Asphalt mixes properties and pavement structure mechanics

Silvia Cápayová[1, a], Ivan Gschwendt[1], Andrea Zuzulová[1, b]

[1] *Department of Transportation Engineering, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Bratislava, Slovakia*

[a] silvia.capayova@stuba.sk
[b] andrea.zuzulova@stuba.sk

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ABSTRACT

A. The review of deformation characteristics and properties of asphalt mixes for road pavement construction. In addition review of changing and development in properties of asphalt binder and asphalt mixes (e.g. modification). Some results from the laboratory tests of asphalt mixes production with chemical agents (polymers) and additives improving adhesion to aggregates, enable the mixing procedure under low temperature (WMA).
B. The requirements on asphalt mixes properties and description of laboratory tests. The most important properties decisive for serviceability and bearing capacity of pavement structures. Design of asphalt mixes composition, requirements on mixes composition exercised in Slovakia. Catalogue sheets of asphalt mixes with requirements according traffic load of road, prepared with empirical approach to composition design.
C. Energy consuption on mixes production for procedure HMA and WMA, comparison. The new low energy asphalt mixes, energy saving possibilities. Factors and way to protect the environment.
D. Pavement design and calculation of structures with asphalt layers with different quality. Theoretical solution of multilayer system with imput data as a design values (E, μ, h), not real. Influence of temperature on stresses and strain distribution in models of pavement structure. Partition the year on time periods with different layers temperature. Theoretical approach to calculation of pavement surface permanent deformation. The rut depth as criterium in pavement design.
Discusion : radial strain or radial stress in the bottom of critical pavement layer as criterion.

Keywords: Design of pavement, Emissions, Energy saving, Testing

1. INTRODUCTION

European standards of class 13108 state the requirements on asphalt mixtures materials. By implementing them into Slovak normalization system it was necessary to decide on selection of asphalt mixtures characteristics and categories with determination of their parameter´s values in dependence on use of particular technologies by pavement construction and traffic load class according STN 73 6114 [4]. In Slovakia basic types of asphalt mixtures used in surface and subbase layers include AC, SMA, PA, MA and BBTM (Table 1).

Table 1: Use of asphalt mixtures in pavement structure

Mixture name		Mixture identification
AC	Asphalt Concrete	AC 8 O, AC 11 O, AC 16 O
		AC 16 L, AC 22 L,
		AC 16 P, AC 22 P, AC 32 P
SMA	Stone Mastic Asphalt	SMA 8 O, SMA 11 O, SMA 16 O
PA	Porous Asphalt	PA 8 O, PA 11 O
BBTM	Béton Bitumineux Très Mince	BBTM 8A O, BBTM 8B O,
		BBTM 11A O, BBTM 11B O, BBTM 11C O
MA	Mastic Asphalt	MA 11 O, MA 16 O, MA 4 O, MA 8 O
		MA 11 L, MA 16 L
		MA 16 C

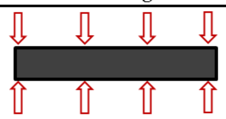
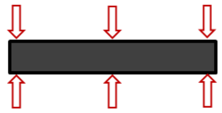
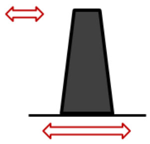
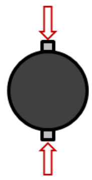
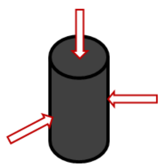
Options for asphalt mixtures use in pavement structure depend on pavement´s quality and traffic load classes as stated in Table 2.

Table 2: Asphalt mixtures use in pavement structure

Type of mixture	Quality class	Highest allowed traffic load class		
		Wearing course	Base course	Subbase layer
AC 8	II[1)]	IV	-	-
AC 11	I	I	-	-
AC 11	II[1)]	IV	-	-
AC 16	I	I	I	I
AC 16	II[1)]	IV	IV	IV
AC 22	I	-	I	I
AC 22	II[1)]	-	IV	IV
AC 32	I[1)]	-	I	I
AC 32	II[1)]	-	IV	IV
SMA 11	-	I	-	-
SMA 16	-	I	-	-
PA 8	-	I	-	-
PA 11	-	I	-	-
BBTM 8	I	I	-	-
BBTM 11	I	I	-	-
BBTM 8	II	IV	-	-
BBTM 11	II	IV	-	-
MA	I	I	I	-
MA	II	IV	-	-
[1)] *In the case of ascending lanes and other sections loaded with heavy vehicles (e.g. bus stop) asphalt mixtures must comply with the requirements on resistance to permanent deformations stated for AC of quality class I.*				

