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Methods for determining increased maintenance of pavement structures in the city

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Professional paper

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Methods for determining increased maintenance of pavement structures in the city

A data collection method, and methods for determining increased maintenance of pavement structures in the city, are presented in the paper. Three types of urban road network were selected for the analysis, i.e. pavement structures for the urban main road, urban road, and collection street were analysed. On-site data and laboratory test results were used in the study. After presentation of all data collected for the analysis, a technical solution for pavement structure is given, and it is concluded that an increased maintenance, i.e. full-scope rehabilitation, must be made for all three pavement structure types.

Key words:

increased maintenance, pavement structures, urban environment

Stručni rad

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Metode određivanja pojačanog održavanja kolničkih konstrukcija u gradu

U radu je dan prikaz metode za prikupljanje podataka, a nakon toga i metode za određivanje pojačanog održavanja kolničkih konstrukcija u gradu. Za analizu su uzeta tri tipa gradske cestovne mreže, odnosno analizirane su kolničke konstrukcije za gradsku magistralu, gradsku prometnicu i glavnu ulicu. Korišteni su podaci koji su uzeti na terenu i dobiveni rezultati laboratorijskih ispitivanja. Nakon prikazanih svih prikupljenih podataka, dano je tehničko rješenje kolničke konstrukcije, a potom se dolazi do zaključka da treba izvesti pojačano održavanje, odnosno rekonstrukciju sva tri tipa kolničkih konstrukcija.

Ključne riječi:

pojačano održavanje, kolničke konstrukcije, urbana sredina

Fachbericht

Danijel Kukaras, Miloš Šešlija, Igor Peško, Dejan Jovanov, Miodrag Počuč

Methoden zur Festlegung der verbesserten Instandhaltung von Fahrbahnkonstruktionen in der Stadt

In der Abhandlung wird eine Darstellung der Methode zur Datenerfassung dargelegt, und danach auch die Methode zur Festlegung der verbesserten Instandhaltung von Fahrbahnkonstruktionen in der Stadt. Für die Analyse wurden drei Typen von städtischen Straßennetzen ausgewählt, beziehungsweise es wurden Fahrbahnkonstruktionen für die Stadtautobahn, die Stadtstraße und die Hauptstraße analysiert. Herangezogen wurden Felddaten sowie die erhaltenen Ergebnisse der Laboruntersuchungen. Nach Darlegung aller zusammengetragenen Daten wurde eine technische Lösung für die Fahrbahnkonstruktion vorgelegt, und danach kommt man zum Schluss, dass eine verstärkte Instandhaltung, beziehungsweise eine Rekonstruktion aller drei Fahrbahnkonstruktionstypen durchzuführen ist.

Schlüsselwörter:

verstärkte Instandhaltung, Fahrbahnkonstruktionen, urbane Umgebung

1. Introduction

Road infrastructure ranks among the most valuable assets of every society and it is an indicator of development of national economies [1]. The urban road network implies a network of structures that assume multiple functions, starting for moving and parking of vehicles in all modes of transport, to ensuring road access to urban amenities. The urban and rural transport networks present many similarities but also exhibit numerous significant differences in the way they operate. The main point is that the objectives of urban road networks are more complex, limitations are stricter, and road types are more diverse [2]. The term method denotes a conceived and planned course of action aimed at achieving a successful outcome. In road engineering, methods for determining the need for an intensive maintenance of pavement structures in urban areas are defined by several parameters, such as [3]:

- composition of the existing pavement structure,
- properties of materials incorporated in the pavement structure,
- damage to pavement surfacing,
- structural and mechanical properties of the pavement,
- traffic load, and
- traffic conditions.

These parameters are used for determining or designing an appropriate pavement structure. Conditions are normally much more difficult in urban roads compared to rural roads, because an alternative solution must be found in case of dense traffic to avoid traffic jams. To explain the overall methodology of intensive maintenance of pavement structures in urban areas, some typical examples are given, i.e. several streets situated in selected Serbian towns are analysed. An overview of all analysed parameters is given, appropriate theoretical explanations are provided, and results obtained by practical investigations are presented. An emphasis is placed on the bearing capacity of pavement structure and types of materials used in all analysed layers, as well as on design solutions for subsequent rehabilitation.

According to available literature data, most researchers analyse maintenance or road management from the standpoint of data collection and subsequent processing using the HDM-4 computer software. Thus, Pradena and Houben [4] provide criteria for sustainable design of urban pavements with an overview of a number of related papers. The IRI criterion relating to speed limits in urban areas, i.e. the so called IRI (city) criterion, is proposed in the above paper. An overview of measurements relating to longitudinal evenness of pavement, expressed by the so called international roughness index (IRI), is presented in [5]. An existing method for pavement evenness measurement is considered, and the condition of road network in the Republic of Serbia is analysed, but only for rural sections 13,191.34 km in total length. An interesting account of the *Contract on the maintenance and repair of roads* according to the Output and Performance-Based Contracting for Roads (OPBC) is presented in [6]. Savings realized by using this type of road management and maintenance contracts are also presented in the paper. Sršen [7] describes a multi-purpose measuring device for modern technologies and its use in the analysis of road condition and behaviour, i.e. a vehicle called ARAN for the automatic road analysis is described. All vehicle parameters are presented theoretically, without presentation of a practical example. The issue of road management is also considered in [8] for Zagreb County. Here, the HDM-4 model is used to determine funding required for maintenance activities. Ahmed and Tarefder [9] conducted a comparative analyses of two pavement condition testing devices: ground penetration radar (GPR) and falling weight deflectometer (FWD). They described the methodology applied in these devices, and the way in which they operate; the devices were tested on three selected sections in New Mexico. The testing revealed that both methods can be used for data collection and for determining condition of road pavement structures.

2. Methods for determining intensive maintenance of pavement structures in urban areas

Appropriate data must be collected for determining an adequate intensive maintenance method for road pavement structures in both urban and rural areas. Data collection involves realisation of a set of activities. Each item and data that is collected requires time, effort and money for the collection, storage, retrieval and use. When study of the cause of damage shows that the sample originates from the bottom base course of pavement structure, then one of the following activities needs to be undertaken (Figure 1):

- pavement structure must be strengthened by construction of new layers,
- rehabilitation - partial or complete.

