Improvements regarding the procedure of rutting prediction of asphalt pavements

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ABSTRACT

In terms of the verification to the fatigue of asphalt pavements by using the method of the RDO Asphalt 09 a lot of experiences could be gained. These experiences were used to advance the technical regulations. On the other side the valuation of the deformation behavior of asphalt pavements is currently based on the assessment of the rutting on the basis of deviatoric equivalent stresses. With this procedure only comparative assessments of different designs and materials can be made. So the plastic deformation properties of the materials are not considered. Furthermore, no information of the temporal plastic deformation behavior of the construction, as well as the depth of the ruts at a specific time of usage can be made. In recent years there have been made some improvements to the method of the prediction of rutting. Now all load conditions were used, which are taken into account in the dimensioning process. For the different stress conditions triaxial or uniaxial cyclic compression tests on slim specimens were made to determine material-dependent impulse creep curves and then they were described based on a model. In this paper, the statistical material model of the deformation behavior and the improvements regarding the procedure of the prediction of rutting are explained and results of calculations are presented.

Keywords: Design of pavement, Mechanical Properties, Performance testing, Stone Mastic Asphalt

1. INTRODUCTION

The assessment of the permanent deformation behaviour of asphalt pavements with the current german standard of computational dimensioning of pavement structures (RDO Asphalt 09) is done only by estimating the rutting on the basis of comparison deviatoric stresses. The scale for it is the maximum of the occurring deviatoric stresses in the asphalt surfacing and asphalt binder course (or in absence of the binder course: upper 12cm of the asphalt pavement) at the highest axle load of the dimensioning process. But with this procedure only comparative assessments of different constructions and materials can be made for estimating the rutting susceptibility. The permanent deformation properties of materials are not considered and a statement on the temporal plastic deformation behaviour of the pavement and the rut depth after any period of usage can therefore not be made.

Furthermore the current version of RDO Asphalt proposes a further procedure for the evaluation of the deformation behaviour. It's a uniaxial cyclic compression test, where the maximum of the calculated deviatoric stresses inside the asphalt surfacing and asphalt binder course under a specific condition (highest occurring temperature and maximum permissible axle load 11,5t) and a slender specimen (h=200mm, d=100mm) were used.

These laboratory studies of permanent deformation behaviour have to be made for asphalt surfacing and asphalt binder materials. The determined impulse creep curves (increase of the permanent deformations depending on the number of loading cycles) of these experiments are used to assess the plastic deformation behaviour of asphalts. Because of the consideration of only one loading condition in this procedure only comparative assessments can be made. The procedure for description of the deformation behaviour needs to be extended and adapted for the estimation of future maintenance procedures / maintenance intervals.

Wellner et al. [1], Kayser et al. [2], Geike et al. [3] and Dragon et al. [4] developed a methods for rutting prediction that uses all loading conditions, which are considered in the dimensioning process. For different stresses material-dependent impulse creep curves are determined by using triaxial tests and uniaxial cyclic compression tests and then described by a model. The calculation of the ruts is made by accumulating the permanent deformations of the different loading conditions by considering the deformation history. Although, because of the missing calibration, the rut depths calculated with this procedure are only fictive, a far better constructive and monetary evaluation of deformation behaviour of the materials and the entire construction is possible.

2. MODELLING OF THE PAVEMENT DEFORMATION BEHAVIOUR

The property that is relevant for the description of the permanent deformation of asphalt pavements is the so called impulse creep curve. This function is defined by the developing of the permanent axial deformations of asphalt specimen depending on the number of loading cycles under specific loading conditions. The impulse creep curve, which are necessary for the rutting prediction, were determined by triaxial tests, where any multiaxial stress conditions could be realized [2]. Because of its three dimensional stress condition the triaxial test is especially suited for investigating the material behaviour as realistically as possible.

Geike et al. [3] determined the impulse creep curve for the creation of the statistical material model for the description of the permanent deformation behaviour with an asphalt surfacing material (SMA 11 S), an asphalt binder course material (AC 16 B S) and an asphalt base course material (AC 22 T S). This was done with triaxial tests on specimens with a diameter of 150 mm and a height of 300 mm and under varying the deviator and the temperature. Due to the immense effort associated with the preparation of the specimens and the experimental procedure not all stress conditions, which occur in the asphalt pavement and which are relevant for a realistic rutting prediction, could be tested with triaxial tests. The stress conditions, which were examined by Geike et al. (Table 1), were the basis of the following statistical modelling of the deformation behaviour.

Dragon et al. [4] used for the verification of the statistical material model of Geike et al. [3] an asphalt surfacing material (SMA 8 S) and the uniaxial cyclic compression test with specimens that got a diameter of 100mm and a height of 200mm. By varying the deviator ($\sigma_{DEV}=\sigma_1$, because $\sigma_{2/3}=0$) and the temperature the determination was twice. The chosen combination of temperatures and stresses are shown in Table 2.

