Evaluation and Rehabilitation of Composite Pavement on Motorway Network in Serbia

S. Erjavec
The Highway Institute Inc., Belgrade, Serbia and Montenegro

ABSTRACT: In the eighties the pavements on motorway roads were built with the sub-base layer made with high strength of cement-treated aggregates. After a period of considerable fall of transit traffic and lack of maintenance ensued from the political isolation of the country, by the beginning of new century the transit traffic was returning on "arterial" road facilities in Serbia. This period was marked with extensive investments in road rehabilitation. It was required to prepare the model for pavement existing conditions assessment for about 450 km motorway network and planning of pavement maintenance within the short period. By measuring surface deflections with HWD Dynatest, and by having at hand reliable data on pavement structure, thus the basis was formed for creating the mechanical pavement model. After the analysis of pavement surface deflections, idealized models of future condition were established, so-called “pavement condition matrix”. That matrix includes three classes of foundation condition and six classes of pavement condition. Each homogenous section of the analyzed motorway network may be represented by one of models in “pavement condition matrix”. Those models define efective modules of particular layers (for calculation overlay), residual bearing capacity of relevant pavement layers, and other information, significant for calculation. A basis was made that way for calculation of overlay structure. A significant percentage of asphalt layers and cement-treated aggregates layers possess residual bearing capacity. That is the reason to design maintenance strategies through a concept of preventive maintenance for pavement structure within design period of 20 years in service.

KEY WORDS: Pavement condition matrix, residual bearing capacity, preventive maintenance

1 GENERAL

In the eighties the pavements on motorway roads were built with the sub-base layer made with high strength of cement-stabilized stone aggregates. The analysis of pavement overlay needs, as well as the analysis of possible variants for pavement maintenance took place by applying the preventive conservation of sub-base layer concept. The design period considered were 20 years in service, and the equal residual bearing capacity at the end of design life. The advantage when comparing with previously applied approach ("Network Level" and "Project Level") is a coherent consideration of residual bearing capacity and uniformly defining technical measures for rehabilitation within the entire motorway network. The basis for such approach, where 450 km of a highway may be analyzed as a uniform whole at "Project Level", was discovered in fact that the pavement structure composition was homogenous. That was confirmed by a statistical analysis of file-recorded project designs. Road foundation represents the embankment, constructed of fine-grain material (voluminous records are present also on physical-mechanical properties of that material); capping layer is the same along the entire length, constructed of natural graded stone. Data on bituminous layers characteristics is also available (supervision).

2 SUBJECT PRESENTATION

Foundation and pavement were constructed, as stated before, in eighties of twentieth century. The road was constructed on low embankment of dusty material with two separated carriageways along the major motorway length, but along the sectors with lower traffic (nearby state borders with Hungary, Bulgaria and FYR of Macedonia) only the first motorway phase was constructed – reduced motorway profile – now used for both-directional traffic (Figure 1).

between 25 and 40 cm, and that material is riverbed gravel with good properties, when natural (continuous grading curve, small particles admixtures are not plastic - Plasticity Index Ip < 6).

The pavement structure composition was established by taking core samples along the whole 450 km long motorway. Samples were tested using χ^2 tests. It was confirmed that the observed random values set behaves following Gauss Distribution Law.

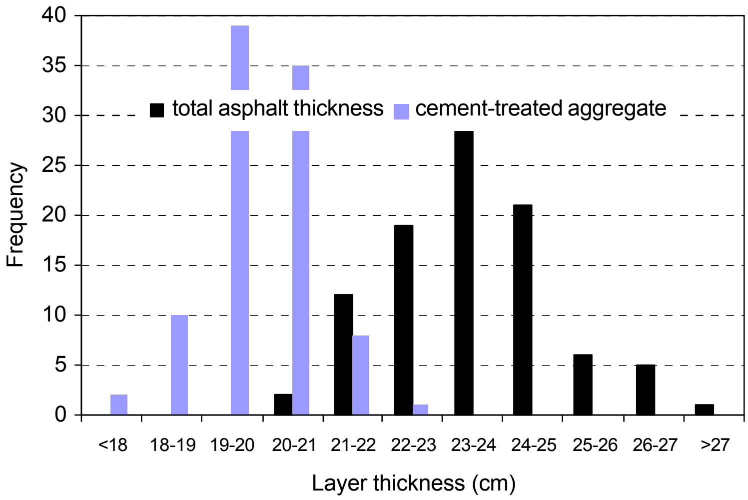


Figure 2 Histogram of Measured Thickness of Asphalt Layers and Layers of Materials Treated With Hydraulic Binders

