New dimensions in bridge construction in Norway

Neue Dimensionen im Brückenbau in Norwegen

La construction de ponts aborde de nouveaux rivages en Norvège

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1. Steienbridge

1.1. Background

Steienbridge is situated in Alvdal municipality. Alvdal is located in Hedmark County, 380 km north of the capital Oslo. The bridge is located in highway 3, which is one of the main roads connecting the east and mid-Norway. Daily traffic is about four thousand vehicles. The bridge crosses the river Glomma and will be a new landmark for the village Alvdal.
The new bridge replaces the old Steien road bridge built in 1953 and a parallel pedestrian bridge built in 1983. The new bridge is designed with traffic loads according to EN-1991-2 and with a 100-year design-life.

Figure 1: The old Steien bridge

The network arch bridge has a single span reaching 88 meters. The slab is made of reinforced pre-stressed light-weight concrete that also works as the tie for the arches. The slab carries the tension load, which is in balance with the arch compression force. The vertical loads working on the slab are distributed to the arch through a total of 68 cables in the network cable system. One of the main benefits of using this type of bridge in this specific location is addressed to the slenderness of the deck structure. A normal beam bridge would have led to that the whole road had to be elevated to a higher level to overcome a 200 years flooding. The adjusted level would correspond to the height of the girder. The bridge carries two traffic lanes and two 3 meter wide pedestrian walkways.

1.2. Structural performance of the network arch bridge

A key feature of the network bridge is that it almost does not experience bending moments in the arch. This is the case as long the majority of the hangers are in tension. The buckling strength in the arch is high, so is the stiffness regarding vertical deflection. The network system with inclined hangers allows for a very efficient structural response, which leads to very homogeneous hanger dimensioning. The cross section for the hangers is the same along the bridge.

Figure 2 and 3 shows the results from a comparison between the network arch concept for Steien bridge and a traditional 3 hinged arch bridge regarding moment distribution and vertical deflection due to asymmetric loading combined with self-weight of the structure.

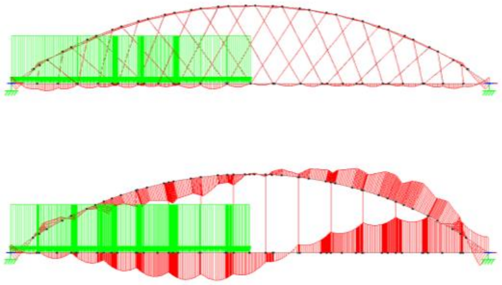

Figure 2: Bending moment

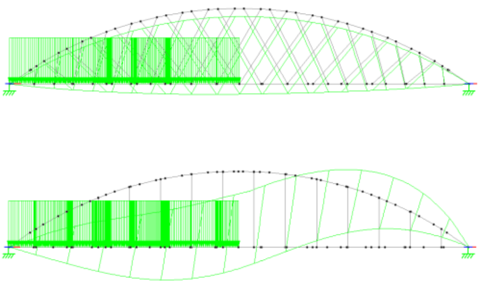

Figure 3: Vertical deflection

The arches are made as part of a circle; giving an evenly distributed bending moment in the cords and making the production easier. The upper node of the hangers are placed equidistantly along the lower arch and the hangers are not merged in the nodal points; this gives an optimal support in the in plane buckling and evens out the bending moment.

1.3. Design for the new Steienbridge

Preliminary studies for the replacement for the existing Steien bridge showed that a network arch bridge where competitive to other relevant alternatives. The tender matching the cost estimates also confirmed this.