Each asphalt mixture must comply with requirements defined in relevant standard and regulation. In **empiric design** of asphalt mixtures we can talk about *general and empiric requirements* which asphalt mixtures have to fulfil. These requirements are defined in Catalogue sheets of asphalt mixtures [10] and it's Addendum [11]. Basic *general requirements* refer to asphalt mixture grading and mixture´s void content. In Catalogue sheets are also defined, in dependence on quality class, other general requirements on mixture. In the case of quality class I they are determination of asphalt mixture water sensitivity ITSR (%), which is the ratio of indirect tensile strength on specimen tempered in water and specimen with laboratory temperature and determination of mixture´s resistance to permanent deformation - PRD_{AIR} (%), WTS_{AIR} (mm). In quality class II it is necessary to indicate the asphalt mixture immunization on water ITSR (%). *Empiric requirements* for quality class I involve minimal amount of asphalt binder B_{min} (%) and recommended asphalt binder type. For quality class II it is, in addition to previous requirements, minimal and maximal percentage of voids in aggregate filled with asphalt VFB (%).
For determination of optimal mixture (grading composition of mixture´s aggregate, optimal amount of asphalt binder) it is necessary to evaluate so called volumetric characteristics of asphalt mixture: density, maximum density, voids content, percentage of voids in aggregate filled with asphalt. In the past, the optimal asphalt mixture was determined on the basis of results of Marshall test (currently for road pavements this test is not used, valid is only standard for asphalt pavements on airport areas STN EN 12 697-34 [6]) in which the Marshall stability (kN), Marshall flow (mm) and Marshall quotient (-) were determined on five mixtures with various batches of asphalt binder. As optimal was the mixture with the highest Marshall quotient (the highest achieved force by the smallest strain) chosen. From these results it was possible to assume how the mixture will behave from the strength and deformation point of view, in the resistance to permanent deformation test, by fatigue resistance ε_6 and stiffness modulus S_m determination. It is more difficult to assume this from the results of volumetric characteristics tests.
Another asphalt mixture design option is mixture **design on the basis of functional requirements** – grading composition and optimal amount of asphalt binder design on the basis of required mixture characteristics from its strength and deformation performance point of view. Currently design of asphalt mixture according *functional requirements* is required only by high modulus asphalt concrete HMAC [9]. These functional requirements involve maximal S_{max} (MPa) and minimal stiffness S_{min} (MPa) of asphalt mixture and fatigue resistance ε_6. Beside that [9] states also *extended requirements* – binder and aggregate adhesiveness (%). The way of asphalt mixture design on the basis of functional requirements is more preferred in practise and there is a tendency to include it also into Slovak regulations. Concrete tests belonging to functional requirements on asphalt mixtures are in Table 3.

Table 3: Tests of mechanical characteristics of asphalt mixtures – functional requirements

Test	Test result	Test temperature (°C)	Test configuration
4-point bending test	- Deformation - Complex modulus - Fatigue curve - Resistance to fetigue	0 11 27 *Note: Particular temperatures are not stated by standard. Mentioned temperatures are used in present pavement design method.*	
3-point bending test			
2-point bending test			
Indirect tensile strength	- Tensile strength - Stiffness modulus S_m (MPa) - Deformation - Resistance to fetigue	for -5 to +25	
Repeated load triaxial test	- Resistance to permanent deformation	40 60	

