CHALLENGES OF THE SUPERSTRUCTURE “ÄLVSBACKA BRIDGE”

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Summary

The main purpose of this conference paper is to show the opportunities for using timber in bridges and share our experience regarding some of the challenges related to this, in many ways, complicated superstructure in timber.

This paper presents two of the main challenges:

- The dynamic behaviour for this superstructure with a span of 130 m made of timber that has to fulfil the requirements according to the Swedish Bridge Code “Bro 2004”
- The erection of the superstructure which has been done with a method developed for this project and as far as we now never has been used before.

In the late summer 2011 this new cable stayed pedestrian bridge passing over the river of Skellefteå in Skellefteå city was taken into use, named “The Älvsbacka Bridge”.

The client of the bridge, the municipality of Skellefteå has a great interest in timber construction and had a vision that this bridge could be built in timber in a cost effective way. After an evaluation the municipality ordered the bridge into two separate contracts, one for the foundations in concrete from Skanska and one for the timber superstructure from Martinsons Träbroar AB.

Fig. 1: Views of the final result of "The Älvsbacka Bridge"

Some short facts:
Distance between pylons, span length: 130 m, total length 182 m.
Free width of decking: 4 m
Height of pylons: 24 m
Amount of timber: Approximately 200 ton, 400 m3
Amount of steel: Approximately 70 ton, 9 m3

Keywords: Cable stayed bridge, timber bridge, dynamic properties, assembling method

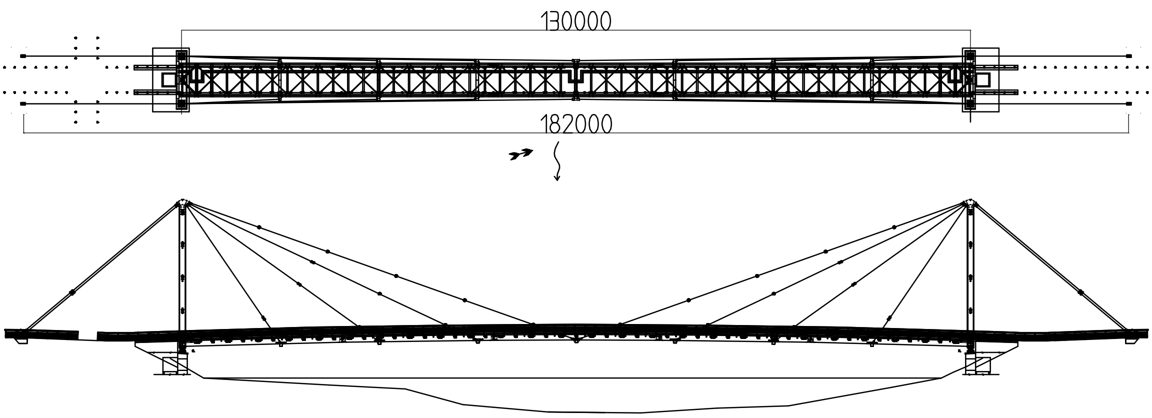
1. Introduction

Martinsons Träbroar has designed and produced timber bridges for the last 20 years. Around 40-50 bridges is produced each year. This actual pedestrian bridge, "The Älvsbacka Bridge", is very unusual and unique among these bridges. The bridge is large, has a rather difficult type of design, and has surrounding conditions at constructions site like

- streaming river that made it difficult to be with a larger barge in the water
- lack of area for mobile cranes and trucks with bridge parts.

One very important issue like always when it comes to timber bridges was to achieve a performance that protect timber from the influence of climate and ensure durability for the superstructure for a long time.

The final design of the bridge is presented in the Fig. 2. The primary construction parts are built up from glue lam and steel. The primary glue lam parts are made of untreated spruce protected with coating and cladding panel. All steel parts are protected against corrosion with hot dip galvanization.



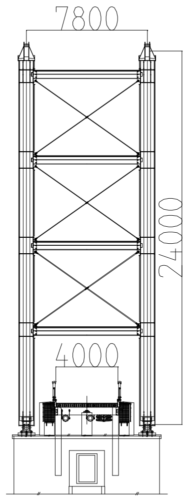


Fig. 2: Elevation, plan and section of “The Älvsbacka Bridge”

The assembling time of the bridge on site where approximately 5 weeks, 2 weeks to erect the pylons and launching the bridge deck and 3 weeks with complementation of joints and cladding, demounting temporary materials, adjustments and electrical and water tube installations.

