Sustainability & Environment

Modelling the nonlinear behavior of unbound granular materials in flexible pavements with thin asphalt layer

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Abstract

In Germany, roads are usually constructed empirically with a minimum asphalt surface layer of 120 mm. Experience from other countries shows, however, that it is possible to build flexible pavements with thin asphalt wearing courses of 40 to 50 mm and a satisfactory service life. The advantage of such constructions is that they require less material and energy resources and can be realized quickly and cost-effectively compared to thicker asphalt structures. This is especially interesting for low volume roads. To analyse the overall behaviour of a road construction, respectively the performance of each pavement layer in dependence of all acting thermic and traffic conditions, a mechanistic empirical design approach should be applied. In case of flexible pavements with thin asphalt layers the nonlinear behaviour of unbound granular materials in unbound granular base layers must be considered. This contribution presents selected results of a research about the performance and durability of flexible pavements realized with one thin single asphalt layer. The research carried out covers a wide range of widely used unbound base materials and asphalt mixes, both with large quality differences and under consideration of a wide span of temperature and traffic conditions as well as construction types. The performance of the selected construction types was modelled using the finite element method. For the unbound base course materials, among others, a nonlinear stress dependent material model describing both material dependent stiffness and Poisson's ratio was used after comprehensive validation. With the help of finite element modelling the input data for design life calculation can be provided to analyse the overall behaviour of flexible pavements with thin asphalt layers taking into account nonlinear material behaviour.

This paper was first published in 2020 in version 1.0 of the proceedings of the 7th E&E Congress. This second edition (version 1.1.) of the proceedings is published in June 2021. The content of this paper has not changed, but the author(s) may have provided additional information in the form of an annex.

1. INTRODUCTION

In Germany, roads are usually constructed empirically with a minimum asphalt surface layer of 120 mm. However, experiences from other countries shows, however, that it is possible to build flexible pavements with thin asphalt wearing courses of 40 to 50 mm and a satisfactory service life. The advantage of such constructions is that they require less material and energy resources and can be realized faster and more cost-effectively compared to thicker asphalt structures. This is especially interesting for low volume roads.

To analyse the overall behaviour of a road construction, respectively the performance of each pavement layer in dependence of all acting thermic and traffic conditions, a mechanistic empirical design approach should be applied. However, the design process for flexible pavements with thin asphalt wearing courses differs from that for standard (thick) asphalt constructions.

It's a well known fact that unbound granular materials show a nonlinear stress dependent behaviour. For “thick” asphalt pavements it can be assumed that the non-linear behaviour of the unbound base course materials has no noticeable influence on the performance of the asphalt layers. Following the stiffness of the unbound layers can be defined as constant within the scope of design procedures. However, in case of flexible pavements with one thin single asphalt layer the nonlinear behavior of unbound granular materials in unbound granular base layers must be considered.

The best known material model to describe the stress dependent material performance of unbound granular materials is the Modified Universal Model. However, this model, as well as other well established models, do not take into account a stress dependent Poisson’s ratio. For the design and analyses of flexible pavements with thin asphalt wearing courses it is indispensable to use a material model describing both the material dependent stiffness and Poisson’s ratio by stress dependent functions.

One model regarding this concern is the DRESDEN Model. This model has been developed and further developed many years before ([1, 2, 3]). However, based on available publications it is not possible to determine the required material parameters for the DRESDEN Model, as communicated by interested scientists.

In the following, the reader is shown a way of reliably determining the material parameters of the DRESDEN Model based on triaxial test results. Limitations of the model and changes recommended for the application of the model are also shown.

With the help of finite element modelling the input data for design life calculations can be provided to analyse the overall behaviour of flexible pavements with thin asphalt layers taking into account nonlinear material behaviour.

2. MATERIALS AND TESTING CONDITIONS

The selection of representative unbound materials was carried out depending on the elastic deformation behaviour of a larger number of materials investigated by triaxial tests conducted within earlier research projects. The materials generally differ from each other with regard to their origin and the adjusted water content. The triaxial test data included in this contribution were carried out by Numrich [4] with the goal to investigate the elastic deformation behaviour of unbound granular materials providing both vertical and horizontal strain components.

Figure 1 shows for a list of preselected materials the relationship between the deviatoric axial strain $\epsilon_{1,d}$ and the applied deviatoric stress σ_d. The order of the material series shown correlate with the water contents present in the materials in relation to the respective optimum water content (taking into account the type of material and particle size distribution). This relationship of water content is given for all materials in brackets at the end of a material name. The number before indicates the absolute difference between optimum and existing water content. Table 1 summarises relevant volumetric information regarding measured densities and water contents of three selected materials. The interested reader can find a breakdown of the graphs in Figure 1 according to material type and particle size distribution in [5]. Additional figures show that there is no linear relationship between the vertical strain components and the ratio of the existing water content to the optimum water content within a material group. This fact should be taken into account, especially in the development of new material laws.