If the analysis of pavement condition reveals that the structure is essentially sound, then structural strengthening may also be needed but subject to fulfilment of certain conditions. A significant deficiency of a pavement layer may be compensated by appropriate strengthening, but a detailed risk analysis must be undertaken beforehand to determine the risk that is assumed if the defective layer is not replaced. Rehabilitation is often more cost-efficient compared to construction of a thick strengthening

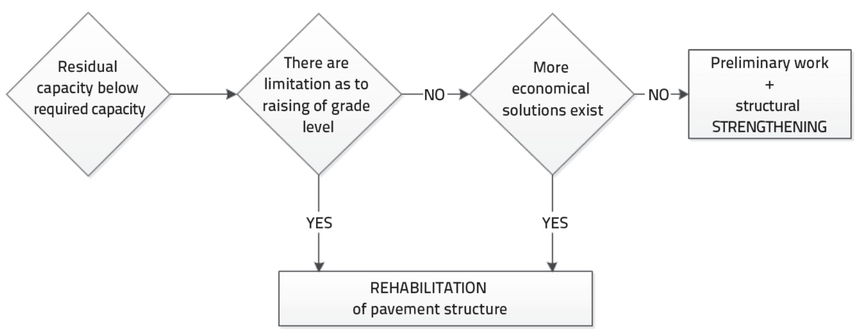

Figure 1. Algorithm for the design of pavement rehabilitation when pavement structure strengthening is necessary

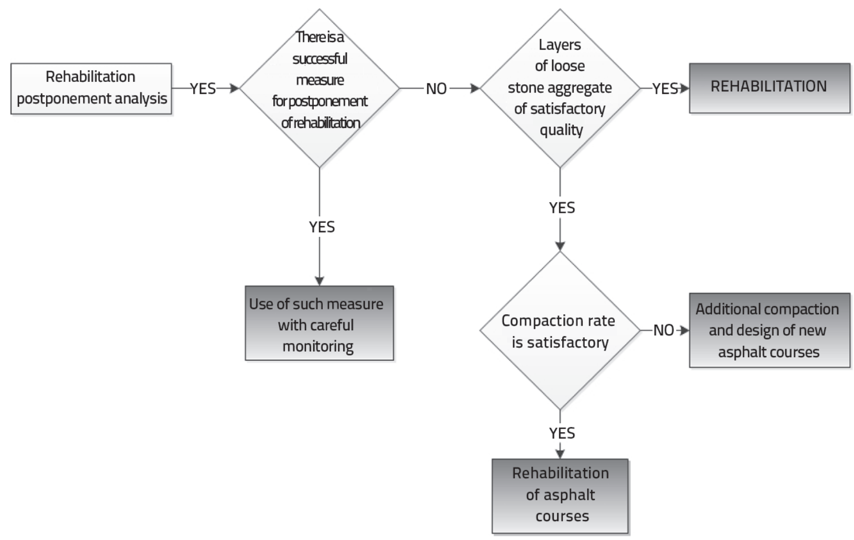

Figure 2. Algorithm for pavement rehabilitation design

layer. At that, the period devoted to the analysis of alternative solutions should be sufficiently long so that all advantages and deficiencies of design alternatives can properly be explored. If it is determined that the damaged layer exhibits a rapid deterioration tendency even after appropriate strengthening, then an advantage should be given to rehabilitation activity. The principle of pavement rehabilitation design is shown in Figure 2.
This sections deals with a considerable number of issues that have to be resolved by pavement structure designers during determination of specific repair activities, i.e. intensive maintenance activities for pavement structures in urban areas.

2.1. Composition of existing pavement structures

The structure of existing pavement must be analysed to determine thickness of individual pavement layers on the road section under study. The thickness of individual layers is determined by excavating appropriate trial pits or boreholes. The use of appropriate mechanical plant is needed for excavation of trial pits, and specific boring devices are needed for borehole drilling. Both of these methods are popular and so trial pits are used quite frequently, although in urban areas preference is often given to boreholes. After drilling, all pavement layers and their positioning data are presented graphically, so as to enable proper evaluation of pavement condition.

2.2. Properties of materials incorporated in pavement structure

After sampling from trial pits or boreholes, the material extracted in this way from pavement structure is subjected to an appropriate analysis. Each pavement structure is made of the following layers: subgrade, coarse crushed stone aggregate (0-63 mm), fine crushed stone aggregate (0-31 mm), and asphalt layers. These layers can most often be differentiated after sampling. The testing of individual pavement layers will be presented separately in the following section, where standards used in the testing will also be specified.

2.3. Surface damage

The surface damage measurement involves determination of various types of damage, from cracking to surface deformations such as deformation by rutting. Three groups of techniques are used for the detection of surface damage. Manual techniques are based on topographic and visual survey of damage, after which the data are recorded on paper either manually or by means of an appropriate computer technique.

2.4. Structural and mechanical properties of pavements

Structural and mechanical properties of pavements can be measured using various devices such as the falling weight deflectometer (FWD) (Figure 3). Structural and mechanical properties of pavements are measured indirectly through pavement deflections.

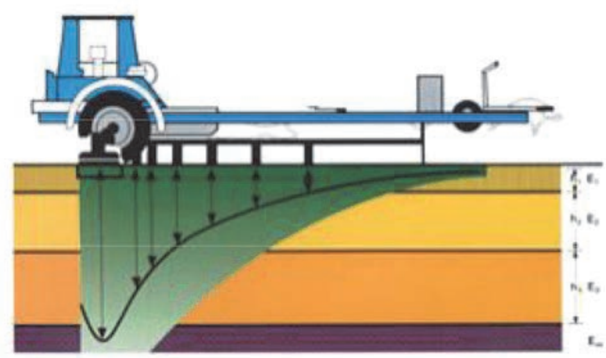

Figure 3. Falling weight deflectometer (FWD) - operating principle [10]

2.5. Traffic load

The traffic data collection system consists of either one or several sensors and of the data collection unit, i.e.: vehicle classification sensor, vehicle type detection sensor, and equipment for axle load measurements.

3. Presentation and analysis of survey results

Several streets were analysed for the presentation and subsequent analysis of results, and the analysis focused on the primary road network, i.e. one street was analysed for each type of primary urban road network. The analysis was conducted for urban main roads, urban roads, and collector streets. Roads included in the secondary road network were not analysed, as they require less investigations compared to the primary urban road network.

3.1. Composition of existing pavement structures

Exploratory drilling operations were conducted for urban main roads in order to determine composition of pavement structure. Drill cores were extracted at every 500 m of an urban main road section approximately 3 km in total length, and the composition of the pavement structure was determined. Exploratory drilling procedures were also conducted for urban roads and collector streets. The urban road and collector road sections subjected to this testing measured approximately 1100 m and 600 m in length, respectively. Three drill cores 220 mm in diameter and 2.0 m in total depth were extracted from the urban road section. The collector road was also analysed using different diameter boreholes (Ø146 and Ø220), and the total of two boreholes 2.0 m in total depth were drilled.
Borehole structures for the sections under study are presented in the following figures (Figure 4, Figure 5 and Figure 6). Presentation of chainage and layer thicknesses for the analysed road.