A large amount of time has been invested in design work. A close collaboration between the consultant firm in bridge design, Cowi, and Martinsons has been established and resulted in solutions, general one and detailed one, that satisfied the manufacturer and client in relation to the initial conditions like a tight budget and time schedule. The prefabrication and the assembling on site have technically been carried out in a successful way when it has been done according to the plan from the design phase and without any larger deviations The assembly method is also unique and definitely something that we will continue to work with and develop further if we are into building such a bridge again.

2. Selection of global performance of the superstructure

Early in the planning process of this bridge the municipality of Skellefteå was in contact with a local architectural firm. This cooperation ended up with a suggested superstructure in timber with one pylon in the middle of the river shown in Fig. 3. One advantage with this design was that no parts of the bridge would trespass on the land area at the bridge ends. In both ends of the planned bridge there were sites with houses and not so much free area.

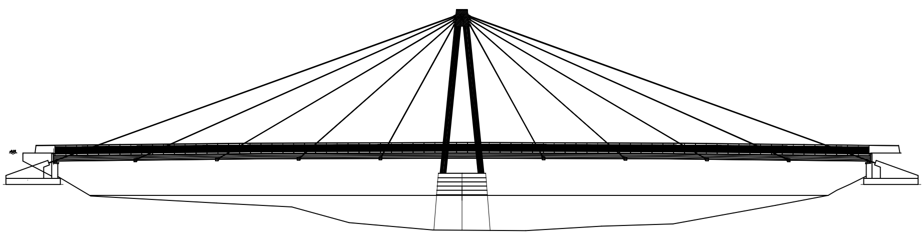


Fig. 3: Elevation of initially suggested solution

The suggested bridge performance also had an appealing esthetical value, a distinct landmark. However, after the first offers from different potential contractors it had a higher cost than what the municipality had estimated the maximum cost to and made the budget for. So now the question was gathered – what can be done to get down the cost? After a new procurement process with fewer requirements on the design and more focus on the possible maximum cost, new alternative solutions were developed and offered. One conclusion from the first alternative was that “we have to get up from the water to bring down the cost”. The original alternative with one foundation and pylon in

the middle of the streaming river was a great part of the total cost. So, - how can a bridge in timber without supports in the river be built we thought.
Martinsons in cooperation with Cowi suggested a cable stayed design with a pylon at each landside, as near the water as possible to get shortest possible span length and to achieve area for the anchoring bars on land. With a relatively steep slope of the anchor bars the solution seemed possible without trespass the close house sites too much. The great advantage with this solution was the price, at the same level for the originally suggested superstructure but with much less estimated cost for the foundation work.

However some more difficult challenges and questions rise with this alternative solution.

- One was the span length, especially transverse the bridge, that now increases from approximately 65 m to 130 m. Doubling the span increases the uncertainties regarding dynamic behaviour. This will also produce an increased static strain.
- Temporary supports and temporary road or bridge to the middle of river that could have been used to assemble the superstructure was now disappearing
- Will this new solution create the same landmark sign as the initial alternative?
- Will the anchor bars on each landside have an acceptable influence and not disturb the persons living closest to the bridge.

The dynamic behaviour of this solution seemed as such a great challenge that a pre study was done of Cowi and Martinsons. Conclusion from it was that the superstructure should have an acceptable dynamical behaviour.
Conclusion regarding the other challenges mentioned above where that they could be handled or were in an acceptable level.

After the municipality had evaluated different proposals of the superstructure they chose to contract Martinsons

3. The design process

Below are some of the most important challenges and difficult work during the design phase described, dynamic behaviour and method for assembling the superstructure on construction site.

3.1 Dynamic behaviour

A primary concern for the bridge was to verify that the dynamic behaviour would be acceptable. This means both comfort criteria for pedestrians on the bridge and effects due to the wind.

The complete bridge with main girders, pylons, cables and the supporting piles were modelled in a general all-purpose FEM – software.

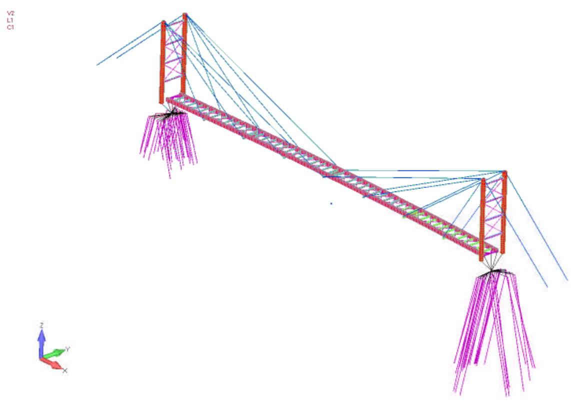


Fig. 4: FE-model

The dynamic analysis indicated that the bridge was relatively weak. The first horizontal mode had a natural frequency 0.6 Hz and the first vertical mode had frequency 1.4 Hz