Figure 4: Illustration of Steienbridge

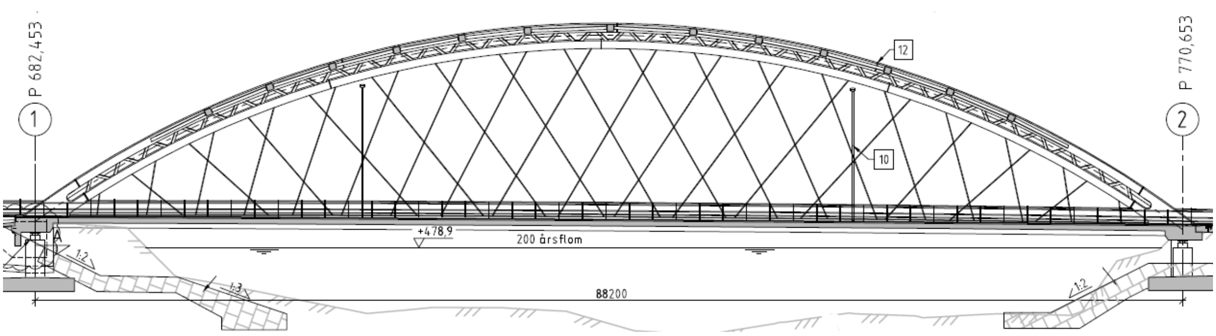

Figure 5: Steienbridge

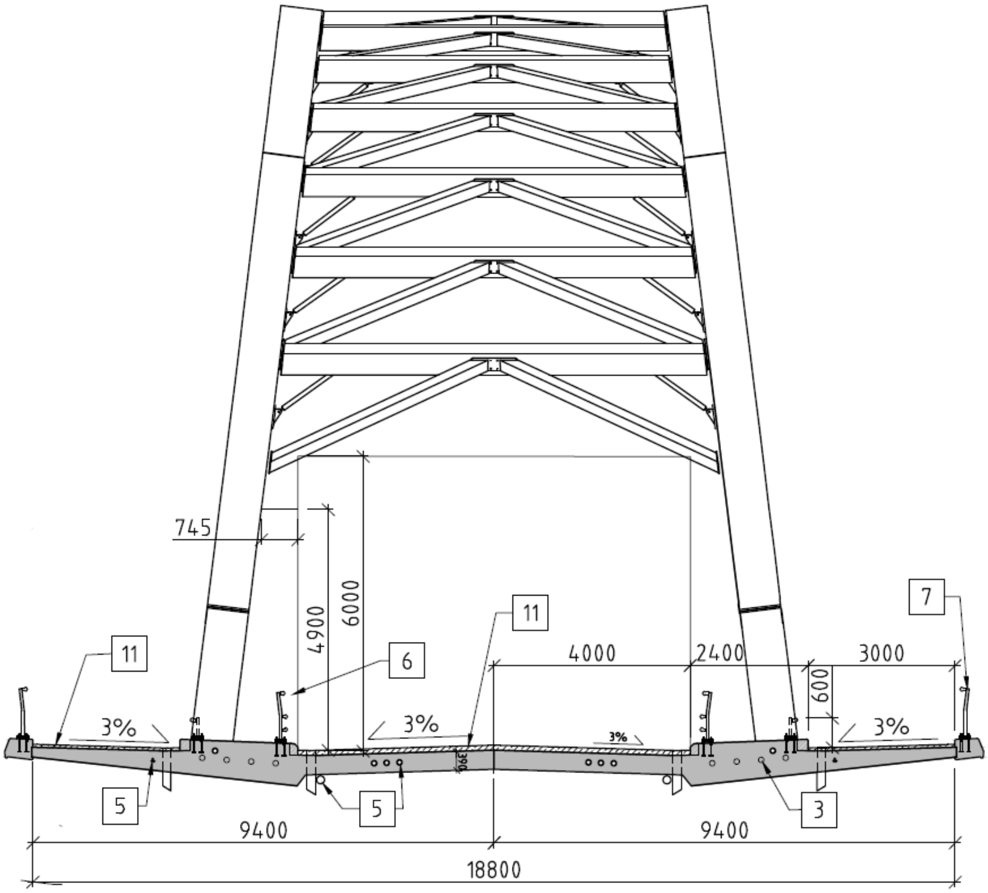

Figure 6: Steienbridge, sectional cut

Figure 7: Steienbridge, 3D illustration

The new bridge showed in figure 4 to 7, will have a single span length of 88.2 meters and arches that rise 15 meters. The bridge carries two traffic lanes with a total width of 8 meters and two 3 meter wide pedestrian walkways. The total width of the slab is 19.8 meter.

