Timber Bridge Inspection Project in Sweden

スウェーデンにおける木橋の点検調査プロジェクト

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ABSTRACT Many modern timber bridges have been built in Sweden during the last 15 years, but there are still not many instructions for inspection of the timber structures. In this project, the experience from timber bridges in Sweden was used to evaluate inspection methods to ensure systematic and effective inspections of timber bridges.

The project included close inspections of some Swedish timber bridges. At these inspections no serious damages were found that will reduce the performance of the timber bridges during the next ten years. Defects of the inspected bridges were mainly related to cracks and delaminations, surface treatments, moisture contents, steel coatings, connections, pre-stressed steel bars, paving and connections to abutments. The principally used field method was the resistive moisture measurement, as moisture is the most critical parameter for the decay of wood. Swedish timber bridges with good design will have a long service life provided that regular maintenance and inspections are performed.

Keywords : *modern timber bridge, inspection, moisture content, technical lifespan, timber bridge code*
近代木橋、点検調査、含水率、技術的耐用年数、木橋技術基準

1. Introduction

The background of this project was a need for better knowledge about the performance of the modern timber bridges in Swedish climate and about systematic and effective inspection methods that was required by the Swedish Road Administration (SRA) as the timber bridges were becoming a more common element in the road network system. The aim of the project was to use the experience from timber bridges in Sweden to evaluate inspection methods for timber bridges in general. The project included some close inspections of Swedish timber bridges.

1.2 Building of timber bridges in Sweden

The development of modern timber bridges in Sweden started in the early 1990's as in many other European countries and Japan. In addition to the advances of wood engineering technology, rich Swedish forest resources, assistance of the government's policy and public opinion about the importance of the environment and a sustainable society, the Swedish wood industry had a strong interest to support development of timber bridges. More than 650 modern timber bridges have been built. Wood is a light-weight construction material and also has an advantage in the total building costs because the possibility to improved efficiency in the production. Many of the timber bridges in Sweden are built with programmed designs and effective production methods in factories and transported in large parts to the building sites. More than half of the bridges are pedestrian bridges and many of the road bridges are smaller bridges on access roads for forest machinery. The timber bridges often have spans from 5 m up to 30 m (the longest pedestrian bridge has 230 m). They are built with different bearing structures, for example beams, stress-laminated deck plates, arches and trusses. The bridges are usually placed on concrete abutments.

1.3 Development of technical regulations for timber bridges in Sweden

As most bridges in Sweden have been built of concrete and steel, there were not many regulations before 1990 for building and maintenance of timber bridges. Ritter (1992) [1] was used as a reference during the first years. Design regulations have been developed continuously by the SRA and included in the Swedish national code for bridge building "Bronorm". The first regulations for timber bridges were stated in "Bro 1994" and since "Bro 2002" timber bridges have been accepted also as road bridges in the same way as bridges of concrete and steel. A first manual for inspections was made by Pousette et. al. in 2002 as a report of SP Trätek. [2]

