ontribution to Structural Details on Timber Bridges

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Summary

The paper makes a contribution to details on timber bridges based on the experience gathered by the Norwegian Public Roads Administration (NPRA). The design errors which are included in this paper are selected because they are important with respect to durability. Most of what is stated in this paper may appear to be obvious. However, the problematic details are still used in the design of timber bridges and are therefore not obvious for all designers.

Construction of modern timber bridges in Norway started in 1995. Some were constructed in the 1960s and 70s, but using a different approach. We therefore have nearly 20 years' operating experience with modern timber bridges. The experience so far indicates that some of these bridges will not last as long as intended; however, some will most likely be in operation for more than 100 years. The difference lies in the detailing – in most cases related to design to keep water away. We are convinced that in the future we will find further damage that will influence the service life of these bridges.

The most serious problems are leakage of membranes, members placed on top of the other in stagnant water, cracks in exposed timber surfaces where the cracks collect water, and corrosion on tendon bars. This can cause a substantial reduction in service life compared to the expected 100 years.

Keywords: Details, timber bridges, deterioration, decay, moisture content, protection of timber, service life issues.

Fig. 1 Evenstad Bridge, constructed in 1996, five spans, dual carriageway, total length 180 m

1. Introduction

Construction of modern timber bridges in Norway started in 1995. We therefore have nearly 20 years' operating experience – not very long compared to the intended service life, but long enough to ascertain what will definitely not work. During the 19th century, a large number of timber bridges were constructed in Norway. None of these are in service today. The last one was probably demolished in the 1960s, when a new era of CCA-preserved timber bridges began. Most of the CCA-preserved timber bridges from the 1960s are still in use; however, some have needed comprehensive maintenance because of poor detailing and most of them have acquired a shabby appearance.

Today the Norwegian Public Roads Administration (NPRA) has approximately 60 timber bridges on the national road network and 70 on the county road network. In addition there are some on the municipal road network and some few private timber bridges. In total we have nearly 200 timber bridges, both road and pedestrian.

The design service life for bridges in Norway is 100 years. This requirement also applies to timber bridges. We know from moisture measurements that the moisture content in general is around 12 –17% for protected members and that this is fairly independent of both location and surroundings. This level of moisture content is well below that where fungus may develop.

The main bridge types used in Norway are arch bridges and some truss bridges. For smaller bridges both slab and girder types are used. Stress-laminated deck with creosote-impregnated lamellas, waterproof membrane and asphalt wearing course is widely used. Both glulam and sawn timber are used as lamellas.

The cross-sectional size of members of the main load-bearing structure mostly requires block gluing of glulam elements. In such cases the glulam is built up using copper-treated lamellas. In addition the members are normally treated with creosote and generally have metal cladding on top, often copper sheeting. If the members are too large to be accommodated in the creosote treatment tank, the lateral faces are provided with structural protection, frequently with a timber louver boards.

1.1 Monitoring of five timber bridges

1.1.1 Moisture content

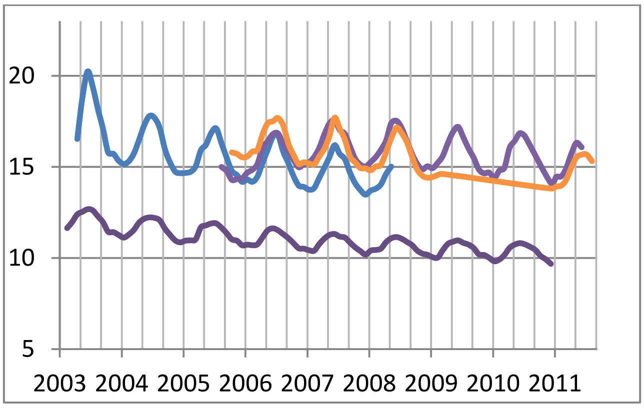

Fig. 2 Moisture content from monitoring of four bridges [1] plus in-house adaptation

Error! Reference source not found. shows he measured moisture content of four different bridges. With the exception of one, the bridges experience very similar moisture levels. However all the measurements show that the moisture content continues to decline after erection, and the lowest graph represents Evenstad Bridge which is also the oldest of the monitored bridges.

The intention of measuring is to document the durability of timber bridges and to understand their response to different climates. In addition, it is important that the moisture level is not rising.

1.1.2 Stress reduction on tendons over time

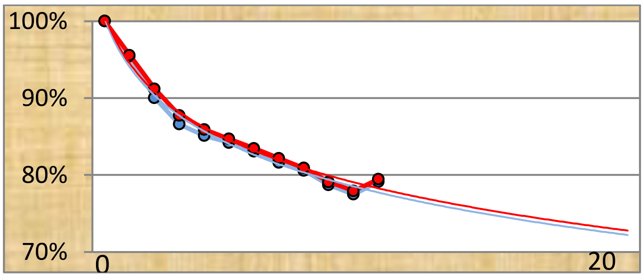

Fig. 3 Yearly average tension forces in steel bars over ten years at Evenstad Bridge [1].

