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23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

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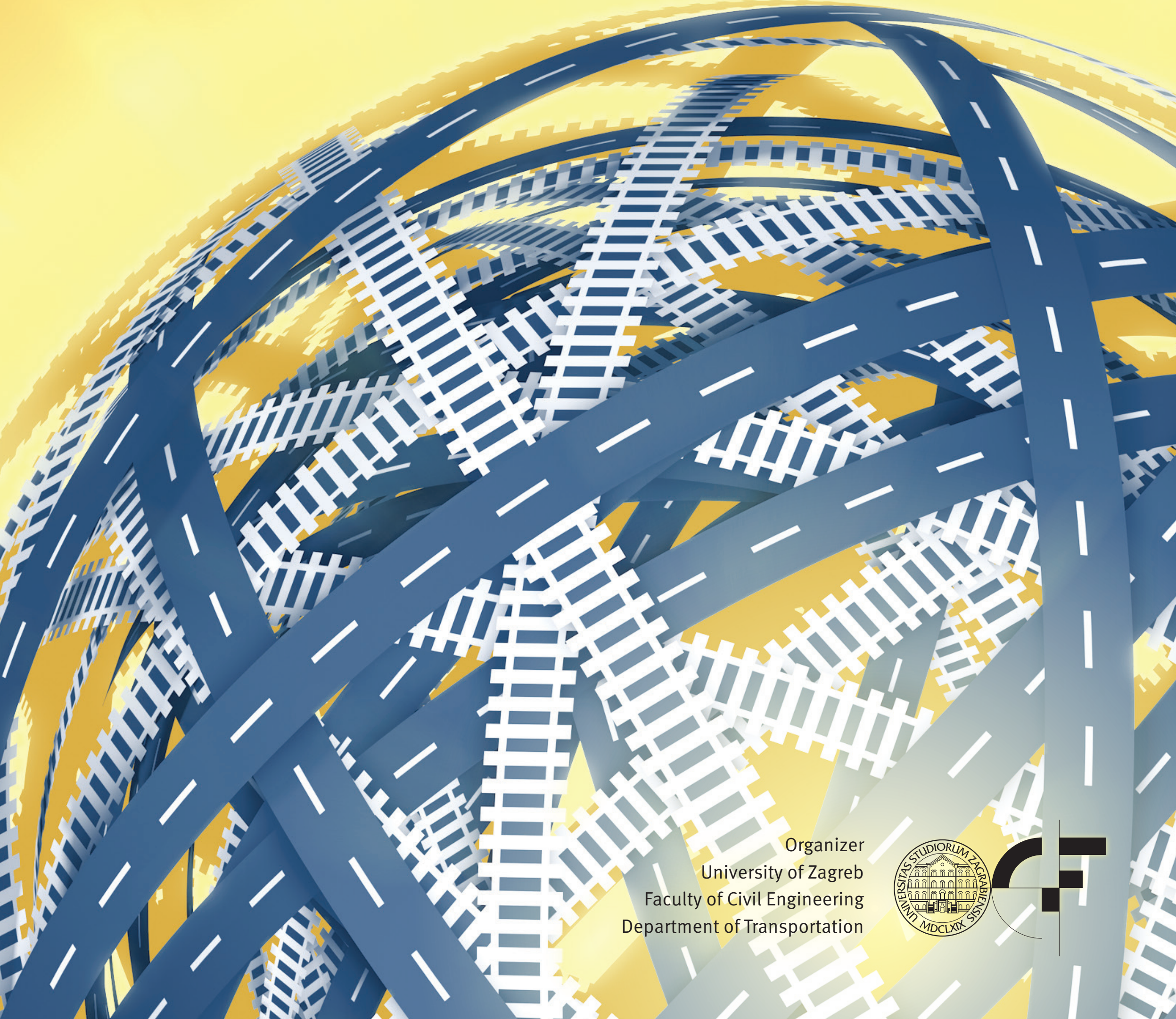

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Road and Rail Infrastructure IV

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BITUMEN SELECTION APPROACH ASSESSING ITS RESISTANCE TO LOW TEMPERATURE CRACKING