Arches made of rectangular glulam sections define the bridge. The wind bracings are made of glulam sections in combination with compression steel bars. All glulam elements are treated with creosote and copper impregnation. The crossing hangers are made of steel bars. The arches are inclined 7 degrees inwards.
The slab is made of in situ casted lightweight concrete with pre-stressing. The hangers are48 mmMacalloy520 steel rods delivered with adjustable fittings. The breaking capacity is 795 kN.
Zink plates cover the top of the glulam elements.

1.4. Details

Figure 8, 9 and 10 shows some typical details for the bridge

Figure 8: Details of the truss arch

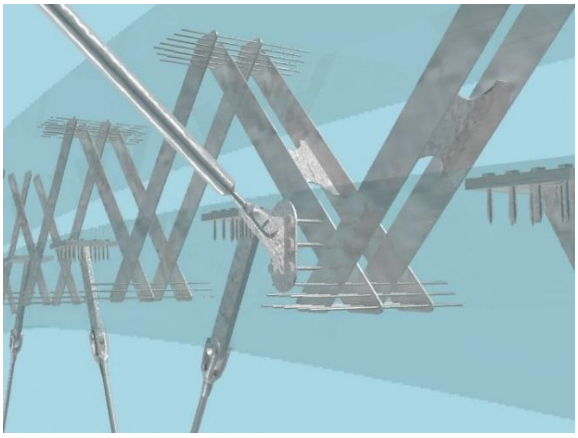

Figure 9: Transparent view through the arch

At the upper part the hangers are connected to steel plates that are going through the lower arch and are welded to a top steel plate. The plate transfer the axial load from the hanger directly into the arch through compression perpendicular to the grain. In addition, screws are used between the top plate and the arch in order to transfer shear loads. The diagonals in the truss arches are made of 10 mm thick stainless steel plates that are connected to the glulam with stainless D12 dowels.

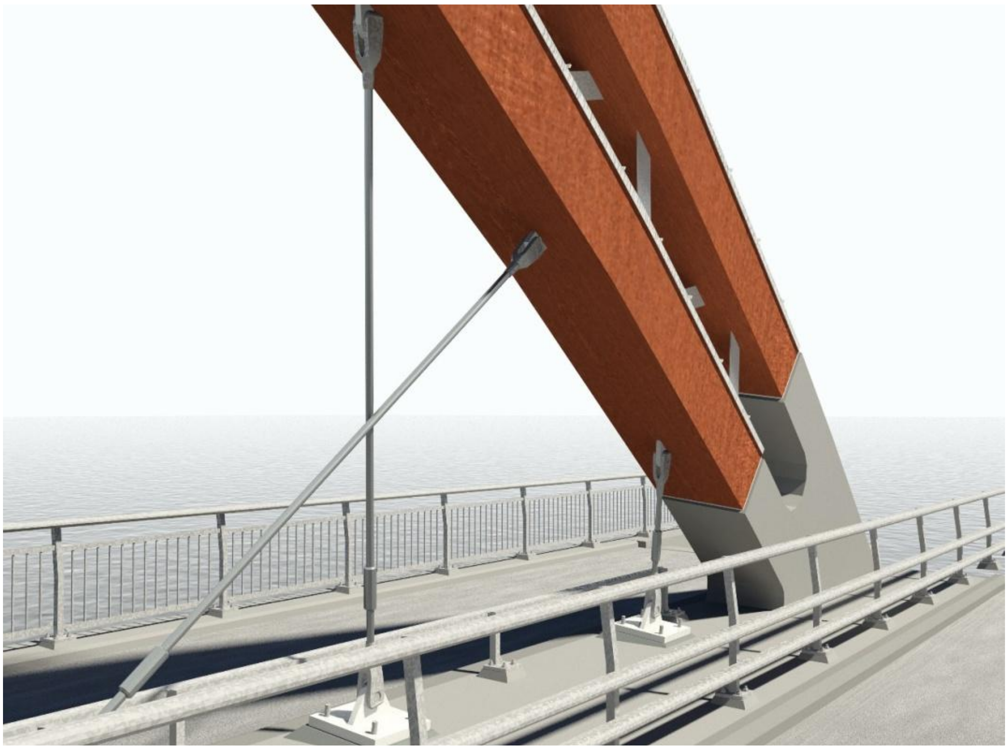

Figure 10: Detail of the hanger connections

1.5. Fabrication, transportation and assembly

The bridge is assembled on site. A temporary bridge was placed prior to the demolition of the existing bridges. The abutments and slab are completed before the arch is mounted.

