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WOVEN STEELCORD NETWORKS AS REINFORCEMENT OF ASPHALT ROADS

UN TISSU EN FIL D'ACIER COMME RENFORCEMENT DES ROUTES ASPHALTEES

STAHLDRAHTGEWEBE ALS BEWEHRUNG FÜR ASPHALT-STRASSEN

The fatigue characteristics of different asphalt layers are of major importance in the design of asphalt roads, in particular on soft soils. Each wheel load repetition causes strains in the asphalt layers, which in classical design are reduced to an acceptable level by aggregate layers. So, asphalt fatigue characteristics in fact determine the life-time of any asphalt road. Since steel takes high stresses at relatively low strains the durability of asphalt roads can be extended considerably by reinforcement with steelcord networks. Indeed, several calculations based on linear elastic stress strain relations show the favourable effect of steelcord networks.
In particular at soft subsoils, such as in the Netherlands, the allowable number of wheel load repetitions can thus be enlarged by a factor 3 to 10. This contribution outlines fundamental mechanisms, such as plate bending and load distribution.

Zur Bemessung von Asphalt-Strassendecken ist es - besonders bei weichen Böden - wichtig, die Ermüdungscharakteristiken des Materials zu kennen. Jede Radlastenwiederholung verursacht Dehnungen in Asphaltschichten, die bei klassischer Bemessung durch die Zuschlägskörner auf ein zulässiges Mass begrenzt werden. Das heisst, dass die Ermüdungseigenschaften letztlich die Lebensdauer jeder Asphaltstrasse bestimmen. Da Stahl schon bei kleinen Dehnungen relativ hohe Spannungen überträgt, kann die Lebensdauer einer Asphaltstrasse deutlich erhöht werden, wenn man Stahlnetzbewehrungen verwendet. Einige linear elastischen Berechnungen zeigen der vorteiligen Effect der Stahlnetzbewehrungen deutlich. Besonders auf weichem Untergrund, wie in den Niederlanden häufig vorkommt, kann die zulässige Anzahl von Lastwechseln um einen Faktor 3 bis 10 erhöht werden. Dieser Beitrag erläutert die zugrunde liegenden Mechanismen wie zum Beispiel Plattenbiegung und Lastverteilung.

1. INTRODUCTION

Geotextiles have been used in road foundations for several years already. Their main functions in these applications are (i) separation of aggregate layer and subsoil, (ii) filtration and (iii) reinforcement. The importance of the reinforcement function is growing, since geotextiles with a high tensile strength contribute significantly to the bearing capacity of roads. The reinforcement function is defined as the action of the geotextile that causes a change in the stress state in the road profile. Two types of reinforcement can be distinguished: lateral restraint and membrane action. Lateral restraint is the restraint of lateral movement of the aggregate over the geotextile. Consequently, the aggregate shows a stiffer behaviour and spreads the traffic load over a wider area. Deformations of the road and stresses and strains in the geotextile are small. Lateral restraint is assumed to be important in roads on rather good subgrade ($C_u > 50$ kN/m²). In that case the application of geotextiles is yet not always necessary. The membrane type of reinforcement is predominant in roads on a relatively weak subgrade. During rutting the geotextile is strained like a membrane.
The traffic load on the subgrade is spread by the vertical components of the stresses induced in the geotextile, see figure 1.

