A NEW DESIGN METHOD FOR PREDICTION OF RUTTING IN ROADS

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ABSTRACT RÉSUMÉ

Rutting is an important performance factor, which influence the road safety and future maintenance costs. A model to predict future rutting for different design alternatives is therefore necessary and important for the possibility to minimize the maintenance and life cycle costs. It is also possible to use this model to minimize future accidents, depending on aqua planning.

A road design model for prediction of future rutting has been developed and calibrated in a Nordic project. Together with some standardized test methods, this model has been calibrated to the real rutting of 8 roads after 10 – 20 year.

The model is easy to use and the design with this model not time consuming. One prediction with 9 different temperatures can be done in less than 8 hours.

Some interesting findings during calibration is that:

- It is possible to predict rutting with good accuracy, when the stress level doesn’t exceed the “Plastic Shakedown Limit”.
- The Shakedown theory is valid for real roads.
- There is a continuous creep deformation at stresses over the Shakedown Limit.
- It is possible to predict the performance of a road, when it is built of local or/and recycled material, which is not described in the standard of a country.

1. INTRODUCTION

It is important to understand the real behaviour of a road structure during its life time, to understand the reasons for different kinds of deterioration. It is also important to evaluate the quality of the executed work on site, when the road is opened for traffic. Therefore it must be a connection from test methods and test results to prediction models, and after that to the future performance of the road.

The test methods must be well described and possible to repeat with good accuracy, and it must be possible to use the results as input data in the prediction model.

The prediction models should not consist of statistical values from a lot of other roads in a country. The prediction model must also be easy to use and make the calculations in a reasonable short time.

One of the most important failure modes on the road network is rutting. The rutting is the most common reason for rehabilitation and maintenance measures on the road network. The rutting causes many types of problems for the road users and the road administration. The costs, associated with rutting, are high every year. Models for prediction of rutting can therefore give the administration better planning base for maintenance measures. In the planning phase there is also the complication of what measures to use and here a better understanding of the rutting phenomena can give us the ability to better comparisons between measures. It also enables the administration to make better LCC calculation and make estimations of residual values.

There are several reasons for the rutting in a road. This makes it difficult to predict the rutting with one universal model. The main reasons for rutting are:

- Compaction.
- Shear deformation.
- Wear from studded tires.
- Stone loss.

2. ROAD TECHNOLOGIC KNOWLEDGE AS BACKGROUND

2.1. Fatigue “Shakedown” of unbound friction materials

During the years 1990 to 2000, several researchers in road technology described how unbound friction materials, which were tested in triaxial tests, had a limited and relative stabile permanent deformation growth up to a certain stress level. This level is called the “Plastic Shakedown Limit”. This means that the rate of permanent deformation is decreasing for every loading. For a stress situation over this level, the rate of permanent deformation is proportional to the amount of loadings up to another certain level. This level is called the "Plastic Creep Limit”, see figure 1. For a stress situation over this level, a friction material will collapse relatively fast.

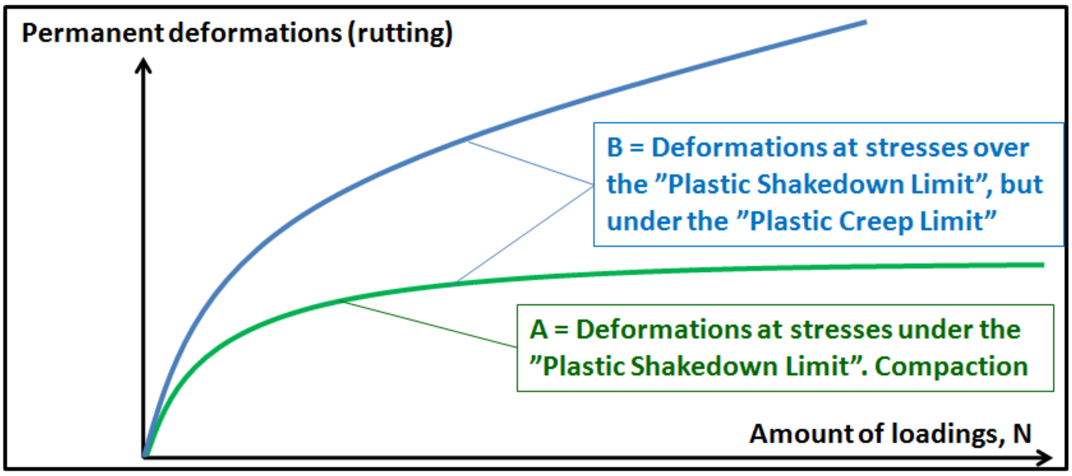

Figure 1: Permanent deformations in unbound friction material depending on stress level.

In the standard EN 13286-7:2004, ref [1] two different stress levels are defined in the evaluation of triaxial tests. These levels are situated between three “areas of stress level”, which is called Range A, B and C. These “Ranges” are defined with consideration to the permanent deformation behaviour of the material:

- ”Range A”; the rate of permanent deformations in an unbound friction material decrease with the amount of loadings, and approaches zero (under the “Plastic Shakedown Limit”).
- ”Range B”; the rate of permanent deformations in an unbound friction material continue unchanged and in proportion to the loadings. In the end, after a large amount of loadings, the material failure (between ”Plastic Shakedown Limit” and “Plastic Creep Limit”).
- ”Range C”; the rate of permanent deformations in an unbound friction material increase per loading for an increasing amount of loadings, and reach rather soon the failure.
- The static failure load for an unbound friction material is bigger than the border line between “Range B and C”.

This also means that if the stress level goes over the failure line, the friction material will be plasticized, which results in a changed stress distribution in the road structure see figure 2.

In this project, the border lines between the different the different levels (Ranges), is presented in a diagram with medium stress and deviator stress, see figure 3. Base material from the motorway project, Rv 40 east from Borås, has been used. The correlation between calculated data and a straight line is very high, almost 1. A presentation of the stress levels in a road structure in a diagram with medium and deviator stress is also very valuable for other analysis of a project.

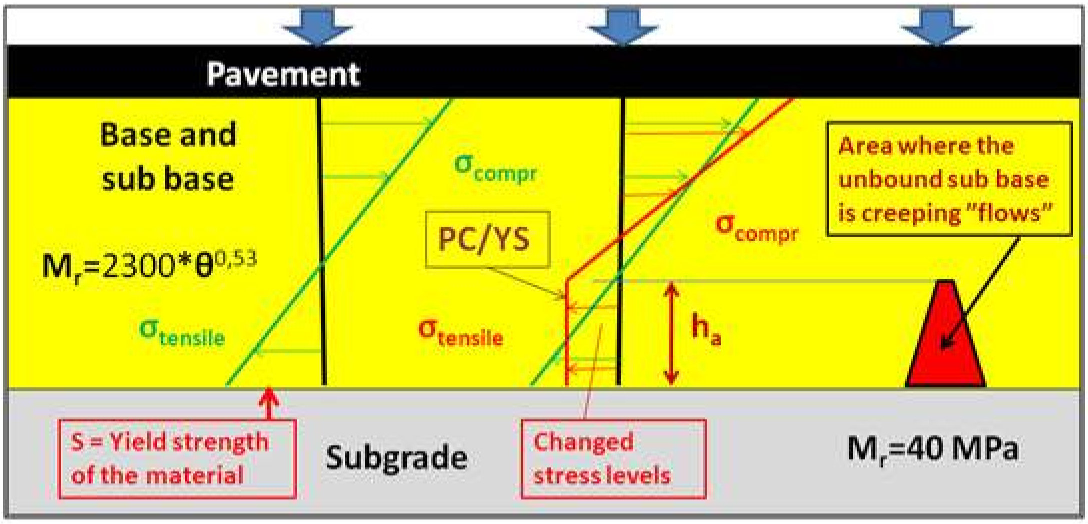

Figure 2: Schematic image of the horizontal stresses in a road structure with traffic load, and the limitation that the stress level should not exceed the inner cohesion at the failure line (perhaps the "Plastic Creep Limit).