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Abstract

Low temperature cracking or thermal cracking is one of the most important distress in asphalt pavements located in cold regions. The development of it results in higher pavement roughness, faster pavement deterioration and requires millions of euros of repair and maintenance annually. The proper bitumen selection for asphalt mixture production restricts the formation of low temperature cracking. However, most designers do not consider bitumen susceptibility to low temperature cracking, because it needs to carry out additional laboratory tests and it requires supplementary cost and time in asphalt mixture selection. Consequently, this paper is focused on approach how to select bitumen assessing its resistance to low temperature cracking in easy and fast way. First, 11 bitumens of which 6 bitumens were polymer modified bitumens, were investigated. The critical temperature of bitumen, below which low temperature cracking occurs in the pavement, was calculated based on bending beam rheometer (BBR) experimental data by American Association of State and Highway Transportation (AASHTO) specifications. The performance grades (PG) low limits of bitumens were also determined using 3 °C step. The performance grade low limit varied from -16 °C up to -28 °C. Four polymer modified bitumens were not prone to low temperature cracking even at -28 °C temperature. Second, Lithuania was divided into 3 zones according to minimum pavement temperature. It gave possibility for designers to choose bitumen assessing its resistance to low temperature cracking based on road location. The implementation of this procedure will restrict low temperature cracking in asphalt pavements and will result in significant lower maintenance cost.

Keywords: bitumen, thermal cracking, low temperature cracking, bending beam rheometer (BBR), critical temperature, performance grade

1 Introduction

Low temperature cracking or thermal cracking is the dominant failure type in asphalt pavements located in cold regions. The opening and development of this kind distresses increase pavement roughness and create the opportunity for water penetration into pavement. It leads to lower bearing capacity of base and subbase, especially through freeze-thaw cycles, and results in faster pavement deterioration. The repair and maintenance of these consequences require millions of euros annually.

Low temperature cracking occurs because asphalt pavements contract under severe temperature changes. The crack opens when the thermal stress induced at low temperature exceeds the tensile strength of the asphalt pavement. Many researches [1-5] improved that bitumen performance at low temperature correlates very well with asphalt mixture performance at low-temperature and can be a specification in restriction of low temperature cracking. However, most designers, especially in Lithuania, do not consider bitumen susceptibility to low

temperature cracking, because it needs to carry out additional laboratory tests and it takes supplementary cost and time in asphalt mixture design.
These problems are solved applying the Strategic Highway Research Program (SHRP) Performance Grade (PG) specifications [4], which have being used in the USA since the 1990`s. There bitumens are classified on the basis of the rheological properties measured in the linear viscoelastic range at pavement service temperatures. The bitumen criterion for low temperature cracking is based on Readshaw`s work [3]. He concluded that low temperature cracking could be minimized by using bitumen which does not exceed 200 MPa stiffness after a loading time of 2 hours at the lowest pavement service temperature. SHRP research team adjusted this value up to 300 MPa and applied the time-temperature superposition principle. It means that bitumen stiffness at 60 seconds at T ˚C temperature is approximately equal to the stiffness at 2 hours at T-10 ˚C temperature [4]. Furthermore, the m-value was introduced as an additional parameter. It should not be lower than 0.3 at the lowest pavement service temperature. Otherwise, bitumen too slow relaxes the thermal stresses that build up at low temperatures.
Bitumen susceptibility to low temperature cracking is assessing by its critical cracking temperature, which is defined as the temperature, at which bitumen cannot withstand induced thermal stresses. The determination of critical cracking temperature depends on the test type and method [6-11]. According to current American Association State Highway and Transportation Officials (AASHTO) specification critical cracking temperature of bitumen is determined using data from the bending beam rheometer (BBR) and the direct tension tester (DTT).
In Europe PG classification is not practically used. There bitumens are usually classified by penetration at 25 ˚C and softening point and there are not any requirements restricting low temperature cracking. The practice in Europe shows that the low temperature cracking might occur after 2-4 years since pavement construction even if bitumen meets requirements according to EN standards. Researchers [12], [13] tried to assess the performance of bitumens at low temperature based on the data from BBR. The investigation revealed that critical cracking temperature of unmodified bitumens varies from -13 ˚C up to -22 ˚C depending on penetration at 25 ˚C which was from 20 mm^{-1} up to 70 mm^{-1}. Modified bitumens represented lower critical cracking temperatures than unmodified bitumens. They were from -18 ˚C up to -29 ˚C. However, there were analysed only a small part of familiar bitumens usually using in Europe. Therefore, there is a need to conduct a wider experiment and to suggest a reasonable approach of bitumen selection assessing its resistance to low temperature cracking.

