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DOI: 10.35117/A_ENG_18_11_11

Field assessment of low-temperature cracks and bearing capacity of selected road sections in North-Eastern Poland

Abstract: Article presents the comparison of performance of selected road sections in north-eastern Poland constructed under typical contract conditions, with the usage of High Modulus Asphalt Concrete and typical Asphalt concrete The field investigation comprised of the assessment of: the number of transverse thermal cracking, the bearing capacity and the load transfer coefficient around the thermal cracks. The FWD test confirmed lower deflections of the road sections constructed with base courses made of High Modulus Asphalt Concrete and presented two times higher values of the stiff ness modulus of those pavements. The load transfer coefficient for pavements constructed with base course made of High Modulus Asphalt Concrete indicated almost lack of load transfer around the thermal cracks. In was very surprising as the tested roads were quite new (2-7 years) and with high bearing capacity. The article was made on the basis of the paper presented on BESTInfra conference, which was held in Prague.

Keywords: Low-temperature cracking; Bearing capacity; Pavement

Introduction

Asphalt concrete technology with a high stiffness modulus (AC WMS) was developed in France in the 1970s and 1980s [4]. Compared to typical asphalt concrete, it has a higher resistance to rutting and fatigue. For use in Poland, AC WMS was introduced at the beginning of 2000 as one of the activities to prevent excessive plastic deformation. After the first promising attempts in Poland and abroad [3],[4],[5],[6],[14],[16],[18], it was widely used in the construction of highways and national roads with large traffic load. However, some road experts suggested that due to the materials used, especially very hard for Polish 20/30 road asphalt conditions, the surface built using asphalt concrete with a high stiffness modulus may be characterized by increased susceptibility to low temperature cracking. These fears were confirmed after the winter of 2012 when a very large number of low-temperature transverse cracks was observed on the surface of many newly constructed roads [11],[12],[17]. The article presents an analysis of the field assessment of sections located in the coldest, north-eastern region of Poland, where the number of new thermal fractures observed was one of the highest. Asphalt concrete with a high stiffness modulus used on these sections was designed based on Polish technical requirements and was quite different from the original French mixture. It was characterized by a more closed structure (2-4% of the free space content) and a slightly lower bitumen content (about 5% by weight). The high stiffness modulus (minimum 14 000 MPa tested in a 4-point beam test at 10 °C and 10 Hz) was obtained by using 20/30 asphalt. The level of strain in the fatigue test after 1 million cycles of beam load remained the same as in the mixture designed using the French method and amounted to $\varepsilon_6 = 130\ \mu$ strain.

In recent years, due to the experience related to the behavior of asphalt concrete with a high rigidity modulus at low temperatures, intensive research has been carried out to adapt the AC WMS mixture to Polish climatic conditions. The range of asphalt that can be used has been extended, tending more towards modified and highly modified asphalt, as well as the requirements for stiffness and fatigue resistance, have been modified [1]. The changes proposed as a result of the research work are aimed at avoiding the situation of 2012 while maintaining high functional parameters of the designed asphalt concrete with a high stiffness modulus.

The main objective of this article is a comparative analysis of the surface work of selected road sections located in north-eastern Poland with the foundation of asphalt concrete with a high rigidity modulus and the foundations of typical asphalt concrete. Three technical aspects were assessed: the intensity of low-temperature fractures, the load-bearing capacity of selected sections and the quality of load transfer within low-temperature transverse cracks.

Field assessment

Sections selected for the field assessment in North-Eastern Poland were part of a larger research program [13],[10] implemented on behalf of GDDKiA in the years 2012-2014. 9 sections with a length of about 1 km each were selected for the study. The entire research program covered the field assessment (assessment of the number of low-temperature cracks and rut depth assessment) of 80 sections located throughout Poland, of which 33 sections were built with tie layers and asphalt concrete substructures with a high stiffness modulus. To exclude the number of factors that may influence the number of transverse cracks, all selected sections were built with the main substructures from unbound mixtures and their service life ranged from 1 to 12 years.

