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Towards a mechanistic structural design procedure for emulsion-treated base layers

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Existing guidelines on the use of emulsion-treated materials do not provide the necessary information for mechanistic analysis and design, and the structural design of these materials is mainly based on the experience of practitioners. Recent laboratory and heavy vehicle simulator testing provide some insight into the behaviour of emulsion-treated materials which has led to the development of interim transfer functions that may be used in a mechanistic analysis. Emulsion-treated materials behave in two phases, a pre-cracked and post-cracked phase. In the pre-cracked phase, the material has a stiffness that is similar to that of lightly cemented material, while in the post-cracked phase it has a stiffness that is comparable to that of the untreated material. During the pre-cracked phase the material will behave similarly to a lightly cemented material and will fail in fatigue. In the second phase the material will behave similarly to a granular material with a reduced resistance to permanent deformation. This paper describes a mechanistic design procedure for the structural design and analysis of emulsion-treated materials, based on the principles of the South African Mechanistic Pavement Design Procedure. An interim design catalogue based on these principles was developed and is also presented.

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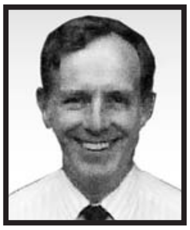

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INTRODUCTION

Over the past 30 years, success has been achieved by South African road engineers with the technique of adding small quantities of bitumen emulsion to gravels of fair to good quality. The introduction of in-situ recycling makes the use of bitumen emulsion in the rehabilitation of existing pavements attractive and this technology is becoming increasingly popular. Although emulsion-treated materials have been used with great success for a number of years, their structural performance has not been investigated in detail.

The objective of this paper is to define the life cycle behaviour and failure criteria of pavement layers treated with bitumen emulsion and to present interim transfer functions for the mode of failure that can be used in mechanistic pavement design. This work is based on an extensive laboratory study and heavy vehicle simulator testing on several test sections where a ferricrete material was stabilised, as reported in the first author's MEng thesis (Liebenberg 2003).

HISTORY OF AND BACKGROUND TO THE STRUCTURAL DESIGN OF EMULSION-TREATED MATERIALS

Emulsion was added to pavement layers initially to enhance the water-resisting properties of the layer and to improve cohesion on the surface to allow the road to be opened to traffic soon after construction in order to prevent or limit ravelling of the base layer. In the first experiments in South Africa (Otte & Marais 1979) no cement was added to the emulsion-treated layer and it was treated as a granular layer during the structural design process.

Santucci (1977) did research on emulsion treated material with high bitumen contents (11 % by volume or 5–5,5 % by mass). He developed transfer functions for emulsion-treated as well as emulsion- and cement-treated materials. The maximum horizontal tensile strain at the bottom of the treated layer and the maximum vertical compressive strain at the top of the subgrade were used to determine the thickness of the pavement. The method assumed that the properties of the emulsion-treated layer were similar to that of asphalt.

Marais and Tait (1989) made some adjustments to the method of Santucci (1977) to allow for South African conditions.

In 1993 SABITA published manual 14 (SABITA 1993) and provided different approaches for modification and stabilisation. The structural design for the stabilisation approach was based on the work of Santucci (1977) and Marais and Tait (1989). In the modification approach, the emulsion-treated material was treated similarly to a granular material.

De Beer and Grobler (1994) developed transfer functions based on research done on the Heilbron heavy vehicle simulator (HVS) test sections. The method was regarded as too conservative because it proposed thick structures, contrary to the experience of practitioners.

Theyse (1998) provided guidelines and a

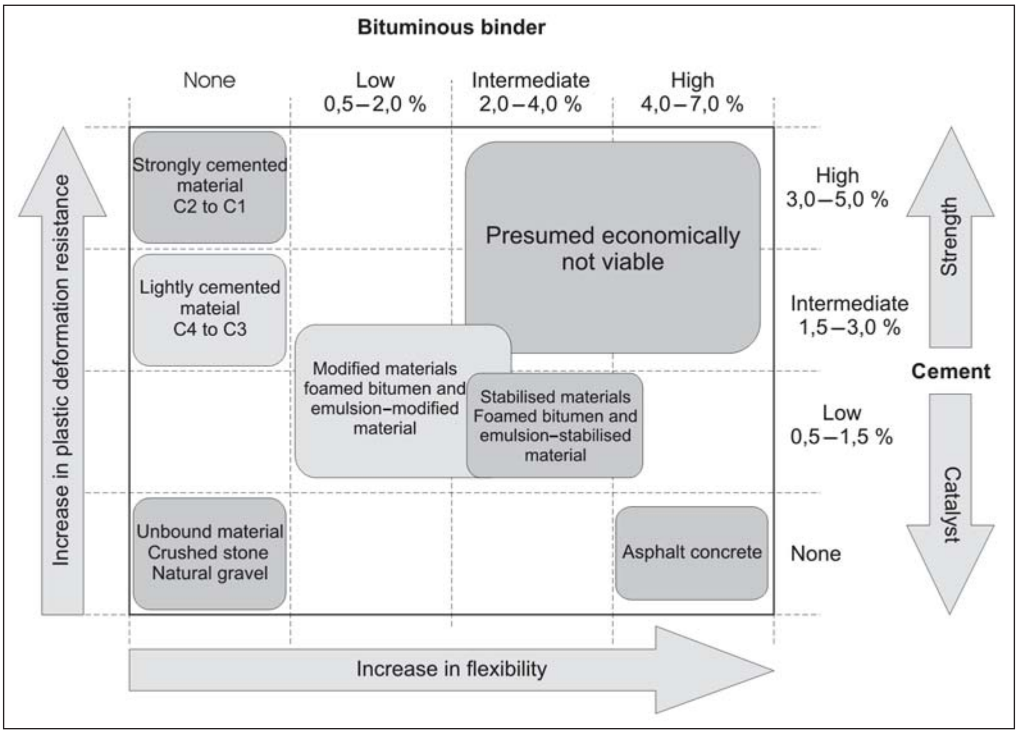


Figure 1 Emulsion-treated materials relative to other materials (Liebenberg 2003)

Table 1 Proposed classification of emulsion-treated materials

Material classification	UCS (kPa)	ITS (kPa) @ 23 °C
ET1	1 200 – 2 000	300 – 500
ET2	1 200 – 2 000	100 – 300
ET3	750 – 1 200	300 – 500
ET4	750 – 1 200	100 – 300

proposed design catalogue for pavements containing emulsion-treated materials with low bitumen content (less than 1,8 % net bitumen) based on the DCP design approach.

