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Calculating the equivalent temperature for mechanistic pavement design according to the French method for Hungarian climatic conditions

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Abstract: The French pavement design method provides a very comprehensive, probability-based design approach. It also provides a fairly sophisticated method for establishing the equivalent pavement temperature, which has been used worldwide for different applications. The objective was to analyse the applicability of the French method for calculating the equivalent pavement temperature for Hungarian climatic conditions. It considers the thickness of the pavement structure and facilitate pavement temperature distribution. It was found that the French method provides a comprehensive approach and can facilitate variable climatic conditions and pavement temperature distribution while considering the thickness of the pavement structure. This provides fit for purpose solutions and eliminates the overly simplified approach to use a single equivalent pavement temperature for variable climatic and pavement conditions. Real pavement temperature data provided crucial input into the accuracy of the methodology. Asphalt modulus values and asphalt fatigue properties at different temperatures were estimated using an internationally well accepted method. The next focus item of this research work will be to refine the calculations based on asphalt modulus master-curves and fatigue data collected from laboratory testing at different temperatures.

Keywords: pavement design; climatic conditions; equivalent temperature

1. Introduction

Strains and deformations of any asphalt pavement is influenced by the distribution of the pavement temperature. Pavement engineers and researchers have been trying to describe the temperature dependency of a given pavement structure by an easily manageable index which provides an equivalent pavement temperature.

For both full depth asphalt pavements and concrete pavements, the environmental impact should be considered at the design phase, which has been proven as a very complex task. The international practice usually simplifies the complex environmental impact to two items, namely the temperature and precipitation [1] [2].

The temperature influences the properties and performance of the materials mixed with bituminous binders, while the precipitation and moisture have an impact on the unbound granular pavement layers. This impact should be considered at the time of the pavement design [3]; also, the impact on the mix design of hot mix asphalt [4]. and on the mix design of base layers treated with bitumen [5] should be carefully considered.

Due to limited access to real temperatures in the pavement structure in the past, it was also important to derive the in-depth temperature from air temperature readings. Capturing air temperature is relatively simple by established and widely used weather stations; measuring pavement temperatures is becoming less expensive, therefore access to such a dataset is becoming more common [6]. However, establishing such a weather station for pavement in-depth temperatures still remains difficult especially when the probes have to be placed under traffic into a road pavement in service.

In order to overcome the difficulties and minimise computing volumes, various methods have been developed since the early 1960s to use equivalent pavement temperatures [7]. This approach uses the core of the Miner’s hypothesis [8]; accordingly, the effective stress generated in a given pavement structure characterised by a single pavement temperature is equivalent to the cumulative stress generated in the same pavement structure under variable temperature conditions. The calculation can be performed according to Equation (1).

$$N_{eff} = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{N_i}\right)} \quad (1)$$

where

N_{eff} = the effective loading cycles at the effective single temperature applied for the design according to Miner's hypothesis,

N_i = the actual allowed loading cycles calculated on the basis of various temperatures,

n = the number of temperature brackets.

The French pavement design method provides a very comprehensive, probability-based design approach. It also provides a fairly sophisticated method for establishing the equivalent pavement temperature, which has been used worldwide for different applications [6] [9].

The objective of this paper is analysing the applicability of the French method for calculating the equivalent pavement temperature for Hungarian climatic conditions. The input data is the measured pavement temperature distribution for the region of Budapest. It is expected that this methodology would provide more accurate pavement design outcomes for different climatic conditions within Hungary. This way using the overly simplified average pavement temperature models would be discontinued and the new method would provide an optimised pavement structure for a given climatic condition.

2. The Equivalent (Design) Temperature in the French Pavement Design Method

Detailed calculation for the equivalent temperature is provided in Laboratoire Central des Ponts et Chausees [10]. The equivalent temperature is defined according to Equation (2), which is based on the Miner hypothesis.

$$\sum_{i=1}^{n} n_i \cdot d_i = 1 \qquad (2)$$

where

n_i = the number of equivalent axle passages undergone by the pavement,

d_i = the elementary damage.

The elementary damage is expressed in Equation (3).

$$d_i = \frac{1}{N_i} \qquad (3)$$

where

d_i = the elementary damage,

N_i = the number of loadings causing fatigue failure at a strain level $\varepsilon(\theta_i)$.

