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Flisa Bridge, Norway—a record-breaking timber bridge

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Over the past decade several timber bridges have been built in Norway, particularly in Hedmark County. The unique experience gained from these projects has enabled bridge engineers to build increasingly larger bridges. On 5 June 2003, the new Flisa Bridge opened. It is the world's longest timber bridge designed for full traffic loads with respect to clear span (70·34 m), and one of the longest with respect to total length (196 m). The bridge crosses the river Glomma in Hedmark County, approximately 150 km north of Oslo, and is placed on the foundations of the old bridge. The trusses and parapets are constructed using glued-laminated timber, and the bridge deck is a stress-laminated deck plate of sawn timber. The new superstructure consists of almost 900 m^3 glued-laminated and sawn timber (utilising more than 7000 trees), and more than 200 t of steel. The total cost of the bridge is about 30 million Norwegian kroner (or €3·5 million/ £2·4 million). This paper describes the design and construction of this unique project.

1. INTRODUCTION

In Norway, as in many other countries, timber was the most common bridge material until the late nineteenth century when steel and concrete became the preferred construction material. In the twentieth century very few timber bridges were built until about 1960, when the use of glued-laminated timber became more common. In the following years, several pedestrian bridges were built. Many of these glued-laminated bridges gained a bad reputation due to poor detailing and protection from the elements, which resulted in repairs being required and a shabby appearance.

In the early 1990s the development of modern timber bridges in Norway began with pedestrian bridges and some smaller road bridges in Hedmark County. The experience gained from these smaller projects was used to build bridges with increasingly longer span, culminating in the Flisa Bridge, which has the longest span and length worldwide thus far. The research performed and the knowledge gained through the Nordic Timber Bridge Programme has greatly contributed to the development of timber bridges in Norway. This programme operated from 1994 to 2001, and was in cooperation with participants from Finland, Norway and Sweden (and Denmark for parts of the programme). The timber industries, road/bridge authorities and research institutions worked closely together with the objective of increasing the competitiveness of timber bridges compared to other materials such as steel and concrete. The main results of the programme are that many new timber bridges have been built and that there is considerably more interest in timber bridges in the Nordic countries.

Timber has also been used in high-profile building projects in Norway during the past decade. Examples are the Skating Hall in Hamar for the 1994 Winter Olympics and the new main airport terminal at Gardermoen near Oslo completed in 1998.

When the old Flisa Bridge was opened in 1912, it was considered to be an excellent, futuristic construction. The three-span steel superstructure with spans of 55·5, 56·0 and 70·5 m was a truss bridge with hinges in the two end spans. The old bridge was supported by abutments and piers made of high-quality dressed stones on pile foundations. The existing steel superstructure was in a poor condition and was not suitable for today's traffic load and road width. The old bridge is shown in Figs 1 and 2.

In spring 2000, a project team was formed to plan and carry out the project for a new Flisa Bridge, consisting of a structural engineer, an architect, the glulam manufacturer and experts from the Public Roads Administration. Previous investigations showed that the existing substructure was in a good condition. It was therefore logical to develop a concept with a new superstructure on the old substructure. A premise was that the road level should not be elevated due to adjacent road links. This made a concrete girder or a built-up girder of steel unsuitable

Fig. 1. The old Flisa Bridge

Fig. 2. The old Flisa Bridge, stone pier

because the superstructure could not be lowered due to flooding. This led to the decision that the new superstructure should be of the same type as the old one, and be developed further to satisfy today's demands with respect to road width, free height and load capacity. With this considered, a new superstructure of timber was selected. One reason that timber was chosen instead of steel is that timber can compete with steel in price for truss bridges. In addition, the Public Roads Administration's development and experience in the field of timber bridges also contributed to the decision.

In this phase a three-dimensional (3D) conceptual model of the bridge was developed by the architect to illustrate the new bridge (shown in Fig. 3).

2. SUPERSTRUCTURE

The bridge is part of the national road network and is designed in accordance with the Norwegian national traffic load regulation, which specifies a uniformly distributed load of 9 kN/m and a 60 t lorry (represented by three equivalent axle loadings of 210 kN) per lane.