The expected 95%-reliable mean of asphalt and cement-treated aggregates layer thickness will enter within limits of the following table:

Table 1 Reliability Interval of Mean Thickness of Pavement Structure Layers

Asphalt layers	$23.2 \le \mu \le 23.8$
Layers of materials treated with hydraulic binders	$19.6 \le \mu \le 20.2$

Average layers thickness was used with further analysis[1].

Considering existing asphalt layers, one may conclude that the high-penetrable bitumen was used. Penetration class 90 (1/10mm) was established during bitumen extraction. Considering "bitumen ageing " phenomena, one may assume that penetration originally was >135 (1/10 mm) when considered motorway section was constructed and released to service. Those are first indicators (having on mind the sub-base layer of cement-treated aggregates presence) for deep ruts occurrence.

Bitumen participation in asphalt mix, and filler participation in wearing and tack course mix grading (those layers are bituminous concrete with maximal grain size D_{max} =11mm) leads to the necessity to divide the above set into mixtures of same characteristics (in the

[1] Motorway E-75 pavement structure layer thickness average values are:

	233 mm	Asphalt layer
	199 mm	Cement-treated aggregates layer
		Capping layer
		Embankment

sense of consequences to permanent deformation). Thickness of each of above listed layers is 40-50 mm. The following mixture sub-groups were separated through above data analysis:

Table 2 Characteristics of Wearing and Binder Course Asphalt Mixtures

	Bitumen presence by weight (%)-average	Grading (by weight)		
		< 0.09 mm	0.09 – 2.00mm	≥ 2.00mm
Asphalt mix AM1	6.33	13.2	32.2	54.6
Asphalt mix AM2	5.71	10.9	28.5	60.6
Asphalt mix AM3	5.22	9.8	27.1	63.1

2.2 Preliminary Visual Survey

Preliminary visual survey has shown that no road body deformation appeared. Transverse reflected cracks dominate. Irregularity of cross section, characterized by ruts presence, was observed with some sections. Rut shape and presence of cement-treated aggregates layer confirm the opinion on reasons for rut appearance as described with section 2.1. Fatigue cracks were observed on two sections (cracks in vehicle wheel track).

3 PRECISE DEFINITION OF THE PROBLEM

Two groups of issues that ask for answer within design were identified. The first group of issues is connected to questions that may be answered by deflection bowls analysis, and questions themselves are connected to effective moduli and residual bearing capacity and durability of particular pavement structure and foundation layers.

The second group of issues is connected to ruts within asphalt layers. Inclination of asphalt layers to plastic deformation was confirmed through the analysis of recorded data. Ruts measuring confirmed the assumption that rut depths are directly dependent on characteristics of wearing and tack course, as described above in Section 2. The conclusion was made therefore that each asphalt layer should be removed, along all sectors where asphalt mixture demonstrates characteristics, being described as mixture type AM2 and AM3 in Section 2. The proposed technical measure is to remove layers that incline to plastic deformation and to place new asphalt layers of same thickness. That measure should be applied independently of necessary strengthening (except when the reconstruction is proposed the optimal technical rehabilitation measure). The problem was so reduced to definition of necessary strengthening of the existing pavement structure.

Deflection measurement on pavement surface took place as to answer the questions arouse. Measurement was accomplished by spot-tests at uniform distances (RANDOM). The distance between successive trial spots was 200 m. Reliability was identified afterwards (it is a direct function of particular section length). Detailed visual inspection took place also within areas where cracks with wheel tracks were observed.

