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^{o}C … -20^{o}C in winter and +35^{o}C …. +40^{o}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 subgrade 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^{o}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 subgrade 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.

1. INTRODUCTION

Climatic influence on asphalt mixture behaviour 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 behaviour 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 behaviour 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 subgrade 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).

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 subgrade 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 of Bucharest depending on temperature, frequency and number of load cycles.

Table 1 - Stiffness modulus values for asphalt mixture (values for pavement desgin)

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, - MASF 8 type.	 wearing course wearing course	 3300 3000	 4000 3600

Table 2 - Limit values for asphalt mixtures stiffness modulus

Asphalt mixture	Stiffness modulus at 15°C, MPa, min.
Prepared with no paraffins bitumen for roads/ additives bitumen, for wearing course	4500
Prepared with no paraffins 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 MASF12.5, MASF16	 4000 4500

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).

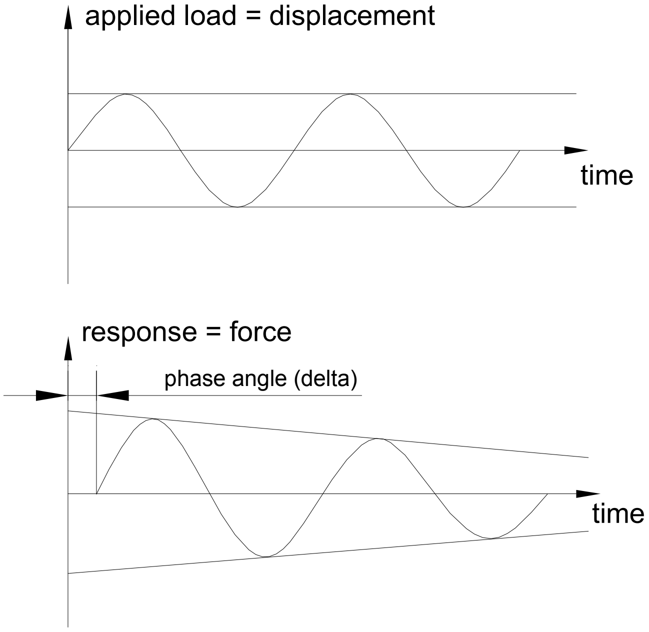

Figure 1 - Sinusoidal applied load and response

In case of a linear viscoelastic material, the complex modulus is characterized by norm (absolute value) and phase angle. The norm of complex modulus |E*| (dynamic modulus) is an indicator of material stiffness and is characterized by the two components, the elastic one, E_1 and the viscous one, E_2:

$$|E^*| = \sqrt{E_1^2 + E_2^2} \tag{2}$$

$$|E^*| = \frac{\sigma_0}{\varepsilon_0} \tag{3}$$

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 [^{o}C]	Frequency or loading time
IT-CY	20	124μs
4PB-PR	20	8 Hz
2PB-TR	15	10 Hz

3. THE INFLUENCE OF CLIMATIC CONDITIONS IN PAVEMENT DESIGN

Starting from idea that flexible pavement design based on elastic multistrat 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).

Based on 4PB-PR test (see Table 3) it was 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^{o}C (Figure 2 and Figure 3). Values of stiffness which can’t be obtained in laboratory tests result from master curves of each asphalt mixture.

