Asphalt surfacing on timber bridges

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Summary

It is difficult to get adequate information about the load-bearing properties of the different asphalt systems which are used for the surfacing of modern timber road bridges. The authors have participated in a research project to investigate the load-bearing behaviour of different, asphalt-based road surfacing systems under service loads. First, suitable material combinations and layer compositions were selected for detailed research. The transfer of horizontal forces through the composite construction was a special research interest. A number of test series was carried out to investigate the adhesion between the surfacing and the timber deck. The test results were comparable to those obtained for surfacing placed on concrete and steel bridge decks. The tests confirm that the requisite bonding strength can be achieved with similar systems such as those used in steel and concrete bridges. Structural recommendations for the practical application are also presented in the paper.

Keywords: asphalt surfacing systems, shear resistance, adhesion tensile strength, blistering, monitoring

1 Introduction

Nowadays, mastic asphalt and rolled asphalt are both used for the surfacing of timber road bridges. A durable sealant between the asphalt layer and the timber deck is of enormous importance for both systems [1], [2]. It protects the timber deck from direct contact with the molten asphalt during the pouring phase. Later on, it prevents the entry of water. In systems without shear connection between asphalt structure and bridge deck, there is the risk of the development of "surface waves" caused by high braking and acceleration forces. In Germany for instance, only systems with shear connection are permitted for traffic road bridges.

In surfacing systems without a shear connection, a separation layer, e.g. glass-fleece and oil-impregnated paper, lies between the timber bridge deck and the bottom from the sealant, which is attached to the asphalt structure on top (Figure 1). In a typical system with shear connection, the surface coating replaces the separation layer (Figure 2). The surface coating is the “glue” which holds the timber bridge deck and the sealant together.

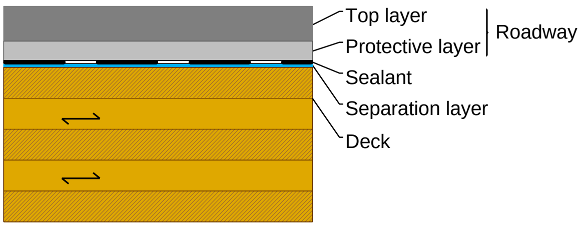

Figure 1: Sketch of a system without a shear connection between asphalt and bridge deck

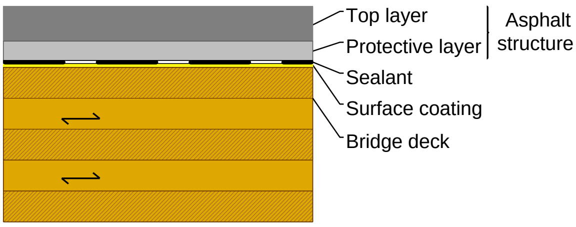

Figure 2: Sketch of a system with a bonded shear connection between asphalt and bridge deck

In comparison to concrete and steel bridges, research work on the surfacing of timber bridges has been rather modest. The authors have participated in a research project to investigate the properties of different, asphalt-based road surfacing layers under service loads. The research project was concerned with the shear resistance of the surfacing, and with the problem of “blistering” which may occur when hot asphalt is poured on a timber deck. The research work included the scientific observation and monitoring during the renovation of the surfacing of the Bubenei Bridge in Canton Berne, Switzerland [3].

The paper will give an overview of the test set-ups and the results obtained. The monitoring of the resurfacing of the Bubenei Bridge gave useful inputs which also helped in the formulation of recommendations for the practical application.

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2 Materials and methods

2.1 Shear tests

Systems without a shear connection and systems with a shear connection between asphalt structure and deck material are both used for road bridges. The tests performed during the research work were limited to systems with a shear connection. All test specimens included a layer of temperature modified mastic asphalt (pouring temperature 200 °C) because they are more favoured in systems with shear connection. No rolled asphalt was used. Figure 3 shows the principal cross section of the test specimens.

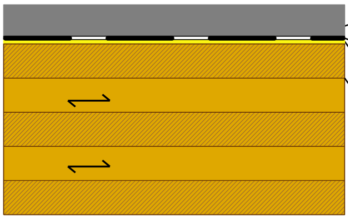

Figure 3: Principal cross section of the shear test specimens

The following parameters were also investigated:

a) The deck material, such as steel, concrete, cross laminated timber (CLT) and laminated veneer lumber (LVL).

b) The sealant system, such as polymer bitumen membranes and liquid synthetic sealants (based on polymethyl methacrylate, PMMA) together with various surface coatings.