2 Experimental research of bitumen performance at low temperature

In experimental research were analysed 11 different bitumens, which are widely used in Europe: 5 – unmodified bitumens (20/30, 35/50, 50/70, 70/100 and 100/150), 4 – polymer modified bitumens (PMB 10/40-65, PMB 25/55-60, PMB 45/80-55 and PMB 45/80-65) and 2 – highly polymer modified bitumens (PMB 25/55-80 and PMB 45/80-80). Highly polymer modified bitumens are an innovation in road building materials industry and are not widely used. All analysed bitumens were characterized by:
- penetration at 25 ˚C temperature (EN 1426);
- softening point (EN 1427);
- elastic recovery (only polymer modified bitumens, EN 13398);
- critical cracking temperature;
- PG grade.

The critical cracking temperature was determined by data from BBR (EN 14771). The critical cracking temperature was a higher (less negative) temperature at which the creep stiffness at a loading time of 60 s was 300 MPa or m-value at a loading time of 60 s was 0.3 and 10 °C was subtracted due to used time-temperature superposition principle. Test temperature was changed at 6 ˚C intervals such that S(60)≤300 MPa or m(60)›0.3 at T ˚C and S(60)›300 MPa or m(60) ‹0.3 at T-6˚C. All bitumens before BBR were short and long term aged according to RTFOT (EN 12607-1) and PAV (14769). The classification into PG grades was done on the basis of critical cracking temperature. PG grades changed at 3 ˚C intervals.

3 Results

In experimental research determined characteristics of analysed bitumens are represented in Table 1. All analysed bitumens met European specification requirements of penetration at 25 °C temperature (EN 12591 and EN 14023). Unmodified bitumen 20/30 ($25.1 \cdot mm^{-1}$) and polymer modified bitumen PMB 10/40–65 ($26.9 \cdot mm^{-1}$) showed the lowest penetration. Bitumens with low penetration are hard and become brittle at low temperature. In cold regions are preferable softer bitumens because they are less susceptible to low temperature cracking.
All analysed bitumens except bitumen 20/30 met European specification requirements of softening point (EN 12591 and EN 14023). The softening point of unmodified bitumen 20/30 (63.6 °C) was higher than the European specification requirement (from 55 °C up to 63 °C).

Table 1 Characteristics of bitumens

Bitumen	Penetration [mm^1]	Softening point [˚C]	Elastic recovery [%]	$T_{limiting}$-10 [˚C]		T_{cr} [˚C]	Low temperature PG
				S(60)	m(60)		
20/30	25.1	63.6	–	-24.73	-16.56	-16.56	-16
35/50	39.0	54.4	–	-26.02	-23.25	-23.25	-22
50/70	59.7	49.6	–	-26.98	-24.98	-24.98	-22
70/100	81.7	46.0	–	-28.17	-27.60	-27.60	-25
100/150	123.0	42.3	–	-28.81	-29.65	-28.81	-28
PMB 10/40–65	26.9	71.1	73	-26.86	-21.28	-21.28	-19
PMB 25/55–60	33.7	63.9	79	-26.64	-22.99	-22.99	-22
PMB 45/80–55	64.7	64.5	90	-28.58	-27.52	-27.52	-25
PMB 45/80–65	57.8	73.7	90	-28.83	-28.26	-28.26	-28
PMB 25/55–80	40.8	98.7	94	-28.97	-28.20	-28.20	-28
PMB 45/80–80	59.8	91.2	96	-30.09	-28.75	-28.75	-28