The superstructure was analysed by a 3D element program. A model of the whole superstructure with more than 1100 elements was made. Typical element length of the curved chords in the truss was about 1·4 m. The results from the analysis were used in the design of the truss, while steel cross-beams, deck plate and parapets were designed based on local models.

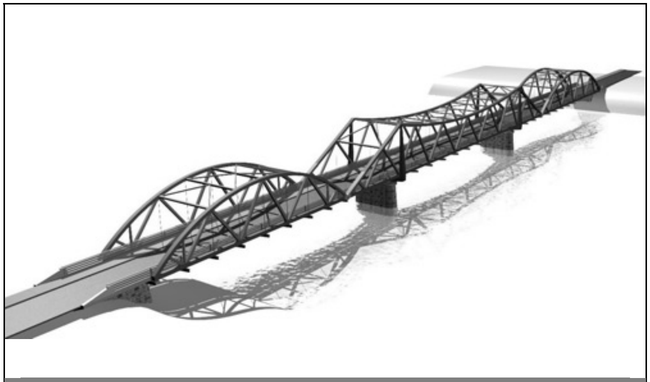

Fig. 3. 3D model of the new bridge

A truss system similar to the one on the old bridge was used. The middle section was cantilevered from the piers to support the two end spans, which are simply supported as shown in Fig. 4.

The glued-laminated truss girders in the middle section are cantilevered out about 17 m from the piers, which gives a section length of almost 90 m. The truss has a curved upper chord with the tallest height over the pillars being 9·5 m. A 5·6 m spacing between the steel cross-beams gave a favourable span configuration for the bridge deck. The glued-laminated elements were

(*a*) upper chord = 0·71 × 0·60 m
(*b*) lower chord = 0·61 × 0·53 m
(*c*) diagonals = 0·48 × 0·43 m.

Vertical steel rods of diameter 60 mm suspended the steel cross-beams between the truss joints. Lateral stability and transfer of wind forces are taken care of by a wind truss between the upper chords. The wind truss gives a free height of 5·9 m above the carriageway, which is higher than required by the client. The wind truss ends on the piers where the upper chords are laterally supported by a vertical steel column placed on the outside of each truss wall. These columns are rigidly fixed to the cross-beam, which makes the columns and cross-beam form a U-frame as shown in Fig. 5 (from installation with only one column fixed).

The end spans are simply supported truss girders with arched upper chords supported at the cantilevered middle section and at the abutments. The two end sections/spans are 38·4 and 53·6 m long as shown in Fig. 4. The height of the arches is 8·0 and 9·0 m, respectively. The truss member dimensions are similar to those used in the middle section. Lateral stability and transfer of wind forces are taken care of by a wind truss between the upper chords. Near the ends the wind forces are transferred to the deck by vertical steel columns in the truss rigidly fixed to the cross-beams as shown in Fig. 6.

Two traffic lanes each 3·25 m and an elevated 2·5 m wide pavement gives the bridge a total width of 9·0 m (see Fig. 7). The new superstructure is more than twice as wide as the old one, therefore the piers and abutments were too small. This was solved by using large steel cross-beams to support the truss girders. Fig. 5 shows the cross-beam at the top of the pier after one truss has been installed.

The new bridge has a span of 70·34 m and a total length of 196 m including the bridge deck behind the abutments. This makes it the world's longest timber bridge with respect to clear span designed for today's traffic loads, and one of the longest with respect to total length. The two other long timber bridges in Hedmark County are Tynset Bridge, built in 2001 with a span of 70 m; and Evenstad Bridge, built in 1996 with a total length of 180 m.

3. CONNECTIONS

The design and detailing of connections in timber bridge structures are critical to their load-bearing capacity and durability. Simple connections such as nails, bolts and timber connectors have too little capacity. In addition they give greater slip than desirable. The preferred connection has been embedded steel plates in sawn slots in the members to be connected.