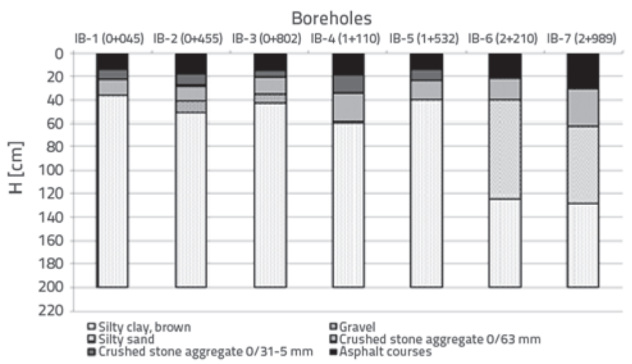

Figure 4. Graphical presentation of pavement structure of a urban main road

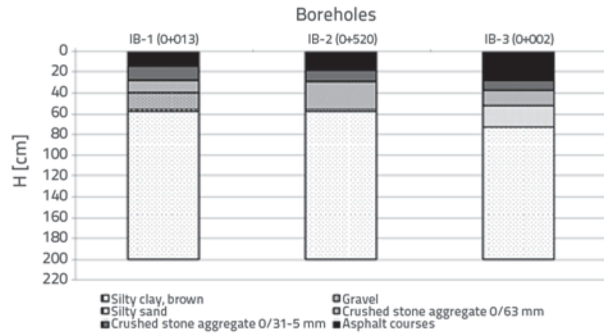

Figure 5. Graphical presentation of pavement structure of a urban road

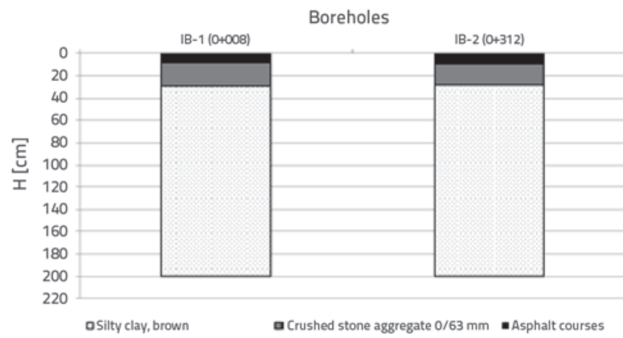

Figure 6. Graphical presentation of pavement structure of a collector street

3.2. Properties of materials incorporated in pavement structure

After borehole drilling and presentation of composition and thickness of layers, laboratory tests are conducted to determine

Table 1. Laboratory test results for material grading

Borehole	Grading				Atterberg consistency limits			*AASHTO* cllasif.	Compaction level [%]
	clay	silt	sand	gravel	wl [%]	wp [%]	I_p		
IB 1 GM	15	80	4	1	40	24.9	15.1	A-7-6	97
IB 2 GM	23	74	3	0	53	25	28	A-7-6	98
IB 3 GM	25	71	4	17	65	27	38	A-7-6	100
IB 4 GM	22	72	6	0	53	26	27	A-7-6	100
IB 5 GM	18	70	12	0	51	24	27	A-7-6	101
IB 6 GM	15	72	13	0	53	24	29	A-7-6	96
IB 7 GM	0	18	82	0	-	-	-	A-1	98
IB 1 GS	18	55	10	17	52	26	28	A-7-6	97
IB 2 GS	23	74	3	0	57	29	36	A-7-6	97
IB 3 GS	0	80	18	2	48	22	28	A-7-6	97
IB 1 SU	22	56	18	4	53	25	28	A-7-6	99
IB 2 SU	10	64	25	1	46	22	24	A-7-6	97

IB - borehole; GM - urban main road; GS - urban road; SU - collection street

properties of materials incorporated in the pavement structure, i.e. laboratory testing and quality checks are conducted for the materials contained in the following layers:
- subgrade,
- bottom base course (0/31.5 mm and 0/63 mm),
- asphalt courses.

3.2.1. Properties of subgrade materials

The following subgrade tests were conducted:
- determination of grading (SRPS U.B1.018:2005),
- Atterberg consistency limits (SRPS U.B1.020:1980),
- determination of moisture and dry density of samples (SRPS U.B1.038:1997) - standard Proctor test,
- laboratory determination of California bearing ratio (CBR) (SRPS EN 13286-47).

Presentation of laboratory tests for the determination of material grading is given in Table 1. High plasticity clay is a dominant material. Only one out of twelve samples exhibits plasticity that can be characterized as low plasticity clay or as sand or soil of low plasticity. After presentation of all results, it was observed that only three out of the total of twelve samples exhibit plasticity of 100 % or more. Cohesive material of high plasticity ($I_p \geq 25$) is dominant in the subgrade of the pavement structure. Material exhibited cohesive properties at medium to low moisture content. Material moisture changes very slowly which makes it difficult for the work in the field and in laboratory. The load carrying capacity of subgrade was tested by determination of California bearing ratio according to SRPS SRPS EN 13286-47. Test results are presented in Table 2. The analysis of test results revealed that the load bearing capacity of subgrade made of coherent material is low or very low. All coherent material samples exhibit bearing capacity of more tha CBR = 4 %

Table 2. Laboratory test results for bearing capacity of subgrade

Borehole	CBR. lab [%]
IB 1 GM	4,5
IB 2 GM	4,2
IB 3 GM	5,8
IB 4 GM	4,9
IB 5 GM	6,6
IB 6 GM	5,8
IB 7 GM	4,4
IB 1 GS	6,8
IB 2 GS	4,3
IB 3 GS	4,9
IB 1 SU	7,6
IB 2 SU	8,9
IB - borehole; GM - urban main road; GS - urban road; SU - collection street	

3.2.2. Properties of material from bottom bearing layer made of loose granulated material - sandy gravel 0/63 mm

The bottom bearing layer made of loose granulated material was subjected to the following tests:
- grading (SRPS U.B1.018), and
- material classification (*AASHTO* i *UCS*).

