Considerations regarding the influence of climatic conditions on pavement with asphalt layers

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Abstract: - Recent climate changes have led to the occurring of numerous distresses in asphalt layers from flexible pavement.
Romania is faced with large differences in seasonal temperature: -15°C…-20°C in winter and +35°C….+40°C in summer, this variations leading to permanent deformation and fatigue and thermal cracking.
The Romanian Norm used to design a pavement structure with asphalt layers stipulate the calculus of fatigue damage ratio at the bottom of asphalt layers and limit the vertical strain value at sub-grade level. This is possible by establishing the stress and strain state using specialized software. In this norm, the recommended values for asphalt mixture stiffness are the minimum one given for an equivalent temperature of 15°C. However, what happen when the temperature changes? Moreover, what is the influence of the vehicle speed?
This paper has the goal to emphasize the time behavior changing of a pavement structure concerning to fatigue damage ratio at the bottom of asphalt layers and vertical strain at the sub-grade level in a pavement structure under the action of Romanian axle loads. The calculus is based on stiffness experimental values obtained on asphalt mixture in laboratory. The results obtained from calculus are presented like influence graphs.

Key-Words: - stiffness, fatigue life, asphalt mixture, pavement design, wearing course, fatigue damage ratio

1 Introduction

Climatic influence on asphalt mixture behavior is based on modification of properties and thus the state of stresses in a road structure, which leads to variations of lifetime of a road.

Important material properties for asphalt mixture, regarding the climate changes, are a good stability at high temperature, resistance to water and moisture, and flexibility to variations of bearing capacity of unbound materials from foundation.

Material properties of asphalt are closely dependent on temperature due to reduced stiffness with increased temperature, which means reduced deformation properties, reduced load distribution, increased loading on sub-layers.

The mechanical design of asphalt pavement structures can be performed by constructing a multi-layer system. The mechanical behavior of each individual layer is determined by various data being characteristic to the material of the layer, so to say, the thickness of the individual layers, as well as their stiffness moduli, Poisson-numbers and fatigue curves.

The French pavement design method consists in a pavement mechanistic analysis based on the Burmister multilayer elastic model (1943) (LCPC software ALIZE, 1982). In that model, the Huet-Sayegh behavior is taken into account with its equivalent elastic modulus at the 15°C French average temperature and a 10 Hz frequency. That frequency value is assumed to be equivalent to the standard 72 km/h French vehicle speed. Such semi-analytical calculations provide relatively good stress and strain fields for heavy traffic pavements but it is less satisfactory for flexible pavements with low traffic, for high temperature gradients and for the analysis of damages under slow heavy loads.

As it know, the Romanian Norm used to design a pavement structure with asphalt layers stipulate the calculus of fatigue damage ratio at the bottom of asphalt layers and limit the vertical strain value at sub-grade level. This is possible by establishing the stress and strain state using specialized software, based on Burmister multilayer elastic model. In this norm, the recommended values for asphalt mixture stiffness are the minimum one given for a temperature of 15°C. These values are given in table based on the climatic type of the area where the road is designed [5] (Table 1) and they are coming from laboratory tests of indirect tensile on cylindrical samples (IT-CY: SR EN 12697-26, annex C), according to SR 174-2009 [6] (Table 2).

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Table 1. Stiffness modulus values for asphalt mixture (values for pavement design) [5]

Asphalt mixture type	Course type	Climatic type I & II	Climatic type III
		Stiffness modulus (E), [MPa]	
Asphalt mixtures with D80/100 bitumen type	wearing course	3600	4200
	binder course	3000	3600
	base course	5000	5600
Asphalt mixtures with modified bitumen	wearing course	4000	4500
	binder course	3500	4000
Asphalt mixture stabilized with fibers: - MASF 16 type,	- wearing course	3300	4000
- MASF 8 type.	- wearing course	3000	3600

Table 2. Limit values for asphalt mixtures stiffness modulus [6]

Asphalt mixture	Stiffness modulus at 15°C [MPa] min.
Prepared with no paraffin bitumen for roads/ additives bitumen, for wearing course	4500
Prepared with no paraffin bitumen for roads/ additives bitumen, for binder course	4000
Prepared with modified bitumen, for wearing course	4500
Prepared with modified bitumen, for binder course	4000
Stabilized with fibers and with no paraffin bitumen for roads or modified bitumen, for wearing course MASF8	4000
MASF12.5, MASF16	4500

This paper has the goal to emphasize the influence of climate changes on asphalt layers of a road structure, based on variation of stiffness moduli with temperature, concerning to fatigue damage ratio at the bottom of asphalt layers and vertical strain at the sub-grade level in a pavement structure under the action of Romanian axle loads. The calculus is based on stiffness experimental values obtained on asphalt mixture in Roads Laboratory of Technical University of Civil Engineering Bucharest depending on temperature, frequency and number of load cycles.