Figure 11: The construction site

The glulam elements are produced and pre-assembled at the glulam factory. Each arch are divided into four elements that will be supported by temporary columns rising from the deck. Each element is transported to the site complete with steel parts. After the assembly of the hangers connecting the arch and the slab, the framework is lowered and removed.

Figure 12: Stainless steel parts at the lower end of the arch.

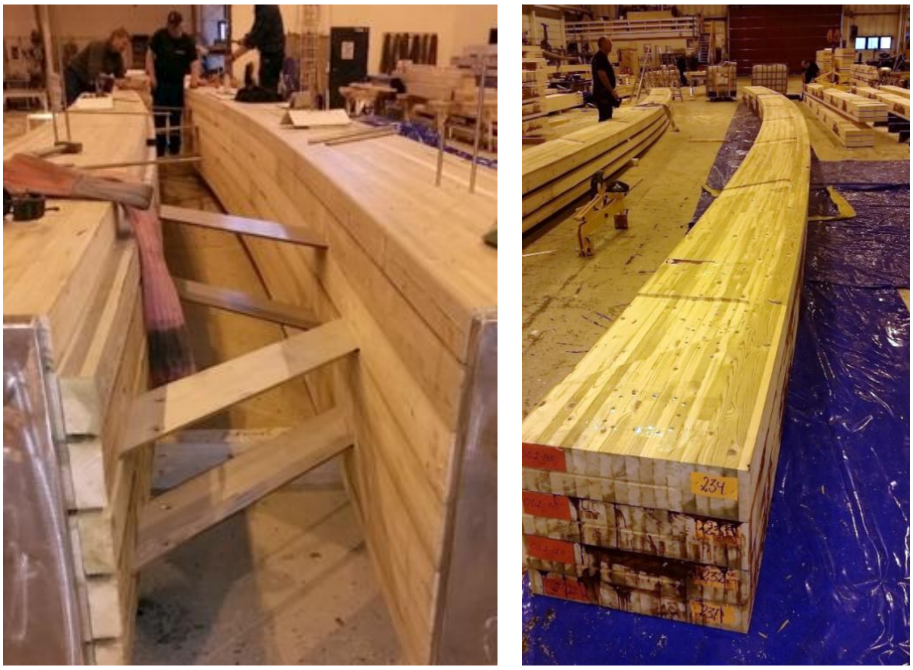

Figure 13: Pre-assembly of the arches in the glulam factory

A significant challenge is to ensure that the hangers are actually getting the defined tensile load and thus achieves the intended geometrical shape of the bridge. The behavior of the system is non-linear in terms of the effect of tensioning or de-tensioning of the hangers. Due to the system's non-linear behavior, and avoiding complex tensioning procedures, the slab is given an oversized pre-camber. In this way, the hangers can be adjusted to their final theoretical lengths in unstressed condition accounting for measured geometrical imperfections, and installed without use of jacks. The hangers are checked after removing all temporary framework, and adjusted with jacks if they are outside a rage of +/- 10% of the design force.
The bridge will be finished in the spring of 2016.

2. Norsengabridge

2.1. Background

The Norsengabridge is placed in Kongsvinger, Norway. It will replace an existing concrete/steel bridge from 1960. The existing bridge is 76 m long and divided into three spans. The existing bridge has a limited load capacity, which has been a problem for timber transportation in the area. The new bridge must also include a lane for pedestrians, which the existing bridge has not. The existing bridge crosses over two railroad tracks, with a clearance of 5,9 m.

Figure 14: The bridge site

The Norwegian government's agency for railway services, Jernbaneverket, demands a clearance of 7,2 m. Consequently means that the new bridge must be higher above the railway track. Because of the area around the bridge, the new bridge deck should be as thin as possible to reduce the height of fillings. The chosen superstructure has a stress-laminated timber deck, which is a slim deck solution. The bridge is also placed beside the largest timber storage area in Norway. A timber bridge was therefore both a good and natural solution.