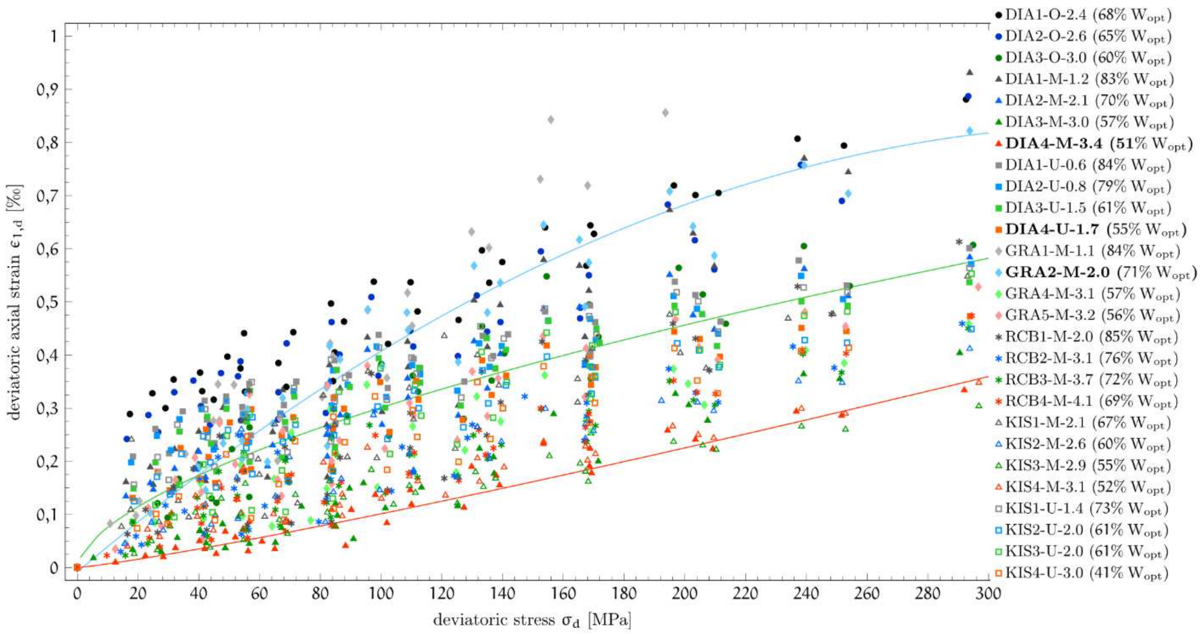


Figure 1: Relationship between deviatoric axial strain $\epsilon_{1,d}$ and applied deviatoric stress σ_d; for selected unbound granular materials analysed by triaxial tests

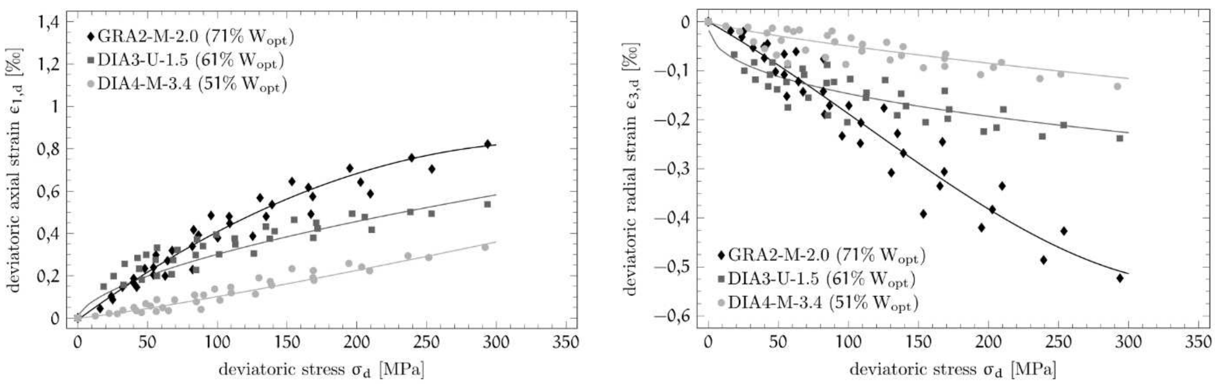


Figure 2: Relationship between deviatoric axial strain $\epsilon_{1,d}$ respectively radial strain $\epsilon_{3,d}$ and applied deviatoric stress σ_d; for selected unbound granular materials analysed by triaxial tests