2 Stiffness modulus of asphalt mixtures

The stiffness modulus of asphalt mixture is a fundamental property that gives information about how much the material deforms under a given load and is closely related with the fatigue cracking and permanent deformation because of time temperature dependence [3].

Stiffness modulus S is a term introduced by Van der Poel to distinguish S from the modulus E of elastic responses:

$$(S)_{t,T} = \left(\frac{\sigma}{\varepsilon}\right)_{t,T} \tag{1}$$

where: t is the loading time;
T is the test temperature.

Complex modulus is the relationship between stress and strain when the sample is subjected to a sinusoidal waveform load depending on time (figure 1).

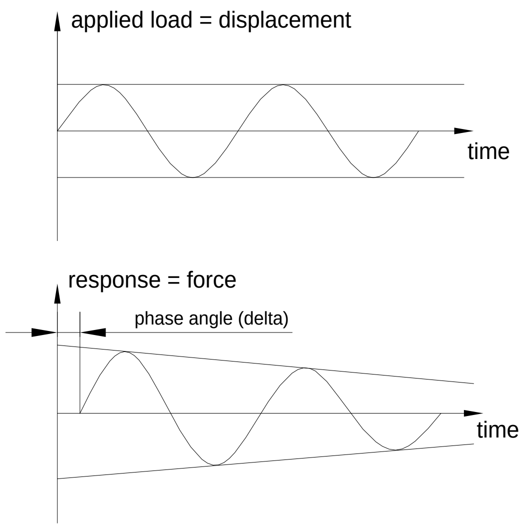

Fig. 1. Sinusoidal applied load and response

In case of a linear visco-elastic material, the complex modulus is characterized by norm (absolute value) and phase angle. The norm of complex modulus |E*| (dynamic modulus) is an

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indicator of material stiffness and is characterized by the two components, the elastic one, E_1 and the viscous one, E_2:

$$|E^*| = \sqrt{E_1^{\,2} + E_2^{\,2}} \qquad (2)$$

$$|E^*| = \frac{\sigma_0}{\varepsilon_0} \qquad (3)$$

where: σ_0 is the stress amplitude;
ε_0 is the strain amplitude.

The elastic or dynamic modulus of material (ignoring the viscous effects) may be determined by the ratio of the peak stress to strain amplitudes from the complex modulus test. In linear elastic multi-layer calculations for instance the E* modulus is generally used as input value for Young's modulus. So, the stiffness modulus is the absolute value of the complex modulus |E*|.

In European Norm SR EN 13108-20 three tests are stipulated for stiffness modulus determination [8]:

- Test applying Indirect Tension to cylindrical specimens IT-CY, according to SR EN 12697-26 Annex C [7]. In this test the applied load (force) is constant in time. The loading time is (124 ± 4) ms and the measured stiffness modulus is the mean of five pulses of applied load;
- Four Point Bending test on prismatic specimens 4PB-PR, according to SR EN 12697-26 Annex B [7]. In this test the specimen is subjected to four-point periodic bending with free rotation and (horizontal) translation at all load and reaction points. The strain amplitude, constant in time, is maximum (50 ± 3) microdef and the initial stiffness modulus shall be determined as the modulus for a load cycle between the 45th and the 100th load repetition;
- Two Point Bending test on trapezoidal specimens 2PB-TR, according to SR EN 12697-26 Annex A [7]. In this test the strain amplitude is constant and less or equal to (50 ± 3) microdef. The stiffness modulus is determined for 30s to 2 min.

The samples are deformed in their linear range, under repeated loads or controlled strain rate loads.