2. LABORATORY TESTS OF ASPHALT MIXTURES

As was mentioned in previous text, strength and deformation characteristics of asphalt mixtures can be determined by various laboratory tests. Department of Transportation Engineering is within its own research, national and international, focusing this problem. During several years research in this field the department's research was aimed on the influence of various compositions of asphalt mixture on its strength ad deformation characteristics. The selection of most appropriate mixture composition can increase its stiffness, resistance to fatigue and resistance to permanent deformation. One of the options is, in basic mixture composition (aggregate, filler, asphalt binder), use of modified or stiffer asphalt binders. In the case of binder modification it means the use of polymer modified binders or in the case of low-temperature asphalt mixtures (WMA) binder modification with various additives – natural or chemical; or binder characteristics can be changed by its foaming eventually. Application of various additives is from the practical point of view simpler than foamed asphalt technologies. In Slovakia several types of natural additives e.g. on the wax base (e.g. FT additive Sasobit) or various types of chemical, surfaces active substances (e.g. Rediset LQ, Evotherm DAT) were used. In the case of foam asphalt technologies synthetic or natural zeolites (Zeocem) were applied. In 2014 was performed first practical verification of foam-asphalt mixtures in Slovakia produced by company Colas. Other possibilities verified in Slovakia were use of natural asphalt mixture Trinidad Epuré Z 0/8 (TE) and of hydrated lime. By applying 3 % of TE into mixture AC 22 P[1] with binder PmB 10/40-65 increased stiffness modulus (determination method IT-CY) approximately 40 % and decreased relative rut depth approximately 33 % was achieved. Use of hydrated lime as replacement for part of filler in mixture has proved as reasonable - mixture has higher resistance to permanent deformation as well as resistance to fatigue and according the results from abroad significant prolongation of service life. By use of harder asphalt binders increase the stiffness moduli values of mixtures as well as the resistance of asphalt mixture to permanent deformation can be achieved. In this case is it HMAC, in Slovakia regulated by specification [9] and standard STN EN 13108-1, but it is not included in Catalogue sheets of asphalt mixtures [10]. This mixture is defined according STN EN 13108-1 with derived design stiffness modulus value in rank from 9000 to 14 000 MPa [9].

As example are shown concrete results of laboratory tests on asphalt mixtures´ permanent deformation resistance and values of their stiffness moduli stated in research projects [1] and [3]. Evaluated were changes of mixtures´ parameters in dependence on asphalt binder modification with various additives and by adding of precise amount of recycled material into mixture respectively. The assumption was the increase of evaluated parameters in comparison with reference mixtures.

2.1 Resistance to permanent deformation

Resistance of asphalt mixtures to permanent deformation is determined by empiric wheel-tracking test according STN EN 12697-22+A1 [5] and functional repeated load triaxial test according STN EN 12697-25 respectively. These processes are defined for asphalt concrete (including HMAC), stone mastic asphalt and adjustment of chippings.

Final values stated in Table 2.1 were measured on mixtures AC 11 O and AC 22 P by small size device by method B (50 °C, air) with determination of relative rut depth PRD_{AIR} (%) and rut rate WTS_{AIR} ($mm/10^3$ loading cycles) according [6]. Reference mixtures were classical mixtures with 50/70 penetration bitumen, compaction temperature of specimen was 150 °C. Further, there where WMA mixtures with organic FT additive (130 and 140 °C respectively) and chemical additives IterLow (130 °C) and ZycoTherm (150 °C). Mixture AC 22 P has 5 % of asphalt recycled material. Standard STN EN 13108-8 [7] allows use of up to 20 % of recycled material to subbase layer, but the use of only 10 % of particular recycle material caused negative decrease of void content to 3.2 % (according [10] is for AC 22 P minimum void content 4.0 %). It is allowed, according above stated standard, to exceed the recommended maximum amount of recycled material, but it is necessary to declare final results with corresponding technical regulations. Recycled material used in concrete case into mixture AC 22 P has not allowed this but the use of another recycled material has (mostly from the point of view of grading = influence on void content). Improvement of strength and deformation characteristics of asphalt mixtures using recycled material in amount of 40 % to wearing course, 50 % to base course and in the amount up to 70 % to subbase layer confirm also results from older researches of our department included in the article [2].

Limit values according [10] - mixtures AC 11 O => $PRD_{AIR\ max}$ = 5 % and $WTS_{AIR\ max}$ = 0.07 mm,
- mixtures AC 22 P => $PRD_{AIR\ max}$ = 5 % and $WTS_{AIR\ max}$ = 0.10 mm.

From values in Table 4 is clear that mixtures AC 11 O stated conditions fulfil. The exception is low-temperature mixture with IterLow additive, where is obvious more significant excess of WTSAIR value (with reference mixture almost 3-times) and the highest PRD_{AIR} value. Possible ground for this can be void content of mixture M = 5.6 % (reference mixture AC 11 O, M = 2.6 %), which can cause additional setting of mixture. From the point of view of both

[1] According to [9] asphalt mixtures are with type of mixture, max. size of aggregate (mm) and layer of pavement (O = wearing course, L = binder course, P = base course) defined.

marker additives has no significant influence on resistance characteristics to permanent deformation, almost two times increase of WTS_{AIR} was caused by ZycoTherm additive.

