Investigation of timber bridges

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1. Introduction

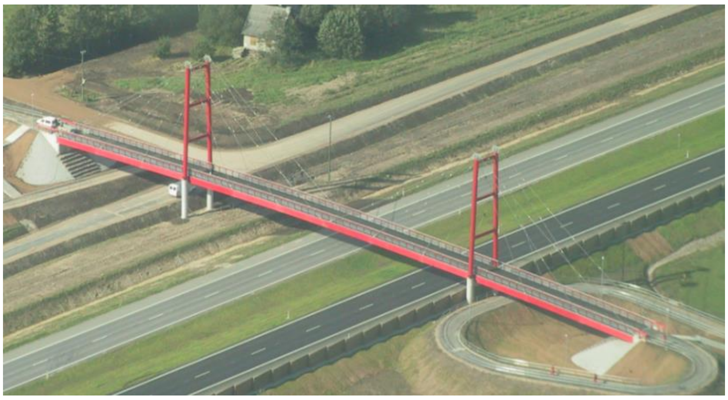
During this research, inspections on 17 timber bridges in Estonia were conducted by authors of this paper in the autumn of 2014. The study was ordered by the Estonian Road Cluster and was performed by SP Technical Research institute of Sweden and Tallinn University of Technology.
Among the examined bridges were 9 beam bridges, 6 arch brides, 1 cable stayed and 1 covered truss bridge. 4 of the bridges were road bridges, 13 pedestrian bridges. Bridges were situated in different locations all over the country.
Inspection included visual survey of joints, occurrence of rot and measuring of moisture content. All inspections were made according to the guidelines in the Swedish road administrations handbook in Batman and "Bridge Inspector's Reference Manual" of the US.

2. Bridge inspections

The most important findings of the investigated bridges are explained by the following examples. The examples are chosen to describe the biggest weaknesses for the purpose of learning from them and avoiding them in the future.

2.1. Vaida footbridge

Vaida footbridge is a cable stayed bridge with glulam girders and pylons of Comwood. Main span 62 meters. Main characteristics of the bridge are shown in Figure 1.
The inspection of the glulam in girders and pylons were made with a resistograph and a resistance moisture meter. Each glulam member was tested in at least 3 points. The bridge was inspected on 8th of December 2014. That is roughly six years after the building of this bridge.
Inspection showed that the bridges' superstructure is in fair to poor condition. Six of the glulam members in the girders were in poor condition and should be replaced. The moisture content was very high in the beams below the deck plate. Most of the glulam beams had just minor fungal decay, isolated to the upper 100-300 mm of the beam. Deck was seriously damaged by fungal decay along the edges. Part of the deck was completely rotten and collapsed. See Figure 4.



Year of construction	2008
Total length	124m
Practicable width	4m
Span length	31+62+31m
Type of structure	Cable-stayed bridge
Timber Beams and Deck: Pylons:	 not impregnated Spruce; pressure impregnated Comwood of Spruce
Vertical eigenfrequency	2,4 Hz

Figure 1: Vaida footbridge

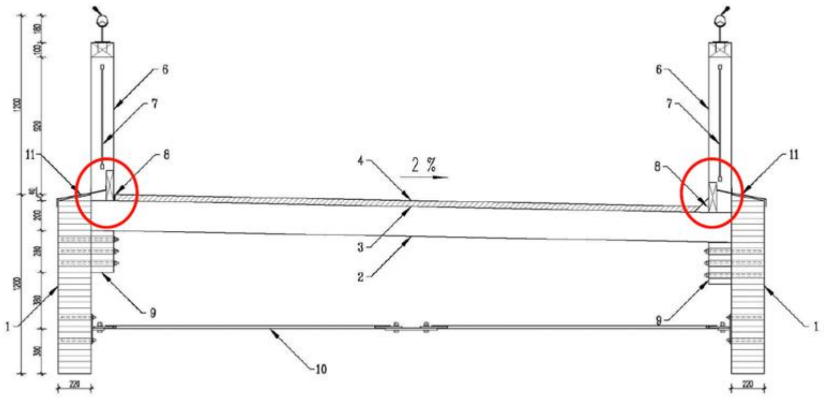


Figure 2: Section of the bridge.