Presentation of grading for the 0/63 mm crushed stone aggregate fraction is given in Table 3.
Fines content is very low. In other words, none of the twelve tested sables contains more that 5 % of fines. The results

Table 3. Laboratory test results for layers of loose granulated material - 0/63 mm sandy gravel

Borehole	Grading [%]			Classification of loose granulated material	
	Fines content	0.06-2.00 [mm]	2.00-60.00 [mm]	*UCS*	*AASHTO*
IB 1 GM	3	30	67	GP	A-1
IB 2 GM	2	18	80	GP	A-1
IB 3 GM	1	23	76	GP	A-1
IB 4 GM	3	24	73	GP	A-1
IB 5 GM	2	13	85	GP	A-1
IB 6 GM	1	24	75	GP	A-1
IB 7 GM	4	15	81	GP	A-1
IB 1 GS	2	22	76	GP	A-1
IB 2 GS	3	16	81	GP	A-1
IB 3 GS	3	14	83	GP	A-1
IB 1 SU	4	25	71	GP	A-1
IB 2 SU	2	20	78	GP	A-1
IB - borehole; GM - urban main road; GS - urban road; SU - collection street					

have confirmed the observation made during the macroscopic inspection of material conducted during excavation of trial holes, i.e. that the material exhibits low sensitivity to the change in moisture. Atterberg consistency limits could not be determined. These are the materials with a very low content of fines that do not exhibit plasticity. According to AASHTO classification, the material belongs to the group A-1, while according to UCS classification it belongs to the group GP, i.e. it is classified as poorly granulated gravel.

3.2.3. Properties of material from bottom bearing layer made of loose granulated material - sandy gravel 0/31.5 mm

The same tests that were used for loose granulated material - 0/63 mm sandy gravel were also conducted for material considered in this subsection. Test results for grading and classification of loose granulated 0/31.5 mm material are presented in Table 4.

Results presented in Table 4 show that the content of fines is very low. In other words, none of the twelve tested sables contains more that 5 % of fines. Grading test results have confirmed the observation made during the macroscopic inspection of material conducted during excavation of trial holes, i.e. that the material exhibits low sensitivity to the change in moisture. Atterberg consistency limits could not be determined. These are the materials with a very low content of fines that do not exhibit plasticity. According to AASHTO classification, the materials belong to the group A-1, while according to UCS classification they belong to the group GP, i.e. they are classified as poorly granulated gravel.

3.2.4. Properties of materials contained in asphalt layers

Asphalt samples (cores) were also extracted between the trial holes using the diamond bit 100 mm in diameter so as to identify individual layers of the pavement structure. Marshall samples were prepared fo individual asphalt sample (cores) tests, and the following physicomechanical properties were determined on these samples:

- stability (SRPS U.M8.090:1967),
- sample density (SRPS EN 12697-5),
- asphalt mix density (SRPS EN 12697-6),
- voids content in sample (SRPS EN 12697-8),
- voids content in stone material mix (SRPS EN 12697-8),
- voids filled with binder (SRPS EN 12697-8),
- grading of mineral mix (SRPS EN 933-1).

After completion of all tests, relevant statistical parameters - bitumen content per layer, voids content in sample, compaction level in sample, and grading for asphalt concrete and bituminized base course - are presented in the following tables.

Thickness of asphalt courses

Thickness of asphalt courses was determined according to the prevailing standard SRPS EN 12697-20. Thicknesses are presented in the form of statistical data, with mean values, standard deviations, coefficients of variation, and minimum and maximum thicknesses of asphalt courses. Statistical data for urban main road, urban road and collector street are presented in Table 5.

After analysis of results, it was concluded that all asphalt courses on the analysed urban road network are homogeneous.

Table 4. Laboratory test results for layers of loose granulated material - 0/31.5 mm sandy gravel

Borehole	Grading [%]			Classification of loose granulated material	
	Fines content	0.06-2.00 [mm]	2.00-60.00 [mm]	UCS	AASHTO
IB 1 GM	2	21	77	GP	A-1
IB 2 GM	1	39	60	GP	A-1
IB 3 GM	2	29	69	GP	A-1
IB 4 GM	3	24	73	GP	A-1
IB 5 GM	2	13	85	GP	A-1
IB 6 GM	-	-	-	-	-
IB 7 GM	-	-	-	-	-
IB 1 GS	2	28	70	GP	A-1
IB 2 GS	3	37	60	GP	A-1
IB 3 GS	3	29	68	GP	A-1
IB 1 SU	-	-	-	-	-
IB 2 SU	-	-	-	-	-
IB - borehole; GM - urban main road; GS - urban road; SU - collection street					

Table 5. Statistical indicators for asphalt course grading on urban main road

Statistical parameters	Urban main road	Urban road	Collector street
Mean value	16.25	22.40	9.75
Standard deviation	3.74	5.03	1.71
Coefficient of variation	0.23	0.22	0.18
Min	10.00	15.00	8.00
Max	25.00	29.00	12.00

Table 6. Statistical indicators for asphalt course grading on urban main road

Statistical parameters	Filler	Pijesak Homogeneous section 1	Pijesak Homogeneous section 2	Stone chippings
Mean value	8.55	22.47	16.20	70.55
Standard deviation	1.02	3.09	0.71	4.77
Coefficient of variation	0.12	0.14	0,04	0,07
Min	7.30	17.50	15.70	64.00
Max	10.50	25.50	16.70	76.80

Table 7. Statistical indicators for asphalt course grading on urban road

Statistical parameters	Filler Homogeneous section 1	Filer Homogeneous section 2	Sand	Stone chippings
Mean value	11.90	7.85	18.38	72.76
Standard deviation	1.27	2.65	1.70	2.73
Coefficient of variation	0.11	0.34	0.09	0.04
Min	11.00	7.10	16.60	68.40
Max	12.80	8.60	20.90	76.30

Table 8. Statistical indicators for the grading of asphalt courses on collector street

Statistical parameters	Filler	Sand	Stone chippings
Mean value	7.83	40.06	98.13
Standard deviation	1.09	3.40	1.64
Coefficient of variation	0.14	0.08	0.02
Min	6.90	33.40	95.70
Max	10.70	45.70	99.70

The urban main road exhibits the greatest coefficient of variation, which is quite logical as it has a relatively big sample for analysis, and thus the dispersion of results is quite visible, when minimum and maximum asphalt layer thicknesses are observed. Quite good asphalt thickness results were obtained at collector street, although it should be noted that the smallest number of samples were taken from that section.

Grading of asphalt courses

Seven grading tests were conducted on the asphalt wearing course of the urban main road. The material is quite homogeneous as to filler content. Two homogeneous sections can be differentiated with regard to sand content:

1. Homogeneous section 1 – includes samples in the zone from km 0+000 to km 0+700,
2. Homogeneous section 2 – includes samples in the zone from km 0+700 to 3+013. Statistical indicators are presented in Table 6.