4 MODELING OF THE PAVEMENT

The analysis of homogenous section was carried out using the procedure as follows:
1. Data set on deflection bowl, measured equal-distanced.
2. Cumulative differences method
3. Defining homogenous sections
4. Calculation of deflection characteristic values on particular sensors (85 %-values)

5. Choice of characteristic deflection bowl for each homogenous section (deflection bowl being the best representative of characteristic deflection values) and back-analysis of modulus

The results, being obtained by back-analysis modulus calculation as per liner-elastic theory, were directly applied to asphalt layers (unified asphalt layer) as well as to cement-treated aggregates layer. Lower layer moduli, being obtained by elastic theory calculation, were not directly applied, but REVISED AASHTO OVERLAY DESIGN PROCEDURE (1993) was used for subgrade (considered as an infinite semi-massif, composed of embankment, as described with Section 2, and capping layer of unbound material, 25-40 cm thick). The Miner's rule for fatigue damage was used.

5 BASIC CHARACTERISTICS OF PAVEMENT AND FOUNDATION MATERIALS

In the initial service period semi-rigid pavement structure comprises the contact between asphalt layers and cement-treated aggregates layer (continuity of displacements at the interfaces). Asphalt layers are subjected to small elongation, but cement-treated aggregates layer accepts major stresses (sub-base). After a time, this layer of materials treated with hydraulic binders becomes damaged by fatique. Sliding takes place at the interface between the base and sub-base layers and the modulus of sub-base layer reduces. During the damaging process, modulus of sub-base made of materials treated with hydraulic binders becomes reduced. Since then, asphalt layers accept extensive strain and are damaged due to fatigue, but the modulus of the course, made of materials treated with hydraulic binders, does not demonstrate any significant loss.

5.1 Layer Of Materials Treated With Hydraulic Binders

The cement-treated aggregates layer will be considered a highly fatigue-resistant sub-base layer (conforming to above described model) if it meets the requirement that stress-leading-to-failure value, after 10^6 cycles of referent loading, should be equal $\sigma_6 \geq 0{,}7$ MPa. If that course was constructed to meet high-resistance against fatigue criteria, then, according to results of French research (CONCEPTION ET DIMENZIONNEMENT DES STRUCTURES DE CHAUSSEE), the layer modulus should be $E_{max} \geq 15000$ MPa. Therefore, tensile strength of core sample with $\sigma_{z360}=1{,}0$ MPa, coincides to high layer modulus. The end of service life (in the sense of capability to accept tensile stresses) will be demonstrated by modulus reduction to $E_{max}/5 \leq 3000$ MPa (for modeling needs). If the constructed layer stiffness would be minor than required, fatigue strength of such layer should be considered insufficient, and the deterioration mechanism would follow some other low. Fatigue curve gradient in bi-logarithmic scale is b=1/12. Initial, relatively non-altered modulus, may be determined by effective modulus calculation for layers of materials treated with hydraulic binder within deflection bowl on overtaking lanes. The same principle is applicable for defining asphalt layers modulus. Actually, through this layer modulus calculation by measuring deflections on overtaking lane, the following condition classes may be determined for cement-treated aggregates layer:

Condition class 1 – This class is characterized by high layer stiffness; elasticity modulus in cement-treated aggregates layer, at the beginning of service life amounts $E \geq 12000$ MPa. The pavement in service follows the described model.

Condition class 2 - This class is characterized by absence of residual bearing capacity in layer of cement-treated aggregates, but some stiffness with such layer is still present. Modulus of such layer on motorway overtaking lane amounts $E<12000$ MPa. A layer, demonstrating such stiffness, is not considered a bearing one, in the sense of resistance against high frequency of tensile stresses (the required fatigue resistance is not accomplished) With a pavement structure simplified model, the modulus of such layer is not expressed in measured values, but by those that will be reached in service very soon; quantitatively expressed, it means modulus value being equal to 3000 MPa.

Condition class 3 – Elasticity modulus in cement-treated aggregates layer on overtaking lane amounts E<3000 MPa. Such value of modulus on relatively undamaged overtaking lane presents a low cement-treated aggregates modulus, indicating a material without any strength that would enable some fatigue resistance capacity in such layer. With a pavement structure simplified model, the modulus of such layer is not expressed in measured values, but by those that will be reached in service very soon; quantitatively expressed, it means modulus value being equal to 500 MPa.