Figure 1. Road bridge built in 2006

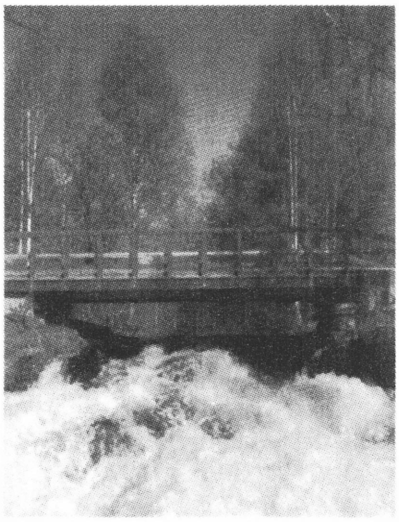

Figure 2. Road bridge built in 1999

1.4 Wood protection in timber bridges in Sweden

The wood species that are used in Swedish bridges are mainly European red pine and Norway spruce. The larger beams are made of glulam. Many of the earlier bridges are built with chemically treated wood in order to ensure a long life. Arsenic, chromium and creosote are not allowed for use in bridges, and mostly copper or borate based wood preservatives are used today. With increased requirements on wood protection by design the needs of treated wood are now decreasing. Claddings and other weather protections prevent high moisture contents in the structures, and often a combination of chemical treatment and protection by design is used. Instructions about wood protection by design are stated in the code "Bro 2004" of the SRA [3]. According to Bro 2004 the timber bridges are now designed for a technical lifespan of 40 or 80 years, with different requirements on protections. For timber bridges with 40 years technical lifespan, surfaces which lean less than 30 grades from horizontal plane (except bottoms), joint areas which do not locate under the protection of deck plate or other kinds of roof, sides and supports of pre-stressing bars of bridge plate and ends of wood constructions shall be covered by weather protections, while timber bridges with 80 years technical lifespan need to be protected by coverings on their all surfaces except bottoms and surfaces located under deck plate or other kinds of roof.

2. Types of damages

Timber bridges in Sweden can be subjected to deterioration from decay or mechanical damage. Many kinds of damages applicable for bridges of other materials can also be found on timber bridges, for example breakage or deformation as a result of cars bumping into them, ground movements at abutments, and corrosion on steel details. Damage typical for timber bridges is mostly related to moisture content. Physical influence of moisture can cause cracks and scaling, and biological influence can cause decay.

The moisture content in wood tends to come to equilibrium with the relative humidity of the air, which depends on the temperature. As the climate changes during the year the moisture content in wood will change. In Sweden the structures are usually most dry in the summer when the temperature is high and the relative humidity of the air is low. Increased moisture content will make the wood swell and sometimes small washers can be pressed into the wood giving cracks in the surrounding wood fibres. Decreased moisture content will shrink the wood members and bolt connections can become non-rigid. Cracks or blisters in the wearing surface can be signs of problems with moisture in the timber deck. Waterproof membranes of asphalt wearing surfaces must be kept intact to protect the deck.

2.1 Moisture and decay

Decay in timber bridges is normally caused by decay fungi, where the three main types are brown rot fungi, white rot fungi and soft rot fungi. Decay fungi will decompose the wood fibers, reduce the bearing capacity and change the colour. Decay fungi need moisture, oxygen, heat, and nourishment (wood material) to grow. For outdoor timber structures the only factor that can be controlled is the moisture content, by keeping the wood dry. The moisture content of wood is ordinarily expressed as a percentage of the weight of ovendry wood. If moisture content higher than 20 % and up to 30 % are found in some parts, the cause should be investigated. Moisture content above 30 % should be considered as damage, and it is important to correct defected details.

If the wood after some time of wetting has the possibility to dry, it will not be seriously affected. The rate of drying depends on the moisture level and the temperature. The lower the moisture content the slower is the drying process. Surface treated wood dries quite slowly, but it also depends on the type of paint and colour. Chemically treated wood is more resistant to rot, but should also be kept as dry as possible, as the moisture affects several qualities of the wood. Decay will often develop in cracks and delaminations and around fasteners especially where end grain is exposed.

2.2 Moisture and cracks

Influence of cracks on the service life of structures depends on the size and location of the cracks, the wood species, any chemical treatment, surface treatment, and the moisture content of the wood. Larger cracks should be measured during an inspection for future controls. Variations in moisture content will cause cracks in the wood and in surface treatments. The wood material shrinks when it dries, mostly in the direction perpendicular to the grain which give cracks along a beam. Cracks have a large influence on the moisture pickup. Water on a surface treated wood member can easily come into the wood through cracks in the treatment, but is difficult to dry out. Cracks have great influence on the moisture content, but not directly on the strength. High moisture content increases the risk of decay, which in the long run can influence the strength and durability. Larger cracks often develop in large wood members but more seldom in glulam. Exposed glulam often results in delamination, that is cracks along the glue lines.

