Structural resistance of Bridge Deck Pavement Systems

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ABSTRACT

For the water protection of concrete bridge decks specific asphalt pavement systems are used. These asphalt pavements have to fulfil a lot of requirements regarding different parameters (bitumen, mixtures), but so far test methods and procedures for assessing their structural resistance and functionality are missing. In a recent Swiss research project different asphalt pavement systems for bridge decks were chosen. Roller compacted asphalt and mastic asphalt for wearing and protection layers as well as waterproofing layers with polymer bitumen sheets (PBD), liquid polymer (FLK) and mastic asphalt (MA) and their system behavior was investigated using different mechanical tests. The investigation provided a ranking for the different systems and showed that the predicted system behavior given by different tests often varies for the applied test methods and investigated parameters. For example, it is interesting to see that the rutting prediction for some systems differs and the ranking changes when using cyclic compression tests instead of rutting tests conducted with the French rutting tester.

Keywords: bridge deck, structural resistance, asphalt pavements, system behavior, rutting.

1. INTRODUCTION

For the protection of concrete bridge decks from water and de-icing substances different systems are used in Switzerland combining soft bituminous layers and classical stiff layers. Since traffic on bridge decks is extremely canalized and due to high summer temperatures and sun exposure, bituminous bridge deck pavements are particularly subjected to rutting. Further, failing surface and binder courses due to water and ice may lead to cracking, allowing the infiltration of water between the layers or even the propagation through the layers onto the concrete causing corrosion of the supporting structure.

The need for structural resistant bridge deck pavement systems is therefore very important. The multifunctional requirements for these systems (noise reduction and insulation against water and de-icing agents) results in the development of new pavement structures and products whose applicability has to be proven. There are a lot of tests for determining stability and structural resistance for the individual layers (cyclic compression tests, rutting tests), but their significance for the durability and effectiveness of the whole pavement system has not been evaluated so far [1], [2]. As to account for this shortcoming, a research project was launched to evaluate test methods for durability and resistance of Swiss bridge deck pavement systems. Within the frame of this project 8 respectively 4 different bridge deck pavement systems according to the Swiss standard Norm SN 640450 [3] were chosen and the performance of different test methods such as cyclic compression test, rutting test, dynamic creep test and interlayer bond test was evaluated for the system structure [4].

2. EXPERIMENTAL PROCEDURE

For the evaluation different bridge deck systems as shown in Table 1 were used. All systems were constructed on a standard concrete bridge deck plate with dimensions of 2600mm by 1600mm. The concrete surface was cleaned and in case of systems 1-6 sandblasted. The polymer modifiers of the bituminous waterproofing membranes (PBD) were elastomer SBS (systems 2, 3 and 4) and in one case (system 1) plastomer APP. Alternatively in systems 5 and 6 liquid polyurethane polymer (FLK PU) and liquid polymer acrylic glass (FLK PMMA) were used. The thickness for the water proofing layers was 3-5mm. For systems 7 and 8 the waterproofing consisted of mastic asphalt. Here, the waterproofing was applied without bonding to the concrete by putting an oiled paper on top of the concrete surface. All protection layers were constructed using mastic MA 16 or MA 11. In case of systems 3 and 4 a binder layer of mastic asphalt MA was applied. The surface layers were mastic asphalt MA 11 or MA8. For systems 3 and 8 a semi-dense low noise asphalt (SDA 8) surface layer according to the Swiss pre-standard SNR 640436 [5] was used

SDA has a gap graded aggregate curve, a binder content of 6% and an air void contents between 8vol-% and 16vol-%. The waterproofing layers and the layers of mastic asphalt were laid by hand under optimal climatic conditions. For systems 3 and 8 SDA was compacted with a hand roller.