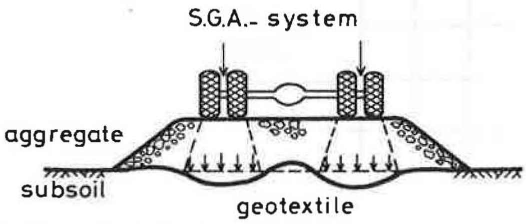

Figure 1a: Membrane action of geotextile

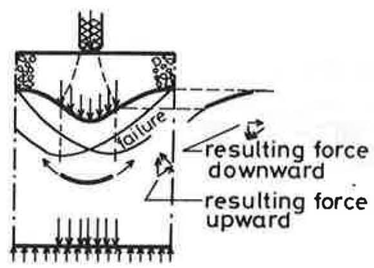

Figure 1b: Stress distribution by reinforcement

The membrane type reinforcement is an interaction between subgrade and geotextile. It is more effective if the geotextile has a high modulus of elasticity. Such a geotextile may contribute considerably to the bearing capacity of the road or may reduce the required height of aggregate. A good design method for taking into account the geotextile as a structural reinforcement element has been developed by Sellmeijer a.o. (1). Since steel can take large stresses at low strains it may be an appropriate material to perform the reinforcement function. This paper deals with woven steelcord networks as reinforcement of asphalt roads and its effect on the durability of such roads.

2. WOVEN STEELCORD NETWORKS

The GEO-FLEXIMAT® GF 10/10, developed by Bekaert-Belgium, is a woven network made of steelcord and/or textile, with adjustable strength up to 3 MN/m'.
As a coating brass, zinc or pvc are used. Depending on the field of applications mesh width, flexibility and strength can be varied. For a woven steelcord network reinforcement to be useful in asphalt road foundations following considerations are important:
- sufficient strength required for a reasonable plate action;
- mesh width not too large to avoid cracking of asphalt top layer. If the steelcord reinforcement network is used in reconstruction or reparation of existing roads a relatively narrow mesh width will prevent the occurence of reflective cracking;
- sufficient flexibility during execution;
- cost-analysis compared to geotextiles.

In view of these considerations a woven steelcord network is taken with mesh dimensions 3 x 3 cm². Reinforcement in both horizontal directions consists of strands composed of three cords with a diameter of 0.6 mm each; modulus of elasticity of steel $E = 2.10^{11}$ N/m², see figure 2.

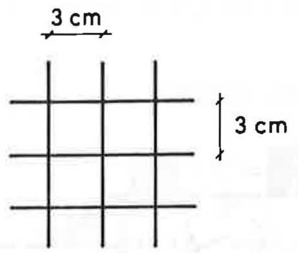

Figure 2a: Upper view steelcord network

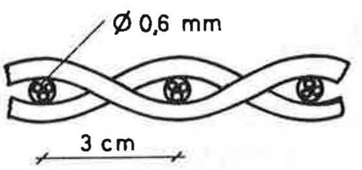

Figure 2b: Cross section: strand with 3 cords

A series of calculations have been set up in order to investigate the effect of a woven steelcord reinforcement on stresses, strains and deformations in asphalt layers, aggregate and subgrade due to traffic load. Based on fatigue characteristics of Shell for asphalt the calculation results have been evaluated to the allowable number of load repetitions and its increase by the reinforcement of a steelcord network.

3. THE CALCULATION MODEL BISAR

The computercode BISAR (BItumen Structures Analysis in Roads) has been developed by Shell (2). It calculates stresses, strains and deformations in any point of an elastic multi-layer system which is subject to one or more uniformly spread circular surface loads (both vertical normal and shear stresses). Layers can move horizontally with or without slip. The basic assumptions in the model are:
- horizontal, homogeneous layers.
- isotropic linear-elastic behaviour of materials;
- the layers extend to infinity in horizontal directions, the lowest one also in vertical direction.

This means, that an equivalent thickness has to be taken for the reinforcing steelcord layer, simulating properly the stress-strain behaviour of the steelcord network. This thickness d is chosen such, that the strain ε at a normal force F equals the one in the steelcord network. For the network we have:

$$\varepsilon = \frac{1}{E} \cdot \frac{F}{\frac{b \cdot A}{a}}$$

With a = strand distance (m)
b = considered width (m)
E = modulus of steel (N/m²)
A = cross-sectional surface of a strand (m²)

Since for the replacing steel plate

$$\varepsilon = \frac{1}{E} \cdot \frac{F}{bd}$$

equating strains yields for the equivalent thickness d:

$$d = \frac{A}{a}.$$

With $A = 3 \cdot \frac{1}{4} \cdot \pi \cdot (0.6\ 10^{-3})^2$ and $a = 3.10^{-3}$ it follows $d = 2.82\ 10^{-5}$m.
The steelcord network now is replaced by a thin steel-plate with the same stiffness and stress-strain behaviour.

