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QUALITY OF ROAD INFRASTRUCTURE

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ABSTRACT

Climate conditions and their impact on road design and construction. The concept of solution of problems related to changes of climate conditions and their impact on road design and construction comprises a scenario of changes in climate conditions, an analysis of the temperature regime in pavement structures, results of research of partial problems, and recommendations for road pavement design and construction.

Changes in climate conditions that recently manifested themselves in the territory of Slovakia through increased average air temperatures, the often surpassing of temperature records and more frequent intensive rains have led to a review of the requirements for characteristics of road construction materials, to a need to revise the procedure and criteria for pavement design, and to the preparation of basic data and documents for the amendment of technical and technological standards.

1. GENERAL

The suitability of approaches in road construction projects, the selection of materials and technological procedures, as well as procedures of maintenance on the road network, is continuously verified in practice. One of the basic criteria of technical correctness is the resistance against climate impacts of the environment (within a certain territory). In the case of a very simplified description of climate conditions and only considering the temperature conditions and precipitation amount, their impact is taken into account:

– in roads projects through the longitudinal and cross slope of the formation level, cross-section layout, minimum or maximum slope of ditches, adaptation of ditch bottom, and inclination and trimming of bottom slopes;
– in the selection of materials for construction of pavement courses (resistant against permanent deformations) and in protection of road pavement against freezing effects;
– in the selection of technological procedures, especially for earthworks and roadbed construction (e.g. with protection of formation level, course filling and compacting),
– in the design of all parts of the drainage system.

Several requirements are formulated in the technical standards for road construction, technical conditions and regulations. Fast-changing conditions require accelerated amendments of standards and different regulations (if solutions are known), as well as operational decisions on procedures in practice.

The conception of solving problems related to the change of climate conditions comprises a scenario of changes in climate conditions, an analysis of the present state of road projects, and a number of partial research problems. Measurements and supplementary measurements of different characteristics are almost always required.

2. TEMPERATURE REGIME OF ROAD PAVEMENTS AND ITS CHARACTERISTICS

The temperature regime of road pavements and their subgrade is best described by road surface temperatures, the temperatures of the individual layers and of the subgrade, and the temperature gradient in the structure of the pavement (Gschwendt, 1999). Average annual values of these characteristics, as well as extreme and so-called design values, are applicable in practice. Design characteristics are obtained from the statistically processed data of so-called long-term measurements – min. 25 years. Measurements performed in the past (more than 50 years ago in Slovakia) showed that characteristics are in a certain relation to the altitude of a certain point and to the average annual air temperature, and can be derived from them (Staňo, 1975). Such measurements of road pavement temperature conditions were taken in a locality situated 130 m above sea level with average an annual air temperature of 9.8°C, in a locality situated 370 m above sea level with an average annual air temperature of 7.4°C, and in a locality situated 700 m above sea level with an average annual air temperature of 5.8°C. They are documented in graph form (figure 1).

