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The implication of climatic changes to asphalt pavement design

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Abstract

The climatic characteristics in Slovakia are defined by the average daily air temperature and the average annual temperature and the frost index (during winter period). These are relevant input data for dimensioning of road construction (design and analysis based on thermal resistance). The research activities carried out by the authors brought the objectified correlation dependence of frost index values from the above sea level altitude. These results were objectified from measuring during period from 1971 to 2010. The results showed the differences between frost indexes from long-term monitoring and frost indexes determined according to STN 73 6114 Pavement of Roads Basic Provision for structural design. The using of the objectified correlation dependence of frost index is precondition for creating successful objectification of spending money to build roads, which are among the financially demanding civil engineering.

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Keywords: Climatic characteristics; Frost index; Thermal resistance; Asphalt pavement.

1. The asphalt pavement design in Slovak Republic

Along with traffic load, climatic conditions are amongst the constant external factors adversely affecting the physical and mechanical properties of asphalt pavements. First amongst the climatic factors detrimental to pavement and earth pavement construction layers is a frost. Frost is destructive of the structural system, particularly in conjunction with water. Prolonged exposure to cold causes frost penetration, with subsequent damage to civil engineering works.

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The effects of frost can be conditioned by the intensity of freezing, its duration, and the effect of very low temperatures and the alternation of temperatures below and above zero during the winter period. High summer temperatures also have a significant adverse impact on pavements. At higher temperatures, the strength and deformation characteristics of asphalt layers decrease, leading to increased stress. Similarly, high temperatures adversely affect concrete pavements.

For the purposes of traffic engineering, climate is usually described by the following characteristics:

- average annual temperature T_m
- number of snow, ice and frost days
- amount and intensity of rainfall
- freezing index I_m.

Most of these characteristics are obtained by evaluating the measurements of air temperatures. According to international conventions, temperature is measured at 2m above ground and at 7, 14 and 21 hours during the day. For the purposes of the Slovak Republic these measurements are regularly conducted by the Slovak Hydro-meteorological Institute in Bratislava. The impact of climatic conditions on asphalt roads is researched at the Žilina University in the long-term [1] to [4].

Also the quality of materials and the quality of production decide about the long-term performance, durability and serviceability of asphalt pavements [5].

2. Climate characteristics

Out of the climatic characteristics, the design of road pavement constructions is directly affected by the average annual air temperature T_m and the freezing index I_m. Air temperature varies depending on several factors. The intensity of solar radiation is decisive. Air temperature is characterized by cyclical changes during the day and throughout the year, with maximum and minimum temperatures – fig.1.

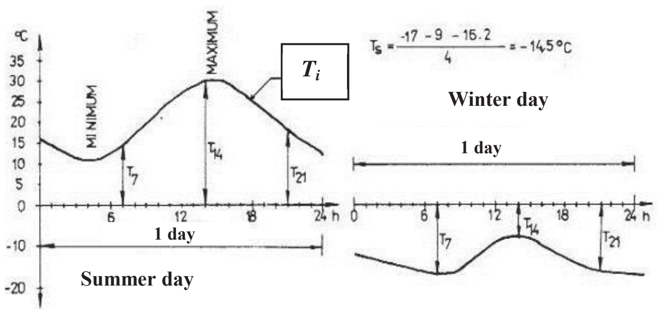

Fig.1. Course of temperature during the summer and winter day.

For practical purposes, the flow of daily temperature is expressed by the ***average daily temperature***, calculated as:

$$T_S = (T_7 + T_{14} + 2.T_{21})/4 \tag{1}$$

where index 7, 14 and 21 is the time at which air temperature T is measured. The temperature of pavement structures changes along with the change of air temperature. Examples of specific changes in asphalt pavement construction layers and subsoil are presented in fig.2.