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		100	0.27

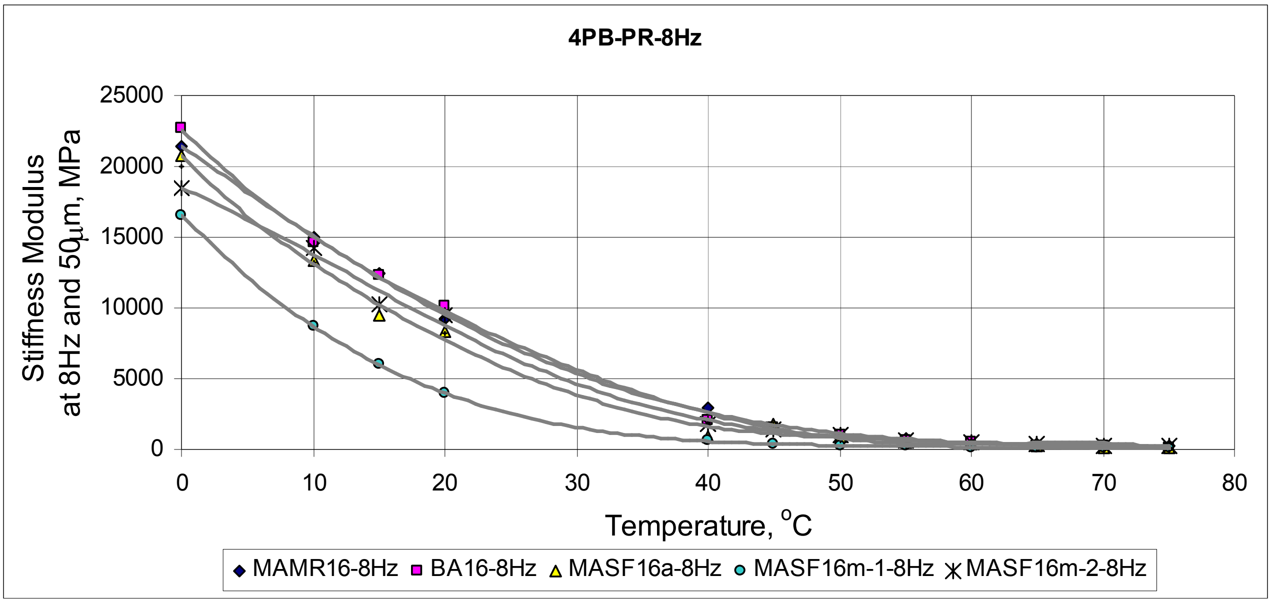

Figure 2 - Stiffness modulus versus temperature for 4PB-PR test at 8 Hz

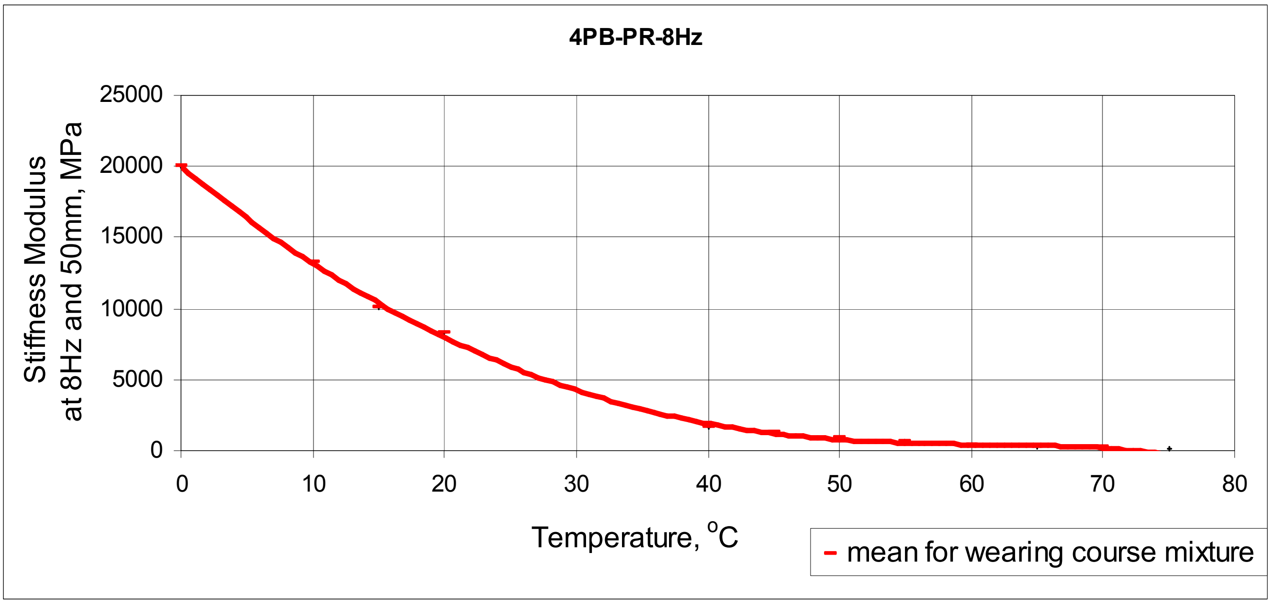

Figure 3 - Mean values of asphalt mix stiffness versus temperature

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

Correspondence between frequency of test in laboratory and vehicle speed it is presented in Figure 4.

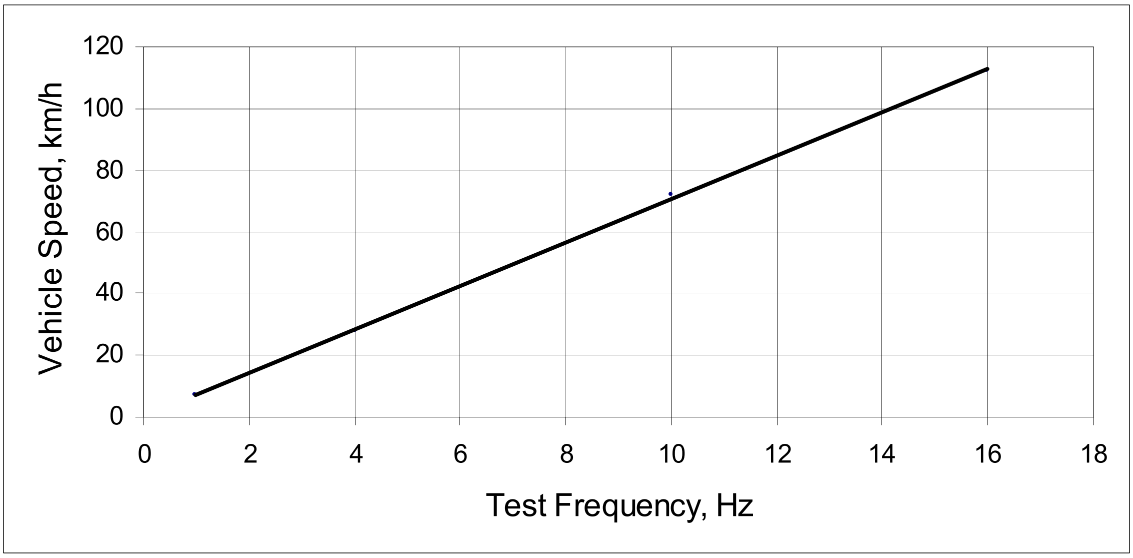

Figure 4 - Vehicle speed versus test frequency

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

Type of test	Temperature, (x) °C	$y = Ax^2-Bx+C$			Stiffness Modulus, (y) E_m, MPa
		A	B	C	
4PB-PR-8Hz	0	7.1449	741.82	19923	19923
	5				16393
	10				13219
	15				10403
	20				7945
	25				5843
	30				4099
	35				2712
	40				1682
	45				1333

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. 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 subgrade level.

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

Correspondence between air temperature and asphalt layer temperature was considered according with Shell, 1978, Figure 5.