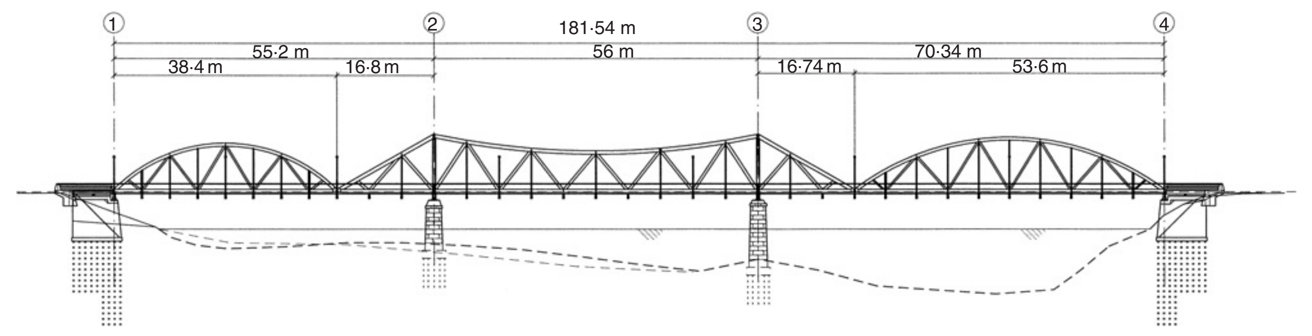

Fig. 4. Bridge elevation

By using dowels through holes in the plates, forces are transferred between the steel plates and the wood material. This makes it possible to have many parallel plates in a connection, which gives a high load-carrying capacity.

The main development that has taken place over the past decade, reducing the cost of glulam as a structural material, is the mechanisation of the connection process. Originally, drilling of holes for the dowels was carried out by hand, and because of the accuracy required, this was a slow and expensive procedure. This is now a mechanised process where the drilling of holes can be done quickly with pipes, using a template to secure accurate positions of the holes (see Fig. 8) and as such is much cheaper to carry out.

The design of these connections is based on a fully plastic behaviour of both the dowels and timber material. Rules are given in the Norwegian code NS 3470-1[1] which is based on Eurocode 5.[2] The code does not give direct formulas for this type of connection, but formulas can be deduced using theoretical background material for the formulas in the code. Fig. 9 shows an inner part of a connection with two steel plates, a dowel and the transverse load acting on the dowel. The dowels are assumed to be built-in and have their yield moment at the face of the steel plate. The load transfer is governed either by yielding in the dowel or by the embedding strength of dowel to wood. The optimum distance between the steel plates is obtained when yielding occurs for the embedding strength.

Fig. 5. New concrete top and steel cross-beam at pier top

The connections used in the Flisa Bridge are designed to transfer tensile forces up to 5600 kN in the ultimate limit state. Typically 8 mm thick steel plates and 12 mm dowels were used. The centre distance between the steel plates is about 80 mm which is near optimum distance. The most stressed connections have eight parallel plates and 46 dowels in each of the elements to be connected.

The length of the wood members is limited due to transport and size of available creosote impregnation tanks. The upper and lower chords were divided into several parts with a length of up to about 28 m and were reconnected using the same type of connection used when connecting the diagonals to the chords. For chords with dominating compression forces, cement mortar was grouted into the joint between the chord members to take the compression forces because this is more efficient than dowels (which take the tension force). In Fig. 10, a connection in the

Fig. 6. Steel column for stabilising the upper chord in the truss in the end span