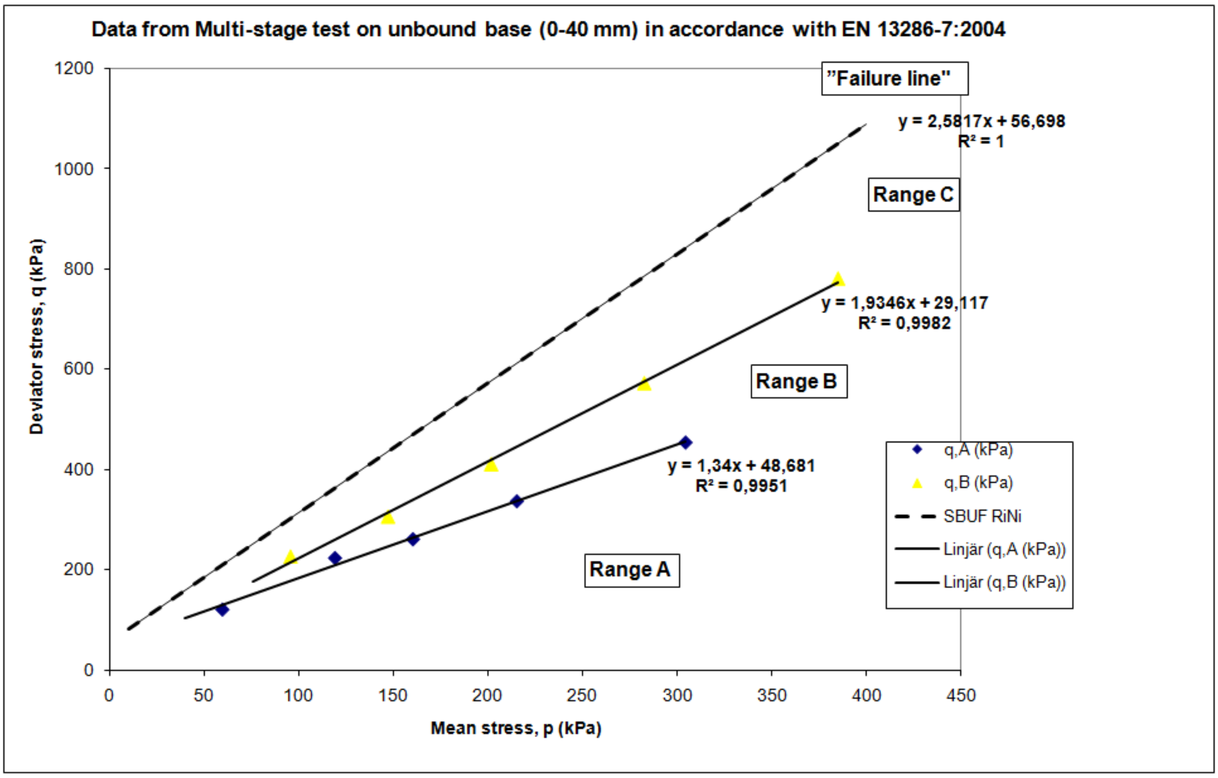

Figure 3: Result from tests on an unbound base material on the project Rv 40 east from Borås (a part of a another project "Active Design", tested by Richard Nilsson, Skanska).

Parts of evidence for the different kind of causes for rutting, comes from the accelerated pavement test in full scale in New Zealand. Alabaster et al, see ref [2]. These tests showed that there were two kind of rutting, one initial rapid rut development followed by a slower rut development over the whole life of the pavement, see figure 4. They call the first kind of rutting for compaction and the second kind for wear.

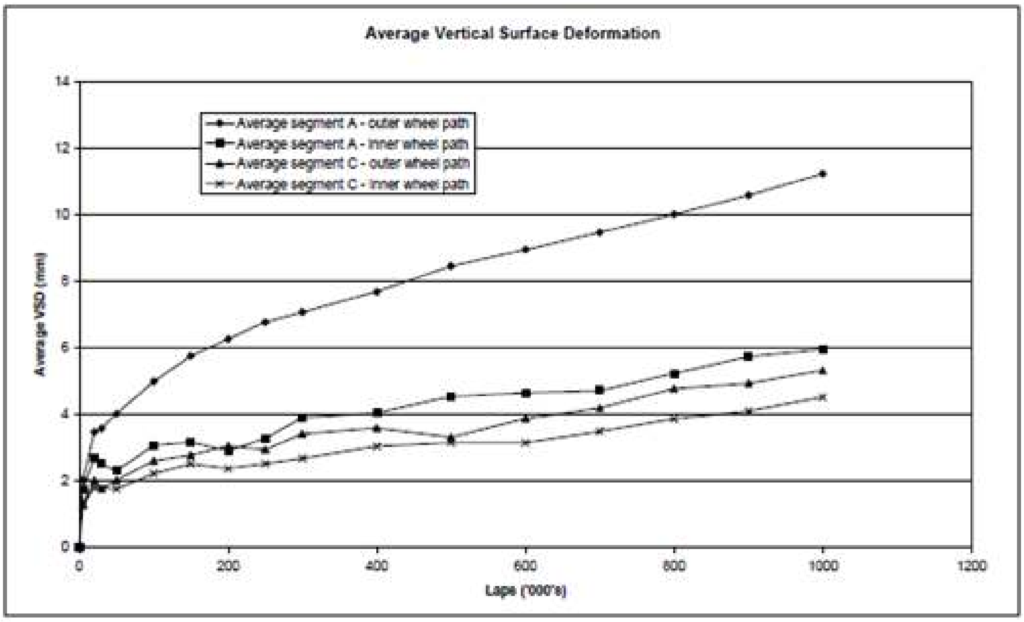

Figure 4: Rutting, result from full scale testing in New Zealand, Alabaster et al 2002.

2.2. General background to all models

All investigated models consist of two or three parts, which are used to predict the permanent deformation, ε_p, see equation 2.2.1. The first part f(N), describes the influence from the amount of load cycles, N. The second part, f(q/p), describes the influence from the stress level, shear and compression stress, q and p. The third part f(creep; N/q/p) describes the influence from the creep in the material, see 2.1.

$$\boldsymbol{\varepsilon_p = f(N) \cdot f(q/p) +/\cdot\ f(creep; N/q/p) \qquad (2.2.1)}$$

This has been visualized in figure 5, where the blue line has been divided into the compaction part, the green curve, and the creep part, the orange line.