Table 6 – Traffic classes for national roads in Romania

Traffic class	Symbol	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

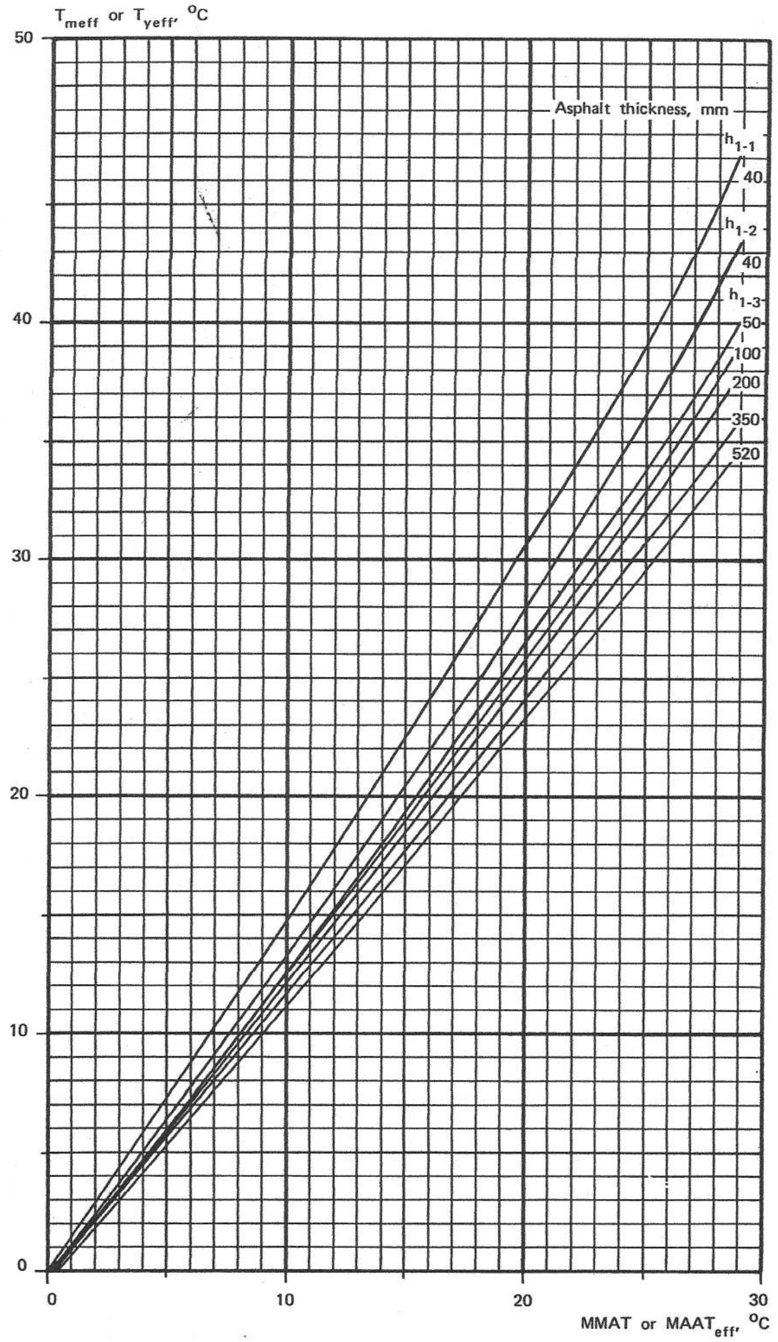

Figure 5 - Characteristic relationship between $T_{m\ eff}$ (monthly temperature effective in asphalt layer) and MMAT (medium monthly air temperature) or $T_{y\ eff}$ (annual temperature effective in asphalt layer) and $MAAT_{eff}$ (medium annual air temperature effective) for different asphalt sub-layers (Shell, 1978) [4]

In graphics from Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, Figure 11, Figure 12, Figure 13, Figure 14, Figure 15, Figure 16 and Figure 17 are presented obtained results: increasing of fatigue damage ratio and increasing of vertical strain at subgrade level with increasing of air temperature each traffic class considerate (T0 … T5).