Designed solution *Built solution* *Fungal damage*

Figure 3: Joint of the deck edge.

Figure 4: Collapse of the deck in 2014 due to completely rotten deck at supports.

The damage was caused by non-ventilated joints between deck plate and main girder. Deck was covered by water tight layer and asphalt. In contradiction with the designed solution, the support area at the edges of wooden deck plate was also covered by asphalt and the drying of wood of the deck plate at the edges was blocked. The water barrier shown in red in Figure 3 was missing.

Comwood pylons were in satisfactory condition. Moisture content was very high at the pylon foot. Wooden pylon was supported directly on the concrete contrary to designed solution. Pylon was made of pressure impregnated spruce. The pressure impregnation helped to avoid the destructive fungal damage during the first six years although the moisture content was very high. The transverse beams between the pylons are in satisfactory condition. Very high moisture content in the wood due to lack of water repellent paint system and/or protective cladding was discovered.

All wooden parts of Vaida footbridge except pylons were made of unimpregnated spruce (Picea Abies) instead of chemically treated pine (Pinus Silvestris). Unimpregnated spruce does not have noticeable durability without proper cladding.
The regular bridge inspections made by Estonian Road Office did not discover any damage during these 6 years. Most probably there is no proper system for inspection of timber bridges specifically.
Recovering of damages of the bridge should consist of the replacement of deck structure and replacement of at least two glulam beams (hit by the collapse). The bridge owner – Estonian Road Office – decided to demolish this bridge and build a new steel-concrete bridge instead.

2.2. Reopalu footbridge

Year of construction	2008
Practicable width	4m
Span length	33m
Type of structure	Arch bridge
Timber	Arches and Deck: impregnated Pine (Pinus Silvestris)
Vertical eigenfrequency	5,5 Hz

Figure 5: Reopalu footbridge.

Reopalu footbridge in Mid-Estonia is an arch bridge with span of 33 meters. Main structural elements are made of pressure impregnated pine and covered by paint. Bridge deck is pressure impregnated pine.
The bridges' superstructure is in very good condition. There is no cladding, sheet metal or other wood protection on the arches or other parts of the super structure. The moisture content in the glulam, is very high close to the bearings, over 25%. The moisture content will remain very high until all weather exposed parts are covered with cladding.
The paint on wooden parts is in poor condition on the south sides. See Figure 6.
During the inspection the poor maintenance has been recorded. At the supports there were dirt and gravel as well as vegetation discovered close to the timber load bearing elements. With some preventative maintenance, the bridge will be in excellent condition.

Figure 6: Arches are uncovered. Some cracks discovered on the upper side.

Figure 7: Dirt and gravel on all parts of the substructure due to lack of preventative maintenance.

2.3. Merirahu footbridge

Year of construction	2001
Practicable width	3,2m
Length	25,6m
Type of structure	Arch bridge
Timber Arches and Beams: Deck:	 not impregnated Spruce impregnated Spruce (Picea Abies)
Vertical eigenfrequency	7,4 Hz

Figure 8: Merirahu footbridge.

Merirahu footbridge is an arch bridge with span of 24,5 meters. Bridge has a balcony on the sea side. Main structural elements are covered by five layers of alkyd paint. Bridge deck is covered by bitumen emulsion and gravel layer. All the steel elements of this bridge are made of stainless steel. Main characteristics of the bridge are shown in Figure 8. The bridge was repainted with a dark paint on 2010. Author of this paper do not have information about the chemical content of the paint.

Figure 9: View of the bridge and deck edge detail.

The inspection discovered that the bridges' superstructure was in a serious condition. Probably the dark colour of the new paint led to cracks and allowed the water insertion into the wood. Drying of wood was blocked and that led to development of fungal damage in the arches and cross-beams.

The most critical damage is severe decay and deformation in one transversal beam. The beam was considered as fracture critical during the inspection. The transversals condition is beyond corrective action due to decay in connecting points and along the upper quarter of all sides. See Figure 10.

Condition of two arches was beyond corrective action due to decay at supports. The arches were in fair to poor condition and the south east side was recommended to be replaced. The moisture content was high, 20-24% and the decay process could continue until the arches are covered with cladding. The arches are made of spruce. These problems could have been avoided with chemically treated arches and/or protective cladding.