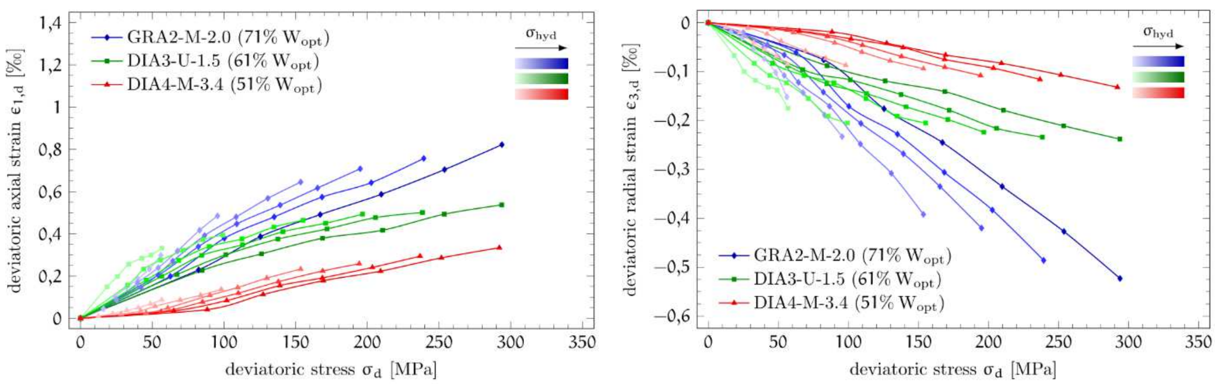


Figure 3: Relationship between deviatoric axial strain $\epsilon_{1,d}$ respectively radial strain $\epsilon_{3,d}$ and applied deviatoric stress σ_d separate for different hydrostatic stress conditions; for selected unbound granular materials analysed by triaxial tests

Most of the materials presented in Figure 1 clearly show a stress dependent material behaviour. However, there are also materials that show almost linear material performance. For three selected materials with clearly different stress-dependent material behaviour the relationship between deviatoric axial strain $\epsilon_{1,d}$ and applied deviatoric stress σ_d is also represented as averaged function. In Figure 2, the underlying data points can be better assigned to the three selected materials for axial and radial loading conditions. Figure 3 additionally shows the same stress path in dependence of the hydrostatic stress conditions.

Table 1. Densities and water contents of the three selected materials

Material name	Material description	Achieved density ρ_d [g/cm³]	Optimal water content W_{opt} [%]	Adjusted (total) water content W_{tot} [%]	Ratio adjusted to optimal water content W_{tot}/W_{opt} [%]
GRA2M2.0	Granodiorite	2.24	7.0	5.0	71.4
DIA3U1.5	Diabase	2.30	3.8	2.3	60.5
DIA4M3.4	Diabase	2.47	7.0	3.6	51.4

Both the Granodiorite material (GRA2-M-2.0) and the Diabase materials (DIA4-M-3.4 and DIA3-U-1.5) can be assigned to material class 0/32.

3. MATERIAL MODEL WITH STRESS DEPENDENT STIFFNESS MODULS AND POISSON'S RATIO

The most widely used material model to describe the stress dependent material performance of unbound granular materials is the Modified Universal Model. However, this model, as well as other well established models, do not take into account a stress dependent Poisson's ratio. For the design and analyses of flexible pavements with thin asphalt wearing courses it is absolutely necessary to use a material model describing both the material dependent stiffness and Poisson's ratio by stress dependent functions.

One model regarding this concern is the DRESDEN Model. This model has been developed and further developed many years before ([1, 2, 3]). However, based on available publications it is not possible to determine the required material parameters for the DRESDEN Model, as communicated by interested scientists. In the following, the reader is shown a way of reliably determining the material parameters of the DRESDEN Model based on triaxial test results. The limitations of the model and changes recommended for the application of the model are also shown. A detailed discussion of the model development is presented in [5].

3.1. Model development

The DRESDEN Model was developed for isotropic elastic behavior of homogeneous solid materials. It is based on Wellner's observations made during plate load tests ([2]). According to these observations, the deformation resistance of unbound granular base course materials increases with increasing compressive stress. The physical formulation of this behaviour was first based on Hertz's theory for the description of the behaviour of sphere packing ([6]).

According to this theory it is assumed that each individual sphere deforms under load, whereby the distance between two centres of gravity changes and a load-dependent deformation of the entire sphere packing results. It is also assumed that with increasing load the pressure between two spheres also increases and thus the contact surfaces between two elements increase. Due to the increase in pressure from the outside and the associated enlargement of the contact surfaces, a resistance against a further approach of the centre of gravity of the spheres is increasingly formed within the individual elements. Hertz describes this load-dependent non-linear behaviour by means of the relationship between the load applied and the resulting change in the distance between two spherical centers of gravity by means of a power function.

The evidence of the transferability of Hertz's theory to unbound granular mixtures, consisting of differently large elements (here single grains), took place by Landau and Liefschitz ([7]) based on similarity considerations. Accordingly, the equations valid for Hertz's theory of spheres can also be applied to packings consisting of individual elements of geometry different to that of spheres. The consideration of the respective geometry (such as shape and size) is done by material-specific parameters to be adapted in the model.