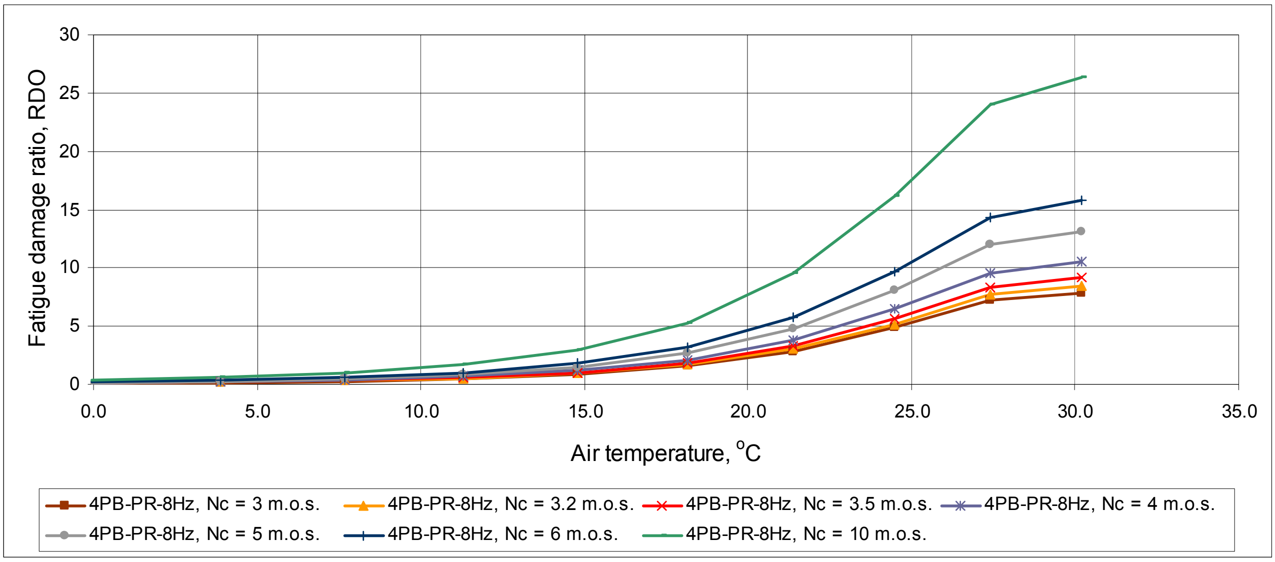

Figure 6 - Fatigue damage ratio versus air temperature for T0 traffic class

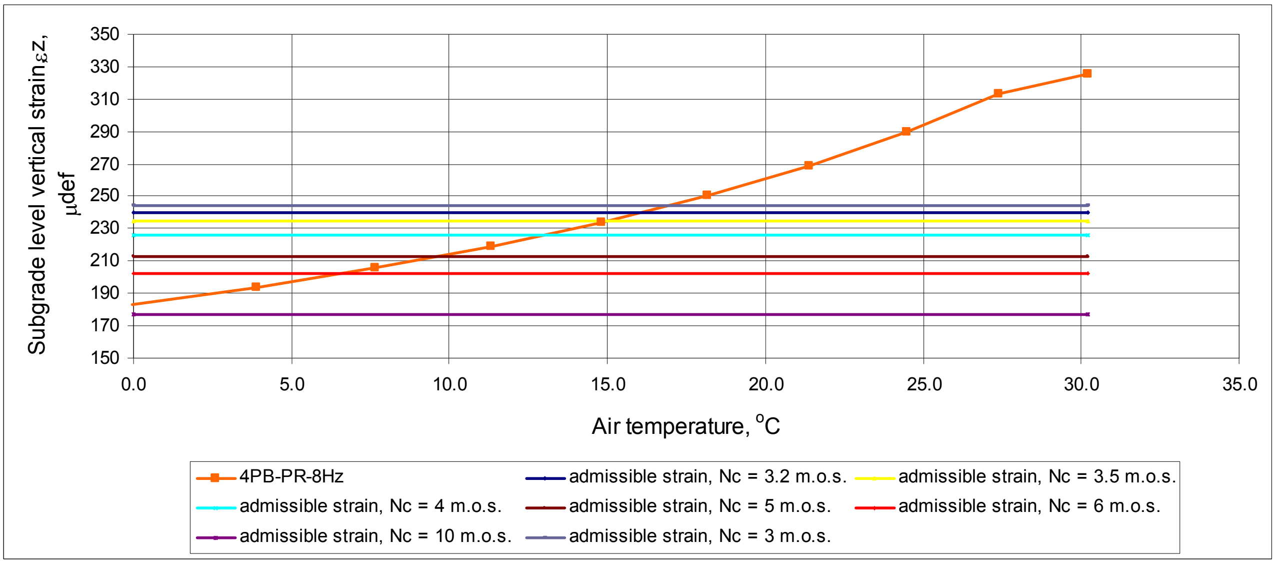

Figure 7 - Subgrade level strain versus air temperature for T0 traffic class

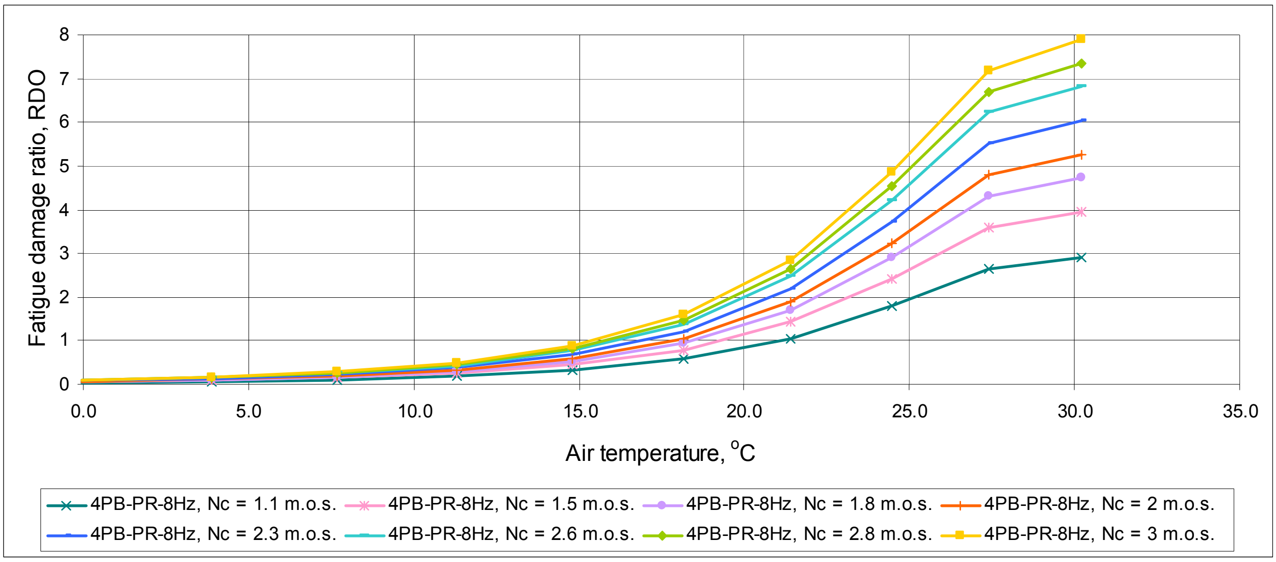

Figure 8 - Fatigue damage ratio versus air temperature for T1 traffic class