TABLE 1 Investigated bridge deck pavement systems

System No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Surface layer	MA 11	MA 11	SDA 8	MA 8	MA 11	MA 11	MA 8	SDA 8
Binder layer	-	-	MA 11	MA 11	-	-	-	-
Protection layer	MA 16	MA 16	MA 16	MA 16	MA 16	MA 16	MA 11	MA 11
Water proofing	PBD APP	PBD SBS	PBD SBS	PBD SBS	FLK PU	FLK PMMA	MA 8	MA 8
Interlayer bond test	x	x	x	x	x	x	x	x
Cyclic compression test	x	x	x	x	x	x	x	x
Rutting test	x	x			x	x		
Dyn. creep test	x	x			x	x		

Testing was performed using different test methods as shown in Table 1. Apart from the interlayer bond test, all test methods were originally designed for testing single layers as opposed to whole systems. For interlayer bond testing and cyclic compression test all 8 systems were investigated, while according to financial restrictions the rutting test and the dynamic creep test was performed only on systems 1, 2, 5 and 6.

3. INTERLAYER BOND TESTING

Interlayer bond testing was done using the Layer-Parallel Direct Shear (LPDS) test device. LPDS is an Empa modified version of equipment developed in Germany by Leutner [6] being more versatile in geometry and more defined in the clamping mechanism [7].

All interlayers of a system were investigated and the mean value of shear force calculated from 6 samples with diameter of 150mm. The all tests were conducted at 20°C. Figure 1 summarizes the results according the material type at the interlayer.

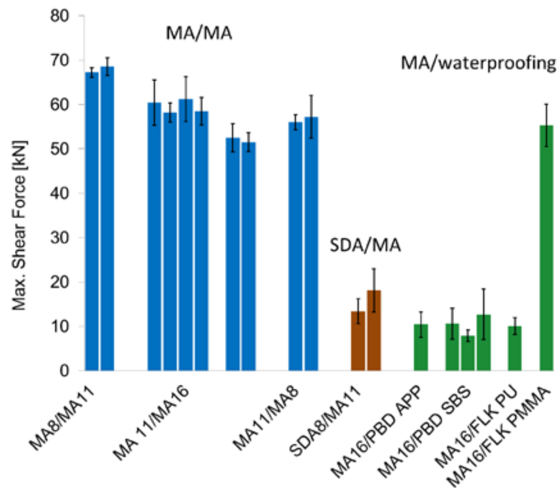

FIGURE 1 Interlayer bond results for all systems and interlayers

From Figure 1 it is obvious that the bond between the mastic asphalt layers MA/MA is not at all critical reaching values of >60kN. For the semi-dense low noise asphalt on mastic asphalt SDA/MA (systems 3 and 8) the situation is different and the requirement of the Swiss standard of 15kN for the bond between surface and binder layers cannot always be met. The interlayer bond values of all waterproofing layers are between 8kN and 12kN, showing no differences between the APP and the SBS modified bituminous membranes (systems 1-4). The same applies for the liquid polyurethane polymer FLK PU (system 5) while in contrast, the acrylic glass liquid polymer waterproofing FLK PMMA (system 6) has a high value of 55kN.

4. CYCLIC COMPRESSION TESTING

The cyclic compression test is a European standard and a German standard test [8], [9]. The main difference in the two procedures is the size of the upper plate. In the German standard the larger loading plate allows a more uniform distribution of stresses on the sample. The test temperature is 50°C, the upper stress 0.2MPa and the lower stress 0.026 MPa. The duration of a load cycle is 1.7s, the duration of the load 0.2s and duration of the rest period 1.5s. The cyclic creep curve displays the cumulative axial strain, expressed in %, as a function of the number of cycles. The test is finished when more than 10’000 load cycles are reached or when the cumulated strain comes up to 4%. The slope of the creep curve in the inflection point of the cyclic creep curve is a measure for the deformation of the specimen. For testing, 3 cores of 150mm diameter were taken for each system and the concrete bridge deck plate was cut to a thickness of 150mm. The mean value for these 3 tests represents the result for the cyclic compression test for a system as shown in Figure 2; in addition the scatter in terms of maximum and minimum value is given.