Table 1 explains the parameters of the test specimens for the shear tests. Three specimens were manufactured for each of the 12 layer compositions shown.

Table 1: Layer composition of the test specimens for the shear tests

Deck material	Surface coating	Sealant
Concrete	Sanded epoxide	PBM
Concrete	LS primer	LSS
Steel	Primer	PBM
Steel	LS primer	LSS
CLT	Sanded epoxide	PBM
CLT	LS primer	PBM
CLT	LS primer	LSS
CLT	Epoxide primer	LSS
LVL	Sanded epoxide	PBM
LVL	LS primer	PBM
LVL	LS primer	LSS
LVL	Epoxide primer	LSS

PBM: polymer bitumen membrane; LSS: liquid synthetic sealant

The selected material combinations and layer compositions were subjected to shear and tensile bonding (adhesion) tests. Figure 4 and Figure 5 show the set-up for the shear tests.

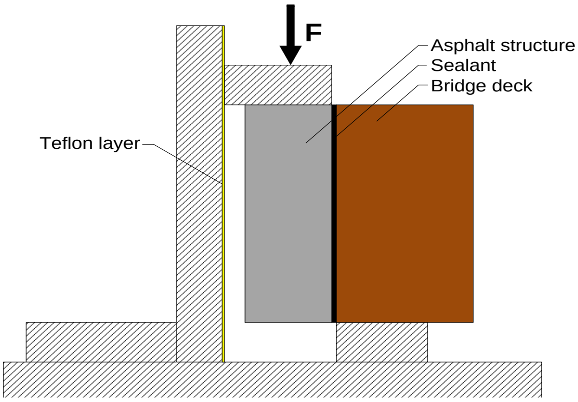

Figure 4: Test set-up for the shear tests

Figure 5: Detail of the test machine readied for a shear test

2.2 Adhesion tensile tests

Adhesion tensile tests are the most common in-situ testing method. Material tests can be carried out on site with a mobile testing machine. The test arrangement is regulated in the Swiss Standard SN 640450a.

The layer compositions of the test specimens are listed in Table 2 below. Three specimens were tested of each layer composition. Only a relatively small number was selected for the adhesion tensile tests: these preliminary tests were intended to give a general idea of the adhesion properties of the surfacing on the wooden base. A larger number of samples will be tested at a later stage in order to make a statistical analysis of adhesion tensile tests.

Table 2: Layer composition of the test specimens for the adhesion tensile tests

Deck material	Surface coating	Sealant
LVL	Sanded epoxide	PBM
LVL	LS primer	LSS

PBM: polymer bitumen membrane; LSS: liquid synthetic sealant

The researchers were primarily interest in the adhesion tensile strength between the sealant and the wood base, so the specimens were prepared without any asphalt layer (Figure 6).

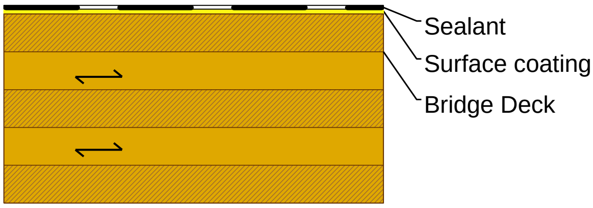

Figure 6: Principal cross section of the tes specimens for the adhesion tensile tests

The mobile testing machine used has a stamp-like head called “indenter” which pulls the test specimen from the wooden base. The surface of the test specimens needed to be properly prepared so that they could be glued to the indenter of the testing machine. The PBM polymer bitumen membrane was heated with a Bunsen burner so that the top-most layer of sanded epoxide could be removed. The primer of the LSS liquid synthetic sealant was removed with alcohol.

A layer of cyanoacrylate adhesive was used to attach the test specimen onto the indenter of the testing machine. The testing area of the surfacing was cut free from the surrounding surfacing area, so that only this area was subjected to the pulling force (Figure 7, Figure 8). The tests were carried out in the laboratories of the Bern University of Applied Sciences in Biel by the company BTS Baucontrol. The tests were force-regulated at a rate of 300 N/s.