SABITA manual 21 (SABITA, 1999) provides guidelines on the mix design and construction of emulsion-treated layers. It only proposed the use of a catalogue included in the document for structural design purposes.

Extensive laboratory testing and heavy vehicle simulator testing on Road P243/1 between Vereeniging and Balfour in Gauteng was carried out by CSIR Transportek in 2001. The testing includes static and dynamic triaxial tests, flexural beam tests, UCS, ITS and CBR tests, and heavy vehicle simulator tests at 40, 80 and 100 kN wheel loads. The results of the testing and research are reported by Liebenberg (2001, 2003) and Liebenberg and Visser (2003) and are not repeated here.

THE STABILISATION OF MATERIALS WITH BITUMEN AND CEMENT

The addition of chemical agents to soil and gravel to improve the engineering properties and thus performance of materials are commonly used in pavement engineering. The interaction of bitumen and the cement on the properties are not always appreciated.

Figure 1 provides an outline of the range of materials that is found by including different percentages of bitumen and cement. Emulsion-treated materials lie somewhere between asphalt concrete materials with its high bitumen contents and cement-treated materials. Cement-treated materials are usually very stiff, but with low flexibility which make them prone to cracking once the bending strength has been exceeded under loading. Asphalt materials have high flexibility and stiffness, but are usually expensive solutions that are restricted to high-volume roads.

THE BEHAVIOUR OF EMULSION-TREATED MATERIALS

The general behaviour of emulsion-treated materials is similar to that of lightly cemented materials in the sense that emulsion-treated materials also exhibit a phased behaviour. The first phase is a fatigue life phase similar to cemented materials, while the second phase is an 'equivalent granular' phase similar to granular unbound materials. The cement content of the emulsion-treated material will determine the degree of resemblance to lightly cemented material. With higher cement content they behave similarly to lightly cemented materials, while with low cement content they will have either a high fatigue resistance or behaviour similar to granular material, depending on the net bitumen content.

Laboratory tests (Liebenberg 2003) showed that the cement dominates the unconfined compressive strength (UCS) and indirect tensile strength (ITS) at high cement content (above initial consumption of lime or ICL) and that the addition of bituminous binder reduces the UCS and ITS of the material. At lower cement content (lower than ICL) the effect of the cement is much less and an increase in bitumen tends to have a slight increase in the UCS and/or ITS. The cement has little strengthening effect on the material when the ICL requirement is not met, and could therefore describe the greater effect of the bituminous binder on the material at low cement content. An increase in binder content in excess of 3 % might have a positive influence on the ITS value regardless of the cement content. The material could then behave in a visco-elastic manner with similar properties to that of asphalt materials. Additional research is however required to prove this theory.

CLASSIFICATION OF EMULSION-TREATED MATERIALS

In SABITA manual 21 (SABITA 1999) emulsion-treated materials are divided into two classes, namely E1 and E2. This classification is based mainly on the material mix design. An E1 material would typically consist of parent materials of G1 to G3 or cement treated base (CTB) quality materials with a residual bitumen content of less than 1-1,5 %. E2 type materials would typically consists of parent materials of G4 to G5 quality material with residual bitumen content of less than 1,8 %.

A new classification system for emulsion-treated materials is proposed to take into account the influence of cement in the mix. Emulsion-treated materials can be constructed with high or low cement content and with high or low net bitumen content. These variations have an effect on the strength and flexibility of the material.

A classification system compatible with that of foam bitumen (Asphalt Academy 2002) is proposed.

The minimum UCS limits were set according to SABITA manual 21 (SABITA 1999). The maximum UCS limits were selected by assuming that an emulsion-treated material would not have maximum UCS values similar to that of a C3 lightly cemented material. The maximum value required for a C3 was then reduced by 1 000 kPa to obtain the maximum limit for emulsion-treated materials. The above values were generated, as little research is available on desirable maximum allowable UCS for emulsion-treated materials. A maximum limit is important to ensure that the layer is not built to such strength that the benefit of the emulsion in providing flexibility is overshadowed by the cement in the mix.

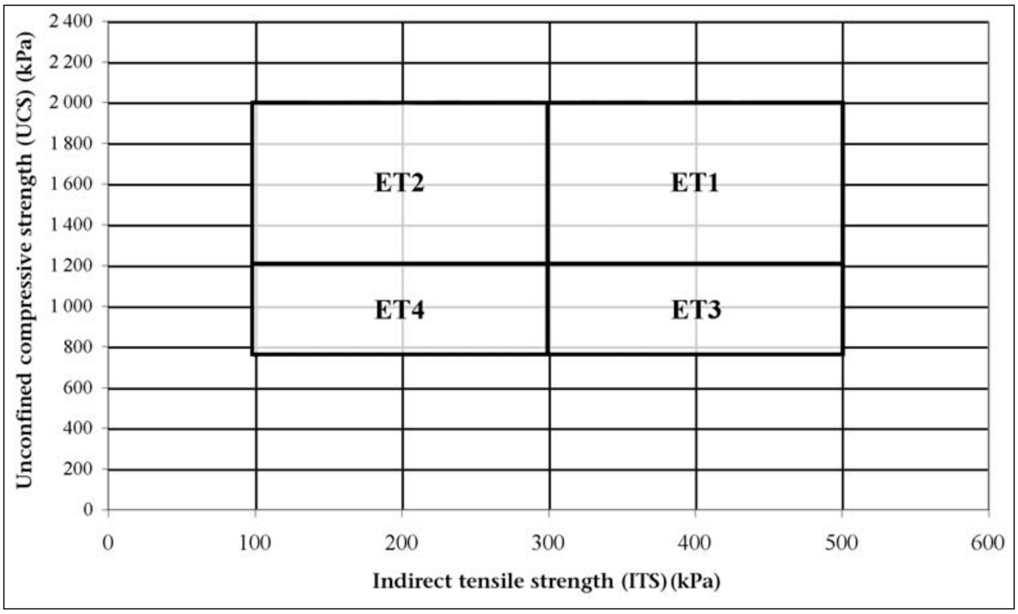


Figure 2 Proposed classification of emulsion-treated materials

Table 2 Typical composition of emulsion-treated material per class

Emulsion-treated material class	Typical parent material	Typical net bitumen content	Typical cement content
ET1	G3 to G6 or recycled cement-treated base	> 1,8 %	> ICL
ET2	G3 to G6 or recycled cement-treated base	0,6 to 1,8 %	> ICL
ET3	G1 to G5 or recycled good quality cement-treated base	> 1,8 %	< ICL
ET4	G1 to G5 depending on requirements of traffic loading	0,6 to 1,8 %	< ICL

Little information is available on the limits for the ITS of emulsion-treated material. Values of between 250 and 600 have been reported (Louw 1997). Until further research provides more information, it is proposed that the guidelines used in foam bitumen be adopted. This may be applicable because of the similarity between foam bitumen-treated and emulsion-treated materials. The classification system and the UCS and ITS limits are presented in figure 2 and table 1.