Figure 15: Existing concrete/steel bridge

To replace the existing bridge it was necessary to build an interim solution to the east of the crossing. This was done using a steel element bridge shown below. This was built in 2014/2015. In this way the existing bridge could be demolished and the new bridge can be built without interrupting traffic.

Figure 16: Interim bridge east of the existing bridge

2.2. Structure

The glulam trusses are symmetrical on both sides. The steel crossbeams beneath the deck are oriented about 45 degrees and follows the railway tracks. The deck, cross-braced members from the concrete pillars and rigid steel frames in the middle of bridge give the bridge the necessary lateral stiffness. There is no horizontal cross bracing between the upper girders, which gives the bridge an open expression.

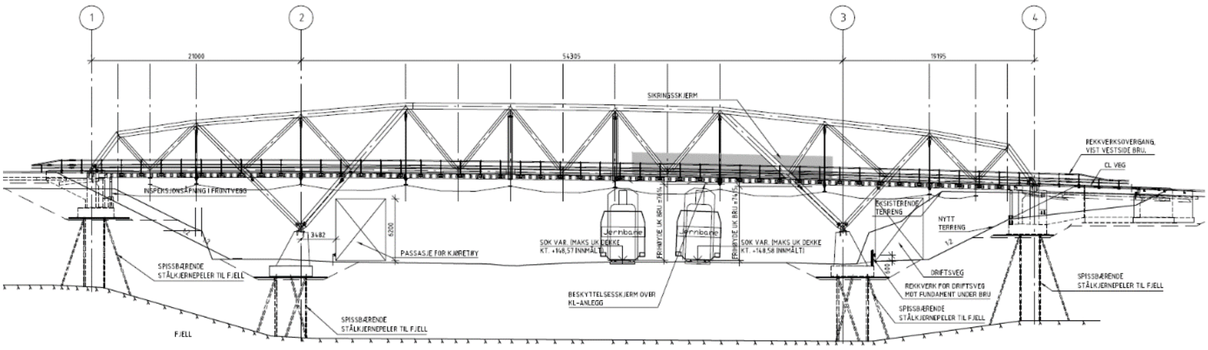

Figure 17: Norsengabridge, upright projection

The total length of 94,5 m is divided into three spans, 21,0 m, 54,3 m and 19,2 m. The pedestrian lane is placed outside the east glulam truss. See figure beneath. It is also a bit longer than the rest of the bridge in the north end to reduce fillings. There is also room for two small roads under the bridge in addition to the railway tracks.
All exposed glulam beams are covered with Zink-cladding on the top surfaces. The timber deck is covered with 30 mm bitumen rich asphalt, 12 mm Topeka and 55-140 mm asphalt layer on top. This will give the bridge deck a robust cover.