Figure 7: Mobile adhesion tensile testing machine of the company BTS Baucontrol

Figure 8: The indenter is pulling at the barely visible PBM sealant underneath it

2.3 Resurfacing Bubenei Bridge

The surfacing of the Bubenei Bridge needed to be redone because of numerous cracks in the asphalt. No sealant was used in the old surfacing. The timber deck had a very high moisture content of 18 – 20 %. The distribution was very uneven: in some places the moisture content was measured to be over 100 %.

For cost reasons, the owners and the project engineer decided to leave the timber deck in position despite the extraordinary moisture content. Their reasoning was that the new sealant would prevent more water from getting to the timber deck. The fact that the new sealant would also prevent the timber from drying upwards was an accepted risk: the engineer estimated that the drying downwards away from the sealant would be slow but adequate.

Because of the high moisture content of the timber deck, there was a risk of severe blistering when the mastic asphalt would be poured. Despite the risk of "surface waves" caused by braking and acceleration forces, the project engineer decided to use a surfacing system without a shear connection to the bridge deck. The selected solution is shown in Figure 9 below: it had two important advantages to mitigate the risk of blistering. First, a separation layer of glass-fleece and oil-impregnated paper was combined with closely drilled release openings for the controlled discharge of any water vapour which might form during the pouring of the mastic asphalt. The second measure was the massive reduction of energy input by using temperature-modified mastic asphalt with a relatively low pouring temperature of 200 °C. The thickness of the lowest asphalt protective layer was reduced to 25 mm and it was placed carefully by hand.

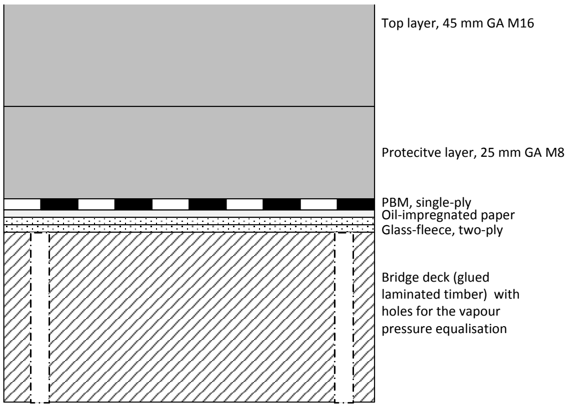

Figure 9: Layer composition of the new surfacing of the Bubenei Bridge

The researchers were given two monitoring assignments on the Bubenei Bridge. Before the new surfacing was poured, they mounted temperature gauges at different depths of the timber deck to clarify if the temperatures would rise high enough to cause the moisture in the timber to vaporise. Moisture measuring instruments were mounted in several places to monitor the expected, long-term drying of the timber downwards, away from the newly placed sealant.

3 Results

3.1 Shear tests

The test results showed different load-bearing behaviours for the two sealants used. Layer compositions with polymer bitumen membranes (PBM) exhibited very ductile behaviour: the yield shear stress of 0.2 - 0.6 N/mm^2 was attained at an elastic deformation of 1 - 2mm. The plastic deformation after the yielding was considerable: the tests were stopped after a deformation of 10 mm was attained (Figure 10). After the tests, the elastic deformation of the specimens was slowly but fully recovered after a few days.

Figure 10: Plastic deformation of a test specimen with PBM sealant on CLT (left) and on concrete (right)

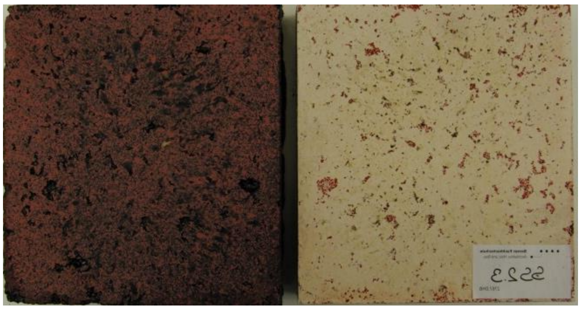

Figure 11: Brittle failure of the shear connection of the LS sealant on a steel deck

On the other hand, layer compositions with liquid synthetic sealants (LSS) exhibited very brittle load-bearing behaviour. The failure shear stress was 2.5 - 5 times higher than the values obtained for the specimens with PBM. In all the tests, failure always occurred at the interface between the LSS and the mastic asphalt (Figure 11).