Table 2 provides a summary of the typical composition of the different emulsion-treated classes.

The different types of emulsion material provide the designer with a pavement structure that could be strong and/or flexible. The parent material available for emulsion treatment plays an important role in the decision of the quantity of stabilising agent (cement, lime or emulsion) to be added in order to obtain a predetermined level of performance. ET1 materials are therefore not necessarily superior to ET2 or ET3 materials, neither are ET4 materials only suitable for low-volume roads. A G1 crushed stone material stabilised with no cement and 1,0 % bitumen emulsion may be as good a product as a G4 material stabilised with 2 % cement and 3 % bitumen emulsion. In this case, the G1-stabilised material will be categorised as an ET4 material, while the G4-stabilised material will be categorised as an ET1 or ET3. The performance of materials which fall into the ET3 and ET4 material classes has not been researched, and the structural design of these materials are excluded from this study. Experience (Bergh 2001) has shown, however, that these materials performed well in practice.

Table 3 provides a guideline for the parameters used as input into the mechanistic design procedure. The values provided here should be regarded as *interim guidelines* until further research on these materials has been undertaken. The parameters given in table 3 should preferably be determined by laboratory testing before the design process commences. However, this is often expensive, time consuming and impractical. The information on C4 and EG5 materials is given for comparison only.

Initial stiffness

The initial stiffness is the elastic stiffness (elastic modulus) of the material at the beginning of the fatigue life phase, that is, just after construction. The initial stiffness is highly dependent on the cement stabilisation of the material and high cement content will increase the value.

Table 3 Proposed emulsion-treated material properties for structural design

Property	ET1	ET2	ET3	ET4	C4	EG5
Initial stiffness (MPa)	1 200 – 2 700 (1 800)	1 200 – 2 700 (1 800)	N/A(*)	N/A(*)	1 500(a)	–
Terminal stiffness (MPa)	300–600 (500)	300–600 (500)	N/A(*)	N/A(*)	–	200(a)
Poisson's ratio	0,35(b)	0,35(b)	0,35(b)	0,35(b)	0,35	0,35
Strain at break	230	145	N/A(*)	N/A(*)	145(a,c)	–
Cohesion(c) (kPa)	200–300 (250)	200–300 (250)	N/A(*)	N/A(*)	283–502(d) 335(e)	40
Friction angle (ϕ)	50°	50°	N/A(*)	N/A(*)	–	43°
c-term(g)	1 374	1 374	N/A(*)	N/A(*)	–	147(a,f)
ϕ-term(h)	6,55	6,55	N/A(*)	N/A(*)	–	3.43(a,f)

(*) No research data available
(a) Jordaan (1994)
(b) Assumed value, not measured
(c) De Beer (1985)
(d) De Beer (1989)
(e) Long *et al* (2001)
(f) Moderate moisture condition

(g) $c_{term} = 2.K.c.\tan(45 + \frac{\phi}{2})$ (2)

(h) $\phi_{term} = K(\tan^2(45 + \frac{\phi}{2}) - 1)$ (1)

Note: Values in brackets used in development of the interim design catalogue.

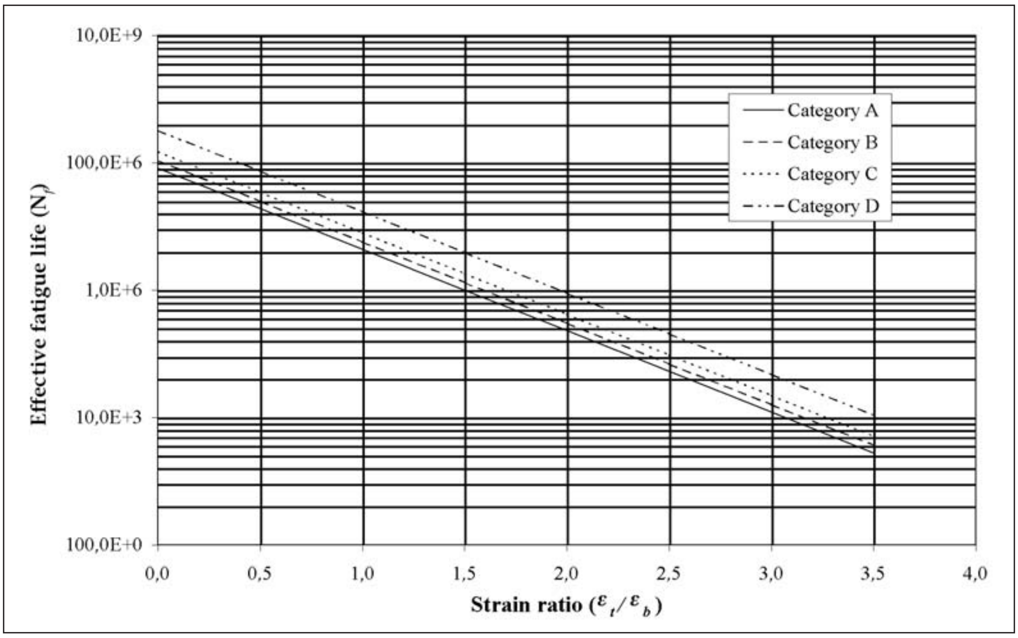


Figure 3 Effective fatigue transfer function for emulsion-treated materials

Terminal stiffness

The terminal elastic stiffness is the stiffness the material will converge to when it reaches the end of its fatigue life. A value of 500 MPa has been back-calculated for the material tested (Liebenberg 2003), but the value will vary depending on the quality of the parent material and the amount of stabilisation. Better-quality parent materials will have higher terminal stiffness values, while lower-quality material will have lower stiffness values. The range of values proposed are typical of terminal stiffnesses and were estimated from the type of parent materials that would be used in emulsion stabilisation. The designer should become familiar with the parent material and select an appropriate stiffness accordingly. The cement content appears to have a larger influence on the terminal stiffness than the bitumen content, therefore similar values for the terminal stiffness were proposed for ET1 and ET2 materials.