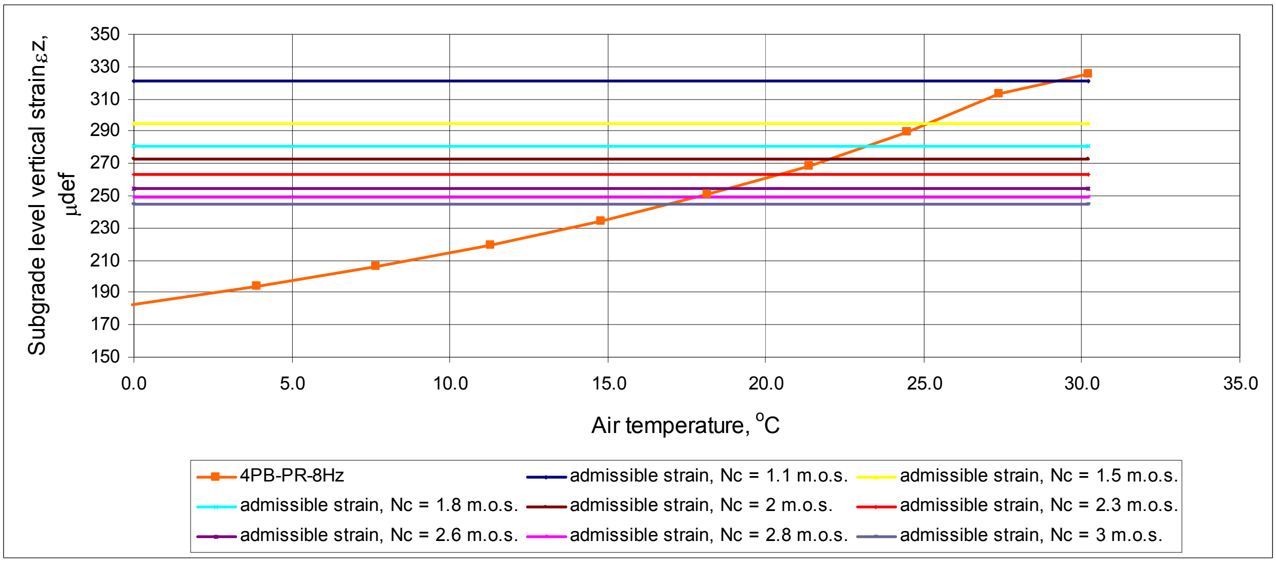

Figure 9 - Subgrade level strain versus air temperature for T1 traffic class

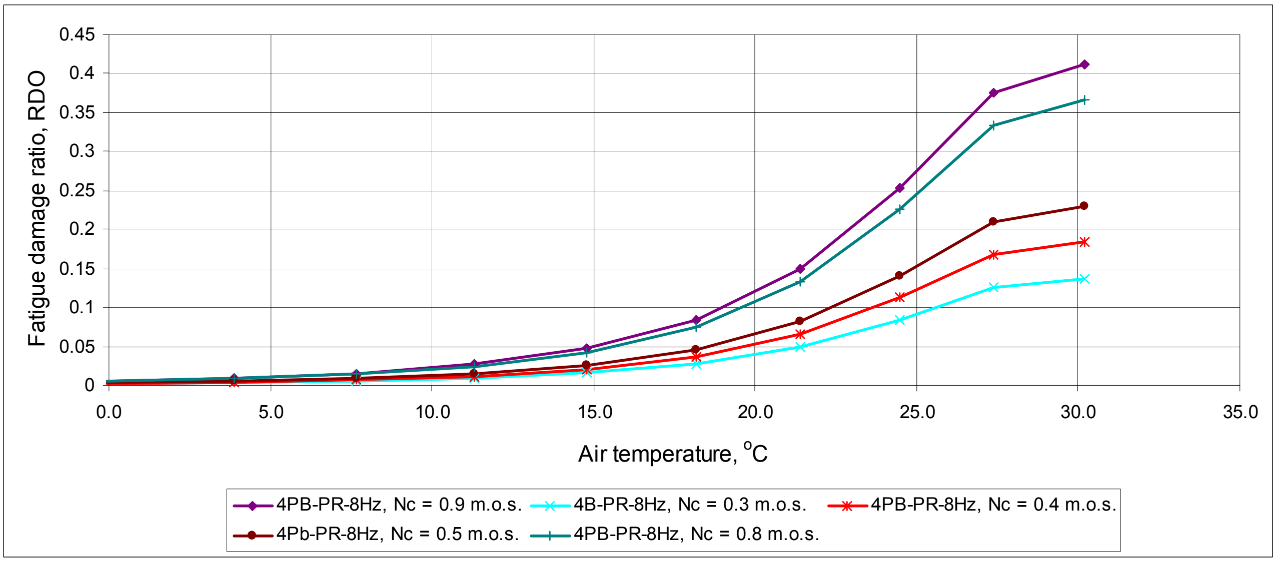

Figure 10 - Fatigue damage ratio versus air temperature for T2 traffic class

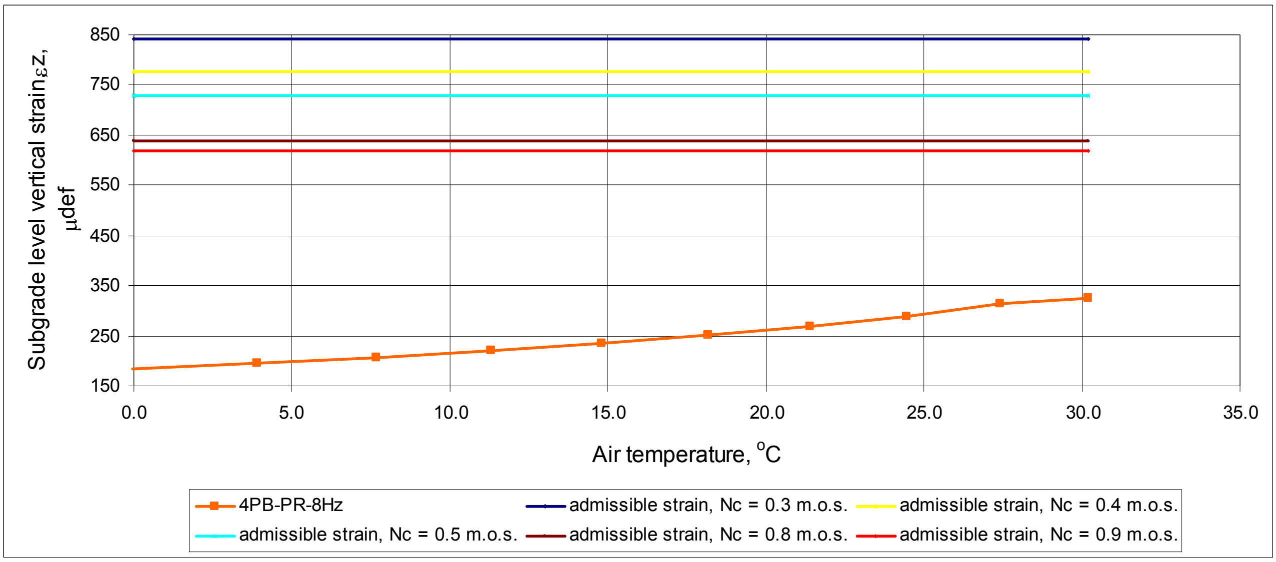