The shear force / deformation diagrams below confirm that the results of the shear tests depended mainly on the type of sealant used: the test specimens with PBM all exhibited ductile behaviour, whilst the LSS all exhibited brittle failure modes. The type of bridge deck did not seem to be of any importance: there were no significant differences when timber, steel or concrete bridge decks were used (Figure 12, Figure 13, Figure 14, Figure 15).

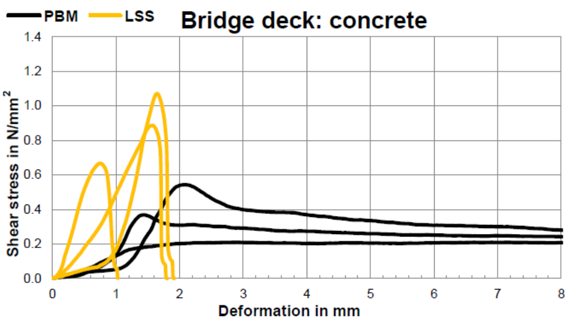

Figure 12: Shear stress and deformation diagrams for different surface compositions on a concrete deck

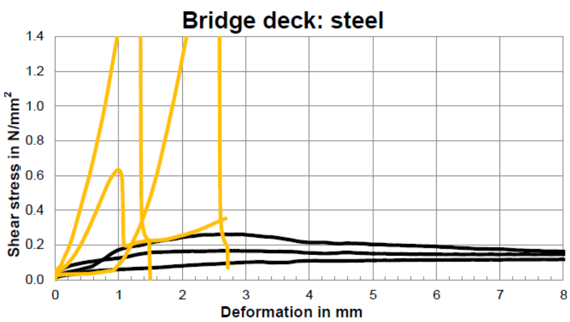

Figure 13: Shear stress and deformation diagrams for different surface compositions on a steel deck

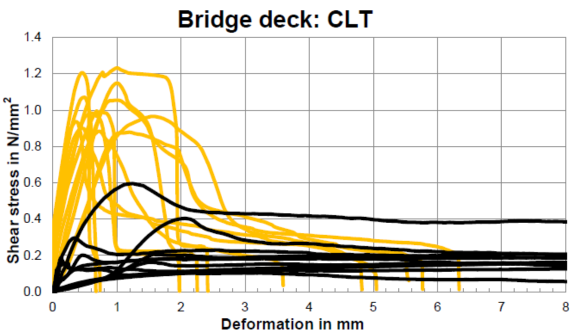

Figure 14: Shear stress and deformation diagrams for different surface compositions on a CLT-deck

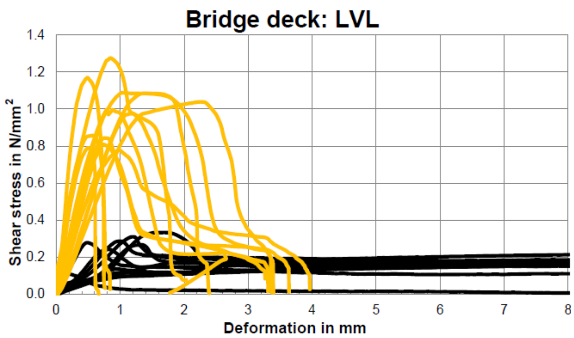

Figure 15: Shear stress and deformation diagrams for different surface compositions on a CLT-deck

3.2 Adhesion tensile tests

All test specimens fulfilled the adhesion tensile strength requirements according to the standard SN 640450a:2009. Figure 16 and Figure 17 show two test specimens after the adhesion tensile tests. The evaluation of the adhesion tensile tests for the PBM sealant is shown in Figure 18. The required strength values (red line) were surpassed by all test specimens.

In the case of the test specimens with LSS liquid synthetic sealant, the first 3 tests had to be repeated because the adhesion of the test specimen to the indenter of the testing machine yielded prematurely. The test specimens 4 – 6 fulfilled all the requirements of the standard with regard to the individual strength value and the average values (Figure 19).