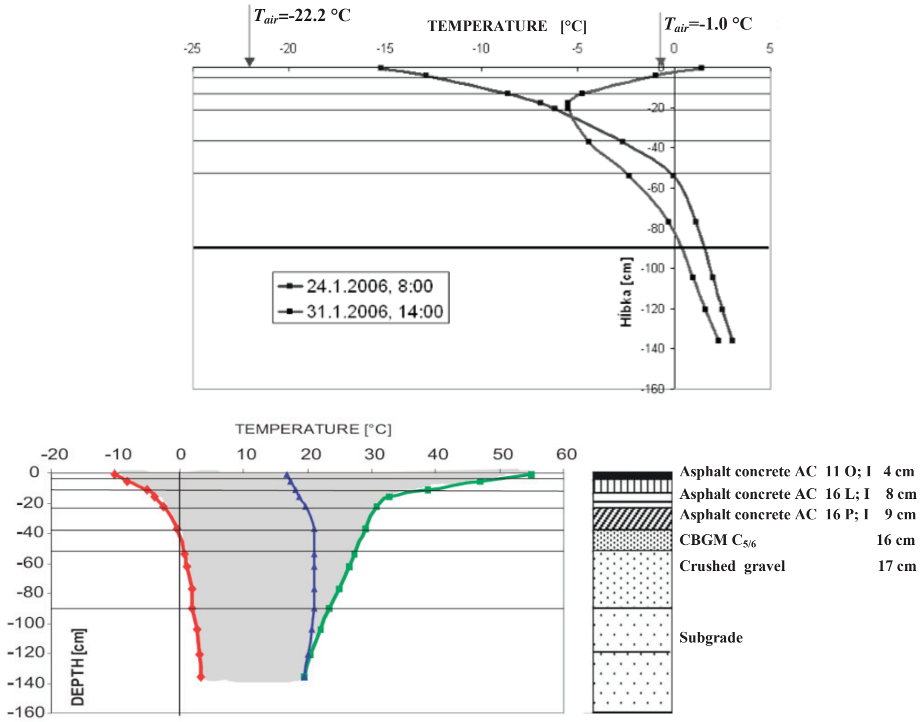

Fig. 2. The course of temperature variation in the pavement at The Experimental Centre for Research of Pavement Mechanics (EC RPM) of the Department of Highway Engineering SvF ŽU.

Average annual air temperature T_m is expressed by the following formula:

$$T_m = \sum_{i=1}^{365} T_{s,i} \, / \, 365 \tag{2}$$

Air temperature has a cyclical character repeated in daily and annual cycles, approximately of sinusoidal shape. Graphical presentation of air temperatures over the annual cycle is shown in fig.3.

3. Climatic characteristics used in road pavement design

Out of the climatic characteristics, the design of road pavement constructions is directly affected by the average annual air temperature T_m and the freezing index I_m.

Air temperature varies depending on several factors. The intensity of solar radiation is decisive. Air temperature is characterized by cyclical changes during the day and throughout the year, with maximum and minimum temperatures.

Frost index I_m [°C, day] is determined as the sum of absolute values of consecutive negative average daily temperatures in winter. Frost index for Slovakia in the design of roads frequently used by climate characteristic. In experimental measurements of air temperature freezing index is set by adding the negative of the average daily air temperatures T_s in winter by the following relationship:

$$I_m = \left| \sum_{t_z}^{t_k} T_s \right| \qquad (3)$$

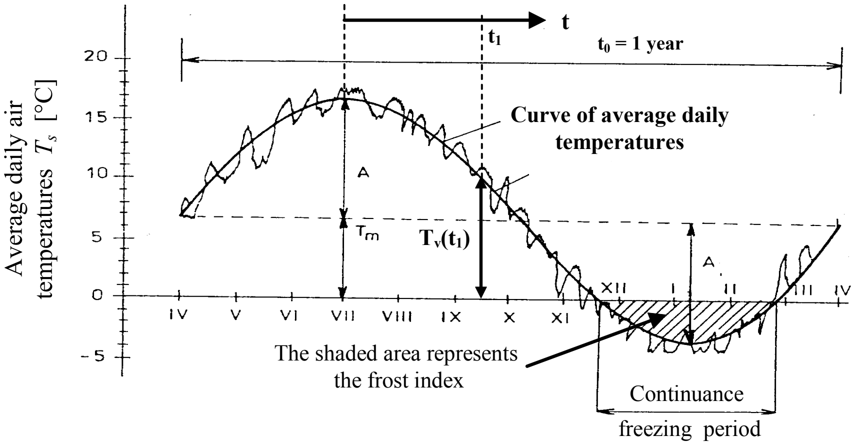

Fig. 3. Schematic presentation of air temperature characteristics, the shaded area represents Frost index I_m.

