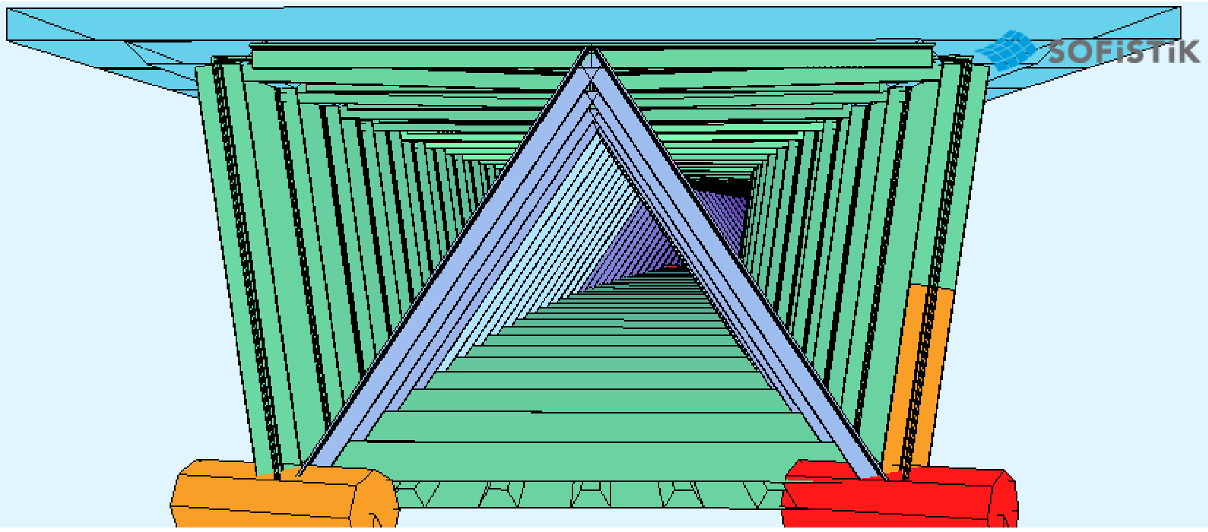


Figure 50: Truss system view, steel-box variant

Transverse system elements:

- L-profiles (250x250x35mm) for diagonal and upper elements

Table 22: L-profile data, steel-box variant

A [m2]	Ay [m2]	Az [m2]	Iy [m4]	Iz [m4]	ysc [mm]	zsc [mm]	E [N/mm2]
0,0163	0,0074	0,0074	0,000	0,000	55,3	55,3	210000

- 2*L-profiles (500x250x28mm) for vertical elements

Table 23: 2*L-profile data, steel-box variant

A [m2]	Ay [m2]	Az [m2]	Iy [m4]	Iz [m4]	ysc [mm]	zsc [mm]	E [N/mm2]
0,0265	0,0052	0,0052	0,000	0,000	-13,9	0,00	210000

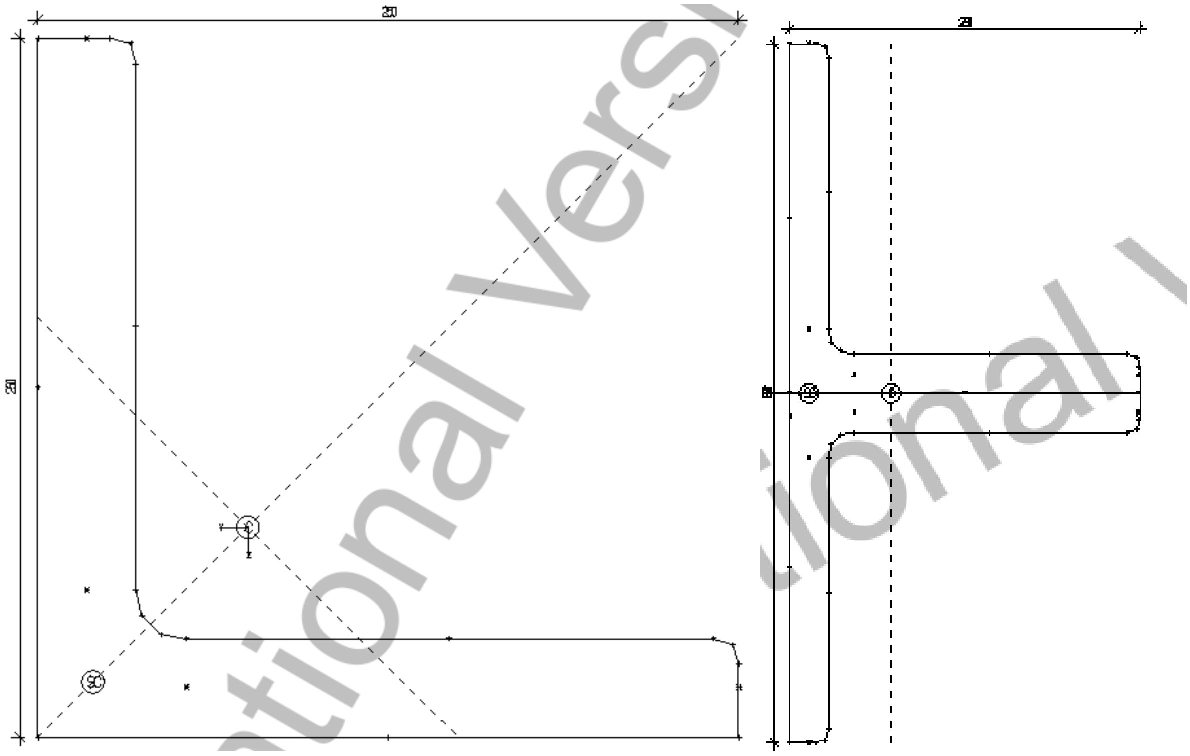


Figure 51: Profiles of truss members: from the left: diagonal elements, vertical elements

Calculation model – longitudinal pull-up

Analysis will be performed on longitudinal beam for the figures showed before (Figure 45-47). Models created in SOFIPLUS-X module.
Structure undergoes constant height of cross section, starting from abutment until the pier of 5m. Cross sections of a model are shown in graphics before with truss members (Figure 49-51). Automatic reinforcement has been installed of #32 diameter rebars of B500C, distance 80mm.

Analysis will be done simultaneously on 3 parts of longitudinal pull-up and will be divided into following sections:

- Construction stages analysis,
- Tandem System and Uniformly Distributed Load for vehicles and pedestrians after opening,
- Superposition of cases and final results,
- Optimization of truss cross-sections, if needed.

Construction Stages Analysis

Construction Stages are implemented to each part of process and are presented in table below.

Table 24: Construction stages for longitudinal pull-up, steel-box variant

Stage Number	Title	Type	Duration [d]	Humidity [%]	Temperature [°]	Creep steps
10	Selfweight	G_1 - Selfweight				
20	Selfweight	G_1 - Selfweight				
30	Selfweight	G_1 - Selfweight				
40	Selfweight	G_1 - Selfweight				
41	Creep in construction	C_1 - Creep until opening	14.0	70.00	20.00	1
42	Pavement+asphalt	G_2 - Additional Dead Load				
50	Selfweight	G_1 - Selfweight				
51	Creep in construction	C_1 - Creep until opening	14.0	70.00	20.00	1
52	Pavement+asphalt	G_2 - Additional Dead Load				
60	Selfweight	G_1 - Selfweight				
61	Creep in construction	C_1 - Creep until opening	14.0	70.00	20.00	1
62	Pavement+asphalt	G_2 - Additional Dead Load				
63	Creep until infinite	C_2 - Creep after opening	30000.0	70.00	20.00	3

First three “Selfweight” stages (10-30) show the pull-up phase of truss system, after which the concreting phase of concrete plate takes place (40). After first creep stage (41), we create additional load of concreting the parapet and laying the asphalt (42). Afterwards concreting begins again on next section, until complete creep of section.
Analysis will be performed in a table with given results of bending moments for concrete slab and thin-walled section, and axial forces for truss members and concrete reinforcement. We will focus on worst loadcases only, i.e. cantilever phase, long-span phase, concrete-on-span phase and hardening with asphalt and parapet.

Table 25: Construction stages analysis, part 1, steel-box variant

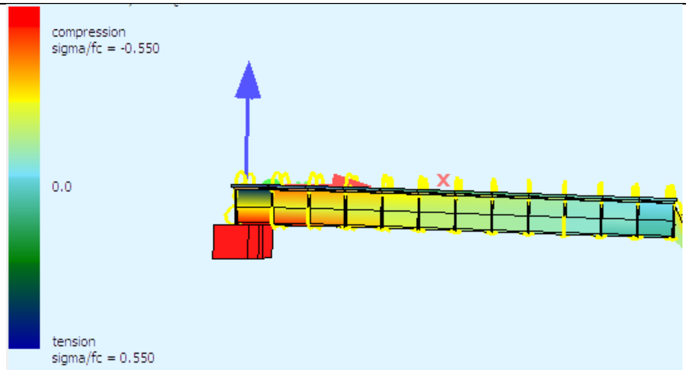
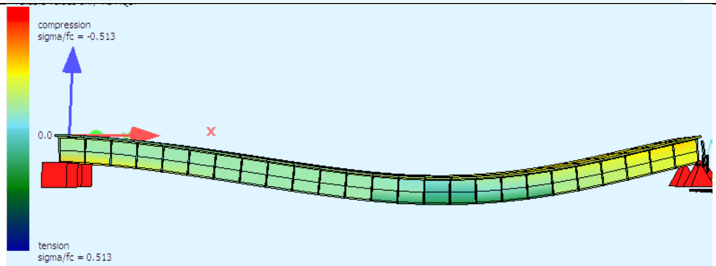
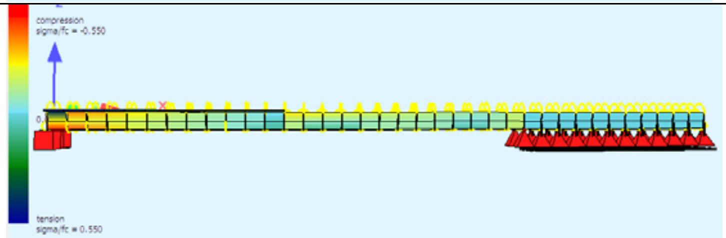
Section nr	Construction stage	Static system	Maximum bending moment [kNm]	Maximum axial force [kN]
1	Cantilever phase (10-selfweight)		52 715,00	0,1520
	Long-span phase (20-selfweight)		24 427,00	0,4110
	Concrete-on-span phase (40-selfweight)		13 050,00	1,9500

Table nr 25 continued

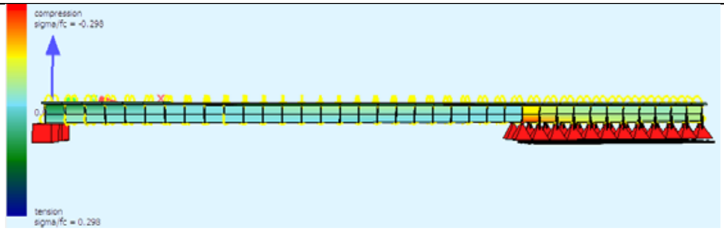
	Hardening with asphalt and parapet (63- creep until infinite)		-12 614,00	-754,6000

Table 26: Construction stages analysis, part 2, steel-box variant

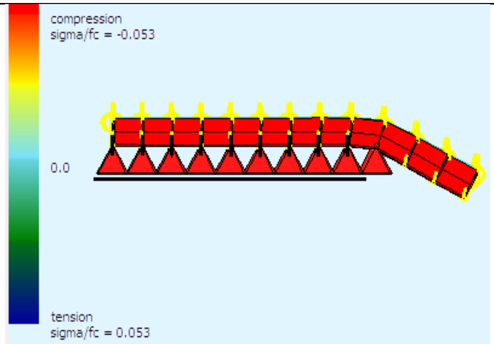
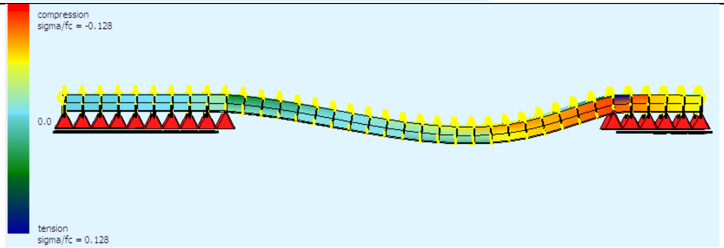
Section nr	Construction stage	Static system	Maximum bending moment [kNm]	Maximum axial force [kN]
2	Cantilever phase (10- selfweight)		64,1 (-3 251,00)	-434,3
	Long-span phase (30- selfweight)		4 065,00 (-7 840,00)	445,4

Table nr 26 continued

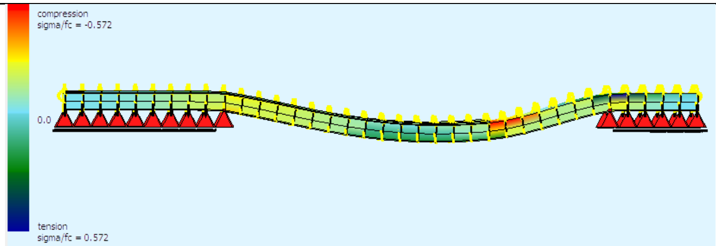
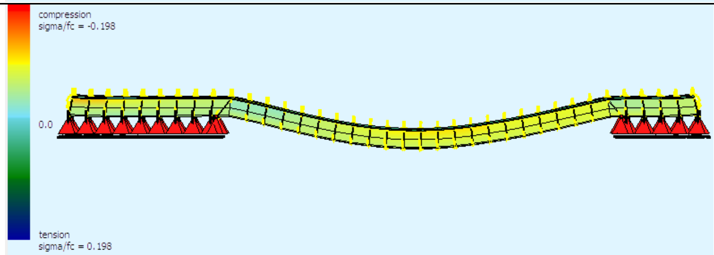
	Concrete-on-span phase (40- selfweight)		35 848,00 (-30 528,00)	1858,0
	Hardening with asphalt and parapet (63- creep until infinite)		5 633,00 (-2 556,00)	665,8

Table 27: Construction stages analysis, part 3, steel-box variant

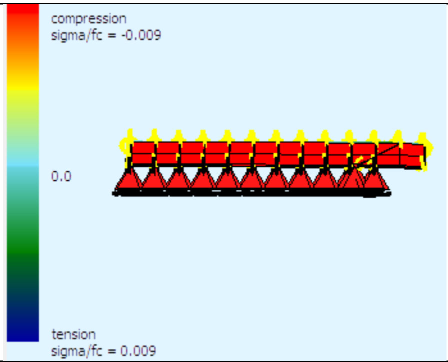
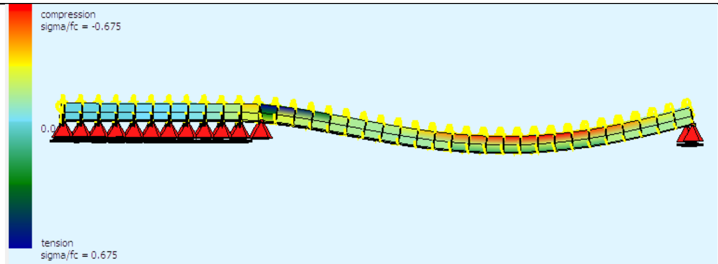
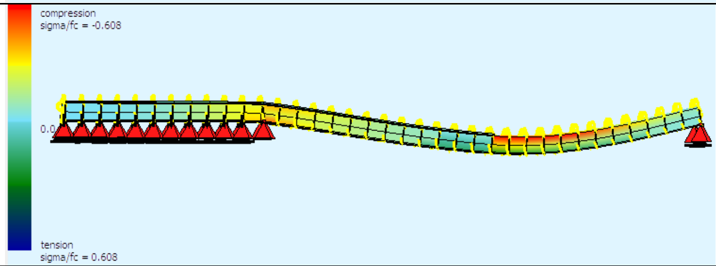
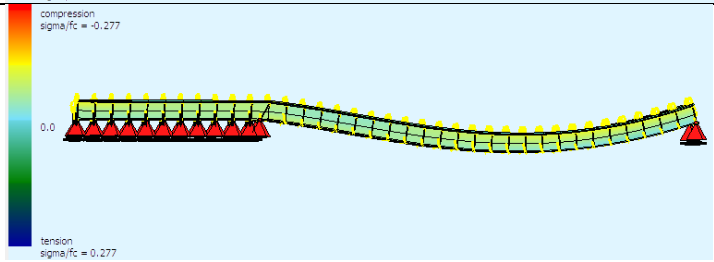
Section nr	Construction stage	Static system	Maximum bending moment [kNm]	Maximum axial force [kN]
3	Cantilever phase (10- selfweight)		64,1 (-471,3)	20,9

Table nr 27 continued

	Long-span phase (30-selfweight)		28 528,00 (-42 030,00)	2 655,0
	Concrete-on-span phase (40-selfweight)		38 388,00 (-27 986,00)	-4 996,0
	Hardening with asphalt and parapet (63- creep until infinite)		4 446,00 (-6 296,00)	419,0

Tandem System and Uniformly Distributed Load

Table 28: Result comparison of Tandem System, steel-box variant

Loadcases presented in section before (page 51, Figure 48).