Strain at break

The strain at break gives an indication of the flexibility of the material. It is highly dependent on the cement and bitumen content. A high bitumen content increases the value, while an increase in cement content decreases the value (Liebenberg 2003). ET3 and ET4 materials should have a higher strain at break than ET1 and ET2 materials, because of its lower cement content. ET1 and ET3 materials would have a higher strain at break over ET2 and ET4 materials, however, because of their higher bitumen content. The values given in table 3 are the average values expected for the specific type of emulsion-treated material.

Cohesion and friction angle

The cohesion and friction angle are the shear strength parameters which determine the permanent deformation behaviour of the emulsion-treated materials in the second behaviour phase, that is, the 'equivalent granular' phase. The laboratory study (Liebenberg 2003), as well as studies by Maree (1978, 1982) and De Beer (1989), shows that the friction angle is dependent on the parent material and is not sensitive to the addition of stabilising agents. A typical friction angle for emulsion-treated materials is proposed in table 3, which does not differentiate between the different types of emulsion-treated materials. The cohesion is much more dependent on the addition of cementitious stabilising agents than the friction angle (Liebenberg 2003) and the addition of emulsion to a cemented material should not change the cohesion significantly. A typical range of values are proposed from the results of the laboratory study and the work done by Otte (1972) and De Beer (1990) on cemented materials.

MECHANISTIC ANALYSIS OF AN EMULSION-TREATED PAVEMENT

Loading

The same principles as in TRH4 (COLTO 1996) and in the South African Mechanistic Pavement Design Method (Jordaan 1994) apply. The load is a 40 kN dual wheel load with a tyre pressure of 620 kPa. The reason that the tyre pressure is 620 kPa is that it gives a uniform load contact area. That is also the value used in the development of the interim transfer functions.

Layer thickness

The layer thickness of an emulsion-treated material layer may vary between 125 mm and 300 mm. Because of construction tolerances, it does not seem practical to build a layer thinner than 125 mm, while layers thicker than 300 mm may be expensive and difficult to compact.

Mechanistic modelling of pavement behaviour

The mechanistic analysis and design procedure proposed here only considers emulsion-treated materials. Other materials are discussed in the South African Mechanistic Pavement Design Method (Jordaan 1994, Theyse et al 1996).

A pavement with an emulsion-treated material should be analysed in two phases: (i) the fatigue life phase and (ii) the 'equivalent' granular phase.

Fatigue

Fatigue cracking is primarily the result of cumulative damage caused by the bending of the layer under traffic loading. The horizontal tensile strain in an emulsion-treated layer is used to determine the fatigue life of the pavement. The fatigue life is defined as the number of load repetitions until the elastic modulus reduces to a value of about 500 MPa or 25 % of the initial stiffness. The fatigue criteria for the different road categories are as follows:

$$\text{Category A: } N_{f_A} = 10^{7,9183-1,2775\left(\frac{\varepsilon_t}{\varepsilon_b}\right)} \tag{3a}$$

$$\text{Category B: } N_{f_B} = 10^{8,0331-1,2775\left(\frac{\varepsilon_t}{\varepsilon_b}\right)} \tag{3b}$$

$$\text{Category C: } N_{f_C} = 10^{8,1747-1,2775\left(\frac{\varepsilon_t}{\varepsilon_b}\right)} \tag{3c}$$

$$\text{Category D: } N_{f_D} = 10^{8,5066-1,2775\left(\frac{\varepsilon_t}{\varepsilon_b}\right)} \tag{3d}$$

where N_f = number of load repetitions to end of fatigue life
ε_t = maximum tensile strain at bottom of layer
ε_b = strain at break

Category A roads are usually high-volume major interurban freeways and major rural roads roads with a high importance. Category B roads are usually interurban collectors and rural roads with a reasonable importance, while category C roads are lightly trafficked or strategic roads with a lesser importance. Category D roads are usually rural access roads with a low importance.

The maximum horizontal strain is not always at the bottom of the layer, and may be somewhere within the layer. Jordaan (1988) provided a procedure to test whether the maximum tensile strain is at the bottom of the layer.

The maximum horizontal tensile strain is at the bottom of the layer when:

$$\left(\frac{E_3}{E_2}\right)^2 h_c < K \tag{4}$$

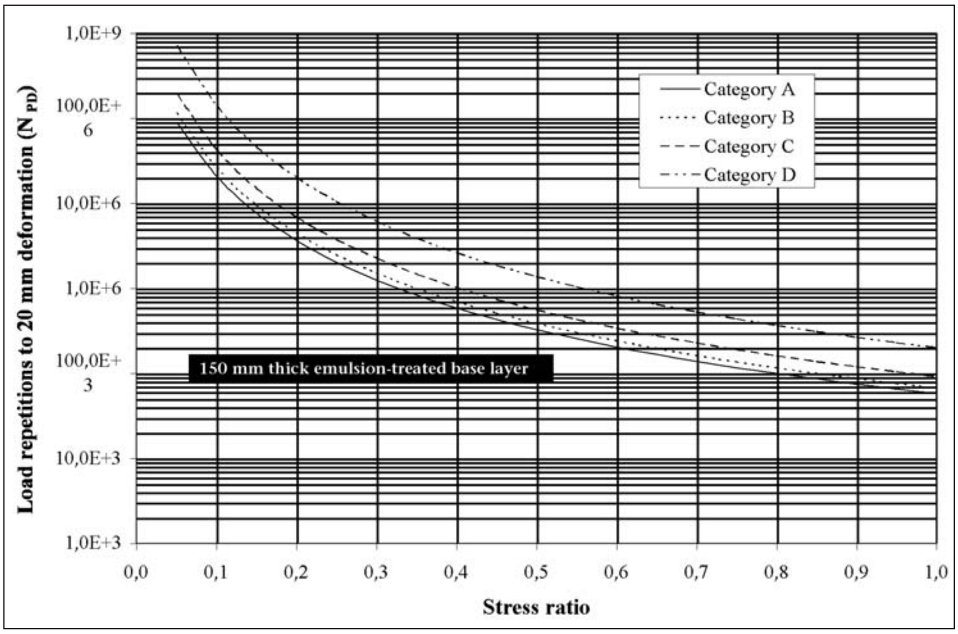


Figure 4 Permanent deformation transfer function for emulsion-treated materials

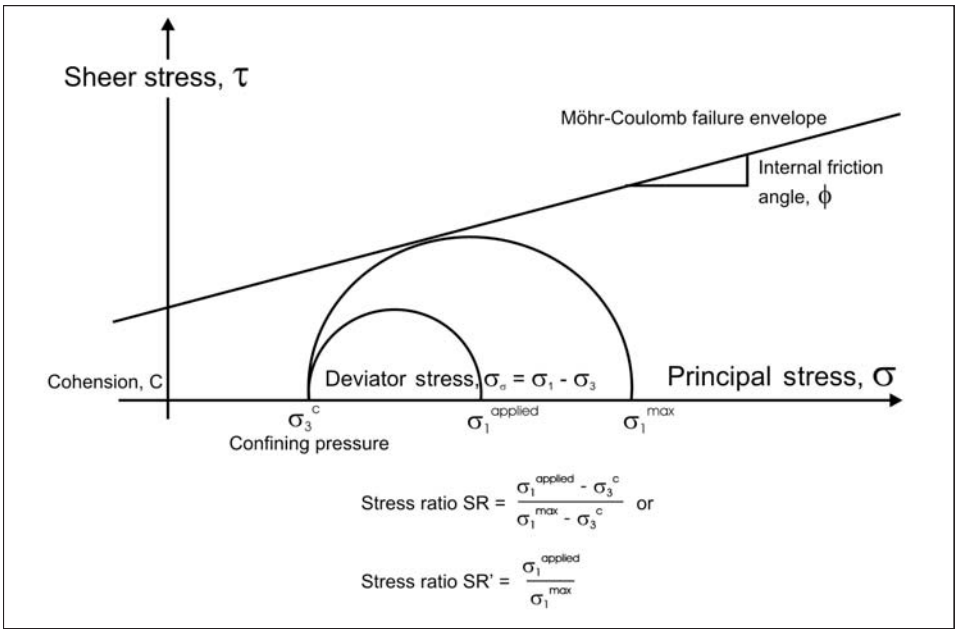


Figure 5 Möhr stress circles representation of the stress ratio concept (Theyse 2000)

with $h_c = h_1\left(\frac{E_1}{E_3}\right)^{\frac{1}{3}} + h_2\left(\frac{E_2}{E_3}\right)^{\frac{1}{3}}$ (5)

where E_1 = elastic modulus of the asphalt layer (MPa)
E_2 = elastic modulus of the emulsion-treated layer (MPa)
E_3 = elastic modulus of the supporting subbase layer (MPa)
h_1 = thickness of the asphalt layer (mm)
h_2 = thickness of the emulsion-treated base layer (mm)
K = constant = 128

Procedure

1. Determine the initial elastic properties of all pavement layers.
2. Select an appropriate effective elastic modulus for the emulsion-treated material from the recommended ranges in table 3.
3. Use the modulus for all the pavement layers as determined in 1 and 2 to determine the pavement response, using an appropriate computer program.
4. Determine whether the maximum tensile strain is at the bottom of the layer, using the procedure proposed by Jordaan (1988) described above. If not, a more detailed analysis of the layer is required.
5. Determine the strain at break either from laboratory testing or using the guidelines in table 3.
6. Use the appropriate transfer function for the category of road from equations 3a to 3d to determine the effective fatigue life of the layer.

Permanent deformation ('equivalent granular' phase)

In the second phase the emulsion-treated layer will be more susceptible to deformation. The stress state in the layer determines the permanent deformation behaviour of the layer. Research (Liebenberg 2003) had shown that approximately 80 % of the permanent deformation observed on the surface originated from within the emulsion-treated layer. It was therefore assumed that 80 % of the 20 mm of deformation would originate from the emulsion-treated layer while the remaining 20 % would be from the other layers in the pavement structure.

The failure criteria to 20 mm of total deformation on the surface for the different road categories are as follows:

Category A:
$$\log N_{PD_A} = \left(\frac{54,005}{t} + 4,4736\right) * \left(SR + 0,0664\right)^{-0,2313} \quad (6a)$$

Category B:
$$\log N_{PD_B} = \left(\frac{54,005}{t} + 4,5389\right) * \left(SR + 0,0664\right)^{-0,2313} \quad (6b)$$

Category C:
$$\log N_{PD_C} = \left(\frac{54,005}{t} + 4,6775\right) * \left(SR + 0,0664\right)^{-0,2313} \quad (6c)$$

Category D:
$$\log N_{PD_D} = \left(\frac{54,005}{t} + 5,0213\right) * \left(SR + 0,0664\right)^{-0,2313} \quad (6d)$$

where: N_{PD} = Number of load repetitions to 20 mm deformation on surface
t = thickness of the emulsion treated layer (mm).
SR = critical stress ratio defined as:

$$SR = \frac{\sigma_1^a - \sigma_3}{\sigma_3\left[\tan^2\left(45° + \frac{\phi}{2}\right) - 1\right] + 2.c.\tan\left[45° + \frac{\phi}{2}\right]} \quad (7)$$

or $SR = \frac{\sigma_1^a - \sigma_3}{\sigma_3 . \phi_{term} + c_{term}}$ (8)

where: ϕ = friction angle (degrees) (measured in laboratory)
c = cohesion (kPa) (measured in laboratory)
σ_1 = major principal stress
σ_3 = minor principal stress
ϕ_{term} = friction angle term from table 3
c_{term} = cohesion term from table 3

The stress ratio of a material is the ratio between the applied stress and the maximum shear strength at the failure envelope of the material. Theyse (2000) derived equation 7 for the calculation of the stress ratio. It is graphically presented in figure 5. The

