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THE IMPLICATIONS OF CLIMATE CHANGE CONDITIONS IN THE PAVEMENT DESIGN

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Abstract

The design of pavement structure is as a set of several activities related to the design of road construction, dimension and model calculations. This includes calculations of load effects, taking into account the properties of the materials, the subgrade conditions, and the climatic conditions. The measurements of climatic conditions in Slovakia were the basis for assessing changes in average daily air temperatures in individual seasons. Since the 19^{th} century we have seen in Slovakia an increase in the average air temperature of 1.5 ° C. Currently, there are scenarios of climate change until 2100. An increase in air temperature is assumed, with an increase in average monthly temperatures of 2.0 to 4.8 °C. In road construction, as well as in other areas of engineering, we must respond to current climate change and also to expected changes. The average annual air temperature and the frost index are the critical climatic characteristics are the main for the design (input parameter) and evaluation of pavement. From the practical side it is possible to use the design maps of average annual air temperature and frost index according to STN 73 6114 from year 1997. In cooperation with the Slovak Hydrometeorological Institute from the long-term monitoring of temperatures, different meteorological characteristics were measured in the current period. From the measurements of twelve professional meteorological stations for the period 1971 to 2020, the dependence between two variables in probability theory is derived. The average annual air temperatures used for prognoses are collected from long-term measurements (fifty years). The design of road constructions and calculations of road construction models, which are in the system design solution (comparative calculations of asphalt pavement- and cement-concrete pavement models), we have also tested road construction materials - especially asphalt mixtures. The results were used to correct the values of input data, design criteria, as well as measures to reduce the impact of changes in climate conditions.

Keywords: climate change, pavement design, cc slab, asphalt mixtures

1 Climate change in Slovakia

Analyses, which it is can point out that since the 19^{th} century we have seen in Slovakia the average air temperature increase by 1.5 °C, regime changes and total atmospheric precipitation. Since 1988, climate change has begun to emerge more rapidly, has been globally registered since 1985. After 1987, only one year had the average air temperature below the long-term average, otherwise, the average temperature was higher. Air temperature will continue to rise and by 2075 we can expect an increase in average monthly temperatures of 2.0 to 4.8 °C - in the cold half-year of about 1.8 °C, in the warm half of the year up to 3.8 °C.

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The data sources for the assessment of climatic conditions in Slovakia are the measurements of the Slovak Hydrometeorological Institute. Major experts use them and analyse the conditions for the needs of different sectors (industry, agriculture, energy, etc.). The total increase in the average summer temperature can also be observed on the basis of a comparison of temperatures in the period 1961-2019 (Fig. 1) [8]. For example, for the Bratislava locality, the average annual temperature increased to 12.6 °C in 2019 and the deviation from the normal for the period 1981-2010 reaches 2.0 °C and for the normal period 1961-1990 reaches 2.8 °C.