The testing of the specimens were done in both research projects with a force controlled harmonic sinus load without loading interruption and with a defined top and under load. The test frequency was f=10Hz. The determined permanent axial strains ε_{plN} of the triaxial tests and the uniaxial cyclic compression tests and the number of loading cycles N were approximated with a regression and the method of the least square differences to the impulse creep curve. This happened on the basis of the TP Asphalt-StB, part 25 B1. The function to the turning point can be described as follows (see Figure 1):

$$\varepsilon_{plN} = a \cdot \log_{10}(N+1)^b \tag{1}$$

a, b parameters of regression of the impulse creep curve

Table 1: Testing program for the triaxial tests [2]

T [°C]	σ_{O1} [MPa]	$\sigma_{O2/O3}$ [MPa]		
30	0,80	0,20	0,30	0,40
	1,00	0,25	0,35	0,45
	1,20	0,25	0,35	0,45
40	0,80	0,20	0,30	0,40
	1,00	0,25	0,35	0,45
	1,20	0,25	0,35	0,45
50	0,80	0,20	0,30	0,40
	1,00	0,25	0,35	0,45
	1,20	0,25	0,35	0,45

Table 2: Testing program for the uniaxial cyclic compression tests [4]

T [°C]	σ_{O1} [MPa]				
20	0,30	0,40	0,50	0,60	0,70
30	0,20	0,30	0,40	0,50	0,60
40	0,20	0,30	0,40	0,50	0,60
50	0,10	0,20	0,30	0,40	0,50

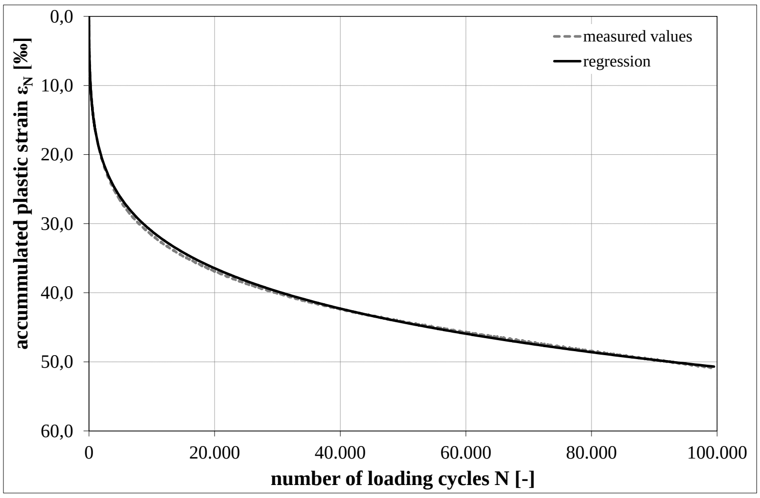

Figure 1: Example of an impulse creep curve

The regression parameters of the impulse creep curve can be presented in dependence on the respective test conditions. Out of these results a statistical model should be derived. For this considerations Geike et al. [3] used the approach of Beckedahl et al. [5], which concluded the permanent out of the elastic displacements.

The dependence of the permanent strains $\varepsilon_{ini,pl}$ from the initial elastic strains $\varepsilon_{ini,el}$, which were determined with the uniaxial cyclic compression test, is shown exemplary in Figure 2. The determination of the permanent axial strains was done at the number of 100 loading cycles. The determination of $\varepsilon_{ini,el}$ is according to the method, that is described in the AL Sp-Asphalt 09. The relationship between $\varepsilon_{ini,pl}$ and $\varepsilon_{ini,el}$ can be described by:

$$\varepsilon_{ini,pl} = c_0 \left(\left| \varepsilon_{ini,el} \right| \right)^{c_1} \tag{2}$$

c_0, c_1	regression parameters of the impulse creep curve
$\varepsilon_{ini,el}$	initial elastic strain at the number of 100 loading cycles
$\varepsilon_{ini,pl}$	permanent axial strain at the number of 100 loading cycles

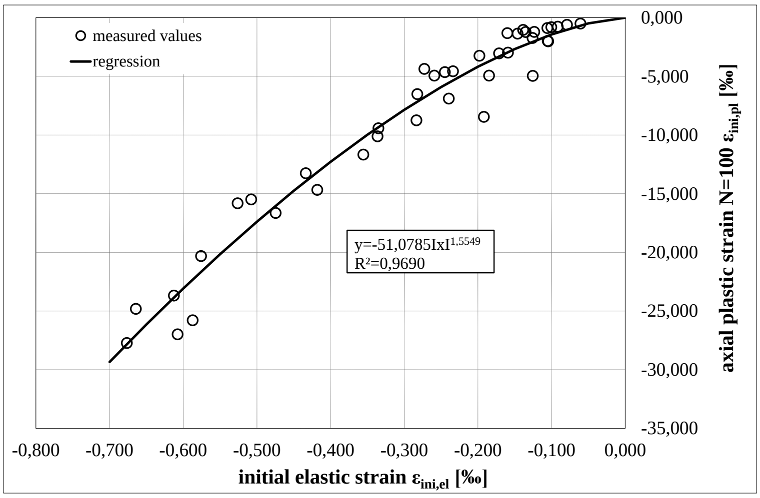

Figure 2: Permanent strain $\varepsilon_{ini,pl}$ at the Number of 100 loading cycles into dependence of initial elastic strain $\varepsilon_{ini,el}$, results of uniaxial cyclic compression tests [4]