Tandem System

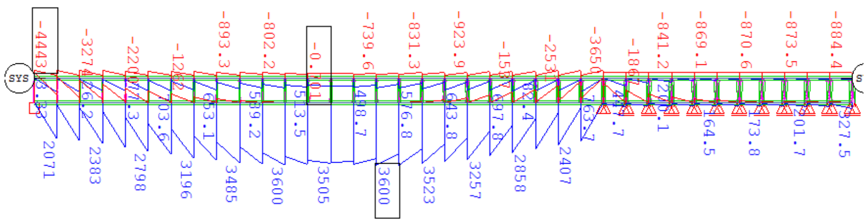
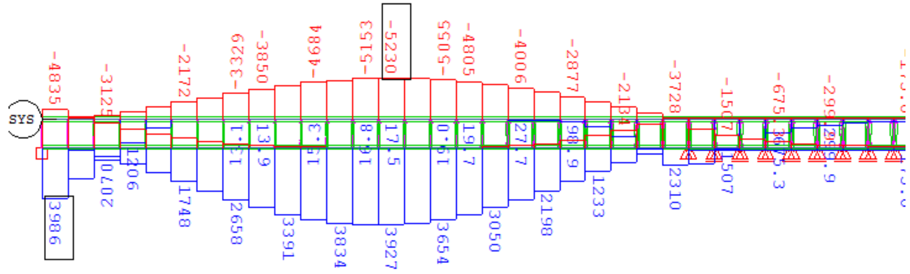
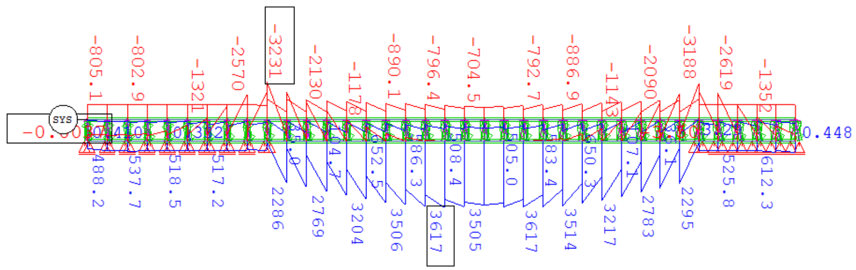
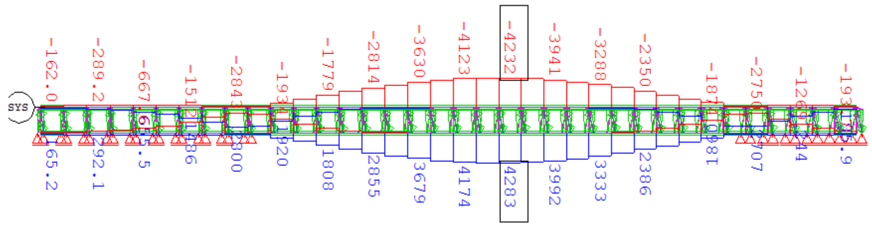
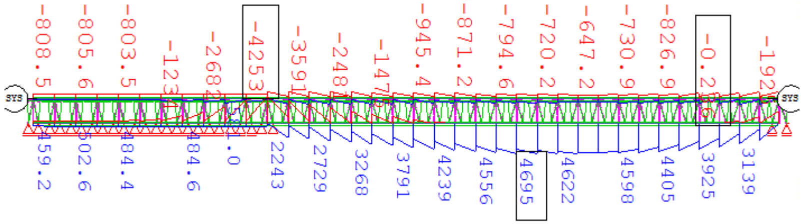
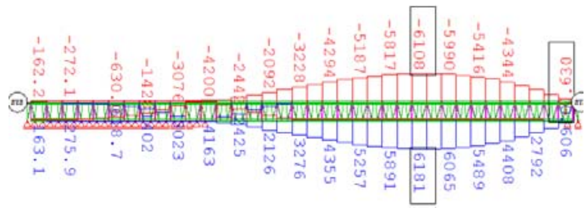
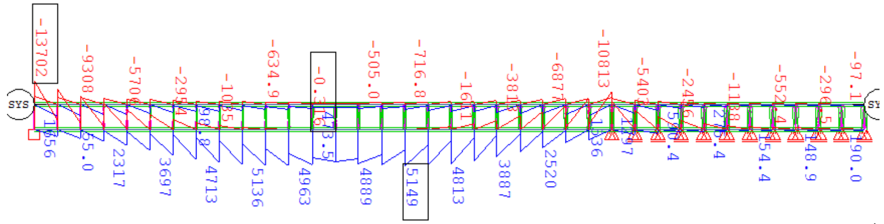
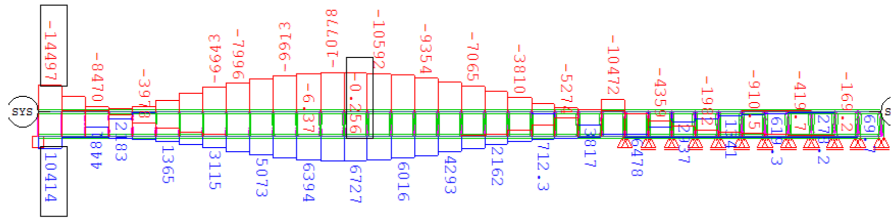
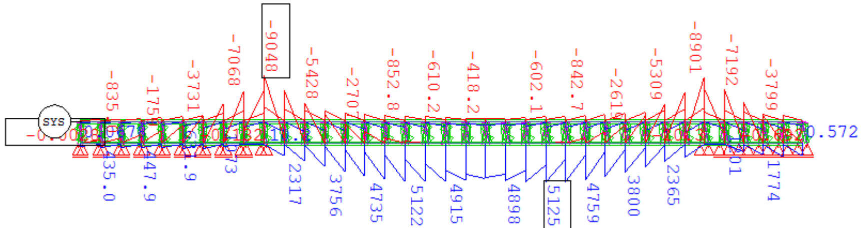
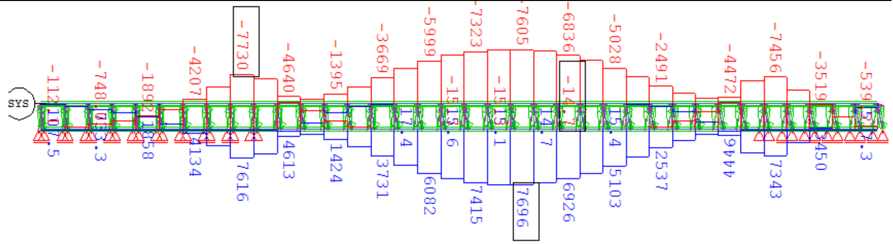
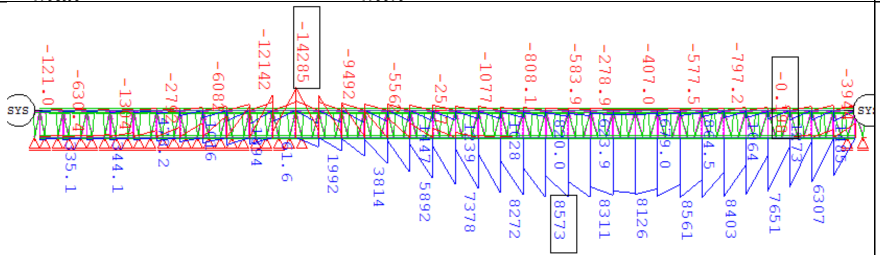
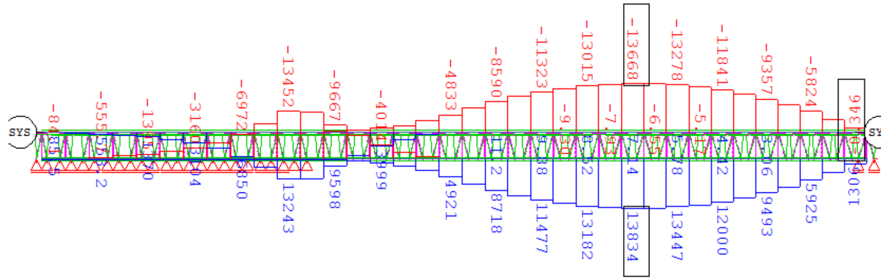
Sect nr	Bending moments envelope	Axial forces envelope
1	 $M_{max} = 3600\ kNm \quad M_{min} = -4443\ kNm$	 $N_{xmax} = 3986\ kN \quad N_{xmin} = -5230\ kN$
2	 $M_{max} = 3617\ kNm \quad M_{min} = -3231\ kNm$	 $N_{xmax} = 4283\ kN \quad N_{xmin} = -4232\ kN$
3	 $M_{max} = 4695\ kNm \quad M_{min} = -4253\ kNm$	 $N_{xmax} = 6181\ kN \quad N_{xmin} = -6100\ kN$

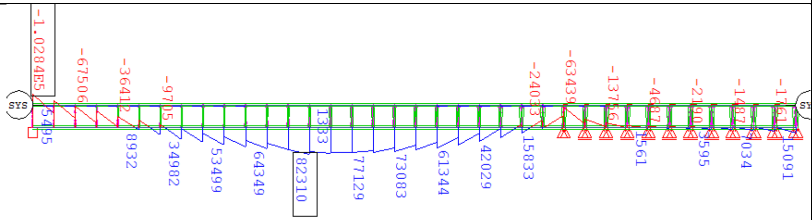
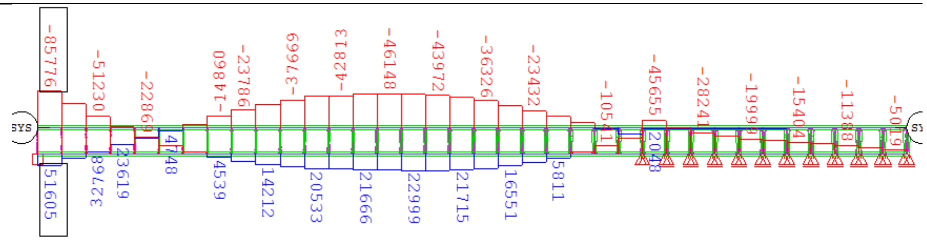
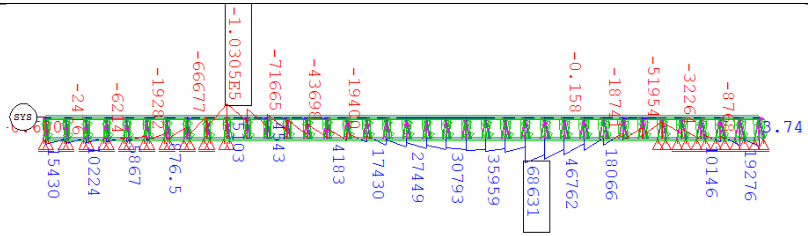
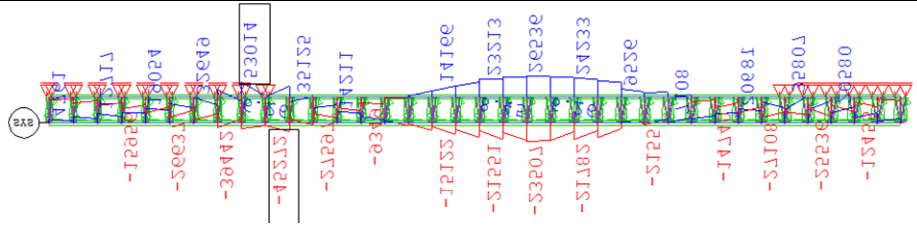
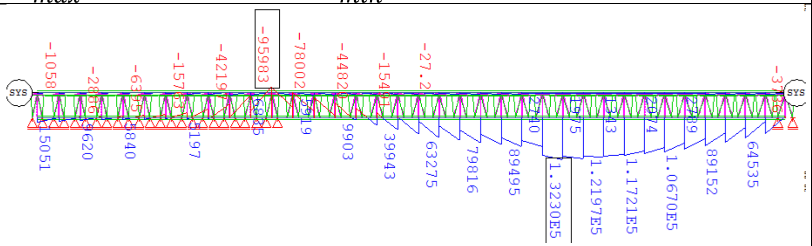
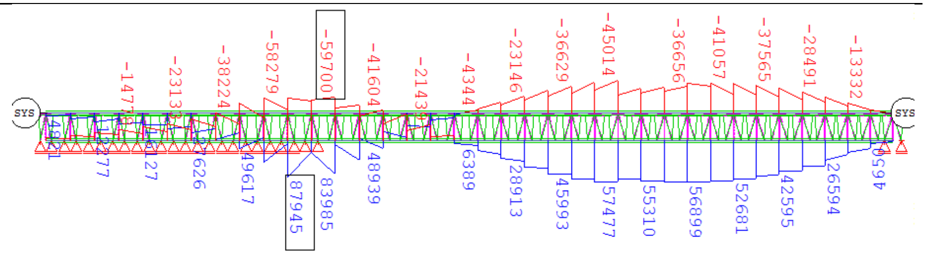
Table 29: Result comparison of Uniformly Distributed Load, steel-box variant

Uniformly Distributed Load		
Sect nr	Bending moments envelope	Axial forces envelope
1	 $M_{max} = 5149\ kNm$ $M_{min} = -13702\ kNm$	 $N_{xmax} = 10414\ kN$ $N_{xmin} = -14497\ kN$
2	 $M_{max} = 5125\ kNm$ $M_{min} = -9048\ kNm$	 $N_{xmax} = 7696\ kN$ $N_{xmin} = -7730\ kN$
3	 $M_{max} = 8573\ kNm$ $M_{min} = -14285\ kNm$	 $N_{xmax} = 6181\ kN$ $N_{xmin} = -6100\ kN$

Superposition of loadcases

Table 30: Superposition of loadcases, steel-box variant

Superposition module performed for ULS design for maximum compression and tension stresses in cross section.

Section nr	Maximum bending moments	Maximum axial forces
1	 $M_{max} = 82310\ kNm \quad M_{min} = -1{,}028 * 10^5\ kNm$	 $N_{xmax} = 51605\ kN \quad N_{xmin} = -85776\ kN$
2	 $M_{max} = 68631 kNm \quad M_{min} = -1{,}031 * 10^5\ kNm$	 $N_{xmax} = 53014\ kN \quad N_{xmin} = -45272\ kN$
3	 $M_{max} = 1{,}323 * 10^5 kNm \quad M_{min} = -95983\ kNm$	 $N_{xmax} = 87945\ kN \quad N_{xmin} = -59700\ kN$

Optimization of cross sections

Optimization of cross-sections will be performed with regard to EC requirements of designing composite cross-section. According to EC and [4], if we deal with bended cross-section consisting of two or three materials, but connected during construction stages, we can transform this heterogeneous cross-section into homogenous one, with constant elasticity module E. We can do it by substitution of given layers, thickened or widened in axial direction, in a correlation:

$$\alpha = \frac{E_i}{E_2} \tag{9}$$

Example below shows geometrical characteristics of composite cross-section, consisting of 3 materials:

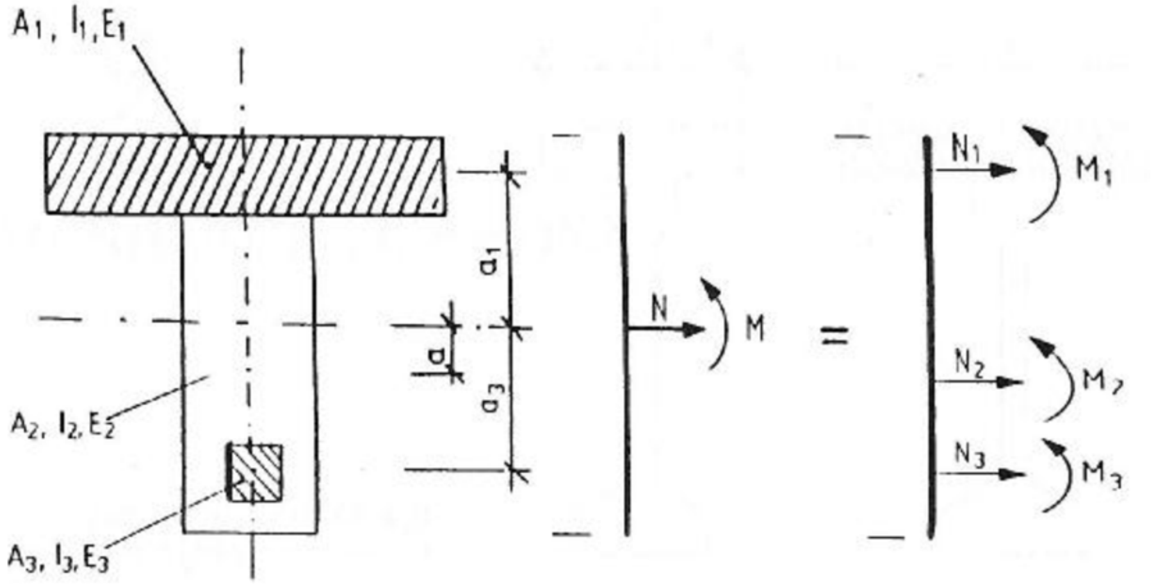


Figure 52: Composite cross-section characteristics, steel-box variant

$$A = \alpha_1 A_1 + \alpha_2 A_2 + \alpha_3 A_3 \tag{10}$$

$$a = \frac{1}{A}(\alpha_1 A_1 a_1 - \alpha_3 A_3 a_3) \tag{11}$$

$$I = \alpha_2 I_2 + \alpha_1[I_1 + A_1 a_1(a_1 - a)] + \alpha_3[I_3 + A_3 a_3(a_3 + a)] \tag{12}$$

In case of steel-box variant, we deal with two materials of concrete slab and steel thin-walled section, so $A_3=I_3=E_3=0$:

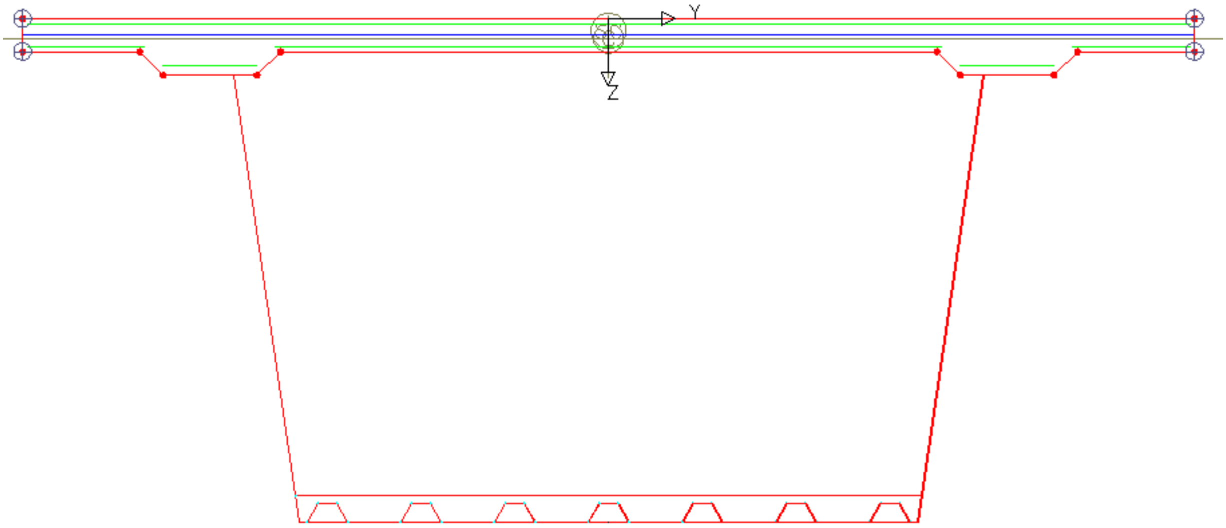


Figure 53: Calculation model of composite cross-section, steel-box variant

Table 31: Calculation elements for optimization process, steel-box variant

Element	A_1	I_1	E_1	z_c	$a_{1,2}$
	[m^2]	[m^4]	[MPa]	[m]	[m]
Concrete slab	5,000	0,094	36283,00	0,212	0,873
Thin-walled section	0,276	0,500	210000,00	0,924	3,353

Characteristics, used from (9), (10), (11) and (12):

$$\alpha_1 = \frac{E_1}{E_2} = \frac{36283MPa}{210000MPa} = \mathbf{0,173}$$

$$\alpha_2 = \frac{E_2}{E_2} = \mathbf{1,0}$$

$$A = \alpha_1 A_1 + \alpha_2 A_2 + \alpha_3 A_3 = 0{,}173 * 5m^2 + 1 * 0{,}276m^2 = \mathbf{1,141\ m^2}$$

$$a = \frac{1}{A}(\alpha_1 A_1 a_1 - \alpha_3 A_3 a_3) = \frac{1}{1{,}141m^2}(0{,}173 * 5m^2 * 0{,}873m - 0) = \mathbf{0,662\ m}$$

$$\begin{aligned} I &= \alpha_2 I_2 + \alpha_1[I_1 + A_1 a_1(a_1 - a)] + \alpha_3[I_3 + A_3 a_3(a_3 + a)] \\ &= 1 * 0{,}5m^4 + 0{,}173 * [0{,}094m^4 + 5m^2 * 0{,}873m * (0{,}873m - 0{,}662m)] \\ &+ 0 = \mathbf{0,6756m^4} \end{aligned}$$

By using force equilibrium condition in cross-section we can now derive component inner forces in each section. For given cross-section, subdued to bending moment and axial force, EC introduces following equations:

$$M_1 = \alpha_1 * I_1 * \frac{M}{I} \tag{13}$$

$$M_2 = \alpha_2 * I_2 * \frac{M}{I} \tag{14}$$

$$N_1 = \alpha_1 * A_1 * \left[\frac{N}{A} - \frac{M}{I} * (a_1 - a)\right] \tag{15}$$

$$N_2 = \alpha_2 * A_2 * \left[\frac{N}{A} + \frac{M}{I} * a\right] \tag{16}$$

In order to start optimization process, we are introducing step nr '0' with initial conditions, cross-sections and materials, in order to create starting point for further adjustments. Values are taken from "Superposition of loadcases section", the worst case scenario gives us situation in:

- section nr 3 for maximum bending moments: $M^+ = M_{max3} = 1{,}323 * 10^5 kNm$
- section nr 2 for minimum bending moments: $M^- = M_{min2} = -1{,}031 * 10^5\ kNm$
- section nr 3 for maximum axial force: $N^+ = N_{max3} = 87945\ kN$
- section nr 1 for minimum axial force: $N^- = N_{min1} = -85776\ kN$

Cross-section checked for "0 step", equations from (13), (14) and (15):

$$M_1 = \alpha_1 * I_1 * \frac{M}{I} = 0{,}173 * 0{,}094m^4 * \frac{M}{0{,}6756m^4} = 0{,}024 * M$$

$$\begin{aligned} N_1 &= \alpha_1 * A_1 * \left[\frac{N}{A} - \frac{M}{I} * (a_1 - a)\right] \\ &= 0{,}173 * 5m^2 * \left[\frac{N}{1{,}141m^2} - \frac{M}{0{,}6756m^4} * (0{,}873m - 0{,}662m)\right] \\ &= 0{,}865 * (0{,}877 * N - 0{,}313 * M) \end{aligned}$$

$$M_2 = \alpha_2 * I_2 * \frac{M}{I} = 1 * 0{,}5m^4 * \frac{M}{0{,}6756m^4} = 0{,}74 * M$$

$$\begin{aligned} N_2 &= \alpha_2 * A_2 * \left[\frac{N}{A} + \frac{M}{I} * a\right] = 1 * 0{,}276m^2 * \left[\frac{N}{1{,}141m^2} + \frac{M}{0{,}6756m^4} * 0{,}662m\right] \\ &= 0{,}276 * (0{,}877 * N + 0{,}979 * M) \end{aligned}$$

Table 32: Optimization step 0, calculation matrix, steel-box variant

Element	$M^+ = 1{,}323 * 10^5 kNm$	$N^+ = 87945\ kN$	$M^- = -1{,}031 * 10^5\ kNm$	$N^- = -85776\ kN$
M_1	$M_1^+ = 3184{,}521\ kNm$		$M_1^- = -2481{,}664\ kNm$	
N_1	$N_1^+ = 30930{,}543\ kNm$		$N_1^- = -37174{,}661\ kNm$	
M_2	$M_2^+ = 97912{,}967\ kNm$		$M_2^- = -76302{,}546\ kNm$	
N_2	$N_2^+ = 57053{,}034\ kNm$		$N_2^- = -48631{,}402\ kNm$	

Based on derived single-element inner forces, we can now check stresses in each element by standard stress equation and its correlation to compressive strength for concrete, or yield strength for steel:

$$\sigma = \frac{N}{A} + \frac{M}{I} * z \leq (f_{ck}; f_{yk}) \tag{17}$$

For concrete slab:

- compressive stresses:

$$\sigma^- = \frac{N}{A} + \frac{M}{I} * z = \frac{N_1^-}{A_1} + \frac{M_1^-}{I_1} * (-z_c)$$
$$= -\frac{37174{,}661kN}{5m^2} - \frac{2481{,}664kNm}{0{,}094m^4} * -0{,}212m$$
$$= -1837{,}988\ kPa = \mathbf{-1{,}838\ MPa} < f_{ck} = \mathbf{45\ MPa}$$

$$\eta^- = \frac{1{,}838MPa}{45MPa} * 100\% = \mathbf{4{,}08}\%$$

- tensile stresses:

$$\sigma^+ = \frac{N}{A} + \frac{M}{I} * z = \frac{N_1^+}{A_1} + \frac{M_1^+}{I_1} * (h_1 - z_{c1})$$
$$= \frac{30930{,}543kN}{5m^2} + \frac{3184{,}521}{0{,}094m^4} * (0{,}6m - 0{,}212m)$$
$$= 19330{,}729\ kPa = \mathbf{19{,}33\ MPa} > f_{ct} = \mathbf{4{,}2\ MPa}$$

Tensile stresses exceed the tensile strength of the slab, yet we supplied the cross section with reinforcing bars of #32 diameter rebars of B500C, distance 80mm. This reinforcement will surely bear the capacity of cross-section, therefore will be reduced to standard, programmed cross-section before adjustment, i.e. #32 diameter rebars of a distance 150mm. This change of distance will not affect bearing capacity, moreover it will increase the efficiency of cross-section.