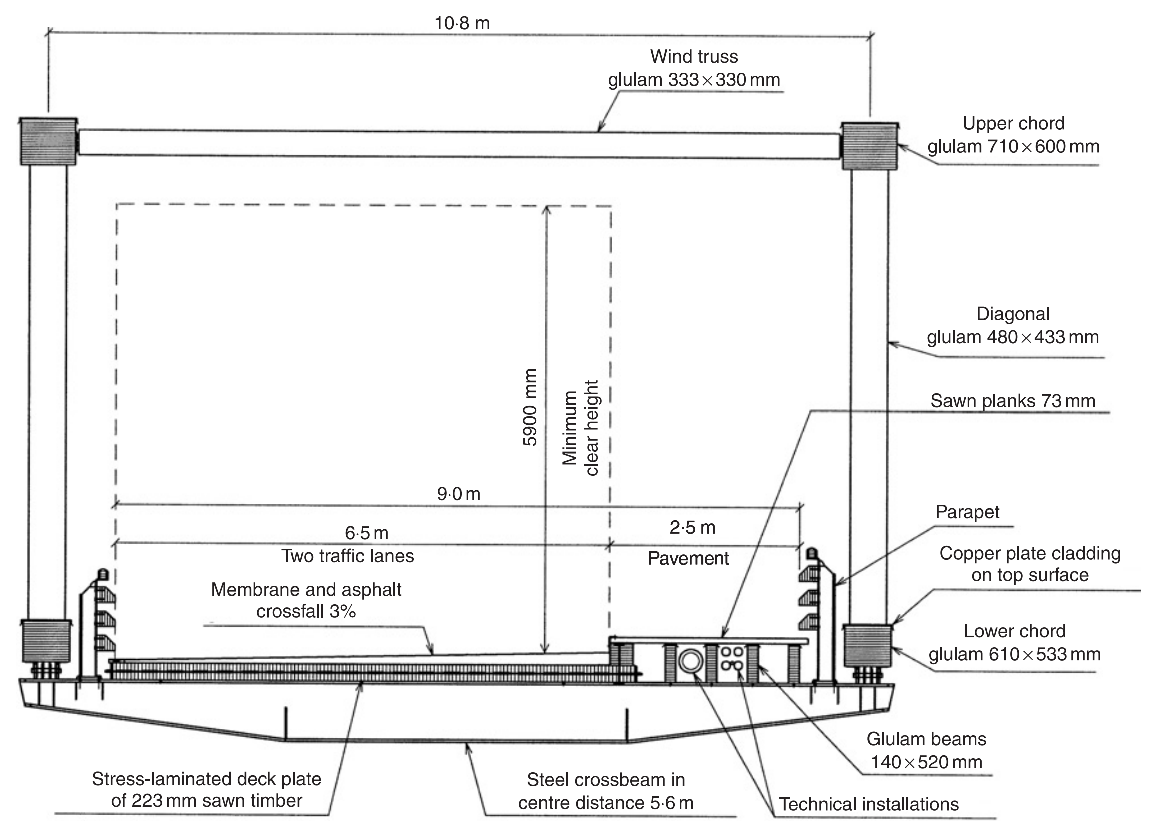

Fig. 7. Typical cross-section

lower chord in the middle section is shown, while Fig. 8 shows the same connection in the fabrication hall with the template for drilling holes for the dowels at the top face. Fig. 11 shows a connection between the upper chord, the diagonals, the steel rod and the wind truss in the truss in the end span.

4. THE BRIDGE DECK

A stress-laminated deck plate of sawn timber was used as the bridge deck. Steel or aluminium decks have been shown to be more expensive and were therefore rejected. A concrete deck causes considerable self-weight which was considered to be unfavourable, particularly for the existing substructure. Fig. 7 shows a typical cross-section of the deck in the middle section.

A stress-laminated deck plate consists of common plank or glulam clamped together on their wide face by prestressed high-strength steel rods. Due to the timber material's mechanical properties (lower stiffness and strength perpendicular to the fibres than parallel to them), the deck acts as an anisotropic plate, and the design is based on that.

Planks with dimensions 48 × 223 mm prestressed with 15 mm high-strength steel rods spaced at 600 mm centres were used. The rods were stressed up to 140 kN. The bridge deck spans in the bridge direction between the steel cross-beams spaced at a maximum distance of 5·6 m. This 5·6 m span has been shown to be the maximum for available sawn planks in Norway. The deck