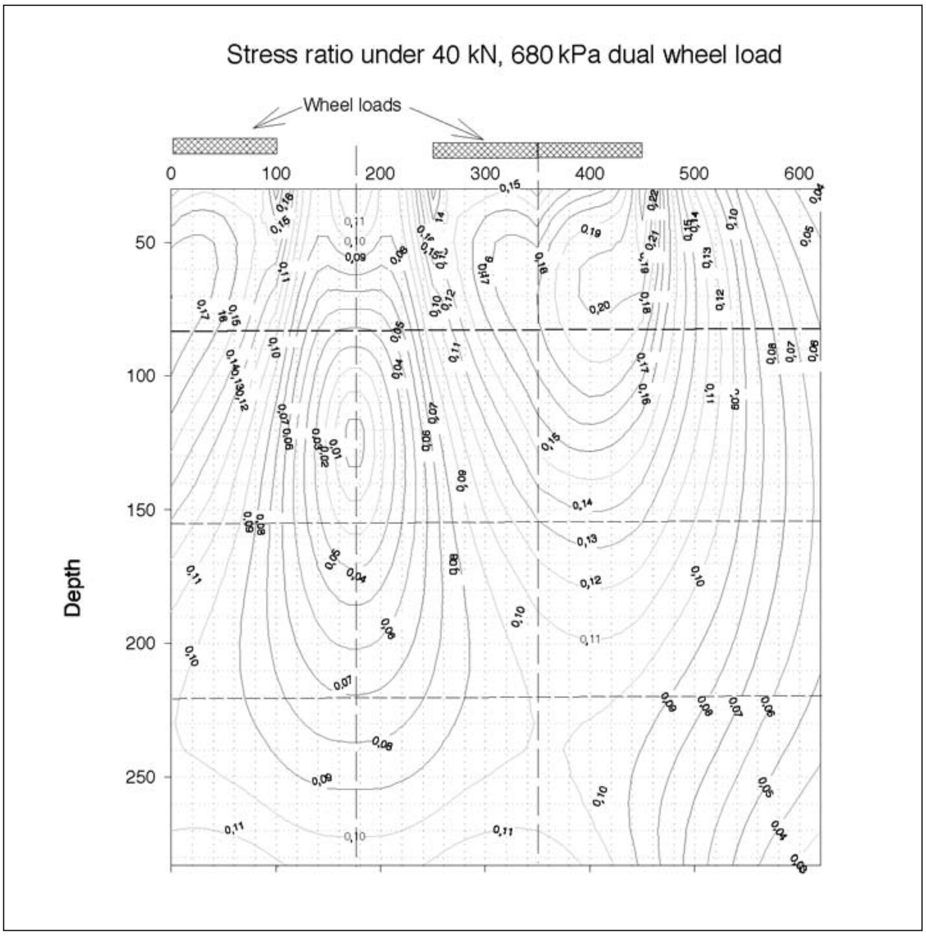


Figure 6 Contour plots of the stress ratio on HVS pavement under 40 kN, 680 kPa dual wheel load

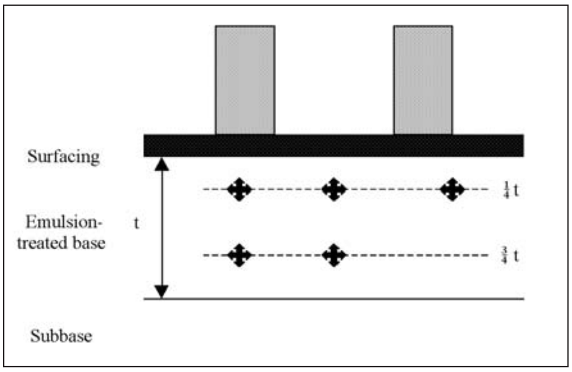


Figure 7 Recommended positions to calculate the critical stress ratio

stress ratio is the inverse of the factor of safety used in the mechanistic analysis of granular unbound pavement layers.

One of the major shortcomings of the linear elastic theory is that tensile stresses are allowed in the material. This may be applicable in the case of asphalt and cemented materials, but unbound materials are not able to withstand tensile stresses.

When a beam is flexed, tensile strains develop at the bottom of the beam. Since $\sigma = \varepsilon.E$, where E is the modulus of elasticity, the stress (σ) will be negative if strain (ε) is negative (E is always positive). In practice, granular materials will 'redistribute' the stresses so that the tensile stresses at the bottom are eliminated. Models to model this behaviour effectively are not widely in use.

The current practice in the South African Mechanistic Pavement Design Method is to 'shift' the Möhr circle so that the minor principal stress (σ_3) becomes zero, and increase the major principal stress (σ_1) by the same magnitude. The radius of the Möhr circle remains the same, which means that the deviator stress (σ_d) remains the same.

This adjustment gives a more reasonable result and is a better approximation of the stress state in an unbound pavement layer. It is recommended that the same practice be followed in the analysis of emulsion-treated materials.

Critical positions of the stress ratio

The current practice in the South African Mechanistic Pavement Design Method is to calculate the critical parameter (factor of safety) in the centre of the layer, either under the load or between the loads, in the case of a dual wheel load.

Unbound materials fail when the shear strength of the materials is exceeded. An analysis of the deviator stress, octahedral shear stress and stress ratio (Liebenberg 2003) at different loads and contact pressures indicated that the critical shear stresses are mostly in the upper quarter of the layer underneath the load. Figure 6 shows a typical contour plot of the stress ratio under a 40 kN dual wheel load as calculated by a linear elastic model. From the stress ratio contour plot it appears that the critical stress ratio is not at the centre of the layer but somewhere in the upper part of the layer. The risk of the shear strength being exceeded is critical at these points. The analysis showed that the stress ratio at the centre of the layer is actually the lowest and not the critical location. The position of the critical stress ratio will vary as the composition of pavement structures varies.

From the analysis it appears that the critical stress ratio varies between several positions in the pavement. A detailed analysis of the stress ratio would be ideal, but is not often practical and difficult to analyse. It is therefore proposed that stress ratios be calculated at the positions indicated in figure 7. The most critical (highest) stress ratio should then be used for purposes of design and analysis.

Five critical positions for the stress ratio have been identified. These are as follows:

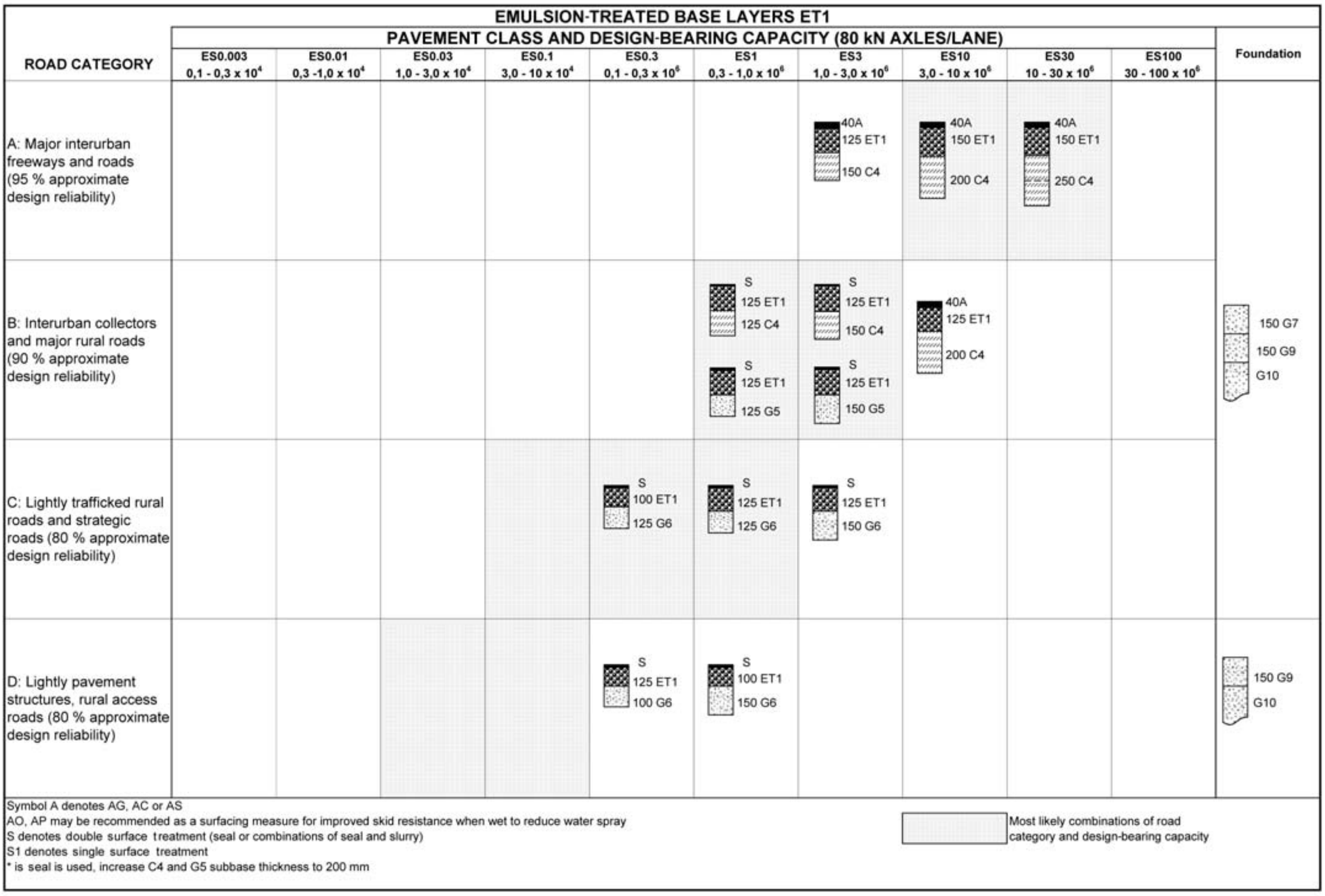
- $\frac{1}{4}$ from the top of the layer under the centre of the load
- $\frac{1}{4}$ from the top of the layer between the loads
- $\frac{1}{4}$ from the top of the layer at the outer edge of the load
- $\frac{1}{4}$ from the bottom of the layer under the centre of the load
- $\frac{1}{4}$ from the bottom of the layer between the loads

Procedure

1. Determine the initial elastic properties of all pavement layers in the second phase.
2. Select an appropriate effective elastic modulus for the emulsion-treated material in its second phase ('equivalent' granular) from the recommended ranges in table 3.
3. Use the modulus for all the pavement layers as determined in 1 and 2 to determine the pavement response at the positions indicated above, using an appropriate linear elastic computer program.
4. Use the procedure described above to shift the minor principal stress if it is tensile.
5. Calculate the stress ratio using equation 7 or 8 by using the recommended values in table 3, at the proposed positions as indicated above.
6. Use the appropriate transfer function for the category of road from equations 6a to 6d to calculate the bearing capacity of the layer to 20 mm of deformation on the surface.

The total life of the emulsion-treated layer is the sum of the fatigue life and the bearing capacity to 20 mm deformation and can be expressed as follows:

$$N = N_f + N_{PD} \tag{9}$$



EMULSION-TREATED BASE LAYERS ET1

PAVEMENT CLASS AND DESIGN-BEARING CAPACITY (80 kN AXLES/LANE)

ROAD CATEGORY	ES0.003 0,1 - 0,3 x 10^4	ES0.01 0,3 -1,0 x 10^4	ES0.03 1,0 - 3,0 x 10^4	ES0.1 3,0 - 10 x 10^4	ES0.3 0,1 - 0,3 x 10^6	ES1 0,3 - 1,0 x 10^6	ES3 1,0 - 3,0 x 10^6	ES10 3,0 - 10 x 10^6	ES30 10 - 30 x 10^6	ES100 30 - 100 x 10^6	Foundation
A: Major interurban freeways and roads (95 % approximate design reliability)							40A 125 ET1 150 C4	40A 150 ET1 200 C4	40A 150 ET1 250 C4		
B: Interurban collectors and major rural roads (90 % approximate design reliability)						S 125 ET1 125 C4 S 125 ET1 125 G5	S 125 ET1 150 C4 S 125 ET1 150 G5	40A 125 ET1 200 C4			150 G7 150 G9 G10
C: Lightly trafficked rural roads and strategic roads (80 % approximate design reliability)					S 100 ET1 125 G6	S 125 ET1 125 G6	S 125 ET1 150 G6				
D: Lightly pavement structures, rural access roads (80 % approximate design reliability)					S 125 ET1 100 G6	S 100 ET1 150 G6					150 G9 G10

Symbol A denotes AG, AC or AS
AO, AP may be recommended as a surfacing measure for improved skid resistance when wet to reduce water spray
S denotes double surface treatment (seal or combinations of seal and slurry)
S1 denotes single surface treatment
* is seal is used, increase C4 and G5 subbase thickness to 200 mm

▨ Most likely combinations of road category and design-bearing capacity

Figure 8 Interim structural design catalogue for ET1 emulsion-treated base layers

INTERIM DESIGN CATALOGUE

A proposed design catalogue based on the mechanistic-empirical functions presented here is included in figures 8 and 9. The catalogue deals with most of the factors that have to be considered by the designer, including the road category and the design traffic loading over the design period. It should be used as an interim guideline and should not take precedence over the experience of the practitioner.

The catalogue was compared with other published catalogues on emulsion-treated materials (De Beer & Grobler 1994; Theyse 1998). The pavement structures presented here are lighter than the pavement structures proposed by De Beer and Grobler (1993), but the catalogue agrees well with the catalogue proposed by Theyse (1998).

The catalogue allows the use of seals on roads with low design traffic volumes. It does not include practical considerations such as drainage, compaction or pavement cross-section. These aspects should be considered according to the TRH4 (COLTO 1996).

The catalogue provides the use of ET1 and ET2 types of emulsion-treated materials. No catalogue for ET3 and ET4 types of material was developed.