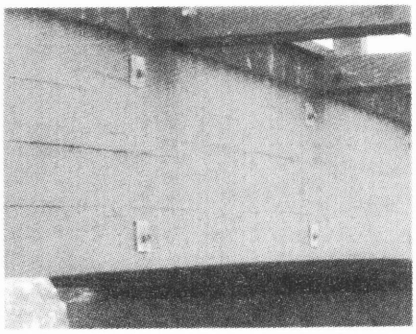

Figure 3. Cracks and delamination

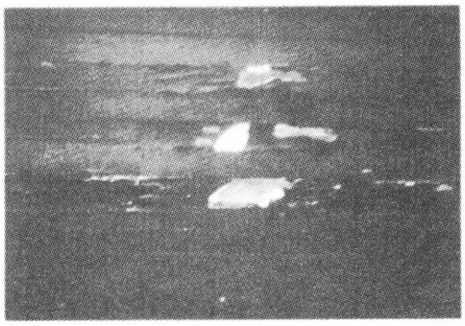

Figure 4. Delamination and scaling

Surface treatments can get cracked or flaked, which can expose the wood member to moisture and decomposition. Their origin are usually changes in the moisture content and the cause must be found and rectified to avoid further damage and to facilitate a touch up of the surface. The treatment should protect the surface against moisture changes and ultraviolet radiation from the sun. There are many different types of paints to use, with different characteristics and amount of pigment.

3. Inspections

The timber bridge inspection project included a survey of modern timber bridges built in Sweden concerning types, spans and locations. An inquiry was made to some of the road managers to get their opinions about maintenance of timber bridges. From these studies some bridges were then chosen for close inspections.

3.1 Inquiry of bridges

Timber bridges like other bridges need some maintenance to get a good durability. The Swedish Road Administration performs systematic inspections of their bridges and registers all bridges and inspections in a computer database. But even bridge inspectors of SRA have had little experience of timber bridges, and many municipals and private bridge owners do not usually have the same routines as SRA, and lacking resources sometimes result in long periods between inspections.

An inquiry to around one hundred state, municipal and private road managers was made about timber bridges, inspections, and maintenance. For a few bridges there existed maintenance plans, mainly about cleaning and painting. The modern timber bridges in Sweden are relatively young and not much maintenance had been done so far. Some bridges had not been checked at all during these first years. Larger repairs had been needed for a few accidents like flooding, fire or car collisions. Also damages from snow removal vehicles were reported. The most frequent defects and measures for the bridges concerned railings, surface treatments and fasteners.

3.2 Inspection methods

The inspections were performed with general inspection equipment such as hammer, knife, drill, wrench and measuring tape, moisture content meters, force measurement equipment and coating thickness meters. For some inspections a crane was used to reach all parts, but for most bridges a ladder was enough. All inspections were made in the summer. The time required for an inspection was about 2-8 hours at the bridge site depending on the size and type of bridge.

The general condition of the bridges was assessed through visual inspection of all construction parts, especially with consideration of deformations, surface treatments, cracks and joints. Larger damages were documented with photos and for example the width and length of larger cracks was measured.

The main field measurements were moisture measurements. The moisture content in wood can be measured with many different methods, the ovendrying method, resistive methods, dielectric methods, microwave methods, infrared methods etc. The ovendrying method is the most exact method, but it requires cutting pieces from the wood and a long time and is difficult to use in the field. Therefore portable resistive and dielectric moisture content meters were used. They have quite good accuracy and are nearly non-destructive measurements. The measured moisture contents can vary about ±2 % compared to the ovendrying method at 18 % moisture content. Two bridges were prepared for long term studies with wood pieces for ovendry measurements, which were used at the inspections.

