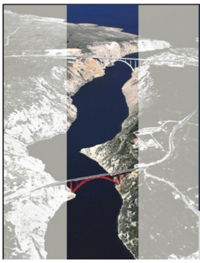

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COHESION OF LAYERS OF THE WATERPROOFING – ASPHALT SYSTEM ON BRIDGES

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Abstract: *The condition of adhesion to the base, i.e. to the bearing slab, and between system layers, is not clearly defined within the process of dimensioning of waterproofing – asphalt systems on bridges; the starting point is the assumed adhesion level. The cohesion between layers has a direct impact to the durability and functionality of the system and to the occurrence of defects on the pavement driving surface.*

The Paper describes cohesion testing methods as per Leutner (ALP A-StB), used for testing of adhesion strength (PULL-OFF) in compliance with HRN EN 1542/13596 and the four-point shear test. Laboratory and field investigations of the base strength and the adhesion strength of individual waterproofing and asphalt layers were conducted. Furthermore, cohesion of the system was tested at the level of cohesion of the waterproofing and the base and at the level of cohesion between two asphalt courses. The tests were carried out on laboratory samples and cores drilled from the completed waterproofing system – asphalt on the structure. The testing results were analysed taking into consideration the applied testing method and the comparison of results obtained in laboratory and in situ was carried out, i.e. the differences between the laboratory samples and samples taken from the competed bridge pavement were analysed. The causes of poor system cohesion were determined based on the analysed results and the conclusions were reached on how to improve this important property of waterproofing and asphalt pavement behaviour in exploitation.

1 INTRODUCTION

The adhesion of waterproofing to the bearing slab of the bridge, as well as the adhesion between the layers of the system, including asphalt layers, is determined through application of proscribed testing methods. The quality of adhesion between system layers has a direct impact to the durability and functionality of the waterproofing – asphalt pavement system. Certain defects of the pavement driving surface, such as sliding of asphalt on waterproofing layer, occurrence of cracks and rutting, may relate to the property of adhesion of pavement system layers on the structure. Investigation work of *Medani* and co-authors [1] and *Huurman* and co-authors (2004) [2] performed with application of the *Finite Element Code CAPA-3D*, *Scarpas* indicates that the waterproofing shear stiffness is related to the behaviour of the overall structure.

2 CONDITIONS OF SYSTEM ADHESION

Different allowed minimal adhesion values for layers within the waterproofing – pavement asphalt layers system are quoted in literature. The German work group H2 (*CROW1981*) [3] proposed the expected adhesion amounting to 0.3 N/mm^2, while *Fondriest* claimed as early as in 1969 [4] that the adhesion level had to amount to 1.38 N/mm^2. According to *Harre* [5] the adhesion of a layer has to range between 0.8 and 1.0 N/mm^2 at low temperatures. According to the Technical Conditions in force in Croatia [6] the average strength of the bond between the sealing waterproofing layer and the base layer has to amount to at least 0.8 N/mm^2 and individually it should not amount to less than 0.4 N/mm^2. The adhesion strength of the protective waterproofing layer to the sealing layer has to amount to 1.0 N/mm^2 in average and individually it should not amount to less than 0.7 N/mm^2. The deficiency of these conditions is dependence on the temperature at testing, since the adhesion of material of layers in question varies with temperature change. In case of poor adhesion between the asphalt pavement and the steel slab, the tensile strength may occur at the bottom of asphalt layer and it may reflect to the pavement driving surface (position B in Figure 1).