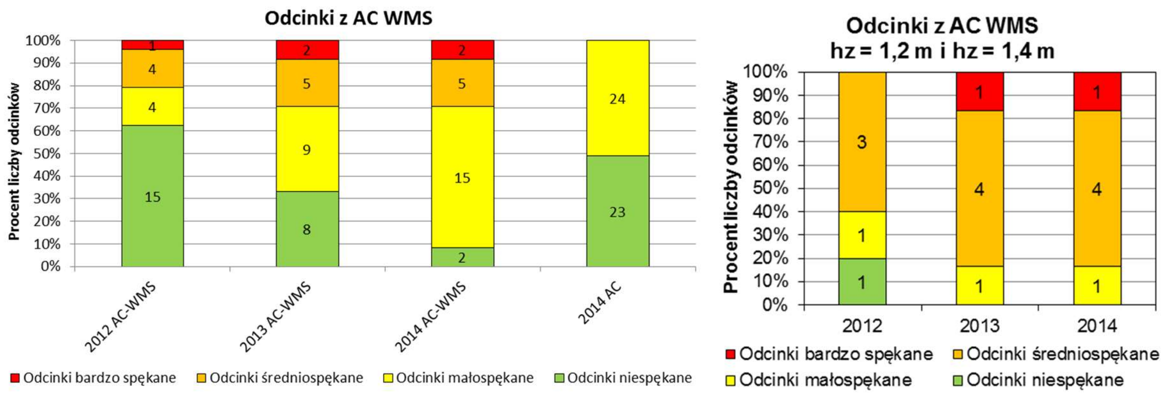
The structure of the upper layers of pavement sections with asphalt concrete with a high stiffness modulus consisted in each case with 27 cm of asphalt layers (of which 23 cm from mixtures with high stiffness module with 20/30 road asphalt) and from a layer made of a mixture of unbound thickness 22 -23 cm. In the case of sections with typical asphalt concrete, the construction of the upper layers of the surface consisted of 28 cm of asphalt layers and a mixture of unbound 20 cm thickness. Asphalt concrete for the binding layer and the foundation layer, in this case, was produced using asphalt 35/50.

For each of the selected sections, field assessment of damages [7],[15] was made, focusing on low-temperature transverse fissures (both in technological connections and outside). During the field evaluation, other damages were also observed (including ruts), but their range was negligible and did not affect the assessment of the technical condition of the entire section. Detailed information on the analyzed sections located in North-Eastern Poland together with a comparison with data obtained from sections in the rest of Poland is presented in Table 1. The change of fracture intensity for sections with AC WMS and AC located in other regions of Poland and only in the region analyzed in detail in Figure 1.

Tab. 1. Results of technical assessment of the analyzed road sections

No.	Section of research (year of putting into service)	The construction of the upper layers of the surface	FWD research (mileage of sections)	The number of low-temperature cracks per kilometer)		
				(2012)	(2013)	(2014)
1	S8 Jeżewo – Białystok (2012)	4 cm SMA 23 cm AC WMS 23 cm MN	1) 623+000 – 624+000 L 2) 620+000 – 621+000 P	2,12	3,47	5,3 1,7
2	S8 Obwodnica Zambrowa (2012)	4 cm SMA 23 cm AC WMS 23 cm MN	3) 3+000 – 4+000 L 4) 1+500 – 2+500 P	0,0	2,0	0,7 2,3
3	DK8, Białystok – Katrynka (2009)	4 cm SMA 23 cm AC WMS 22 cm MN	5) 649+000 – 650+000 P 6) 648+000 – 649+000 L 7) 649+000 – 650+000 L	8,8	15,7	8,7 8,7 8,7
4	Autostrada (2008/2010)	4 cm SMA 24 cm AC 20 cm MN	8) 25+000 – 29+000 L 9) 83+000 – 87+000 L	not assessed	not assessed	1,7 1,2
5a	Sections with AC (national average, 2014)					1,0
5b	Sections from AC WMS - hard road asphalt (national average, 2014)					3,5
5c	Episodes from AC WMS - modified asphalt (national average, 2014)					1,5

Notes: a) information on low-temperature crack in 2012 and 2013 is given informatively and includes information on fissures observed over the entire length of research sections, information from 2014 concerns only low-temperature crackings observed near the sections selected for evaluation by FWD deflectometer



(a) (b)

1. Changes in the intensity of cracks in low temperature sections in the following years of evaluation: (a) sections located throughout the country (b) sections from AC WMS located in north-eastern Poland

The presented illustration clearly shows the impact of the location of the section on the intensity of low-temperature cracks expressed in the number of cracks per kilometer, as well as its change with the length of the surface's service life. The sections located in the north-eastern region of the country, built using hard 20/30 road asphalt, are characterized by a much higher intensity of low-temperature cracks and their much faster growth along with the increase in the life of the surface. While the problem of low-temperature cracks on surfaces with layers of asphalt concrete with a high stiffness modulus also occurs in other regions of the country, it is not as intense as in the region analyzed in detail.3. Analysis of test results from FWD

The FWD deflectometer was tested in November 2013 and in October 2014. The average temperature of the asphalt layers was in the range of 8 to 21°C. On sections with asphalt concrete with a high modulus, the pavement deflection stiffnesses were made on the right lane every 25 m on sections of 1000 meters in length. In the case of a highway made of typical asphalt concrete, the deflection tests were performed every 100 meters for sections with a length of 4000 meters. The obtained deflection results were then standardized to a wheel load of 50 kN and a temperature of + 20°C.