The test conditions for the three test exemplified above are stipulated in SR EN 13108-20 standard (Table 3).

Table 3. Type testing according to SR EN 13108-20

Type of test	Temperature [°C]	Frequency or loading time
IT-CY	20	124µs
4PB-PR	20	8 Hz
2PB-TR	15	10 Hz

Depending on type of test, different results were obtained in Roads Laboratory of Technical University of Civil Engineering Bucharest (figure 2). Generally speaking, higher results we have for stiffness resulted from 4PB-PR and lower results for stiffness resulted from IT-CY, for testing in conditions according to European norm.

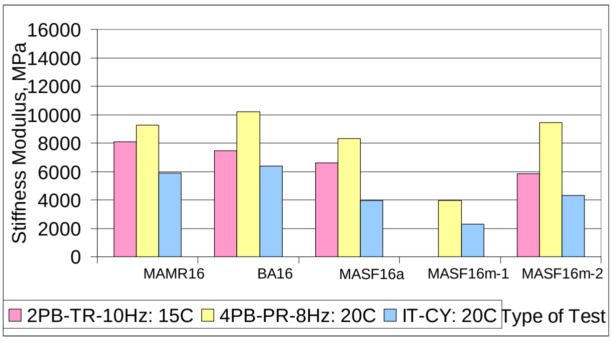

Fig. 2. Stiffness Modulus depending on type of test

3 The influence of climatic conditions on pavement design

Starting from idea that flexible pavement design based on elastic multi-layer theory it must be took on consideration the values obtained in laboratory for stiffness modulus of asphalt mixtures depending on testing conditions (temperature, loading, frequency), authors propose a road structure to do case studies, according with Romanian norm for pavement design (Table 4).

Table 4. Road structure proposed for design

Road layer	Layer thickness [cm]	Stiffness modulus [MPa]	Poisson number
Asphalt mixture in wearing course	4	E_m	0.35
Asphalt mixture in binder course	5		
Asphalt mixture in base course	6		
Foundation of crushed rock	20	500	0.27
Ballast foundation	30	260	0.27
Soil type: P1, according to Romanian norm [5]	∞	100	0.27

In the summer time, in very hot days, the air temperature could be reach 40°C which leads to

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65°C–70°C at the surface of asphalt mixture from wearing course.

Based on 4PB-PR test (see Table 3) were obtained in Roads Laboratory of T.U.C.E.B different values for wearing course asphalt mixture stiffness at each temperature testing: 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75°C (Figure 3). Values for stiffness which can't be obtained in laboratory tests result from master curves of each asphalt mixture (figure 4).

Values of stiffness modulus E_m considerate in pavement design are presented in Table 5. We have considered temperatures below 45°C, this being for working in elastic domain with ALIZE 5 software.

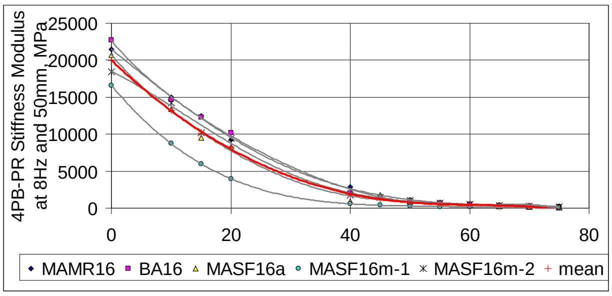

Fig. 3. Stiffness modulus and mean values versus temperature for 4PB-PR test at 8 Hz

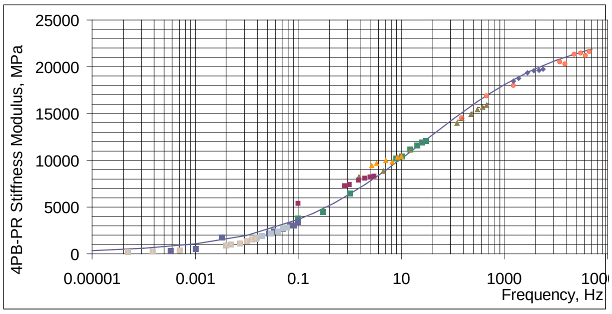

Fig. 4. Example of master curve (MASF16, 4PB-PR, T=15°C)

Table 5. Stiffness modulus calculation values for asphalt layers (E_m)

Type of test	Temperature [°C]	Stiffness Modulus, E_m, [MPa]
4PB-PR-8Hz	0	19923
	5	16393
	10	13219
	15	10403
	20	7945
	25	5843
	30	4099
	35	2712
	40	1682
	45	1333

Correspondence between frequency of test in laboratory and vehicle speed it is presented in Figure 5.