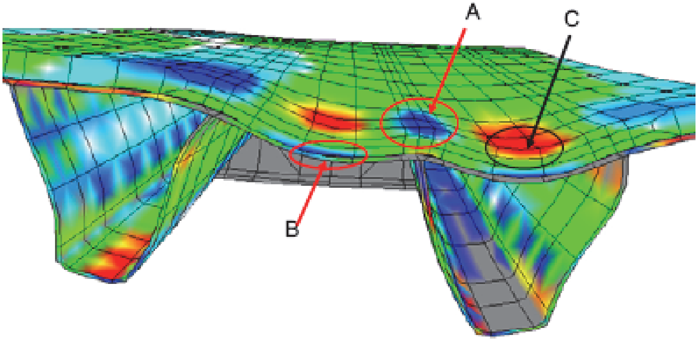

Figure 1: Stresses in the cross section of an orthotropic steel bridge

Possible causes of destruction or decrease of adhesion of pavement system layer are the following:

- Placement of asphalt mixture at high temperatures (around 220 ^{0}C) may result in high stresses at the surface of the steel slab. Problems arise when pavement structure relaxes when returning to the normal exploitation temperatures.
- High shear force between asphalt pavement and the bearing slab occurs due to the acceleration or deceleration of vehicle wheels, which has a direct impact to the decrease of adhesion.
- Certain road management bodies in Germany state that the vibrations of bearing pavement slabs due to the fast dynamic traffic cause decrease of adhesion of the asphalt – waterproofing – bearing slab system.
- Shear forces (longitudinal and perpendicular to the bridge axis) increase with the increase of the pavement slab's inclination on the bridge. Shear results in cracking, which occurs through pavement courses in the direction of the driving surface.
- In the report on six bridges in South Africa, *Blight* and co-authors [7] established that the separation of layers occurred on the driving surface, as well as on the edges of pavement where there was no traffic. They concluded that the decrease in adhesion occurred due to different coefficients of temperature expansion of asphalt pavement and steel slab. Their conclusion was that asphalt, as anisotropic material, had different temperature expansion in different directions, as high as up to 2.5 times. Similar conclusions were reached by *Sedlacek* and *Bild* [8].
- It is known that the dynamic axial load in asphalt pavements on the route is 40% higher than the static load [9]. Vibrations have a significant impact to the asphalt pavements of orthotropic steel bridges. It is known that vibrations of bridges are not only due to action of vehicles, but also due to the behaviour of the bridge itself. Dynamic behaviour of bridges depends on their geometry, damping, natural frequencies, weight of vehicles, frequency of vehicles with distribution of wheel load and the number of vehicles driving over the bridge simultaneously.

Good adhesion of layers implies the behaviour of the system as a composite within the temperature range of bridge exploitation. When taking into consideration the mechanism of bonding of different system layers, the impact of vehicles and conditions of exploitation, it is required to define the behaviour of waterproofing separately. Figure 2 presents distribution of stress in the cross section of steel bridge asphalt pavement in case of the total cohesion with bearing slab (left) and the lack of cohesion when adhesion equals zero (right).

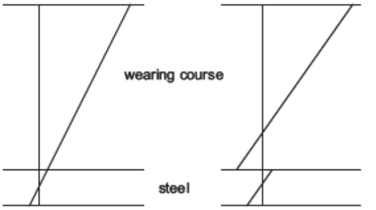

Figure 2: Assumed stress distributions within the cross section of the bridge

However, it is not possible to confirm, theoretically or experimentally, the assumed distribution of stress since the actual cohesion of asphalt pavement and bearing slab at the level of waterproofing is between these two assumptions. *Hameau* [10] developed an investigation programme on two-span beam model. The model was tested under sinusoidal load with amplitude of 400 N. The measurement of strain through the depth of asphalt layer and steel slab clearly indicated that the strains through the depth of asphalt were non-linear. This non-linearity may be attributed to the non-linear behaviour of asphalt or waterproofing and/or to geometry of the structure. The research clearly indicates that the assumed theory of composites is not completely correct. *Xianhua* [11] investigated the problems concerning local displacements within the pavement system layers under heavy truck load and defined the principle conditions of occurrence mechanisms. The author proposed the procedure of mechanical – experimental designing of pavement through application of new models, which enable more precise description of the composite bond between asphalt layer and steel slab, as well as the connection between occurrence of cracking in asphalt layers and adhesion of the sealing waterproofing layer.