For steel thin-walled section:

- compressive stresses

$$\sigma^- = \frac{N}{A} + \frac{M}{I} * z = \frac{N_2^-}{A_2} + \frac{M_2^-}{I_2} * (z_{c2} - h_2)$$
$$= -\frac{48631{,}402kN}{0{,}276m^2} - \frac{76302{,}546\ kNm}{0{,}5m^4} * (0{,}924m - 4{,}764m)$$
$$= 409802{,}82\ kPa = \mathbf{409{,}802\ MPa} < f_{yk} = \mathbf{460\ MPa}$$

$$\eta^- = \frac{409{,}802MPa}{460MPa} * 100\% = \mathbf{89{,}08}\%$$

- tensile stresses:

$$\sigma^{+} = \frac{N}{A} + \frac{M}{I} * z = \frac{N_2^{+}}{A_2} + \frac{M_2^{+}}{I_2} * z_{c2}$$
$$= \frac{57053{,}034 kN}{0{,}276 m^2} + \frac{97912{,}967\ kNm}{0{,}5 m^4} * 0{,}924 m$$
$$= 387657{,}054\ kPa = \mathbf{387{,}657\ MPa} < f_{yk} = \mathbf{460\ MPa}$$

$$\eta^{-} = \frac{387{,}657 MPa}{460 MPa} * 100\% = \mathbf{84{,}27}\%$$

Both compressive and tensile stresses are within bearing capacity of cross-section. Moreover, the correlation between values reaches almost 90%, which is the first aim of optimization process. Therefore optimization process will halt on step ‘0’, since it is sufficient for designed cross-section.

Bill of quantities

The preparation of bill of quantities will divide into elements of:

- concrete amount for slab,
- reinforcement amount for concrete slab,
- thin-walled section steel amount,
- truss members steel amount:
  - transverse section,
  - diagonal, in-line section,
  - support section

Concrete amount for slab

Previous part of optimization process showed the cross-section area of concrete slab used in calculation: $A_1 = 5{,}00\ m^2$
Length of concrete slab as for bridge length: $L = 540m$.
Therefore volume of section: $V = 5m^2 * 540m = \mathbf{2700m^3}$

Reinforcement amount for concrete slab

- tensile reinforcement

  In the programmed section, we used #32mm rebars of a distance 150mm.
  Programmed reinforcement is showed in figure below:

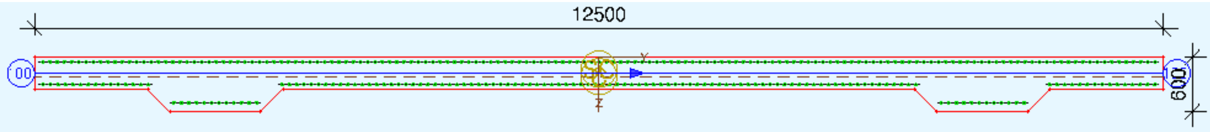


Figure 54: Programmed cross-section with tensile reinforcement, steel-box variant

Lengths of line reinforcement are: 12,4m + 1,25m + 1,00m + 7,1m + 1,00m + 1,25m =24m

Number of elements in a cross-section: $n = \frac{L}{d} = \frac{24m}{0{,}15m} = 160$

Since optimization process has not covered optimization of line reinforcement, we will assume lengths of reinforcement through whole bridge length of same distance and diameters. Therefore total length of line reinforcement equals: $L_{TOT} = 160 * 540m = 86400m$. Density of #32mm reinforcement taken from point 3.1. “Concrete variant”, section of “Stirrup reinforcement” : $\rho_{\#32} = 4{,}834 \frac{kg}{m}$.

Weight of line reinforcement: $L_{TOT} * \rho_{\#32} = 86400m * 4{,}834 \frac{kg}{m} = \mathbf{417\ 657{,}6\ kg}$.

Thin-walled section steel amount

Previous part of optimization process showed the cross-section area of thin-walled section used in calculation: $A_2 = 0{,}276\ m^2$

Length of thin-walled section as for bridge length: $L = 540m$.

Therefore volume of section: $V = 0{,}276m^2 * 540m = 149{,}04m^3$.

Density of S460NL steel: $\rho_{S460NL} = 7850 \frac{kg}{m^3}$

Weight of thin-walled section: $V * \rho_{S460NL} = 149{,}04m^3 * 7850 \frac{kg}{m^3} = \mathbf{1\ 169\ 964{,}0\ kg}$

Truss members steel amount

- transverse section

  Transverse section of truss consists of 3 elements of L-profile and 2 elements of 2*L profiles, as in a figure below:

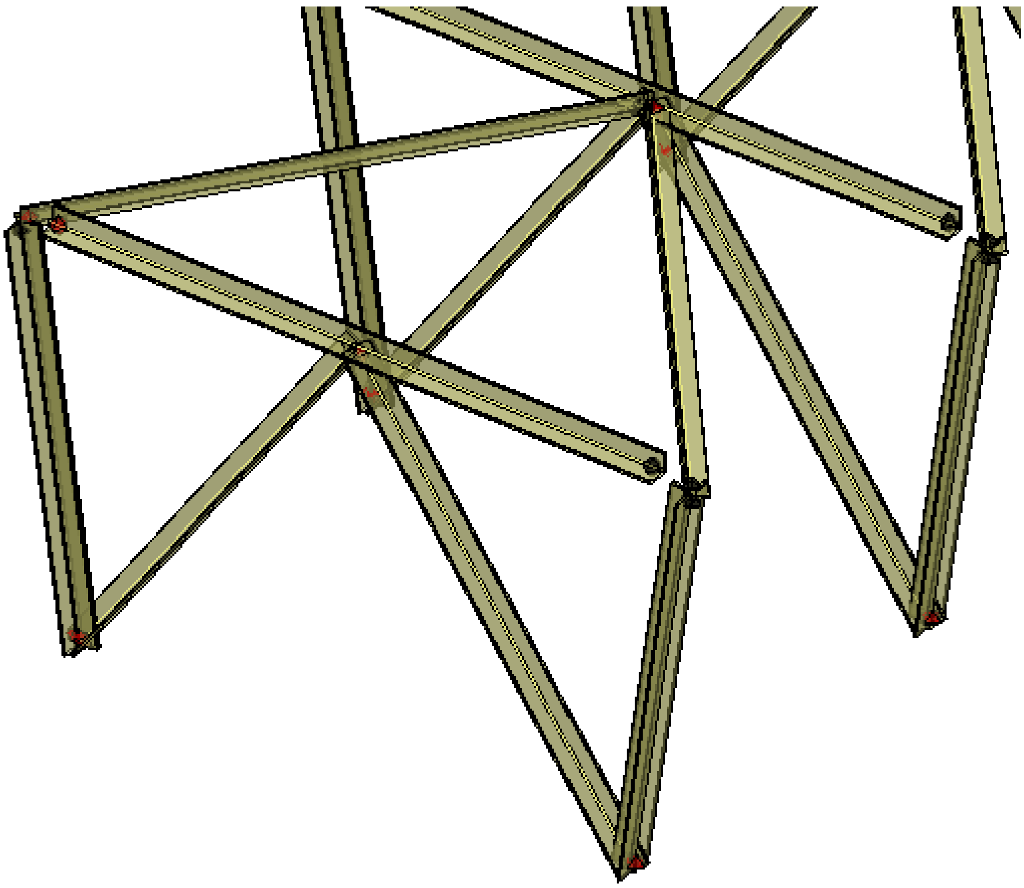


Figure 55: Autodesk AutoCAD visualization of truss members, transverse and diagonal, steel-box variant

Program visualization gives also lengths of members which are:

- upper L-profile elements single length = 7,25m

  L-profile used as aforementioned: $A = 0{,}0165\ m^2$
  Volume of single element: $V = L * A = 7{,}25m * 0{,}0165m^2 = 0{,}119m^3$
  Density of S355NL steel: $\rho_{S355NL} = 7850\frac{kg}{m^3}$
  Weight of single element: $V * \rho_{S355NL} = 0{,}119m^3 * 7850\frac{kg}{m^3} = 934{,}15\ kg$

- diagonal L-profile elements single length = 3,3m

  L-profile used as aforementioned: $A = 0{,}0165\ m^2$
  Volume of single element: $V = L * A = 3{,}3m * 0{,}0165m^2 = 0{,}055m^3$
  Density of S355NL steel: $\rho_{S355NL} = 7850\frac{kg}{m^3}$
  Weight of single element: $V * \rho_{S355NL} = 0{,}055 * 7850\frac{kg}{m^3} = 431{,}75\ kg$
  Weight of diagonal section: $2 * 431{,}75\ kg = 863{,}5\ kg$

- vertical 2*L-profile elements single length = 4,815 m

  2*L-profile used as aforementioned: $A = 0{,}0265\ m^2$
  Volume of single element: $V = L * A = 4{,}815m * 0{,}0265m^2 = 0{,}127m^3$
  Density of S355NL steel: $\rho_{S355NL} = 7850\frac{kg}{m^3}$
  Weight of single element: $V * \rho_{S355NL} = 0{,}127 * 7850\frac{kg}{m^3} = 1001{,}64\ kg$
  Weight of diagonal section: $2 * 1001{,}64\ kg = 2003{,}28\ kg$

Weight of a transverse section: $934{,}15kg + 863{,}5kg + 2003{,}28kg = 3800{,}93\ kg.$
Number of transverse sections in a truss, distance between sections 5m: $\frac{540m}{5m} + 1 = 109.$
In total, weight of transverse sections in a truss: $3800{,}93 * 109 = \mathbf{414301{,}37\ kg.}$

- diagonal, in-line section

Diagonal, in-line section of truss consists of 2 elements of L-profile as in a Figure 55.
From the program we also obtain single length of member: $L = 6{,}412m.$
L-profile used as aforementioned: $A = 0{,}0165\ m^2$
Volume of single element: $V = L * A = 6{,}412m * 0{,}0165m^2 = 0{,}106m^3$
Density of S355NL steel: $\rho_{S355NL} = 7850\frac{kg}{m^3}$
Weight of single element: $V * \rho_{S355NL} = 0{,}106 * 7850\frac{kg}{m^3} = 830{,}51\ kg$
Weight of diagonal section: $2 * 830{,}51\ kg = 1661{,}02\ kg$

Number of diagonal sections in a bridge, distance of 5m between next sections: $\frac{540m}{5m} = 108\ elements.$
Total weight of diagonal, in-line section: $108 * 1661{,}02\ kg = \mathbf{179\ 390{,}16\ kg.}$

- Support section

Support section comprises of two supports on V-shaped pillars, as shown on figure below. First support of length 100m and second of 80m comprise of 6 sections, similar of cross section and truss system to the ones in superstructure, welded after put in place.

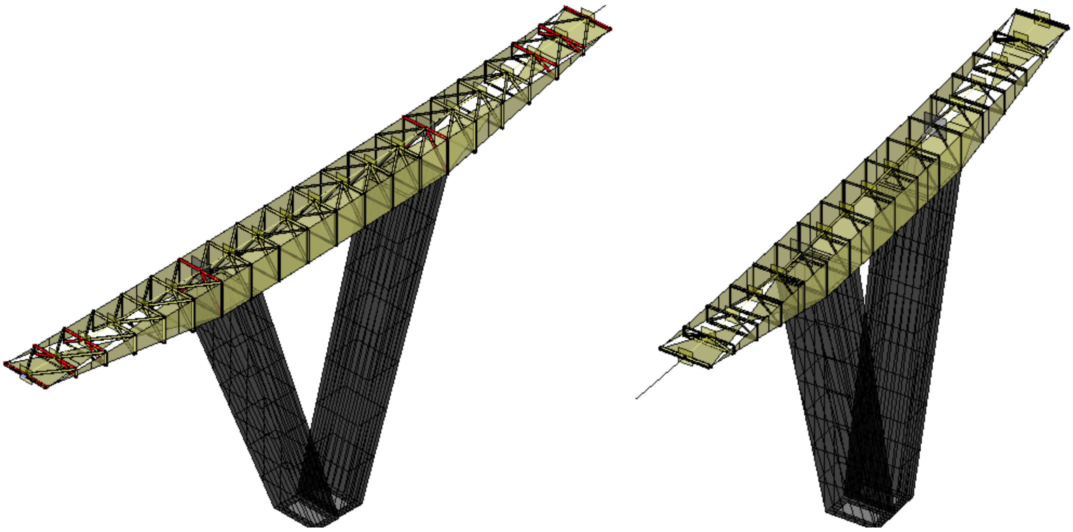


Figure 56: SOFIPLUS-X visualization of support sections, from left-side western part till eastern part, steel-box variant

Program visualiztion gives also lengths of single elements of system:

- *Steel thin-walled section*, thickness 10mm
  Section is changeable within length, varying from 240mm at edge of truss, till 5000mm at support.
  Within western support, length of system is: $L = 100m.$, eastern: $L = 80m.$

  Western support

  - Height change function is linear and gives us a triangle of dimensions: $AxBxC = 30m\ x\ 4{,}76m\ x\ 30{,}375m$, and small rectangle element of dimensions: $AxB = 30\ m\ x\ 0{,}24m$
    Area of thin-walled element: $A = \frac{1}{2} * 30m * 4{,}76m + 30m * 0{,}24m = 78{,}6m^2$
    Volume of thin-walled element: $V = 78{,}6m^2 * 0{,}001m = 0{,}0786m^3$.
    Volume of 4 thin-walled elements: $V_{TOT} = 4 * 0{,}0786m^3 = 0{,}3144\ m^3$

  - Lower plate dimensions are: $AxBxt = 7m\ x\ 30{,}375m\ x\ 0{,}001m$
    Volume of thin-walled element: $V = 7m * 30{,}375m * 0{,}001m = 0{,}213m^3$.
    Volume of 2 thin-walled elements (2 bottom plates): $V_{TOT} = 2 * 0{,}213m^3 = 0{,}426m^3$

  - There is also a middle part of constant height of cross-section
    Area of cross-section: $A = 0{,}017m^2$
    Length of section equals: $L = 40m.$
    Volume of section: $V_{TOT} = 40m * 0{,}017m^2 = 0{,}68m^3$

Entire volume of entire thin-walled section on western support: $V_{western} = 0{,}3144m^3 + 0{,}426m^3 + 0{,}68m^3 = 1{,}4204m^3$

Density of S355NL steel: $\rho_{S355NL} = 7850\frac{kg}{m^3}$.

Weight of entire thin-walled section on western support: $M_{western} = 1{,}4204m^3 * 7850\frac{kg}{m^3} = \mathbf{11\ 150, 14\ kg}$.

<u>Eastern support</u>

- Height change function is linear and gives us a triangle of dimensions: $AxBxC = 25m\ x\ 4{,}76m\ x\ 25{,}449m$, and small rectangle element of dimensions: $AxB = 25\ m\ x\ 0{,}24m$

  Area of thin-walled element: $A = \frac{1}{2} * 25m * 4{,}76m + 25m * 0{,}24m = 65{,}5m^3$

  Volume of thin-walled element: $V = 65{,}5m^2 * 0{,}001m = 0{,}0655m^3$.

  Volume of 4 thin-walled elements: $V_{TOT} = 4 * 0{,}0655m^3 = 0{,}262\ m^3$

- Lower plate dimensions are: $AxBxt = 7m\ x\ 25{,}449m\ x\ 0{,}001m$

  Volume of thin-walled element: $V = 7m * 25{,}449m * 0{,}001m = 0{,}178m^3$.

  Volume of 2 thin-walled elements (2 bottom plates): $V_{TOT} = 2 * 0{,}178m^3 = 0{,}356m^3$

- There is also a middle part of constant height of cross-section

  Area of cross-section: $A = 0{,}017m^2$

  Length of section equals: $L = 30m$.

  Volume of section: $V_{TOT} = 30m * 0{,}017m^2 = 0{,}51m^3$

Entire volume of entire thin-walled section on western support: $V_{western} = 0{,}262m^3 + 0{,}356m^3 + 0{,}51m^3 = 1{,}128m^3$

Density of S355NL steel: $\rho_{S355NL} = 7850\frac{kg}{m^3}$.

Weight of entire thin-walled section on western support: $M_{western} = 1{,}128m^3 * 7850\frac{kg}{m^3} = \mathbf{8\ 854, 8\ kg}$.

- *Truss members* comprise of given L-profile section, see figure below. Program visualization gives the lengths of elements in truss system:

  <u>Western support</u>

  - Transverse sections

    Sections are changeable within height as the thin-walled section. Program calculated lengths of elements as:

    $L = 294m$, for horizontal members,

    $L = 143{,}36m$, for vertical members,

    $L = 213{,}22m$, for diagonal members.

- Diagonal, in-line sections

Program calculated lengths of elements as: $L = 244m$.

Total lengths of truss members is:
$L_{TOT} = 294m + 143{,}36m + 213{,}22m + 244m = 894{,}58m$
Area of cross section: $A = 0{,}0133\ m^2$.
Volume of members: $V = 894{,}58m * 0{,}0133m^2 = 11{,}897m^3$.

Density of S355NL steel: $\rho_{S355NL} = 7850 \frac{kg}{m^3}$.
Weight of entire truss members section on western support: $M_{western} = 11{,}897m^3 * 7850 \frac{kg}{m^3} = \mathbf{93\ 391{,}45\ kg}$.