To the left a graph represents the yearly average tension force in three neighbouring bars. The intention of measuring the tension force is to find the point of time where the bars have to be re-stressed. According to the design rules, a loss of bar force of 50% for sawn timber and 40% for glulam beams must be allowed for. The collected data show that 20 years between re-stressing should be sufficient.

1.2 Expected service life for timber bridges

Timber structures in Norway have lasted for more than 900 years when properly maintained. Creosote-treated electricity pylons with no other protection than the treatment or maintenance last for more than 60 years. The timber bridges have structural protection and in combination with creosote impregnation we expect them to be in service for a very long time.

1.3 Maintenance on timber bridges

In general the maintenance on newer timber bridges has been very little to date. Where problems occur they are mainly design issues and some details will need reconsideration. As the bridges are assembled on site, it will likewise be possible to disassemble the bridges and change parts if necessary.

1.4 Appearance of deterioration (decay) of structural timber

We have recognised that some bridges are deteriorating far too fast. This is nearly always due to lack of attention to precipitation and water flow. Timber will not endure moisture content above 22% for a long time.

Reduced service life may be due to various causes, such as poor detailing, construction errors, failure to repair damage and poor maintenance in general. Even if a bridge is designed to be virtually maintenance free, some maintenance will always be required. In this paper we wish to highlight the causes of reduced service life related to poor detail design, as this is the basic precondition for a long service life.

During recent years we have carried out a number of special inspections of our timber bridges with particular focus on durability and design errors. As the same observations have been made on various parts of the structure, we have tried to group the findings according to the structural effect:

- Precipitation running off from one member to one below
- Stagnant water which is absorbed into the timber sections
- Dirt or debris on the construction section keeping the moisture content high
- Horizontal member without structural protection
- Ionian water dripping onto metal with lower ionian potential
- Movement of dowels
- Corrosion on the pre-stressing bars (tendons)

2. Precipitation running off from one member to the one below

Problem description

Fig. 4 The rainfall follows the steel parts to the timber parts.

Precipitation collected by a bridge part, and emitted in a concentrated form on the bridge construction, occurs more frequently than expected. An example is the parapet posts fixed to the side face of the bridge deck – see figure to the left. Rainwater gathers on the post and is directed to the side face of the timber deck causing a concentration of moisture in the timber. This solution is very rarely used today.

Fig. 5 Parapet post which do not lead water to the deck

Instead of a plate direct bolted to the side face, shown in the previous image, we have a bolt connection between the post and an anchoring plate which is direct connected to side face of the deck – see fig. 5. The two upper bolts is approximately 1 meter and skewed into a steel plate slotted in between to lamellas in the deck. The two lower bolts are very short. The drip nose on the deck allows the water to drip outside of the all anchoring plates.

Fig. 6 A V-shaped column with stays.

In the figure to the left a wet top face of a V-shaped column is shown. Water follows the top face of the inclined members and is concentrated at their joint. From there the water runs down the side and is sucked up by the end grain.

The increased moisture at the end grain is in general probably one of the more serious problems we have with timber bridges. It occurs at several locations on a several timber bridge.

Consequences for service life and maintenance action

Heightened moisture content due to a concentration of water from leakages is a serious problem. The seriousness depends on the precipitation and could at worst lead to a substantially reduced service life. Maintenance action will be to tighten the leakage, direct it to a location where it will not harm, or to change deteriorated members.

Possible alternative, improved design

The parapet post should have a drip nose facing away from the bridge deck. The leakage between the edge beams could be avoided by mitre-cutting the beams such that the cut faces upwards. The columns should have a cladding that conducts water away from the lower sections.

3. Stagnant water which is absorbed into adjacent timber sections

Problem description

Fig. 7 Pole sleeve at support.

Fig. 8 Exterior steel plate collects moisture.

Sometimes adjacent structural members retard the drying of wood because proper circulation of air is prevented. This is the case with all exterior steel plates and sleeves. Even if there are drainage hole in the sleeves, the moisture will remain there for a long time and will eventually cause decay to the timber. Fig. 7 shows a typical example.

The steel plate on the outer side of the structure will in addition to the original intention prevent the wood from drying out. The bolts and the pressure against the wood cannot prevent moisture from penetrating behind the plate. In this particular case the moisture comes from behind the plate. In this case separate washers would most likely be a better solution.