All analysed modified bitumens represented higher than 63.5°C softening point. Highly modified bitumen PMB 25/55–80 showed the best result (98.7 °C).
According to the European specification requirements (EN 14023), there is required not less than 50% elastic recovery of polymer modified bitumen. All analysed polymer modified bitumens recovered more than 70%. Highly modified bitumen PMB 25/55–80 and PMB 45/80–80 demonstrated even 94% and 96% elastic recovery.
In 90.9% cases, limiting temperature determined by m-value at 60 s was higher than limiting temperature determined by stiffness at 60 s. Thus, m-value was a decisive factor determining critical cracking temperature.
The determined critical cracking temperature and PG grade for analysed bitumens showed their reasonable usage. Unmodified bitumen 100/150, polymer modified bitumen PMB 45/80-65 and highly polymer modified bitumen PMB 25/55-80 and PMB 45/80-80 are not prone to low temperature cracking at higher than -28 °C pavement temperature. Meanwhile, the bitumen 20/30 can be used only at higher than -16 °C pavement temperature.

4 Bitumen selection for asphalt mixture production

Low temperature cracking in asphalt pavements is minimized ensuring critical cracking temperature lower than minimum pavement design temperature. Minimum pavement design temperature is 1-day-minimum pavement temperature measured at the pavement surface at the project location. Usually temperature at the pavement surface is measured in Road Weather Stations (RWSs). If there is available data of meteorological stations, air temperatures have to be converted to the pavement temperatures at the pavement surface.
The determination of minimum pavement design temperature at any project location is simplified if mapping is done. The country is zoned considering to long period (10, 20 or more years) data of 1-day-minimum pavement temperature measured at the pavement surface in the RWSs. Typically, the intervals change in the same high as for PG grades.
In Lithuania RWSs were started to install in 1999. RWSs have temperature sensors at the pavement surface. Therefore, the lowest temperatures at the pavement surface of 2005–2015 years were analysed. The temperature repeatability in each interval of 2.5 °C below -15 °C was also analysed. It enabled to eliminate errors. For example, in RWS "Seirijai" the lowest temperature during 2005–2015 period was -26 °C in 2012. However, this temperature was recorded only one time and other low temperatures are higher than -20 °C. Thus, -19 °C that was recorded in 2014 was assumed as the lowest temperature during 2005–2015 period instead of -26 °C.

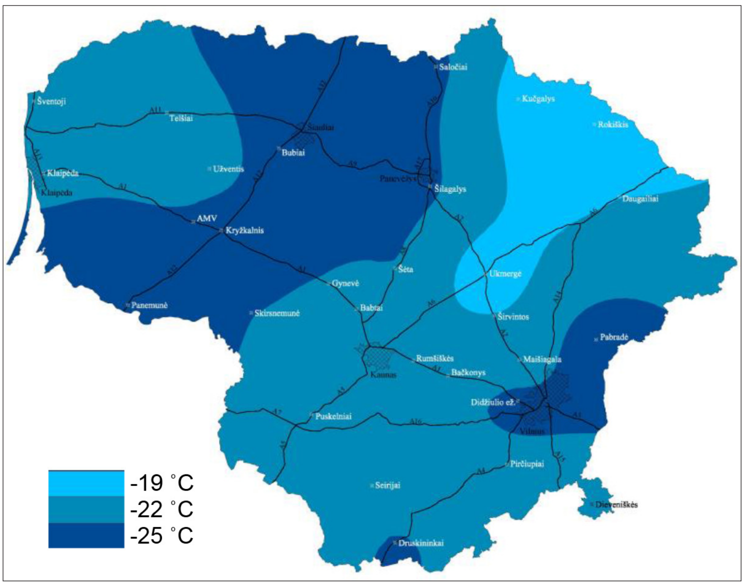

Figure 1 Lithuanian mapping according to minimum pavement design temperature

The lowest temperatures in 29 RWSs during 2005–2015 period are represented in Table 2. Lithuania was mapped using Autocad Civil 3D. The surface was smoothed using the Kriging method which provides spherical semivariogram model. Lithuania was zoned into 3 zones (Fig. 1). The highest low temperature zone (-19 °C) is in the North-east of Lithuania (in Ukmergė and Rokiškis region). The highest part of Lithuania (along coastal, Samogitian Highlands and the West-east of Lithuania) belongs to zone of -22 °C. The lowest pavement temperatures (up to -25 °C) are in the North-east of Midstream Lithuanian Lowland and in Pabradė, Vilnius, and Druskininkai region. The low temperature in RWS "Kryžkalnis" was significantly lower than in surrounding area. Thus, we referred this point to zone of -25 °C. However, the temperature data and conditions that may influence the results have to be detailed because pavement