So it could be checked in the next step, if there is a functional relationship between the parameters of the impulse creep curve of equation (1) a_{axial} and b_{axial} and $\varepsilon_{ini,el}$. Figure 3 to Figure 4 show graphically the dependence of the results of the triaxial tests of Geike et al. [3] and Figure 5 to Figure 6 of the results of the uniaxial cyclic compression tests of Dragon et al. [4]. The following functional relationship between a_{axial} and $\varepsilon_{ini,el}$ can be made:

$$a_{axial} = a_0 \cdot \left|\varepsilon_{ini,el}\right|^{a_1} \tag{3}$$

a_{axial}	regression parameter of the impulse creep curve [-], $a_{axial}(0)=0$
$\varepsilon_{ini,el}$	initial elastic strain [‰], $\varepsilon_{ini,el} \leq 0$
a_0, a_1	regression parameter

The following model equation can be assumed for the functional relationship between b_{axial} and $\varepsilon_{ini,el}$:

$$b_{axial} = b_1 \cdot \ln\left|\varepsilon_{ini,el}\right| + b_0 \tag{4}$$

b_{axial}	parameter of the impulse creep curve [-]
$\varepsilon_{ini,el}$	initial elastic strain [‰], $\varepsilon_{ini,el} \leq 0$
b_0, b_1	regression parameter

Table 3: Regression parameters of a_{axial} and b_{axial} of the impulse creep curve into dependence of $\varepsilon_{ini,el}$

material	**SMA 11 S**	**AC 16 B S**	**AC 22 T S**	**SMA 8 S**
Test	Triaxial test	Triaxial test	Triaxial test	Uniaxial cyclic compression test
a_1	1,6510	1,4000	2,9130	2,2281
a_0	-2,0510	-2,2730	-8,6610	-16,0860
b_1	-0,8950	-0,6675	-1,1940	-0,7530
b_0	0,6663	0,3853	-0,2167	1,8280
$R^2(a)$	0,9109	0,9547	0,8916	0,9399
$R^2(b)$	0,8184	0,8365	0,8615	0,7422

The estimated regression parameters according to the model approaches of equation (3) and (4) of the examined variations are summarized in Table 3. The relatively high coefficients of determination, which are mostly larger than

0,8, show that the discovered model equations describe the dependence of the parameters of the impulse creep curve a_{axial} and b_{axial} of the initial elastic strains $\varepsilon_{el,anf}$ very well.

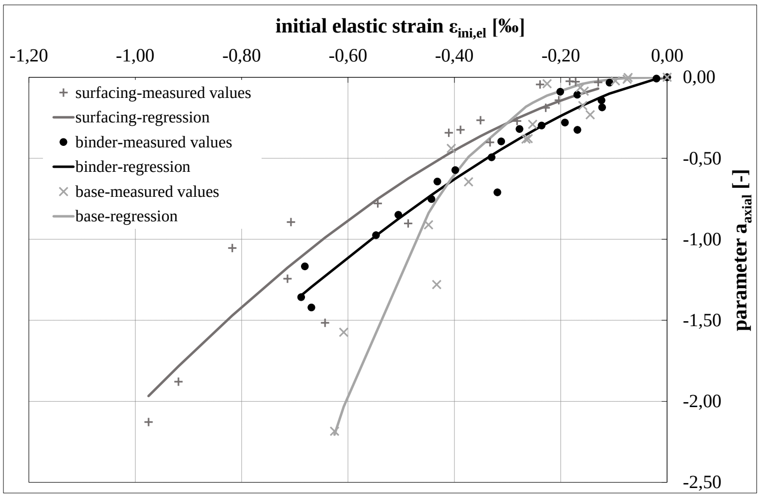

Figure 3: Regression parameters a_{axial} of the impulse creep curve into dependence of the initial elastic strain $\varepsilon_{ini,el}$, results of triaxial tests [3]