4. STRESS-STRAIN CALCULATIONS WITH BISAR

4.1. Without reinforcement by woven steelcord

The road profile of figure 3 is representative for dutch conditions. It is designed to serve for many years without reinforcement under highway traffic loads on soft soils. The basic idea is the following. As a base a sand layer of at least 50 cm thick is put on the in situ clay. Then successively three layers of gravel-asphalt mix (each 6 cm thick), a 4 cm thick layer of open-graded asphalt concrete and a 4 cm thick layer of closed asphalt concrete are placed on the sand base.
To reap the fruits of the total extra costs for integrating woven steelcord reinforcement in the road profile the profile of figure 4 with reduced thickness of layers is taken as basic case. As the maximum effect of the reinforcing network can be expected in case of soft subgrade, the presence of a 3 m thick soft clay layer is assumed, which often is the case in the Netherlands.
Underneath there is a firm sand layer.

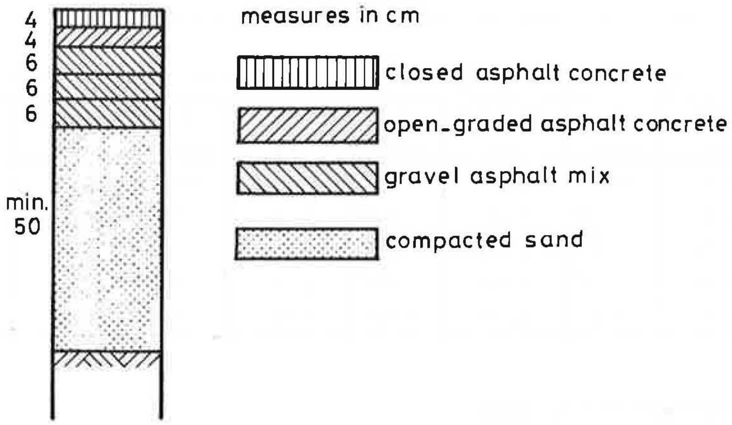

Figure 3: Representative cross section of asphalt road foundation for highways in the Netherlands

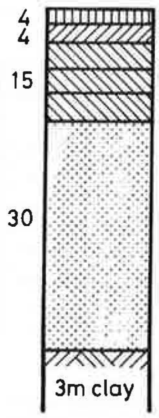

Figure 4: Basic profile with reduced layer thickness legend see figure 3

The load exerted on the road by a tandem-rear axle with double wheels of a truck is taken as representative. Now, stress distribution is a depth effect and fatigue of the thin asphalt layers is mostly predominating the design. Therefore it is assumed that mutual influence of left and right hand wheelset can be neglected.
Figure 5 shows an upper view of loads of two times two wheels with a total axle load of 100 kN. For each wheel this means a load of 25 kN on a circular surface with radius, say, 0.125 m, leading to a surface pressure of q = 5.09 10^2 kN/m^2.