Fig. 5: Horisontal mode, f = 0.6 Hz

Fig. 6: Vertical mode, f = 1.4 Hz

The Swedish Bridge code [1] includes a force model for walking pedestrians. The force depends on the size of the bridge and the natural frequency. The model gives the damping for a timber bridge (ξ = 0.6%) and an acceptance criteria for vertical acceleration $a_{rms} \leq 0.5$ m/s^2. The model does not give any directions regarding horizontal vibrations.
The Älvsbacka Bridge can be considered a horizontal beam with a 130 m span so horizontal vibrations must obviously be considered. In the literature there are recommendations regarding the horizontal force from pedestrians. It is approximately 10% of the vertical force and $a_{rms} \leq$ 0.2 m/s^2. These recommendations were used for the design.

Due to requirements from the municipality Skellefteå for installations on the bridge different mass cases was also included in the design.

The analysis indicated that the accelerations would be above the level accepted (~1 m/s^2) in the code for vertical accelerations, Fig. 7, while the horizontal was acceptable. But it was also deemed that the assumed damping was conservative so the complete bridge would probably meet the requirements. The option to install damping elements was also discussed with the municipality of Skellefteå and the bridge was prepared for such an installation.

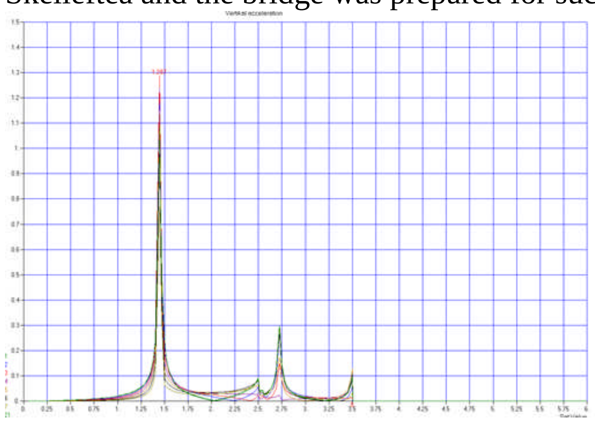


Fig. 7: Dynamic response plot: Acceleretion(f)

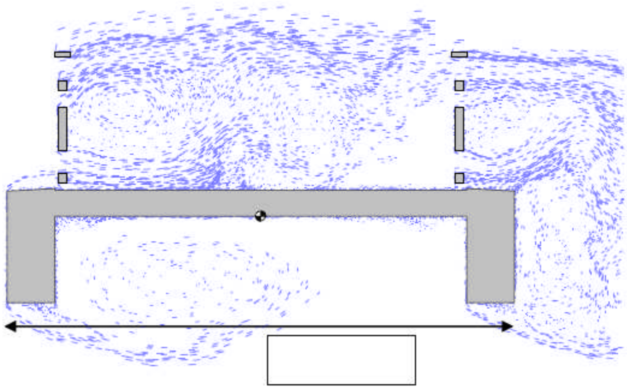


Fig. 8: Results from flow analysis for the bridge section

The second challenge related to dynamic was the wind. There are simplified methods that COWI and Martinsons have used in the past for smaller cable stayed bridges. But due to the size of this bridge these methods were not deemed as reliable.

For the Älvsbacka bridge the method was instead to use calculated natural frequencies and mode shapes from the FEM-model. This information combined with the mass and mass moment of inertia for the bridge was used by COWI Denmark, Major Bridges, to analyse the bridge for wind effects. The results were critical wind speeds for aerodynamic instability. Phenomena such as vortex shedding, flutter, galloping, torsional divergence and buffeting were studied and the critical wind speeds were above the design wind speeds. Accelerations and force effects on the bridge due to wind effects were also calculated and deemed acceptable. Force effects were based on flow analysis, se Fig. 8. The FEM – model was also used in the static design for verification purposes.

3.2 Planning of the assembling method

One of the most difficult things with this bridge was the erection of the superstructure. The initial idea was to apply Martinsons method developed for shorter span cable-stayed bridges, using mobile cranes to lift out the pylons, tension bars and the deck pieces. In this case, a really large crane, and many of them, would have been needed. When studying this method closer we realised that the method would be complex and expensive.
So, new ideas came up. Could it be possible to first erect the pylons and all of the tension bars including transverse beams and after that stress up tension bars and then pull out the bridge deck with help of the ordinary transverse beams as supports? The answer was yes, the greatest effort seemed to be minimized the cost for mobile cranes and less demand of land area for all the cranes needed. A great planning work to find solutions for this method started and continued parallel with the design of the superstructure. The planning work ended up in a rather detailed description of the assembling process.