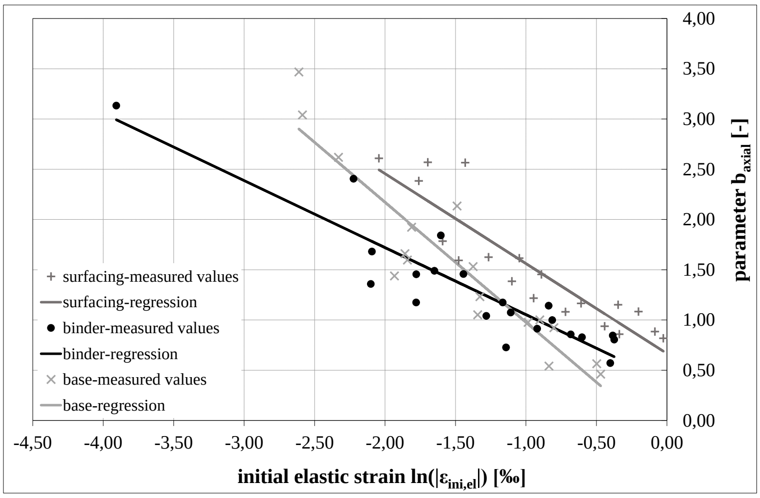

Figure 4: Regression parameter b_{axial} of the impulse creep curve into dependence of the initial elastic strain $\varepsilon_{ini,el}$, results of triaxial tests [3]

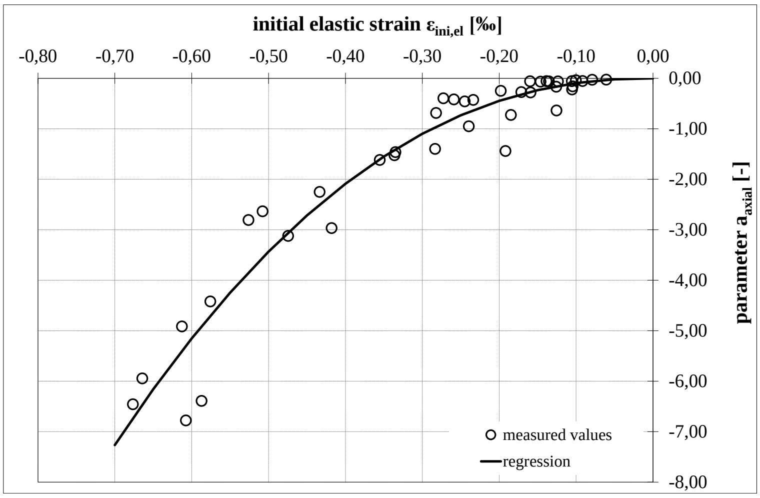

Figure 5: Regression parameter a_{axial} of the impulse creep curve into dependence of the initial elastic strain $\varepsilon_{ini,el}$, results of uniaxial cyclic compression tests [4]

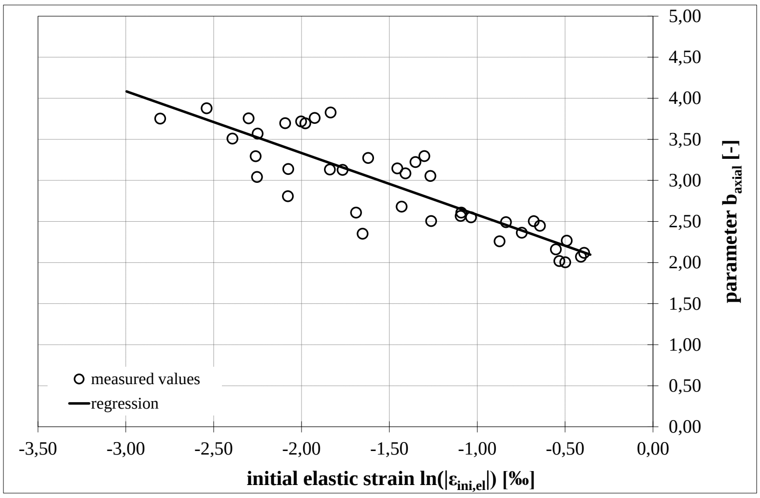

Figure 6: Regression parameter b_{axial} of the impulse creep curve into dependence of the initial elastic strain $\varepsilon_{ini,el}$, results of uniaxial cyclic compression tests [4]

3. DESCRIPTION OF THE PROCEDURE OF THE RUTTING PREDICTION

The gained knowledge of Wellner et al. [1] and Kayser et al. [2] in terms of a procedure for the rutting prediction in asphalt pavements could be developed in the research project “Development and adaptation of predicting methods for estimating the structural substance and the rutting as the basis of risk analysis” by Geike et al. [3].

The impulse creep curves determined with triaxial tests and uniaxial cyclic compression tests describe the progress of the permanent axial deformation of an asphalt specimen into dependence of the number of loading cycles at specific loading conditions. The model parameters a_{axial} and b_{axial} of the impulse creep curve (equation (1)) are depending on the initial elastic strain in the specimen (chapter 2). The impulse creep curves can be estimated for any loading conditions after the model parameters a_{axial} and b_{axial} are determined.

3.1 Determination of the strains in the asphalt pavement

The stiffness module temperature function is needed for the determination of the elastic strains in the asphalt pavement based on the linear elastic material model which is used because of the less calculation time.