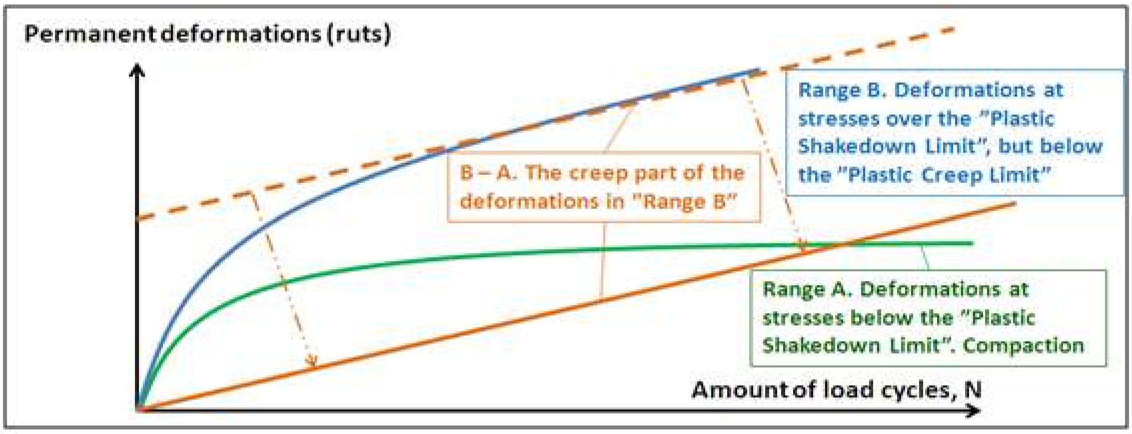

Figure 5: Permanent deformations in an unbound friction material over the "Plastic shakedown Limit" divided into one compaction part and one creep/fatigue part.

The most common description of the first part is an exponential function, presented by Sweere (1990), see equation 2.2.2. This function describes a form of compaction of the material depending on the amount of load cycles, and where the strain level decrease with the amount of load cycles.

$$\varepsilon_p = a \cdot N^b \qquad (2.2.2)$$

Where:

ε_p = Permanent deformation (strain)
N = Number of load cycles
a, b = Regression parameters

The regression parameters are mostly predicted with help of the results from triaxial tests at certain load levels. One problem is that the parameters are different for different load levels, see figure 6.

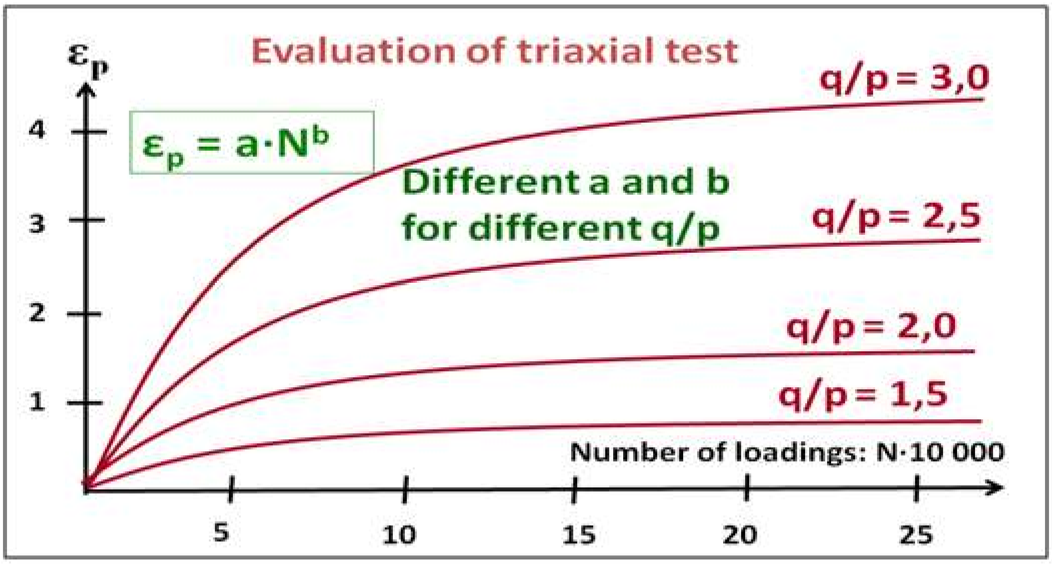

Figure 6: Permanent strain (compaction) of a road building material, depending on the stress level.

In order to solve this problem, the different models have added different functions, which take the different stress situations into consideration, f(q/p).

At stress levels over certain values, the strain is not decreasing with the amount of loadings. In some of the models, this is predicted with help of a “creep” function f(creep; N/q/p).

3. MATERIAL MODELS FOR PREDICTION OF RUTTING IN FLEXIBLE PAVEMENTS

3.1. Background

As a basis for the development of a system of models for prediction of future performance of a road, research results from MEPDG (Design Guide, USA), ref [3], SAMARIS (LCPC in France), ref [4], and other research projects were used. Knowledge and experience from the EN 13286-7:2004 Standard, “Cyclic load triaxial test for unbound mixtures”, ref [1] has also been used.

3.2. Prediction of the elastic response in a road structure

Material models for prediction of rutting are sensitive for the stress level in different parts of a road structure. Two factors have an important influence on this stress level:

- The nonlinear behavior of unbound friction base materials and
- The elasticity modulus for asphalt pavements at different temperatures.

Unbound friction materials have a resilient modulus, which is strongly nonlinear; it is dependent of the actual stress level in the material. A friction material gets harder when the compression stress increase. On model that describes this behavior is the K-Θ model, where the resilient modulus, $M_R = K_1 \cdot \Theta^{K2}$, and $\Theta = (\sigma_1 + \sigma_2 + \sigma_3)$, which is the sum of the principal stresses. The stress levels in a road structure are described in a more realistic way with help of this material model. The K_1 and K_2 can be calculated from triaxial test results.

The elastic/resilient modulus of an asphalt pavement can vary between 500 MPa for temperatures of 35 to 40 °C and 20 000 MPa for temperatures under 0 °C. The resilient modulus of asphalt can be predicted for different temperatures with help of the Indirect Tensile Test (IDT).

From the chosen models, it is obvious that the elastic stress level (or elastic strain level) in a road structure has an important influence on the permanent deformations. The following models have been used for the prediction of the elastic stress/strain level in a road structure:

- The asphalt material is assumed to work as a linear elastic material, $\varepsilon_r = \sigma/M_r$, where the resilient modulus, M_r, is strongly dependant of the temperature in the asphalt. This means that the stress situation in a road structure is very different at different temperatures. Because of that, between five and nine different calculations of the elastic stress/strain have been made for the different temperatures.
- The unbound friction materials are assumed to work as non linear elastic materials. The model, which have been used for this behaviour is the K – θ model where the resilient modulus, M_r, is dependant of the stress level in the material: $M_r = K_1 \cdot \theta^{K2}$ and $\varepsilon_r = \sigma/M_r$.
- The subgrade material has normally been assumed as a linear elastic material. One reason for this is that the extra stress, depending on loading from traffic is low. Another reason is that materials like clay and silty friction materials, with high content of water, are almost linear elastic.