Fig. 8. Connection between lower chord and diagonals in the middle truss

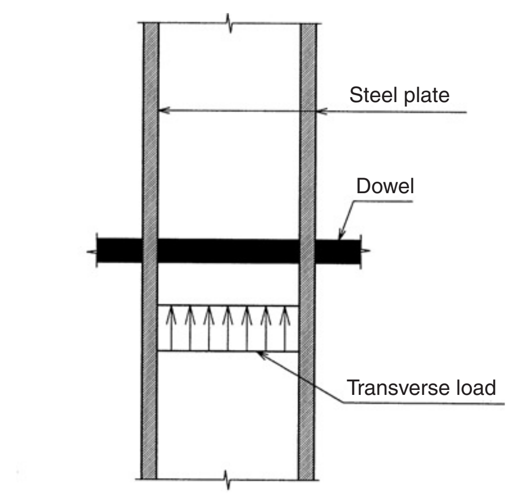

Fig. 9. Inner part of a connection

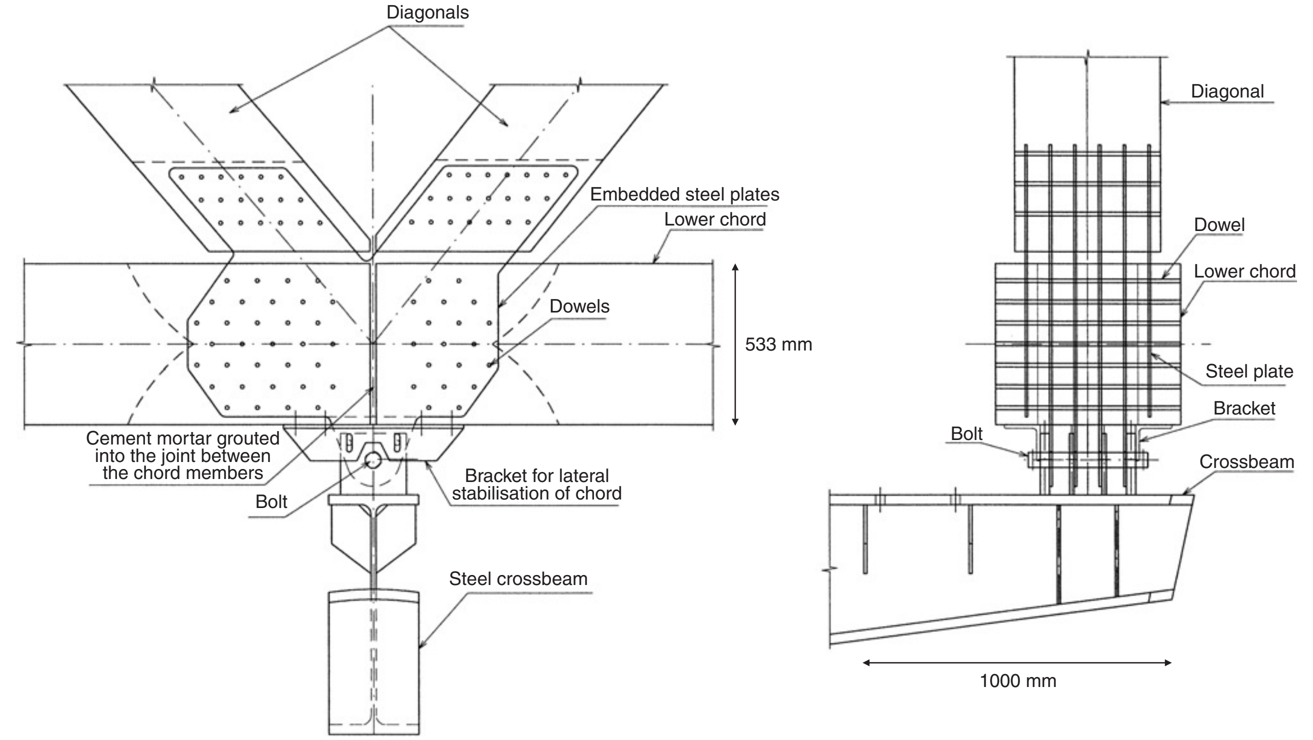

Fig. 10. Elevation and section of connection between lower chord and diagonals in the middle truss (cladding, bridge deck and parapet are not shown)

has a membrane of Topeka and asphalt. The pavement consists of 140 × 520 mm longitudinal glulam beams with a layer of 73 × 148 mm sawn planks on top in order to be able to carry a single wheel load of 130 kN.

Because the trusses were placed outside the deck, the cross-beams were 10·8 m long. Cross-beams of steel have been shown to be more favourable compared to timber cross-beams, mainly due to the low shear capacity of timber. Therefore steel cross-beams (European wide flange beams HE 800 B) tapered towards the ends were selected.

The bridge parapet consists of longitudinal glulam beams supported by steel posts. The posts are connected to the steel cross-beams. Due to the large spacing of the cross-beams (up to 5·6 m), heavy parapet beams were required. The parapets are terminated against concrete guard blocks.