4. The road pavement construction design

For the area of pavement construction design and evaluation the following Slovak basic standards and regulations are used:

- STN 73 6114 Pavement of roads. General provisions for design, 1997 [6],
- STN 73 6133 Road Building. Roads embankments and subgrades (in Slovak), 2010 [7],
- TP 3/2009 The design of flexible and semi-rigid pavements, MDPaT SR, 2009 [8],
- KLAZ 1/2010 Catalogue of asphalt mixtures. MDPaT SR, 2010 [9].

One of the criteria used in pavement design and evaluation is *Assessment of pavement protection against frost heave effect*. Road design according to [6] and [8] conforms when the heat resistance of structure R_V [$m^2.K.W^{-1}$] is equal to or greater than the required thermal resistance of $R_{V,p}$ [$m^2.K.W^{-1}$] determined by the requirement not to allow more freezing earth in the subsoil as permitted. The condition is expressed by the formula:

$$R_V \geq R_{V,p} \qquad (4)$$

Thermal resistance of the pavement R_V is calculated from the equation:

$$R_{v,sk} = \sum_{i=1}^{n} \frac{h_i}{\lambda_i} \qquad (5)$$

where: h_i thickness of layer and road structure [m],
λ_i calculated value of the coefficient of thermal conductivity of material layers [$W.m^{-1}.K^{-1}$].

The required thermal resistance of the road structure in cases with mild frost heave, normal frost heave and dangerous frost heave of the subsoil is given by the equation:

$$R_{V,p} = 0{,}102 \cdot I_{m,n}^{0,3} - \frac{h_{z,dov}}{\lambda_z} \qquad (6)$$

where: $I_{m,n}$ design value of the index at zero frequency for construction n [°C],

$h_{z,dov}$ allowed freezing soil thickness in the subsoil [m],
λ_z thermal soil coefficient [$W.m^{-1}.K^{-1}$].

For the soil coefficient of thermal conductivity material λ_o=1,75 $W.m^{-1}.K^{-1}$ the relation (6) is presented:

$$R_{v,potr} = \frac{0{,}178 \cdot I_{m,n}^{0,3}}{\lambda_o} - \frac{h_{z,dov}}{\lambda_z} \qquad (7)$$

5. Dependence of frost indexes from height above sea-level

The research activities carried out by the authors were statistically evaluated by the average daily temperature of 9 Slovak meteorological stations covering most of SR. In [3] and [4] there were presented correlation dependence of frost indexes from the height above Sea-Level of meteorological stations in Slovakia during the period from 1971 to 2000.

Based on the logical premise of the frost index depending on the height above Sea-Level (HSL) the objectified correlative dependences of the frost index values on HSL from the periodicity n were modified for the period from 1971 to 2011 and shown on fig.4.

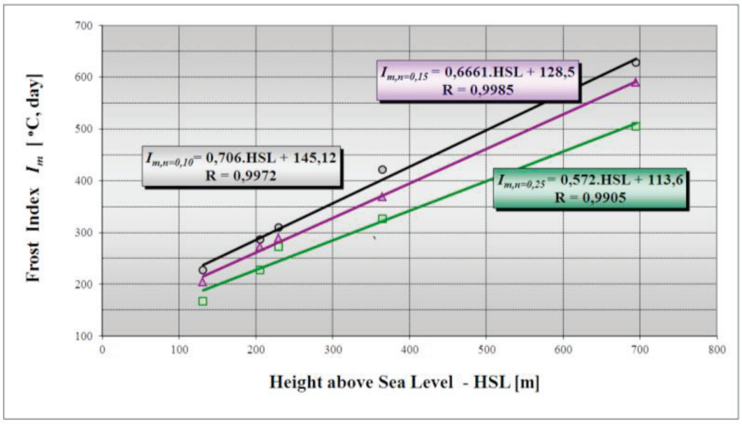

Fig.4. The frost index dependence on the height above Sea-Level for the periodicity n=0,10 according to [6].