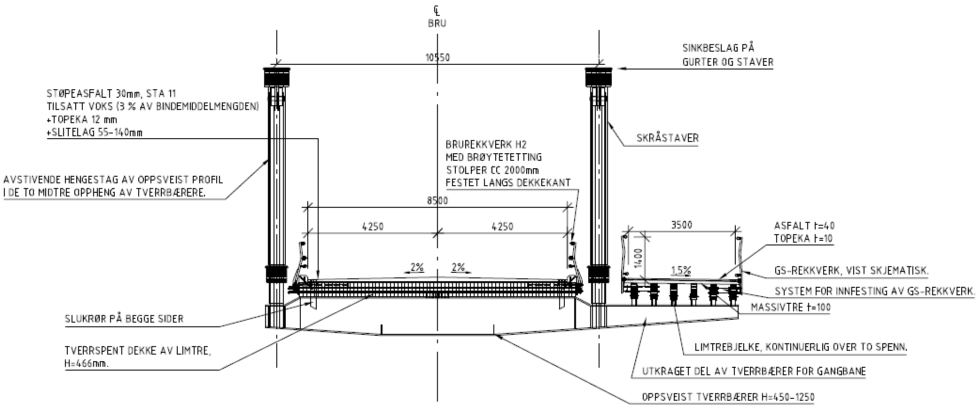

Figure 18: Norsengabridge, section in the middle of the bridge

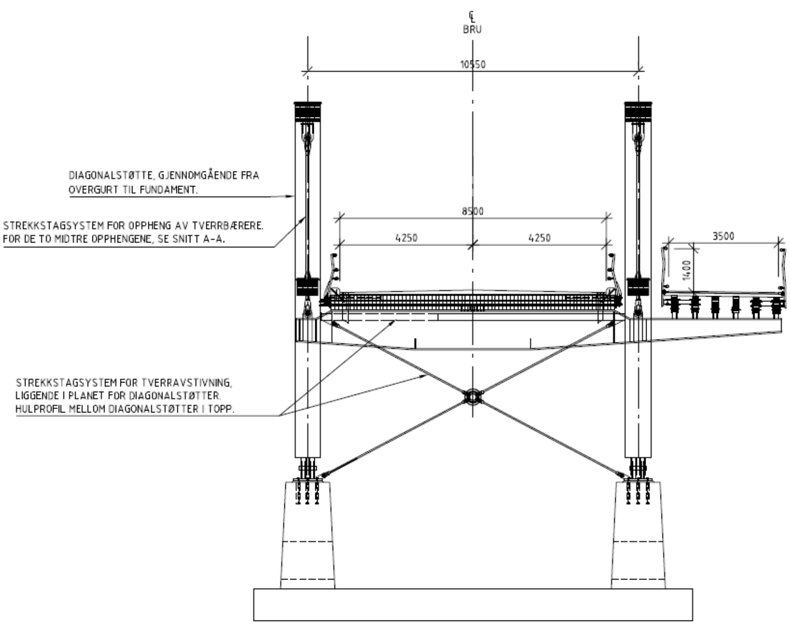

Figure 19: Norsengabridge, section through pillar

The glulam trusses have relatively low weight compared to the stiffness. This makes it possible to lift large parts of the bridge over the railway tracks, which again reduces the necessary stops in the train traffic. The low weight also reduces the amount of piles for the foundation near the railway tracks.

2.3. Assembly

The construction of the bridge will start up in 2015/ 2016. The assembly is planned as written beneath, but the contractor is free to choose the way he thinks is the best. Construction time is estimated to one year.

1. Establish foundations
2. Install the outer part of trusses incl. tie rods
3. Install the inner part of trusses incl. tie rods
4. Install transversal beams
5. Install cross bracing for the trusses in axes 2 and 3
6. Install the main deck, prefabricated in parts
7. Install the pedestrian deck, prefabricated in parts

See also the figure below for the assembly.