By combining Equations (2) and (3), Equation (4) follows:

$$\sum_{i=1}^{n} \frac{n_i}{N_i} = 1 \tag{4}$$

Pavement structural design is performed at a constant temperature, referred to as the equivalent temperature θ_{eq}. This temperature is such that the cumulative damage undergone by the pavement over a year, for a given temperature distribution, is equal to the damage that the pavement would undergo with the same traffic but for a constant temperature θ_{eq} [10]. The equivalent temperature is determined by Equation (5), which is the Miner hypothesis written in a different format (Equation (2)).

$$\sum_i \frac{n_i(\theta_i)}{N_i(\theta_i)} = \frac{\sum_i n_i(\theta_i)}{N(\theta_{eq})} \tag{5}$$

where

$N_i(\theta_i)$ = is the number of loadings causing failure due to fatigue for the strain level $\varepsilon(\theta_j)$,

$n_i(\theta_i)$ = is the number of equivalent axle passes undergone by the pavement at a temperature (θ_i),

$N(\theta_{eq})$ = is the number of loadings causing failure due to fatigue for the strain level $\varepsilon(\theta_{eq})$,

θ_{eq} is the equivalent temperature.

Equation (6) is derived from Equation (5) after re-organising the parameters.

$$\frac{1}{N(\theta_{eq})} = \frac{1}{\sum_i n_i(\theta_i)} \left[\sum_i n_i(\theta_i) \left\{\frac{1}{N_i(\theta_i)}\right\}\right] \tag{6}$$

Loading cycles $N_i(\theta_i)$ which cause failure can be deduced from the pavement response at a temperature $\varepsilon(\theta_i)$ and the laboratory test results $\varepsilon_6(\theta_i)$ according to Equation (7).

$$N_i(\theta_i) = \left\{\frac{\varepsilon(\theta_i)}{\varepsilon_6(\theta_i)}\right\}^{1/b} \cdot 10^6 \tag{7}$$

where

$\varepsilon(\theta_i)$ = pavement response at a given temperature,

$\varepsilon_6(\theta_i)$ = fatigue properties from laboratory test results.

The reciprocate of $N_i(\theta_i)$ as defined in Equation (7) equals, by definition, the elementary damage $d(\theta_i)$ at the strain level $\varepsilon(\theta_i)$ (Equation (8)).

$$\frac{1}{N_i(\theta_i)} = d(\theta_i) = \left\{\frac{\varepsilon_6(\theta_i)}{\varepsilon(\theta_i)}\right\}^{1/b} \cdot 10^{-6} \tag{8}$$

Equation (9) be derived by the combination of Equations (6) and (8).

$$\frac{1}{N(\theta_{eq})} = \frac{1}{\sum_i n_i(\theta_i)}\left[\sum_i n_i(\theta_i)\left\{\frac{\varepsilon_6(\theta_i)}{\varepsilon(\theta_i)}\right\}^{1/b} \cdot 10^{-6}\right] \tag{9}$$

The total elementary damage at different temperatures (right side of Equation (9)) is calculated; the equivalent temperature (design temperature) θ_{eq} is the temperature where the elementary damage for $\frac{1}{N(\theta_{eq})}$ equals to the total elementary damage at different temperatures [10] [11].

The value of $\varepsilon_6(\theta)$ can be obtained from laboratory testing or by using the correlation Equation (10) at 10^6 loading cycles (EN 12697-24–2012) [12].

$$\lg(N) = a + \left(\frac{1}{b}\right) \cdot \lg(\varepsilon) \tag{10}$$

where

N = number of load cycles,

a = constant,

b = slope of fatigue line,

ε = strain (microstrain).

Table 1 illustrates an example used for the calculation according to Laboratoire Central des Ponts et Chausées (1997) [10]. The temperature distribution, expressed in 5 °C intervals, and with the relative duration of the designated temperature is shown in the table.