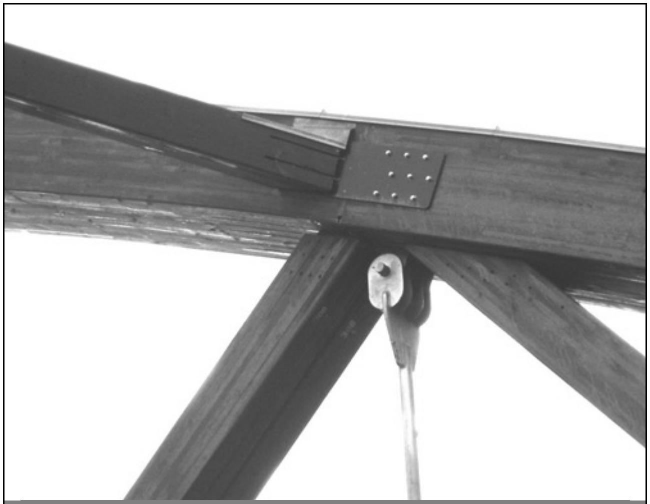

Fig. 11. Connection in the upper chord in the end span

5. SUBSTRUCTURE

The old foundations were in good condition and could support the new superstructure. It was important not to damage the old stone walls.

The upper part of the piers was carefully removed and replaced by new concrete adjusted to fit the new superstructure (see Figs 2 and 5). The old piers were strengthened using steel piles bored into the bedrock to carry the increased load from the new bridge. Bored steel piles were used because they did not require a heavy rig, which made it possible to install the piles from the old bridge deck before it was demolished.

The old abutments were too small for the new superstructure and had to be rebuilt. As for the piers, the concrete shelf for the bearings was removed and replaced by new concrete. To carry the horizontal forces from the bridge deck, a concrete friction plate behind the abutment was constructed in both bridge ends as shown in Fig. 12.

6. DURABILITY, OPERATION AND MAINTENANCE

The Public Roads Administration requires all permanent bridges to be designed for a 100-year service life, with only a minimum of maintenance needed. This requirement also applies to timber bridges.

The service life is governed by several conditions: the quality of the timber (in Norway, glulam is produced from pine), engineering, craftsmanship and environmental factors such as weather, temperature and sunlight at the site.

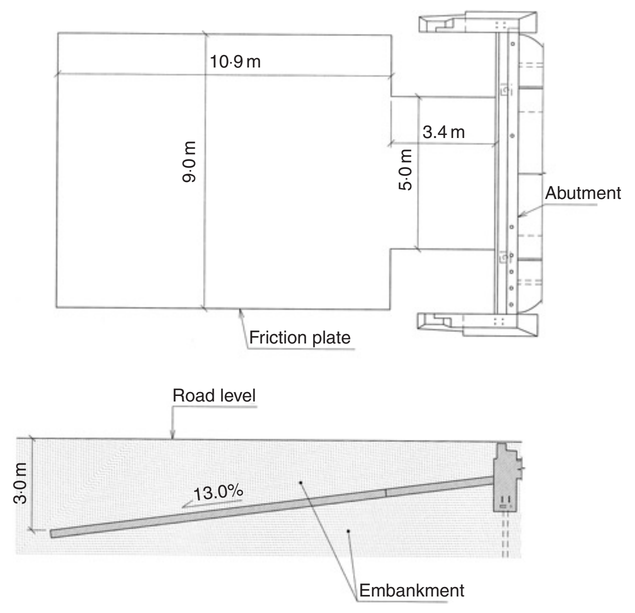

Fig. 12. Friction plate, plan and section

Experience shows that protection against moisture and wind is important. For the Flisa Bridge, all exposed upper surfaces are covered using copper plate cladding. It is very important that the cladding work is done correctly so that the cladding plates do not collect moisture.