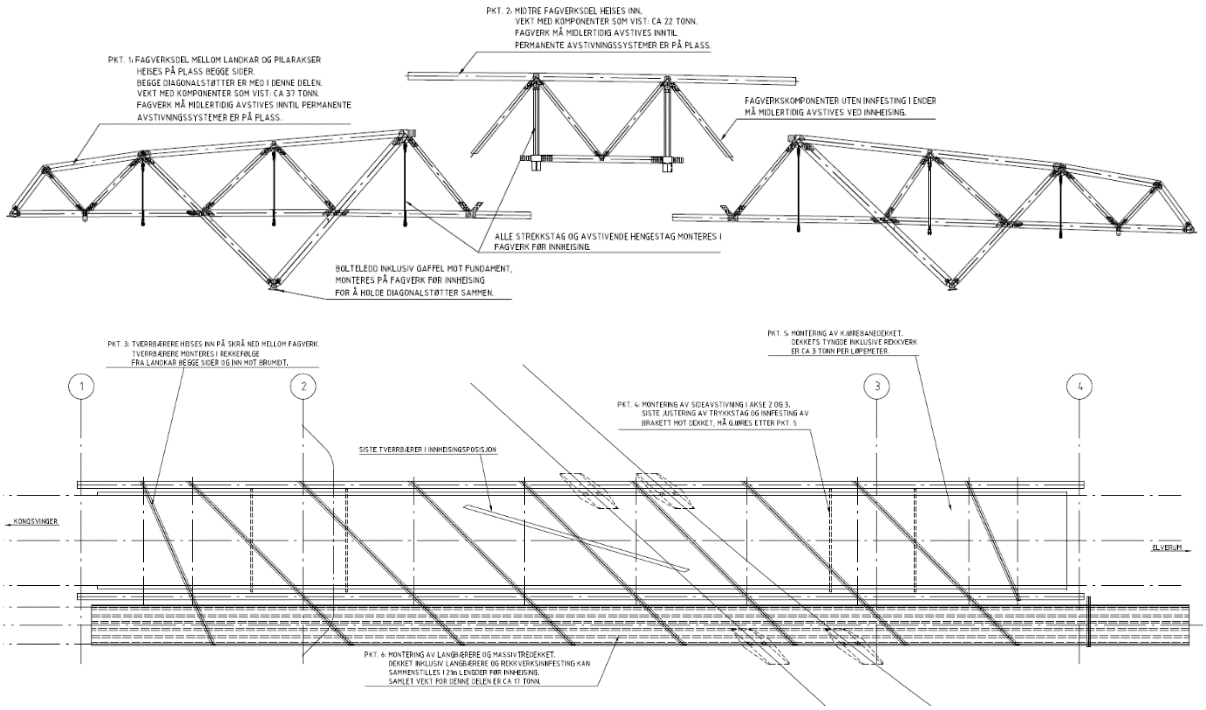

Figure 20: Norsengabridge, assembly

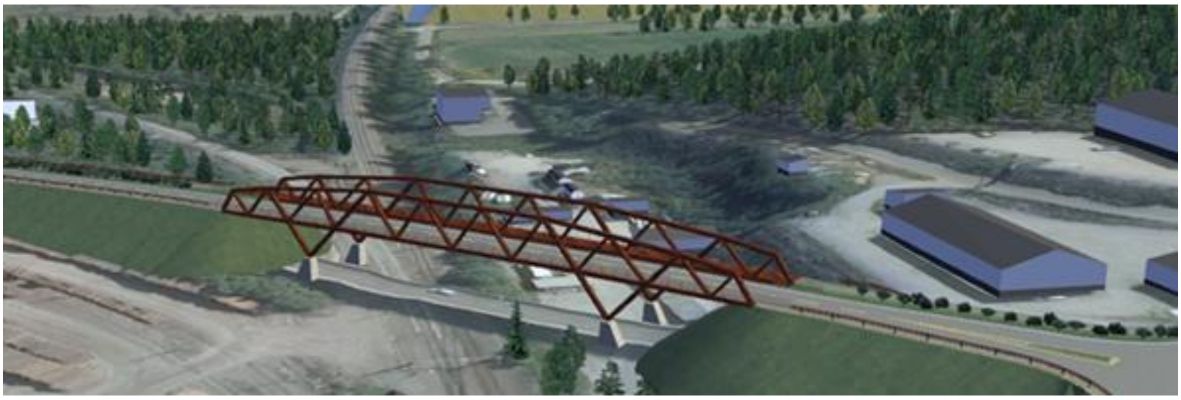

Figure 21: Norsengabridge, illustration

3. Mjøsabridge (Mjøsbrua)

3.1. Summary

Pre-studies are performed on how to cross Lake Mjøsa in Norway for a new 4-lane link on Highway E6 between the cities Hamar and Lillehammer. Preliminary design is also performed for timber bridges in several alternatives. The timber alternatives are truss bridges with two underlay timber trusses composite with a concrete bridge deck. Typical span width is 69m. Main spans are suggested to be cable stay spans with the same timber truss solution and span widths 120.75m. Total length of the bridge is approximately 1750m.
The conclusions from preliminary design have been that a concrete extra dosed alternative or a timber truss alternative with cable stayed main spans is to be preferred.
A research program was recently launched by the Norwegian Ministry of Transportation in order to investigate critical aspects involved in construction of such a large timber bridge. The research will focus on the large scale aspects, durability and the technical solution.