The strains in each layer or element of the road model were calculated with the stiffness module for a certain asphalt pavement. They always refer to a defined loading condition. Each loading condition is characterized by a defined traffic load and a defined temperature distribution along of each construction layer [2]. The calculation of the strains is made for the different load conditions, which are relevant for the prediction.

3.2 Prediction of the permanent deformation behaviour

The accumulation of the permanent strains is made from the lowest to the highest loading condition in the procedure of Wellner et al. [1] for the rutting prediction. The developed procedure of Kayser et al. [2] uses additionally random processes for the load magnitude and, because of its relevance and to save calculation time, only temperatures above 20°C. Geike et al. [3] and Dragon et al. [4] modified the procedure of Kayser in the way that a loading condition is now defined by the calculated elastic strain. So the relationship between loading condition and permanent strain can be made with impulse creep curves, which are dependent of the elastic strain (see chapter 2). Each loading condition is a specific combination of a temperature and a traffic load. The procedure of Kayser et al. [2] uses any number of loading cycles that depends on the probability of the load magnitude of each loading condition. In this procedure not only the combinations of the load magnitude (temperature and traffic load) are random, the order of the loading conditions is it too. This procedure was already described in detail by Kayser et al. [2] and the explanation of the development of the accumulation process was made by Dragon et al. [4].

The permanent strains can be determined for any order of loading conditions k_B and amounts of loading cycles ω with this developed accumulation process.

The absolute deformation of each layer or element is calculated by multiplying the permanent strain of this layer or element η with the thickness of this layer or element d_η. The permanent vertical deformation of the asphalt pavement U_{perm} were determined by summation of the absolute deformation of all layers or elements:

$$U_{perm} = \sum_{\eta=1}^{\lambda} \left(\frac{d_{\eta} \cdot \varepsilon_{\omega,k_B,\eta}}{1000} \right) \tag{5}$$

U_{perm}	total permanent vertical deformation of the asphalt pavement [mm]
$\varepsilon_{\omega,k_B,\eta}$	permanent axial strain for each loading condition k_B and amount of loading cycles ω [‰]
d_{η}	thickness of the layer or element η [mm]

It is possible to use phase specific material parameters for the strain behaviour because of the independent consideration of phases of compression and tension. Until now there were no research projects for the tensile behaviour of asphalt materials. That is the reason, why the simplified assumption was made, that the impulse creep curve of a material are equal for the compression and the tensile behaviour.

The maximum of the average of the right and left rut depth MSPT in mm according to the ZTV ZEB-StB is the measure of the permanent vertical deformation in the cross section. Because of the fact, that fictive asphalt pavement has no crossfall the right and left rut depth are equal. The calculation of the total vertical permanent deformation U_{perm} of the pavement was done with equation (5) for a number of locations y_i in the cross section for the pavement life of 30 years (see Figure 7 and **Error! Reference source not found.**) to determine the maximum rut depth MSPT. 1.000 single prediction calculations with a different random load order were done with the random procedure of Kayser et al. [2]. So 1.000 results of U_{perm} for each location y_i of the cross section were obtained. A frequency distribution which is similar to the normal distribution (see Figure 8) is gained by discretising the results of the prediction calculations. So for each location y_i the average of 1.000 prediction calculations of the total permanent vertical deformation can be calculated. The maximum of the rut depth $MSPT_{ND}$ per year is (see also Figure 9):

$$MSPT_{ND} = \max U_{perm,ND} - \min U_{perm,ND} \tag{6}$$

$MSPT_{ND}$	maximum of the rut depth per year of pavement life [mm]
$\max U_{perm,ND}$	maximum of the total vertical permanent deformation of the asphalt pavement per year of pavement life [mm]
$\min U_{perm,ND}$	minimum of the total vertical permanent deformation of the asphalt pavement per year of pavement life [mm]

Table 4: Statistical calibration distribution of yearly asphalt surface temperatures and temperature patterns (%) [8]

T_{OF} [°C]	ncT1	ncT2	ncT3	ncT4	ncT5	ncT6	ncT7	ncT8	ncT9	ncT10	ncT11	ncT12	Σ
-12,5	0,040	0,400	0,020										0,46
-7,5	0,440	1,780	0,080										2,30
-2,5	2,200	5,800	0,360	0,020			0,040						8,42
2,5	5,460	9,900	0,860	0,080	0,020	0,080	0,180	0,040					16,62
7,5	5,480	7,860	1,300	0,240	0,100	0,200	0,400	0,140					15,72
12,5	3,560	5,500	2,160	0,440	0,260	0,320	0,540	0,340				0,040	13,16
17,5	2,420	4,400	2,800	0,620	0,500	0,520	0,840	0,660	0,020		0,040	0,100	12,92
22,5	1,680	2,480	2,040	0,960	0,740	0,740	0,960	0,980	0,080	0,040	0,120	0,200	11,02
27,5	0,820	0,820	0,680	1,220	1,080	0,860	0,600	0,860	0,120	0,140	0,240	0,340	7,78
32,5	0,180	0,120	0,080	0,960	1,160	0,620	0,180	0,340	0,260	0,300	0,400	0,380	4,98
37,5				0,420	0,760	0,260		0,040	0,360	0,500	0,520	0,200	3,06
42,5				0,100	0,280	0,060			0,320	0,740	0,460	0,040	2,00
47,5					0,060				0,160	1,060	0,280		1,56
Σ	22,28	39,06	10,38	5,06	4,96	3,66	3,74	3,40	1,32	2,78	2,06	1,30	100,0

Figure 10 presents an example for a predicted developing of the maximum rut depth for the pavement life of 30 years.