5.2 Asphalt Layers

The service life of an asphalt layer should be considered the time period between the service life beginning (6500 MPa is then the characteristic value of modulus, defined on non-damaged asphalt layer of overtaking lane at asphalt temperature $t_{asphalt}$ = 20°C) and the moment of theoretical failure (when modulus value diminishes to one half of the initial one). That service life, looking idealistically, may be quantified related to effective modulus of the layer. Residual bearing capacity was expressed with presented model in three effective modulus condition classes of unified asphalt layer. The first class possesses full residual bearing capacity (100% of residual bearing capacity) when the effective layer modulus amounts $E_{eff.} \geq$ 5500 MPa, the second class, with one-half of initial residual bearing capacity, when the effective layer modulus amounts $E_{eff.}$ =4000-5500Mpa, and the third class, without any residual bearing capacity, when the effective layer modulus amounts $E_{eff.}$<4000MPa. The characteristic of asphalt base layer (relevant asphalt layer), related to fatigue life, is ε_6 = 90 $\mu\varepsilon$[2]. Fatigue curve gradient in bi-logaritmic scale is b=1/5.

5.3 Pavement Foundation

Subgrade is an infinite semi-massif, composed of embankment, as described in `Section 2, and capping layer of unbound granulated material, 25-40 cm thick Mr modulus calculation was carried out using REVISED AASHTO OVERLAY DESIGN PROCEDURE (1993), deflection as measured on sensors, distanced d=900 mm from impact plate.

6 IDEALIZED CONDITION CLASSES

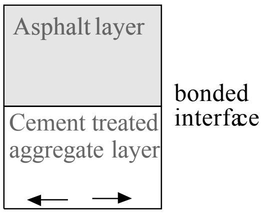
In conformity with above listed assumptions, six idealized cases of deterioration evolution in rigid layers (divided into six idealistic conditions), which were post-checked by physical opening of pavement at selected typical locations, as well as three classes of bearing capacity in infinite semi-massif (foundation).

6.1 Condition Classes of Cement-Treated Aggregates layer and Asphalt layers

Calculation layer modulus was classified into six classes:

[2] ε_6 – Deformation at 10^6 loading cycles, at 10^0C and 25 Hz (″grave bitumen″,GB) defined by standard NF P 98-138

Table 3 Condition Classes of Cement-Treated Aggregates layer and Asphalt layers

<table>
<tr><td></td><td>Pavement class 1

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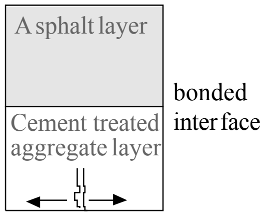
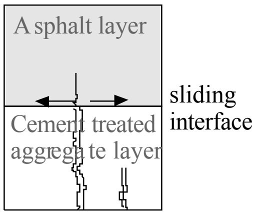

</td></tr>
<tr><td>Cement treated aggregate layer</td><td>Modulus of this layer has $E_{eff.} \geq 12000$MPa and residual bearing capacity is 100% of initial fatique capacity value. Thus the calculation modulus is $E_{cal.}$=12000MPa</td><td>Modulus of the layer is between 7000 and 12000MPa and residual bearing capacity is 50% of initial fatique capacity value. Thus the calculation modulus is $E_{cal.}$=7000MPa</td></tr>
<tr><td>Asphalt layer</td><td>Asphalt layers are subjected to small elongation and have modulus equal to the initial one.</td><td>Asphalt layers are subjected to small elongation and have modulus equal to the initial one.</td></tr>
<tr><td></td><td>Pavement class 3