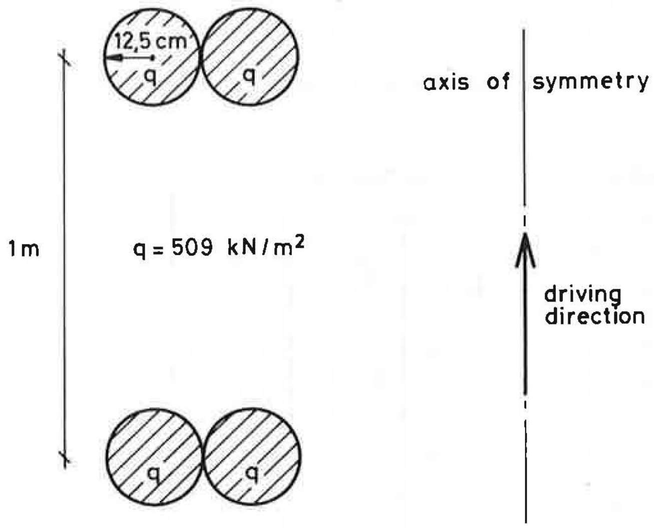

Figure 5: Upper view of loads exerted by tandem rear axle with double wheels

Stress-strain calculations without reinforcement have been made with varying stiffness of the clay and varying thickness of the gravel-asphalt layer (see table 1). The Poisson ratio ν is taken 0.35 for asphalt, 0.33 for the compacted sand base and 0.5 for soft clay.

4.2. Calculations with reinforcement by woven steelcord

Based on the cases I-V of table 1 calculations have been made with GEO-FLEXIMAT® as reinforcement layer. The level at which the reinforcement is placed is varied as well as the degree of slip either between steel and asphalt or between asphalt and sand base. In table 2 these calculations are summarised; Roman numerals refer to the basic cases without reinforcement of table 1.

5. RESULTS

The road foundation in fact bends to a certain extent under each traffic load. Strains occur in the respective foundation layers. It was found that maximum strains occurred in the asphalt layers between two adjacent wheels. The magnitude of the calculated strain of course depends on stiffness parameters and thickness of the foundation layers. Since compression is not predominant with respect to fatigue of asphalt, only positive and thus horizontal, strains have been considered.
Table 3 shows the calculated maximum value of horizontal strains in the asphalt layers; ε_x, ε_y are horizontal strains in transverse and driving direction respectively, ε_z is the vertical strain. In almost all cases the strain ε_y is found to be predominating. Also the allowable number N of load repetitions is given and the calculated horizontal stresses to be taken by the steelcord network.
The allowable number N of load repetitions is obtained from the Shell Pavement Design Manual (see figure 6) based on strains per single load passage.
As an example figure 7 demonstrates the effect of a steelcord reinforcement on the predominant horizontal strain ε_y in the driving direction.
It shows a strain reduction to 68 % of the strain in a profile without reinforcement, resulting in an increase of the allowable number of load repetitions by a factor of ten.

Table 1: Thickness and stiffness of layers as input for strain calculations without reinforcement

	case I		case II		case III		case IV		case V	
	thickness (m)	E (N/m²)	thickness (m)	E (N/m²)	thickness (m)	E (N/m²)	thickness (m)	E (N/m²)	thickness (m)	E (N/m²)
closed asphalt	0.04	$3\cdot10^{9}$	0.04	$3\cdot10^{9}$	0.04	$3\cdot10^{9}$	0.04	$3\cdot10^{9}$	0.04	$3\cdot10^{9}$
open-graded asphalt	0.04	10^{9}	0.04	10^{9}	0.04	10^{9}	0.06	10^{9}	0.06	10^{9}
gravel-asphalt mix	0.15	10^{9}	0.15	10^{9}	0.10	10^{9}	0	0	0	0
sand	0.30	10^{8}	0.30	10^{8}	0.30	10^{8}	0.50	10^{8}	0.50	10^{8}
clay	3.00	10^{7}	3.00	$5\cdot10^{7}$	3.00	$5\cdot10^{7}$	3.00	10^{7}	3.00	$5\cdot10^{7}$

Table 2: Geometry of calculations with GEO-FLEXIMAT® reinforcement
Roman numerals refer to Table 1