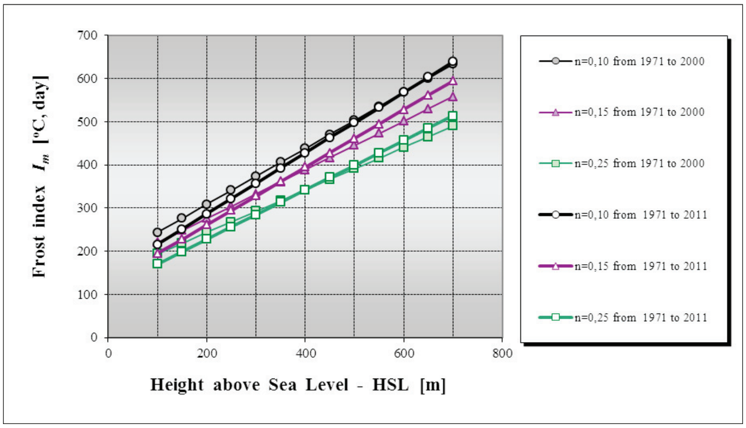

Fig.5. Correlation dependence of the frost index from height above Sea-Level for the period from 1971 to 2000 [2] and the period from 1971 to 2011.

The TP 3/2009 states that the design frost index value is taken according to STN 73 6114 for different periodicity n depending on the class of the road load (TDZ) for TDZ I and II n=0,10; for TDZ III and IV n=0,15 and for TDZ V and VI n=0,25. For periodicity n = 0,10 and the period from 1971 to 2011 was found following equation:

$$I_{m,n=0,10} = 0{,}706 \cdot HSL + 145{,}1 \quad (8)$$

The compare of the objectified correlation dependence of frost indexes from the height above Sea-Level (from statistically evaluated the average daily temperatures of Slovak meteorological stations) in a period from 1971 to 2000 and a period from 1971 to 2011 is shown on fig.5.

6. Conclusion

The climatic characteristics (in Slovakia) are defined by the average daily air temperature and the average annual temperature and the frost index (during winter period). These are relevant input data for dimensioning of road construction (design and analysis based on thermal resistance) and its precise determination is very important.

The importance of observed correlation dependences is illustrated in the case of design of asphalt pavement section D1 Jánovce–Jablonov. The maximum alignment of D1 Jánovce –Jablonov is 600 m above sea-level, making these values correspond to frost indexes:

- $I_{m,n=0,10}$ = 700 °C, determine the frost index according to STN 736114,
- $I_{m,n=0,10}$ = 570 °C, determine the frost index according to relation (8).

For such values of frost indexes, allowed freezing depth $h_{z,dov}$=0,6 m and the coefficient of thermal conductivity material of subgrade improving layer λ_z = 2,0 W.m^{-1}.K^{-1}, in order to protect against adverse effects of frost was necessary to propose the construction of asphalt pavement according to tab. 4. Optimized design of asphalt pavement construction from aspect of meeting this criterion was carried out according to the relation 4-7 and allowed freezing values of subgrade according TP 3/2009 [8]. The total thickness of asphalt pavement designed using the objectified correlative dependences of the frost index values on the height above Sea-Level (period from 1971 to 2011) is 9 cm less.

Tab. 4 Optimized design of asphalt pavement section D1 Jánovce –Jablonov.

Construction layer	**Designation by**	**relation (8)**		**STN 73 6114**	
	KLAZ 1/2010	**[cm]**	**λ [W.m^{-1}.K^{-1}]**	**[cm]**	**λ [W.m^{-1}.K^{-1}]**
Stone mastics asphalt, 11	SMA 11	4	1,5	4	1,5
Asphalt concrete 16	AC 16 L; I	6	1,4	6	1,4
Asphalt concrete 22	AC 22 P; I	9	1,15	9	1,15
Cement stabilization	CBGM $C_{5/6}$	18	1,75	18	1,75
Crushed gravel	ŠD	27	2,0	36	2,0
Total road thickness		**64**		**73**	
Thermal resistance of pavement [m^2.K.W^{-1}], actual ≥ required		***0,386 > 0,383***		***0,431 > 0,426***	

As presented above the design of roads is carried out according to objectively identified results of research. From the foregoing it can be concluded that the presented results of research are possible for the conditions of SR almost immediately used in the design of roads and particularly for road structures.

We also can anticipate that the correlation dependence is precondition for creating successful objectification of spending money to build roads, which are among the financially demanding civil engineering.

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