Both types of mixture with FT additive achieve void content approximately 5% (reference mixture AC 22 P, M = 5 %). In comparison to reference mixture by applying of FT additive negative values of both markers have decreased and results were on the edge of conditions respectively. Only low-temperature variant with 2% FT additive and 3% FT additive and 5% of recycled material complies with conditions on maximum value of both markers for mixture AC 22 P.

Table 4: Results of resistance to permanent deformation laboratory tests

Asphalt mix	**Binder**	**Recycled material (%)**	**PRD_{AIR} (%)**	**WTS_{AIR} ($mm/10^3$ cycles)**
AC 11 O	Bitumen 50/70	-	2.2	0.026
AC 11 O + 3 % FT		-	2	0.019
AC 11 O + 1 % IT		-	4.5	0.074 ✗*
AC 11 O + 0,1 % ZT		-	2.6	0.048
AC 22 P		-	5.6 ✗*	0.16 ✗*
AC 22 P + 2 % FT		-	2.8	0.07
AC 22 P + 3 % FT		-	3.5	0.11 ✗*
AC 22 P		5 % ARM	4.3	0.13 ✗*
AC 22 P + 2 % FT			3.2	0.11 ✗*
AC 22 P + 3 % FT			3.7	0.09

Note: FT = Fisher-Tropsch additive (FT additive, Sasobit), IT = IterLow, ZT = ZycoTherm, ARM = asphalt recycled material
** Non-conforming value according [5]*

2.2 Stiffness modulus

Stiffness moduli S_m (MPa) were determined with IT-CY method (repeated stress in indirect tensile strength on specimen of cylinder shape) in accordance with STN EN 12697-26. This standard does not state by what temperature the test has to be performed. In selecting the temperature, it is necessary to take account on the most possible real conditions to be simulated. In regard to the fact that research projects were performed in the cooperation with TU Bratislava, Slovakia and TU Prague, Czech republic the temperatures were selected as follows: for AC 11 O the measurements were performed by 5, 15 a 27 °C temperatures (standardly tested temperatures at TU Prague), for AC 22 P the measurements were performed by 0, 15, 27 a 40 °C temperatures. In regard to design method TP 03/2009 it would be better to perform other measurement of stiffness moduli by temperature of 11 °C.
Final result of stiffness moduli measured on mixture AC 11 O summarised in Table 5 point out the change of mixture stiffness after its modification by FT, IT and ZycoTherm additives. Temperature sensitivity was determined from the stiffness moduli ratio by 5 a 27 °C temperatures. By mixture with FT additive was confirmed the assumption about mixture stiffness improvement - by temperature of 27 °C it achieves the highest values of stiffness modulus and has the lowest temperature sensitivity from all compared mixtures including reference mixture. The worst results were achieved by use of ZycoTherm additive.

Table 5: Stiffness modulus S_m (MPa) – AC 11 O

Asphalt mix	**Binder**	**S_m (MPa)**			**Temperature sensitivity**
		5 °C	**15 °C**	**27 °C**	
AC 11 O	Bitumen 50/70	14 050	6 500	1 800	7.8
AC 11 O 3% FT		13 500	7 150	2 500	5.4
AC 11 O 1% IT		11 650	5 850	2 050	5.7
AC 11 O 0,1 ZycoTherm		12 350	3 100	1 300	9.5

Final results of stiffness moduli measured on mixture AC 22 P summarised in Table 6 show the change of mixture stiffness after its modification by FT additive and recycled material addition respectively. Temperature sensitivity was determined from stiffness moduli ratio by 0 and 40 °C temperatures. FT additive caused mild increase of stiffness moduli – by 0 °C temperature on 6.5 % in comparison with reference mixture, by combination of FT additive and recycled material in mixture was the increase of stiffness modulus on 12 %; by temperature of 40 °C was the increase of modulus on 35 % by use of FT additive and on 54 % by use of FT additive and recycled material. The best results were achieved by mixture with FT additive and 5% of recycled material.