Figure 11 - Subgrade level strain versus air temperature for T2 traffic class

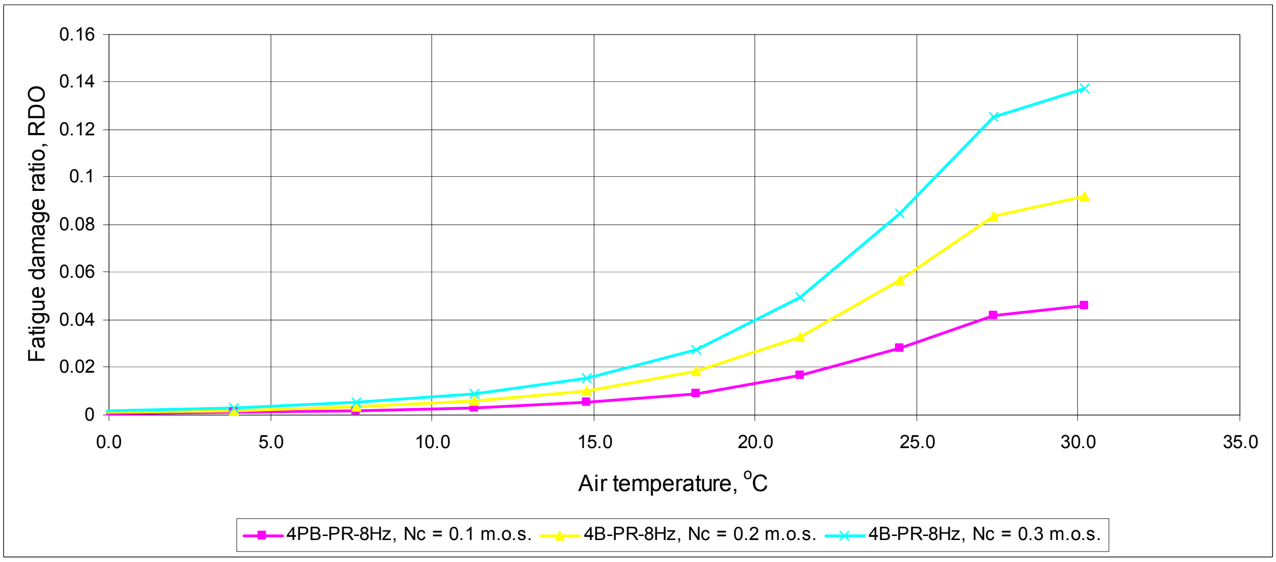

Figure 12 - Fatigue damage ratio versus air temperature for T3 traffic class

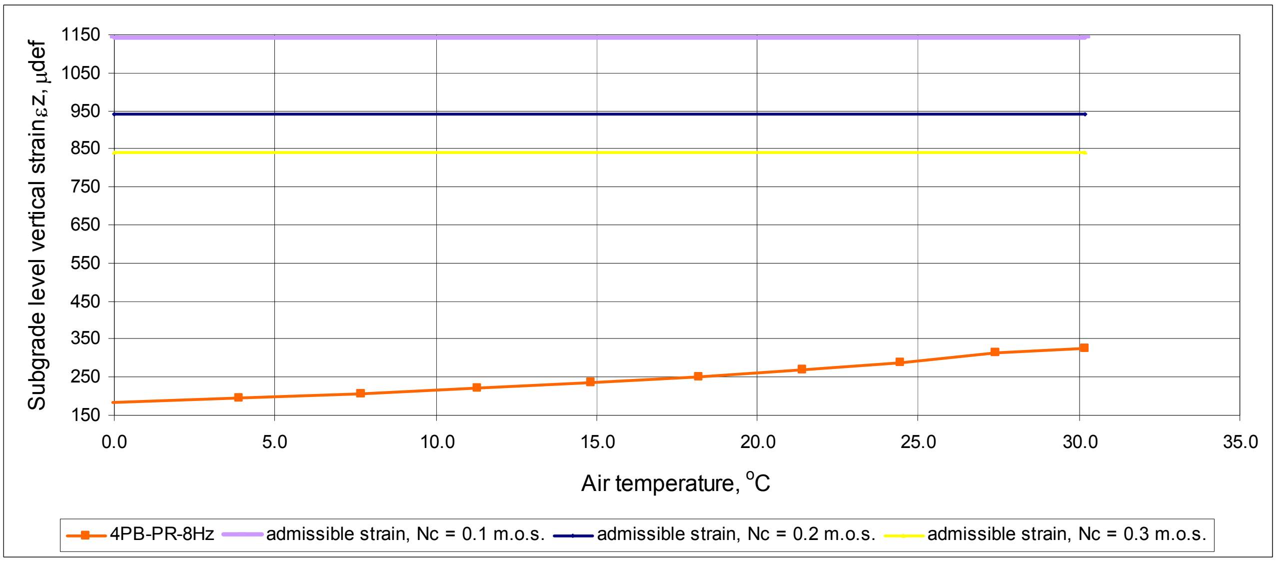

Figure 13 - Subgrade level strain versus air temperature for for T3 traffic class