The deck was in fair to poor condition. It's a nail laminated deck made of surface treated spruce covered with a thin bitumen layer with washed gravel on top. The deck should have been made of treated pine instead of spruce. The bitumen layer was too thin, and damaged, to protect the deck. Lack of preventive maintenance was also discovered.

The condition of the top followers of the railing was also beyond corrective action due to decay by fungi. The deck had some spots with minor decay. All wood parts were made of spruce (Picea Abies) instead of chemically treated Pine (Pinus Silvestris). The use of spruce instead of a more durable material in weather exposed bridge elements may shorten the service life.

Fungal damage of the transversal beam

Rotten zone and insects in the arch foot

Figure 10: Main fungal damages of the bridge.

Recovering of damages of the bridge should consist of the replacement of two arches and transversal beams. Paint should be removed from the remained structural elements and replaced with the proper protection systems including wooden or steel claddings on the surfaces exposed to direct weathering.

The bridge owner decided to repair the bridge in 2017.

2.4. Tehvandi rollerski bridge

Year of construction	2004
Practicable width	4,5m
Length	24,5m
Type of structure	Arch bridge
Timber	
Arches and Beams:	impregnated Pine
Deck:	not impregnated Spruce

Figure 11: Tehvandi rollerski bridge.

Tehvandi wooden bridge is an arch bridge with length of 24,5 meters. Bridge is built for rollerski track. Main structural elements are made of pressure impregnated pine. Deck is made of solid wood and covered by asphalt pavement. Main characteristics of the bridge are shown in Figure 11.

Inspection showed that the bridges' superstructure was in good condition. The most critical damage was severe decay and lost parts of the railing that was in an imminent failure condition. All parts made of wood needed to be replaced. The railing was noticed to be relatively low 0,98 – 1,06 m. Some railing posts were tilted out from the bridge. Fasteners used in the railing were very small and weak.

Arches were in satisfactory condition and will need a cladding. The moisture content in the glulam, close to the abutments, was very high, 23-37%. The moisture content will remain very high until all weather exposed parts are covered with cladding. Abutments were affected by increased humid environment from plants and earth. See Figure 12.

The deck was in very good condition. It's a nail laminated deck with an asphalt wearing surface on top. The deck was made of spruce.

Arches need re-painting and covering on top | *Railing needs replacement* | *Bridge girders are in contact with ground and need cleaning*

Figure 12: Main findings during the inspection.

The bridge should have been re-painted years ago. There is no cladding, sheet metal or other wood protection on the arches or other parts of the super structure. With some preventative maintenance, the bridge should have been in much better condition.

Generally, the bridge is in good conditions. The owner of the bridge made maintenance on 2016 consisting re-painting of the bridge and cleaning the abutment areas.

2.5. Tõrva footbridge

Year of construction	1988
Practicable width	2m
Length	38m
Type of structure	Arch bridge
Timber	not impregnated Spruce (Picea Abies)
Vertical eigenfrequency	4,4 Hz

Figure 13: Tõrva footbridge.

Tõrva footbridge is an arch bridge with span of 38 meters. Age of the bridge is about 30 years. Bridge elements are not impregnated nor covered by claddings. The bridge has currently the longest span among timber bridges in Estonia. Main characteristics of the bridge are shown in Figure 13.
The inspection showed that bridges' superstructure was in very poor condition and the bridge should be closed to traffic. The arches have recently been re-painted and some minor repairs have been done. The arches condition was beyond corrective action due to decay in connecting points and along both bottom, top and outer side of the arches.

Deformation and decay in the top of the arch, the hinge is lost.

Decay at the support of the arch.

Figure 14: Main damages of the bridge.

The deck and railing have been replaced and were in good condition. Railings and deck are made of spruce (Picea Abies) instead of chemically treated Pine (Pinus Silvestris).
The abutments had some minor damages, cracks and some efflorescence. It is obvious that there have been no or very little maintenance on the abutments.
The arches are made of pine, not treated, and were in very bad condition. The top of the bridge was approximately 100mm lower at the east side than the west side. See Figure 15 on the right. This tilt was caused by deformation in connecting points. The deformation was a result of decay in the joints of glulam arches.
Moisture content, measured on the bridge was between 15 and 30%. The difference between the moisture content above and below the crack in the paint is shown in Figure 15 on the left. The paint did not allow wood to dry out. Water that entered the crack was collected below the crack and coud lead to invisible fungal damage inside the wooden element. The risk is that finally the damaged part of the beam does not have any strength left. The region where the crack can be formed cannot be predicted. The proper paint system that allows wood drying is therefore very important.