<u>Eastern support</u>

- Transverse sections

Sections are changeable within height as the thin-walled section.
Program calculated lengths of elements as:
$L = 238m$, for horizontal members,
$L = 112{,}88m$, for vertical members,
$L = 170{,}78m$, for diagonal members.

- Diagonal, in-line sections

Program calculated lengths of elements as: $L = 195{,}2m$.

Total lengths of truss members is:
$L_{TOT} = 238m + 112{,}88m + 170{,}78m + 195{,}2m = 716{,}86m$
Area of cross section: $A = 0{,}0133\ m^2$.
Volume of members: $V = 716{,}86m * 0{,}0133m^2 = 9{,}319m^3$.

Density of S355NL steel: $\rho_{S355NL} = 7850 \frac{kg}{m^3}$.
Weight of entire truss members section on western support: $M_{western} = 9{,}319m^3 * 7850 \frac{kg}{m^3} = \mathbf{73\ 154{,}15\ kg}$.

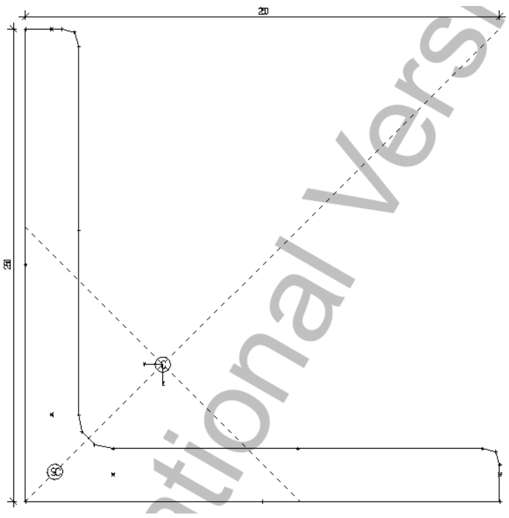


Figure 57: Truss member profile for support section, steel-box variant

Table 33: L-profile geometry, support section, steel-box variant

A [m2]	Ay [m2]	Az [m2]	Iy [m4]	Iz [m4]	ysc [mm]	zsc [mm]	E [N/mm2]
0,0133	0,0059	0,0059	0,000	0,000	56,8	56,8	210000

Final bill of quantities

Table 33: Bill of quantities, steel-box variant

Prices taken from Statistisk Sentralbyrå [5] steel provider Norsk Stål [6]. Bill of quantities does not cover addition to steel connections and steel-concrete connection.

Element	Amount	Unit	Price per amount [NOK/m^3 or kg]	Price [NOK]
Reinforcement B500C (180kg/m3): - Longitudinal reinforcement	417 657,60	kg	78,0	32 577 292,80
Steel truss members of S355NL: - Transverse system - Diagonal, in-line system - Supports	414 301,37 179 390,16 166 545,60	kg kg kg	26,6	20 222 307,66
Thin-walled sections of S460NL: - Superstructure - Supports	1 169 964,00 20 004,94	kg kg	53,4	63 544 341,1
Concrete B45 SV-40 - Concrete slab	2 700,00	m^3	1 750,0	4 725 000,00
			SUM	**121 068 941,9**

Presented bill of quantities with partial cost estimate is fairly lower than proposed cost estimate position from preliminary design

Table 34: Comparison of values with regard to preliminary cost estimate, steel-box variant

No.	Element	Values from proposed preliminary cost estimate [1000 NOK]	Values from analysis [1000 NOK]	Difference [1000 NOK]
6.	Bridge concrete superstructure	27 780,000	4 725,000 (concrete) 32 577,293 (reinforcement)	9 522,293
7.	Bridge steel-box superstructure	112 490,000	20 222,308 (truss system) 63 544,341 (thin-walled)	-28 723,351
			Overall	**-19 201,058**

3.3. Project boundaries

Zoning plans have divided investment area into 5 parcels:

- Parcel 1: Eggemoen plateau
- Parcel 2: Randselva
- Parcel 3: Randselva – Kleggerud
- Parcel 4: Kleggerud – Rønnerud
- Parcel 5: Rønnerud – Olum

Randselva bridge is located in the parcel nr 2.

3.4. Documentation

Table 35: Documentation analyzed for the project (most important highlighted in green)

Document name	Date	Description
Plan description	25.04.2014	Plan description for detailed regulations
Risk analysis	24.04.2014	Risk and vulnerability analysis
Plan map and regulations	24.03.2014	Regulations to the detailed planning
Noise calculation report	19.02.2014	Road traffic noise calculation
Preliminary designs	14.02.2014	Preliminary designs of constructions
Preliminary design – Randselva bridge – steel-box variant	**20.12.2013**	**Preliminary design of Randselva bridge steel-box variant**
Preliminary design – Randselva bridge – concrete cantilever variant	**20.12.2013**	**Preliminary design of Randselva bridge concrete cantilever variant**
External environmental plan	02.07.2013	External environmental plan for zoning plan
Notice of startup	16.05.2013	Notice of startup of zoning plan
Soil quality documentation	07.08.2012	Confirmation of soil quality
Municipal plan	10.11.2010	Municipal plan for roadways
Noise and air quality report	09.11.2010	Report from noise and air quality analysis
Natural environment report	08.11.2010	Report from natural environment analysis
Natural resources report	08.11.2010	Report from natural resources analysis
Mass balance and landfill report	11.2010	Report note from mass balance and landfill investigations
Cultural heritage report	14.10.2010	Report from cultural heritage structures in the investment area
Geological survey report	29.09.2010	Report from ground geological surveys
Feasibility study	22.02.2010	Feasibility study of investment
Geotechnical survey report	01.01.2010	Report from ground geotechnical surveys

4. Projection method

4.1. Method and implementation

Estimation process is conducted in accordance with HB 217. The process is not set up on the stakeholders list. Calculations for the bridge will be divided into two parts of the proposed variants, that have moderate correlations for the price elements.

4.2. Objectives

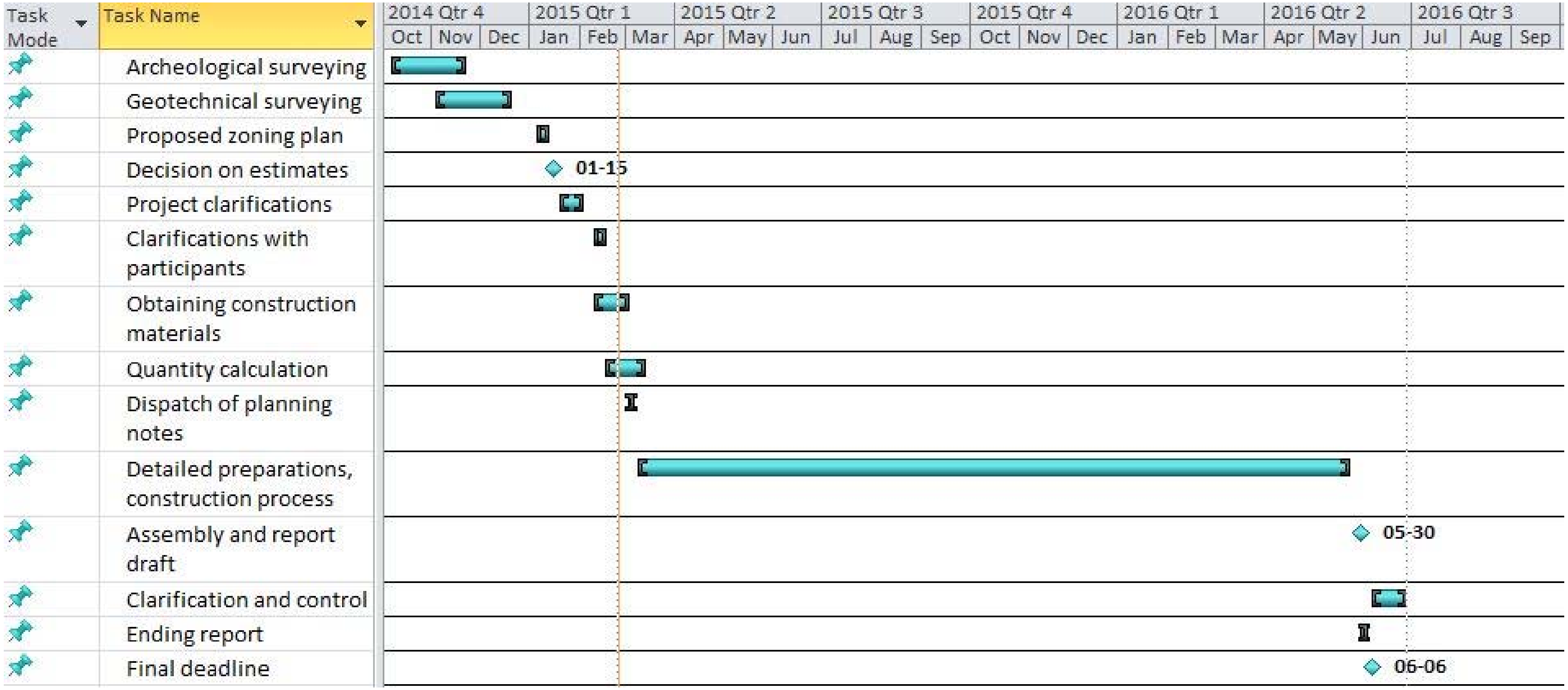
Estimation/projection method review shall:

- Ensure that all assumptions that give basis to the analysis are right and close to reality,
- Identify the most uncertain factors and impacts on the project,
- Set the uncertainties in the cost estimates,
- Find the realistic cost of uncertainty in the project including all measures,
- Compare the estimates of both propositions and select the more profitable one
- Compare the estimates within the price elements levels, from general to detailed ones

4.3. Estimated work schedule

Due to the fact, that project is still in preliminary phase, most of time ranges are roughly estimated, based on final decision of construction alternative, eventual changes to the project and weather conditions. Most of them are estimated through documentation obtained, comparison of similar projects and engineering practice.
Work schedules have been prepared in Microsoft Project 2013 software.

Table 36: Estimated work schedule, assumed for both construction variants



4.4. Assumptions

- Price level: 2013
- MVA: Full MVA 25% introduced from the beginning of the year 2012-13 for all costs except land acquisition,
- Plan Level: Municipal level
- Accuracy Requirements: +/- 25%
- Call / competition shape: Unit Price Contract
- Estimated construction start: no later than 3rd quarter 2014
- Estimated construction period: ca. 4 years, opening autumn 2018.

4.5. Interface considerations

Interface analysis is performed on the popular SWOT analysis. Table below shows the results, to be completed or updated in the future considerations.

Table 37: SWOT analysis of the project

STRENGTHS: - New bridge will not preclude activities such as hiking, fishing or swimming - No lasting impact on the river - Traditional solution. Known finishing, adapted to the practical challenges on site - Construction clear / raw - Great remote effect	WEAKNESSES: - Area within bridge affected by noise - Construction phase will interfere with the local municipality (touching the local area)
OPPORTUNITIES: - bridge structures have good height so that congestion will not be a problem.	THREATS: - It is important to focus on pollution during the construction phase for Rand River and other waterways throughout the construction period. - uncertainty round effects for the vulnerable nature freshwater pearl mussel. - Construction activities will result in large barren surfaces and during heavy rainfall may be significant erosion and increased particle content Rand river and side streams that can affect life in the river system negatively. - West slope of the river must be secured during construction due to landslide

4.6. Level of ambition

Table 38: Level of ambition for the project

Ambition factor	Level
Accessibility	High
Security	Medium
Services	Low
Environment	High
Functionality	High
Esthetics	Medium
Management	High

4.7. Complexity factors

Table 39: Complexity factors for the project

Complexity factor	Rating
Topography	Medium
Rock works	Low
Soil works	High
Earthworks	Medium
Access/availability	Medium
Traffic	Low
Natural conditions	High
Stakeholders	Medium
Requirements for environmental	High
Housing environment, existing buildings and infrastructure	Low
Technical complexity	Medium

Ambition level and complexity factors are the 2 aid means that serve as point of reference of estimation process. The result of estimation will be then used to calibrate the approach and will be useful for evaluating the end result of estimation.

4.8. Sitemap

Situation map is a tool that is used to describe the project's potential for uncertainty as participants in the resource group intuitively see it. It is used to communicate the assessed conditions and control basis for evaluation of the result. Main purposes of situation map are to:

- serve as a point of reference to evaluated results of analysis
- classify information (in relevance to the situation)
- classify tools used (in relevance to the situation)

In given project, situation map will describe bridge project status in relation to given information amount from obtained documentation. Main points are taken into account that project is in preliminary stage, some uncertainties still remain to be solved.

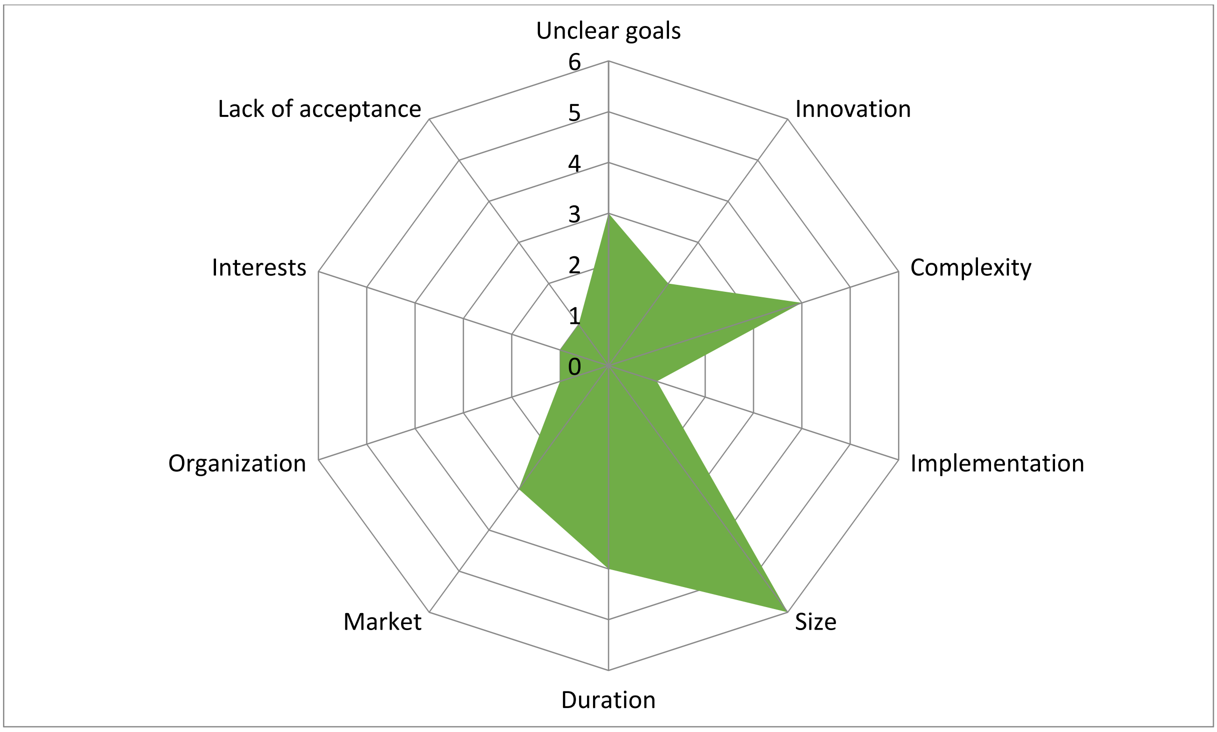


Figure 58: Sitemap of project topics

Unclear goals: 3 due to unclarified cultural heritage inspections, preliminary cost estimate.
Innovation: 2, due to rather traditional method of construction
Complexity: 4, due to complex activities related to construction (adjustment to the aerial conditions and safety of the river banks, scaffolding and formworks of the bridge)
Implementation: 1 so far, not assessed
Size: 6 due to magnitude of investment, bridge span, construction method and material transport
Market: 2 due to market situation, oil prices – freezed market for execution
Organization: 1 not assessed yet
Interests: 1 not assessed yet
Lack of acceptance: 1 not assessed yet

4.9. Maturity rating

A maturity rating of the project is an assessment which is used to control the project in relation to the necessary basis, clarifications and material plans. Most important thing to focus on is that if the maturity of the prject on a proper level in relation to the planning phase we are in. Maturity assessment also provides signals relative to the uncertainty areas and the possible need for uncertainties.

The pie chart for maturity assessment is organized into project options:

- early phases
- plan level

In the Randselva bridge project, most of plan level options lack information due to preliminary stage, therefore more improved are the early stage options.

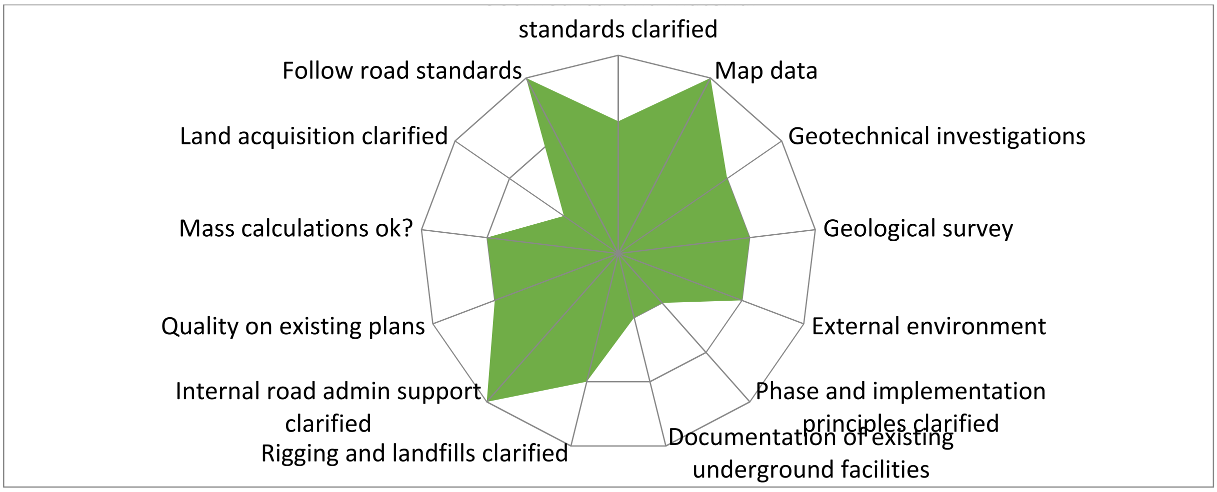


Figure 59: Maturity rating of a project

(Scale 1(not good enough), 2(should be better), 3 (ok):
Geometrical and material standards clarified – **2-** construction drawings and cost estimates better in concrete variant, steel variant needs more information,
Map data – **3** – all maps of geotechnical, geological, municipal and construction available with detailed data,
Geotechnical investigations – **2** – all investigations but one in Randselva bridge region met (alum shale repositories),
Geological survey – **2** – same as before, alum shale repositories blocking drilling methods for obtaining detailed results of land masses,
External environment – 2 – hilly landscape, wide valley between hills,
Phase and implementation principles clarified – **1** – project still in preliminary stage, archeological surveys blocking further enterprise,
Documentation of existing underground facilities – **1** – not obtained, archeological stage in progress,
Rigging and landfills clarified – **2** – landfills of alum shale not clarified, only estimated,
Internal road admin support clarified – **3** – all roadway variants assessed and chosen, road axes and directions known,
Quality on existing data – **2** – archeological surveys unavailable, need for better alum shale masses estimation creates lots of uncertainty,
Mass calculations ok? – **2** – not fully assessed,
Land acquisition clarified – **1** – conversations with landowners still in progress,
Follow road standards – **3** – road standards met with national normatives.

4.10. Uncertainty factors

Factors lists is divided into 3 parts of concrete, steel structures and excavations Most of factors are taken from Norwegian construction cost index SSB 2014 3rd quarter. Subparts are derived in table sets below: concrete structure, steel structure and excavation.