The test results (impulse creep curves) can be transferred with the suggested model to all relevant loading conditions (combinations of axle loads and temperature condition). However the meaningfulness of each model depends on the kind and the amount of the tests. How far it could not be verified in both research projects whether the results of uniaxial cyclic compression tests and of triaxial tests corresponds to the reality. The accuracy of the prediction could be substantially improved by adjusting the model in a calibration.

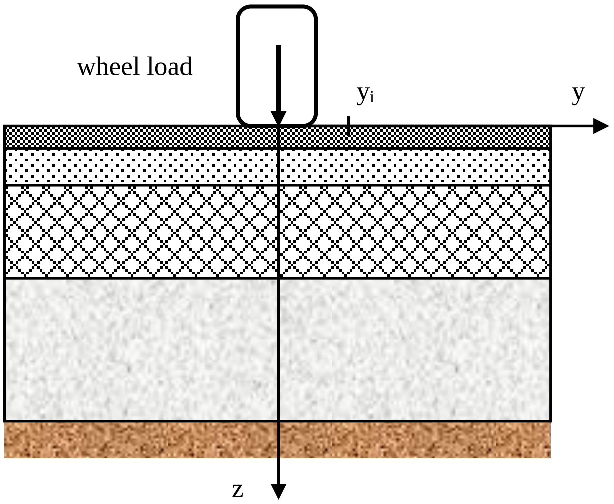

Figure 7: Schematic representation of asphalt pavement with coordinate system

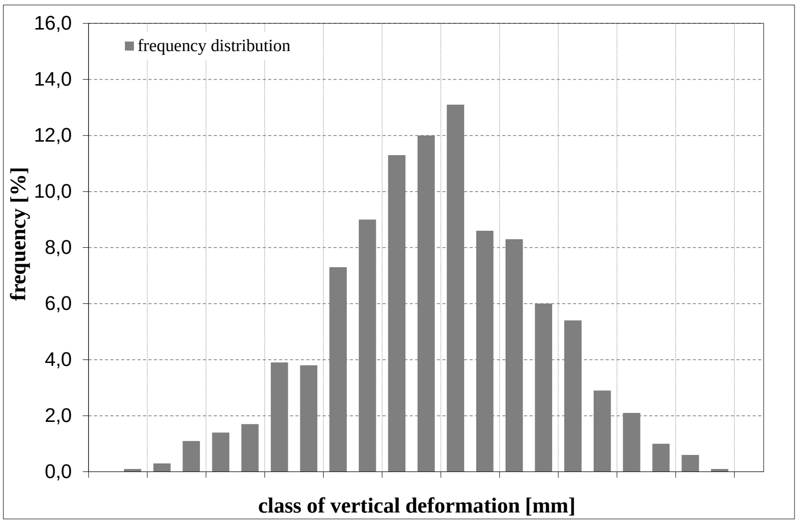

Figure 8: Frequency distribution of the total vertical permanent deformation of an asphalt pavement at y_i

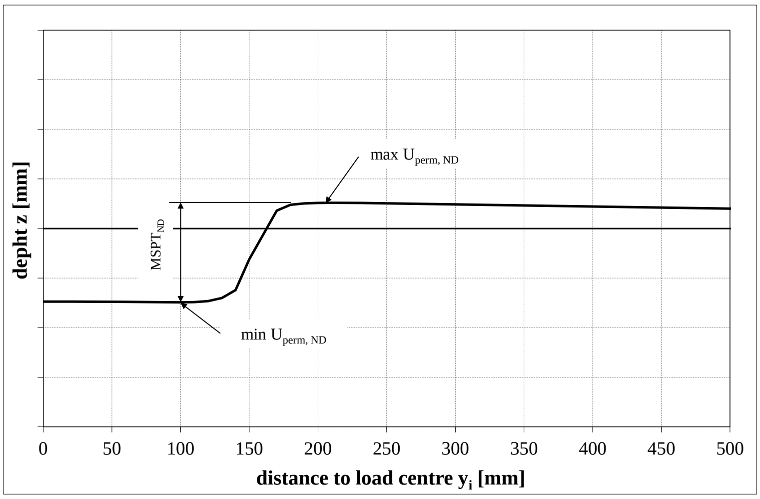

Figure 9: Schematic representation of a calculated rut of an asphalt pavement for a pavement life ND