3.2. 1st Mjøsa Bridge

Figure 22: Overview of 1st Mjøsa Bridge

The 1st Mjøsa Bridge was opened to traffic in 1985 and is a part of the main north-south highway in Norway, the E6. The bridge crosses the largest lake in Norway, Lake Mjøsa, and is in total 1311m long. It is a concrete box girder bridge with typical span widths of 69m. The bridge is founded on piles, some to rock, some as friction piles. At the bridge site, the lake is app. 30-40m deep, giving a considerable free span in water for each pile. The bridge has two lanes of traffic and a pavement for walking/bicycling. An overview picture og the bridge is shown in Fig. 22.

3.2 Feasibility study 2006

Since traffic is increasing on the E6, plans have been introduced to increase capacity across Lake Mjøsa. In 2006, Norwegian Public Roads Administration carried out a feasibility study in order to investigate if it was possible to cross Lake Mjøsa with a bridge in vicinity to the existing one. The study also identified another possible alignment for the crossing further south, this however requiring deep sea foundations.

3.3 The timberbridge background

The Norwegian Public Roads Administration Region East is responsible for construction and operation of the possible 2nd crossing. This region has been the leading developer of timber bridges in Norway. Through a large number of timber bridge projects, the knowhow and expertise has grown over the years, making this region one of the leading timber bridge environments in the world. Since Mjøsa Bridge is situated in the very heart of this timber bridge society, it is only natural that there are strong interests to consider a timber bridge alternative for the new crossing. The fact that this will be the world's longest bridge of its kind, if carried out as a timber bridge, only strengthen this attitude. In 2010, a timber bridge seminar was held close to the bridge site in order to determine whether a timber bridge alternative was feasible for Mjøsa Bridge. Experts from the whole industry were invited, and the conclusion was positive. The seminar even introduced three different technical solutions as basis for further work.

3.4 Large scale challenges

The bridge will be the longest timber bridge in the world if chosen. Hence it has been vital to the project to identify what challenges this introduces. A list of topics has been outlined as follows:

- Composite behavior with concrete (internal force transfer, different material characteristics)
- Deliverance capacity (manufacturing, transportation, assembly)
- QA (certificates, guarantees)
- Durability (large scale effects)

3.5 Durability

The bridge will be designed for a 100 year life. The project must however make sure this is feasible in reality for such a large scale project. For normal size bridges it is more relevant to do repair and rehabilitation on exposed parts of the structure, but with the size of the Mjøsa Bridge it is of vital importance to ensure durability through technical solutions, treatment and planning.
To place the timber trusses beneath the wide concrete deck as proposed will make timber less exposed to sun, temperature differences, rain, salt treatment, etc. The environment should therefore be the best to increase durability. In addition, the experience from the many neighbouring timber bridges will constantly improve the durability, giving the best state of the art design available as a reference.

Figure 23: Illustration of the proposal for 2ndMjøsa Bridge

3.6 Aesthetics

The idea of the truss timber bridge was developed from the requirement of relatively large spans. This requirement was agreed to be vital both from aesthetical and economic reasons, to avoid costly foundations and to avoid the common barrier look that the long strait crossings with small spans often tend to have.
It was also agreed that the introduction of longer mid spans was beneficial to the overall looks of the bridge. These spans underline the bridge as an icon, and also emphasize the proposed ship channel areas. It was also a discussion of how many towers should be introduced. The common opinion within the project group was that a number of 3, 5, 7 etc. would be better than 2, 4, 6 etc.

Figure 24: Illustration of the proposal for 2ndMjøsa Bridge

3.7 Research programme

The Norwegian Department of Transportation has recently launched a research programme to make the timber bridge alternative for the 2ndMjøsa Bridge competitive to other solutions with regards to the technical challenges involved. The research programme will focus on the following aspects:

- Large scale effects on timber bridges
- Cable stay solutions on timber bridges
- Large spans on timber bridges
- Temperature effects on timber bridges
- Material specifications on timber
- Preservation of timber
- Composite behavior between timber and concrete

Figure 25: Timber truss system

3.8 Conclusions

The conclusion of the feasibility study and preliminary design of the 2nd Mjøsa Bridge is that a timber truss alternative is recommended as one of the alternative solutions. The bridge will have a total length of 1750m. A research programme is now being launched in order to bring this alternative up to level of other recommended alternatives. The program will focus on large scale aspects, durability and technical solution.

Figure 26: Overview of the timber truss alternative