Table 6: Stiffness modulus S_m (MPa) – AC 22 P

Asphalt mix	Binder	Reclaimed material (%)	S_m (MPa)				Temperature sensitivity
			0 °C	15 °C	27 °C	40 °C	
AC 22 P	Bitumen 50/70	0	21 499	9318	3 049	865	24.9
AC 22 P 3% FT			22 894	10978	3 957	1 167	19.6
AC 22 P		5	21 923	9577	3 074	873	25.1
AC 22 P 3% FT			24 080	11682	4 415	1 329	18.1

3. DESIGN AND CALCULATION OF PAVEMET STRUCTURES

In clarifying the general questions of pavement structures´ design on roads is always said that the design method content must include principles for layout of layers and rules for material selection for these layers, ways of expressing the impacts of traffic load and climate conditions and what is most important they prescribe criteria for evaluation of correctness of designed structure. What must be considered as part of the design is that the pavement structure needs to be optimised from the point of mechanics (use of mechanical characteristics of selected road building materials), technological point (e.g. use of efficient equipment) and form social point (economical serviceability and rehabilitation). In pavement design number of factors must be considered which can significantly influence the selection of materials and layout of pavement structure. These are factors of technical, technical-organisational and economic nature. For the material selection of individual pavement layer we need to know their characteristics, for sure deformation and strength characteristics as well as some of the physical characteristics which influence the operability of pavement. One of the main factors with the influence on operability and efficiency of pavement is pavement surface evenness. From the cause´s analysis of origin and development of asphalt pavement deformations (and so transverse unevenness) results that besides traffic load volume are significant also deformation characteristics of layer´s materials.

3.1 Calculation of permanent deformations

Permanent deformations of pavement layers which are "added" and occur as unevenness and pavement surface ruts depend on stresses. In calculation of layer stress and deformation are mostly used pavement structure models and application of flexible multilayer semi-space.
Methodology of permanent deformation of asphalt pavements was elaborated by Verstraeten as one of the first, who derived the permanent (plastic) material deformation from the relation to flexible deformation and flexible relative strain. Permanent (plastic) deformation of material ε_p is defined as:

$$\varepsilon_p = \varepsilon_{el} \,.\, f\,(N)$$

where: ε_{el} is flexible (elastic) relative strain of material,
f function of number of repeated load which value is defined as "deformation coefficient".

Above relation between permanent and flexible material deformation was applied also to relation between permanent and flexible deformation of pavement layers and is defined by relation:

$$y_{trv} = y_{pr} \,.\, f\,(N) \quad \text{(mm)}$$
$$y_{trv,i} = y_{pr,i} \,.\, K_i \quad \text{(mm)}$$

where: y_{trv} is permanent deformation of pavement layer (mm),
$y_{trv,i}$ permanent deformation of pavement layer i (mm),
K_i deformation coefficient of layer i.

Total permanent deformation of asphalt pavement surface can be calculated as summary of permanent deformations of individual pavement layers and subgrade by relation:

$$y_{trv} = y_{podl} \cdot K_{podl} + \sum_{i=1}^{i=n} \cdot K_i \left(y_{pr,i} - y_{pr,i+1}\right) \qquad \text{(mm)}$$

where: y_{podl} is flexible deformation on subgrade surface (mm),
K_{podl} deformation coefficient of subgrade soil,
$y_{pr,i}$ flexible deformation of layer i (mm),
$y_{pr,i+1}$ flexible deformation of layer i+1 (mm),
K_i deformation coefficient of layer i in which the relation is valid:

$$K_i = a_i \cdot N^{bi}$$

where: a,b are material characteristic,
N is traffic load defined as number of design axle passes but only for period of spring, summer and autumn.

Flexible layer deformation has to be calculated by deformation characteristic of individual layers for concrete conditions i.e. for temperatures of spring, autumn and summer.