Figure 16: Test specimen with PBM sealant after successful adhesion tensile test [5]

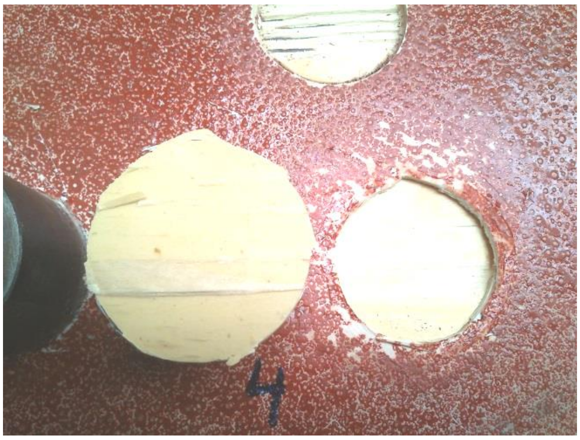

Figure 17: Test specimen with LSS sealant after successful adhesion tensile test [5]

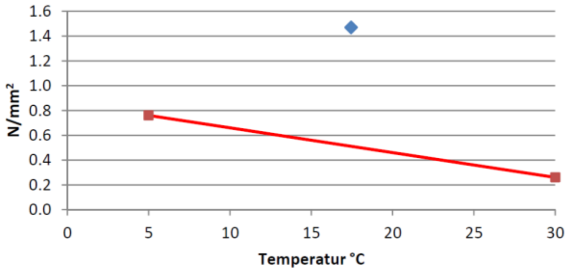

Figure 18: The average value of the PBM specimens (blue dot) lies well above the red line of SN 640450a:2009 [5]

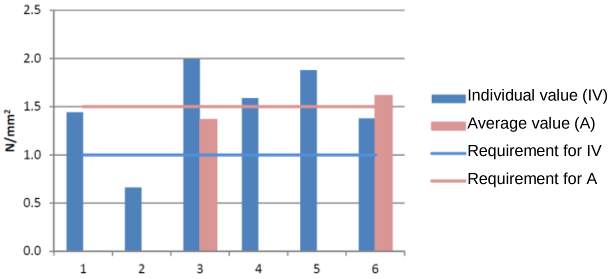

Figure 19: The LSS specimens fulfil the requirements of SN 640450a:2009 for the adhesion tensile test [5]

3.3 Observed blistering during the manufacture of the test specimens

During the manufacture of the test specimens for the shear tests, in particular during the pouring of the hot asphalt onto the bridge deck, some remarkable observations of blistering were made. Many of the specimens with an epoxide primer suffered some clear blistering. The epoxide primer is known to be open to water vapour diffusion. The heat of the asphalt apparently caused water vapour to rise from the timber to accumulate directly at the bottom face of the sealant. The water vapour caused a partial separation of the sealant from the timber deck: in some places it penetrated the sealant and collected as “blisters” in the asphalt (Figure 20, Figure 21, Figure 22).

Figure 20: No blistering observed in this specimen of asphalt surfacing on CLT

Figure 21: Clear blistering in the surfacing of this specimen of asphalt surfacing on CLT