Table 40: Concrete types uncertainty factors, concrete structure

Element type	Concrete type		Low	High
		Factors	0,81	1,19

Description

<u>Basis for description</u>:
Data from project description regarding concrete types used in construction:
B45 SV-40, B55 SV-40, B65 SV-40

<u>Derivation of factors</u>:
Given concrete types have characteristic compressive strength given as follows:
$f_{ck,b45} = 45\ MPa, f_{ck,b55} = 55\ MPa, f_{ck,b65} = 65\ MPa$

By assuming B55 type as point of reference, we can derive the proportions between concrete resistances to obtain uncertainty actors:

$$u_{low} = \frac{f_{ck,b45}}{f_{ck,b55}} = \frac{45MPa}{55MPa} = 0{,}81$$

$$u_{high} = \frac{f_{ck,b65}}{f_{ck,b55}} = \frac{65MPa}{55MPa} = 1{,}19$$

Table 41: Transportation uncertainty factors, concrete structure

Element type	Transportation		Low	High
		Factors	0,95	1,06

Description

<u>Basis for description</u>:
Map data for distances of concrete providers, provided by Google Maps ©.
Chosen concrete providers: Unicon Avd. Hønefoss, John Myrvang AS Prestmoen Grustak, NorBetong Bærum (Oslo)

<u>Derivation of factors</u>:
By obtaining distances from providers to the building site and leveling time per concrete truck as the same for each provider, factors will depend solely on kilometrage.
The closest provider is Unicon Avd. Hønefoss = 10,1km
The middle-close provider is John Myrvang AS Prestmoen Grustak= 10,6km
The furthestest provider is NorBetong Bærum = 11,3km

By assuming middle-close provider distance as point of reference, we can derive the proportions between distances to obtain uncertainty actors:

$$u_{low} = \frac{L_{UAH}}{L_{JMAS}} = \frac{10{,}1km}{10{,}6km} = 0{,}95$$

$$u_{high} = \frac{L_{NB}}{L_{JMAS}} = \frac{11{,}3km}{10{,}6km} = 1{,}06$$

Table 42: Reinforcement uncertainty factors, concrete structure

Element type	Reinforcement		Low	High
		Factors	0,88	1,08

Description

Basis for description:
Fatigue and stretch resistance tests results of reinforcement B500C used as slack reinforcement in given concrete bridge structure. Tests are provided by Celsa Steel Service. Celsa Duktil 500C steels meet the fatigue requirements of BS 4449:2005 Grade B500C. Test are carried out on full section bars using a sinusoidal tensile load. Tests are run for maximum length of span to obtain most effective result.

Derivation of factors:
Values obtained from test results are:

- Lowest value = 187,5 MPa
- Mean value = 231 MPa
- Highest value = 250 MPa

By assuming mean value as point of reference, we can derive the proportions between results to obtain uncertainty actors:

$$u_{low} = \frac{\sigma_{low}}{\sigma_{mean}} = \frac{187{,}5MPa}{231MPa} = 0{,}88$$

$$u_{high} = \frac{\sigma_{high}}{\sigma_{mean}} = \frac{250MPa}{231MPa} = 1{,}08$$

Table 43: Labor costs uncertainty factors, concrete structure

Element type	Labor costs		Low	High
		Factors	0,92	1,25

Description

Basis for description:
Index values of labor costs obtained from Construction Cost Index (Statistisk Sentralbyrå) for different types of construction works, % of the type of construction. This section is roughly assumed, as there is no time schedule for the works.

Derivation of factors:
Values obtained from CCI are:

- Road construction = 33%
- Open roads construction = 35,6%
- Concrete bridges construction = 44,7%

By assuming “Open roads constr.” % as point of reference, we can derive the proportions between percentages to obtain uncertainty actors:

$$u_{low} = \frac{33\%}{35{,}6\%} = 0{,}92$$

$$u_{high} = \frac{44{,}7\%}{35{,}6\%} = 1{,}25$$

Table 44: Machinery uncertainty factors, concrete structure

Element type	Machinery		Low	High
		Factors	0,92	1,25

Description

Basis for description:
Index values of machinery costs obtained from Construction Cost Index (Statistisk Sentralbyrå) for different types of construction works, % of the type of construction. This section is roughly assumed, as there is no time schedule for the works.

Derivation of factors:
Values obtained from CCI are:

- Road construction = 19,1%
- Open roads construction = 24,5%
- Concrete bridges construction = 8,4%

By assuming "Road construction" % as point of reference, we can derive the proportions between percentages to obtain uncertainty actors:

$$u_{low} = \frac{8{,}4\%}{19{,}1\%} = 0{,}43$$

$$u_{high} = \frac{24{,}5\%}{19{,}1\%} = 1{,}28$$

Table 45: Market factor uncertainty factors, concrete structure

Element type	Market factor		Low	High
		Factors	0,97	1,1

Description

Basis for description:
Stability ratios taken from www.tradingeconomics.com , from Norway Industrial Production ratio, over last 2 quarters of 2014.

Derivation of factors:
Stability ratios are themselves uncertainty factors, as they define market stability over past months which can be good indicator for future investments.:
3rd Quarter – market drop - -3% → $1 - 3\% = 97\% = 0{,}97$
4th Quarter – market rise - +10% → $1 + 10\% = 110\% = 1{,}1$

Table 46: Steel type uncertainty factors, steel structure

Element type	Steel type		Low	High
		Factors	0,93	1,21

Description

<u>Basis for description</u>:
Minimum yield strengths of steel types used in superstructure construction:
S355NL - S460NL

<u>Derivation of factors</u>:
Given steel types have will evaluate the lowest class steel for minimum yield strengths, assessed for different thicknesses:

- Minimum yield strength $R_{EH,min} = 275\ MPa$
- Mean yield strength $R_{EH,mean} = 295\ MPa$
- Maximum yield strength $R_{EH,max} = 355\ MPa$
-

By assuming mean yield strength as point of reference, we can derive the proportions between yield strengths to obtain uncertainty actors:

$$u_{low} = \frac{R_{EH,min}}{R_{EH,mean}} = \frac{275MPa}{295MPa} = 0{,}93$$

$$u_{high} = \frac{R_{EH,max}}{R_{EH,mean}} = \frac{355MPa}{295MPa} = 1{,}21$$

Table 47: Transportation uncertainty factors, steel structure

Element type	Transportation		Low	High
		Factors	0,96	1,39

Description

<u>Basis for description</u>:
Map data for distances of steel providers, provided by Google Maps ©.
Chosen steel providers: Norsk Stål (NS) with 2 centrals in Oslo, SSAB Svenskte Stål AS.

<u>Derivation of factors</u>:
By obtaining distances from providers to the building site and leveling time per concrete truck as the same for each provider, factors will depend solely on kilometrage.
The closest provider is SSAB Svenskte Stål AS = 47,8km
The middle-close provider is Norsk Stål , central 1= 49,5km
The furthestest provider is Norsk Stål, central 2 = 69,2km

By assuming middle-close provider distance as point of reference, we can derive the proportions between distances to obtain uncertainty actors:

$$u_{low} = \frac{L_{SSAB}}{L_{NS1}} = \frac{47{,}8km}{49{,}5km} = 0{,}96$$

$$u_{high} = \frac{L_{N2}}{L_{NS1}} = \frac{69{,}2km}{49{,}5km} = 1{,}39$$

Table 48: Reinforcement uncertainty factors, steel structure

Element type	Reinforcement		Low	High
		Factors	0,88	1,08

Description

<u>Basis for description</u>:
Fatigue and stretch resistance tests results of reinforcement B500C used as slack reinforcement in given steel bridge structure. Tests are provided by Celsa Steel Service. Celsa Duktil 500C steels meet the fatigue requirements of BS 4449:2005 Grade B500C. Test are carried out on full section bars using a sinusoidal tensile load. Tests are run for maximum length of span to obtain most effective result.

<u>Derivation of factors</u>:
Values obtained from test results are:

- Lowest value = 187,5 MPa
- Mean value = 231 MPa
- Highest value = 250 MPa

By assuming mean value as point of reference, we can derive the proportions between results to obtain uncertainty actors:

$$u_{low} = \frac{\sigma_{low}}{\sigma_{mean}} = \frac{187{,}5MPa}{231MPa} = 0{,}88$$

$$u_{high} = \frac{\sigma_{high}}{\sigma_{mean}} = \frac{250MPa}{231MPa} = 1{,}08$$

Table 49: Labor costs uncertainty factors, steel structures

Element type	Labor costs		Low	High
		Factors	0,92	1,25

Description

<u>Basis for description</u>:
Index values of labor costs obtained from Construction Cost Index (Statistisk Sentralbyrå) for different types of construction works, % of the type of construction. This section is roughly assumed, as there is no time schedule for the works.

<u>Derivation of factors</u>:
Values obtained from CCI are:

- Road construction = 33%
- Open roads construction = 35,6%
- Steel bridges construction = 44,7%

By assuming “Open roads constr.” % as point of reference, we can derive the proportions between percentages to obtain uncertainty actors:

$$u_{low} = \frac{33\%}{35{,}6\%} = 0{,}92$$

$$u_{high} = \frac{44{,}7\%}{35{,}6\%} = 1{,}25$$

Table 50: Machinery uncertainty factors, steel structure

Element type	Machinery		Low	High
		Factors	0,92	1,25

Description

Basis for description:
Index values of machinery costs obtained from Construction Cost Index (Statistisk Sentralbyrå) for different types of construction works, % of the type of construction. This section is roughly assumed, as there is no time schedule for the works.

Derivation of factors:
Values obtained from CCI are:

- Road construction = 19,1%
- Open roads construction = 24,5%
- Steel bridges construction = 8,4%

By assuming "Road construction" % as point of reference, we can derive the proportions between percentages to obtain uncertainty actors:

$$u_{low} = \frac{8{,}4\%}{19{,}1\%} = 0{,}43$$

$$u_{high} = \frac{24{,}5\%}{19{,}1\%} = 1{,}28$$

Table 51: Market factor uncertainty factors, steel structure

Element type	Market factor		Low	High
		Factors	0,97	1,1

Description

Basis for description:
Stability ratios taken from www.tradingeconomics.com , from Norway Industrial Production ratio, over last 2 quarters of 2014.

Derivation of factors:
Stability ratios are themselves uncertainty factors, as they define market stability over past months which can be good indicator for future investments.:
3rd Quarter – market drop - -3% → $1 - 3\% = 97\% = 0{,}97$
4th Quarter – market rise - +10% → $1 + 10\% = 110\% = 1{,}1$

- Excavations

Excavation difficulty assessed by the alum repositories and slope distribution.

Table 52: Axle 1 uncertainty factors, excavations

Element type	Axle 1		Low	High
		Factors	0,74	1,34

Description

Basis for description:
Geotechnical and geological data, maps and cross-sections of bridge landscape.

Derivation of factors:
Factor estimation by soil conditions and slope geometry – axle 1 sits on vast alum repositories and high slope, which can contribute to landslides, therefore we assume decrease factor of

- 0,8 due to high slope
- 0,95 due to alum repositories.

Factors are computed through distances of pillars to river bank:
Left column = 97,5m
Columns axis = 99,5m
Right column = 101,5m

By assuming column axis distance as point of reference, we can derive the proportions between distances to obtain uncertainty actors:

$$u_{low} = \frac{97{,}5m}{99{,}5m} * 0{,}8 * 0{,}95 = 0{,}74$$

$$u_{high} = \frac{101{,}5m}{99{,}5m} * \frac{1}{0{,}8 * 0{,}95} = 1{,}34$$

Table 53: Axle 2 uncertainty factors, excavations

Element type	Axle 2		Low	High
		Factors	0,86	1,16

Description

Basis for description:
Geotechnical and geological data, maps and cross-sections of bridge landscape.

Derivation of factors:
Factor estimation by soil conditions and situated foundation conditions.
As axle 2 is situated on the riverside, there are weaker soil conditions obtained through geotechnical surveys: moraine soils and alum repositories. Moreover, due to foundation situated by the river, there is a risk of inundation. Low slope is advantageous for building site. Therefore we assume decrease factors of:

- 0,9 due to inundation risk
- 0,95 due to low steepness and alum repositories

Uncertainty factors computed through decrease factors only.

$$u_{low} = 1 * 0{,}9 * 0{,}95 = 0{,}86$$

$$u_{high} = \frac{1}{0{,}9 * 0{,}95} = 1{,}16$$

Table 54: Axle 7 uncertainty factors, excavations

Element type	Axle 7		Low	High
		Factors	0,86	1,16

Description

Basis for description:
Geotechnical and geological data, maps and cross-sections of bridge landscape.

Derivation of factors:
Factor estimation by soil conditions and situated foundation conditions.
As axle 7 is situated on plains, there are better soil conditions with low risk of landslide and influence on foundations. There is also an issue of building technology of the temporary columns and its uncertainty of effectiveness. Therefore we assume decrease factors of:

- 0,95 due to soil conditions and
- 0,8 due to building technology uncertainty

Uncertainty factors computed through decrease factors only.

$$u_{low} = 1 * 0,8 * 0,95 = 0,76$$

$$u_{high} = \frac{1}{0,8 * 0,95} = 1,32$$

5. Calculation

5.1. Concrete cantilever alternative

Calculation will be performed on the first method of concrete cantilever bridge type. Analysis will be performed on the preliminary cost estimation provided from documentation:

Table 55: Preliminary cost estimation of concrete cantilever method, values in 1000NOK

No.	Description	Cost
1	Preparatory measure and general cost	55071,500
2	Abutment axis 1	9054,000
3	Abutment axis 7	1412,000
4	Columns with viaduct foundation	13240,000
5	Pillars with foundation axis 2	21890,000
6	Bridge concrete superstructure	130905,000
7	Temporary structures using columns	12374,000
8	Bridge equipment	11394,000
9	Specified work process	255340,500
10	Unspecified work process 8 (estimated 10% of specified)	25534,050

5.1.1. Calculation table

Calculation table has been prepared in ANSLAG program.

Table 56: Calculation table of concrete variant

Post	Tekst	enhet	lav	sannsynlig	hoy	veiet middel	kostnad eks. faktorer
B	Randselva concrete bridge	RS	0	0	0		passiv
B1	Prep measures, general cost	RS	53 419 355	55 071 500	58 926 505	55 981 773	55 981,8
B2	Abutment axis 1	RS	7 757 126	9 054 000	11 284 052	9 439 611	9 439,6
B3	Abutment axis 7	RS	1 242 431	1 412 000	1 807 326	1 505 288	1 505,3
B4	Columns with via foundation	RS	11 175 668	13 240 000	16 256 900	13 633 623	13 633,6
B5	Pillars with foundation axis 2	RS	17 903 490	21 890 000	26 043 656	21 959 069	21 959,1
B6	Bridge concrete superstructure	RS	113 645 672	130 905 000	168 369 606	139 254 288	139 254,3
B7	Temporary structures using columns	RS	10 477 148	12 374 000	15 240 784	12 774 798	12 774,8
B8	Bridge equipment	RS	9 681 195	11 394 000	14 082 937	11 797 360	11 797,4
B9	Not specified work process 8	RS	12 626 890	21 044 816	29 462 743	21 044 816	21 044,8
Sum byggherre:							287 390,6
Sum prosesskalkyle:							0,0
Sum usikkerhetsvurderinger:							26 126,4
Resultat:							313 517,0

5.1.2. Calculation results

Table 57: Calculation results of the concrete variant

Estimations	
Price range	2013
Requirements for accuracy	+/- 25%
P50 Cost	280,875 Mil. Kr.
Expected cost	313,517 Mil. Kr.
Standard deviation	69,842 Mil. Kr.
Relative standard deviation	22,2%
There is 90% probability that the estimate is between	
Lower value	235,1 Mil. Kr.
Highest value	391,9 Mil. Kr.

Relative standard deviation is smaller than the required accuracy. That means cost estimation is valid within set uncertainties and amounts.

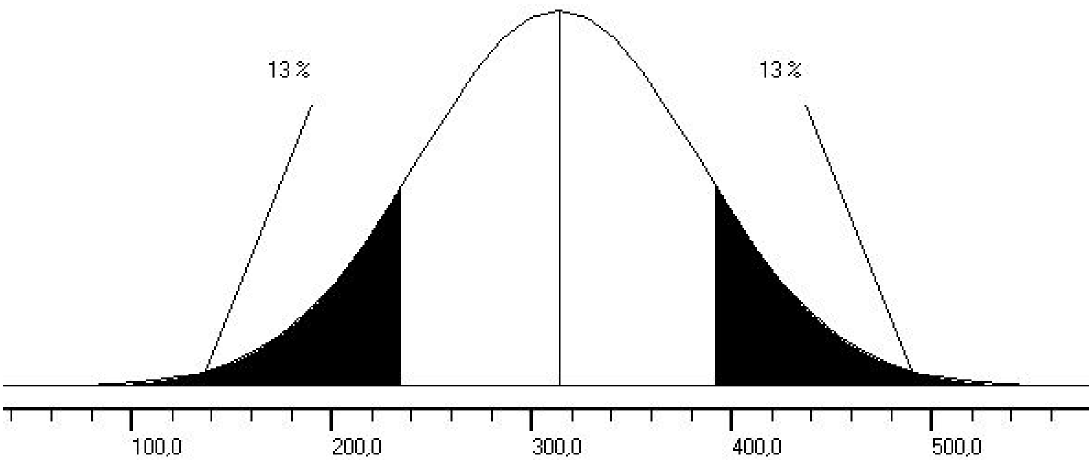


Figure 60: Probability distribution of costs (concrete variant)

S-Curve

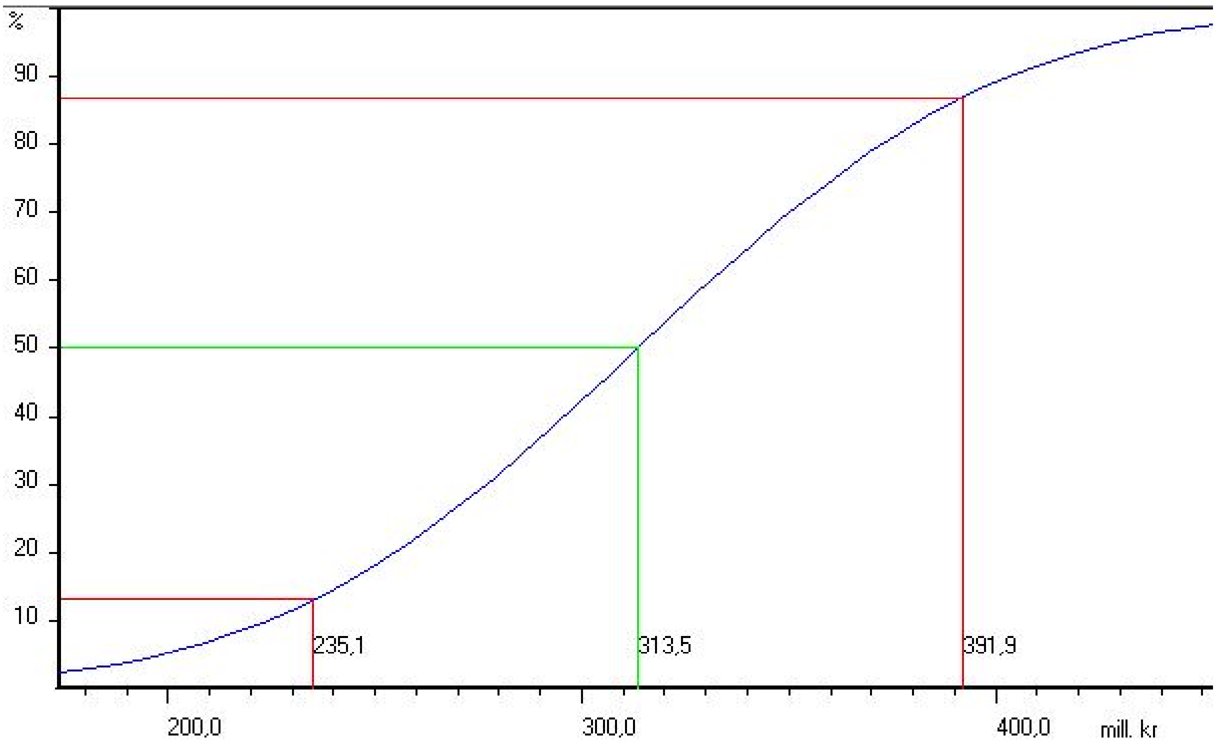


Figure 61: S-Curve, concrete variant

Uncertainty profile

Figure 62: Uncertainty profile, concrete variant

Additional measures

From the uncertainty profile we can see that to decrease major uncertainties we have to:

- Improve cost estimation regarding bridge concrete superstructure to avoid overestimation in this element
- Review geotechnical investigations, implement tools and methods to avoid additional costs regarding handling the alum repositories
- Improve the working schedule and logistics of material transport to implement faster and better construction/design phases

5.2. Steel-box alternative

Calculation will be performed on the second method of steel-box bridge type. Analysis will be performed on the preliminary cost estimation provided from documentation:

Table 58: Preliminary cost estimation of steel-box method, values in 1000NOK

No.	Description	Cost
1	Preparatory measure and general cost	44602,800
2	Abutment axis 1	9090,000
3	Abutment axis 4	2030,000
4	Pillars with foundation axis 2	24990,000
5	Pillars with foundation axis 3	15130,000
6	Bridge concrete superstructure	27780,000
7	Bridge steel-box superstructure	112490,000
8	Bridge equipment	11230,000
9	Specified work process (sum of 1-8)	202740,000
10	Unspecified work process 8 (estimated 10% of specified)	20274,000

5.2.1. Calculation table

Calculation table has been prepared in ANSLAG program.