Analysis of tested LTTP-roads shows that most of the permanent deformations in the roads take place in the unbound friction materials. The elastic stress, especially the shear stress, has an important influence on the permanent deformations in an unbound friction material. This means that it is important to do a so realistic calculation of the elastic response in a road structure as possible. The response model should fulfil the following demands:

- The model should be reliable and give a good prediction of the elastic response in a road structure. In the description of MEPDG, ABAQUS 3D finite element program is described as the program that gives the most realistic predictions, see ref [5].
- It should be possible to use the model without previous knowledge about finite element modelling. It should also be possible for a consultant to use the model for simulations of different road structures on a real project. This also means that the time for and work with loading input data should be as short and easy as possible.
- It should be easy to use the output data from different simulations.
- It is of value if the model can simulate the real geometry of the road, which gives even more realistic results.

The only found program, which could fulfil these four demands, was VagFEM, see ref [6]. This program may briefly be described as follows. The input data comprise road geometry, thickness of layers, position of loading, elasticity modulus for the bituminous bound layers and linear elastic or nonlinear elastic resilient modulus ($M_R = K_1\Theta^{K2}$) for the unbound layers. The weight of the road material is included in the model. VagFEM is built on modules from ABAQUS, which is also the program that carries out the calculations. The output data comprises data of elastic, stresses and strains in different parts of the road structure.

All input data for one chosen road structure takes less than a half hour to load. The calculations of the elastic response in the computer take between 15 minutes and one hour to do.

VagFEM also includes an Excel program for prediction of permanent strain, with four different material models. This program makes a summation of permanent strain to a predicted rutting, with consideration to the different conditions during the years like temperatures, moisture and amount of loadings (N).

3.3. Model for prediction of rutting in bituminous bound layers

The model in MEPDG, for prediction of permanent deformations in bituminous bound materials, is initially based upon the statistical analysis of triaxial tests, which have given:

$$\boldsymbol{\varepsilon_p / \varepsilon_r = a_1 \cdot N^{a2} \cdot T^{a3}} \qquad \textbf{(3.3.1)}$$

Where;

ε_p = Accumulated plastic strain at N repetitions of load
ε_r = Resilient strain of the asphalt material
N = Number of load repetitions
T = Temperature
a_i = Non-linear regression coefficients

This equation consists of three parts:

- $a_x \cdot N^{a2}$ describes the influence from compaction, see 2.2 above.
- $a_y \cdot T^{a3}$ describes the influence from the temperature.
- ε_r describes the influence from the stress level (the elastic strain level).

Where $a_x \cdot a_y = a_1$.

In the equation 3.3.1, $f(N) = N^{a2}$, $f(q/p)$ is represented by ε_r, where $\varepsilon = M_r \cdot \sigma$, and the creep is represented by T^{a3} (a bigger T, a warmer asphalt, has a bigger creep).

After running the MnROAD cells (sections); the predicted rut depth (as a function of depth within the AC layer) was compared to the measured rut depths from the trench study. Using these results, an empirical model was developed to correct the rutting model to reflect the same trends of the measured rut in the asphalt layers as a function of depth within the AC layer. The resulting model has been used in this project.

3.4. Model for prediction of rutting in unbound layers of friction materials

LCPC has developed “A new approach for investigating the permanent deformation behaviour of unbound granular material using the triaxial tests”, see ref [7].

This model, called the Gidel model, consists of the following equation:

$$\varepsilon_1^p(N) = \varepsilon_{10}^p\left(1-\left(\frac{N}{N_0}\right)^{-B}\right)\cdot\left(\frac{L_{max}}{p_a}\right)^n\cdot\frac{1}{m+\frac{s}{p_{max}}-\frac{q_{max}}{p_{max}}} \qquad \textbf{(3.4.1)}$$

Where:

ε_1^p = Permanent axial strain;
p_{max}, q_{max} = Maximum values of the mean normal stress p and deviatory stress q;

N = Number of load cycles.

N_0 = Reference number of load cycles.

$L_{max} = \sqrt{p_{max}^2 + q_{max}^2}$

P_a = Reference pressure equal to 100 kPa.

S and m are parameters for the failure line of the material, of equation q = m·p+s; (from experience, m = 2.5 to 2.7 and S = 20 – 80 kPa)

ε_{10}^{p} , B and n are parameters, which has been evaluated from laboratory tests.

The different parts of the equation in the Gidel model are presented graphically in a q/p-diagram see figure 7.

The model consist of one part, A, which describe the influence from the amount of load cycles, f(N), at a certain spot, and two parts, B and C, which describe the influence from the stress level, f(q/p), at a certain spot. In this model there is no part that describes the influence from creep.

From the part C of equation 3.4.1 it is obvious that high stress levels, close to the failure line, will give big permanent deformations. In a contact with P. Hornych, LCPC, he told that this model should not be used when the stress level was too high.

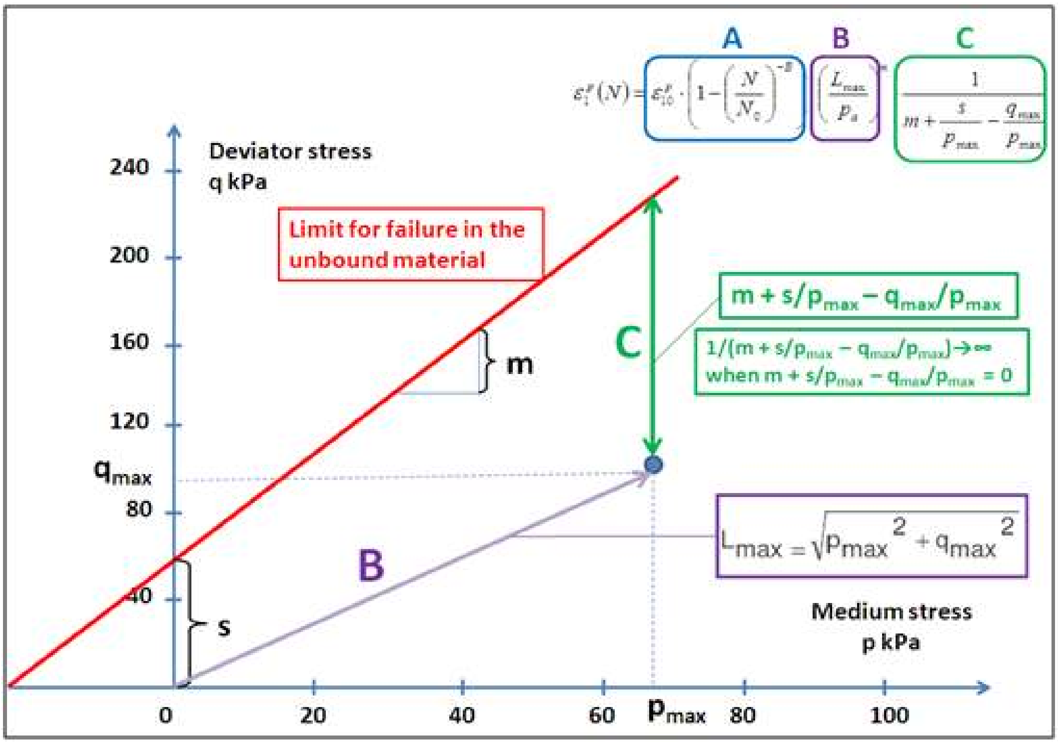

Figure 7: Graphically presentation of the parts of the Gidel model, which describe the influence of the stress level.