That of Wellner ([2]) and Queck ([1]) defined material model considers both the nonlinear stress-dependent behavior of the stiffness modulus and the Poisson's ratio. The model relations are represented in Equ. (1) and Equ. (2):

$$E_{DM}(\sigma_i) = \left(Q + C \cdot \sigma_I^{Q_1}\right) \cdot \sigma_{III}^{Q^2} + D \qquad \text{Equ. (1)}$$

$$\nu_{DM}(\sigma_i) = R \cdot \frac{\sigma_{III}}{\sigma_{II}} + A \cdot \sigma_I + B \qquad \text{Equ. (2)}$$

With $\sigma_I < \sigma_{II} < \sigma_{III}$ and:

E_{DM}	$[kPa]$	Stiffness modulus	ν_{DM}	$[-]$	Poisson‘s ratio
σ_I	$[kPa]$	Smallest principal stress (absolut value)	R	$[-]$	Material parameter
σ_{III}	$[kPa]$	Largest principal stress (absolut value)	A	$[kPa^{-1}]$	Material parameter
Q	$[kPa^{(1-Q_2)}]$	Material parameter	B	$[-]$	Material parameter
C	$[kPa^{(1-Q_1-Q_2)}]$	Material parameter			
Q_1	$[-]$	Material parameter			
Q_2	$[-]$	Material parameter			
D	$[kPa]$	Material parameter			

The original development of the DRESDEN model was based on the assumption of a rotationally symmetric homogeneous stress state, as it can be expected under conditions such as in the triaxial test. An application of the material model for structures in which locally limited loads are applied (as it is the case when simulating the plate load test or a pavement structure under traffic load) requires the conversion of the stresses considered in the material model into stresses which can also represent inhomogeneous stress states. This means required stresses have to be converted to stresses independent from the coordinate.

If pavement constructions are to be simulated (with homogeneous stress conditions occurring only under the load axis) hydrostatic and octahedral stress conditions (Equ. (3) and Equ. (3)) should be included. The author recommend to adapt the DRESDEN model for these cases by replacing σ_I and σ_{III} according to Equ. (5) and Equ. (6). Since the exponents in the DRESDEN model (Equ. (1)) can be fractional numbers, σ_I and σ_{III} must always be positive. In principle, no tensile stresses are permitted in the DRESDEN model due to the fact that unbound granular materials are not able to absorb tensile stresses.

$$\theta = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3) \qquad \text{Equ. (3)}$$

$$\tau_{oct} = \frac{1}{3}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{1/2} \qquad \text{Equ. (4)}$$

$$\sigma_I = \left| |\theta| - \frac{1}{\sqrt{2}}\,\tau_{oct} \right| \qquad \text{Equ. (5)}$$

$$\sigma_{III} = \left| |\theta| + \sqrt{2}\,\tau_{oct} \right| \qquad \text{Equ. (6)}$$

3.2. Parameter determination

On the basis of Hertz's ball theory shortly explained above, the axial and radial strain components in a rotationally symmetric system (comparable with the changes in the distance between two element centers of gravity) are composed as follows:

$$\epsilon_1 = L \cdot \sigma_1^{1-\omega} - M \cdot \sigma_3 \qquad \text{Equ. (7)}$$

$$\epsilon_3 = F \cdot \sigma_1 - G \cdot \sigma_3^{1-\omega} \qquad \text{Equ. (8)}$$

With:

$\sigma_1; \sigma_3$	$[kPa]$	axial; radial stress
$\epsilon_1; \epsilon_3$	[‰]	axial; radial strain
ω	$[-]$	stress exponent according to Hertz; $\omega = 1/3$ [6]
L; F	$[kPa^{-(1-\omega)}]$	factors in the relations of the rotationally symmetric stress state
M; G	$[kPa^{-1}]$	factors in the relations of the rotationally symmetric stress state

L and M as well as F and G are material-dependent parameters which, according to the former idea of development, are to be determined experimentally on the basis of triaxial tests. This means that the material-dependent parameters L, M, F and G were originally determined by evaluating a system of equations by including at least two value pairs of strains, determined in the test at different stress ratios σ_1/σ_3 and constant radial stress conditions σ_3. The author recommends, in the context of such a stepwise parameter determination, to determine the parameters L, M, F and G under consideration of a complete group of value pairs ($L_{\sigma_3,i}$; $M_{\sigma_3,i}$ respectively $F_{\sigma_3,i}$; $G_{\sigma_3,i}$) for $\sigma_{1,variabel}$ and $\sigma_{3,constant}$ and then to determine the mean value for each parameter set. This results in a material-dependent parameter pair L; M and F; G for each material. It must be pointed out that, for this approach, for σ_3, the target values must be used instead of the actual applied stresses. One completely discussed example including all calculation steps and intermediate results (for three materials) is reported in [5].