Table 1. Example calculation of the equivalent temperature
Source: Laboratoire Central des Ponts et Chausees (1997) [10]

θ_i (°C)	–5	0	5	10	15	20	25	30
Duration (%)	10	12	18	14	18	18	8	2
ε_t ($\times 10^6$) – pavement response (microstrain)	24	27	32	40	51	68	98	149
$\varepsilon_6(\theta_i)$ ($\times 10^6$) – fatigue performance (microstrain)	95	95	94	92	96	100	110	121

The sum of the weighted elementary damage $d(\theta_i)$ is 0.15 in this example. The equivalent temperature is determined by interpolation, where the single elementary damage is equal to this value; this results in an equivalent pavement temperature of 18.7 °C in this example.

The above calculation for the equivalent pavement temperature is based on fundamental mechanics and considers real pavement structure responses and asphalt fatigue properties. The calculation requires detailed input on the pavement temperature distribution. When real and accurate data can be obtained for the pavement structure for a certain climatic environment, it could provide reliable input into the mechanistic pavement design as described in the rest of this paper.

3. Calculating the Equivalent Temperature for Hungary using the French Method

3.1. Data collection

The vertical temperature distribution of the pavement structure depends on weather conditions and the properties of the subgrade, subbase and upper pavement layers [13]. In order to capture the full extent of the variation, a weather station was established on a private road in Budapest. Sensors were established in a full depth asphalt pavement following completion of the roadworks. The device measured the temperature of the pavement at 0, 2, 7, 14, 29 and 49 cm at a frequency of every 10 minutes. The internal resolution of the temperature sensors were 0.0625 °C and the accuracy of the output was 0.1 °C. Over a period of one year this provided 52,560 data point for each depth, which is considered fairly detailed characterisation of a pavement structure [14].

3.2. Data input

The calculation of the equivalent temperature using the French method was carried out on for two full depth asphalt pavement structures with different thicknesses. One pavement structure was complying with the Hungarian pavement design catalogue [15] for loading class R (extremely heavy traffic) and the other one for loading class D (medium volume traffic). The individual layer thickness, the asphalt moduli and the total pavement thickness is summarised in Table 2. In these calculations it was considered that the subgrade has a consistent support of 50 MPa (surface modulus).

Table 2. Layer moduli for different pavement temperatures – input into the models

Asphalt layer type	***Thickness (mm)***		***Relative temperature distribution in the pavement structure (%)***							
	Traffic category		–5	0	5	10	15	20	25	30
	R	D	Modulus at the pavement temperature bracket (MPa)							
AC11 wearing (50/70) (heavy duty)	40	40	21,900	17,700	13,800	10,400	6,640	3,980	2,320	1,200
AC22 intermediate (35/50) (heavy duty)	80	80	24,000	19,700	15,900	12,500	9,160	5,790	3,520	2,070
AC22 base (50/70) (heavy duty)	190	90	22,700	18,500	14,600	11,000	7,230	4,460	2,670	1,440
Subgrade	N/A	N/A	50	50	50	50	50	50	50	50
Total pavement thickness (mm)	310	210								

The asphalt fatigue properties ($\varepsilon_{(6)}$) for the Hungarian asphalt pavement catalogue were established using the BANDS software. In these calculations the asphalt base layer fatigue performance was predicted at the equivalent temperatures of 10 °C and 10 Hz. It should be noted that since the catalogue was developed a number of modifications were suggested to these parameters; however, these modifications have not been implemented. Also, type testing of asphalt is carried out at significantly different test conditions. In order to remain consistent with the catalogue, for these calculations. The fatigue properties were established using the BANDS software (Shell) and this value returned 100 microstrain (10 °C, 10 Hz). This value was also converted to the various temperature brackets as outlined in Table 2. The BANDS software (Shell) was also used for establishing the various asphalt layer moduli; the properties in Table 3 were used for calculating the properties in Table 2.