Calculated permanent pavement deformations and rut depth of asphalt pavement surface are different values. It is shown also on the example of measurement of deformed asphalt surface shape on relatively loaded road of I. class (Figure 1). Expected ruts´ depth on the surface of flexible asphalt pavement can be derived from empiric relation:

$$H_k = 1{,}40\ y_{trv} \qquad \text{(mm)}$$

or on the surface of semi-rigid pavement with the relation

$$H_k = 1{,}20\ y_{trv} \qquad \text{(mm)}$$

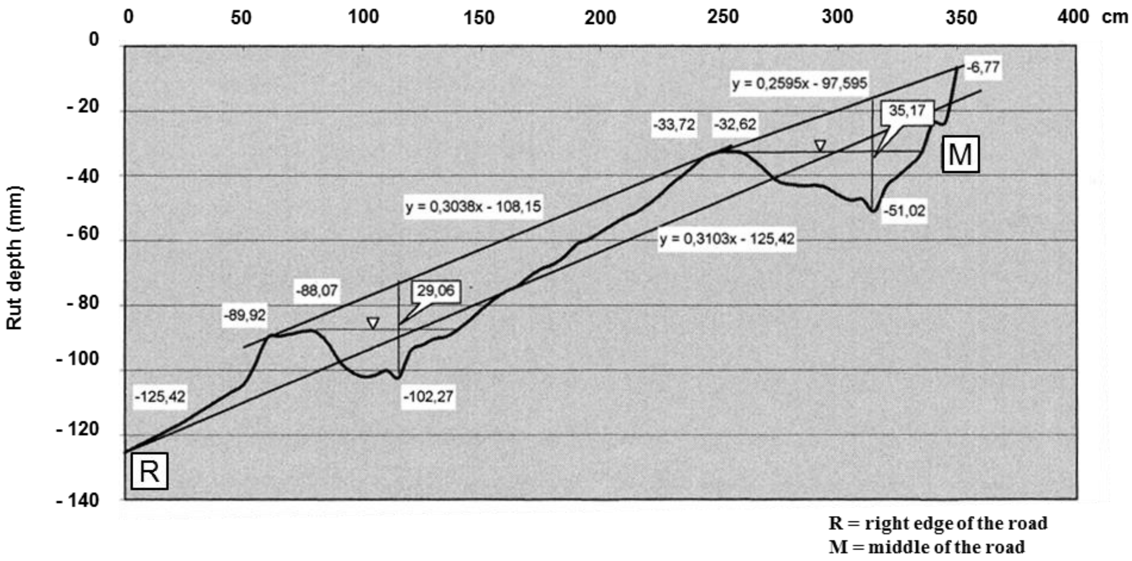


Figure 1: Shape and depth of ruts on asphalt pavement (road I/63 in Šamorín village)

With the acceptation of solution by flexible semi-space theory used for the calculation of permanent deformation of asphalt pavement is connected the acceptation of precondition that the greater the thickness of asphalt mixture layer is the greater the permanent deformation. On Figure 2 are results of calculated permanent deformations of semi-rigid pavements with various asphalt layers thickness (15 to 18 cm) on the subbase with the thickness 25 to 30 cm.

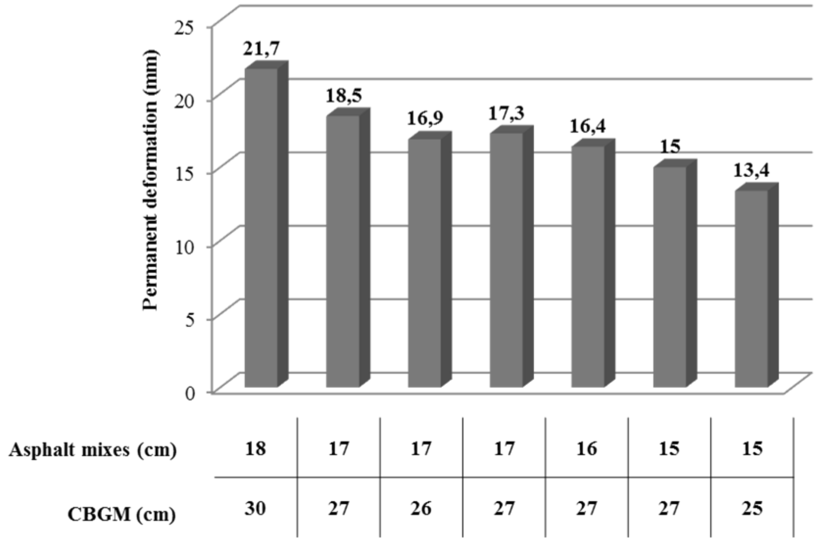


Figure 2: Permanent deformation of pavements with various asphalt layer thickness

Algorithm of permanent deformation (and rut depth) calculations is part of the LAYMED programme for calculation of stresses and strains of pavement layers by their design. By comparison of calculations results and measurements in situ it was discovered that the value were different. Calculations were evaluated as approximate but they were usable for comparison of resistance of various pavement types against rut creation. It is possible to compare flexible and semi-rigid asphalt pavement, modified asphalt mixture (by change for standard asphalt mixture) and mixture with high stiffness. The difference between the structure of flexible and semi-rigid asphalt pavement is shown on the scheme on Figure 3.