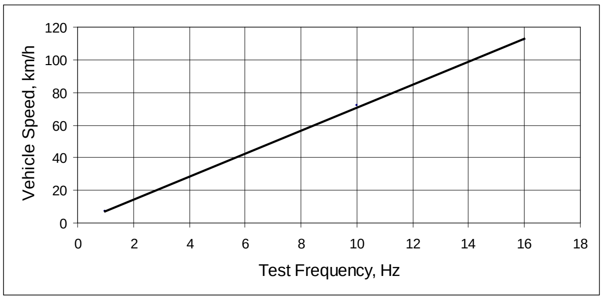

Fig. 5. Vehicle speed versus test frequency

Using the program ALIZE 5 (based on Burmister theory) it was established stress and strain state in road structure under action of standard 115kN axle (Romanian Equivalent Single Axle Load).

The standard 115kN axle has the following characteristics:
- dual wheels load: 57,5 kN;
- contact pressure: 0.625 MPa;
- equivalent radius of tire-surface contact area: 0.171 m.

So, it could be determined the fatigue damage ratio based on horizontal tension strain (ε_r) at the bottom of asphalt layers, and vertical strain (ε_z) at sub-grade level.

Fatigue damage ratio is the ratio between the design traffic volume N_c and the admissible traffic volume N_{adm} which can be taken by asphalt layers according to strains state at the bottom of them.

The admissible traffic volume is established by fatigue lines of asphalt mixture, depending on traffic class [5]:
- for N_c > 1m.o.s.:

$$N_{adm} = 4.27 \cdot 10^8 \cdot \varepsilon_r^{-3.97} \quad \text{(m.o.s.)} \tag{4}$$

- for $N_c \le$ 1m.o.s.:

$$N_{adm} = 24.5 \cdot 10^8 \cdot \varepsilon_r^{-3.97} \quad \text{(m.o.s.)} \tag{5}$$

The calculated fatigue damage ratio must be not greater than admissible value:
- ≤ 0.80 for motorways and express roads;
- ≤ 0.85 for European roads;
- ≤ 0.90 for national main roads and streets;
- ≤ 0.95 for national secondary roads;
- ≤ 1.00 for county roads and municipal roads.

The vertical strain (ε_z, μdef.) at sub-grade level should be smaller than admissible vertical strain ($\varepsilon_{z\,adm}$, μdef.):

$$\varepsilon_z \le \varepsilon_{z\,adm} \tag{6}$$

The admissible vertical strain is calculated by following [5]:

- for N_c > 1m.o.s.:

$$\varepsilon_{z\,adm} = 329 \cdot N_c^{-0.27} \quad (7)$$

- for $N_c \leq$ 1m.o.s.:

$$\varepsilon_{z\,adm} = 600 \cdot N_c^{-0.28} \quad (8)$$

For calculation it was considered several values of design traffic volume N_c for a perspective period (service life) of 15 years: 0.01m.o.s. to 10 m.o.s. (m.o.s. means million of standard 115kN axle), according to traffic classification in classes in Romania (Table 6).

Table 6. Traffic classes for national roads in Romania

Traffic class	Symbol	Design traffic volume, Nc, m.o.s. (standard 115 kN axle)
Exceptional	T0	3,0 … 10,0
Very heavy	T1	1,0 … 3,0
Heavy	T2	0,3 … 1,0
Medium	T3	0,1 … 0,3
Easy	T4	0,03 … 0,1
Very easy	T5	< 0,03

Correspondence between air temperature and asphalt layer temperature was considered according to Shell [4]. Figure 6 shows the variation of temperatures in asphalt layer with thickness between 0 (surface) and 18 cm. In table 7 can be find the air temperatures and the corresponding asphalt mix average temperatures.