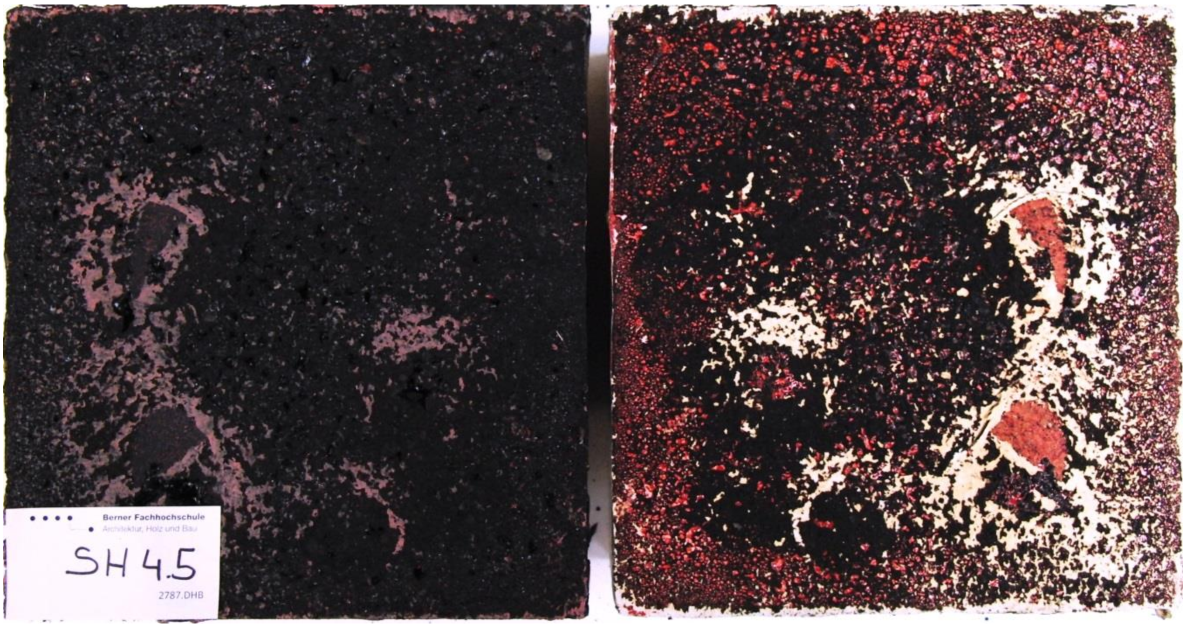

Figure 22: This test specimen has been cut open to display the clear blistering

The effect of the blistering which occurred in some specimens was evident during the later shear tests. The shear strength of samples with blisters was reduced by approximately 10 - 15% as compared to an undisturbed sample. The obvious reason was the reduced contact area for the shear force. It was also observed that the test specimens which exhibited blistering were more ductile in their load-bearing behaviour than the specimens which did not suffer blistering. A plausible explanation might be that the weakened material around the blisters were deformed more readily but then got caught in the indentations on the wood surface (Figure 23, Figure 24).

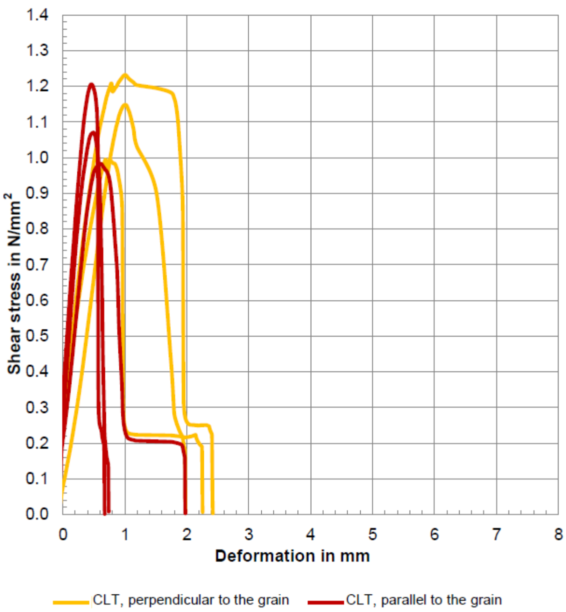

Figure 23: Shear stress / deformation diagram of a test specimen without blistering

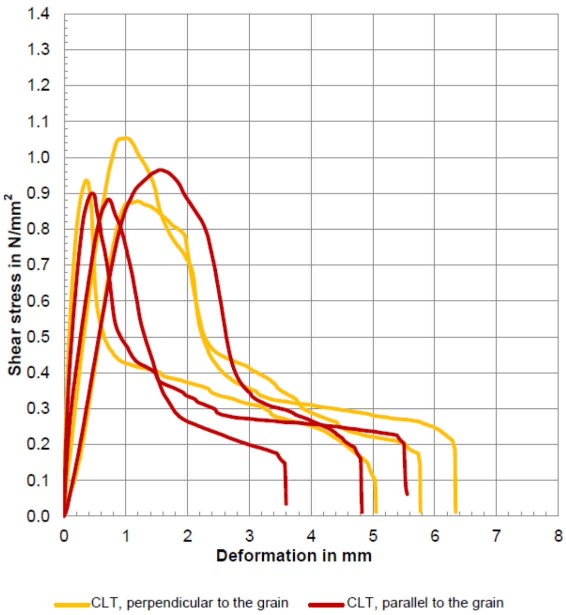

Figure 24: Shear stress / deformation diagrams of test specimens with blistering

3.4 Resurfacing of the Bubenei Bridge

The research team was allowed to scientifically observe the renovation of the surfacing of the Bubenei Bridge (Canton of Berne, Switzerland). The massive timber deck was surfaced with a 25 mm thick asphalt structure [4] supplied with vent holes but without a shear connection (Figure 25). Despite the high wood moisture content, no increased blistering was observed. The temperature in the wooden deck was observed to rise very slowly during the application of the temperature-modified asphalt: a sudden evaporation of water could not occur according to the temperature measurements (Figure 26).