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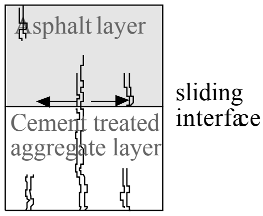
</td></tr>
<tr><td>Cement treated aggregate layer</td><td>Modulus of this layer has $E_{eff.}$<7000MPa (Condition class1) or $E_{eff.}$<12000MPa (Condition class2) and the layer doesn`t have residual bearing capacity. Thus the calc. modulus is $E_{cal.}$=3000MPa.</td><td>Modulus of this layer has $E_{eff.}$<7000MPa (Condition class1) or $E_{eff.}$<12000MPa (Condition class2) and the layer doesn`t have residual bearing capacity. Thus the calc. modulus is $E_{cal.}$=3000MPa.</td></tr>
<tr><td>Asphalt layer</td><td>Modulus of the layer is $E_{eff.} \geq 5500$MPa capacity is 100% of initial fatique capacity value. Thus the calc. modulus is $E_{cal.}$=5500MPa.</td><td>Modulus of the layer is between 4000 and 5500MPa and residual bearing capacity is 50% of initial fatique capacity value.</td></tr>
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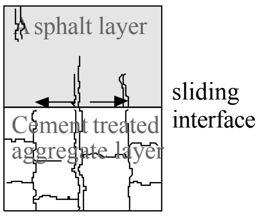
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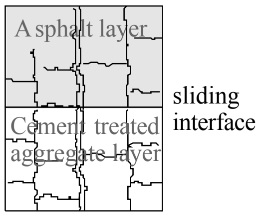
</td></tr>
<tr><td>Cement treated aggregate layer</td><td>Modulus of this layer has $E_{eff.}$<3000MPa (Condition class3) and this layer is modeled as layer of unbound aggregate. Thus the calc. modulus is $E_{cal.}$=500MPa</td><td>Modulus of this layer has $E_{eff.}$<3000MPa (Condition class3) and this layer is modeled as layer of unbound aggregate. Thus the calc. modulus is $E_{cal.}$=500MPa</td></tr>
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6.2 Condition Classes of Foundation

Calculation of subgrade modulus was carried out using methodology as described in Section 4. Calculation subgrade modulus – modulus of infinite semi-massif – was classified into three classes:

Table 4 Values of Calculation Modules for Particular Condition Classes

	Measured value of modulus, Mr	Modulus value for calculation, Mr_{cal}
Foundation class F 1	> 120 MPa	120 MPa
Foundation class F 2	70 MPa – 120 MPa	70 MPa
Foundation class F 3	≤ 70 MPa	40 MPa

6.3 Matrix of Condition Class of Pavement Structure and Substructure

Matrix of 18 possible ideal models, from P1F1 to P6F3, may be obtained by grouping particular homogenous sections, where are considered condition parameters of asphalt and cement-treated aggregates layers, on one side, and subgrade condition class, on the other side. Those 18 models represent finally defined models for calculation of necessary pavement structure strengthening; any homogenous sector within studied motorway network in Serbia may be represented by some of presented models. Accordingly, models define finally modules of particular layers (for calculation of necessary strengthening), residual bearing capacity of particular (relevant) pavement structure layers, and also other information, important for calculation.

6.4 Conclusion on Existing Condition Analysis

The conclusion on existing condition analysis shows that significant residual bearing capacity of pavement structure is present. Such conclusion was confirmed by calculations, and a summary of results is presented with the table below. It is visible that a large percent of pavement with cement-treated aggregates layer is highly rigid, and, consequently, possesses significant residual bearing capacity. On the other hand, only a small percent of total pavement surface demonstrates total damage in both rigid layers.

Table 5 Pavement Percentage with Specified Condition Class

	Foundation class F 1	Foundation class F 2	Foundation class F 3
Pavement class P1	-	18 %	-
Pavement class P2	4 %	30 %	-
Pavement class P3	5 %	16 %	-
Pavement class P4	-	9 %	3%
Pavement class P5	-	10 %	-
Pavement class P6	-	5 %	-

7 REHABILITATION DESIGN

Considering the motorway's great worth and great importance for traffic, the design as an optimal approach proposed the preventive maintenance of pavement structure as a first-priority duty. There is particular social interest to protect the pavement structure. After the end of its service life it will not be thrown away. The condition is that a pavement structure, after 20-years-long observation, still has a certain residual bearing capacity, expecting that relevant base layers should have the same one. Such condition is based on fact that a pavement structure, after 20 years in service, may be strengthened rationally for the next service period. The present design requires that the residual bearing capacity of relevant layers after 20 years in service should amount 30% of the initial bearing capacity.

Maintenance approach was examined through different maintenance strategies for each defined condition class, assuming that each strategy should meet defined requirements and conditions. Examination of strategies was carried out based on control of stresses and fatigue capacity employing during the service. The resulting durability is defined by total number of standard equivalent axes.