Table 3. Layer moduli for different pavement temperatures – input into the models

Asphalt layer	***Bitumen volume of the asphalt mix (%)***	***Poisson's ratio***
AC11 wearing (50/70) (heavy duty)	12.8	0.35
AC22 intermediate (35/50) (heavy duty)	11.4	0.35
AC22 base (50/70) (heavy duty)	11.0	0.35

3.3. Asphalt Fatigue Properties at a Given Equivalent Temperature

Although in metropolitan France the equivalent temperature of 15 °C is used, Laboratoire Central des Ponts et Chausees [10] provides a general approach which can be utilised at any selected temperatures. This methodology can be used over a fairly broad range of positive temperatures, based on the calculation that the approximate value for the dependency of the modulus E and the strain ε_6 can be obtained from Equation (11).

$$\varepsilon_6(\theta) \times E(\theta)^n = constant \tag{11}$$

where

$\varepsilon_6(\theta)$ = fatigue resistance of the asphalt mix, determined at 10^6 loading cycles at the equivalent temperature θ,

$E(\theta)$ = stiffness of the asphalt material at the equivalent temperature θ,

n = material constant.

In the absence of results of fatigue tests for a given material at different temperatures, a mean value of 0.5 can be selected for n and the equation can be re-organised as in Equation (12).

$$\varepsilon_6(\theta_i) = \varepsilon_6(10°C; 10Hz) \times \sqrt{\frac{E(10°C;10Hz)}{E(\theta_i;10Hz)}} \tag{12}$$

Equation (12) provides a model and estimation of the fatigue properties at different temperatures. By using Equation (12), the fatigue properties at any given equivalent temperatures could be readily calculated, given that the standardised fatigue test and a temperature-frequency sweep for stiffness has been completed.

Bodin et al. [16] presented a series of fatigue tests at different temperatures, using two different asphalt materials, which provides validation of the above model. For another validation of the model, flexural fatigue tests were carried out on an Australian EME2 mix at 10, 20 and 30 °C and 10 Hz using four-point bending test. It was found that the fatigue properties at different temperatures can be reliably estimated for Australian test conditions by using Equation (11) with n=0.5. By using a value of n=0.5, Equation (11) can be reorganized as shown in Equation (12) [9].

For the analysis in this paper, it is assumed that the value of n=0.5 is valid for the Hungarian test conditions and Equation (12) is used. In this equation $E(\theta_i)$ is the modulus of the asphalt layer at the given temperature. This is summarised in Table 2; for a more accurate analysis these values need to be established in the laboratory through testing; however, for this paper, the estimated moduli values were used.

The method of calculation is summarised in Tables 4 and 5; the methodology is visualised in Figs. 1 and 2, respectively.

Table 4. Input into calculations for pavement model in the traffic loading category R

θ(°C)	–5	0	5	10	15	20	25	30
Temperature distribution (%)	1.3	12.5	16.2	11.3	9.1	18.7	16.2	14.7
E (θi; 10 Hz) (AC22 base)	22,700	18,500	14,600	11,000	7,230	4,460	2,670	1,440
ε(6), θ(i), n=0.5	70	77	87	100	12	157	203	276
ε(t) (×10⁻⁶) - pavement response	56.0	66.0	81.0	101.0	142.0	210.0	314.0	501.0
ε(6), θ(i) (×10⁻⁶) - fatigue performance	70	77	87	100	123	157	203	276
d (θ,i) (×10⁶) - elementary damage	0.337	0.459	0.708	1.051	2.022	4.275	8.860	19.571
d (θ,i) (×10⁶) - weighted elementary damage	0.004	0.057	0.115	0.119	0.184	0.800	1.433	2.885
d (θ,i) (×10⁶) – total	5.60							
d (θ,i) (×10⁶) – weighted elementary damage (cumulative)	0.004	0.062	0.176	0.295	0.479	1.280	2.712	5.597

Table 5. Input into calculations for pavement model in the traffic loading category D

θ (°C)	–5	0	5	10	15	20	25	30
Temperature distribution (%)	1.3	12.5	16.2	11.3	9.1	18.7	16.2	14.7
E (θi; 10 Hz) (AC22 base)	22,700	18,500	14,600	11,000	7,230	4,460	2,670	1,440
ε(6), θ(i), n=0.5	70	77	87	100	12	157	203	276
ε(t) (×10⁻⁶) - pavement response	56.0	66.0	81.0	101.0	142.0	210.0	314.0	501.0
d (θ,i) (×10⁶) - elementary damage	0.337	0.459	0.708	1.051	2.022	4.275	8.860	19.571
d (θ,i) (×10⁶) – weighted elementary damage	0.004	0.057	0.115	0.119	0.184	0.800	1.433	2.885
d (θ,i) (×10⁶) – total	5.60							
d (θ,i) (×10⁶) – weighted elementary damage (cumulative)	0.004	0.062	0.176	0.295	0.479	1.280	2.712	5.597