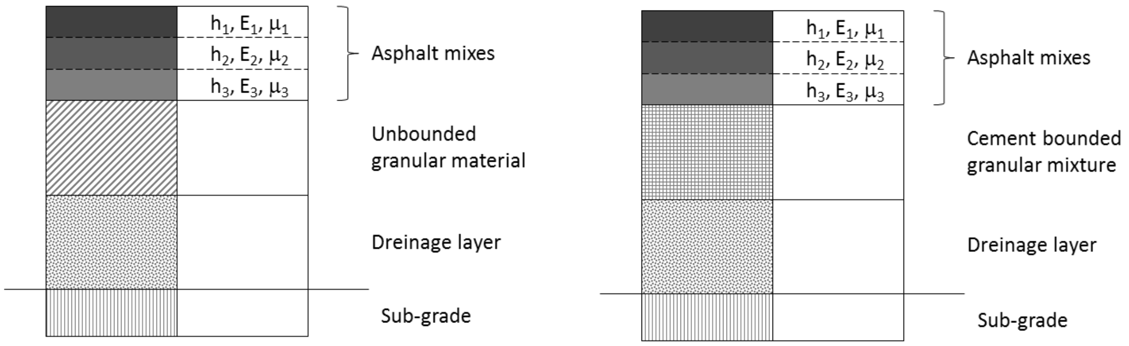


Figure 3: Difference between the structure of flexible and semi-rigid asphalt pavement

For the calculations with the aim of comparing results we chose following pavement structures:

V1 – flexible pavement

- stone mastic asphalt	SMA	40 mm
- asphalt concrete	AC 11 L, PmB	80 mm
- asphalt mixture with high module of stiffness	VMT	80 mm
- mechanically stabilized aggregate	MSK	160 mm
- crushed gravel	ŠD 0/45	200 mm

(subgrade, $E_{p,n}$ = 45 MPa)

V2 – semi-rigid pavement

- stone mastic asphalt	SMA	40 mm
- asphalt concrete	AC 16 L	60 mm
- asphalt concrete	AC 22 P	80 mm
- cement bounded granular material	CBGM C3/4	180 mm
- crushed gravel	ŠD 0/45	200 mm

(subgrade $E_{p,n}$ = 45 MPa).

Load characteristics: 2P = 100 kN, p = 0.60 MPa, Climate conditions: average temperatures of asphalt layers: winter 0 °C, summer 27 °C, spring/autumn 11 °C.

Some results of calculations of module by LAYMED programme with design values of deformation characteristics (E, μ):

Pavement V1:

- *pavement deformation* by temperature 0 °C 0.4142 mm
  11 °C 0.4241 mm
  27 °C 0.4548 mm

- *stresses in critical layer HMAC*: 0.7538 MPa (0 °C)
  0.7840 MPa (11 °C)
  0.7923 MPa (27 °C)

Individual layers of flexible pavement have part on final value of permanent deformation: 1.7+5.4+5.0 (HMAC) + 23.7+42.2 % (also subgrade 22 %).

Pavement V2:

- *pavement deformation* by temperature 0 °C 0.4157 mm
  11 °C 0.4306 mm
  27 °C 0.4737 mm

- *stresses in critical layer CBGM $C_{3/4}$*: 0.1100 MPa (0 °C)
  0.1170 MPa (11 °C)
  0.1330 MPa (27 °C)

- *rut depth for traffic load* Nc = $11.52.10^6$ 8.167 mm
  Nc = $15.00.10^6$ 8.708 mm
  Nc = $22.50.10^6$ 9.610 mm

  By which the layer AC 22 P has part on total permanent deformation with more than 70 %.
  Allowed ruts´ depth 20 mm can be obtained (theoretically) after $4.57.10^8$ 100 kN axle.