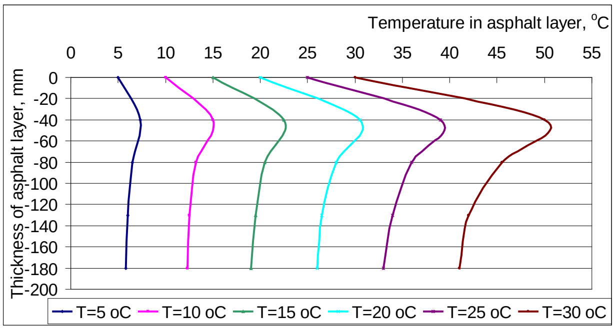

Fig. 6. Variation of asphalt layer temperature in thickness of asphalt layer

In graphics from Figure 7, Figure 8, Figure 9, Figure 10 are presented obtained results: increasing of fatigue damage ratio and increasing of vertical strain at sub-grade level with increasing of air temperature for T0 - exceptional and T5 – very easy.

Table 7. Air and asphalt mixture temperatures

Air temperatures [°C]	Asphalt mixture temperatures [°C]
0	0
3.9	5
7.7	10
11.3	15
14.8	20
18.2	25
21.4	30
24.5	35
27.4	40
30.2	45

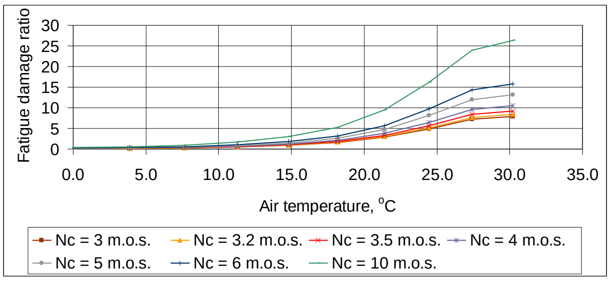

Fig. 7. Fatigue damage ratio versus air temperature for T0 (exceptional) traffic class

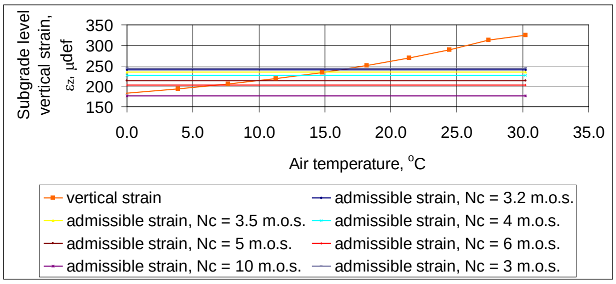

Fig. 8. Sub-grade level strain versus air temperature for T0 (exceptional) traffic class

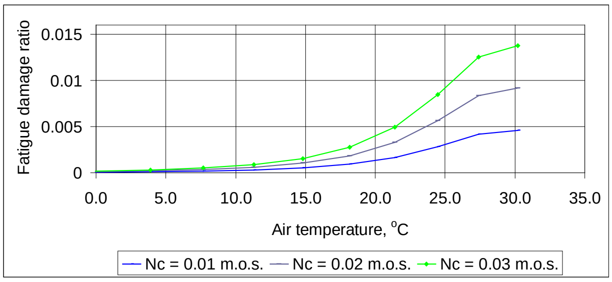

Fig. 9. Fatigue damage ratio versus air temperature for T5 (very easy) traffic class

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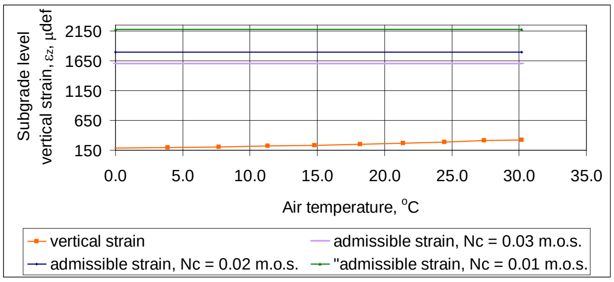

Fig. 10. Sub-grade level strain versus air temperature for T5 (very easy) traffic class

4 Conclusion

Conclusions drawn from this study are the following:

➢ Usually, the Romanian mixture design method use only one reference temperature for determining the required asphalt mixture properties, but, in the field the mixture must face a lot of variations in temperature. It seems that the use of one temperature test it is not sufficient to integrate the mixture in all climate conditions;