The assessment of load transfer within low-temperature fractures was performed on two test sections with the highest number of low-temperature cracks: S8 Jeżewo-Białystok and DK8 Sztabin-Kolnica. The load transfer was calculated using the formulas (1) and (2) based on the binding [8] and reviewed [9] catalog of reinforcements and repairs of flexible and semi-rigid structures.

$$k = \frac{2 \cdot y_2}{y_1 + y_2} \tag{1}$$

$$k^* = \frac{y_2}{y_1} \tag{2}$$

where: k*, k – load transfer factors, y_1 – deflection of the loaded edge, y_2 –. Deflection of the unloaded edge. According to [8], the value of k <0.1 means no load transfer, 0.1 <k <1 means partial load transfer, k = 1 means full load transfer. According to [17], k * <0.7 means no load transfer, 0.7 <k * <0.95 means partial load transfer, k *> 0.95 means full load transfer.

The surface modules of the pavement structure adjusted to the temperature of + 20 ° C are given on the basis of the results obtained from the ELMOD program (determined from the deflections under the plate susceptible to the Boussinesq elastic space).

Inverse calculations of stiffness module values were made on the basis of the deflection dish results using the procedure described in the COST 336 report [2]. Three-layer (asphalt layers, the base foundation of an unbound mixture and improved subsoil) was adopted as a model of elastic half-space, in which each layer is characterized by elastic modulus E and Poisson's ratio ν. Layer thicknesses were adopted in accordance with the data presented in Table 1; Poisson's coefficients were assumed, respectively, 0.3 for asphalt layers and layers of unbound mixtures and 0.35 for the improved substrate. The calculated stiffness values for the asphalt layers were then standardized to + 10 ° C using the formula

$$E_{10} = E_T \times \left(0.77 + 0.023 \times T\right) \tag{3}$$

where: E_{10} – standardized modulus of elasticity (+10°C) [MPa], T – temperature of asphalt layers [°C].

Analysis of test results

The results of the FWD deflectometer test are presented in tables 2, 3, 4 and 5.

Tab. 2. Standardized results of surface deflections (T = + 20°C, load 50 kN)

Characteristics	Deflection of the surface [μm]								
	S8 Jeżewo – Białystok		S8 Zambrowa bypass		DK8, Białystok – Katrynka			Motorway	
The number of the test section, according to table 1:	*1*	*2*	3	*4*	5	*6*	*7*	*8*	*9*
Medium deflection ($U_{śr}$)	95	94	108	94	95	103	105	139	161
Authoritative deflection (U_m)	115	121	137	121	118	130	131	187	195
Co-modality, %	10	14	13	14	12	13	12	17	10
Number of measuring points	34	34	34	34	34	34	34	40	40

Comments: a) $Um = U_{śr} + 2\sigma$, where σ - standard deviation of test results

The analyzed test sections were characterized by high homogeneity of surface deflection values. In each case, the value of the coefficient of variation was lower than 20%, which classifies the sections as very homogeneous, according to the methodology presented in the COST 336 report [2]. Table 3 shows the load transfer coefficients.

Tab. 3. Load transfer factors

Characteristics	Research section					
	S8		DK8 (1)		DK8 (2)	
	k	*k**	*k*	*k**	*k*	*k**
Average	0,78	0,66	0,84	0,73	0,86	0,76
Minimal	0,41	0,26	0,79	0,65	0,66	0,49
Maximal	0,92	0,86	0,94	0,88	0,94	0,88
Co-modality, %	20	29	7	13	9	14
Number of measuring points	90	90	10	10	30	30

Load transfer coefficients were determined only for sections built with layers of asphalt concrete with a high stiffness modulus. On the national road DK8 (7 years of operation) the indicator "k" indicates a partial transfer of loads within low-temperature cracks. On the other hand, the average values of the "k *" index show indirect behavior on the limit of the lack or partial transfer of loads (between 0.73 and 0.76), with a large part of the results showing the lack of load transfer, even in the case of cracks repaired. In the case of the S8 expressway, if the coefficient "k" still shows a partial transfer of loads, which is due to milder criteria, the coefficient "k *" already shows a complete lack of load transfer, with single points showing only partial transfer. It is worth noting that the obtained values are definitely lower than in the case of sections located on the national road DK8. It is all the more surprising that this road has been in operation for only 2 years, with a similar level of traffic load. The probable cause may be a higher coefficient of thermal expansion of asphalt concrete layers with a high stiffness modulus, resulting, inter alia, in by a higher content of a hard bitumen binder. It shows, however, that in the case of asphalt concretes with a high stiffness modulus, attention should be paid to the monitoring, maintenance and quick repair of cross cracks. In the event of negligence, this may result in accelerated destruction of the surface in the area of these cracks.