If a rotationally symmetrical stress state is assumed, the axial strain ϵ_1 and the radial strain ϵ_3 can also be formulated as follows after Hooke (Equ. (8) and Equ. (9)):

$$\epsilon_1 = \frac{1}{E}[\sigma_1 - 2\nu \cdot \sigma_3] \qquad \text{Equ. (9)}$$

$$\epsilon_3 = \frac{1}{E}[\sigma_3 - \nu(\sigma_3 + \sigma_1)] \qquad \text{Equ. (10)}$$

$$\epsilon_1 = \frac{L}{\sigma_1^{1/3}}\left(\sigma_1 - \frac{\sigma_1^{1/3}}{L} \cdot \sigma_3\right) \qquad \text{Equ. (11)}$$

$$\frac{1}{E}[\sigma_1 - 2\nu \cdot \sigma_3] = \frac{L}{\sigma_1^{1/3}}\left(\sigma_1 - \frac{\sigma_1^{1/3}}{L} \cdot \sigma_3\right) \qquad \text{Equ. (12)}$$

$$E_{cal} = \frac{\sigma_1^{1/3}}{L} \qquad \text{Equ. (13)}$$

$$\nu_{cal} = \frac{M}{2L} \cdot \sigma_1^{1/3} \qquad \text{Equ. (14)}$$

To convert in the next step Equ. (7) into Equ. (9), exemplary for ϵ_1, Equ. (9) has to be extended by the term $\frac{\sigma_1^{1/3}}{L}$ so that Equ. (11) follows. The axial strain ϵ_1 in Equ. (9) is now equated with the strain ϵ_1 in Equ. (11). A coefficient comparison can now be used to derive a calculated stiffness modulus E_{cal} (Equ. (13)) and a calculated Poisson's ratio ν_{cal} (Equ. (14)) from Equ. (12).

The index "cal" indicates that these are calculated characteristic values. E_{cal} and ν_{cal} are determined, even if only indirectly, from the strains determined in the triaxial test and are thus used as a kind of reference values (representative for "measured values") for the stiffnesses E_{DM} and the Poisson's ratios ν_{DM} to be calculated with the DRESDEN Model. Equ. (13) and Equ. (14) show that, if the above-mentioned Hertz's sphere theory is cosidered, both the stiffness modulus and the Poisson's ratio are stress dependent.

After determining E_{cal} and ν_{cal} the model parameter in the model functions have to be determined. To calculate in the next step the stiffnesses E_{DM} and the Poisson's ratios ν_{DM} the model parameters in Equ. (1) and Equ. (2) must be varied until the deviations between the measured values (here calculated values) and the model results are minimal. Various mathematical approaches are available to the user for this purpose. Mostly, approximation methods are used for similar mathematical problems. As the number of model parameters increases and the functional approach becomes more complex (here: material model), the reliable determination of model parameters generally increases, depending on the approximation method used.

Originally, the developers of the DRESDEN Model used a step-by-step determination of the model parameters, one step for each constant σ_3. It is assumed that this was favored, since a computer-aided determination of the model parameters was largely impossible at the time the DRESDEN Model was developed. This contribution does not explain this originally intended step-by-step determination of the model parameters. The author recommend, based on extensive research, the use of evolutionary algorithms, such as those provided by Microsoft Excel, for the regression of nonlinear multidimensional functions instead of a step-by-step approach. In this case, the model parameters for one function are determined together by means of regression tests, taking into account all data sets (or selected data sets) resulting from different stress states ($\sigma_{1,variabel}$ and $\sigma_{3,variabel}$) of a multistage test. In detail, this means that the material dependent model parameters must be determined separately for the stress-dependent model functions of stiffness modulus E_{DM} and Poisson's ratio ν_{DM} . The resulting strain (here: axial strain) $\epsilon_{1,g}$ must then be calculated from the stiffness modulus E_{DM} and the Poisson's ratio ν_{DM} according to Equ. (9).

Figure 4 shows exemplary for the material Granodiorite GRA2-M-2.0 the calculated stiffness modulus E_R (based on measured values), Poisson's ratio ν_R and axial strain $\epsilon_{1,g}$ in comparison to the model results $E_{DM,I/II}$, $\nu_{DM,I/II}$ and $\epsilon_{1,g,I/II}$. The indexes "I" and "II" indicate different regression approaches. "I" means that the complete available data set was included in the regression. "II" marks the results which base on reduced data sets. Analyses of all data sets (see Figure 1) show in most cases during the first load stages a material behavior that deviates from the remaining load stages. It is suspected that this is caused by post-compaction processes during the first load stages of the conducted triaxial tests. The author therefore recommends to neglect the first conspicuous load levels when determining model parameters as they are not to be regarded as representative for the investigated materials. However, it must be respected, that the same data set must be used to determine the model parameters of the stiffness modulus function and the Poisson's ratio function independently of each other. As expected, the consideration of reduced data sets (II) led to significantly better regression results in the investigated cases than in the case of non-reduced data sets (I). In principle, at least four data sets were included in the determination of the material parameters. In the graphs in Figure 4, six optically connected data points belong to one load stage of the same radial stress σ_3.