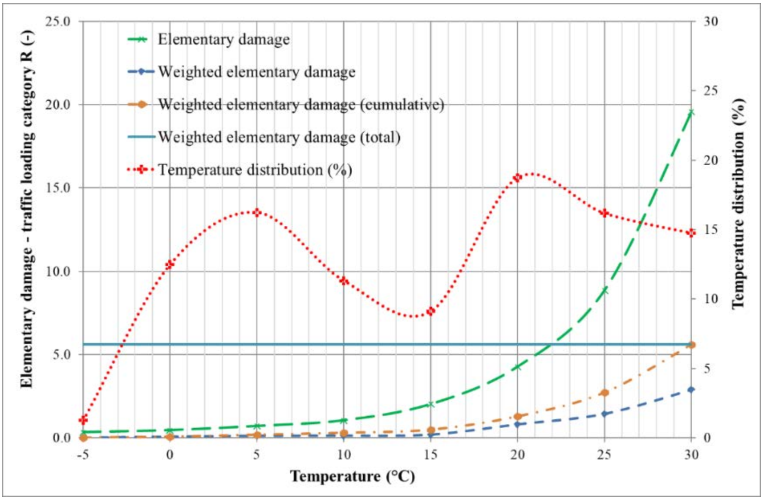

Figure 1. Establishing the equivalent temperature based on the calculation of elementary damage – traffic loading category R

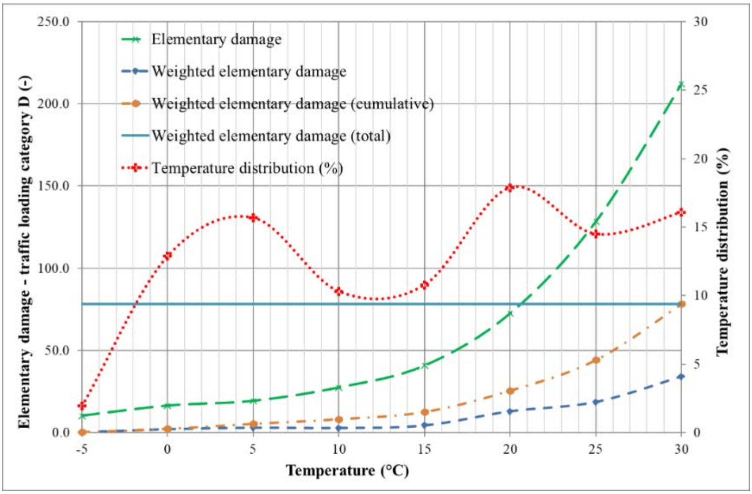

Figure 2. Establishing the equivalent temperature based on the calculation of elementary damage – traffic loading category D

The equivalent temperature (design temperature) θ_{eq} is the temperature where the elementary damage equals to the total elementary damage at different temperatures; this is calculated by interpolating the data set. For the pavement structure for traffic loading category R this value was calculated as 22 °C and for traffic loading category D this was 20.5 °C. By using the average monthly air temperature values the weighted mean annual pavement temperature (wMAPT) was calculated with the SPDM 3.0. software [17] as 17.7 °C.

4. Summary of the Calculations and Practical Application of the Methodology

The current Hungarian pavement design catalogue [15] was developed by Nemesdy et al. in 1992 [18]. Nemesdy et al. utilised the BANDS nomographs for the asphalt types used in the 1990s; the methodology described in this paper utilised the same approach, i.e. using the BANDS nomographs; however, supported by a computer software. Since the asphalt compositions significantly changed since the 1990s, in this work the asphalt moduli were determined based on the combined aggregate grading, bitumen content and air voids contents as outlined in the current Hungarian asphalt specification [19].

The calculations were conducted at 5°C intervals between –5 and +30 °C; the calculated bitumen and the asphalt moduli values are summarised in Table 6. Unmodified binders were selected for this analysis that the BANDS nomographs can be used. While 35/50 binder is not commonly used in Hungary, this was selected in line with best practice that intermediate layers should have a higher rutting resistance.