Figure 25: Picture of the Bubenei Bridge during the asphalt coating

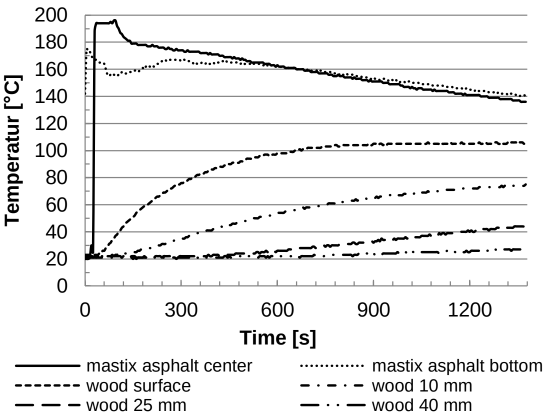

Figure 26: Temperature profile for a timber deck during asphalt coating

The second task of the researchers was the long-term monitoring of the moisture content of the timber beams of the bridge deck. These had suffered considerable wetting because no sealant had been foreseen in the old surfacing. Because of cost reasons, the engineers had decided to reuse the beams. The new sealant prevented a drying upwards through the new surfacing. There was a risk that the drying of the beams downwards might be too slow to prevent fungus attack. The monitoring of the slow drying of the wood is still on-going.

4 Conclusions

The research work largely confirms earlier research work that asphalt surfacing types which are typically used for steel and concrete bridges can – with some appropriate modifications - be safely and reliably used for timber bridges as well. The shear tests performed confirm that the different layer compositions perform equally well on timber, steel or concrete decks.

A durable sealant between the asphalt layer and the timber deck is an important water protection for the timber material. For timber bridges with a shear connection between the asphalt structure and the timber deck, a sealing with a vapour proof surface coating prior to the installation of the sealant or the pouring of the hot asphalt is essential.

Another important need is to prevent blistering, because timber decks typically contain much more moisture than steel and concrete decks. Surfacing types which use an epoxy primer to help activate the adhesion between the sealant and the timber deck are particularly at risk with regard to blistering hazards. This hazard can be mitigated by reducing the energy of the poured asphalt with three measures: first, temperature-modified asphalt with a pouring temperature under 200 °C should be used. Secondly, the protective asphalt layer lying directly on the sealant should not exceed 25 mm. Finally, the hot asphalt should be placed carefully by hand and not with a road finishing machine.

The research work showed that the load-bearing behaviour of the bridge surfacing under shear forces was largely determined by the type of sealant used. Two important sealants types were thoroughly investigated. Although the sealants of the type polymer bitumen membrane (PBM) had a much lower yielding stress that the brittle shear strength of the liquid synthetic sealants (LSS), the former - PBM - is probably more suitable for timber bridges because it can better accommodate the large deformations which may occur between the surfacing and the bridge deck of timber bridges.

Finally, in the adhesion tensile tests, all the test specimens fulfilled the strength requirements of the standard SN 640450a:2009.

5 Acknowledgement

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References

[1] Milbrandt, E.: Konstruktion von Fahrbahnbelägen, in Brücken aus Holz, Informationsdienst Holz, *Construction of Surfacing for Timber Bridges, Information Services for Timber Structures, Germany*, 1999

[2] Schellenberg, K.: Bituminöse Beläge auf Holzbrücken, 11. Int. Holzbau-Forum, Garmisch-Partenkirchen , *Asphalt Surfacing for Timber Bridges, International Forum for Timber Structures, Gartmisch-Patenkirchen, Germany*, 2005

[3] Durret, J.: Technischer Bericht Instandsetzungsprojekt „Instandsetzung Bubeneibrücke“, Ingenieurbüro Bächtold & Moor, *Technical Report “Refurbishing of the Bubenei Bridge”, Consulting Engineers Baechtold & Moor,* 2012

[4] Milbrandt, E., Schellenberg, K.: Eignung von bituminösen Belägen für Holzbrücken, Schlussbericht Deutsche Gesellschaft für Holzforschung (DGfH), *Suitability of Asphalt Surfacing for Timber Bridges, German Society for Timber Research*, 1998

[5] Krüger, M.: Prüfprotokoll Haftzugprüfungen, Bericht Nr. D1.057.99-1, 2013 *Minutes of the adhesion tensile tests, Report No. D1.057.99-1, 2013*