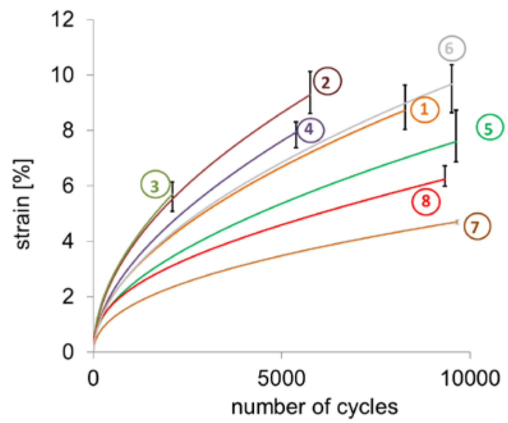

FIGURE 2 Cyclic compression test results for all systems with scatter in terms of minimum and maximum values

The dynamic creep curves reveal no inflection point, showing relatively big deformations for all systems. Especially system 3 for which the strain does not even reach 2500 cycles has a low stability against deformation. The best stability of 8000 load cycles at 4% deformation is reached for system 7, followed by system 8 with approximately 4000 load cycles. For both systems the standard deviation is also small, especially system 7 has an extremely low scatter. System 5 reaches 3000 load cycles at 4% deformation, while all the other systems are below 2000 load cycles at 4% deformation. The examination of the tested samples and the measurement of the layer thickness before and after cyclic compression testing show that in case of systems 1, 2, 5 and 6 the whole specimen and all layers deform. The water proofing membrane for system 2 deforms slightly. For systems 3 and 4 the deformation takes mainly place in binder and protection layer, while the surface layer of system 3 also displays some deformation. For both systems the water proofing layer is pressed to the side. For systems 7 and 8 the deformation can be mainly found in the protection layer MA11 and the water proofing layer MA8. System 8, here the semi-dense low noise surface layer also shows some deformation.

5. RUTTING TESTING

Rutting testing was done using the model mobile load simulator MMLS3 [10] (Figure 3, left). Testing was conducted at 20°C up to 500’000 load cycles. For the evaluation of permanent deformation systems 1, 2, 5 and 6 were tested. These systems were selected to evaluate the influence of the rutting test on the different water proofing systems (PBD APP, PBD SBS, FLK PU and FKL PMMA). For each investigated system 2 profiles were determined, as shown in Figure 3, right. From each profile the average of 3 measurements (left-middle-right) was taken for the rut depth of one profile. For each system the averages of two profiles were then combined for the rut depth measurements given in Table 2. From the rut depth measurements the regression curve was determined and the rutting for 1’000’000 load cycles was calculated.

FIGURE 3 Left: Model Mobile Load Simulator, right: 2 rutting profiles on system 5

According to Figure 4 and the rut depth measurements in Table 2 system 6 shows the smallest rutting and the highest resistance against permanent deformation. All other systems behave quite similar. System 2 with the biggest rutting shows distinct differences between the two rut profiles.

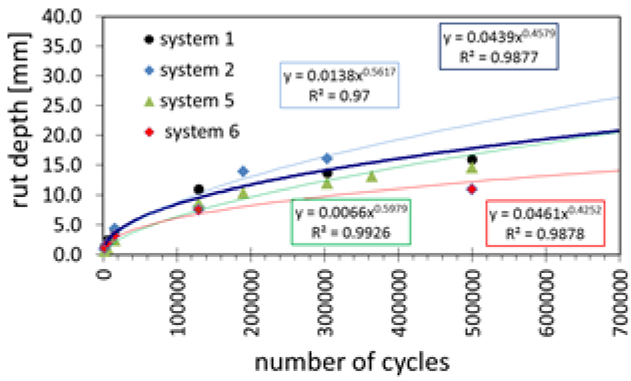

FIGURE 4 Rutting test results for systems 1, 2, 5 and 6 (average of two profiles).