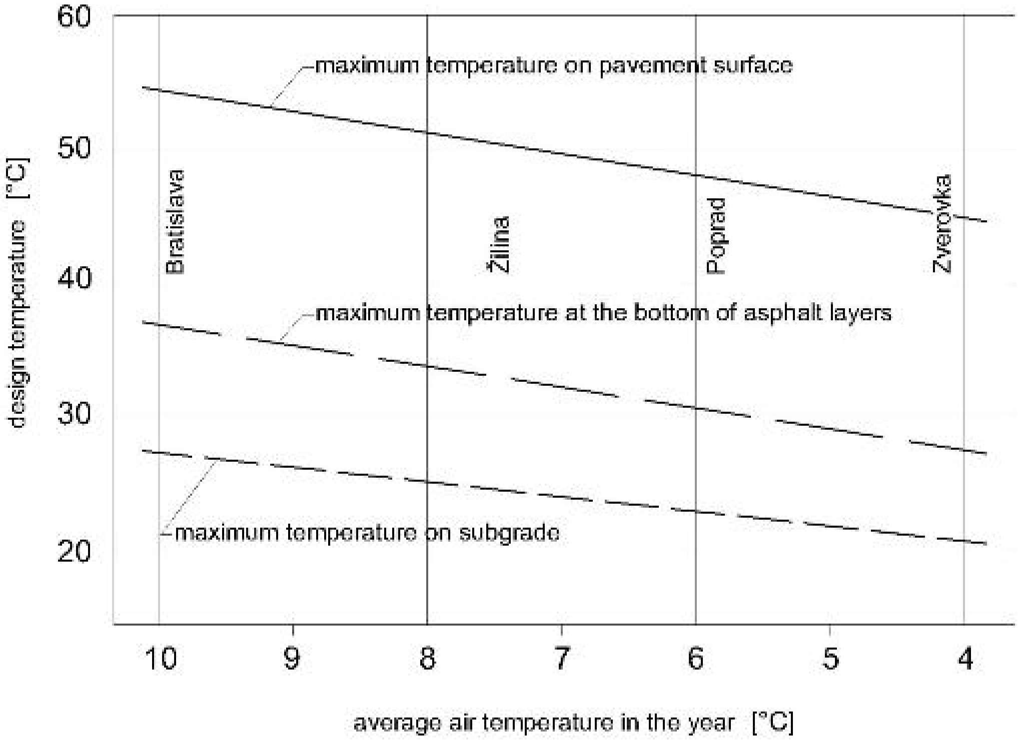

Figure 1 - Temperatures of asphalt pavement at average annual air temperatures

The calculation of so-called design values (characteristics) of the temperature regime of asphalt pavements considered that traffic load – its volume and effects – appears between 06,00 am and 06,00 pm (when five-sixths of the load are realised). Design values of so-called equivalent temperature of asphalt layers in standard conditions are shown in the table below:

Number of days in the year	Aliquot part of the year	Equivalent temperature	Note
75	0,2	0°C	winter
186	0,5	+11°C	spring, autumn
104	0,3	+ 27°C	summer

In the design, calculation and evaluation of asphalt pavements, the effects of temperature change (in annual cycle) on deformation and strength characteristics of asphalt mixes are taken into account through a comparison of the stress in layers and the material strength for three seasons of the year, characterised by different temperatures. The coefficient of utilization of material (asphalt mix) strength SV as a relative value is calculated using the formula:

$$SV = \sum q_i \frac{\sigma_{r,i,j}}{S_{N,i} . R_{i,j}}$$

where q_i - an aliquot part of the year (0.2, 0.3 and 0.5) with different equivalent temperatures of asphalt layers (0°C, 27°C, 11°C),

$\sigma_{r,i,j}$ – flexural tensile stress in the layer *i* under conditions *j*,

$R_{i,j}$ – design material strength in the layer *i* under conditions *j*,

$S_{N,i}$ – material fatigue coefficient of the layer *i* for *N* load repetitions, which is different for asphalt mixes and cement-bound materials.

Deformation characteristics – modulus of elasticity and Poisson's ratio and strength characteristics of selected asphalt mixes of AC type depending on temperature (in conditions marked *j*) are shown in the table below:

Asphalt mixes	Modulus of elasticity (MPa)			Poisson's ratio μ			Flexural tensile stress (MPa)		
	0°C	11°C	27°C	0°C	11°C	27°C	0°C	11°C	27°C
AC wearing c.	7500	5500	3000	0.21	0.30	0.40	4.0	3.1	1.4
AC binding c.	5700	4200	2000	0.21	0.30	0.40	3.40	2.70	1.20
AC binding c., PMB	5700	4600	2800	0.21	0.30	0.40	3.40	2.80	1.30
AC base c.	4500	3050	1250	0.21	0.33	0.44	3.20	2.40	0.95

In the design, calculation and evaluation of pavement with cement-concrete surface the climate conditions are described by:

– average annual air temperature $T_{m,r}$ (°C),
– amplitude of average daily air temperature in annual cycle A_r (°C), and
– value of the frost index, the design value of which is selected with different periodicity (e.g. n = 0.1 for motorways).