4. TEST METHODS FOR THE DETERMINATION OF MATERIAL PARAMETERS

4.1. Bituminous bound materials

The elastic properties of the asphalt pavement differ very much, depending on how warm the pavement is, see chapter 3.2. This gives that the stress level in the unbound base material is very different in different seasons.

A method to determine the elastic dynamic modulus and phase angle for bituminous bound material has been developed by NCSU (North Carolina State University). The test can be done on drilled out cores from an existing pavement on site. All tests have been done with this Indirect Tensile Test method (IDT).

The test method for the determination of parameters in the permanent deformation model is the triaxial test, in accordance with the standard EN 12697-25:2005, test method B

4.2. Model for prediction of rutting in unbound layers of friction materials

All models, which have been chosen in this investigation, has a main background in the study of result from triaxial testing. All tests, for the determination of the parameters in the models have been done with tiaxial tests, where the method is defined in EN 13286-7:2004, the European standard for triaxial testing, see ref [1].

5. LIMITS FOR THE MODEL AND CALIBRATION

5.1. Limitations of the model

The Gidel model has one part; ($m + s/p_{max} – q_{max}/p_{max}$), which become zero for a stress level at the failure border. This gives very high values of the permanent deformations for stress levels close to this border, and a slight change, for example from 0,002 to 0,001 (which is far outside the tolerance for calculations) give the double permanent deformation in this model.

$$\varepsilon_1^p(N) = \varepsilon_{10}^p\left(1 - \left(\frac{N}{N_0}\right)^{-B}\right)\cdot\left(\frac{L_{max}}{p_a}\right)^n\cdot\frac{1}{m+\frac{s}{p_{max}}-\frac{q_{max}}{p_{max}}} \qquad \textbf{(3.4.1)}$$

This is the reason why it must be a limitation in the stress level, if the Gidel model is used for prediction of the permanent deformations.

5.2. LTTP roads, used for calibration of the models

The models and test methods was calibrated to test road E6 bypass Falkenberg, road E6 bypass Dingle and different LTTP projects in Sweden that have been under traffic for 10 – 25 years; Road 46, Trädet, Road 53, Nykoping, Road 31, Nassjo, Road 33, Ankarsrum, Road 33, Vimmerby, Road 34, Malilla and Road 44 Grastorp.

Experiences from these calibrations have been used to develop the soft ware, and to give recommendations to a further development.

6. CALIBRATION OF TEST ROAD SECTIONS

6.1. Prerequisites for the predictions

The predictions have been simplified on some points, which could mean that certain correction factors has to be used in order to predict the real rutting. The following simplifications are done in all predictions:

- The different temperature intervals for 10 or 20 years are simulated to 1 year. This simplification has no big influence on the final result, in accordance to alternative predictions that have been made.
- No correction is done for the ageing or fatigue of the asphalt material. Results from IDT tests on all roads, indicate that the increase in elasticity modulus, depending of ageing, is of the same magnitude as the decrease, depending on fatigue.
- No correction is done for the wheel wander sideways. Experiences from LCPC and conclusions from the SAMARIS project is that the rutting decrease with a factor of 0,7 to 0,8, depending on this factor.
- One assumption in this project is that no permanent deformations arise when the road is frozen (under zero degrees).

Some other factors of influence for the rutting are; the moisture content in the unbound friction materials, how exposed the asphalt surface is to direct sunshine, earlier traffic on the binding layer (before the wearing course is placed) and the real axle loads etc.

6.2. Test road in Halland

The future rutting for E6 in Halland has been predicted with input data from triaxial tests. There have also been special temperature measurements, which have been the ground for the calculation of the elasticity modulus of the asphalt layers.
The superstructure of the road, see table 1.
The accumulated traffic load per lane during 10 years is: N_{ekv} = 10 million heavy axles (10 ton). A reasonable approach is to locate this traffic to one year. After that, all passing of heavy axles are distributed in proportion to the estimated temperature or dynamic modulus of the asphalt pavement, see table 2.

Table 1: Layer thicknesses, section 12.

Layer	Measured Thickness mm	Material	Year
Wearing course	40	HABS 16 (Wearing course)	1996
Asphalt layer	195	AG 22 (Bituminous bound base)	1996
Base	80 (89)	Crushed rock: VÄG 94	1995
Sub base	685 (710)	Crushed rock: VÄG 94	1995
Subgrade		Sandy clay	

Table 2: Distribution of heavy traffic during one year with consideration to the temperature (dynamic modulus).

Temp °C	Dyn modul ABS MPa	Dyn modul AG MPa	Distr %	Distr amount N_{EKV}
40	500	800	0.4	4 000
35	1 000	1 200	1.4	140 000
30	1 800	2 100	4.1	410 000
25	2 800	3 200	8.1	810 000
20	4 200	4 600	15.5	1 550 000
15	6 400	6 400	13.0	1 300 000
10	8 700	8 400	12.5	1 250 000
5	11 100	10 600	21.0	2 100 000
0	13 200	12 700	12.0	1 200 000
- 5	15 600	15 200	12.0	1 200 000

The resilient modulus for the subgrade has been estimated to 120 MPa.
The two parameters for the resilient modulus in the subbase has been estimated to K_1 = 2800 and K_2 = 0,87 and the two parameters for the resilient modulus in the base has been estimated to K_1 = 3500 and K_2 = 0,87, see chapter 3.2.
The parameters in table 3 have been used as a ground for prediction of the permanent deformations in the bituminous bound layers. The regression parameters in the bituminous bound layers have been measured and evaluated from triaxial tests on asphalt samples from the real pavement, which has been under traffic during 12 years.
The curves for prediction of permanent deformations have a steep increase during the first part of traffic loading. The slope of the curve decrease in the later stages.
The model in MEPDG uses a method, where the earlier history of loading has an influence on the permanent deformation, see reference [3].
The model from MEPDG has been used for calculations of permanent deformations in the bituminous bound layers, with the simplification that the temperature cycles are reduced to happen during one year instead of ten years. The calculations starts with the coldest

period, and after that the calculation is done step by step for the closest higher temperature interval, see figure 8. A similar calculation that starts with the warmest temperature (which mathematically should give the highest possible deformation) gives only one to two percent higher permanent deformation.

Table 3: Parameters for calculation of permanent deformations in bituminous bound layers.

Triaxial test values	a_1	a_2	a_3
Väg E6	0.840	0.266	1.696

The amount of permanent strain has been modelled as follows: The calculation of permanent strains for “a new temperature period” starts at the level of permanent strains that is reached during earlier loading/temperature intervals, see figure 8.

The calculations have been done in four steps:

- The elastic response in the road structure has been predicted with help of parameter values from IDT and estimations from other triaxil tests. This calculation has been done for every temperature interval.
- In step 2, the total permanent deformation is calculated with the assumption that the road had had all traffic during every temperature interval.
- In step 3, the permanent deformations are reduced with consideration to the real traffic in the chosen temperature interval.
- In step 4, the permanent deformations in the bituminous bound layers are calculated with help of the model, which is sketched in see figure 8.