Moisture contents measured above and below the crack.

Bridge deck tilted 52mm /m, due to local failure in the arches connection points.

Figure 15: Some examples of the investigation results.

The above mentioned problems could have been avoided with chemically treated arches and/or protective cladding.
The deck and running boards are new and looked good. But there were some things that should have been made different. The crossed layers should have been made of treated pine instead of the used spruce. The floor beams should have been made of treated pine. All fasteners should have been either hot dip galvanized or made of stainless steel.
The strips of wood on the running boards were made for indoor use and were not suited for outdoor use on a bridge deck.
The owner of the bridge made a renovation of the bridge at 2016 consisting making new larger steel plates to extend arch top and foot connections to the undamaged wood.

2.6. Järuska road bridge

Year of construction	2013
Total length	26,4m
Practicable width	3,5m
Type of structure	Truss bridge
Timber	not impregnated Spruce (Picea Abies)
Vertical eigenfrequency	9,5Hz

Figure 16: Järuska covered bridge.

Järuska bridge is the only bridge in Estonia covered by roof. The bridge was made by the community of local enthusiasts to join both sides of the river. Bridge is used by cars and pedestrians.
Inspection showed no damages or weaknesses that could decrease expected durability. From the structural point of view the strength and stiffness was designed with big reserve.

3. Summary

Proper design, careful building according to design, proper inspection and maintenance are the most important aspects to follow when planning and creating timber bridges. The inspection of 17 Estonian timber bridges showed some typical problems that should be dealt with. Overview of the investigations is listed in Table 1 and 2.
Wooden species have different durability. The use of spruce instead of a more durable material in weather exposed bridge elements shortens the service life down to as little as 5 years. Pressure impregnated pine can provide much better durability.
High moisture content is normally caused by wrong design of protection and details. Moisture content that is more than 25% can lead to fungal damage. Almost none of the bridges have steel or wooden cladding on the weather exposed surfaces. This can lead to development of fungal decay.
The inspection of timber bridges by bridge owners was discovered as very poor. Road Office for example does not have proper rules for inspecting timber bridges.
Poor maintenance was discovered on many bridges. Supports were not cleaned from plants, drain systems were blocked. There are simple works that should be done to avoid major problems.

Table 1: Main damages and problems inspected on Estonia's timber bridges.

Bridge	**Main problems investigated**						**Wood specie**	**Pres-sure impr**	**Clad-ding**
	Fungal damage	**High MC >25%**	**Bad paint**	**Bad railing**	**Corro-sion of steel**	**Un-cleaned sup-ports**			
Vaida	x	x	x				spruce	No	Upper surface
Reopalu		x			x		pine	Yes	No
Tehvandi	x	x	x	x	x		pine	Yes	No
Ala-Rõuge							pine	Yes	deck
Keisripalu				x		x	pine	Yes	No
Tõrva	x	x			x		spruce	No	No
Angels bridge	x	x	x	x			spruce	No	Yes
Järuska							spruce	No	roof
Varbola		x				x	spruce	Yes	No
Merirahu	x	x	x	x		x	spruce	No	No
Lükati	x	x	x				spruce	No	No
Pärnu						x	spruce	No	No
Tagavere		x				x	pine	Yes	No
Nuutri			x	x		x	spruce	No	No
Pihla			x	x			spruce	No	No
Kõrgessaare			x			x	spruce	No	No
Keila	x	x		x		x	pine	No	No
Total	**7**	**10**	**9**	**7**	**3**	**8**			

Finally, three bridges among the 17 investigated bridges had serious damages – Vaida, Tõrva and Merirahu. The majority of the bridges were in fair or good conditions. Because of the fast damages of Vaida bridge, Estonian Road Office has made a decision to avoid timber bridges in the future.
The main aim of this work is to give knowledge for avoiding the mistakes in the future.

4. References

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