Table 6. Bitumen and asphalt moduli of the various asphalt types as a function of temperature

Temperature (°C)	***AC11 wearing (heavy duty)***		***AC22 intermediate (heavy duty)***		***AC22 base (heavy duty)***	
Binder type	50/70		35/50		50/70	
	S_{binder} (MPa)	$E_{asphalt}$ (MPa)	S_{binder} (MPa)	$E_{asphalt}$ (MPa)	S_{binder} (MPa)	$E_{asphalt}$ (MPa)
–5	604	21,900	700	24,000	604	22,700
0	387	17,700	455	19,700	387	18,500
5	229	13,800	286	15,900	229	14,600
10	124	10,400	169	12,500	124	11,000
15	60.7	6,640	90.1	9,160	60.7	7,230
20	28.8	3,980	44.9	5,790	28.8	4,460
25	13.1	2,320	21.1	3,520	13.1	2,670
30	5.05	1,200	9.37	2,070	5.05	1,440

Based on the above calculations the results were different for the two different traffic loading categories of R and D, resulting in equivalent temperature values of 22 °C and 20.5 °C respectively; for practical considerations it is recommended using 20 °C as a starting point for the new Hungarian pavement design methodology. At this temperature the asphalt moduli and parameters are summarised in Table 7, where the values are rounded to the nearest 100 MPa for practical reasons.

Table 7. Suggested asphalt moduli and parameters for pavement structural design

Asphalt layer	***Asphalt moduli at equivalent temperature of 20°C (MPa)***	***Bitumen volume of the asphalt mix (%)***	***Poisson's ration***
AC11 wearing (50/70) (heavy duty)	4,000	12.8	0.35
AC22 intermediate (35/50) (heavy duty)	5,800	11.4	0.35
AC22 base (50/70) (heavy duty)	4,500	11.0	0.35

The above described methodology can be refined and updated based on long-term temperature measurement in different Hungarian regions. Considering the differences in different climatic regions within the country, the pavement structure may be further optimised and refined. This way the pavement structures in the different climatic regions would be designed based on real data and not on average values established for the entire country.

The above methodology provided the basis for a fundamental research work. As a result, a new mechanistic pavement design approach was developed for Hungary, which also considers the realistic bearing capacity of the locally available subgrade and base layers. This provided an avenue to further optimise pavement structures in a holistic way, with considering the local climatic conditions and local material availability. It also provides pathways for new and innovative technologies by incorporating the mechanistic properties of newly developed potential materials and technologies. The research work, methodology and outcomes are described in details by Primusz and Toth [20], where the material parameters described in Table 7 were applied for the calculations.

5. Summary and conclusions

The French pavement design method provides a very comprehensive, probability-based design approach. It also provides a fairly sophisticated method for establishing the equivalent pavement temperature, which has been used worldwide for different applications. The objective of this paper was analysing the applicability of the French method for calculating the equivalent pavement temperature for Hungarian climatic conditions. It was found that the French method provides a comprehensive approach and can facilitate variable climatic conditions and pavement temperature distribution while considering the thickness of the pavement structure. This provides fit for purpose solutions and eliminates the overly simplified approach to use a single equivalent pavement temperature for variable climatic and pavement conditions.

Real pavement temperature data provided crucial input into the accuracy of the methodology. Asphalt modulus values and asphalt fatigue properties at different temperatures were estimated using an internationally well accepted method. The next focus item of this research work will be to refine the calculations based on asphalt modulus master-curves and fatigue data collected from laboratory testing at different temperatures.