For the analysis and evaluation of stresses in the pavement structure by monitoring of their importance with the help of layer model, we can use also model of simple three-layered system. For solution, used e.g. by Jones (1962) we need to know parameters:

$$a_1 = a/h_2, \quad H = h_1/h_2, \quad K_1 = E_1/E_2, \quad K_2 = E_2/E_3$$

where: a is radius of circle loading surface (mm),
h_1 thickness of first layer (mm),
h_2 thickness of second layer (mm),
E_1 elasticity modulus of first layer (MPa),
E_2 elasticity modulus of second layer (MPa),
E_3 elasticity modulus of subgrade (semi-space) (MPa).

Model scheme is on Figure 4.

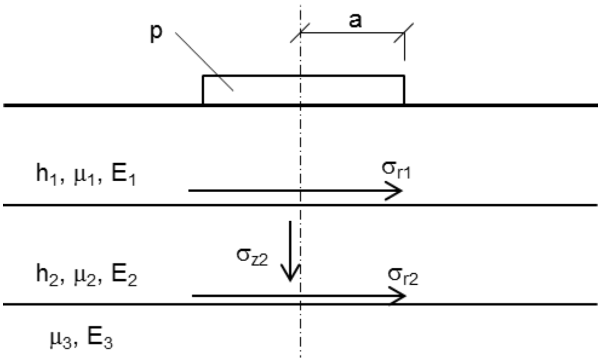


Figure 4: Model of three-layered system

We are interested o radial stresses on the bottom of first and second layer σ_{r1}, σ_{r2}, as well as vertical stress on subgrade (σ_{z2}). These stresses were derived from tables for p = 0,60 MPa and chosen parameters:

$a_1 = 0{,}8$ H = 1 and in the case V1 $K_1 = 2$, $K_2 = 20$
V2 $K_1 = 20$, $K_2 = 2$

Stress values are in the case V1 σ_{r1} = - 0.386 MPa
σ_{r2} = + 0.829 MPa
σ_{z2} = - 0.068 MPa

in the case V2 σ_{r1} = + 1.448 MPa
σ_{r2} = + 0.312 MPa
σ_{z2} = - 0.209 MPa

Case V1 represents pavement in which subgrade is rigid layer with the modulus reaching 20times of subgrade modulus and first layer (e.g. wearing course and base course) has little modulus, flexural stress in second layer gained up to + 0.829 MPa. That means the material has to have relatively high tensile strength, so the structure can have mechanical effectivity. Case V2 is represented by pavement where the ratio of strength between first and second subbase layer is high, moduli ratio is 20:1. This is expressed by high radial stress in first layer σ_{r1} = + 1.448 MPa. In regard to "weak" subgrade is also vertical stress high, σ_{z2} = - 0.209 MPa.
Results of calculation of simple three-layer model point to recommendation that the ration between resilient moduli of adjacent layer ca not be high, at most approximately 1:10. Material with higher stiffness has to have high flexural strength. From the practical point of view this also means that mixture HMAC needs bearing base ad in all cases it is necessary to design and solve the adjustment of subgrade and increase of its bearing capacity.

CONCLUSIONS

Currently are for asphalt pavements´ construction used relatively many types of asphalt mixtures. Laboratory tests of mechanical characteristics are performed according the whole scale of technical regulations – mostly elaborated in EU. There is an effort to include into technical regulations asphalt mixtures design according functional requirements – resistance to permanent deformations, resistance to fatigue and determination of asphalt mixture stiffness moduli. Such design is considered to be more effective than empiric one according basic (volumetric) and empiric characteristics which are stated in Catalogue sheet of asphalt mixtures. Besides results by which help the accordance is verified, the problem is determination of so called input data in design and calculation of pavement structures. Calculations of pavement structures models have shown which rules for stiffness ratio (elastic moduli) of adjacent layer materials are appropriate. Besides stiffness moduli it is necessary to require the flexural strength and resistance to permanent deformation. In semi-rigid pavement only the asphalt mixture layer causes the creation of ruts.
Energy consumption in production and proceeding of various types of asphalt mixtures is different. It depends on concrete technology whereby the use of WMA technologies and recycling in Slovakia is going forward very slow. There are applications of particular WMA technologies in Slovakia but in comparison with other countries it is minimal percentage; the most used technology is still HMA. By use of more environmentally acceptable technologies it is possible to reduce the emission production. Results of these technologies in abroad only confirm the justification of their application from the view of energy savings and greenhouse gasses production.

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