As to all fractions that were analysed in the testing, it can be observed that asphalt mixes on the urban main road are homogeneous, as correlation coefficient values are lower than 0.30, which is an indication of good homogeneity of material. A total of five samples were tested on the urban road in order to determine grading of the wearing course of asphalt. Statistical results for the urban road are presented in Table 7. The material is homogeneous as to the content of sand and stone chippings. As to filler, two homogeneous sections can be differentiated:

1. Homogeneous section 1 – includes samples in the zone from km 0+000 to km 0+300,
2. Homogeneous section 2 – includes samples in the zone from km 0+300 to 1+103.

Table 9. Statistical data on bitumen content in the wearing course and bituminized base course

Statistical parameters	Urban main road		Urban road		Collector street	
	AC surf	AC base	AC surf	AC base	AC surf	AC base
Mean value	4.43	3.89	4.20	3.67	4.13	3.38
Standard deviation	0.99	0.21	0.14	0.22	0.75	0.10
Coefficient of variation	0.22	0.06	0.03	0.06	0.18	0.03
Min	1.65	3.61	4.10	3.55	3.70	3.30
Max	4.97	4.17	4.30	4.17	5.00	3.50
15%-percentile	4.52	3.69	4.10	3.55	3.70	3.32

Table 10. Statistical indicators for voids content in asphalt courses

Statistical parameters	Urban main road		Urban road		Collector street	
	AC surf	AC base	AC surf	AC base	AC surf	AC base
Mean value	5.10	6.32	3.80	6.78	7.27	6.51
Standard deviation	0.78	2.48	1.95	2.25	1.15	0.84
Coefficient of variation	0.15	0.39	0.51	0.33	0.16	0.13
Min	4.00	3.60	1.00	3.40	6.60	5.30
Max	6.10	16.30	6.00	11.80	8.60	8.00
15%-percentile	4.30	4.52	2.08	5.33	6.60	5.62

Samples are homogeneous at the homogeneous section 1 for filler, while samples are not homogeneous at a part of the homogeneous section 2, as shown by the coefficient of variation which is greater than 0.30. Four cores were extracted at the collector street which is 316 m in length. These cores were subsequently tested to determine grading of asphalt courses. Statistical indicators derived from the results are presented in Table 8. Statistical analysis has revealed that the material is homogeneous for all gradings (grain size distributions).

Bitumen content

The bitumen content was analysed in the wearing course and bituminized base course in all categories of the urban road network. A total of seven samples were tested for the urban main road, five samples were tested for the urban road, and four samples were tested for the collector street. Statistical data on bitumen content in the asphalt concrete surface course (AC surf) and in the asphalt concrete base course (AC base) are presented in Table 9.

After analysis of bitumen content test results, it was established that the mean bitumen content value amounts to more than 4 % for asphalt courses, which is an acceptable quantity of bitumen for asphalt wearing courses of type AB 16s. It can be seen on the urban main road that one sample contains a very low quantity of bitumen of 1.65 and, if we observe the 15 % percentile value of bitumen content, it can be seen that the value of the urban main road is relatively good, i.e. that it exceeds 4 %. The problem occurs at collector street where the 15 % percentile value is lower than 4 %. It is assumed that the bearing capacity of asphalt courses has reduced, as will be shown in the part relating to bearing capacity testing by FWD. Bitumen content values for the bituminized base course range from 3.38 to 3.89 %, and all analysed materials are homogeneous, as demonstrated by the coefficient of variation values that are significantly lower than 0.30.

Voids content

Voids content in asphalt courses was determined based on SRPS EN 12697-8. Values obtained by statistical processing are presented in Table 10. This table shows that asphalt concrete course (AC surf) samples and wearing course samples are homogeneous at urban main road and collector street, while samples taken at urban road are not homogeneous. The bottom asphalt course / asphalt concrete base course (AC base) 32sA is homogeneous only at collector street, while it is not homogeneous at urban main road and urban road. A considerable dissipation of voids content results can be observed in AC base compared to AC surf for all urban road networks studied in the paper.

Compaction of asphalt courses

Level of compaction is also a significant characteristic of asphalt courses. The testing was followed by statistical processing of results the aim being to determine homogeneity of samples, the mean value, and the 15 % percentile of the samples. Statistical indicators are presented in Table 11. It was established that in case of the urban main road the asphalt concrete is not fully homogeneous, while other courses on all analysed road networks are homogeneous for both AC surf and AC base. The lowest value and poor compaction was established for AC surf courses at the urban main road as the mean value amounted to 83.87 %, while the 15 % percentile was 75.18 %.

Table 11. Statistical indicators for level of compaction of asphalt courses

Statistical parameters	Urban main road		Urban road		Collector street	
	AC surf	AC base	AC surf	AC base	AC surf	AC base
Mean value	83.87	98.69	100.10	98.53	97.67	98.21
Standard deviation	38.54	2.49	0.94	2.44	1.27	0.62
Coefficient of variation	0.46	0.03	0.01	0.02	0.01	0.01
Min	5.20	88.60	99.00	92.70	96.20	97.20
Max	100.60	101.10	101.60	102.70	98.40	99.20
15%-percentile	75.18	98.82	99.48	97.39	96.86	97.74

3.3. Surface damage

Surface damage was determined for all analysed sections by visual inspection of the route and by detailed inspection of individual instances of damage; the damage was classified by intensity of its occurrence on the pavement. The damage was analysed by determining the type and intensity of damage. A total of four homogeneous sections were observed on the urban main road, and the following was noted for these homogeneous sections:

- the homogeneous section 1 spreading from km 0+000 to km 0+501 is devoid of any damage, i.e. the pavment has recently been strengthened with a thin wearing course, and so no damage has so far formed on the pavement surface.
- the homogeneous section 2 spreading from km 0+501 to km 1+114 is characterised by domination of net-alligator cracks of low to medium intensity, and by transverse cracks of medium intensity. Road patches and rutting occurrences of medium intensity and of lesser extent were also observed.
- the homogeneous section 3 spreading from km 1+114 to km 2+325 is characterised by domination of net-alligator cracks of medium to high intensity, and by transverse cracks of medium intensity. Road patches and rutting occurrences of medium intensity and of lesser extent were also observed.
- the homogeneous section 4 spreading from km 2+325 to km 3+013 is characterised by domination of net-alligator cracks of low to medium intensity, and by transverse and longitudinal cracks of low intensity, the percentage of which is much smaller compared to net-alligator cracks.

The analysis of the pavement surface damage shows that asphalt courses are characterised by medium load bearing capacity.