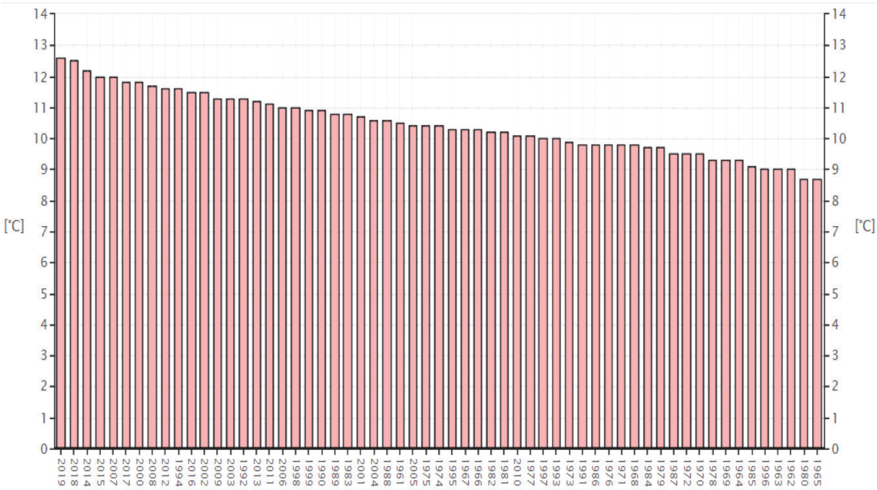

Figure 1 The average annual air temperature in the years 1961-2019 in Bratislava

The changes to the conditions are that road construction has to respond to these changes, not only with adaptation measures. The need for highway and motorway design measures, designing pavement structure, and selection of road building materials and technological processes highlights the increasing number of asphalt pavements failures and defects (track deviations), defects of CC pavements (slab shifts and faults on joints) [1].
With designing and dimensioning of pavement constructions, it is necessary to address the partial problems of improving the properties of road building materials, in particular, asphalt mixtures, the correction of the values of the input data into the calculations as well as the criteria for assessing the design of flexible pavements and rigid pavements.

2 Climatic conditions in the pavement design method

In road construction, a number of building materials are used in pavements structures whose strength and deformation properties are temperature dependent. These properties are very important as input data in analytical design methods and therefore have been the subject of measurement and evaluation. For some parts of Slovakia, were recorded up to 200 - annual series of air temperature measurements. Data are available from the expanded number of meteorological stations of 100 – annual observation period. In earlier data, it is reported that winter (average air temperature 0 ° C) lasts about 2 months and summer 132 days, with a hot summer with average daily air temperatures of more than 20 ° C (only) 49 days [5]. Very valuable are data on the daily air temperature between 1901 and 1950 at various locations in the area, [3]. The temperature regime of the waveforms under different conditions of observation (its characteristics were measured) with different altitudes. Asphalt pavements and pavements with a CC cover were built at the measuring stations.

2.1 Design of asphalt pavements

As an important characteristic of the asphalt pavement temperature regime, we considered the equivalent daily temperature of the layers (not average temperature for the season of the year), when five-sixths of the traffic load is carried by the road. The designed values of the equivalent temperature of asphalt layers and the annual dimensional periods are in Table 1. [6]. The measurements and the data on the annual course of air temperature, surface, and asphalt pavement layers were derived and designed important characteristics for asphalt pavement calculations and design. There are division of the year into three periods, average temperatures of the entire thickness of the asphalt layers, equivalent (calculation) temperatures of the entire thickness of asphalt layers.

Table 1 Dimensional periods of asphalt pavement

Season of the year	Number of days	The proportion of the year	Equivalent temperature
spring, autumn	186	0.5	11 °C
summer	104	0.3	27 °C
winter	75	0.2	0 °C

Surface temperatures and individual asphalt pavements layers are dependent on air temperature. For the average and maximum values, the general equation applies

$$T_{m,asf} = k \cdot T_{m,r} + C \ [°C] \quad (1)$$

where
$T_{m,r}$ - is average annual air temperature,
C - is a constant, altitude function.

A comparison of average temperatures of asphalt layers in changed climatic conditions in Slovakia´s localities is in Table 2.

Table 2 Average temperatures of asphalt layers

Locality	Tm,r (STN 73 6114)	Tm,r (1998 - 2020)
	Tm,asf	Tm,asf
Bratislava	33,74	35,72
Žilina	30,04	32,28
B. Bystrica	30,04	32,81
Poprad	28,46	30,04
Košice	31,36	34,00

2.2 Design of cement concrete pavements

The climatic conditions of the cement concrete (CC) pavements are characterized by the average annual temperature of CC slabs and amplitude of this temperature in the annual cycle, the average and highest values of positive and negative temperature differences between the top and bottom surface of CC slab.