References

[1] P. Pereira, J. Pais, Main flexible pavement and mix design methods in Europe and challenges for the development of an European method. *Journal of Traffic and Transportation Engineering (English Edition)* 4 (4) (2017) pp. 316–346.
doi: *https://doi.org/10.1016/j.jtte.2017.06.001*

[2] X. Gao, Y. Wei, W. Huang, Strain-based equivalent temperature gradient in concrete pavement and comparison with other quantification methods, *Road Materials and Pavement Design* 18 (6) (2017) pp. 1460–1472.
doi: *10.1080/14680629.2016.1218788*

[3] R. Ktari, F. Hammoum et al., Consideration of Seasonal Temperature Changes in the French Pavement Design Method. In P. Kotronis (Ed.), Risk Evaluation and Climate Change Adaptation of Civil Engineering Infrastructures and Buildings, *ISTE Ltd and John Wiley & Sons, Inc.*, London, 2019, pp. 1–55.
doi: *https://doi.org/10.1002/9781119671428.ch1*

[4] A. Saleh, L. Gáspár: Advantages and limitations of using foamed bitumen. *Acta Technica Jaurinensis* (2021).
doi: *https://doi.org/10.14513/actatechjaur.00587*

[5] A. Saleh, L. Gáspár: Functional and environmental impacts of the use of reclaimed asphalt pavement materials and of foamed asphalt. *Acta Technica Jaurinensis* (2021).
doi: *https://doi.org/10.14513/actatechjaur.00590*

[6] M. Pszczola, J. Judycki, Equivalent temperature for design of airport pavements using mechanistic-empirical methods, May 2014.

[7] L. Petho, Influence of temperature distribution on the design of pavement structures. *Periodica Polytechnica Civil Engineering* 52 (1) (2008) pp 45–53. doi: *https://doi.org/10.3311/pp.ci.2008-1.07*

[8] M.A. Miner, Cummulative Damage in Fatigue. *The American Society of Mechanical Engineers* 67 (1945) pp. 159–164.

[9] L. Petho, P. Bryant, P, EME2 fatigue properties and pavement design in a sub-tropical climate. *8th RILEM international conference on mechanisms of cracking and debonding in pavements*, Springer, Nantes, 2016, pp. 431-436.

[10] Laboratoire Central des Ponts et Chaussées (LCPC) 1997, French design manual for pavement structures, LCPC, Paris, France.

[11] Road pavement structural design – Application to new pavements, NF P 98-086–2011 (2011) (in French).

[12] Bituminous mixtures: test methods for hot mix asphalt: part 24: resistance to fatigue, EN 12697-24:2012 (2012).

[13] W. Arand, H. Lorenzl, influence of bitumen hardness on the emergency behavior of asphalt paving of different thickness depending on the capacity of the surface, the traffic load and the temperature; part 2 (original title: Einfluß der Bitumenhärte auf das Ermüdungsverhalten von Asphaltbefestigungen unterschiedlicher Dicke in Abhängigkeit von der Tragfähigkeit der Unterlage der Verkehrsbelastung und der Temperatur). *Forschung Straßenbau und Straßenverkehrstechnik* 696 (1995) pp. 1–40 (in German). URL *https://trid.trb.org/view/996178*

[14] I. Fi, L. Petho, Calculation of the equivalent temperature of pavement structures, *Periodica Polytechnica Civil Engineering*, 52 (2) (2008) pp. 91–96. doi: *https://doi.org/10.3311/pp.ci.2008-2.05*

[15] Designing and strengthening of asphalt pavements, e-UT e-UT06.03.13 (ÚT 2-1.202:2005 (2005) (in Hungarian).

[16] D. Bodin, J. Terrier et al., Effect of temperature on fatigue performances of asphalt mixes. *11th International conference on asphalt pavements*, ISAP, USA, Nagoya, 2010.

[17] C.P. Valkering, The Shell Pavement Design Method on a Personal Computer, *Proceedings of the 7th International Conference on the Structural Design of Asphalt Pavements* (1992) pp. 351–374.

[18] E. Nemesdy, Background of the mechanistic approach of new Hungarian pavement design catalogue (original title: Az új magyar tipus pályaszerkezetek mechanikai méretezésének háttere). *Mélyépitési Szemle* 42 (8) (1992) pp. 293–306 (in Hungarian).

[19] Requirements for Asphalt Pavement Mixtures of Road Structures, ÚT 2-3.301-1-2010 (2010) (in Hungarian).

[20] C. Toth, P. Primusz, New Hungarian Mechanistic-Empirical Design Procedure for Asphalt Pavements. *Baltic Journal of Road and Bridge Engineering* 15 (1) (2020) pp. 161–186.
doi: *https://doi.org/10.7250/bjrbe.2020-15.466*