➢ Due to climate changes in recent years (especially pronounced warming trend during the summer, overlapped with cold winters in our country) in the pavement design calculations should be taken into account temperature susceptibility of asphalt mixtures by taking into account different stiffness modulus values, depending on temperature found in road;

➢ Climate changes requires to increase attention when design a road structure. In Romania, calculus of a road structure is based on stiffness values corresponding of a reference temperature of 15°C, which has an equivalent in air of about 11°C but in practice a way different values of temperature are riched. A temperature of only 30°C (very common in months from the end of spring, summer and start of autumn) in air conduct to a temperature at the middle of asphalt layer thick of 15 cm for 45°C;

➢ The stiffness modulus varies with temperature as: there is a decrease on average by more then 90% of the stiffness modulus when the temperature increases by 100% (from 0°C to 40°C), regardless of asphalt mix type tested (Figure 3); here it should be mentioned that a temperature of 40°C in 15 cm thick asphalt mixture means an air temperature of 30°C; in wearing course (4 cm in thickness) for the same air temperature of 30°C it can be obtained a temperature of 50°C – temperature when the material has no longer an elastic behaviour (Figure 6, table 7);

➢ In pavement design calculation it must take into account the technical class of road, by considering the appropriate frequency of testing to obtain stiffness modulus, this being close related with vehicle speed: a frequency of 8 Hz correspond to a speed of 56 km/h (Figure 5); it is known that stiffness modulus increase with the increasing of frequency, at a given temperature;

➢ Fatigue damage ratio decrease with the increasing of air temperature (Figure 7, Figure 9). Fatigue damage ratio needs to be maximum 1 so the road structure it is verified at standard axle load. If we considered that temperature rise from 11°C in air – for months of starting spring or ending autumn - (which means a temperature of 15°C at the middle of asphalt layer) to 30°C in air – for months of ending spring, summer and starting autumn (which means a temperature of 45°C at the middle of asphalt layer), it can be seen that depending on traffic class, the road structure has a different fatigue behaviour:

- for T0 traffic class (exceptional): the road structure is checked for an air temperature of 11°C when the traffic volume is under 6 m.o.s. but it doesn't check for any values of traffic at 30°C air temperature;
- for T1 traffic class (very heavy): the road structure is checked or an air temperature of 11°C, but it doesn't check for any values of traffic at 30°C air temperature;
- for traffic classes T2 (heavy), T3 (medium), T4 (easy) and T5 (very easy): the road structure is checked for both temperatures 11°C and 30°C.

Increasing the air temperature with 19°C leads to an increasing of about 1450% - 1500% for fatigue damage ratio. The road structure designed for colder period of a year (11°C) fail in warm period of a year (30°C), if no action is taken to reduce traffic in case of traffic classes T0 (exceptional) and T1 (very heavy).

➢ The same as fatigue damage ratio, the strain at sub-grade level increase with the increasing of air temperature (Figure 8, Figure 10), recording the passing of admissible value for a traffic class T0 and T1 around the air temperature presented in Table 8.

Table 8. Air temperatures above which is exceed admissible value strain at sub-grade level

Traffic class	Traffic volume Nc, m.o.s. [standard 115 kN axle]	Air temperature, [°C]
1	2	3
T1	1.1	29
	1.5	25
	1.8	23

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	2	22
1	2	3
T1	2.3	20
	2.6	19
	2.8	18
	3	17
T0	3	17
	3.2	16
	3.5	14.8
	4	13
	5	9.5
	6	6.5
	10	< 0

- In order to limit the influence of climate change is recommended to use bitumen with low temperature susceptibility, modified bitumen in areas with high temperatures which are maintained for a long time, superimposed over a heavy and intense traffic;
- It is recommended the promoting of adequate materials and constructive solutions associated to climate change impact;
- In conclusion, for flexible pavement design, it is necessary to establish minimum requirements concerning correlation of stiffness modulus with design speed, road temperature (climatic conditions), traffic class and technical class of the road;
- For further research we have the intention to draw up the fatigue lines for different asphalt mixtures tested to a range of temperatures between 0^oC and 40^oC and verify the pavement structure for an average fatigue line which depends on air temperature superposed on temperature variation of stiffness moduli value.

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