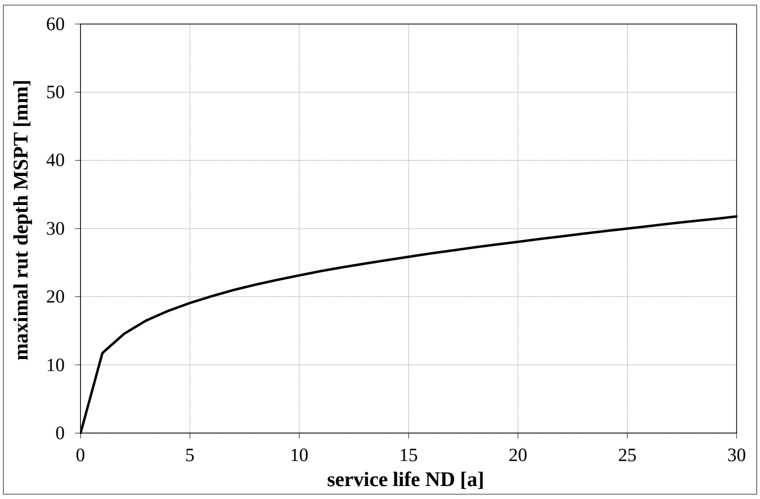

Figure 10: Example of the developing of the maximum rut depth MSPT

4. EXAMPLE CALCULATIONS

4.1 Specifications

The prediction calculations for the rutting with the procedure that is described in chapter 3 were made based on the evaluated and analysed results of laboratory tests. The limit of the maximum rut depth MSPT for the comparative researches was set to 30mm. The following load conditions were assumed for the example calculations:

- Traffic load: traffic load collective “BAB heavy traffic” of the RDO Asphalt 09, B-value of 50Million. AÜ (10t),
- Temperature conditions: temperature developing of Kayser [7]; statistical calibration distribution of the asphalt surface temperatures (see Table 4)

The chosen pavement construction is conform to the RStO 12 (asphalt base course on subbase). The thickness of the frost resistant pavement was set to 75cm. The single asphalt layers are connected by 100%, the other interlayers (asphalt base course / subbase, subbase / subgrade) are at 0%. The bearing ratio on top of the subbase was 120N/mm² and on top of the subgrade 45N/mm². The example calculations were made only with the test results of the uniaxial cyclic compression tests, because there were no representable results of the rutting progression with the results of the triaxial test without using a shift factor.
The calculation examples vary regarding to (see Table 5):

- material parameters of asphalt layers,
- thickness of asphalt surfacing and asphalt binder course

Table 5: Boundary conditions for the example calculations

variant	V01	V02	V03	V04	V05
SMA 8 S, variant 1	X	-	X	-	X
SMA 8 S, variant 2	-	X	-	X	-
AC 16 B S, variant 1	X	X	-	-	X
AC 16 B S, variant 2	-	-	X	X	-
AC 22 T S, variant 1	X	X	X	X	X
thickness asphalt surfacing [cm]	4,0	4,0	4,0	4,0	2,0
thickness asphalt binder course [cm]	8,0	8,0	8,0	8,0	10,0
thickness asphalt base course [cm]	22,0	22,0	22,0	22,0	22,0
thickness subbase [cm]	41,0	41,0	41,0	41,0	41,0

The used stiffness module temperature function of the researched asphalt are shown in Figure 11. The model parameters of the asphalt variants wich were used for the functional relationship between the regression parameters of the impulse creep curve a_{axial} and b_{axial} and the initial elastic strain $\varepsilon_{ini,el}$ (see equation (3) and (4)) are represented in Table 6.

The results of the prediction calculations can only be used for comparative statements of the asphalt pavements because there is no procedure validation and calibration of the prediction procedures of Geike et al. [3] and Dragon et al. [4].

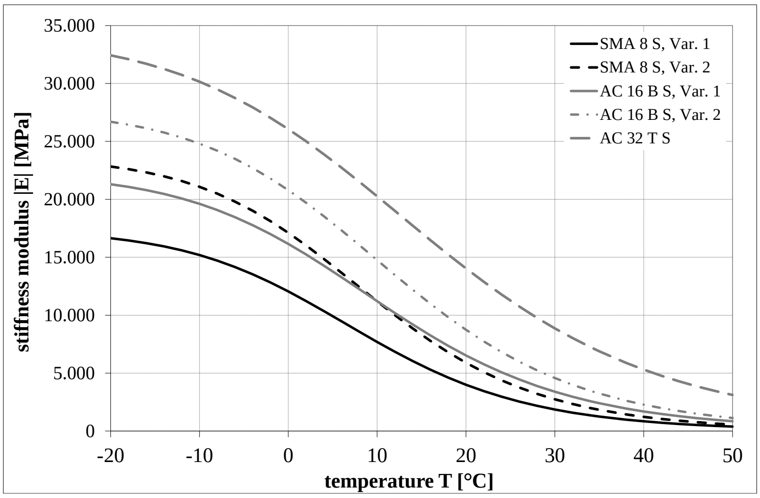

Figure 11: Stiffness module temperature functions

Table 6: Regression parameters of a_{axial} und b_{axial} of the impulse creep curve into dependence of $\varepsilon_{ini,el}$ for the example calculations