3 METHODS FOR DETERMINATION OF ADHESION

Apart from the method of testing of asphalt layers cohesion according to „*LEUTNER*“ and „*PULL-OFF”* methods of testing of the strength of waterproofing layers adhesion, shear and waterproofing adhesion strength are tested through application of the „*THE FOUR-POINT SHEAR TEST”*.

3.1 Leutner

Laboratory method for testing of asphalt layers cohesion is the standardised German method *Leutner ALP A-StB* [12] This method is applied for the quantitative determination of cohesion of layers and it provides data on the force on the shear plane between layers. The testing is performed on cores with diameters amounting to 150 mm or 100 mm. The maximal shear force represents the condition in which the loss of bond between layers occurs. The thickness of the layer tested for shear has to be at least 25 mm, in order for the method to be valid. The maximal shear force and the related deformity depend on a whole range of layers cohesion factors, such as the surface texture of two layers, type and quantity of bonding agent, size of grains in asphalt layer and others. Not only the properties of layers have a significant impact but also the border conditions on the border surface. A jaw of appropriate diameter (Φ=100 or Φ=150 mm) is used in this test method, mounted on a *Marshall* press (Figure 3).

3.2 Pull-Off method

The device presented in Figure 4 is used in application of the *PULL-OFF* method, which is used for testing of surface strength of the base (concrete) and of adhesion strength of the waterproofing primer, as well as for testing of adhesion strength of waterproofing sealing layer in compliance with the harmonised standard [13]. The same method is used for testing of adhesion strength between asphalt layers and the waterproofing sealing layer.

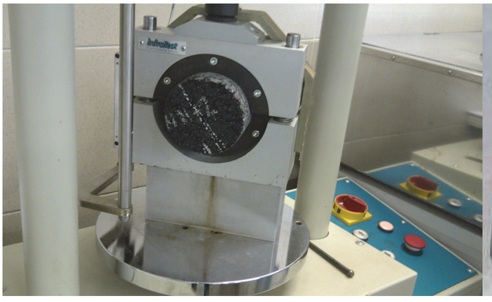

Figure 3: Testing of layers bond

Figure 4: Adhesion testing device

3.3 The Four-Point shear test

The measurement principle is testing of samples on the plane where there is shear force present and the bending moment is zero. The testing of shear is performed in the conditions of controlled displacement through application of monotonic increase of deformity (constant share of deformity) up to break or to the level of registration of LVDT. The thicknesses of tested system sample layers are 10 mm thick steel slab (base) + 3 mm thick waterproofing+ 10 mm thick asphalt, which is glued to aluminium beams and completed for testing as such. Numerical simulation of this test in the first case indicates the phenomenon of numerical repeatability of the testing. For example, at the beginning of testing when the sample is loaded, the effect of poor cohesion is visible at the top of waterproofing material.

4 TESTING RESULTS

4.1 Testing of base strength and adhesion of waterproofing layers

Waterproofing layers were placed on concrete slabs of dimensions 305x305x38 mm, on top of which asphalt layers were executed in moulds, using roll compactors. The *pull-off* method was applied for testing of concrete surface strength and the adhesion strength of the waterproofing primer, as well as for testing of the strength of waterproofing sealing layer adhesion. The strength testing results of the surface of concrete slab serving as the base for application of waterproofing are presented in Table 1 (measurements 1-3). The same Table presents the results of the waterproofing epoxy primer adhesion (measurements 4-6), as well as the adhesion testing results for the sealing layer of single-layered (measurements 7-9) and both layers of two-layered waterproofing using bituminous strips (measurements 10-15). Variation in temperature results in variations in the level of sealing layer adhesion. Due to this, the percentage of bitumen remaining at the bottom layer under the setting block is registered in addition to registration of air temperature and the base during the testing. Low average value of sealing layer adhesion was determined, amounting to 0.6 N/mm^2.