Table 59: Calculation table for the steel-box variant

Post	Tekst	enhet	lav	sannsynlig	hoy	veiet middel	kostnad eks. faktorer
B	Randselva concrete bridge	RS	0	0	0		passiv
B1	Prep measures, general cost	RS	43 264 716	44 602 800	47 724 996	45 340 036	45 340,0
B2	Abutment axis 1	RS	7 676 887	9 090 000	11 167 331	9 364 470	9 364,5
B3	Abutment axis 7	RS	1 776 924	2 030 000	2 584 836	2 154 694	2 154,7
B4	Pillars with foundation axs 2	RS	19 372 231	24 990 000	31 653 715	25 422 209	25 422,2
B5	Pillars with foundation axis 3	RS	12 379 374	15 130 000	18 007 894	15 182 590	15 182,6
B6	Bridge concrete superstructure	RS	21 197 019	27 780 000	35 059 700	28 067 900	28 067,9
B7	Bridge steel-box superstructure	RS	94 231 654	112 490 000	144 684 290	118 248 655	118 248,7
B8	Bridge equipment	RS	9 379 399	11 230 000	13 643 922	11 462 777	11 462,8
B9	Not specified work process 8	RS	16 601 349	20 274 000	25 680 169	20 990 330	20 990,3
Sum byggherre:							276 233,7
Sum prosesskalkyle:							0,0
Sum usikkerhetsvurderinger:							25 112,2
Resultat:							301 345,8

5.2.2. Calculation results

Table 60: Calculation results of the steel-box variant

Estimations	
Price range	2013
Requirements for accuracy	+/- 25%
P50 Cost	267,617 Mil. Kr.
Expected cost	301,346 Mil. Kr.
Standard deviation	66,932 Mil. Kr.
Relative standard deviation	22,2%
There is 90% probability that the estimate is between	
Lower value	226,0 Mil. Kr.
Highest value	376,7 Mil. Kr.

Relative standard deviation is smaller than the required accuracy. That means cost estimation is valid within set uncertainties and amounts.

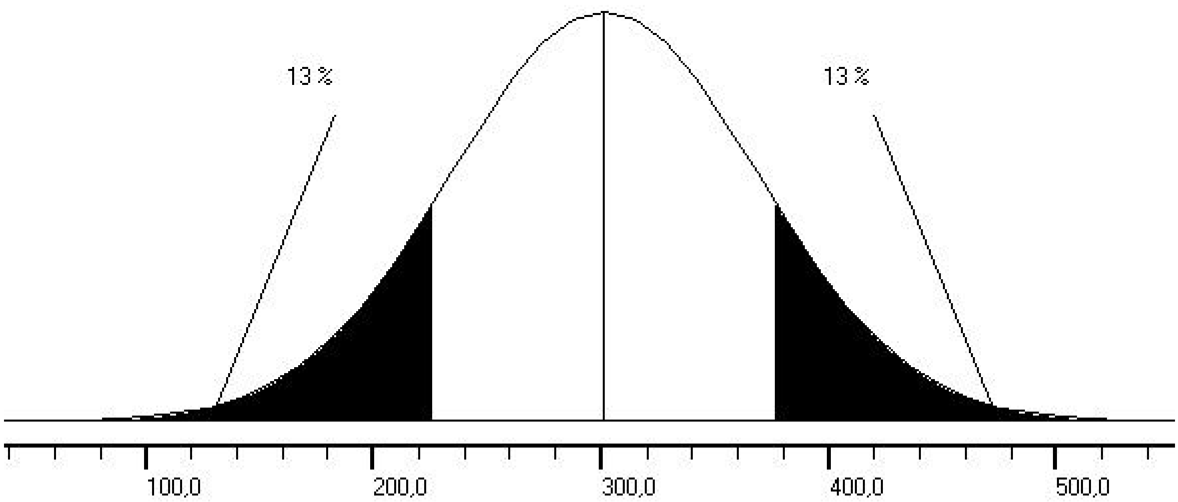


Figure 63: Probability distribution of costs, steel-box variant

S-Curve

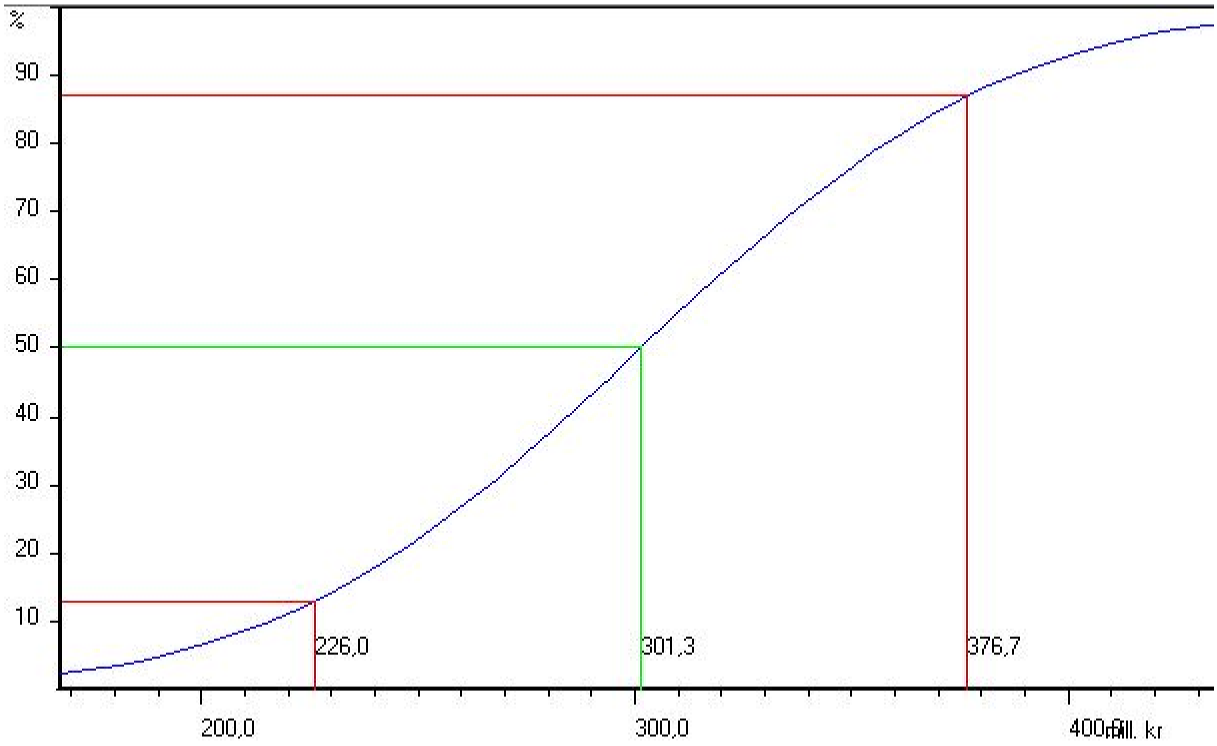


Figure 64: S-Curve, steel-box variant

Uncertainty profile

Post		Poster med storst usikkerhet	Usikkerhetsprofil: (varians av tot. varians)
	F07	Construction time	18 %
	F14	Design and construction phases	18 %
	F04	Geotechnics	15 %
B7		Bridge steel-box superstructure	10 %
	F08	Restricted working time	9 %
	F13	Disturbance	6 %
	F15	Unforseen conditins for the detailing	4 %
	F09	Regarding the aesthetics, environment	3 %
	F06	Market situation	2 %
	F01	Planning, designing	2 %

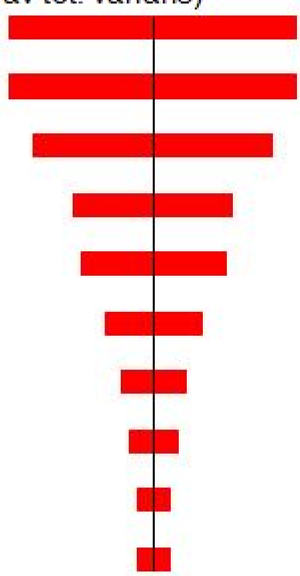


Figure 65: Uncertainty profile, steel-box variant

Additional measures

From the uncertainty profile we can see that to decrease major uncertainties we have to:

- Improve cost estimation regarding bridge steel-box superstructure to avoid overestimation in this element
- Review geotechnical investigations, implement tools and methods to avoid additional costs regarding handling the alum repositories
- Improve the working schedule and logistics of material transport to implement faster and better construction/design phases

6. Discussion

Model comparison

After the calculation of proposed solutions in point 3. Construction analysis, 5. Projection method and additional appendices we can compare them to control the cost and accuracy progress and assess the profitability of the better variant.

- Concrete variant

This construction solution has been updated in 3 steps, next ones more accurate than before. Comparison showed in the figures below.

First cost estimate in point 5 of "Projection method" mentions only preliminary values, roughly estimated by the preliminary studies. That is why the standard deviation from the result has become larger in regard to expected value.

Next cost estimate obtained in further process, (Appendix A) is more accurate within the subsections, e.g. abutment axis explained as formworks, scaffolding, concreting, soilsworks, etc. These subsections contained more valuable and accurate information about our costs, and therefore decreased our uncertainty. The decreased expected cost may result in some lack of information of costs, yet to be updated.

Final cost estimate in step 3 (Appendix B) is more accurate after our construction analysis from point 3. of the project. Accurate information about reinforcement of structure, prestressing steel and concrete used have been most crucial part of bill of quantities which gave more insight into our costs. This more adequate and accurate information has also resulted in decreased uncertainty with higher costs, which was expected.

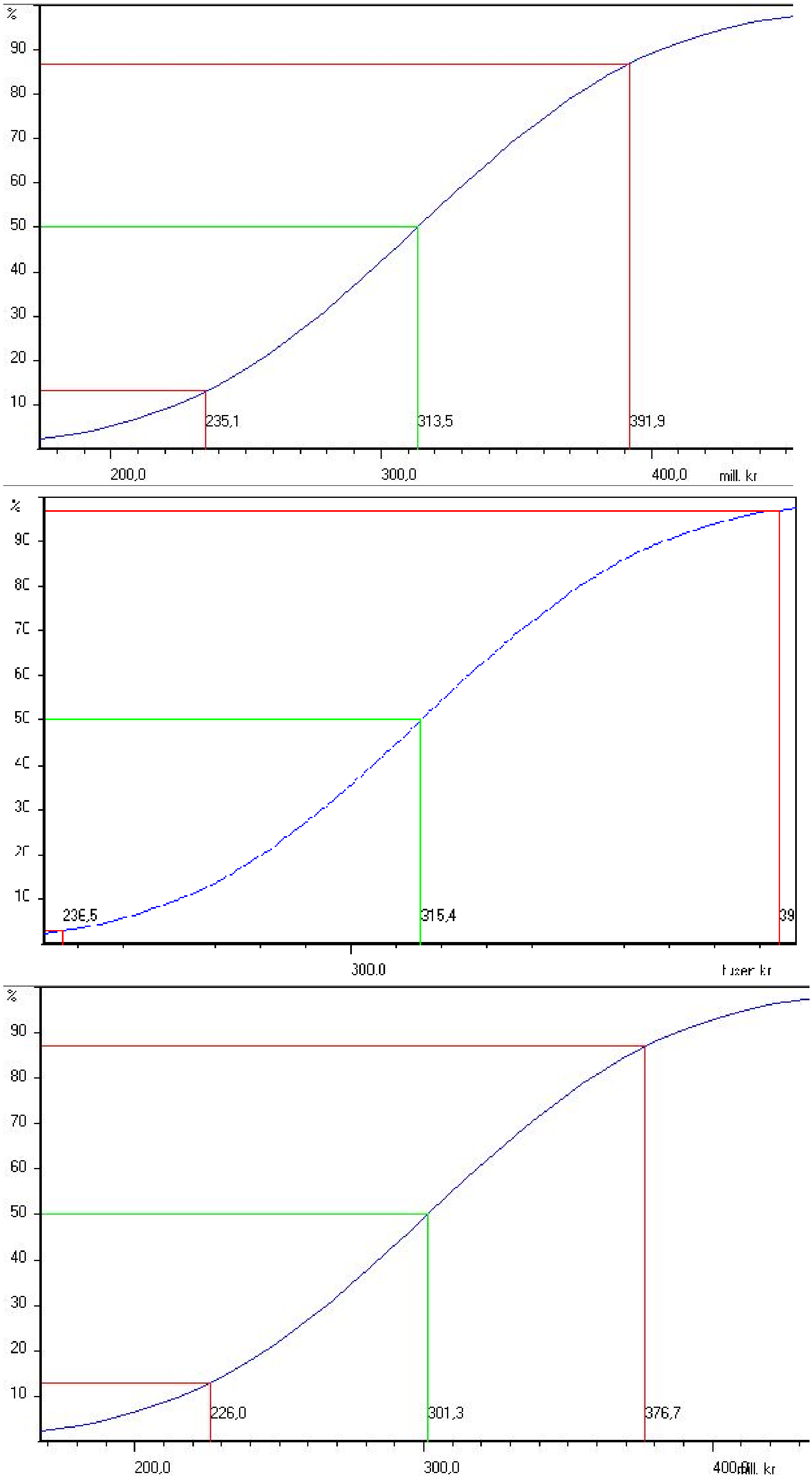


Figure 66: Model comparison in S-Curve, concrete variant, from the top: preliminary, more detailed, post-analysis

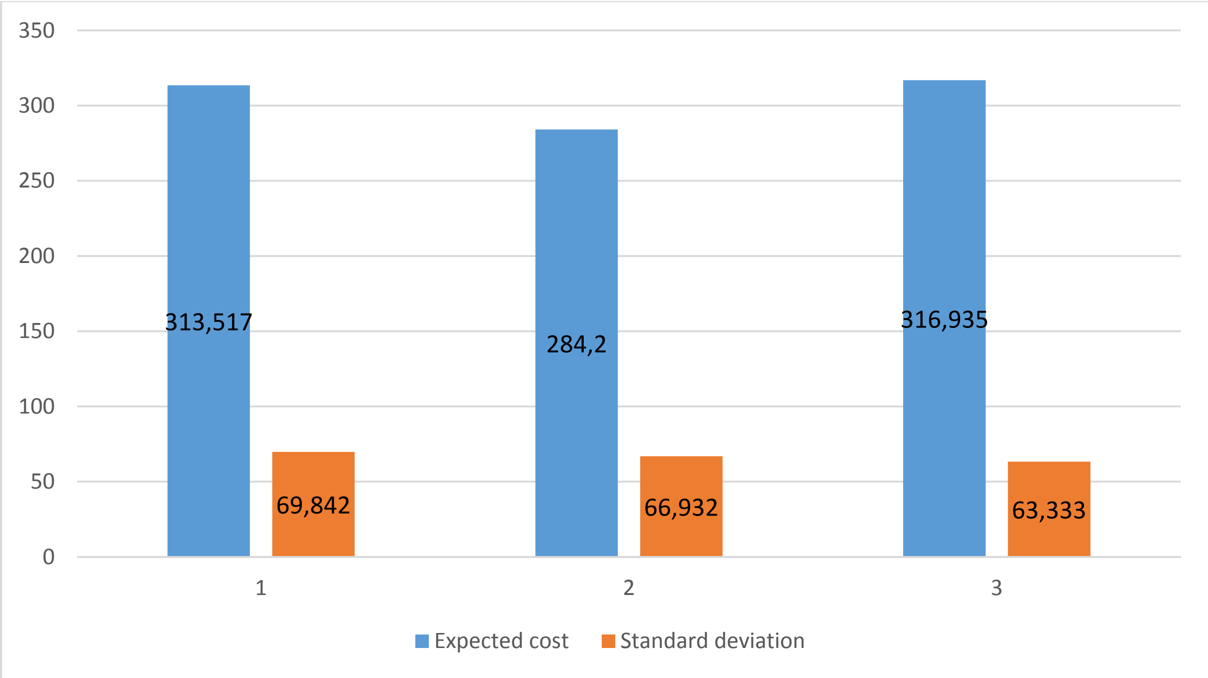


Figure 67: Cost estimation progress, concrete variant

- Steel variant

This construction solution has been updated only 2 times, due to lack of more accurate information about cost items. Comparison in the figures below.

First cost estimate is similar in characteristics to the one from concrete variant. In point 5 of "Projection method" it mentions only preliminary values, roughly estimated by the preliminary studies. That is why the standard deviation from the result has become larger in regard to expected value.

Second, and also final cost estimate in step 2 (Appendix C) is more accurate after our construction analysis from point 3. of the project. Accurate information about concrete slab system, truss system and thin-walled section of both superstructure and supports section used have been most crucial part of bill of quantities which gave more insight into our costs. This more adequate and accurate information has also resulted in decreased uncertainty with higher costs, which was expected.