material	SMA 8 S, variant 1	SMA 8 S, variant 2	AC 16 B S, variant 1	AC 16 B S, variant 2	AC 32 T S, variant 1
a_1	2,2281	1,7997	2,0494	2,4290	2,7856
a_0	-16,0860	-18,6268	-15,9595	-14,5674	-15,1269
b_1	-0,7530	-0,7987	-0,9209	-1,0429	0,9002
b_0	1,8280	1,2656	1,2106	1,5282	0,8532

4.2 Results

Figure 12 illustrations the calculated relative moment, where the researched asphalt pavements reached the set MSPT of 30mm regarding to the comparison variant V01. The absolute results of the usage times for the set MSPT are represented in Table 7. Table 7 shows that the initial variant V01 reached the set MSPT of 30mm after nearly 6 years.
The greatest influence could be noticed for the deformation resistant asphalt surfacing material (variant V02) and for the combination of the deformation resistant asphalt materials of the asphalt surfacing and asphalt binder course (variant V04). The MSPT of 30mm were reached in 3,5 times respectively 5 times of the time of the reference variant V01. Apparently the changes of the material parameters of the asphalt binder course has less influence, because the variant V03 reached MSPT already after 1,3 times of the predicted time of the reference variant. By reducing the thickness of the asphalt surfacing (from 4cm to 2cm) and a simultaneous increase of the thickness of the asphalt binder course (from 8cm to 10cm) the time to reach the MSPT extents to the double, how the variant V05 shows. The construction of this variant is equivalent to a compact asphalt pavement. The calculation results correspond to the aim of this kind of pavement, the high deformation resistance.

Table 7: Results of the calculation variants

variant	description / influence	pavement life at MSPT = 30mm [a]
V01	reference variant	6
V02	asphalt surfacing material	21
V03	asphalt binder course material	8
V04	asphalt surfacing and binder course material	30
V05	thickness asphalt surfacing and asphalt binder course	12

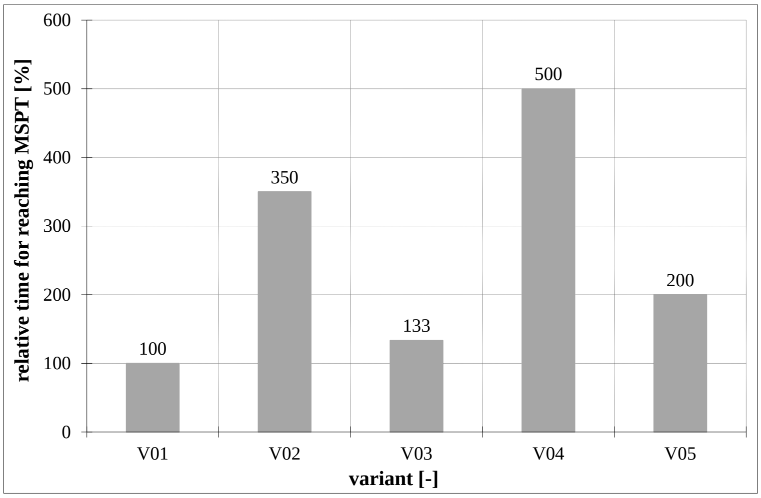

Figure 12: Relative comparison of the time, in which the maximum rut depth MSPT for the examined asphalt pavement were reached

5. SUMMARY AND OUTLOOK

The results of the prediction of the rutting progress on the basis of the elastic initial strains show that there is the possibility to sort the different asphalt materials and the changes of the thicknesses of the asphalt layers regarding to resistance against the permanent deformations with the used procedure. The determined ranking of the considered asphalt construction variants confirms essentially the relationships in practice. These relationships are for example that a softer asphalt surfacing (SMA 8 S, V01) got the higher tendency of rutting than a harder one (SMA 8 S, V02) and the reduction of the thickness of the asphalt surfacing increases the resistance against permanent deformations.

Even if it is possible to sort the asphalt constructions with this procedure in that way, it is unclear how good the test results of the uniaxial cyclic compression tests, which are the basis of this ruts prediction procedure, corresponds to the reality. The material behaviour at tensile stress and the influence of the loading frequency to the assumed model are both still topics of interest.

It is not possible to predict an exact chronology of the rutting progress with the procedure because of the missing validation and calibration. The validation is necessary for the future acceptance and usage of this prediction procedure. Only then it could include in an effective working system of road maintenance. So this validation should urgent be part of further research projects. In such a project the procedure should also be extended by approaches for the susceptibility to cracking.

Even if there are a lot of unanswered questions, this procedure is a huge development regarding to the procedure which is written in the German regulations of the RDO Asphalt 09.

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