We suppose that temperature at the centre of thickness of a cement-concrete slab is equalised with air temperature and therefore its average annual temperature is $T_{m,r}$. An important characteristic of the temperature regime of concrete pavements is the temperature difference of the upper and the lower surfaces, which may be positive (during the day) or negative (during the night). It is expressed in °C/mm of slab thickness. The temperature gradient in CC slab ΔT causes its deformation – warping. In the case of a positive temperature gradient, the slab is dome-shaped. Depending on the slab thickness (weight), dimensions and friction in the area of contact of the slab with the ground, tensions appear in concrete which may achieve values comparable with tensions from vehicle axle load. The impact of temperature gradient on tensions $\sigma_{T,sx}$ for slabs with thickness h_B and subgrade strength k = 100 MN . m^{-3} is shown in figure 2.

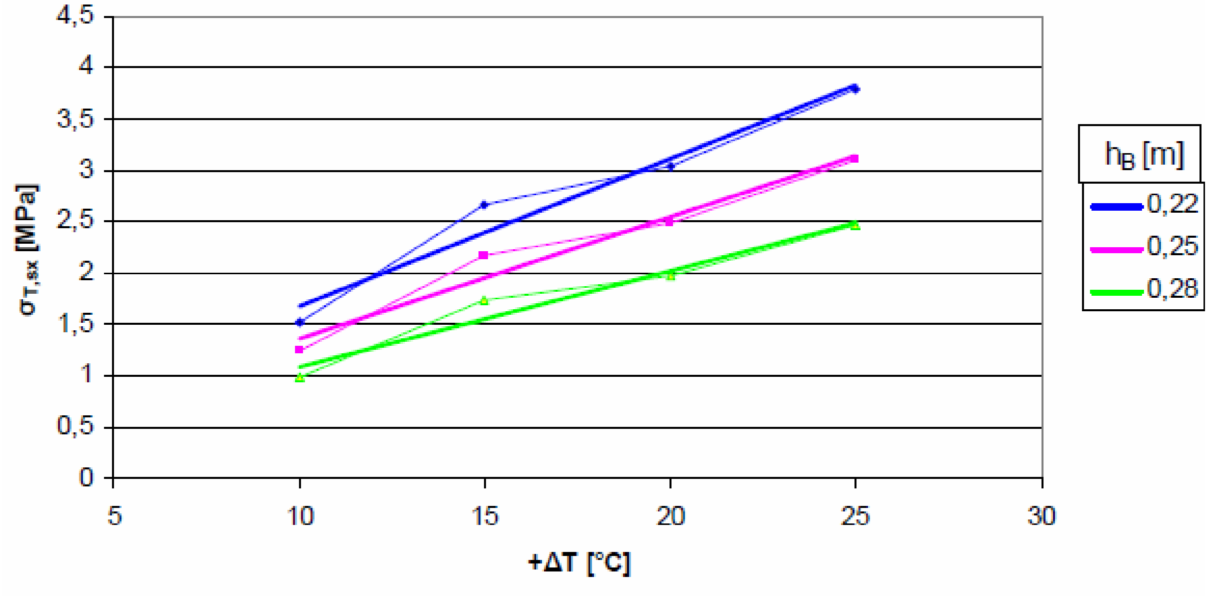

Figure 2 - Flexural tensile stress in concrete slabs from temperature gradient

Characteristics of the temperature regime relevant for calculation of concrete pavements were (in Slovakia) derived from field measurements on different structures, taken in the period of years 1970 – 1980. For the positive temperature gradient of a 220 mm thick slab the following empirical formula was derived:

$$+\Delta T_{n,22} = 18.6 - 0.6\ T_{m,r}$$

For other thickness values of concrete slabs (not exceeding 300 mm) the validity of the formula was extended. In technical regulations we use:

– for positive temperature difference $+\Delta T = 12.44 - 0.6\ T_{m,r} + 0.028\ h_B$,
– for negative temperature difference $-\Delta T = 6.214 - 0.3\ T_{m,r} + 0.0113\ h_B$

Measurements of air temperature taken in the recent period show that average annual temperatures should be corrected and empirical formulas revised.