Posi-tion	Tested layer	Surface strength [N/mm^2]	Strength of adhesion [N/mm^2]	Location of separation, (% of bitumen)	Air / base temperature [C^0]
1	Concrete slab	**4.5**		concrete	18.6 / 19.2
2	Concrete slab	**3.9**		concrete	18.6 / 19.2
3	Concrete slab	**3.9**		concrete	18.6 / 19.2
4	Epoxy (primer)		**4.4**	concrete	18.6 / 19.2
5	Epoxy (primer)		**3.7**	concrete	18.6 / 19.2
6	Epoxy (primer)		**4.1**	concrete	18.6 / 19.2
7	Bituminous strip – single-layered		**0.8**	(50%)	18.6 / 19.2
8	Bituminous strip – single-layered		**0.9**	(100%)	18.6 / 19.2
9	Bituminous strip – single-layered		**0.8**	(20%)	18.6 / 19.2
10	Bituminous strip – first layer		**0.4**	(0%)	17.2 / 15.3
11	Bituminous strip – first layer		**0.6**	(0%)	17.2 / 15.3
12	Bituminous strip – first layer		**0.6**	(20%)	17.2 / 15.3
13	Bituminous strip – second layer		**0.4**	(20%)	17.2 / 15.3
14	Bituminous strip – second layer		**0.4**	(80%)	17.2 / 15.3
15	Bituminous strip – second layer		**0.6**	(85%)	17.2 / 15.3
Average value of sealing layer adhesion:				**0.6 N/mm^2** (0.7 required)	

Table 1: Values of surface strength of concrete and adhesion of waterproofing layers

4.2 Testing of layers cohesion of waterproofing and asphalt layers system

Cores Φ=100 mm were drilled from samples of waterproofing – asphalt layers system (Figure 5), which were prepared for the testing of cohesion.

This method was also applied for testing of cohesion of the system on two levels: the cohesion between asphalt layers (asphalt – asphalt) and cohesion of the system with the base (concrete slab) at the level of waterproofing. The cohesion of sealing layer is determined, since this layer has the lowest strength of cohesion in the waterproofing – asphalt system on concrete base, due to its waterproofing properties. Table 2 presents tested values of the determined maximal force and deformity during testing of shear on the plane of two asphalt layers bond (table to the left) and on the plane of the system bond to the concrete base (on the plane of waterproofing sealing layer, table to the right). Cohesion (P) was calculated from the ratio of the determined force (F) and the known surface of shear plane (A): $P = F / A$ (N/mm^2).

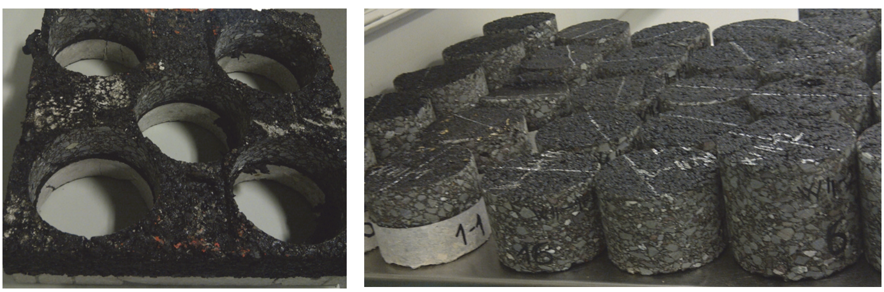

Figure 5: Drilled cores of the system for testing of layers cohesion

Cohesion of asphalt layers ranges from minimal 1.48 N/mm^2 to maximal 2.29 N/mm^2, and the cohesion of the system with concrete base at the level of waterproofing ranges from minimal 0.18 N/mm^2 to maximal 1.24 N/mm^2. The testing confirmed low strength of system cohesion at the level of sealing layer of waterproofing.