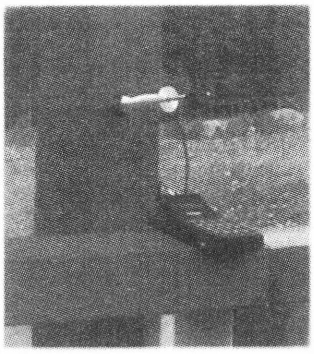

Figure 5. Moisture meter

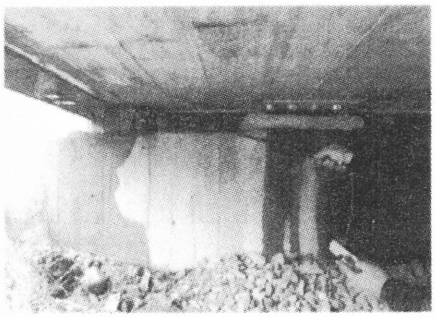

Figure 6. Moisture survey

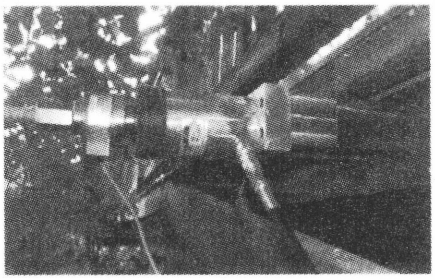

Figure 7. Load cell, jack and steel chair

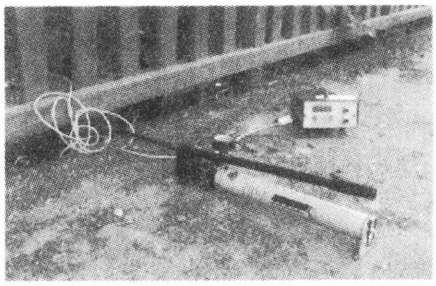

Figure 8. Jack and measuring instrument

The pre-stressing forces of the bars of stress-laminated deck plates were examined with a hydraulic jack. Readings were done with a load cell and measuring instrument. The equipment consisted also of a steel chair in order to get contact to the bar. Two bridges were prepared with load cells for long term measurements, which were used at the inspections.

3.3 Inspected bridges

A total of 13 bridges were inspected during the years 2003-2004. Three of the inspected bridges were road bridges, and the others were pedestrian bridges. The bridges had different designs. They were 2-10 years old and geographically spread out over Sweden.

Two bridges had arches and columns under stress-laminated bridge decks. As for one of them, the lower parts of the outer sides were not protected by the deck. There were several long cracks, about 1-2 m long and 30-50 mm deep on the south side. Surface treatments were flaking on the outer sides of columns and beams. On the north side there were some locations showing high moisture content. The bridge decks did not rest on the inner supports, and moved down when loaded with traffic. This had caused some cracks in the asphalt pavement at the joint to the road. The deck plates had high moisture content at the supports, especially at the corners.

Another one had high moisture content, more than 30 %, in the stress-laminated deck plate and arches. The deck plate had high moisture content at the ends and near holes through the deck for the drainage system. The arches outside the deck had several delaminations and cracks, and the steel covers were insufficient. Transverse beams sticking out from the deck had no covers, and had high moisture content.

One bridge had a board cover along the edges of the stress-laminated deck plate. The surface treatment of the boards had started to flake, especially on the south side. The joint to the land abutment was not tight, and water leaked down and caused delamination.

One bridge with a T-beam deck plate and asphalt paving had a lot of dirt on the bridge and many bushes around. The paint on the railings was quite worn. The stress-laminated deck plate was well protected, only the outer beams were a little affected by moisture from a road bridge close at one side and the bushes on the other side. Plywood along the deck edge was deformed under the anchor plates of the pre-stressing bars.

The sides of a stress-laminated box-beam bridge had no protective clothing. The most serious defect of the bridge was that some of the anchor plates of upper pre-stressing bars of the deck plate were pressed through the thin plywood plate and into the wood. This caused cracks and high moisture content over 30 % in the wood and low pre-stress forces in these bars.

One beam bridge had the steel covers of the beams missing on some parts, and the beams had some smaller delaminations on the outer exposed sides. The outside of beams which had no claddings was worn. The surface treatment of the railings was faded. The transverse beams of a suspension bridge had no protection and high moisture content. Also beams at supports had high moisture content. Some nails of the railings of the suspension bridge were drawn out because of horizontal movements of the bridge.