These characteristics of temperature regime are important for stress and strain calculations of CC slabs. They were derived from measurements on constructions in terrain, from the sum of temperature ranges for 97 % of cases. The average annual temperature of slabs is considered as the annual average of daily air temperatures. The amplitude of the annual air temperature is calculated according to

$$A_{r,h} = T_{m,r} + 36{,}9 - 0{,}038\ h_B\ [°C] \tag{2}$$

where
$T_{m,r}$ - is average annual air temperature (°C),
h_B - is thickness of the CC slab (mm).

The design (calculation) values of the temperature differences of the top and bottom surfaces of the CC slabs are calculated from the relationship to the average annual air temperature, considering the thickness of the slab. Empirically derived formulas have the form:

- for positive temperature difference:

$$+\Delta T_n = 12{,}440 - 0{,}6\ T_{m,r} + 0{,}028\ h_B\ [°C] \tag{3}$$

- for negative temperature difference:

$$-\Delta T_n = 6{,}214 - 0{,}3\ T_{m,r} + 0{,}0113\ h_B\ [°C] \tag{4}$$

A comparison of the temperature regime of CC slabs in changed climatic conditions in Slovakia´s localities is in Table 3.

Table 3 Temperatures regime of CC slabs

Lokality	$T_{m,r}$ (STN 73 6114)								
	hb = 220 (mm)			hb = 250 (mm)			hb = 300 (mm)		
	$A_{r,h}$	$+\Delta T_h$	$-\Delta T_h$	$A_{r,h}$	$+\Delta T_h$	$-\Delta T_h$	$A_{r,h}$	$+\Delta T_h$	$-\Delta T_h$
Bratislava	38,34	12,72	5,76	37,20	13,56	6,10	35,30	14,96	6,66
Žilina	35,54	14,4	6,60	34,4	15,24	6,94	32,5	16,64	7,50
B. Bystrica	35,54	14,4	6,60	34,4	15,24	6,94	32,5	16,64	7,50
Poprad	34,34	15,12	6,96	33,2	15,96	7,30	31,3	17,36	7,86
Košice	36,54	13,8	6,30	35,4	14,64	6,64	33,5	16,04	7,20
	$T_{m,r}$ (1998 - 2017)								
	hb = 220 (mm)			hb = 250 (mm)			hb = 300 (mm)		
	$A_{r,h}$	$+\Delta T_h$	$-\Delta T_h$	$A_{r,h}$	$+\Delta T_h$	$-\Delta T_h$	$A_{r,h}$	$+\Delta T_h$	$-\Delta T_h$
Bratislava	39,84	11,82	5,31	38,7	12,66	5,65	36,8	14,06	6,21
Žilina	37,24	13,38	6,09	36,10	14,22	6,43	34,20	15,62	6,99
B. Bystrica	37,64	13,14	5,97	36,5	13,98	6,31	34,6	15,38	6,87
Poprad	35,54	14,4	6,60	34,4	15,24	6,94	32,5	16,64	7,50
Košice	38,54	12,6	5,7	37,4	13,44	6,04	35,5	14,84	6,6

An important characteristic of the temperature regime of the CC covers is the temperature difference between the top and bottom surfaces of CC slabs. It is most often the temperature gradient, this is - by changing the temperature to the unit thickness of the slab °C/mm, or simply a difference in the temperature of the top and bottom surfaces. The temperature difference is usually positive during the day, negative during the night. The temperature gradient in the CC slab causes deformation, at a positive temperature gradient, the slab has a convex shape. Depending on the thickness of the slab, its dimensions (width and length) and friction on the contact of the slab and the subbase, this can lead to stresses as large as those caused by the vehicle loading [2].

3 Conclusion

After 1985, climate change began to manifest strongly, in the territory of Slovakia too. The growth of the mean annual air temperature was greater than 1.5 ° C. According to climate change scenarios in the next period (until 2100), the increase in average monthly air temperatures may be higher, e.g. in the cold half of the year about 1.8 ° C, in the warm half of the year up to 3.8 ° C

In system solution procedure for design, calculations, and assessment of flexible asphalt pavements and rigid cement concrete pavements, climatic conditions are considered. But expected climatic changes have raised demands for solutions and related issues.

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