Ia	Reinforcement between gravel-asphalt mix and sand; frictionless interface reinforcement/sand
Ib	As Ia, 50 % friction along upper and lower side of reinforcement
Ic	Reinforcement placed 5 cm above interface between gravel-asphalt and sand; 50 % friction along interface gravel-asphalt/sand
Id	As Ic, but reinforcement placed 2 cm above interface between gravel-asphalt and sand
IIa	As Ic; stiff clay $E = 5\cdot10^{7}$ N/m²
IIb	As Id; stiff clay $E = 5\cdot10^{7}$ N/m²
IIIa	Reinforcement placed 2 cm above interface between gravel-asphalt and sand 50 % friction along interface gravel-asphalt/sand
IIIb	Reinforcement placed between open-graded asphalt concrete and gravel-asphalt mix
IIIc	As IIIb; soft clay $E = 5\cdot10^{6}$ N/m²
IVa	Reinforcement placed 2 cm above interface open-graded asphalt/sand; no gravel-asphalt mix layer
IVb	As IVa; Reinforcement placed between open-graded asphalt and sand
Va	As IVb; stiff clay $E = 5\cdot10^{7}$ N/m²

Table 3: Calculated maximum strains ε_x, ε_y and ε_z in asphalt layers and steelcord reinforcements; Resultant allowable number N of load repetitions

strains in 10^{-4}	closed asphalt-concrete		open-graded asphalt-concrete			gravel-asphalt mix			GEO-FLEXIMAT®			
case	ε_z	N	ε_x	ε_y	N	ε_x	ε_y	N	ε_x	ε_y	σ_x (N/m²)	σ_y (N/m²)
I.	2.65	$2\cdot10^{6}$		1.06	> 10^{7}	5.50		$1\cdot5\ 10^{4}$				
I.a	2.14	$6\cdot10^{6}$		0.92	> 10^{7}		3.75	$2\cdot10^{5}$		3.75		$1.06\ 10^{8}$
I.b.	2.45	$3\cdot10^{6}$		0.99	> 10^{7}		4.76	$4\cdot10^{4}$		0.06		$1.09\ 10^{2}$
I.c.	2.61	$2\cdot2\cdot10^{6}$		1.01	> 10^{7}	5.21		$2\cdot10^{4}$	3.17		$8.93\ 10^{7}$	
I.d.	2.14	$6\cdot10^{6}$		0.92	> 10^{7}		3.81	$2\cdot10^{5}$		3.07		$8.71\ 10^{7}$
II.	1.37	> 10^{7}		1.08	> 10^{7}		3.29	$4\cdot10^{5}$				
II.a.	1.38	> 10^{7}		1.06	> 10^{7}		3.29	$4\cdot10^{5}$		2.00		$5\cdot5\ 10^{7}$
II.b.	1.37	> 10^{7}		1.07	> 10^{7}		3.21	$4\cdot2\ 10^{5}$		2.57		$7\cdot2\ 10^{7}$
III.	1.88	> 10^{7}		1.42	> 10^{7}		4.49	$6\cdot5\ 10^{4}$				
III.a.	1.89	> 10^{7}		1.37	> 10^{7}		4.38	$7\cdot10^{4}$		3.36		$9\cdot0\ 10^{7}$
III.b.	1.89	> 10^{7}		1.33	> 10^{7}		4.48	$6\cdot5\ 10^{4}$		1.33		$3\cdot0\ 10^{7}$
III.c. (soft clay)	3.23	$9\cdot10^{5}$		1.23	> 10^{7}		5.47	$1\cdot5\ 10^{4}$		1.22		$2\cdot7\ 10^{7}$
IV.	3.89	$3\cdot5\ 10^{5}$		7.97	< 10^{4}							
IV.a.	3.88	$3\cdot5\ 10^{5}$		7.11	10^{4}					4.87		$1\cdot2\ 10^{8}$
IV.b.	3.82	$3\cdot6\ 10^{5}$		6.80	$1\cdot3\ 10^{4}$					6.80		$1\cdot6\ 10^{8}$
V.	3.22	$9\cdot10^{5}$		7.82	< 10^{4}							
V.a.	3.15	$9\cdot2\ 10^{5}$		6.70	$2\cdot10^{4}$					6.70		$1\cdot5\ 10^{8}$