Fig. 9 Water on a steel beam has over time decayed the timber beam.

The timber bridge to the left has an open deck consisting of planks with small openings resting on beams. The underlying beams are therefore not protected and rot has developed at the cross-girders. The bridge was constructed in 1991 and is CCA-impregnated.

Also where massive bridge decks are used, this can be an issue as water stays on the cross-beam creating a pool of water that causes localised wetting of the deck.

Fig. 10 Open abutment shelf which collects water, dirt and gives high moisture to the sill

Problems at the abutment are by no means only related to timber bridges. However, many of the problems at the abutment of timber bridges are often related to design solutions that are well known from concrete bridges and are applied to timber bridges without giving much consideration to the difference in material behaviour. When dealing with different types of materials, such as at the abutment, where timber and concrete will interact, special care has to be taken. Often standard solutions for concrete bridges do not constitute viable solutions.

In general the use of expansion joints is not really desirable on timber bridges because they normally represent a weak point in the structure. They give rise to additional cost, and also require special attention with respect to maintenance. In addition, they have to be specially created for timber-concrete connections.

Fig. 11 The timber deck are in direct contact with the concrete

Casting concrete directly against the timber deck may look like a good solution at the outset, but over time the timber creeps and moves and cracks are created in the intersection between the two materials. Water will be trapped and remain for a long period before drying.

Consequences for service life and maintenance action

Standing water may be difficult to detect in cracks and around sections that are not easy visible. Also if the bridge is inspected in dry weather, design faults may not be discovered.

Improving alternative design

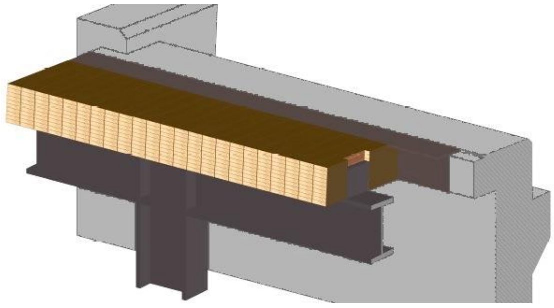

Fig. 12 Possible improved design

For the abutment a new design approach will be tested. The abutment differs from previous designs by having considerable free space below the intersection between concrete and timber in order to prevent standing water and dirt from gathering close to the end wood. In addition the joint between timber and concrete is easily inspectable from below.

4. Horizontal member without structural protection

Problem description

Fig. 13 Fungi is growing on a horizontal member. The photo is taken in 2009.

Horizontal members without any structural protection soon experience fungus attack in the cracks that face upwards. Cracks must be expected in members that are not creosote-impregnated. Upward-facing cracks will collect water that will remain there for some time and dry up very slowly. Fungus spur is always in the timber and starts growing when conditions are amenable to this.

It is not possible to completely avoid this through other means than structural protection. One can postpone fungus growth by using chemicals, but 100 years of service life is unlikely by only chemicals.

Consequences for service life and maintenance action

Fungus attacks in cracks grow from the inside and are difficult to reveal before the attacks are severe.

Improving alternative design

Fig. 14 The Leonardo da Vinci bridge also had fungus attack before it received structural protection to its upper face of the arcs. Constructed in 2005

All timber bridge should have structural protection on the upper side of the sections.

5. Dirt or debris on the construction section keeping the moisture content high

Problem description

Fig. 15 Dirt on the cross-beam

Fig. 16 A clean and better solution as above

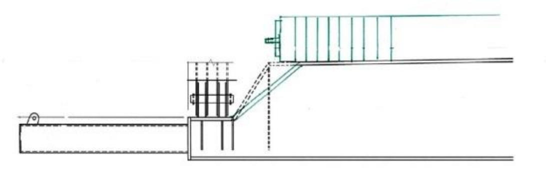

Fig. 17 Possible improved solution

A concrete cross-beam with dirt from the road gathering next to the deck. The dirt will retain moisture. The cross-beam also follows the transversal slope of the deck and road. This will conduct water to the deck. In spite of the deck is lifted up from the beam by a list the water will be transfer to the deck.

The cross-beams to the left will most likely experience the same problem as the above-mentioned cross-beam, but in less degree. An even better design for this cross-beam would be to incline the beam before the edge of the deck see fig 17. In this way dirt and water in general would run away from the deck when washed by rain.

6. Ions dripping onto metal with lower potential

Problem description

Fig. 18 Metals of different relative nobility staying in contact with each other may cause galvanic corrosion.

Using metals with different electronic potential that are in contact with one another can result in reduced service life. When ions transported in water drip from a metal with higher electronic potential onto another metal with a lower potential a bi-metallic corrosion is created. This rapidly tears into the zinc layer of galvanized steel and causes a loss of protection of galvanized members.