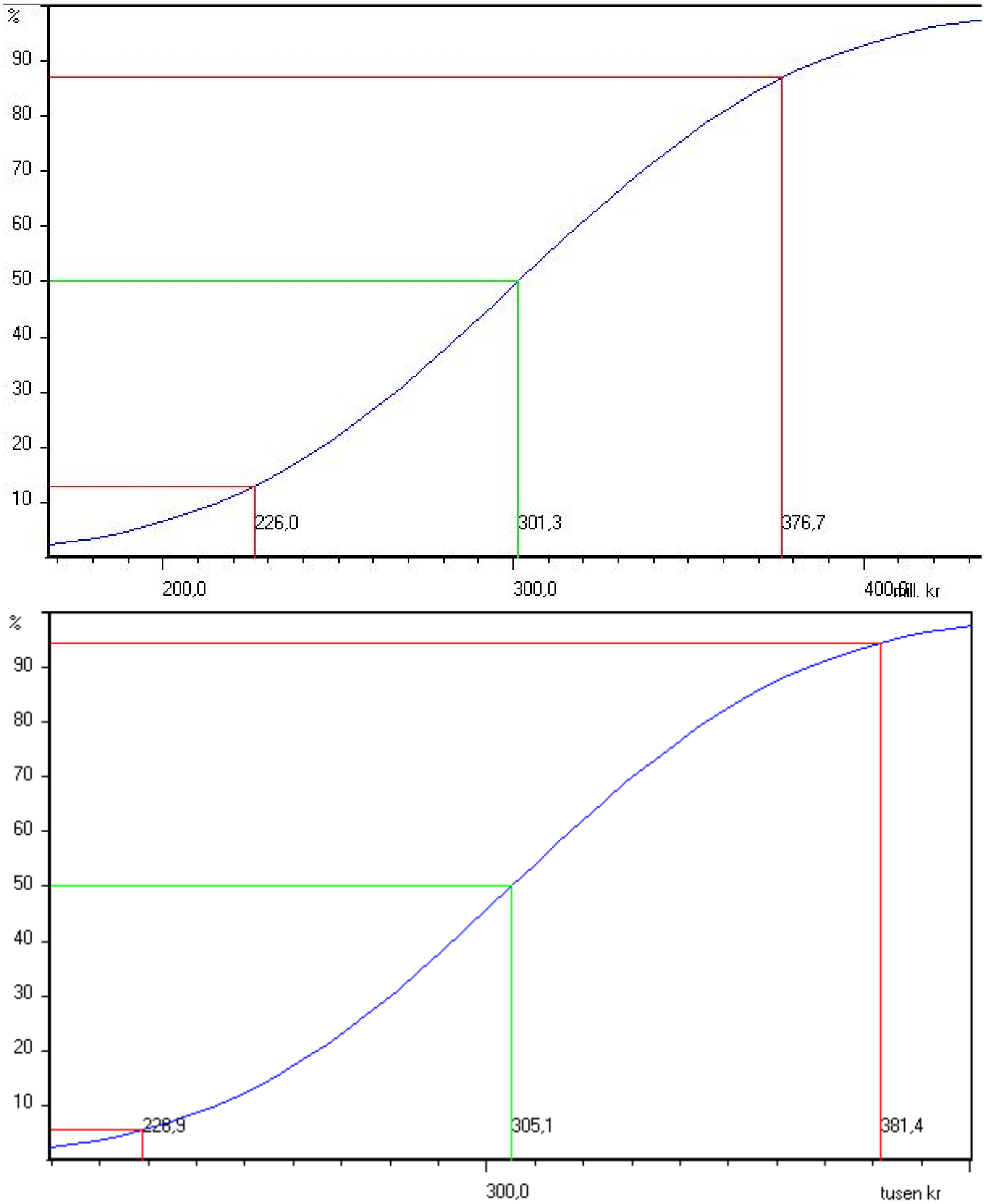


Figure 68: Model comparison in S-Curve, steel-box variant, from the top: preliminary, post-analysis

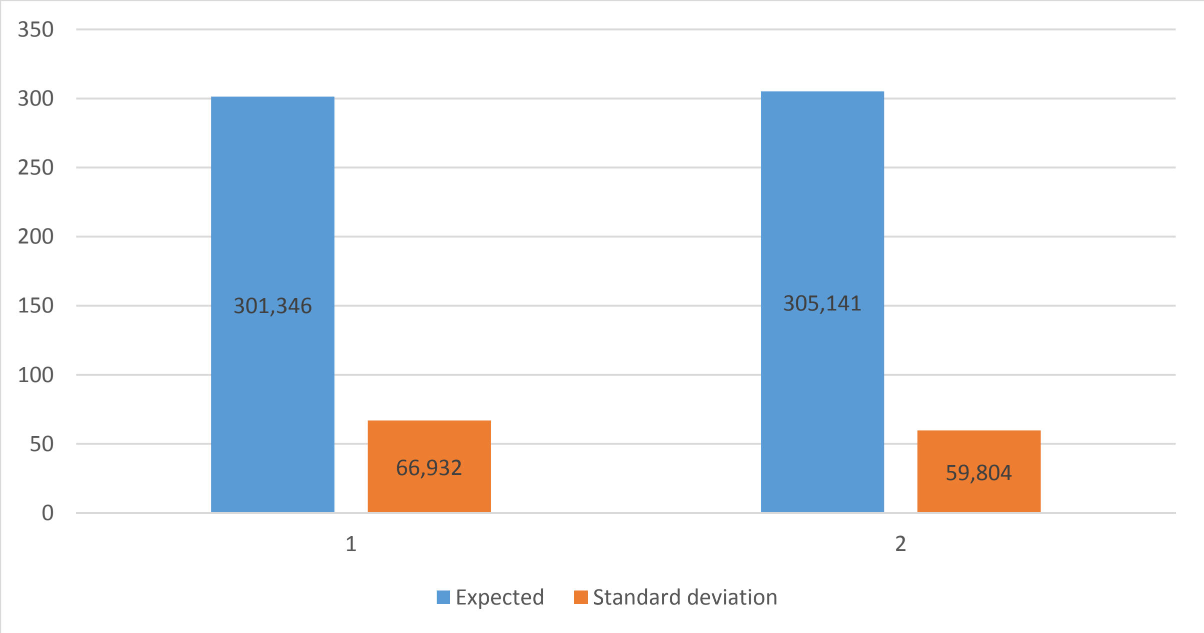


Figure 69: Cost estimation progress, steel-box variant

On the attached figures we can see that within the P10 and P90 quantile proposed concrete and steel-box solution have varied throughout the estimation process:

- 1st step: concrete variant: $\Delta = 391{,}9 - 235{,}1 = 156{,}8\ Mln.kr$
  steel variant: $\Delta = 376{,}7 - 226{,}0 = 150{,}7\ Mln.kr$
- 2nd step: concrete variant: $\Delta = 398{,}0 - 236{,}5 = 161{,}5\ Mln.kr$
  steel variant: $\Delta = 381{,}4 - 226{,}9 = 154{,}5\ Mln.kr$

In both steps, range has not changed significantly, with a mean range of$= 150 \sim 160\ Mln.kr$. This gives us good information about steady progress of estimation, with no extreme values that could readjust the estimates.

From the comparison of figures 67 and 69, we can see that the steel-box variant looks more promising with the expected cost and standard deviation. In the next stages of cost estimation it is likely to occur that the steel-box variant will indicate more profitable figures than the concrete one.

Nevertheless, concrete variant has so far the most detailed cost elements in the estimation. Therefore, we may take this solution into account when revising next estimates. Most crucial step will be when comparing both estimates on the same level of accuracy. Then we will obtain full view of model comparison.

It is also important to mention that whole cost estimation process with comparison is prepared by one individual. When having complete reference group we will obtain more points of view and therefore more points of reference with cost elements to compare and choose the most relevant one.

In the future cost estimation when obtaining more detailed description of price elements, S-Curve will tend to go steeper, then it is recommendable to assess the cost estimation once more to control the accuracy of estimation.

7. Conclusion

7.1. Final remarks

The cost estimation was within the suggested range of accuracy for given Municipal level. As the project evolves and cost estimation will obtain more price elements, it is recommended to adjust the new level of accuracy to control the estimation of price units.

The given material proved worthy and contributed to a good estimate process. The uncertainty factors' list gave a good overview of influences on the project and what challenges does the project face. The estimates agree with the given preliminary cost estimates within range and will provide good point of reference for future estimations.

7.2. Further work

As the work on the project will proceed, new cost estimates will appear with more information and more accurate cost elements. As for the proposed solution in the thesis, the steel-box variant will have to be more improved rather than concrete one. In case of balanced level of accuracy in both alternatives, it will be crucial to choose most profitable option.

In regard to geotechnical investigations and final solutions towards alum repositories, they will have to be presented to the reference group as soon as possible, in order to revise the time schedule and organize building site so that all the works will proceed smoothly and not cause delays.

In my personal opinion, most promising within financing, organizational, static and esthetical aspect will be the steel-box variant. Analysis has shown that it provides exceptional static system with construction method, that is more efficient and therefore less costly than concrete cantilever method. Most important part for the reference group will be to revise the static system, optimize sections and reinforcement in order to reduce costs, as the superstructure element is the most crucial element in cost estimate.

8. References

[1] "Anslagsmetoden Håndbok 217", Statens Vegvesen, Vegdirektoratet Byggherreseksjonen 2011.
[2] "Proactive management of uncertainty using the Successive Principle", Steen Lichtenberg 2002.
[3] "Total construction project management", George J. Ritz, Boston Massachusetts 2011.
[4] "Projektowanie mostow betonowych", Arkadiusz Madaj, Witold Wolowicki, Warszawa 2010.
[5] Statistisk Sentralbyrå, www.ssb.no
[6] Norsk Stål product catalog, www.produktkatalog.norskstaa;.no/Pages/Category.aspx?cat=Org0200&Category=po30

Appendix A – Extended cost estimate, concrete alternative

Calculation records

After obtaining detailed cost estimates for concrete variant from 'Multiconsult' construction company we can develop the cost estimate on a basis of new calculation elements. New table of estimate contains (prices in 1000 NOK):

Table 61: Extended cost estimate, concrete alternative

No.	Description	Cost
1	**Preparatory measure and general cost**	**55071,500**
2	**Abutment axis 1**	
2.1.	Soilsworks	200,000
2.2.	Formworks	290,000
2.3.	Reinforcement (200kg/m3)	2160,000
2.4.	Concrete	1044,000
2.5.	Drilled piles #1200 in ground	4860,000
2.6.	Bits	500,000
3	**Abutment axis 7**	
3.1.	Soilsworks	100,000
3.2.	Formworks	190,000
3.3.	Reinforcement (200 kg/m3)	540,000
3.4.	Concrete	252,000
3.5.	Steel core piles	330,000
4	**Columns with viaduct foundation**	
4.1.	Soilsworks	400,000
4.2.	Scaffolding	980,000
4.3.	Formworks	2400,000
4.4.	Reinforcement B500C (200kg/m3)	5940,000
4.5.	Concrete B45 SV-40	2970,000
4.6.	Steel core piles	550,000
5	**Pillars with foundation axis 2**	
5.1.	Soilsworks/Construction pit	1740,000
5.2.	Scaffolding	850,000
5.3.	Formworks	4440,000
5.4.	Reinforcement B500C (200kg/m3)	6840,000
5.5.	Concrete B45 SV-40	3420,000
5.6.	Drilled piles #1500 into rock	2100,000
5.7.	Rig and mobilized drilled piles with bits	2500,000
6	**Bridge concrete superstructure**	
6.1.	Scaffolding	6000,000
6.2.	Formworks	33600,000
6.3.	Addition to edge beams	3240,000
6.4.	Reinforcement B500C (180kg/m3)	32760,000
6.5.	Span reinforcement	37125,000

Table nr 61 continued

6.6.	Concrete B65 SV-40	18180,000
7	**Temporary structures using columns**	
7.1.	Soilsworks	100,000
7.2.	Scaffolding	430,000
7.3.	Formworks	1512,000
7.4.	Concrete B45 SV-40	2232,000
7.5.	Reinforcement B500C (200kg/m3)	4500,000
7.6.	Drilled piles	600,000
7.7.	Demolition/removal of temporary columns	1000,000
7.8.	Construction over railway	2000,000
8	**Bridge equipment**	
8.1.	Moisture insulation type A3-4	2106,000
8.2.	Asphalt (80mm)	1404,000
8.3.	Outer steel railings	3240,000
8.4.	Middle steel railings	1404,000
8.5.	Transition railings	140,000
8.6.	Pot bearings	350,000
8.7.	Joints	650,000
8.8.	Water drainage	100,000
8.9.	Electric works	2000,000

Results of calculation

Results of the calculus are presented in program ANSLAG 4.0. printouts.

Table 62: Calculation results, concrete variant, extended cost estimate

Estimations

Price range	2014
Requirements for accuracy	+/- 25% (zoning plan phase)
P50 Cost	281,4 Mil. Kr.
Expected cost	284,2 Mil. Kr.
Standard deviation	66,932 Mil. Kr.
Relative standard deviation	23,5%
There is 90% probability that the estimate is between	
Lower value	255,8 Mil. Kr.
Highest value	312,6 Mil. Kr.

Conclusion

From the obtained results we can see that clearly detailed pricing has reduced the cost of the enterprise and its relative standard deviation. Therefore we eliminated one of core problems of non-detailed cost estimate. From additional measures (still dependent on documentation status):

- Geotechnical investigations have to be still improved in order to secure alum repositories
- Time schedule has to be obtained to reduce process time and revise stages periods

Prosesskalkyle

Prisniva 2015

Post	Tekst	enhet	lav	sannsynlig	hoy	veiet middel	kostnad eks. faktorer
B	Bru	RS	0	0	0		passiv
B10	Soilsworks	RS	0	0	0		passiv
B11	Abutmnet axis 1	RS	150	200	250	200	0,2
B12	Abutment axis 7	RS	75	100	125	100	0,1
B13	Columns, viaduct	RS	300	400	500	400	0,4
B14	Foundation axis 2	RS	1 305	1 740	2 175	1 740	1,7
B15	Temporary structures	RS	0	100	100	59	0,1
B20	Formworks	RS	0	0	0		passiv
B21	Abutment axis 1	RS	218	290	363	290	0,3
B22	Abutment axis 7	RS	143	190	238	190	0,2
B23	Columns, viaduct	RS	1 800	2 400	3 000	2 400	2,4
B24	Foundation axis 2	RS	3 330	4 440	5 550	4 440	4,4
B25	Bridge superstructure	RS	25 200	33 600	42 000	33 600	33,6
B26	Temporary structures	RS	1 134	1 512	1 890	1 512	1,5
B27	Addition to edge beams	RS	2 430	3 240	4 050	3 240	3,2
B30	Reinforcement	RS	0	0	0		passiv
B31	Abutmnet axis 1	RS	1 620	2 160	2 700	2 160	2,2
B32	Abutment axis 7	RS	405	540	675	540	0,5
B33	Columns, viaduct	RS	4 455	5 940	7 425	5 940	5,9
B34	Foundation axis 2	RS	5 130	6 840	8 550	6 840	6,8
B35	Bridge superstructure	RS	24 570	32 760	40 950	32 760	32,8

Prosesskalkyle

Prisniva 2015

Post	Tekst	enhet	lav	sannsynlig	hoy	veiet middel	kostnad eks. faktorer
B36	Span reinforcement	RS	27 844	37 125	46 406	37 125	37,1
B37	Temporary structures	RS	0	4 500	4 500	2 640	2,6
B40	Concrete	RS	0	0	0		passiv
B41	Abutmnet axis 1	RS	783	1 044	1 305	1 044	1,0
B42	Abutment axis 7	RS	189	252	315	252	0,3
B43	Columns, viaduct	RS	2 228	2 970	3 713	2 970	3,0
B44	Foundation axis 2	RS	2 565	3 420	4 275	3 420	3,4
B45	Bridge superstructure	RS	13 635	18 180	22 725	18 180	18,2
B46	Temporary structures	RS	1 674	2 232	2 790	2 232	2,2
B50	Scaffolding	RS	0	0	0		passiv
B51	Columns, viaduct	RS	735	980	1 225	980	1,0
B52	Foundation axis 2	RS	638	850	1 063	850	0,9
B53	Bridge superstructure	RS	4 500	6 000	7 500	6 000	6,0
B54	Temporary structures	RS	323	430	538	430	0,4
B60	Other steel structures	RS	0	0	0		passiv
B61	Abutment axis 1, drilled piles	RS	3 645	4 860	6 075	4 860	4,9
B62	Abutment axis 1, bits	RS	375	500	625	500	0,5
B63	Abutment axis 7, steel core piles	RS	248	330	413	330	0,3
B64	Columns, viaduct foundation, piles	RS	413	550	688	550	0,6
B65	Foundation axis 2, drilled piles	RS	1 575	2 100	2 625	2 100	2,1
B66	Foundation axis 2, rig with piles	RS	1 875	2 500	3 125	2 500	2,5

Prosesskalkyle

Prisniva 2015

Post	Tekst	enhet	lav	sannsynlig	hoy	veiet middel	kostnad eks. faktorer
B67	Temporary structures, drilled piles	RS	450	600	750	600	0,6
B70	Bridge equipment	RS	0	0	0		passiv
B71	Moisture insulation type A3-4	RS	1 580	2 106	2 633	2 106	2,1
B72	Asphalt 80mm	RS	1 053	1 404	1 755	1 404	1,4
B73	Outer steel railings	RS	2 430	3 240	4 050	3 240	3,2
B74	Middle steel railings	RS	1 053	1 404	1 755	1 404	1,4
B75	Transition railings	RS	105	140	175	140	0,1
B76	Pot bearings	RS	263	350	438	350	0,4
B77	Joints	RS	488	650	813	650	0,7
B78	Water drainage	RS	75	100	125	100	0,1
B79	Electric works	RS	1 500	2 000	2 500	2 000	2,0
B80	Other costs	RS	0	0	0		passiv
B81	Preparatory measures	RS	41 304	55 072	68 840	55 072	55,1
B82	Demolition/removal of temp columns	RS	750	1 000	1 250	1 000	1,0
B83	Construction over railway	RS	1 500	2 000	2 500	2 000	2,0
B84	Not specified work process (10%)	RS	15 020	20 027	25 034	20 027	20,0
P	Prosjektering og byggeledelse	RS	0	0	0	0	0,0

Sum byggherre:	0,0
Sum prosesskalkyle:	273,5
Sum usikkerhetsvurderinger:	31,0
Resultat:	304,4

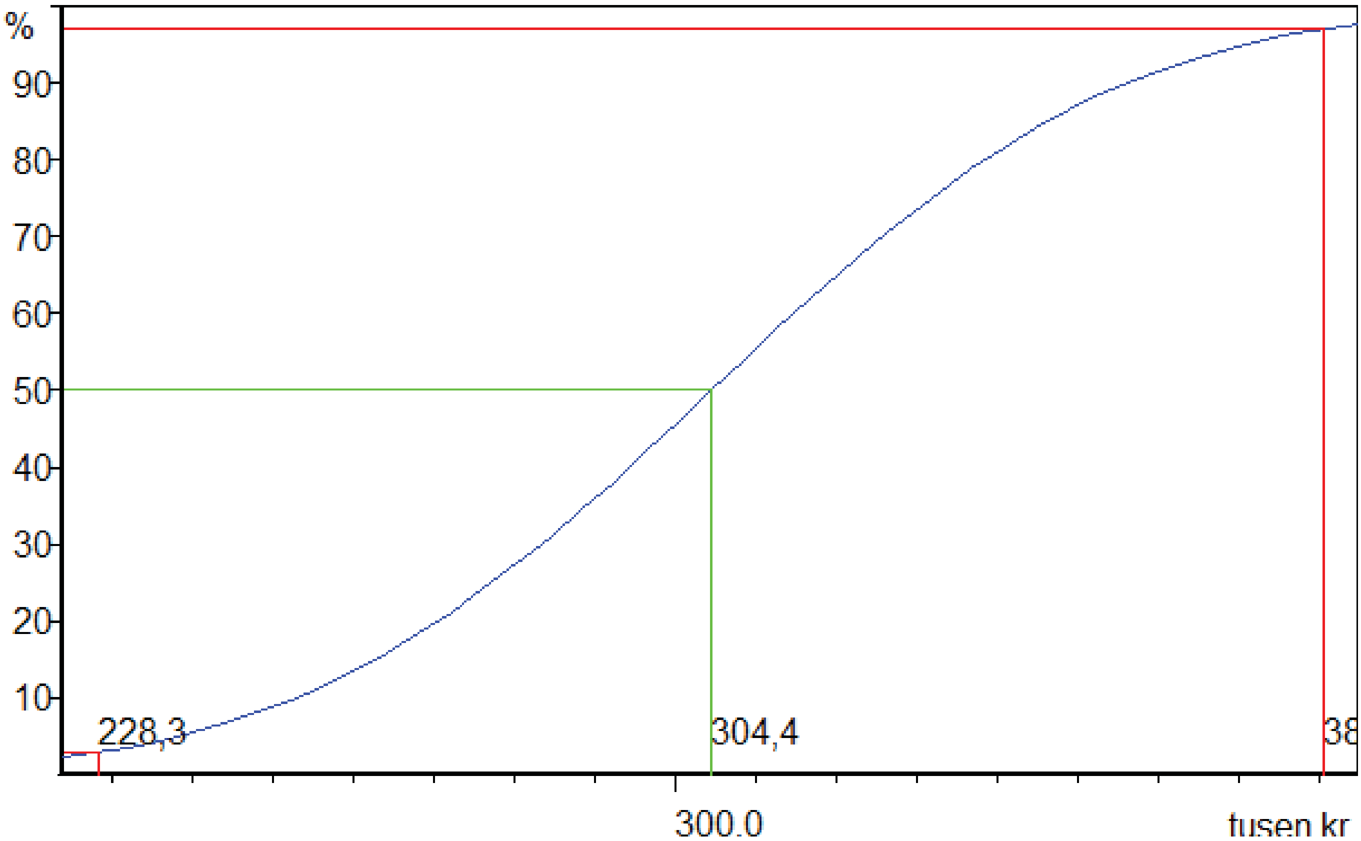
Risikoprofil:

Prisniva 2015

Post		Poster med storst usikkerhet	Usikkerhetsprofil: (varians av tot. varians)
	F05	Labor costs	40 %
	F07	Machinery, reinf+conc	14 %
	F01	Market situation	12 %
B81		Preparatory measures	7 %
B36		Span reinforcement	4 %
	F03	Transportation	4 %
B35		Bridge superstructure	3 %
B25		Bridge superstructure	3 %
	F04	Reinforcement	3 %
B45		Bridge superstructure	1 %

Fordeling:

Prisniva 2015



Appendix B – Extended cost estimate after construction analysis, concrete alternative