CONCLUSIONS

The mechanistic design procedure presented here shows that the performance of an emulsion-treated base layer compares well with other conventional base layer materials and that it may withstand traffic volumes of up to 30 million standard axles. The interim transfer functions developed show that materials treated with bitumen emulsion have an increased fatigue life over lightly cemented layers and show good permanent deformation characteristics.

The design procedure proposed in this paper is based on limited testing and certain assumptions and should be introduced as an interim guideline until such time as more knowledge on bitumen emulsion-treated materials are obtained. Where possible, material properties should be measured in the laboratory and then entered into the structural design process. The material guidelines presented in table 3 should only be used as a guideline.

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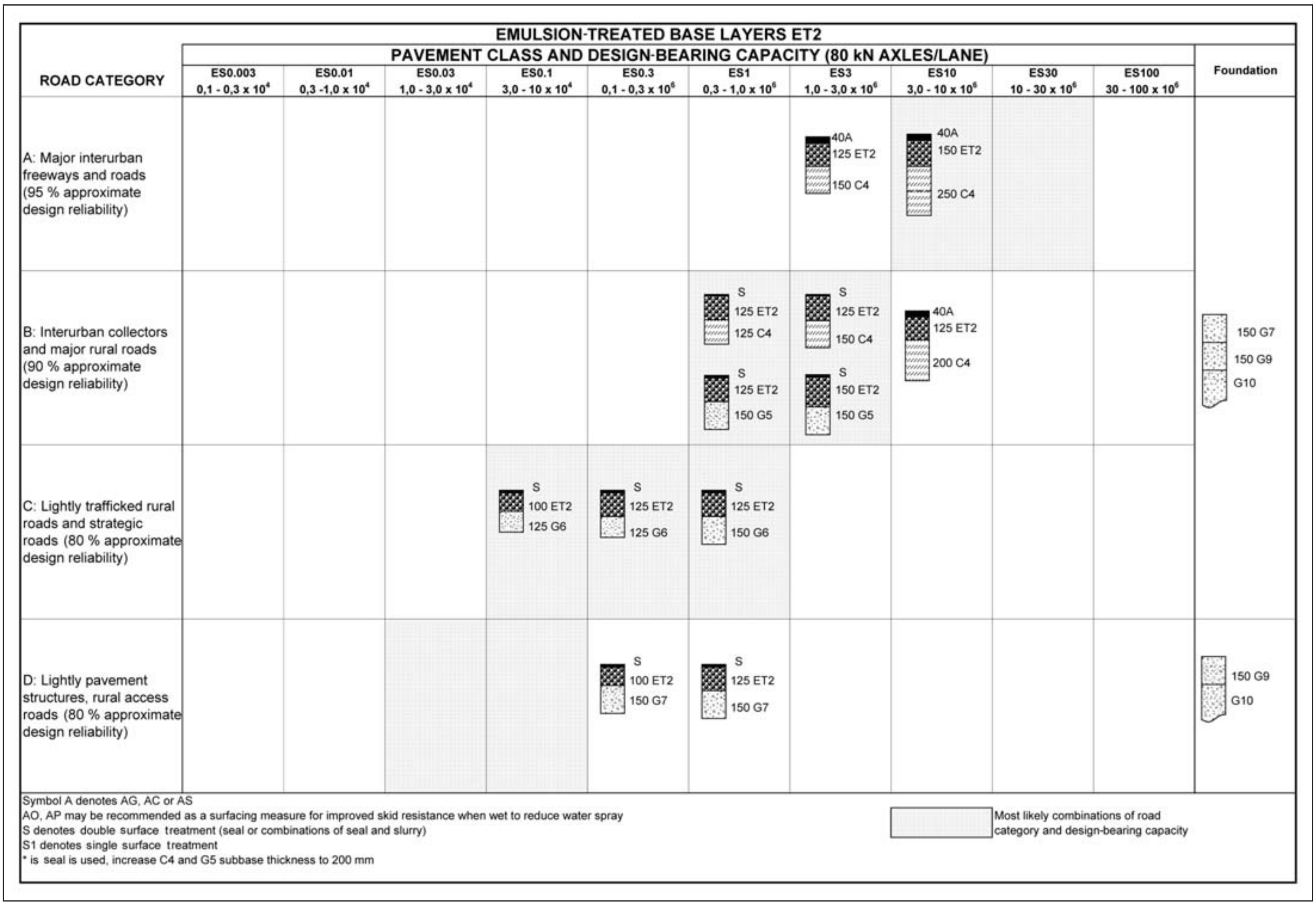

ROAD CATEGORY	ES0.003 $0,1 - 0,3 \times 10^4$	ES0.01 $0,3 - 1,0 \times 10^4$	ES0.03 $1,0 - 3,0 \times 10^4$	ES0.1 $3,0 - 10 \times 10^4$	ES0.3 $0,1 - 0,3 \times 10^6$	ES1 $0,3 - 1,0 \times 10^6$	ES3 $1,0 - 3,0 \times 10^6$	ES10 $3,0 - 10 \times 10^6$	ES30 $10 - 30 \times 10^6$	ES100 $30 - 100 \times 10^6$	Foundation
A: Major interurban freeways and roads (95 % approximate design reliability)							40A 125 ET2 150 C4	40A 150 ET2 250 C4			
B: Interurban collectors and major rural roads (90 % approximate design reliability)						S 125 ET2 125 C4 S 125 ET2 150 G5	S 125 ET2 150 C4 S 150 ET2 150 G5	40A 125 ET2 200 C4			150 G7 150 G9 G10
C: Lightly trafficked rural roads and strategic roads (80 % approximate design reliability)				S 100 ET2 125 G6	S 125 ET2 125 G6	S 125 ET2 150 G6					
D: Lightly pavement structures, rural access roads (80 % approximate design reliability)					S 100 ET2 150 G7	S 125 ET2 150 G7					150 G9 G10

EMULSION-TREATED BASE LAYERS ET2

PAVEMENT CLASS AND DESIGN-BEARING CAPACITY (80 kN AXLES/LANE)

Symbol A denotes AG, AC or AS
AO, AP may be recommended as a surfacing measure for improved skid resistance when wet to reduce water spray
S denotes double surface treatment (seal or combinations of seal and slurry)
S1 denotes single surface treatment
* is seal is used, increase C4 and G5 subbase thickness to 200 mm

▨ Most likely combinations of road category and design-bearing capacity

Figure 9 Interim structural design catalogue for ET2 emulsion-treated base layers

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