One truss bridge had some unfastened screws. Another truss bridge had generally low moisture content, but in the lower parts of the trusses there were some higher values. The bridge was surface treated with dark brown oil. The top and bottom glulam chords of the trusses had some cracks and delaminations, especially on the sunny side. The bridge seemed to have dried and the timber members shrunk since it was built, as most fasteners were loose.

3.4 Field monitoring of timber bridges

Some timber bridges in Sweden have been monitored to evaluate the performance of stress-laminated bridge decks. The monitoring started just after the bridges were built. It involved data-acquisition of ambient temperature, relative humidity, force levels in the steel bars, moisture content in wood and displacement at supports. Field data were gathered continuously every day, by a stand-alone data-logger with a back-up battery, and data was collected intermittently by phone and modem. The monitoring of bridges provide evaluating and verifying structures, improving design through feedback and also health monitoring of timber bridges as part of a maintenance plan.

Two bridges were prepared in some points for manual moisture content measurements, both wood pieces for the ovendry method (T) and pins for the resistive method (R). In one bridge wood pieces in seven places and pins for the meter in four places have been put in the deck plate since the bridge has been built in 1994 and were used to give the moisture content through the bridge deck, see figure 10. The deck plates had the lowest moisture contents at the top, and at the bottom the moisture content was about 16 %. The average moisture content had increased about 1.4 % during the last 8 years. Another bridge which has been also prepared in four places for moisture content measurements gave almost same results.

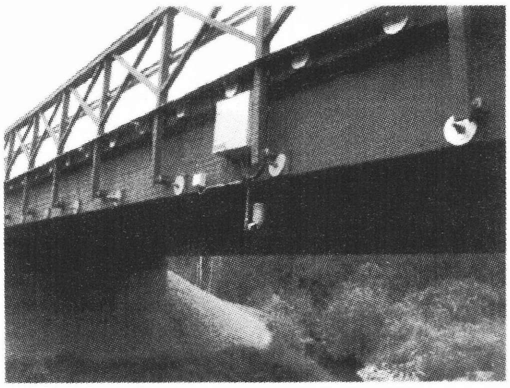

Figure 9. Measuring set-up of stress-laminated box-beam bridge

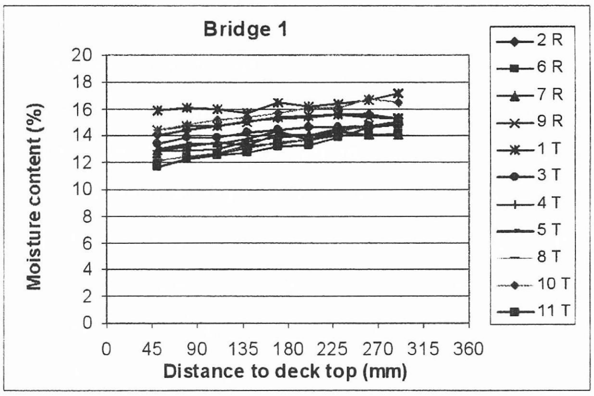

Figure 10. Moisture content in deck plate, prepared with moisture meters in 11 points

4. Discussion and conclusions

Damages and defects of the inspected timber bridges were above all about high moisture contents, small cracks, and delaminations, flaking surface treatments, insufficient claddings, asphalt paving, and joints to the road. At these inspections no serious damages were found that will reduce the performance of the timber bridges during the next ten years, but there were a number of details and occurrences of high moisture levels of some bridges that need to be attended to in the future. Deck plates are mostly exposed along edges and ends. Covers of horizontal surfaces should be controlled if leakage is suspected. Joints and through holes can be critical locations.