Calculation records

After obtaining detailed cost estimate for concrete variant based on construction analysis in point 3. we can develop the cost estimate on a basis of new calculation elements. Positions changed in point 6. New table of estimate contains (prices in 1000 NOK):

Table 63: Extended cost estimate after construction analysis, concrete alternative

No.	Description	Cost
1	**Preparatory measure and general cost**	**55071,500**
2	**Abutment axis 1**	
2.1.	Soilsworks	200,000
2.2.	Formworks	290,000
2.3.	Reinforcement (200kg/m3)	2160,000
2.4.	Concrete	1044,000
2.5.	Drilled piles #1200 in ground	4860,000
2.6.	Bits	500,000
3	**Abutment axis 7**	
3.1.	Soilsworks	100,000
3.2.	Formworks	190,000
3.3.	Reinforcement (200 kg/m3)	540,000
3.4.	Concrete	252,000
3.5.	Steel core piles	330,000
4	**Columns with viaduct foundation**	
4.1.	Soilsworks	400,000
4.2.	Scaffolding	980,000
4.3.	Formworks	2400,000
4.4.	Reinforcement B500C (200kg/m3)	5940,000
4.5.	Concrete B45 SV-40	2970,000
4.6.	Steel core piles	550,000
5	**Pillars with foundation axis 2**	
5.1.	Soilsworks/Construction pit	1740,000
5.2.	Scaffolding	850,000
5.3.	Formworks	4440,000
5.4.	Reinforcement B500C (200kg/m3)	6840,000
5.5.	Concrete B45 SV-40	3420,000
5.6.	Drilled piles #1500 into rock	2100,000
5.7.	Rig and mobilized drilled piles with bits	2500,000
6	**Bridge concrete superstructure**	
6.1.	Scaffolding	6000,000
6.2.	Formworks	33600,000
6.3.	Addition to edge beams	3240,000
6.4.	Reinforcement B500C (180kg/m3)	

Table nr 63 continued

6.4.1.	Cantilever section	23 140,759
6.4.2.	Segment section	27 925,959
6.5.	Span reinforcement	
6.5.1.	Cantilever phase	16 580,805
6.5.2.	Segment phase	8 998,202
6.6.	Concrete B65 SV-40	
6.6.1.	Cantilever phase	16 835,000
6.6.2.	Segment phase	4 006,625
7	**Temporary structures using columns**	
7.1.	Soilsworks	100,000
7.2.	Scaffolding	430,000
7.3.	Formworks	1512,000
7.4.	Concrete B45 SV-40	2232,000
7.5.	Reinforcement B500C (200kg/m3)	4500,000
7.6.	Drilled piles	600,000
7.7.	Demolition/removal of temporary columns	1000,000
7.8.	Construction over railway	2000,000
8	**Bridge equipment**	
8.1.	Moisture insulation type A3-4	2106,000
8.2.	Asphalt (80mm)	1404,000
8.3.	Outer steel railings	3240,000
8.4.	Middle steel railings	1404,000
8.5.	Transition railings	140,000
8.6.	Pot bearings	350,000
8.7.	Joints	650,000
8.8.	Water drainage	100,000
8.9.	Electric works	2000,000

Results of calculation

Results of the calculus are presented in program ANSLAG 4.0. printouts.

Table 64: Calculation results, concrete alternative, cost estimate after construction analysis

Estimations	
Price range	2014
Requirements for accuracy	+/- 25% (zoning plan phase)
P50 Cost	315,4 Mil. Kr.
Expected cost	316,935 Mil. Kr.
Standard deviation	63,333 Mil. Kr.
Relative standard deviation	19,98%
There is 90% probability that the estimate is between	
Lower value	236,5 Mil. Kr.
Highest value	398,0 Mil. Kr.

Conclusion

From the obtained results we have gained more expensive cost estimate in relation to the previous ones. It is because our costs regarding the construction have become more precise and therefore more costly, which was an expected event. It is important to mention that costs will tend to increase, yet with more accuracy obtained. The standard deviation and therefore relative standard deviation have decreased, which is a good sign that we approach more exact cost estimate.

Additional measures:

- In the next cost estimates, more precise cost elements should be derived in order to achieve better accuracy, position to be focused on are: labor costs, machinery and the tendency of market influence;
- Geotechnical surveys are yet to be obtained, therefore these results will also influence additional measures to the construction process and the cost estimate itself, they have to be taken into account as a crucial part;
- Construction analysis has also given additional information for the time schedule, i.e. time of concreting the sections, age of concrete after the process, etc. these position will surely increase the accuracy of schedule and can be taken into account in future scheduling.

Prosesskalkyle

Prisniva 2015

Post	Tekst	enhet	lav	sannsynlig	hoy	veiet middel	kostnad eks. faktorer
B	Bru	RS	0	0	0		passiv
B10	Soilsworks	RS	0	0	0		passiv
B11	Abutmnet axis 1	RS	150	200	250	200	0,2
B12	Abutment axis 7	RS	75	100	125	100	0,1
B13	Columns, viaduct	RS	300	400	500	400	0,4
B14	Foundation axis 2	RS	1 305	1 740	2 175	1 740	1,7
B15	Temporary structures	RS	0	100	100	59	0,1
B20	Formworks	RS	0	0	0		passiv
B21	Abutment axis 1	RS	218	290	363	290	0,3
B22	Abutment axis 7	RS	143	190	238	190	0,2
B23	Columns, viaduct	RS	1 800	2 400	3 000	2 400	2,4
B24	Foundation axis 2	RS	3 330	4 440	5 550	4 440	4,4
B25	Bridge superstructure	RS	25 200	33 600	42 000	33 600	33,6
B26	Temporary structures	RS	1 134	1 512	1 890	1 512	1,5
B27	Addition to edge beams	RS	2 430	3 240	4 050	3 240	3,2
B30	Reinforcement	RS	0	0	0		passiv
B31	Abutmnet axis 1	RS	1 620	2 160	2 700	2 160	2,2
B32	Abutment axis 7	RS	405	540	675	540	0,5
B33	Columns, viaduct	RS	4 455	5 940	7 425	5 940	5,9
B34	Foundation axis 2	RS	5 130	6 840	8 550	6 840	6,8
B35	Bridge superstructure	RS	0	0	0		passiv

Prosesskalkyle

Prisniva 2015

Post	Tekst	enhet	lav	sannsynlig	hoy	veiet middel	kostnad eks. faktorer
B351	Cantilever section	RS	17 356	23 141	28 926	23 141	23,1
B352	Segment section	RS	20 944	27 926	34 907	27 926	27,9
B36	Span reinforcement	RS	0	0	0		passiv
B361	Cantilever phase	RS	12 436	16 581	20 726	16 581	16,6
B362	Segment phase	RS	6 749	8 998	11 248	8 998	9,0
B37	Temporary structures	RS	0	4 500	4 500	2 640	2,6
B40	Concrete	RS	0	0	0		passiv
B41	Abutmnet axis 1	RS	783	1 044	1 305	1 044	1,0
B42	Abutment axis 7	RS	189	252	315	252	0,3
B43	Columns, viaduct	RS	2 228	2 970	3 713	2 970	3,0
B44	Foundation axis 2	RS	2 565	3 420	4 275	3 420	3,4
B45	Bridge superstructure	RS	0	0	0		passiv
B451	Cantilever phase	RS	12 626	16 835	21 044	16 835	16,8
B452	Segment phase	RS	3 005	4 007	5 008	4 007	4,0
B46	Temporary structures	RS	1 674	2 232	2 790	2 232	2,2
B50	Scaffolding	RS	0	0	0		passiv
B51	Columns, viaduct	RS	735	980	1 225	980	1,0
B52	Foundation axis 2	RS	638	850	1 063	850	0,9
B53	Bridge superstructure	RS	4 500	6 000	7 500	6 000	6,0
B54	Temporary structures	RS	323	430	538	430	0,4
B60	Other steel structures	RS	0	0	0		passiv

Prosesskalkyle

Prisniva 2015

Post	Tekst	enhet	lav	sannsynlig	hoy	veiet middel	kostnad eks. faktorer
B61	Abutment axis 1, drilled piles	RS	3 645	4 860	6 075	4 860	4,9
B62	Abutment axis 1, bits	RS	375	500	625	500	0,5
B63	Abutment axis 7, steel core piles	RS	248	330	413	330	0,3
B64	Columns, viaduct foundation, piles	RS	413	550	688	550	0,6
B65	Foundation axis 2, drilled piles	RS	1 575	2 100	2 625	2 100	2,1
B66	Foundation axis 2, rig with piles	RS	1 875	2 500	3 125	2 500	2,5
B67	Temporary structures, drilled piles	RS	450	600	750	600	0,6
B70	Bridge equipment	RS	0	0	0		passiv
B71	Moisture insulation type A3-4	RS	1 580	2 106	2 633	2 106	2,1
B72	Asphalt 80mm	RS	1 053	1 404	1 755	1 404	1,4
B73	Outer steel railings	RS	2 430	3 240	4 050	3 240	3,2
B74	Middle steel railings	RS	1 053	1 404	1 755	1 404	1,4
B75	Transition railings	RS	105	140	175	140	0,1
B76	Pot bearings	RS	263	350	438	350	0,4
B77	Joints	RS	488	650	813	650	0,7
B78	Water drainage	RS	75	100	125	100	0,1
B79	Electric works	RS	1 500	2 000	2 500	2 000	2,0
B80	Other costs	RS	0	0	0		passiv
B81	Preparatory measures	RS	41 304	55 072	68 840	55 072	55,1
B82	Demolition/removal of temp columns	RS	750	1 000	1 250	1 000	1,0
B83	Construction over railway	RS	1 500	2 000	2 500	2 000	2,0

Prosesskalkyle

Prisniva 2015

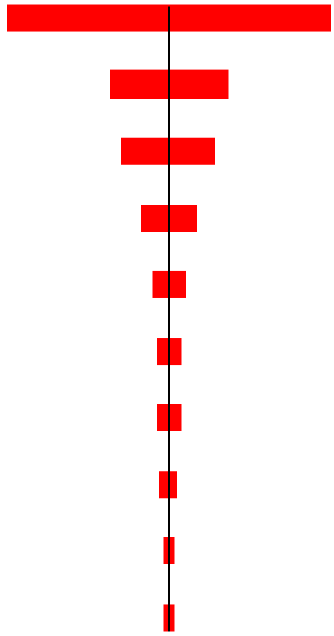
Post	Tekst	enhet	lav	sannsynlig	hoy	veiet middel	kostnad eks. faktorer
B84	Not specified work process (10%)	RS	15 020	20 027	25 034	20 027	20,0
P	Prosjektering og byggeledelse	RS	0	0	0	0	0,0

Sum byggherre:	0,0
Sum prosesskalkyle:	282,9
Sum usikkerhetsvurderinger:	32,5
Resultat:	315,4

Risikoprofil:

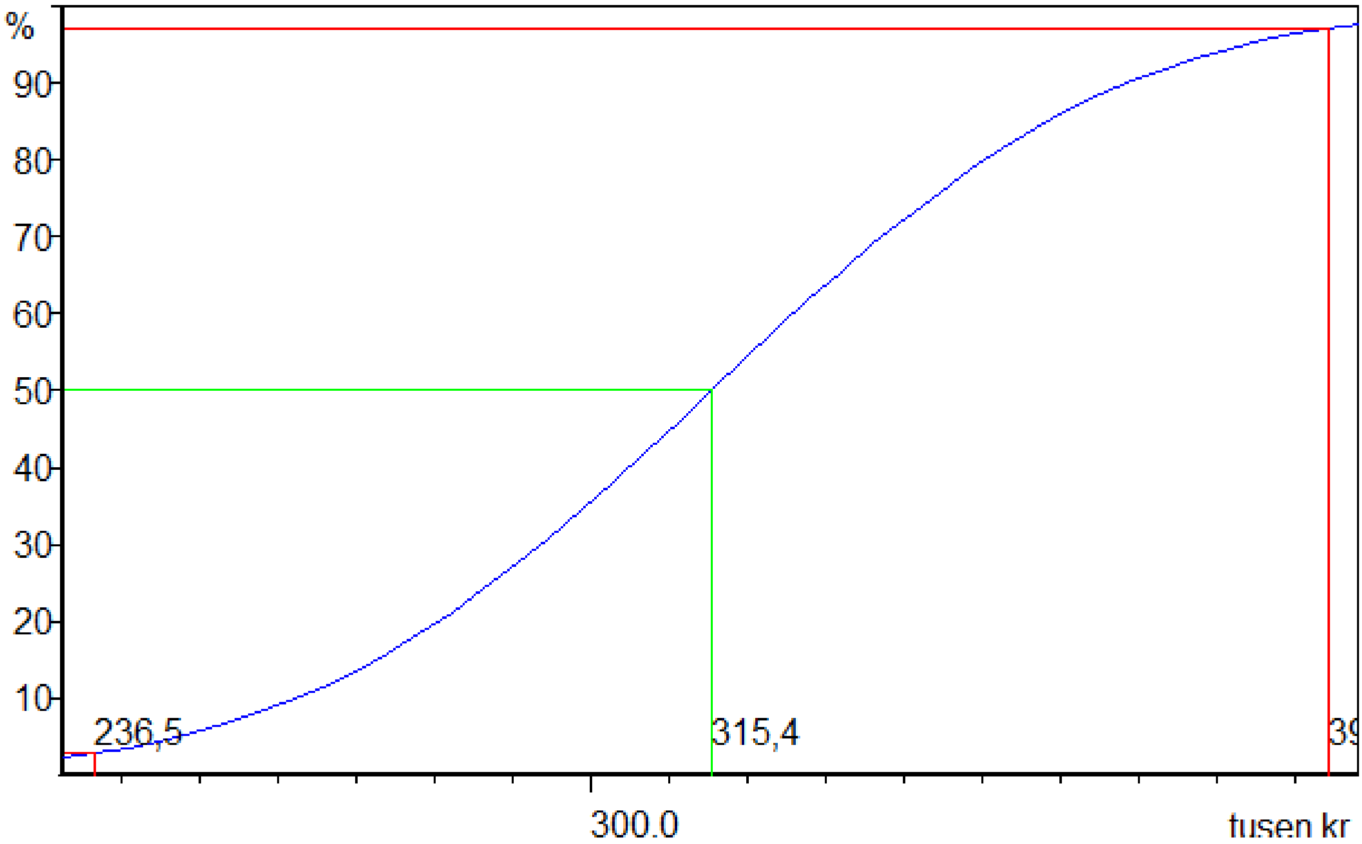
Prisniva 2015

Post		Poster med storst usikkerhet	Usikkerhetsprofil: (varians av tot. varians)
	F05	Labor costs	42 %
	F07	Machinery, reinf+conc	15 %
	F01	Market situation	12 %
B81		Preparatory measures	7 %
	F03	Transportation	4 %
	F04	Reinforcement	3 %
B25		Bridge superstructure	3 %
B352		Segment section	2 %
B351		Cantilever section	1 %
	F02	Concrete, type	1 %



Fordeling:

Prisniva 2015



Appendix C – Extended cost estimate after construction analysis, steel-box alternative

Calculation records

After obtaining detailed cost estimate for steel-box variant based on construction analysis in point 3. we can develop the cost estimate on a basis of new calculation elements. Positions changed in point 6. and 7. New table of estimate contains (prices in 1000 NOK):

Table 65: Extended cost estimate after construction analysis, steel-box alternative

No.	Description	Cost
1	Preparatory measure and general cost	44 602,800
2	Abutment axis 1	9 090,000
3	Abutment axis 4	2 030,000
4	Pillars with foundation axis 2	24 990,000
5	Pillars with foundation axis 3	15 130,000
6	Bridge concrete superstructure	
6.1.	Reinforcement B500C (180 kg/m^3)	32 577,293
6.2.	Concrete B45 SV-40	4 725,000
7	Bridge steel-box superstructure	
7.1.	Steel truss members of S355NL	20 222,308
7.2.	Steel thin-walled section of S460NL	63 544,341
8	Bridge equipment	11 230,000
9	Unspecified work process 8 (estimated 10% of specified)	20 274,000

Results of calculation

Results of the calculus are presented in program ANSLAG 4.0. printouts.

Table 66: Calculation results, steel-box variant, cost estimate after construction analysis

Estimations	
Price range	2014
Requirements for accuracy	+/- 25% (zoning plan phase)
P50 Cost	305,100 Mil. Kr.
Expected cost	305,141 Mil. Kr.
Standard deviation	59,804 Mil. Kr.
Relative standard deviation	19,59 %
There is 90% probability that the estimate is between	
Lower value	228,9 Mil. Kr.
Highest value	381,4 Mil. Kr.

Conclusion

From the obtained results we have gained more expensive cost estimate in relation to the previous ones. It is because our costs regarding the construction have become more precise and therefore more costly, which was an expected event.
It is important to mention that costs will tend to increase, yet with more accuracy obtained. The standard deviation and therefore relative standard deviation have decreased, which is a good sign that we approach more exact cost estimate.

Additional measures:

- Unfortunately we get the point of reference for 2 projections, which may prove insufficient for further proposed costs, yet it indicates the need of more accurate estimates;
- In the next cost estimates, more precise cost elements should be derived in order to achieve better accuracy, position to be focused on are: labor costs, machinery and the tendency of market influence;
- Geotechnical surveys are yet to be obtained, therefore these results will also influence additional measures to the construction process and the cost estimate itself, they have to be taken into account as a crucial part;
- Construction analysis has also given additional information for the time schedule, i.e. time of concreting the sections, time per truss section, etc. these position will surely increase the accuracy of schedule and can be taken into account in future scheduling.

Prosesskalkyle

Prisniva 2015

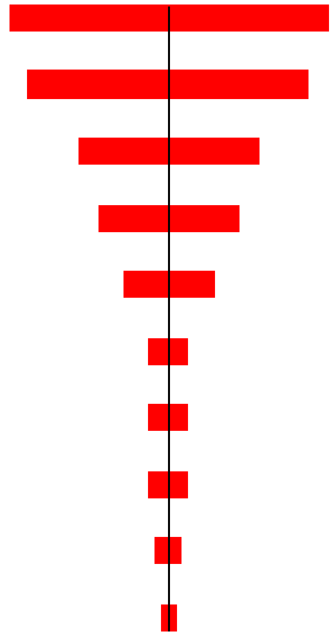
Post	Tekst	enhet	lav	sannsynlig	hoy	veiet middel	kostnad eks. faktorer
B	Bru	RS	0	0	0		passiv
B10	Preparatory measure, general cost	RS	33 452	44 603	55 754	44 603	44,6
B20	Abutment axis 1	RS	6 818	9 090	11 363	9 090	9,1
B30	Abutment axis 4	RS	1 523	2 030	2 538	2 030	2,0
B40	Pillars with foundation axis 2	RS	18 743	24 990	31 238	24 990	25,0
B50	Pillars with foundation axis 3	RS	11 348	15 130	18 913	15 130	15,1
B60	Bridge concrete superstructure	RS	0	0	0		passiv
B61	Reinforcement B500C	RS	24 433	32 577	40 722	32 577	32,6
B62	Concrete B45 SV-40	RS	3 544	4 725	5 906	4 725	4,7
B70	Bridge steel-box superstructure	RS	0	0	0		passiv
B71	Steel truss members of S355NL	RS	15 167	20 222	25 278	20 222	20,2
B72	Steel thin-walled section of S460NL	RS	47 658	63 544	79 430	63 544	63,5
B80	Bridge equipment	RS	8 423	11 230	14 038	11 230	11,2
B90	Unspecified work process 8	RS	15 206	20 274	25 343	20 274	20,3
P	Prosjektering og byggeledelse	RS	0	0	0	0	0,0

Sum byggherre:	0,0
Sum prosesskalkyle:	248,4
Sum usikkerhetsvurderinger:	56,7
Resultat:	305,1

Risikoprofil:

Prisniva 2015

Post		Poster med storst usikkerhet	Usikkerhetsprofil: (varians av tot. varians)
	F05	Labor costs	25 %
	F03	Transportation	22 %
B72		Steel thin-walled section of S460NL	14 %
	F07	Machinery, reinf+conc	11 %
	F01	Market situation	7 %
	F02	Steel, type	3 %
B10		Preparatory measure, general cost	3 %
B61		Reinforcement B500C	3 %
	F06	Machinery, soilsworks	2 %
B40		Pillars with foundation axis 2	1 %



Fordeling:

Prisniva 2015