Tested layers: asphalt - asphalt				**Layers: asphalt – waterproofing – concrete**			
Designation	Force F (kN)	Displa-cement ε (mm)	Bond P N/mm^2	Designation	Force F (kN)	Displa-cement ε (mm)	Bond P N/mm^2
WII1-2/1	11.6	1.6	*1.48*	W-III1-P	2.5	1.1	0.32
WII1-2/2	14.4	1.8	1.83	W-III2-P	1.4	0.8	*0.18*
WII1-2/3	14.5	1.8	1.85	W-III3-P	1.9	2.2	0.24
WII1-2/4	13.8	1.6	1.76	W-III4-P	5.0	0.2	0.64
WII1-2/5	16.1	1.9	2.05	W-III5-P	1.8	1.2	0.23
WII1-2/6	16.4	1.7	2.09	W-III6-P	4.3	1.9	0.55
WII1-2/7	14.9	1.7	1.90	W-III7-P	2.1	1.7	0.27
WII1-2/8	12.1	1.5	1.54	W-III8-P	3.8	1.8	0.48
WII1-2/9	15.4	1.7	1.96	W-III9-P	2.9	1.4	0.37
WII1-2/10	13.2	1.8	1.68	WIII10P	1.7	1.2	0.22
WII1-1/1	13.7	1.9	1.75	W2H-16	2.0	1.3	0.25
WII1-1/3	15.3	2.1	1.95	W2H-17	1.6	0.7	0.2
WII1-1/4	12.2	1.6	1.55	W2H-18	1.6	1.4	0.2
WII1-1/5	18.0	1.8	*2.29*	W2H-19	6.7	2.6	0.85
WII1-1/6	17.0	2.2	2.17	W2H-20	1.8	3.1	0.23
WII1-1/7	12.3	1.9	1.57	W1H-6	2.6	1.5	0.33
WII1-1/8	15.4	2.4	1.96	W1H-7	9.7	0.5	*1.24*
WII1-1/9	16.0	2.0	2.04	W1H-8	2.3	1.7	0.29
WII1-1/10	12.3	2.1	1.57	W1H-9	3.4	0.6	0.43
Medium cohesion = 1.84 N/mm^2 (required 1,0 N/mm^2)				W1H-10	2.8	5.5	0,36
				Medium cohesion = 0.40 N/mm^2			

Table 2: Values of tested parameters of cohesion of waterproofing – asphalt system layers

5 CONCLUSIONS

An important behaviour property of waterproofing – asphalt pavement system on bridges is adhesion/bond between individual system layers and to the base. Testing of surface strength of concrete slab as the base and adhesion of the primer and sealing layers carried out through application of the *pull-off* method and the mutual bond between the asphalt courses within the system and to the concrete slab at the level of waterproofing was tested through application of the shear method per *Leutner*. It was determined that the strength of concrete slab surface was good (3.9-4.5 N/mm^2), as well as the value of the primer adhesion amounting to 3.7-4.4 N/mm^2, considering the minimal requirement of 1.5 N/mm^2. The values of the seal layer adhesion determined through the application of the *pull-off* method range from 0.4 to -0.9 N/mm^2, and the required minimal value amounts to 0.4 N/mm^2; application of the method per *Leutner* determined the average cohesion value of 0.6 N/mm^2, and the values determined within more than 50% testing are below the minimal required value of 0.4 N/mm^2. The testing of adhesion and cohesion at the level of sealing layer indicates low values, which are below the average required value of 0.7 N/mm^2, however the determined cohesion of asphalt layers ranging from 1.48 to 2.29 N/mm^2 meets requirements and the value is above the minimal required value of 1.0 N/mm^2. It was confirmed that there was good correlation between the adhesion values determined on samples of pavement taken from pavement of the bridge and those prepared and tested in laboratory, which was confirmed through in situ testing. The results indicate that the sealing waterproofing layer is the cause of poor cohesion of the system since it is generally bitumen-based, and its properties depend on equiviscous temperature of the binder. In case the sealing layer contains reinforcement made of non-woven textile the stability at temperature load is increased, however the reinforcement stratifies the system and causes decrease of cohesion.

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