The moisture content was usually low and even, but high values were measured in some elements. The highest moisture contents were located in unprotected beams, at ends and supports of beams, arches and columns, in railings, especially down in the lower parts of the balusters, and at the end and verge of deck plates. Some of the defects were caused by poor design of the oldest bridges. Many of these details have been improved in later bridges. Some bridges showed evidence of lacking maintenance, such as cleaning of dirt and leaves. On several abutments there were soil, dirt and leaves, plus dense vegetation around them. Some sealing joints to the road were not working, which caused leakage of water and gravel down on the abutment. Loose screws existed on several bridges and rust on screws and damaged steel covers were observed on some bridges. Cracks and delaminations were found on the outer sides of painted glulam beams, especially on east- and south sides. No repainting had been made since the bridges were built, but some were touched up. The surface treatment on railings was in several cases worn, with flaking, cracks, and algae. On many bridges there were trash and gravel down in the lower parts of the balusters and trusses. Some railings had damages from snow removal vehicles.

The stress-laminated deck plates with waterproofing sheet and asphalt paving, seem to get low maintenance costs and long life. Deck plates are often made of untreated Norway spruce, and painted claddings along the sides protect the deck against sun, rainfall and road dirt. The measured moisture content in the deck plates were about 14-18 %. The anchor of the pre-stressing bars was in some bridges insufficient. The pre-stressing forces were about 40-70 % compared to the initial forces, but high enough for the deck plates to work well. The bar forces will most likely be the same in the future on condition that the anchor will be intact. Minimum requirement force should be stated in design documents of the bridge.

The used inspection methods were adequate for these bridges and provided a good picture of their condition. The bridges were only 2-10 years old and generally in a good condition. No rot was found, but some parts had high moisture content where rot can start. Probing with knife and sounding with hammer was done on some areas suspected for rot, but no boring was needed. More advanced measuring methods like sonic tests, x-ray and tomographic scanners were not used in these inspections as they have high costs and need experts for the interpretation of results. In the future, in 50-70 years when the bridges are getting old, there may be a need for more advanced scanning methods for evaluating their remaining life time.

The results of this project were presented by Pousette, Fjellström in 2004 [4], and the results has been taken into consideration for the inspection of timber bridges during the development of BaTMan, the new database system of the Swedish Road Administration for managing bridge and tunnel structures. In BaTMan facts about the condition of the structures, the design, documents and drawings are collected. When reporting assessment of the load capacity of bridges it is important to calculate and estimate how cracks and other defects will influence the bridge in various circumstances. For timber bridges limiting values of moisture content, cracks and flakes etc, and models of degradation processes are required for the planning process. This project did not establish such values. Future studies can give more experience of damages and the development of the conditions of the bridges. SRA has regulations about inspection intervals. The same rules can be used for timber bridges as for other bridges with a principal inspection every sixth year and general inspection every third year. Regular maintenance should be carried out every year.

Timber bridges with good design will have a long life. This can be realized by a good maintenance with cleaning and fixing damages to keep the wood dry. Regular inspections with field measurements of moisture and bar forces can form the basis of preventive measures to avoid defects.

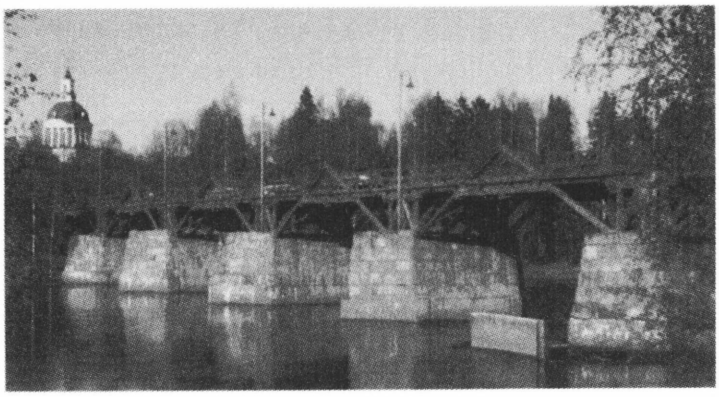

Figure 11. The oldest and longest road bridge in Sweden from 1737

5. Acknowledgements

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