temperature lower than -25 °C was recorded more than 120 times during 2005–2015 period. If the correctness of such low temperature (<-25 °C) in "Kryžkalnis" is proved, the adjustment of map has to be done. Furthermore, the map has to be updated yearly if any significant changes in the lowest pavement temperature appear.
In each zone has to be used bitumen which low critical cracking temperature is lower than minimum pavement design temperature. The reasonable selection of analysed bitumen for asphalt mixture production according to zone is represented in Table 3.

Table 2 The lowest pavement temperature in RWSs during 2005–2015 period

RWS No.	RWS name	The lowest pavement temperature [°C]
981	Šventoji	-21.5
989	Skirsnemunė	-21.5
1012	Bubiai	-25.2
1015	Panemunė	-25.9
1042	Pirčiupiai	-20.8
1063	Druskininkai	-23.2
1066	Telšiai	-21.9
1068	Dieveniškės	-19.6
1071	Puskelniai	-20.0
1104	Pabradė	-25.6
1123	Rokiškis	-14.7
1125	Daugailiai	-19.4
1129	Saločiai	23.7
1132	Maišiagala	-18.5
1134	Širvintos	-19.1
1135	Ukmergė	-15.4
1138	Kučgalys	-16.8
1140	Seirijai	-19.0
1143	Šėta	-23.4
1164	Didžiulio ež.	-24.2
1168	Šilagalys	-23.5
1181	Rumšiškės	-17.9
1183	Gynėvė	-22.1
1185	Kryžkalnis	-28.2
1187	Klaipėda	-21.0
1206	Babtai	-17.0
1208	Bačkonys	-23.7
1209	AMV	-22.0
1222	Užventis	-16.4

Table 3 Bitumen usage according to zone

Zone	Bitumen
-19	35/50, 50/70, 70/100, 100/150 PMB 10/40–65, PMB 25/55–60, PMB 45/80–55, PMB 45/80–65, PMB 25/55–80, PMB 45/80–80
-22	35/50, 50/70, 70/100, 100/150 PMB 25/55–60, PMB 45/80–55, PMB 45/80–65, PMB 25/55–80, PMB 45/80–80
-25	70/100, 100/150 PMB 45/80–55, PMB 45/80–65, PMB 25/55–80, PMB 45/80–80

5 Conclusions

Bitumen classification by penetration and softening point does not represent bitumen performance at low temperatures. There is a need to classify bitumens based on the performance parameter that could restrict low temperature cracking. Critical cracking temperature, which is defined as the temperature at which bitumen cannot withstand induced thermal stresses, could be the key assessing its resistance to low temperature cracking.
All analysed bitumens met European specification requirements of penetration at 25 °C temperature and softening point except unmodified bitumen 20/30 that had 0.6 °C higher softening point. However, softening point is not a decisive factor in low temperature cracking.
The determined critical cracking temperature by BBR data varied from -16.56 ˚C to -28.81 ˚C. Maximum difference is 12.25 ˚C. It confirms the hypothesis that bitumen for asphalt mixture production has to be selected assessing its resistance to low temperature cracking.
In 90.9% cases, limiting temperature determined by m-value at 60 s was higher than limiting temperature determined by stiffness at 60 s. Thus, m-value was a decisive factor determining critical cracking temperature.
Based on the lowest temperatures from 29 RWSs during 2005–2015 period Lithuanian territory divided to three regions. The highest low temperature zone (-19 ˚C) is in the North-east of Lithuania. The lowest pavement temperatures (from -22 ˚C to -25 ˚C) are in the North-east of Midstream Lithuanian Lowland and in Pabradė, Vilnius, and Druskininkai region. The medium low temperature zone (-22 ˚C) is in the rest part of Lithuania.
Setting low temperature regions of the country data has to be analysed after each winter and if lower pavement temperature was recorded in comparison with the introduced values in 29 RWSs, the map has to be updated.
In zone of -19 ˚C can be used all analysed bitumens except unmodified bitumen 20/30. This bitumen is not appropriate for Lithuanian climate on the basis of BBR test. In zone of –22 °C unmodified bitumen 20/30 and polymer modified bitumen PMB 10/40–65 tend to low temperature cracking. In zone of -25 ˚C zone only unmodified bitumen 70/100, 100/150, polymer modified bitumen PMB 45/80-55 and PMB 45/80-65, and highly polymer modified bitumen PMB 25/55-80 and PMB 45/80-80 can be used. Critical cracking temperature for all analysed bitumens was determined by data from BBR on the basis of m-value and stiffness at 60 s after 1 h conditioning. This experimental research has to be extended carrying out direct tension test and applying other methods for critical cracking temperature determination.