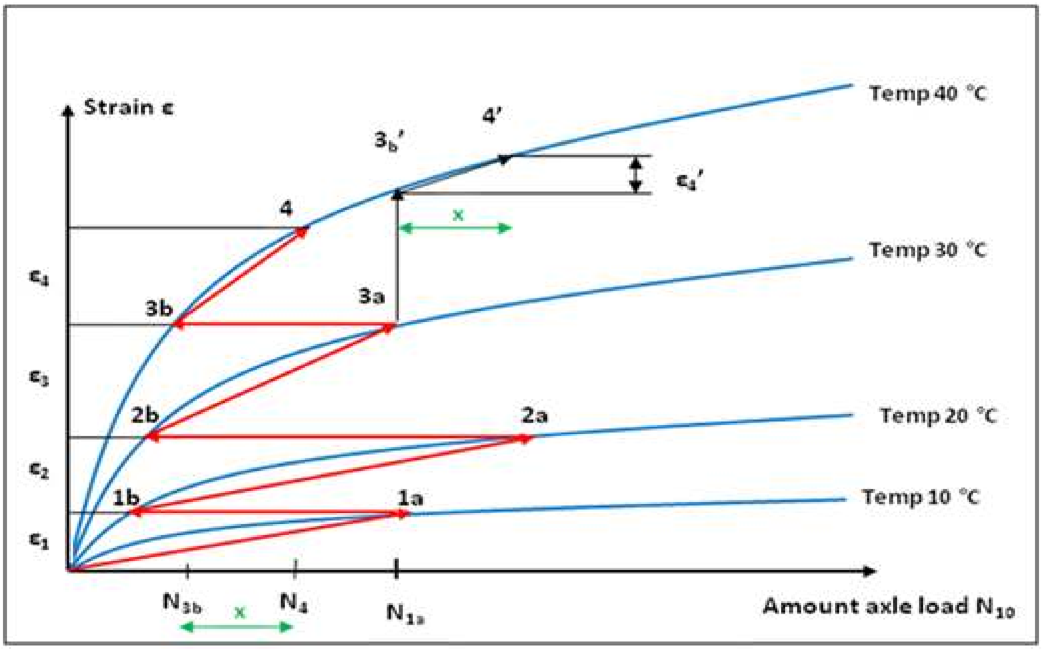

Figure 8: Chosen way for calculation of permanent deformations in bituminous bound layers. The amount of traffic is distributed in relation to the real temperature interval. A 10 year cycle is regarded as one year. The first calculation, N_{1a}, is done for the coldest cycle.

The measured rut depth, depending on deformation in the road structure, is 7,3 mm.

It is possible to estimate the distribution of permanent deformations between bituminous bound material and unbound base plus subgrade material on recently sawn out beams of the asphalt layers.

A rough estimation gives that about 25 % of the permanent deformations come from the unbound materials. The result from this is:

- 7,3*0,75 = **5,48 mm** of the rutting comes from the bituminous bound layers and
- 7,3*0,25 = **1,82 mm** of the rutting comes from the unbound layers.

This can be compared with the calculated rutting, which is:

- **5,61 mm** of the rutting comes from the bituminous bound layers and
- **1,79 mm** of the rutting comes from the unbound layers.

This is a very good result, with background of uncertainties in the measurements, the model and the chosen parameters.

6.3. Test road Rv 46 at Tradet

The predictions for this LTTP road have been adapted to reality and simplified on some points.

- The traffic is not so intense on a road in the night, when the temperature is lower. Therefore an adaption has been done with consideration to the measured distribution of traffic between day time (06 – 22) and night time (22 – 06).
- The predictions of elastic strain and stress, is carried out in the same way as in chapter 6.2. Also the prediction of the permanent deformation is carried out in the same way as in chapter 6.2. The only difference is that 5 instead of 9 temperature intervals are used in these calculations.

The measured rut depth, depending on deformation in the road structure, is **5,5 mm.**
This can be compared with the calculated rutting, which is **5,42 mm**, where:

- 1,56 mm of the rutting comes from the bituminous bound layers and
- 3,86 mm of the rutting comes from the unbound layers.

6.4. Test road Rv 31 at Nassjo

The predictions of permanent deformations for Rv 46, Tradet gave as a result that the permanent deformations for unbound and bituminous bound layers are 20 % larger for a prediction with a period of only 20 ˚C than the total sum of all temperatures. This means that it could be possible to multiply values, which is calculated with temperature 20 ˚C, with 0,8 in order to get a result, which is in accordance with a calculation where all the different temperatures has been used. The permanent deformation in bituminous bound layers that are calculated with the method, presented in chapter 6.2, are 3,6 times higher than the deformation, which is calculated with 20 ˚C. This estimation has been used for a simplified estimation of the permanent deformation.

A calculation of the permanent deformations on Rv 31 at Nassjo with this method gives a total rut depth of 5,3 mm. The calculated rut depth in the asphalt layers is 1,9 mm, which is close to the measured - estimated value of 1 to 3 mm. On the real road, this predicted deformation is reached after about three years. Up to this date, the deformation grows relative rapidly. After three years, the rate of rut development decrease to a constant increase in rut depth every year, see figure 9.

This could be explained by the knowledge about unbound material behaviour. The first, relatively rapid phase depends mainly of compaction of the material and the second phase depends on creep in the material.
An analyze of the stress level in the road structure gives as result the stress level is far over the creep limit and even the failure limit, see figure 10. This probably explains the reason for the continuous rutting during 3 – 20 years.

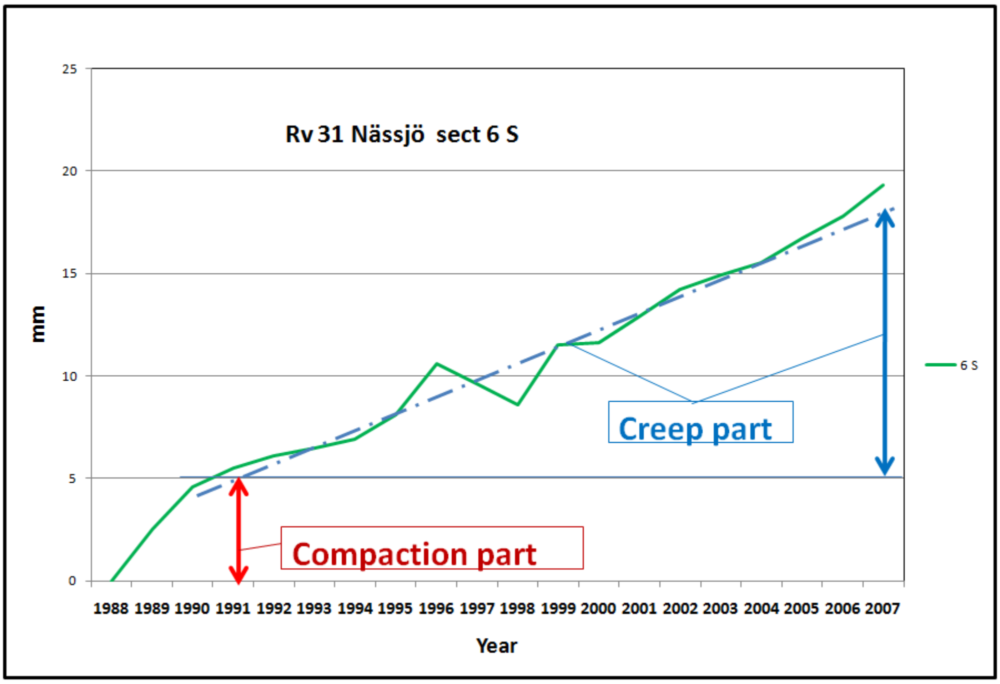

Figure 9 : Measured rut development on section 6S of the LTTP road Rv 31 at Nässjö.