Figure 7. Net-alligator cracks of high intensity (left side) and patches of medium intensity (right side)

The urban road has a total of two homogeneous sections where the following levels of damage were observed:

- homogeneous section 1 - from km 0+000 to km 0+227, with no damage. It was observed that a routine maintenance activity involving wearing course resurfacing was conducted at this section.
- homogeneous section 2 - from km 0+227 to km 1+103, with a greater percentage of net-alligator cracks (of medium to high intensity) and patches (of medium intensity), while the percentage of transverse cracks (of medium intensity) and rutting (of medium intensity) is much lower. Damage typical for this homogeneous section is shown in Figure 7.

Figure 8. High intensity pothole adjacent to net-alligator cracking

Investigation results have revealed that the load bearing capacity of the pavement surface is insufficient.

The collector street is formed on one homogeneous section that contains a high percentage of net-alligator cracks, net-block cracks (of medium to high intensity), and patches (of medium intensity). At this section, a small percentage of damage is attributed to patches (of medium intensity), transverse and longitudinal cracks (of medium to high intensity) and potholes (of high intensity). A high intensity pothole is presented in Figure 8.

The analysis of the type of damage, and spreading of damage along the pavement surface, shows that the load bearing capacity of asphalt courses is insufficient.

3.4. structural and mechanical properties of pavement

Structural and mechanical properties of pavement were determined by means of the Dynatest falling weight deflectometer. The deflection measurement by FWD was conducted via seven geophones spaced at 0, 300, 600, 900, 1200, 1500, and 1800 mm intervals, by applying the force of 50kN onto a circular plate 300 mm in diameter placed on the pavement surface. The contact stress of 0.707 MPa was obtained by this loading. The temperature of asphalt courses in pavement structure was also measured during deflection measurements; thus, the temperature amounted to approximately 21°C for urban main road, while it amounted to 23°C for urban road and collector street. The cumulative difference method based on AASHTO GUIDE for the design of pavement structures was used for classifying homogeneous sections according to their deformability. An average deflection value and a characteristic 85 % value were determined for each homogeneous section.
Comparative analysis of the following three parameters was made in order to classify homogeneous sections according to their deformability, and to obtain the clearest possible picture about the current condition and the remaining bearing capacity of pavement:

- stiffness of load bearing asphalt courses, as expressed via the difference in deflection on sensors d_0 and d_{300} (SCI_{300}),
- quality of subgrade as expressed via deflection on sensors d_{1500}, d_{900}, and d_{600} for urban main road, urban road, and collector street, respectively.
- total stiffness of pavement structure, as expressed via deflection d_0.

The bearing capacity of bound pavement structure courses (SCI_{300}) (d_0 and d_{300}) was classified according to criteria from *COST Action 354* – Performance indicators for road pavements in Europe, which are presented in Table 12.

Table 12. Criteria for bound pavement courses according to COST Action 354 [11]

Pavement condition	Class	SCI_{300} (1/1000 mm) for pavements with base courses of low carrying capacity
Very good	I	<129
↓	II	from 129 to 258
	III	from 258 to 387
	IV	from 387 to 516
Very poor	V	<516

Based on the above data, Figure 9 shows deflection basins of homogeneous sections according to deformability parameter for the urban main road. It can be concluded that the existing asphalt courses on urban main road belong to class IV on homogeneous section 3 (SCI_{300} = 389), while they belong to class II on homogeneous section 2 (SCI_{300} = 356). The homogeneous section 4 (SCI_{300} = 111) belongs to class I, i.e. to the very good class, while section 1 (SCI_{300} = 130) belongs to class II of the studied major road network.
Deflection basins for urban road are shown in Figure 10. It can be seen that the urban road belongs to class II as to homogeneous section 1 (SCI_{300} = 150), while homogeneous section 2 (SCI_{300} = 462), belongs to class IV.

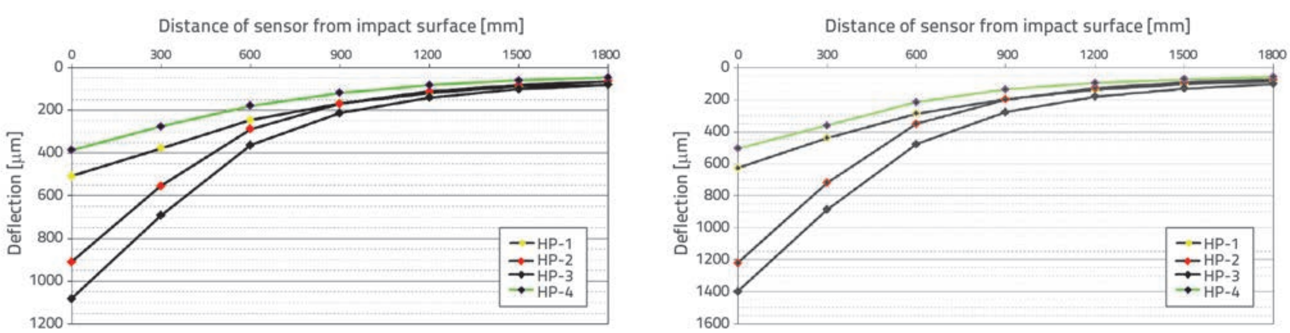

Figure 9. Deflection basins with mean value (left) and 85% (right) for the urban main road

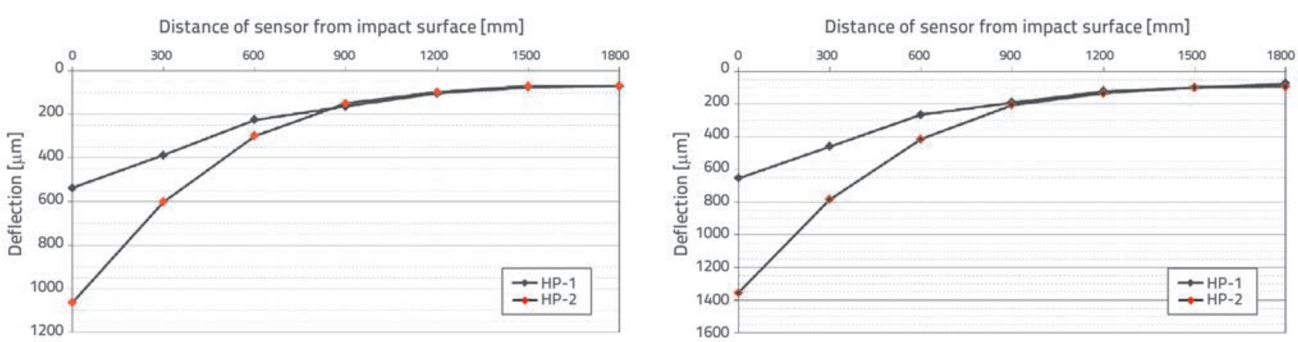

Figure 10. Deflection basins with mean value (left) and 85% (right) for the urban road