References

[1] Jung, D., Vinson, T.S.: Low Temperature Cracking Resistance of Asphalt Concrete Mixtures, Journal of the Association of Asphalt Paving Technologists, 62, pp. 54–92, 1993.

[2] Falchetto, A.C., Turos, M.I., Marasteanu, M.O.: Investigation on Asphalt Binder Strength at Low Temperatures, Road Materials and Pavement Design., 13(4), pp. 804–816, 2012, doi: 10.1080/14680629.2012.735793

[3] Readshaw, E.E.: Asphalt Specifications in British Columbia for Low Temperature Performance, Association of Asphalt Paving Technologists Proc, pp. 562–581, 1972.

[4] Anderson, D.A., Kennedy, T.: Development of SHRP Binder Specification, Journal of the Association of Asphalt Paving Technologists, 62, pp. 481–507, 1993.

[5] Behnia, B., Dave, E.V., Buttlar, W.G., Reis, H.: Characterization of Embrittlement Temperature of Asphalt Materials through Implementation of Acoustic Emission Technique, Construction and Building Materials, 111, pp. 147–152, 2016, doi: 10.1016/j.conbuildmat.2016.02.105.

[6] Lee, N., Hesp, S.A.M.: Low Temperature Fracture Toughness of Polyethylene-modified Asphalt Binders, Transportation Research Record, 1436, pp. 54–59, 1994.

[7] Petersen, J.C., Robertson, R.E., Branthaver, J.F., Harnsberger, P.M., Duvall, J.J., Kim, S.S., Anderson, D., Christensen, D.W., Bahia, H.U., Dongre, R.: Binder Characterisation and Evaluation, vol 4: Test Methods, Washington, D.C.: Strategic Highway Research Program. National Research Council, SHRP-A-370, 1994.

[8] Kim, S.-S.: Direct Measurement of Asphalt Binder Thermal Cracking, Journal of Materials in Civil Engineering, 17 (2005), pp. 632–639, doi: 10.1061/(ASCE)0899-1561(2005)17:6(632)

[9] Gauthier, G., Anderson, D.A.: Fracture Mechanics and Asphalt Binders, Road Materials and Pavement Design, 7 (2006) 1, pp. 9–35, doi: 10.1080/14680629.2006.9690056

[10] Mitchell, M. R., Link, R. E., Zofka, A., Marasteanu, M.: Development of Double Edge Notched Tension (DENT) Test for Asphalt Binders, Journal of Testing and Evaluation, 35 (2007) 3, pp. 1-7, doi: 10.1520/JTE100678

[11] Sui, C., Farrar, M. J., Tuminello, W. H., Turner, T. F.: New Technique for Measuring Low-Temperature Properties of Asphalt Binders with Small Amounts of Material, Transportation Research Record: Journal of the Transportation Research Board, 2179, 2010, doi: 10.3141/2179-03

[12] Radziszewski, P., Kowalski, K. J., Król, J. B., Sarnowski, M., Piłat, J.: Quality Assessment of Bituminous Binders Based on the Viscoelastic Properties: Polish Experience, Journal of Civil Engineering and Management, 20 (2014) 1, pp. 111–120, doi: 10.3846/13923730.2013.843586

[13] Olard, F., Di Benedetto, H., Eckmann, B., Triquigneaux, J.-P.: Linear Viscoelastic Properties of Bituminous Binders and Mixtures at Low and Intermediate Temperatures, Road Materials and Pavement Design, 4 (2003) 1, pp. 77–107, doi: 10.1080/14680629.2003.9689941