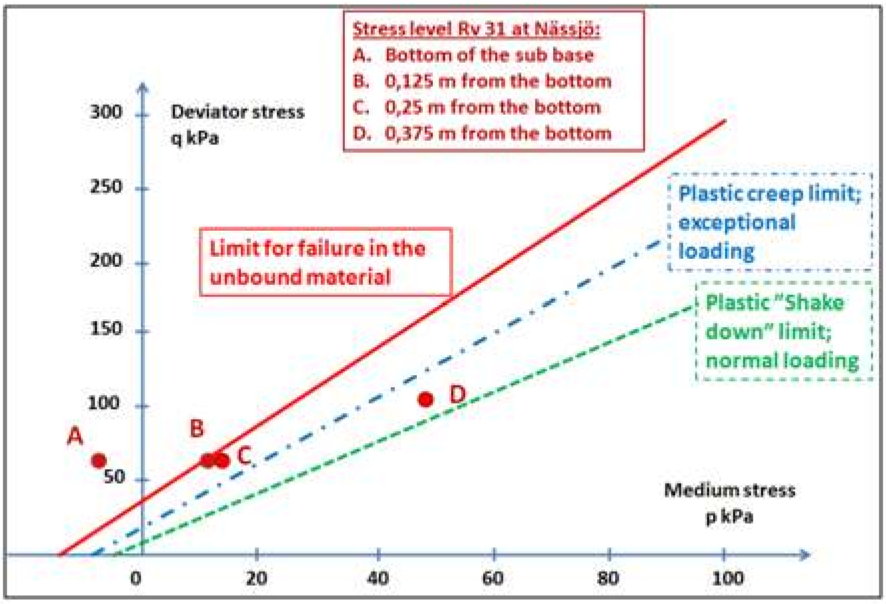

Figure 10: Stress level at different levels in the road structure of Rv 31 at Nässjö.

6.5. LTTP roads at Nykoping, Vimmerby, Malilla and Nassjo

There have not been any triaxial tests on three of the chosen projects. The measured development rutting on these roads have a similar shape. This gives some interesting facts, see figure 11.

It is obvious that all these roads have a development of the rutting that is constant with the time or rather with the amount of heavy traffic. There is a slight increase of rutting during the years, which probably depends on the increase in volume of heavy vehicles per year. All test sections, except one or two, has similar and rather equal development of the rutting. These sections have lower values on the resilient modulus of the subgrade than the rest of the test sections.

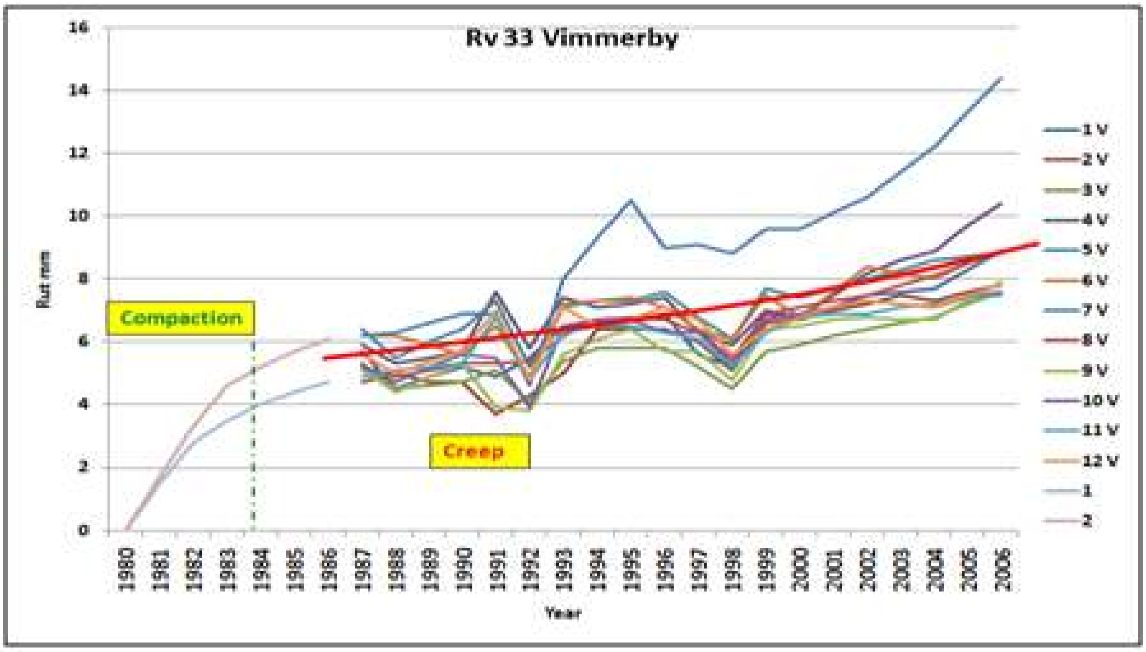

Figure 11: Measured rutting on the east bound lanes of Rv 33 at Vimmerby. The red line is an assumed average increase of rutting between 1986 and 2006, depending on creep.

7. INFLUENCE OF MATERIAL MODEL ON THE STRESS LEVEL

Two calculations have been done of the stress level in the road structure for Rv 46 at Trädet. One of these calculations simulates the subgrade as a linear elastic material with elasticity 330 MPa, A and B in figure 12. The other calculation simulate the subgrade as a non linear material with K_1 = 1900 and K_2 = 0,5, measured from triaxial tests on the real subgrade material, C and D in figure 12. All other input data in the models are the same in both calculations.

From figure 12, it is obvious that the stress level in the bottom of the sub base is lower, if the more realistic non linear model is used.