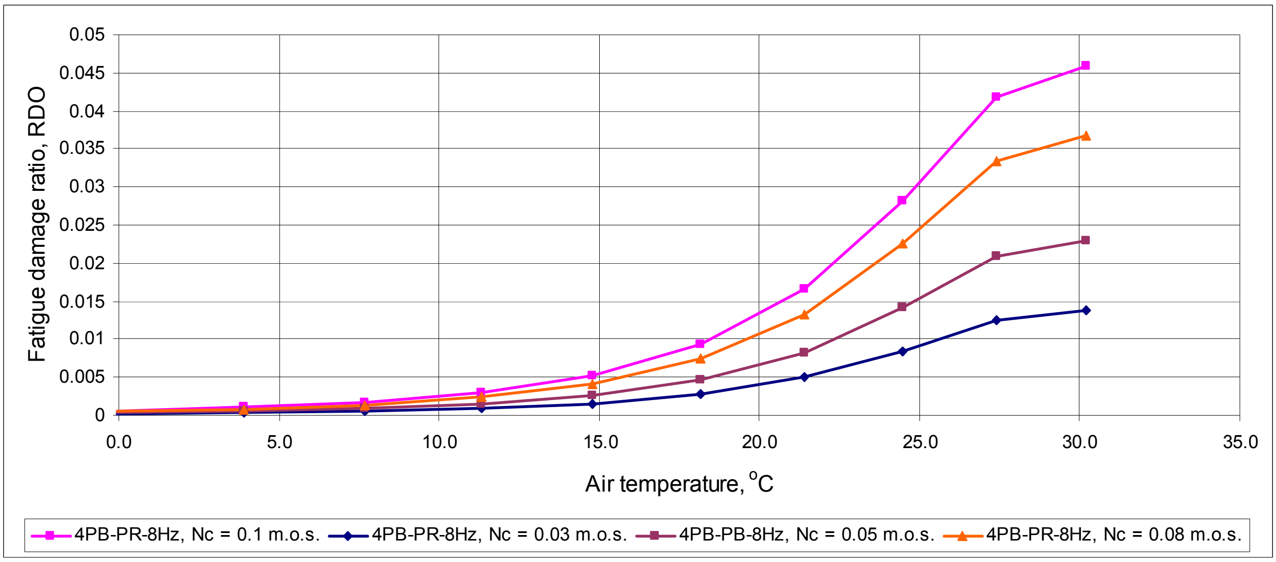

Figure 14 - Fatigue damage ratio versus air temperature for T4 traffic class

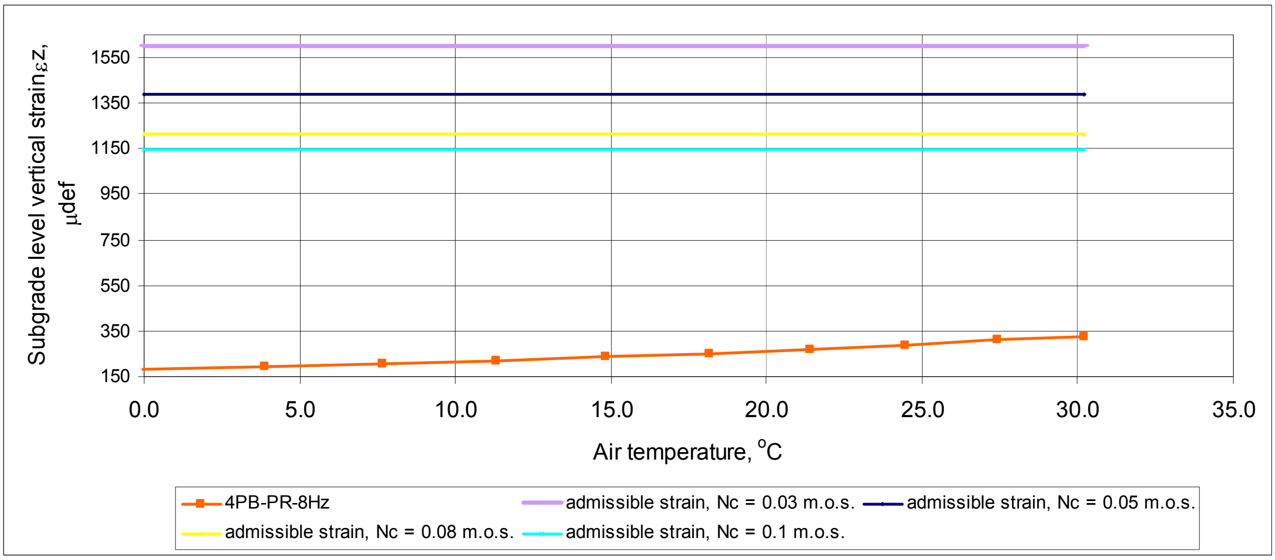

Figure 15 - Subgrade level strain versus air temperature for T4 traffic class

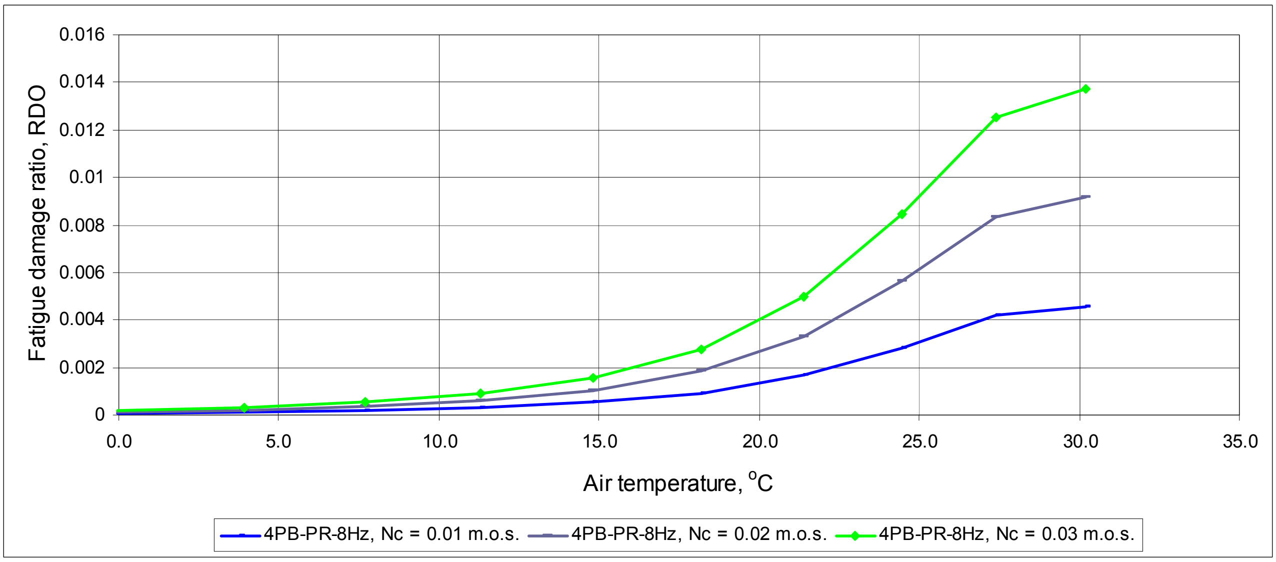

Figure 16 - Fatigue damage ratio versus air temperature for T5 traffic class

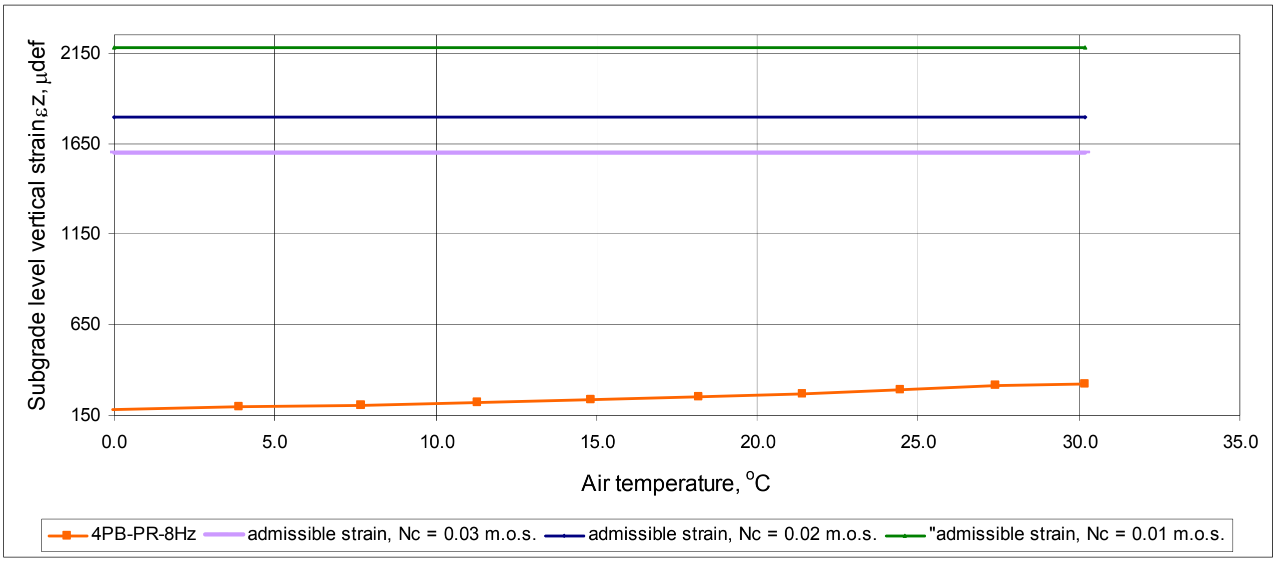

Figure 17 - Subgrade level strain versus air temperature for T5 traffic class

4. CONCLUSIONS

Conclusions drawn from this study are the following:

- Usually, the mixture design methods 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. Calculus of a road structure is based on stiffness values corresponding of a reference temperature of 15^{o}C, which has an equivalent in air of about 11^{o}C but in practice a way different values of temperature are riched. A temperature of only 30^{o}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^{o}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 2 and Figure 3); here it should be mentioned that a temperature of 40^{o}C in 15 cm thick asphalt mixture means an air temperature of 30^{o}C; in wearing course (4 cm thickness) for the same air temperature of 30^{o}C it can be obtained a temperature of 50^{o}C – temperature when the material has no longer an elastic behaviour (Figure 5);

- 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 4); 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 6, Figure 8, Figure 10, Figure 12, Figure 14, Figure 16). Fatigue damage ratio needs to be maximum 1 so the road structure it is verified at standard axle action. 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 and T1.

- The same as fatigue damage ratio, the strain at subgrade level increase with the increasing of air temperature (Figure 7, Figure 9, Figure 11, Figure 13, Figure 15, Figure 17), recording the passing of admissible value for a traffic class T0 and T1 around the air temperature presented in Table 7.

Table 7 – Air temperatures above which is exceed admissible value strain at subgrade level

Traffic class	Traffic volume Nc, m.o.s. (standard 115 kN axle)	Air temperature, °C
T1	1.1	29
	1.5	25
	1.8	23
	2	22
	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 bitumens with low temperature susceptibility, modified bitumens 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.

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