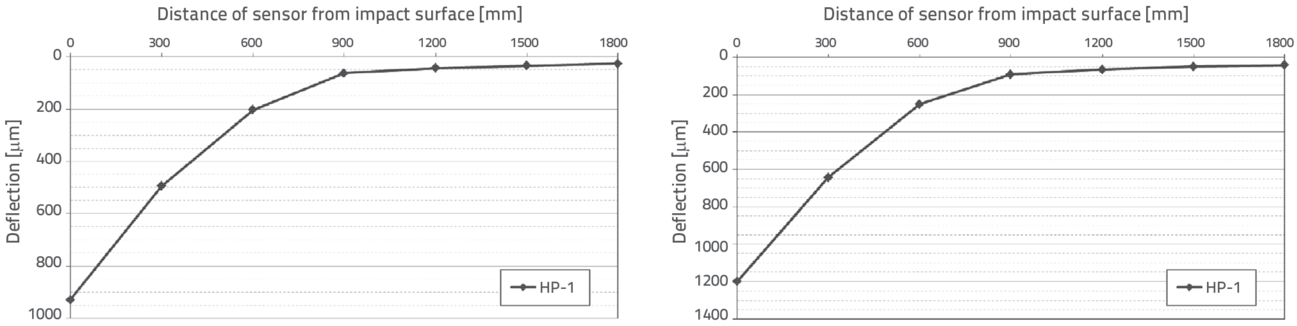

Figure 11. Deflection basins with mean value (left) and 85% (right) for the collector street

Deflection basins for secondary urban road network are shown in Figure 11. The collector street has one homogeneous section (SCI_{300} = 434) and it belongs to class IV, based on criteria set in *COST Action 354* [12].

3.5. Traffic load

Pavement structure is affected by traffic load in two ways:
- fatigue - exceedance of elastic deformation at the bottom part of asphalt course, which results in formation of cracks and in loss of bearing capacity,
- plastic deformation of asphalt courses, namely under influence of high temperature, low speed of travel, and high axle load.

The principal load imposed on pavement structures in urban areas is generated by passenger bus and truck traffic as operated on some urban roads and streets. Equivalence factors (Fe) are calculated according to the type of vehicle and traffic load based on traffic count. The expected equivalent traffic load is calculated for the next ten years, under assumption of an annual increase in traffic. Based on the above discussion and according to Serbian standard SRPS U.C4.010 [10], the equivalent traffic load amounts to:
- $2.5x10^6$ standard axles (80kN) for an urban main road,
- $1.5x10^6$ standard axles (80kN) for an urban road,
- $7.5x10^5$ standard axles (80kN) for a collector street.

4. Rehabilitation activities for urban roads

Final solutions for rehabilitation of pavement structures in urban areas are adopted after presentation of all relevant data. According to the type of works, pavement structure rehabilitation may be categorised as follows:
- repair of a greater number of defects (without surface treatment and without strengthening)
- pavement surface treatment (resurfacing) - a very thin layer is applied to ensure friction on pavement surface, preceded by repair of specific types of local pavement defects,
- strengthening preceded by repair of specific types of local pavement defects,
- partial rehabilitation,
- full rehabilitation.

The effects of individual rehabilitation categories are presented in Table 13. Based on pavement condition as determined by the analysis, an appropriate pavement rehabilitation strategy was adopted; in this particular case it consists of partial rehabilitation involving replacement of some courses of pavement structure. In all three cases, the existing pavement courses were removed due to considerable damage and unfavourable physicomechanical characteristics, i.e. partial rehabilitation activities were conducted by homogeneous sections. Following the analysis, a calculation of parameters regarding pavement structure of the urban main road is presented in Table 14. Modules of the existing pavement structure and the effective structural number are shown in this table.

Table 13. Effects of individual rehabilitation categories

Rehabilitation category	Protects structural integrity	Repairs to improve friction properties	Improves evenness	Extends pavement life and bearing capacity
Local repairs	+			
Pavement surface treatment	+	+		
Strengthening	+	+	+	+
Partial rehabilitation	+	+	+	+
Full rehabilitation		+	+	+

Table 14. Pavement structure analysis for the urban main road

Homogeneous section (HD)	Pavement structure modulus Ep [MPa]	Effective structural number SN_{eff} [cm]
HD-1	560	7.0
HD-2	157	6.4
HD-3	144	6.8
HD-4	664	10.3

Pavement structure strengthening thicknesses were determined by homogeneous sections based on the difference between the effective and required structural numbers of the pavement structure, in accordance with previously defined urban traffic conditions. The effective structural number was defined based on the total pavement structure thickness and the modulus of the existing pavement structure. The required structural number was calculated using the AASHTO Guide for design of pavement structures as per SRPS U.C4.015 [13]. Then the difference between the effective and required structural numbers of the pavement structure was defined, and the delta of the required structural number was obtained and divided with the coefficient for asphalt courses (0.38) and, finally, the thickness of asphalt courses as needed for pavement strengthening was obtained. Proper care was taken during removal of asphalt courses and attention was also paid not do deviate from the existing pavement level. Appropriate asphalt layer thicknesses were obtained based on the above information, and it was established that only lighter rehabilitation was needed in some spots, while full rehabilitation had to be conducted in some homogeneous sections. It was established by a non-destructive method, i.e. by FWD measurements, that the bearing capacity of asphalt courses was insufficient. Parameters specified in the standard are presented in Table 15; these parameters were used to determine an appropraite structural number. The required pavemnet strengthening thickness is shown at the end of Table 15.