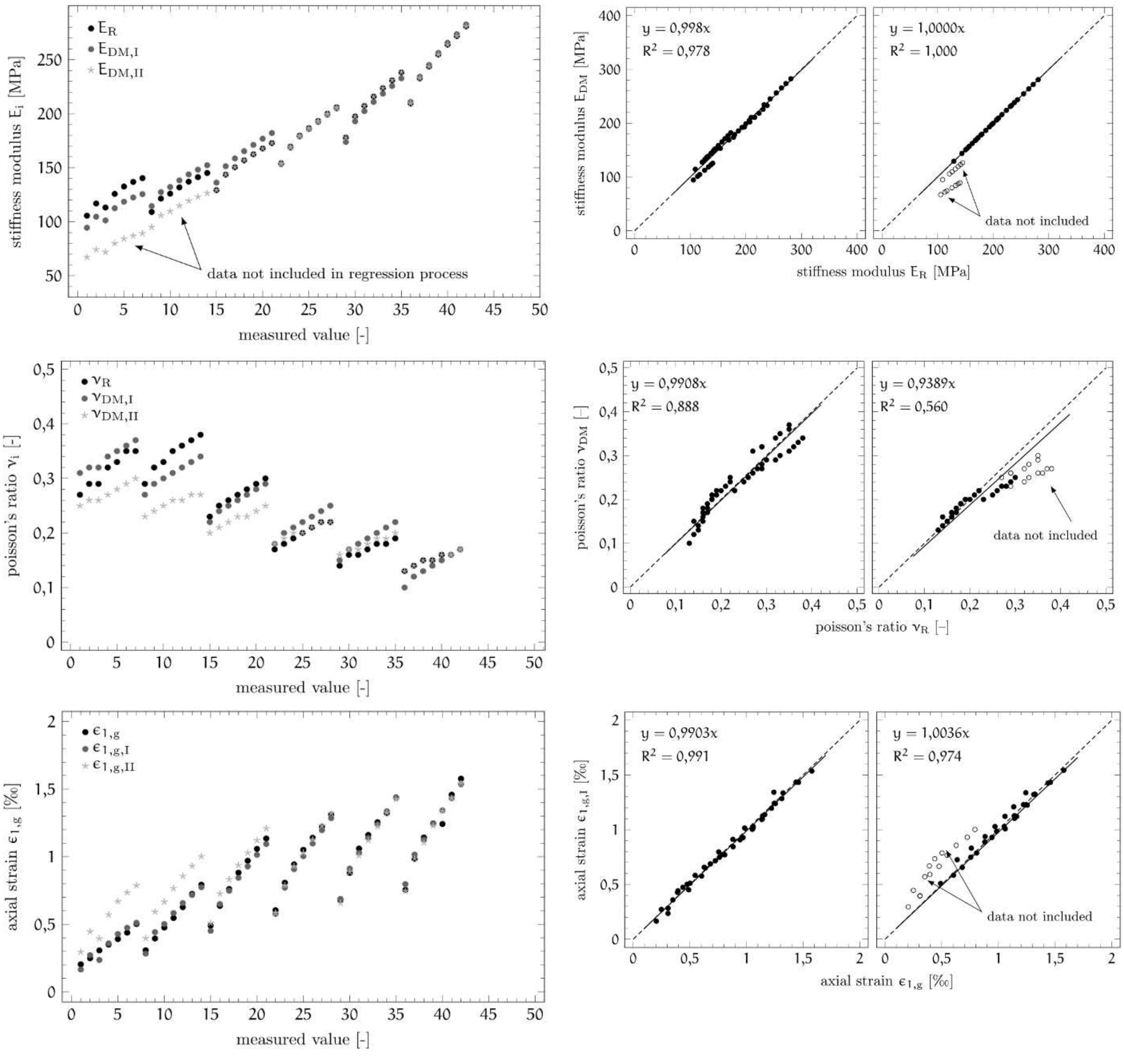


Figure 4: Results of parameter determination; calculated values (based on measured values) compared to values determined with model parameters; I - regression based on all available data sets; II - regression based on selected data sets; for the material Granodiorite GRA2-M-2.0

The parameters for the DRESDEN Model determined for the material Granodiorite GRA2-M-2.0 and the Diabase DIA4-M-3.4 under consideration of reduced (representative) data sets (II) are listed in Table 2.

Table 2. Parameters for the DRESDEN Model determined for material Granodiorite GRA2-M-2.0 and Diabase DIA4-M-3.4 based on results of triaxial tests (Equ. (1) and Equ. (2)); under consideration of reduced (representative) data sets (II)

Material characteristic	Model parameter		Parameter value GRA2-M-2.0	Parameter value DIA4-M-3.4
E_{DM} [kPa]	Q	$\left[kPa^{(1-Q_2)}\right]$	9365.496505	45511.703908
	C	$\left[kPa^{(1-Q_1-Q_2)}\right]$	1058.982340	9823.162414
	Q_1	$[-]$	0.597604	0.230584
	Q_2	$[-]$	1/3	1/3
	D	$[kPa]$	0	0
ν_{DM} $[-]$	R	$[-]$	0.039830	0.052697
	A	$[kPa^{-1}]$	-0.011410	-0.000807
	B	$[-]$	0.307605	0.296593

3.3. Model integration and application

The DRESDEN model described above can be integrated into various numerically working programs for the simulation of any desired loading, respectively stress condition. For the following numerically simulations the nonlinear stress dependent DRESDEN Model was implemented in the program COMSOL Multiphysics. To validate the model integration triaxial tests were simulated based on real testing conditions including before determined model parameters. Finally, the resulting axial and radial strains were determined and compared to the axial strain $\epsilon_{1,g}$ that was calculated from the stiffness modulus E_{cal} and the Poisson's ratio ν_{cal} (both based on measured values). Figure 5 shows this comparison for the material Granodiorite GRA2-M-2.0 for both axial and radial total strain.