The method can roughly be described like:

- Two180 m long temporary cables from each anchor foundations were stressed up. The purpose of these cables where to pull out the bars and transverse beams.

- Delivery of prefabricated pylon columns and other parts belonging to the pylon and putting these parts together on construction site. Three days was planned for this activity.

- Erection of the pylons, anchor bars, the longest tension bars reaching to mid span and its related transverse steel beam. All these parts connected together before and during the erection, se Fig. 9. The bars then were to be stressed up with temporary weights in transverse beam for stabilization.

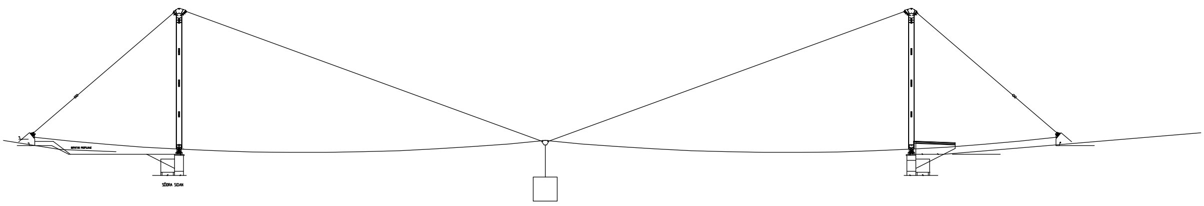


Fig. 9: Pylons, the longest bars and anchorage bars erected and stressed up with weights.

- Pulling out the other 12 bars and the six others transverse beams with help of the temporary cables, a winch and assistance from the barge.

- With all the bars in place, the system shall be stretched up with temporary horizontal bars between transverse beams and to pylon foundations.

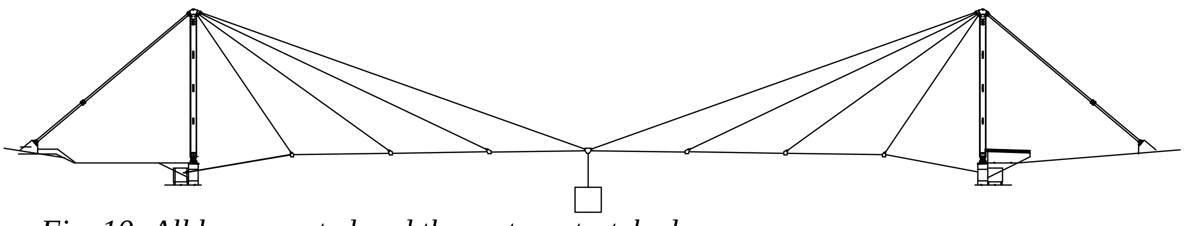


Fig. 10: All bars erected and the system stretched up.

- Then the 130 m long bridge deck, consisting of five parts each about 27 m long, was to be put in place by an incremental launching method from the south end. One important issue for this part of the assembly was the pull out force and to get it as low as possible. Tests of different treatments were conducted in the factory to find as low friction coefficient as possible. The maximum estimated pull out force based on the friction tests where 11 tons. Equipment to do this job has a capacity of 20 tons to allow for some margins. A tow truck was used for launching of the deck.

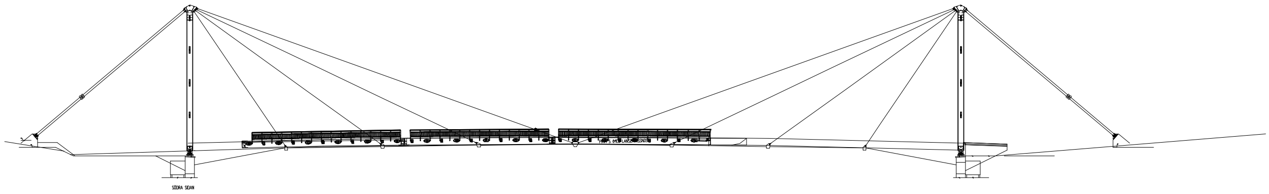


Fig. 11: Three connected bridge deck parts during launching and in position to connect the forth part.

- After launching the bridge deck, about three weeks of work was left with connections, installations, remaining cladding and decking.

4. Production in factory and assembling at the construction site.

An overview of the work in factory and at the construction site is described below.