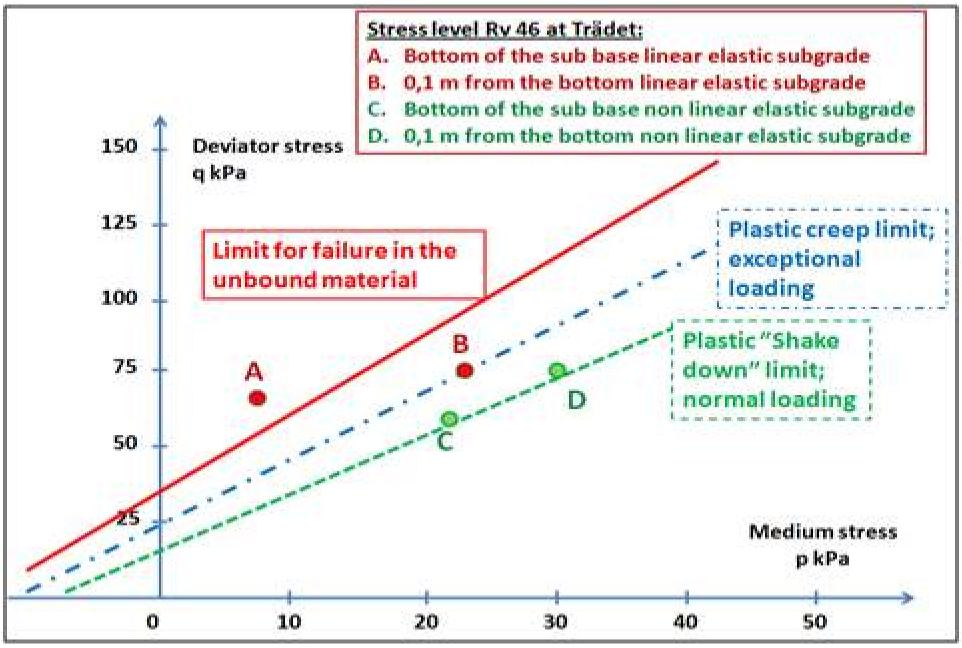

Figure 12: Calculation of stress level in the bottom of the sub base layer. A and B is calculated with the subgrade simulated as a linear elastic material. C and D is calculated with the subgrade simulated as a non linear elastic material.

8. SENSITIVITY ANALYSIS

The Gidel model consists of the following parts:

$$\varepsilon_1^p(N) = \varepsilon_{10}^p * \left(1-\left(\frac{N}{N_0}\right)^{-B}\right) * \left(\frac{L_{max}}{p_a}\right)^n * \frac{1}{m+\frac{s}{p_{max}}-\frac{q_{max}}{p_{max}}} \qquad \textbf{(3.4.1)}$$

Where the value of ε_{10}^p has a direct influence on the result of the calculation of permanent deformation. This means that a double value of ε_{10}^p gives double as high deformation. From this reason, it is important to choose a value of this parameter that comes from triaxial testing of the material on the site.

The value of $\left(1-\left(\frac{N}{N_0}\right)^{-B}\right)$, and the parameter **B** decides the shape of the deformation curve, depending on the amount of heavy loadings (axle loads). An increase of this value from 0,01 to 0,1 gives 5 times as much permanent deformations for 2,5 million heavy load axles (10 ton). The value of the parameter **B** should be around 0,01 to 0,1.

The value of $\left(\frac{L_{max}}{p_a}\right)^n$, and the parameter **n** is one part of the influence from the stress level. For the superstructure on Rv 31 at Nassjo, an increased value of **n** gives increased deformation in the base layer, almost the same deformation in the subbased layer and a decreased deformation in subgrade. This probably means that L_{max} in the subgrade is less than p_a.

The value of $\frac{1}{m+\frac{s}{p_{max}}-\frac{q_{max}}{p_{max}}}$ is the other part of the influence from the stress level. In this part the factor $(m+\frac{s}{p_{max}}-\frac{q_{max}}{p_{max}})$ becomes zero when the stress level reaches the failure line. This means that the permanent deformations will be very high, when the stress level is close to the failure line, which isn’t realistic, because the unbound friction material ought to be plasticized when the stress level lies between the “Plastic Creep Limit” and the failure line, see figure 5 and 7. From this reason, this factor, $(m+\frac{s}{p_{max}}-\frac{q_{max}}{p_{max}})$, has been limited to maximum 1 in the software for the calculations.

9. INFLUENTIAL PARAMETERS ON THE CREEP BEHAVIOUR

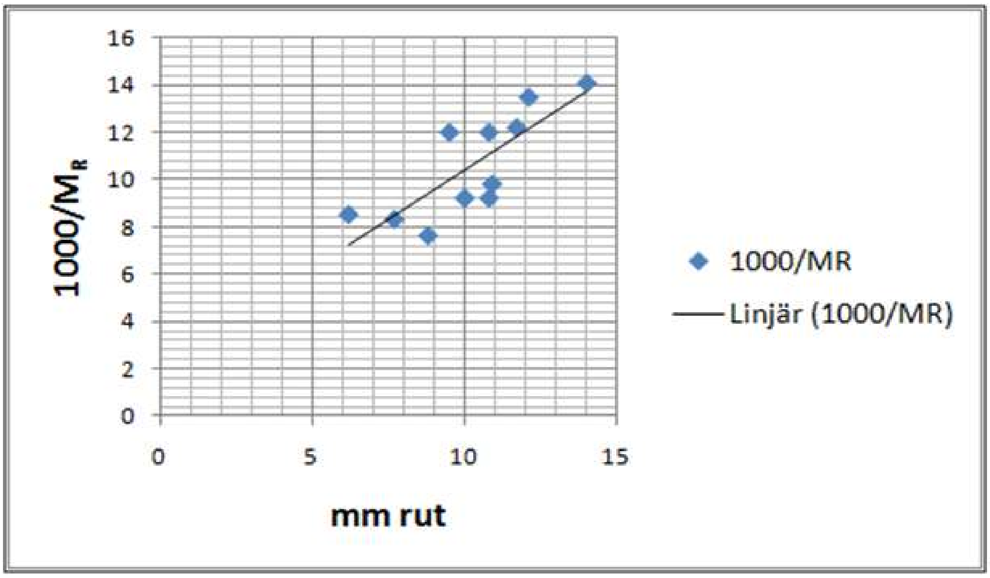

Figure 13: Connection between the rutting and 1000/M_R.

The permanent deformation, which is constant over an amount of years, is called the creep here. To find a preliminary model to estimate this creep, one road has been investigated. One factor of influence is the elasticity modulus of the subgrade. For the project Rv 31 at Nässjö the rutting has been compared with the resilient modulus of the subgrade, M_R, which has been calculated from FWD values, see figure 13

10. SUMMARY AND CONCLUSIONS

- It was possible to calculate the permanent deformations in the bituminous bound layers with a good accuracy for all the investigated roads, when the model in chapter 6.2 was used. The parameters from test road E6 in Halland has been used for all roads with a good result. This probably means that these parameters could be used as standard parameters for many roads in Sweden, and perhaps also in the other Nordic countries.
- It was possible to predict the permanent deformations, rutting, in a road with good accuracy, when the stress level in the road structure was below the "Plastic Shakedown Limit". This type of rutting is called "Compaction" here.
- If these calculations should give correct results, it is important to use correct parameters from material on site, which has been tested in triaxial test.
- It is necessary to use a calculation model, which can simulate the real elastic behaviour of the asphalt material, the non linear behaviour of the unbound material and the real geometry of the road, in order to get the most realistic value of the stress level as possible.
- For stress levels over the "Plastic Shakedown Limit", there is probably also a creep in the unbound friction material, which is proportional to the amount of passing heavy axle loads. With help of measurements of rutting on similar roads, it could be possible to estimate this rutting, which is called "Creep" here.
- The total future rutting is the sum of "Compaction and "Creep".
- There ought to be more research, in order to get a better model to predict the "Creep" deformation in a road structure.

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