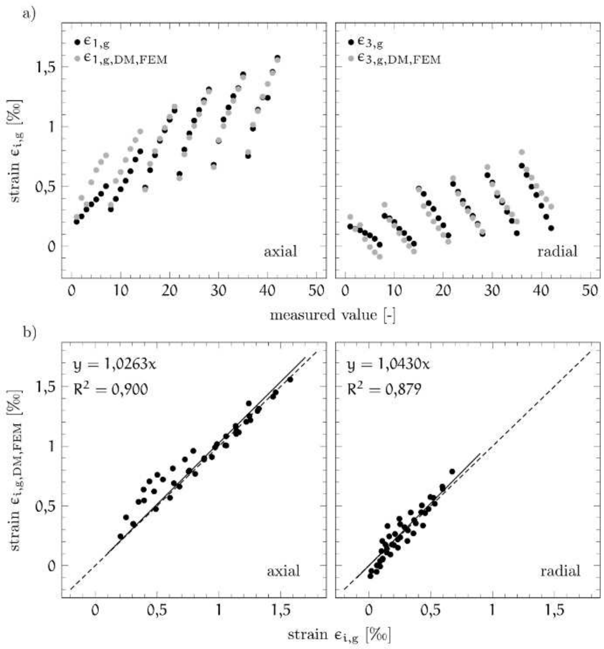


Figure 5: Validation of the implementation of the DRESDEN model in COMSOL Multiphysics; for material Granodiorite GRA2-M-2.0

If unbound materials have a flat geometry, the DRESDEN Model seems to be not fully applicable. Investigations by the author have shown that in such cases the radial strains measured in the triaxial test cannot be reproduced in the simulation. For anisotropic materials, the approach of the DRESDEN Model must be adapted.

Since the non-linear behaviour of unbound base course materials is of particular importance in the design of road constructions with thin asphalt wearing courses, an axial symmetric pavement model for a fictive asphalt pavement with a model radius of 1 m has been built including the following pavement layers: asphalt wearing course (thickness of 4 cm), unbound base course (thickness of 51 cm) and subgrade (thickness of 100 cm). The model boarder was accepted as "free". The stiffness modulus of the asphalt wearing course was assumed as linear elastic. Depth dependent changes in asphalt stiffness's due to depth dependent changes in temperatures were neglected. Instead, two different constant stiffness's (5000 MPa and 20 000 MPa) were exemplary implemented for the asphalt wearing course. For the subgrade a constant stiffness (45 MPa) was also assumed. Further, for the tyre contact area a radius of 150 mm has been selected. The edge area of the tyre contact area was slightly rounded off. For the simulation of the traffic load different wheel loads between one and twelve tons were assumed.

To analyse and understand the performance of flexible asphalt pavements in terms of expected remaining service life different design methods are available worldwide. For example, the German design procedure for asphalt pavements, the "Guidelines for mathematical dimensioning of foundations of traffic surfaces with an asphalt surface course" ([8]) uses for the fatigue proof of asphalt base courses the maximum tensile strain within the lowest asphalt base layer.

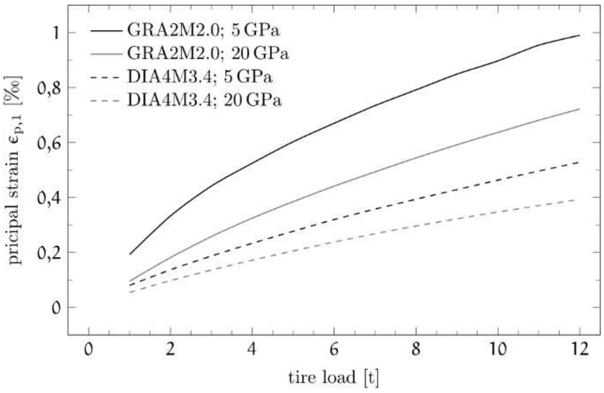
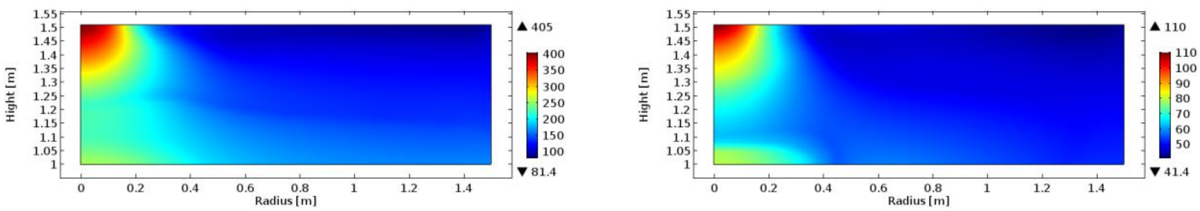
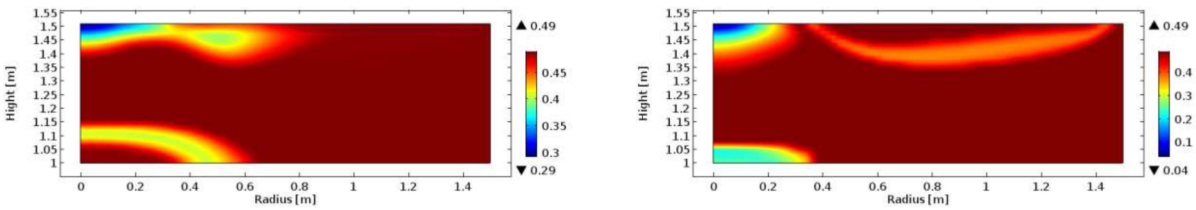