4.1 The production in factory

One of the great possible advantages with timber bridges is the short assembling time on construction site due to the high degree of prefabrication. For this bridge there were high requirements of short time on site and the degree of prefabrication was developed from that perspective and from the cost effective perspective.

The pylons were delivered from the factory in parts.

- Pylon columns with steel members in top, bottom, connections for transverse beams and around 90% of protective cladding
- The transverse beams
- The stabilization bars

The 130 m long bridge deck where delivered in 5 parts. The decks had a high degree of prefabrication, around 90% of the cladding and the decking surface in place. Steel members at the end of each piece had been designed to minimize the time needed at construction site. All the 5 parts had been put together in factory when steel members with dowels where fastened into the primary beams. In this way it had been ensured that they would fit together on site. The “first” bridge deck was performed with a nose with a lifting device to simplify the passage of transverse beams.

A lot of steel bars are used in the superstructure. The main bars carrying vertical loads on the bridge deck, the stabilization bars in the pylons and the bars in the bridge deck distributing the horizontal transverse loads to the foundations. All the bars in the bridge deck were mounted in factory. All the other bars were put together as far as possible and adjusted to the right lengths in factory so the only part missing on constructions site was pins at bar ends.

4.2 Assembling on the construction site

In beginning of June 2011, assembling on the construction site started. During the erection process of the superstructure subcontractors were used to:

- provide mobile cranes taking care of the vertical lift forces
- provide tow truck taking care of the erection forces acting horizontal
- assist with a small barge with a small crane and scissor platforms.

After preparations on both sides with temporary supports, mobile crane surfaces, establishing the barge and stressing up the temporary wires the work with permanent parts could start. Initially the longest bars with the “mid transverse beam” were pulled out with help of the temporary wires. Work continued with putting together prefabricated parts of the pylon. See Fig: 12.

Fig 12: Long bars on their way out (left picture) and assembling of pylon.

After four days work it was time for one of the most critical moments in the erection process, to lift the pylons with the longest bar to its permanent vertical position. This was done with the equipment of five mobile cranes, three tow trucks and the barge.

Fig 13: Start lifting pylon (left picture) and pylons almost in final position (right picture)

When the pylon was vertical and the pins in the bottom had been mounted the final part was to place temporary weights in the transverse beam that stretches up the long bars and make the system stable.

The assembling work continued with pulling out the rest of the 12 bars and six transverse beams. Then the hole system with bars had to be stressed up which were done with horizontal temporary bars between transverse steel beams and stressed against the pylon foundations at ends. With this performance the system was ready to act like support when pulling out the five 27 m long bridge deck parts. The main equipment in this stage was two mobile cranes in the south end of the bridge and one tow truck in the north end pulling all the five parts from south end and heading north. The first deck part, the one ending up in the north end had an elongation of the permanent beams acting like noses that made it possible to pass the transverse beams in an effective way. The noses had also a lifting device that was an important function. This operation was successful and was performed during 3 days. One critical issue during this operation was weather conditions and especially the wind and how it easily can generate oscillations transverse the bridge. This risk had been considered and the bridge was secured with wires from the transverse beams to anchors in the bottom of the river up streams and down streams and at several places along the bridge.

Fig. 14: Bridge on its way out in left picture and almost in final position in right picture.

When all five pieces where in right length position the work with adjustment and permanent looking of connections took place during a couple of days parallel with the concluding work with removing temporary material, put on missing cladding and installation of the electricity equipment and the water tube.

Figure 15: Finishing construction work after pulling out all the bridge decks.

5. Conclusions

In august 2011 the bridge was consecrated and around 500 peoples walked from the south bridge end to the north. The bridge has become very popular among citizens and is frequently used. The client, municipality of Skellefteå, is also very satisfied and proud. The bridge has fulfilled the municipality’s expectations and also became the landmark they wanted. With this result we as a contractor off course also are satisfied

Conclusion regarding the assembling method is that it has worked out well and we will use it again if the opportunity comes up. Tough, there are always things that can be made better. Possibilities we see are

- that fewer mobile cranes is possible during the pylon erection.
- that tow truck worked very well, but for the several of the horizontal pulling forces, equipment with lower cost should be possible to find, develop.
- refined detail solutions to pull out parts on the temporary cables
- excluding some of the temporary parts and use permanent parts instead.

An attractive and challenging question for the future that we have asked ourselves is – can the method be developed further so that the bridge can be erected without working from a barge? The answer is to be searched in the future and if it results in a yes, probably an even more efficient and useful method is created.

6. References

[1] Swedish Bridge Code “Bro 2004”,Publ. 2004:56, ISSN 1401-9612