Table 16. Calculated pavement structure parameters for urban road (GS) and collector street (SU)

Homogeneous section (HD)	Pavement structure modulus Ep [MPa]	Effective structural number SN_{eff} [cm]
GS-1	664	10.3
GS-2	296	7.9
SU-1	115	5.2

Table 15. Required structural number SN_{pot} for urban main road based on SRPS U.C4.015

	HD-1	HD-2	HD-3	HD-4
Equivalent traffic load (ESO_{80})	2.5 x 10^6 ESO_{80}			
Reliability (R [%])	90			
Normal standard deviation (Z_r)	-1.282			
Standard deviation (S_0)	0.45			
Initial present serviceability index (p_0)	4.2			
Final present serviceability index (p_0)	2.0			
Reduction of present serviceability index at the end of design service life (Δp)	2.2			
Subgrade resilient modulus (M_r [MPa])	25	25	15	20
Required structural number (S_{Neff} [cm])	12.1	12.1	14.0	14.2
Strengthening thickness (dpoj [cm])	13.0	15.0	19.0	10.0

Table 17. Required structural number SN_{pot} for urban road (GS) and collector street (SU) based on SRPS U.C4.015

	GS-1	GS-2	SU-1
Equivalent traffic load (ESO_{80})	1.5 x 10^6 ESO_{80}		7.5 x 10^5 ESO_{80}
Reliability (R [%])	90		90
Normal standard deviation (Z_r)	-1.282		-1.282
Standard deviation (S_0)	0.45		0.44
Initial present serviceability index (p^0)	4.2		4.2
Final present serviceability index (p_0)	2.0		2.5
Reduction of present serviceability index at the end of design service life (Δp)	2.2		-
Subgrade resilient modulus (M_r [MPa])	20	25	50
Required structural number (S_{Neff} [cm])	14.2	12.1	9.1
Strengthening thickness (d_{poj} [cm])	10.0	11.0	13.0

The same calculation procedure was also conducted for the urban road and collector street. Calculated values of required data, i.e. of the effective structural number, are shown in Table 16, while the required pavement strengthening thickness is shown in Table 17.
Adopted layer dimensions and types of new layers, arranged by homogeneous sections and types of urban road network, are presented in Figure 12.

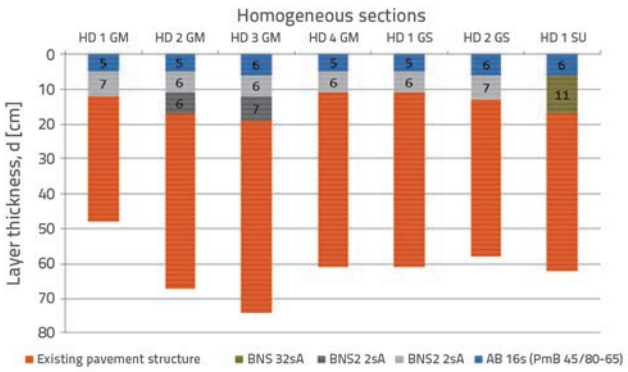

Figure 12. Rehabilitation of pavement structures in urban areas

The scope of works was the greatest at the urban main road, i.e. at its two homogeneous sections. It can be seen that asphalt concrete has a very low compaction rate, which is why it suffered significant damage in the form of medium intensity rutting. Poor bearing capacity was also observed on homogeneous sections 2 and 3, where partial rehabilitation was defined. It was observed that the layer made of granulated material - 0/31.5 mm and 0/63 mm sandy gravel - presents good load bearing properties. According to FWD results as obtained on both homogeneous sections, the bearing capacity of asphalt courses is poor on the urban road. The extent of damage is much more pronounced on the homogeneous section 2, which is why it was strengthened with a thicker asphalt concrete course, and with a thicker bituminized base course. Adequate pavement strengthening measures had to be applied at the collector street, where bearing capacities were low and the extent of damage pointed to significant changes. Hence, significant strengthening of the BNS and AB courses was proposed on this section.

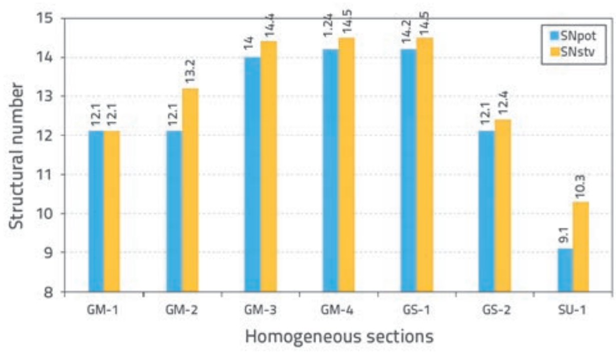

Figure 13. Real and required values of structural number

An additional verification was made in the scope of this study with the purpose of determining the real structural number, i.e. the calculation was made after pavement strengthening; and the values obtained are shown in Figure 13. This figure shows that the real structural number is either greater than or equal to the required structural number, which is why it can be concluded that the requirement of pavement strengthening with asphalt courses has been fulfilled.
The solutions are based on the established pavement condition, on the desired remaining service life of the pavement (ten years), and on the analysis and calculation results relating to intensive maintenance of pavement structures. Figure 12 shows pavement structure strengthening by homogeneous sections defined based on the bearing capacity and level of damage noted by on-site inspection. It was finally decided to use asphalt concrete 16s (PmB 45/80-65) on all analysed sections, while BNS 22sA was adopted for top asphalt base courses, and BNS 32sA was adopted for the collector street. Course thicknesses are presented in schematically; they range from 5 to 6 cm for AB, and from 6 to 7 cm for BNS 22sA. BNS 32sA 11 cm in thickness was adopted for the collector street.

5. Conclusion

The carrying capacity of pavements used in the urban road network is analysed in the paper. The analysis is based on material samples taken from road sections, and on visual inspections of pavement damage. After data collection, appropriate analyses were made to determine best rehabilitation/reconstruction measures to be taken to achieve the desired remaining service life of pavements under study. The following final conclusions can be made:
- some guidelines for the adoption of pavement courses were obtained by deflection measurements,
- pavement bearing capacity was confirmed based on properties of materials tested in the scope of this study. It was established that asphalt courses present much poorer properties as related to the granulated sandy gravelly material fractions of 0/31.5 and 0/63 mm.
- visual inspection of damage has revealed that the bearing capacity data are correct and that asphalt courses locally have poor properties due to the presence of net-alligator cracks, rutting, transverse and longitudinal cracks, and high-intensity potholes,
- the analysis was conducted according to the AASHTO guide for the design of pavement structures, and it resulted in final assessment of the bearing capacity of all sections and typical zones, and in clear definition of mechanical behaviour of individual pavement structure modalities,
- pavement structure strengthening thicknesses were determined on homogeneous sections based on the difference between the effective and required structural numbers of the pavement structure, in accordance with previously defined urban traffic conditions,

- in all three cases, the existing pavement courses were removed due to considerable damage and unfavourable physicomechanical characteristics, i.e. partial and full rehabilitation activities were conducted on homogeneous sections,
- this was followed by definition of the strategy for rehabilitation of pavement structures in urban areas,
- conditions were fulfilled for achieving the required structural number greater than or equal to the real structural number, and the proposed asphalt strengthening layers have shown an appropriate load bearing capacity,
- it can generally be concluded that the presented strategy or method for intensive maintenance of pavement structures in urban areas has proven to be adequate in practical terms, as demonstrated by analysis of real-life pavement sections.

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