TABLE 2 Rut depth measured and calculated (average of two profiles)

Rut depth [mm]	System 1	System 2	System 5	System 6
500'000 cycles (measured)	15.9	13.7 (profile 1) > 20 (profile 2)	14.6	10.9
700'000 cycles (calculated)	20.	26.5	20.6	14.9

6. DYNAMIC CREEP TESTING

The dynamic creep test was conducted according the German standard [11]. Two specimens were used to determine the dynamic creep curve. During the test a cylindrical specimen of Ø150mm is subjected to a cyclic compression similar to the cyclic compression. The load is applied with a plate of 80mm diameter. The cumulated creep under the plate caused by repeated loading is recorded in relation to the number of load cycles at 50°C. As opposed to the cyclic compression test no inflection point of the creep curve is expected. The result of the test is the deformation under the plate at 10'000 load cycles as mean value of 2 specimens. The dynamic creep test was conducted to see if differences in the material (mastic asphalt) could be seen. Therefore, the samples from systems 1, 2, 5 and 6 were prepared by removing the waterproofing layer as well as the concrete layer. Figure 4 shows all test results (single values for systems 1, 2, 5 and 6, left and the mean value calculated from systems 1 and 2 resp. 5 and 6, with an identical layer, right).

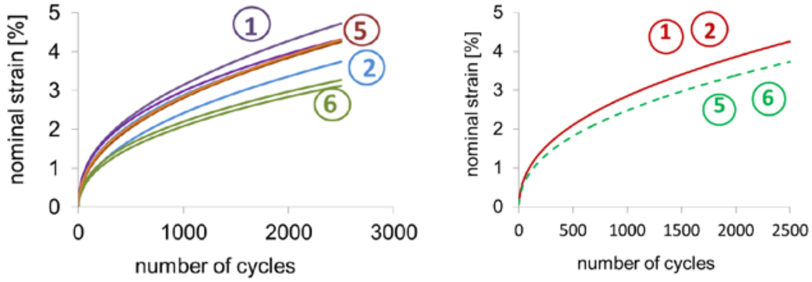

FIGURE 5 Dynamic creep test results, left: all values for systems 1, 2, 5 and 6, right: mean values for systems 1 + 2 and systems 5 + 6.

Similar to the cyclic compression testing, the dynamic creep curves of the tested systems do not reach the expected 10’000 load repetitions, but achieve only between 2000 and 3000 cycles. According to the results, systems 1, 2 are weaker than systems 5 and 6, with system 6 being the stiffest of all tested systems. This results corresponds on one hand to the rutting test results were system 6 was also found to have the least rutting and on the other hand side it confirms the findings from the cyclic compression test giving lower deformation for systems 5 and 6 compared to systems 1 and 2. It is interesting to note, that in the dynamic creep test, again, the scatter for the two specimens taken from system 2 was quite large. This could also be observed in the rutting test, when the difference between the 2 rut profiles was also bigger than for all other systems.

7. CONCLUSIONS

The research shows that test methods developed for asphalt concrete systems cannot be transferred to bridge-deck systems with mastic asphalt or semi-dense surface courses. Further, transferring methods intended for testing single layers to bridge-deck systems; that is testing many layers simultaneously, isn't readily possible.

When comparing stability and deformation resistance in the cyclic compression test, systems with mastic asphalt waterproofing layer perform best, and systems with 3 bituminous layers on top of a polymer modified bituminous waterproofing membrane should be avoided. According to test results semi-dense surface courses, due to their poor stability should not to be favoured over mastic asphalt. For the rutting test systems were selected to evaluate the influence of different waterproofing systems on the permanent deformation. Regarding rutting and dynamic creep testing system 6 shows the least influence of the waterproofing system on permanent deformation. Since it was found that the deformation was mainly concentrated in the upper layer, the rutting test is not capable of evaluating the whole system. Therefore, rutting testing for bridge-deck systems should be done using 1:1 traffic simulators such as Mobile Load Simulator or Heavy Vehicle Simulator. For lab testing with MMLS3 the layer thickness should be reduced.

The interlayer bonding test shows excellent bonding for all mastic asphalt layers, while the semi-dense layers are considerably lower and critical in reference to the requirement 15kN of the Swiss standard. The interlayer bond for all waterproofing layers displays values around 10kN and no difference between APP- and SBS-modified systems is noticeable. In contrast, the liquid acrylic glass waterproofing PMMA displays high values comparable to the mastic asphalt.

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