Figure 6: Influence of tire load on design relevant maximal tensile strains in the asphalt wearing course in dependence of two different asphalt stiffness's (5000 MPa and 20 000 MPa); for the unbound granular base course materials Granodiorite GRA2-M-2.0 and Diabase DIA4-M-3.4

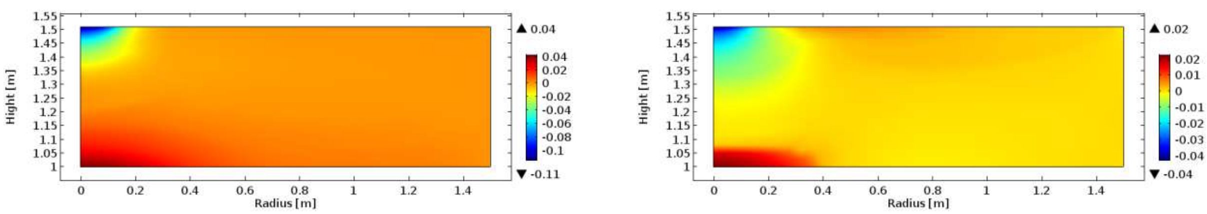
Diabase DIA4-M-3.4 **Granodiorite GRA2-M-2.0**



Stiffness modulus E_{DM} [MPa]



Poisson's ratio ν_{DM} [-]



First principal stress [MPa]

Figure 7: Stiffness modulus E_{DM}, Poisson's ratio ν_{DM} and first principal stress in unbound base layers simulated with the materials Diabase DIA4-M-3.4 and Granodiorite GRA2-M-2.0, exemplary for a tire load of 1 t and an asphalt stiffness of 5000 MPa

Figure 6 shows the influence of different tire loads on design relevant maximal tensile strains in the asphalt wearing course in dependence of two different asphalt stiffness's. As unbound granular base course materials the materials

Granodiorite GRA2-M-2.0 and Diabase DIA4-M-3.4 were involved. The graphs in Figure 6 confirms that the two unbound materials have a stress-dependent material behaviour. If materials with linear material behaviour were taken into account, linear graphs would be obtained. Figure 6 shows also the influence of the nonlinear material behaviour of the unbound materials on the design relevant strains in the asphalt layer of flexible pavements with thin asphalt wearing course layers. Thus, the design relevant strains show also a nonlinear behaviour. It is therefore absolutely necessary, to take into account the stress dependent nonlinear material behaviour of unbound granular materials when analysing the overall performance of flexible road constructions with thin asphalt wearing courses.

Figure 7 shows the distribution of the Stiffness modulus E_{DM} , the Poisson's ratio ν_{DM} and the first principal stress plotted over the cross section of the simulated unbound base layers, again for the two selected materials Diabase DIA4-M-3.4 and Granodiorite GRA2-M-2.0 and exemplary for a tire load of 1 t and an asphalt stiffness of 5 000 MPa. For these simulations the hydrostatic and octahedral stress conditions (Equ. (3) to Equ. (6)) were implemented in the DRESDEN model.

Materials such as the Granodiorite GRA2-M-2.0 show large strains and tend to converge with increasing load clearly worse. However, this has no influence on the design relevant strains in the asphalt layer of flexible pavements with thin asphalt wearing courses. With an increasing tire load the tensile stresses also increase in the lower part of an unbound base layer under the tire load. This effect is greater for materials showing higher strains than for others. With stiffer asphalts the tensile strains that occur in the construction model are reduced.

The remaining tensile stresses in the finite element model can be reduced to an acceptable minimum. Therefor different methods can be used. Three methods were applied and discussed in detail in [5].

4. CONCLUSION

This contribution discusses the application of a material model called DRESDEN Model. This model allow to describe the nonlinear stress dependent behavior of unbound granular materials used for road constructions. It contains both a stress dependent description of the stiffness modulus and of the Poisson's ratio.

The author provides an approach to determine the material parameters of the DRESDEN Model based on triaxial test results. The limitations of the model and changes recommended for the application of the model are also shown.

It can be summed up that the DRESDEN Model has been proved to be suitable for the cases investigated so far.

It provides a good possibility to take into account the non linear behavior of unbound granular materials.

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