The number of commercial vehicles in initial year of service is class TQ =800-1200[3]. Although the traffic load on the section toward the border with Croatia is not on the level from 1990., it has been decided that the whole network should be analyzed for the dominant traffic class. Average rate of traffic flow growth for the analyzed period amounts = 3.0 %.

Table 6 Presentation of Equivalent Standard 115 kN Axes

	Asphalt layers	Layer of cement treated materials
Average coefficient of commercial vehicle aggression	CVA = 0.35	CVA = 0.55
Equivalent traffic load	ESA = 4.0 x 10^6	ESA = 6.5 x 10^6

On the occasion that many maintenance alternatives are possible for some condition class, an economic evaluation of such alternatives shall take place. Economic evaluation uses «Present worth of cost» and equivalent annual costs «EUAC» methods. Road Users Costs, considering the approach of Preventive Maintenance are the same for each possible alternative. The discount rate to convert cost to their present value was chosen to be 8%.

Results of pavement structure maintenance strategies investigated are presented hereinafter. Each of them meets requirement as defined, but for different maintenance strategies. Table 6 shows the pavement maintenance strategies in conformity with condition classes defined as classes P1, P2, P3. These sections make 73% of the whole motorway network length.

Table 7 Pavement Maintenance Strategies In Conformity With Condition Classes Defined as classes P1, P2, P3

Condition Class P1F2, P2F2, P2F1	
First strengthening in 2005 i.e.	Reinforcement mash for Reflected Cracks, and Overlay 5 cm, Bituminous Concrete
Second strengthening in 2018 i.e.	Overlay 4cm, Bituminous Concrete
Condition Class P3F2, P3F1	
First strengthening in 2005 i.e.	Reinforcement mash for reflecting Cracks and Overlay 6cm, Bituminous Concrete
Second strengthening in 2016 i.e.	Overlay 6cm, Bituminous Concrete

Table 7 shows the pavement maintenance strategies in conformity with condition classes defined as classes P1, P2, P3. The sections which are classified as P4 and P5 need the overlay in thickness of two asfalt layers in the first year of maintenance, while the sections classified

[3] TQ-Average daily number of Buses and Articulated Trucks

as P6 require the total reconstruction. The level of pavement distress is confirming this statement.

Table 8 Pavement Maintenance Strategies In Conformity With Condition Classes Defined as classes P4, P5, P6

Condition Class P4F2	
First strengthening in 2005 i.e.	Overlay, two layers 10cm, Bituminous Concrete
Second strengthening in 2017 i.e.	Overlay 5cm, Bituminous Concrete
Condition Class P4F3	
First strengthening in 2005 i.e.	Overlay, two layers 12cm, Bituminous Concrete
Second strengthening in 2018 i.e.	Overlay 6cm, Bituminous Concrete
Condition Class P5F2	
First strengthening in 2005 i.e.	Overlay, two layers 14cm, Bituminous Concrete
Second strengthening in 2018 i.e.	Overlay 7cm, Bituminous Concrete
Condition Class P6F2	
First strengthening in 2005 i.e.	Total Pavement Reconstruction

8 CONCLUSION

In this paper the autor describes the method of the evaluation of the present condition and the method of the pavement rehabilitation design on the motorways with the composed pavement in Serbia. The matter which has been discussed is the motorway (around 450km) which is the part of the trans-european corridor X. The basis was formed for creating the mechanical pavement model by measuring surface deflections with HWD Dynatest and by having at hand reliable data on pavement structure. After the analysis of pavement surface deflections, idealized models of future condition were established, so-called “pavement condition matrix”. That matrix includes three classes of foundation condition and six classes of pavement condition. Each homogenous section of the analyzed motorway network may be represented by one of models in “pavement condition matrix”. Those models define efective modules of particular layers (for calculation overlay), residual bearing capacity of relevant pavement layers, and other information, significant for calculation. Thus the basis for calculation of overlay structure was made. A significant percentage of asphalt layers and cement-treated aggregates layers possess residual bearing capacity. That is the reason to design maintenance strategies through a concept of preventive maintenance for pavement structure within design period of 20 years in service.

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