The development of rot in wood depends on the humidity. If the moisture content is below 20%, the wood will not rot. For structures such as bridges, it is difficult to prevent the wood reaching a higher moisture content at times. Therefore in Norway, the only way to give the wood sufficient long life is to impregnate it using chemicals. Currently there are two methods used: salts (CCA—i.e. copper, chromium and arsenic, or copper only) and creosote. Experience has shown that it is more difficult to achieve full intrusion of the impregnation in glulam than in planks. Therefore a double impregnation using salt and creosote is used. First, sapwood in the interior of the glulam cross-section is preserved by giving each lamella a pressure treatment with CCA-salt solution before flattening and gluing. Second, after shaping, drilling of holes and so on, the entire structural member is given a pressure treatment with creosote oil in order to reduce cracking and make the timber water repellent. This double impregnation is applied to the glulam in the trusses. For the wood in the stress-laminated deck plate, which is protected by a membrane, impregnation with creosote oil only is considered to be sufficient. This is also the case for the wood in the pavement which can be replaced more easily.

The steel is protected against corrosion to different levels: the embedded steel plates and other steel parts are galvanised and spray-painted. The dowels are stainless steel. For other steel parts, galvanising is sufficient in a typical inland climate, but some steel parts are also spray-painted for appearance.

By applying the above-mentioned measures, timber bridges should exceed their 100-year design life.

As with any bridge type, inspection and small repairs will be required on a regular basis. Based on experience, the timber surface will only need refreshing with, for example, tar stain, while inside the wood surface will still be creosote-treated.

Fig. 13. Lifting of the truss for the middle section

7. CONSTRUCTION PERIOD

Because the superstructure was mainly prefabricated and had to be lifted onto the piers and abutments from locations in the river, a temporary embankment area was made. This could only be done in the winter months when the water level in the Glomma River was low. The contractor filled the riverbed at the bridge site so that about 120 m of the shallowest part of the river was closed with only about 50 m of the eastern part being open.

Demolition of the old superstructure started when the old bridge was closed to traffic in November 2002. Simultaneously, prefabrication of the superstructure and work on the substructure started. The truss girders were manufactured and fully assembled in the workshop to make sure the elements fitted together and that the total length of the girders was correct. Then the truss girders were taken apart and impregnated with creosote before they were transported to the bridge site. Assembly of the first sections started in February 2003 and was completed by early spring.

After the main structure was assembled, the remaining components such as the bridge deck and the parapet were

Fig. 14. Front view of the new bridge


Fig. 15. Low angle view of the new bridge

installed. Finally the copper cladding, asphalt and adjacent roads were completed, allowing the new bridge to be opened on 5 June 2003, only seven months after the old bridge was closed. Figure 13 shows the second truss being lifted into place, while Figs 14 and 15 show the completed new bridge.

8. THE ENVIRONMENTAL CHALLENGES

Creosote oil is frequently considered to be hazardous to the environment because of its toxicity. During the first years of service, surplus oil may leak out of the wood on warm and sunny days and then drip onto the ground or into the water. However, this effect is considered to be minor compared with the benefit of ensuring a long life of the structure. The average yearly energy use, emission of environmental gases to the air and so on, is less than it would have been had other preservatives been used.

The use of timber in long-life structures is a means of storing carbon dioxide (CO_2), which is extracted from the air by photosynthesis of the trees. For each 1000 kg of timber, about 1100 kg of CO_2 will have been extracted from the air. As a comparison, the production of 1000 kg of cement will cause an emission of about 800 kg of CO_2 to the air. In this context it is an environmental benefit to have a timber structure last longer.

9. CONCLUSIONS

The new Flisa Bridge marks a milestone in various respects, not only due to its length and the record-breaking span. Above all, it increases confidence in wood as a construction material for road bridges.

Although there are still some issues that must be investigated further, it is now felt that it is possible to design and build safe, durable and aesthetic timber bridges that can compete on price with steel and concrete. The experiences have been positive so far, and it is expected that a number of bridges will be built using timber as the material of choice over the coming years.

10. ACKNOWLEDGEMENTS

The development outlined in this paper was made possible by the interest and willingness of the Norwegian highway authorities to investigate and try new solutions.

The project team consisted of

- client: Norwegian Public Roads Administration
- architect: Plan Arkitekter AS
- consultant: Norconsult AS
- main contractor: Mesta AS
- glulam advisor and contractor of superstructure: Moelven Limtre AS.

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