3. SCENARIO OF CHANGES OF CLIMATE CONDITIONS

Slovakia lies in Central Europe and receives both oceanic and continental climate influences. Regions like this are characterised by very high climate variability and with frequent changes of basic climate characteristics. According to Lapin, 2001, climate conditions in Slovakia have been changing since the 19th century. An increase of average annual air temperature of 1.5°C, changes in the precipitation regime, decrease of relative humidity and increase of potential evaporation (of 10%) were registered. In the period following the years 1985 – 1988, global warming started to become more obvious and the rainfall regime changed. We had years with temperatures that were slightly to strongly above average. Initially precipitation amounts were under the long-term average, but later periods were characterised by increased variability of precipitation: warm periods without precipitation alternated with short periods with very intensive rainfall. The frequency of the occurrence of intensive rains gradually increased.

Climate change scenarios until the year 2100 are prepared on the basis of an analysis of global and regional models (GCMs). In particular, scenarios of increases of average monthly air temperatures and scenarios of changes in monthly precipitation amounts (within the whole territory of Slovakia) were prepared. The scenario of changes in average monthly temperatures shows a continuous rise of air temperature throughout the 21st century (Lapin, 2008). Until the year 2075, average monthly temperatures will increase by at least 1.8 or 2.0°C. This will also impact other climate components, especially air moisture, evaporation and the occurrence of precipitation. From the scenarios of changes in precipitation amounts (for Slovakia) it is clear that precipitation amounts will grow and that the hydrological balance within the whole territory of Slovakia will change significantly. It is assumed that river discharges may be very fluctuating (variable).

From the analysis of the present state of the climate and from scenarios of changes in climate conditions (from 2025 to 2100) with application to the Slovak territory, climatologists have drawn partial conclusions, on the basis of which (in view of road construction) it must be noted that:

- changes in climate conditions are manifested by a change of average monthly air temperatures that have a clear upward trend (until 2100),
- minimum air temperatures will increase, days with air temperatures dropping below the freezing point will become more frequent, and in summer the number of days with the lowest temperature (above 18°C or up to 20°C) will significantly increase;
- in connection with increasing air temperature and precipitation amounts there is a prognosis of a growing intensity of torrential rains, storms and heavy winds, and of larger amount and higher intensity of icing in winter (with risks of thick fog occurrence).

The conclusions initiated different research programmes.

4. RESEARCH OF PARTIAL PROBLEMS

In connection with the temperature regime of asphalt pavements and characteristics of asphalts in mixes for the individual layers, a study was conducted during which temperatures were measured on the surface and in the individual pavement layers in summer and winter periods (throughout Slovakia). From data on air temperature measured by 20 meteorological stations, temperatures of asphalt pavement surface, temperatures on base layer surface and temperatures on upper subbase layer surface were calculated by the use of a rather complicated formula. For a locality with an altitude of 130 m and 95% frequency of occurrence, these temperatures were 55.70°C, 46.70°C and 36.70°C, respectively. The comparison of temperature differences on the surface of the individual layers (at the stations in question) revealed a significant decrease of temperature in relation to depth. The difference between temperatures measured on the pavement surface and at a depth of 130 mm ranged between 20 and 25°C. But in winter the temperature of the upper base course was 7°C higher than the surface (Hroncová, 2008).

If requirements for the physical properties of asphalts were to be determined on the basis of temperatures in the pavement structure, then the three basic characteristics of asphalt – Vicat softening point, penetration and breaking point –would be differentiated for mixes for the individual layers as well as for the different regions. The lowest values of the Vicat softening point would be 55 to 58°C, in standard conditions 59 to 63°C, in a warmer area between 64 to 66°C. Values of the Vicat softening point of base layer mixes would be 10°C lower than those for wearing course mixes, and as much as 20°C lower in the mix for the upper subbase layer.

One of the solutions to the problem of selection of asphalt cement for specific climate conditions is the elaboration of a „temperature chart"(so-called PG chart). Using this chart and on the basis of functional tests of mixes with different binders it will be possible to select a suitable binder. This approach is not new – the basic data were already prepared upon the completion of a SHRP project in the United States. It is more suitable for countries with a larger area or containing areas with very different conditions.