Tab. 4. Standardized surface modules (T = + 20°C, load 50 kN)

Characterisctics	*Surface modules [MPa]*								
	S8, Jeżewo – Białystok		S8 Zambrowa bypass		DK8, Białystok – Katrynka			Motorway	
The number of the test section:	1	*2*	3	*4*	5	*6*	*7*	*8*	*9*
Average	2133	1709	1890	2166	2136	2011	1974	1493	1259
Minimal	1605	1235	1298	1689	1674	1629	1509	1055	1025
Maximal	2888	2220	2418	3209	2840	2495	2597	2136	1617
Authoritative module	1944	1467	1672	1828	1884	1750	1723	1218	1123
Co-modality, %	10	14	13	14	12	13	12	17	10
Number of measuring points	34	34	34	34	34	34	34	40	40

The surface module values determined from the ELMOD program show a high load capacity for each section, with module values above 1100 MPa. Higher load capacity is characterized by sections with layers of asphalt concrete with a high stiffness modulus. The values obtained are from 20 to 70% higher compared to sections built only with typical asphalt concrete.

Tab. 5. Standardized values of elastic modulus determined from inverse calculations (T = +10°C, load50 kN)

Characterisctics	*Moduły sprężystości [MPa]*								
	S8, Jeżewo – Białystok		S8 Zambrowa bypass		DK8, Białystok – Katrynka			Motorway	
The number of the test section:	1	*2*	3	*4*	5	*6*	*7*	*8*	*9*
Average	19736	17351	21718	20017	20766	18333	19008	9073	11718
Percentile 20%	15520	13564	18327	14904	16188	14684	14916	6473	10112
Percentile 80%	23399	21062	25514	23293	24813	20785	22662	11400	13398
Co-modality, %	25%	26%	21%	28%	28%	26%	24%	34%	22%
Number of measuring points	34	34	34	34	34	34	34	40	40

The values of modulus of elasticity (percentile 20%) for the improved substrate and the foundation of the unbound mixture change in a very small range and are similar for all sections. In the case of the foundation from the unbound mixture, the value of the elastic modulus varies from 398 to 482 MPa. In the case of an improved substrate, the range of elastic modulus values varies from 164 to 259 MPa. The obtained values and their variability suggest that the bottom layers of the foundation, the bottom layer of the surface and the layer of the improved substrate were made in accordance with the art of construction, and the quality of both works and materials used is high.

In the case of elastic modulus values determined for asphalt layers, the results are more varied. Sections built with layers of asphalt concrete with a high stiffness modulus show twice higher values of modules than sections made with typical bituminous concrete. In addition, these values (both average and relevant percentiles) are in most cases much higher than required according to the technical requirements of WT-2, with a minimum of 14 000 MPa.

Conclusions

On the basis of the field evaluation and FWD deflection test performed on selected sections of roads in North-Eastern Poland, the following conclusions can be made:

- Sections with layers of asphalt concrete with a high stiffness modulus are characterized by a higher intensity of low-temperature cracks compared to sections with typical bituminous concrete. The average observed number of cracks per kilometer is more than twice as high as in sections built with typical bituminous concrete.
- The influence of the cold climate of North-Eastern Poland has a significant impact on the intensity of cracks. Sections with asphalt concrete with a high stiffness modulus are characterized by a higher intensity of cracks and faster growth of cracks than sections built in the same technology but located in other regions of Poland.
- The results of fracture intensity for the latest (two-year) sections are disturbing. These sections are characterized by the intensity of cracks from 0.7 to 5.3 cracks per kilometer. This is a result significantly higher than the average cracks intensity for sections with typical bituminous concrete (about 1.0 cracks per kilometer), and also higher than the average achieved for bituminous concrete with a high stiffness modulus (3.0 cracks per kilometer, sections from 1 to 12 years of operation).
- The FWD deflectometer tests confirmed that the analyzed sections were constructed in accordance with the construction art, and the quality of the materials used was high. All analyzed sections are characterized by high homogeneity and load capacity, expressed by bending and surface modules.
  - The modulus of elasticity of asphalt layers for sections built using asphalt concrete with a high stiffness modulus is twice as high as in the case of sections built using typical asphalt concrete. In addition, in most cases, the modules obtained are significantly higher than required in the technical requirements of 14,000 MPa. In the case of other surface layers, modules for substructures from unbound mixtures and an improved substrate were similar for all analyzed sections and were on average 450 and 200 MPa.
  - Transverse cracks on sections with asphalt concrete with a high stiffness modulus show irrespective of the applied methodology either partial or no-load transfer, even for short-lived sections (2 years). Particular emphasis should be placed on monitoring, maintaining and repairing low-temperature cracks as quickly as possible to avoid premature damage to the entire surface within these cracks.

Acknowledgments

The authors would like to thank GDDKiA, Branch in Bialystok for their help in carrying out field works and to perform tests using FWD deflectometer.

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