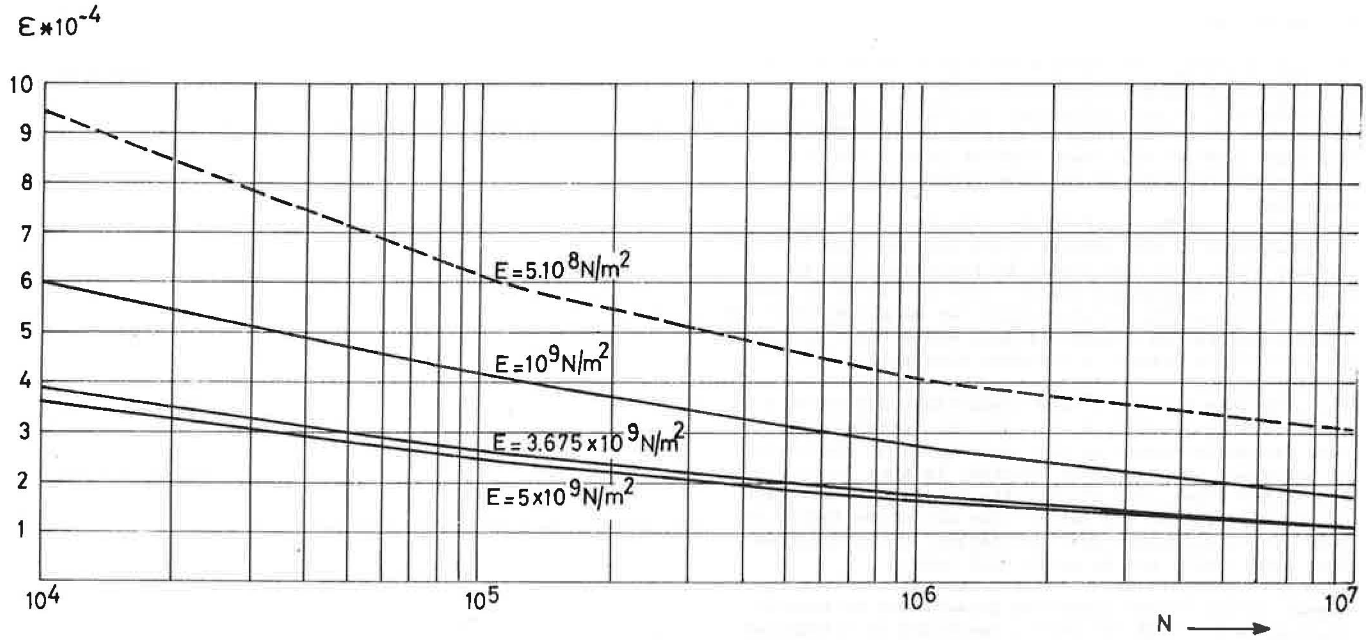

Figure 6: Fatigue characteristics of gravel-asphalt mix (v. Dijk) allowable number N of load repetitions versus strain ε