We have observed this problem when water runs off the cladding and onto cross-members or joints.

Consequences for service life and maintenance action

The metal with the lowest electronic potential will corrode and part of it will disappear. The maintenance action will be to replace the metal that has disappeared and to conduct the dripping water to another location where it does not corrode the underlying part.

Improving the section or introducing an alternative design

The design has to include drainage from an upper section to a suitable location.

7. Moving of dowels

Problem description

Fig. 19 Dowels dislodging from the structure

In some cases the horizontal dowels have moved out of position. This has happened on horizontal dowels with alternating load direction. The dowel is not quite horizontal, and when the load on the members alternates between compression and tension they can dislodge. The problem is observed on some bridges and only on joints which alternate load direction.

Consequences for service life and maintenance action

This movement of dowels may be very serious if they are not pushed back in time. This can reduce the service life of some bridges when it exceeds a certain point. In any case it will increase the maintenance cost. If damage has occurred to the bridge because the dowels have moved too far, the cost of repair may be substantial and the bridge will probably need to be closed for a period.

In the worst case, dowels that have become displaced can result in bridge collapse and this is therefore more of a safety issue than a service life issue.

Improving alternative design

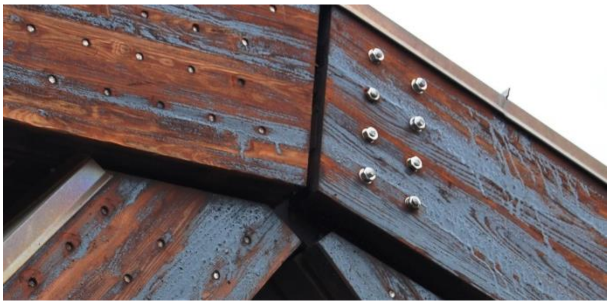

Fig. 20 Dowels fastened with nuts

The improvement is to prevent the dowel from moving out of position by using nuts and bolts instead of a simple dowel – the image to the left. Inserting a screw or nail next to the dowel to prevent it from moving has been shown to be insufficient. The solution has been to use a nut at the end of the dowel as shown in figure 19.

8. Corrosion on tendon bars in the deck

Problem description

Fig. 21 Corroded tendon bar on a 17-year-old bridge

Significant corrosion on tendon bars at the anchoring plates and to some extent inwards has recently been detected. The bars are situated in pre-drilled holes in the creosote-treated deck and originally they were sprayed with zinc. This bridge was only 17 years old.

The nut was placed where the iron piece is shown and the anchored plate was to the left of the iron piece.

It is not known how comprehensive this problem is, but it probably concerns bridges with a stress-laminated deck and may be without drip nose. This bridge has no drip nose. We suppose that a drip nose will improve the problem considerably. Depending on how extensive this problem is it will give the bridge owner an increase in maintenance costs.

Consequences for service life and maintenance action

At least one of the bars have serious attack. This will substantially reduce the service life of the tendon bar. However, it is not currently known how long this corrosion can remain before we have to change the tendon bars, since this depends on the stress and corrosion level of the bar. We have to take action before it breaks, since it could in some situation be dangerous for the environment if it breaks and falls from the construction. The maintenance action will be to replace the bar.

Improving the part or introducing an alternative design

There are several ways to improve this structural detail, consisting of three main alternatives: preventing the water from touching the nut, preventing the bar from corroding, e.g. by wrapping it, or using a non-corrosive tendon bar e.g. a fibreglass bar.

9. Discussion and conclusions

This paper shows some of the main findings from inspection of timber bridges. Some problems of a common and less serious nature have been omitted. In addition to this discussion, some discussion has been included when presenting the problems above.

In some cases the consequences of what we thought was a minor problem were more serious, or we failed to realize the seriousness of the problem. The more serious issues were that the water in some cases flows from one section to another or penetrated the end grain, and water lying on one horizontal member with a timber beam above it. The corrosion on the tendon bar seems to be very serious as well, however, for the time being we do not know how comprehensive this problem is.

Most of the problems were related to water that either followed a wrong path (bad workmanship) or was due to bad design. We found several places where humidity on the surface was increased substantially because of e.g. water situated on a shelf/beam or only dirt remaining close to a timber member. Detailing the water flow is very important. For other problems, such as the moving of dowels and corrosion on tendon bars, new rules need to be written. Another finding was that all part of the timber bridge should be inspectable with visual inspection.

However, with some maintenance work, all or the very most of the timber bridges in Norway should last for the anticipated time.

10. References

[1] Horn H., Monitoring five timber bridges in Norway – result 2012, Norsk Treteknisk Institutt, Oslo, Norway, 2013