The preparation of the PG chart consists in the selection of meteorological stations, the processing of air temperature data over a sufficiently long period, and proposing of areas of PG classes. The PG chart as an informative document for the proposal of asphalt mix can involve the wearing, binding or base courses.

The impact of temperature on the strength or stability of asphalt mixes can be (and was) examined using different laboratory tests (Boros, 2008). One very simple test is the Marshall Stability test performed at standard temperature of +60°C. The change of stability of the mix AC11 under the influence of temperature is apparent from the record:

SM	20°C	48.80 kN	(100%)
	30°C	38.35 kN	(79%)
	40°C	21.03 kN	(43%)
	50°C	14.54 kN	(30%)
	60°C	11.62 kN	(24%)

The change of strength of the same mix in transverse pull is apparent from the record:

P_{max}	-15°C	61 300 N	(100%)
	0°C	53 600 N	(87.4)
	5°C	41 900 N	(68.3)
	15°C	26 700 N	(43.5)
	30°C	11 900 N	(19.4)

The research of characteristics of asphalt mixes that are less temperature- sensitive and more resistant to permanent deformations (road wear-down) led to certain general conclusions (Loveček, 2009):

– Asphalt mix is more resistant when it has a higher share of crushed aggregate, including that of quarry sand.
– A mix is more resistant when the ratio of filler F and asphalt A is between 1.50 and 1.75.
– A mix is more resistant when the asphalt cement (binder) is modified.

Interestingly, recommendations and measures for the improvement of characteristics of asphalt mixes in connection with the temperature regime of a region (area) were differentiated for warm areas and areas with low temperatures. For instance, the following recommendations (measures) were adopted for warm areas:

a. Utilization of asphalt cement of higher hardness (higher value KG)
b. Higher filler asphalt ratio
c. Crushed aggregate – up to 100%, more coarse fraction
d. Smaller content of binder with regard to the higher voids ratio of aggregate.

In cases of areas with low temperatures the following recommendations were made:

a. Softer binder (low breaking point)
b. Lower ratio of filler F to asphalt A
c. Higher content of binder (with regard to the lower voids ratio of aggregate).

5. SUMMARY

Changes in climate conditions that have recently manifested themselves in the territory of Slovakia through increased average air temperatures, more often breaking of temperature records and more frequent intensive rains have led to a revision of the requirements for the characteristics of road construction materials, to the need to revise the procedure and criteria for road design and to prepare basic data and documents for the amendment of technical and technological standards. Some of the problems resulting from the accepted climate change scenario require the implementation of research programmes and international cooperation.

Recommendations for road design:

– For medium-heavy and heavy traffic, to preferably use semi-rigid structures with cement-bound subbase and with lower total thickness of asphalt mix layers;
– To extend the utilization of layers of the porous asphalt (PA) pavement, but always with drainage design;
– To use porous cement concrete in base layers of concrete pavement;
– For roads in cities (residential zones) to preferably use brighter surfaces – e.g. to use brighter aggregate or pigments in asphalt mixes;
– To choose cement concrete slabs of smaller size or square shape, along with contraction joints reinforced by dowel bars to propose dilatation joints (to create dilatation blocks).

Recommendations for material properties:

For wearing, base and subbase layers – but especially for base layers – to use asphalt mixes produced with modified asphalt cement (binder) and to always verify resistance against permanent deformation (ruts).

In accordance with the catalogue of asphalt mixes used in Slovakia the use of the following mixes and asphalts is recommended:

AC 11 0	(AC 16 0)	PMB 45/80 – 75	45/80 – 60
AC 16 L	(AC 22 L)	PMB 45/80 – 55	25/55 – 65
AC 16 P	(AC 22 P)	PMB 45/80 – 55	(alt CA 35/50)
SMA 8	SMA 11	PMB 45/80 – 75	45/80 – 60
PA 8	PA 11	PMB 45/80 – 60	45/80 – 75

Recommendations for technological procedures:

Earthwork management ought to follow changes in conditions and always ensure drainage of the formation level. Embankment slopes must be trimmed and secured very quickly. In both cases standard or special geosynthetics must be available.

6. REFERENCES

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