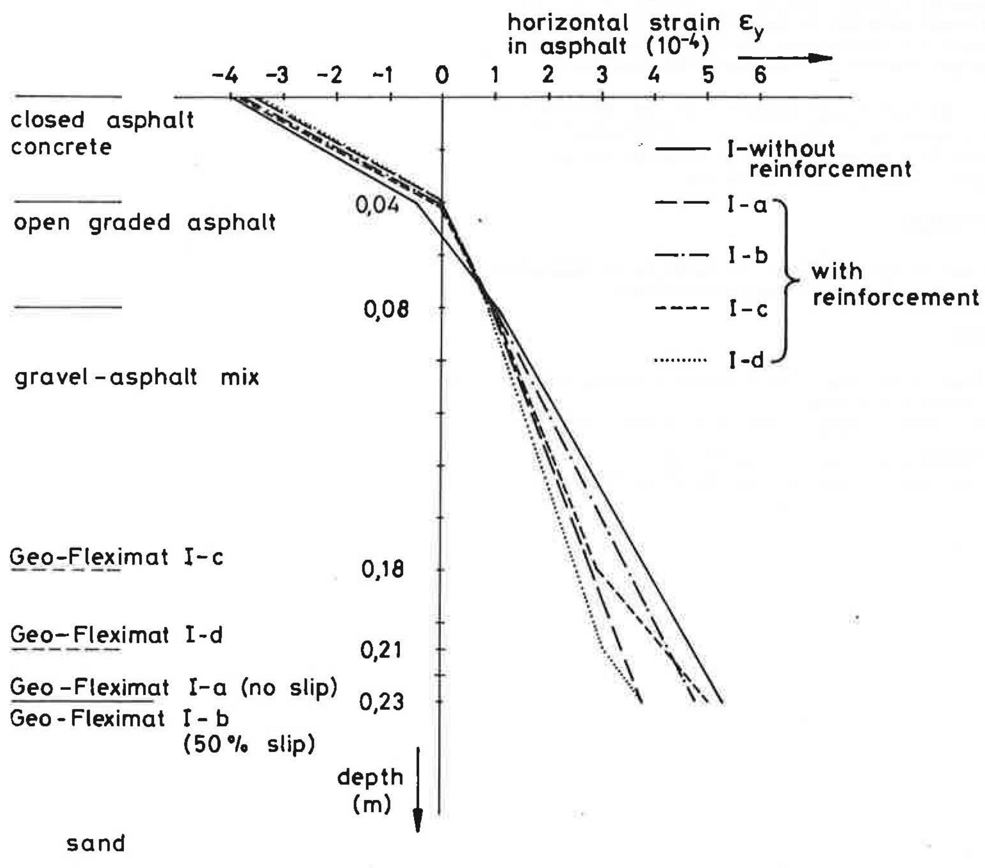

Figure 7: Reduction of strains by reinforcements with a steelcord network

6. CONCLUSIONS

In view of fatigue of asphalt in road foundations the application of woven steel cord networks such as GEO-FLEXIMAT® is most effective at the level in the road foundation where the largest strains occur. That is at the lower side of the lower asphalt layer, i.e. the gravel-asphalt layer or the open graded asphalt concrete.
Best effect can be obtained when the steelcord network is integrated in the asphalt layer with maximum friction against slip. This can easily be realised since in practice the foundation asphalt will be placed in more than one layer. The reinforcement can be put between two asphalt layers. On relatively soft soils (C_u < 50 kN/m²) a considerable effect is obtained with steelcord reinforcement.
The allowable number of load repetitions can raise with a factor 3 to 10. This means that the durability of the road design increases in the same degree or thickness of aggregate layers can be reduced. In some cases one foundation layer, for example the gravel asphalt layer can be dropped. In the latter case attention should be paid to the allowable unit shortening in the subgrade. This aspect will not be dealt with here.
From the calculations it follows that the maximum normal stress in the steelcord network due to traffic loading is $\sigma = 1.06\ 10^5$ kN/m², resulting in a required tensile strength of at least $\sigma_g \geqslant 1.06\ 10^5 \times 2.82\ 10^{-5} = 3$ kN/m', given the equivalent thickness $d = 2.82\ 10^{-5}$m. This means that the tensile strength of the steelcord reinforcement is not its representative property. However, reduction of the number of strands in the steelcord network is hazardous, since this number defines the equivalent thickness and hence the degree of plate action c.q. stress-distribution.

Since steel can take large stresses at low strains the use of woven steelcord networks as reinforcement of asphalt roads is a great advantage compared to geotextiles, particularly for soft soils.

7. ACKNOWLEDGEMENT

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8. REFERENCES

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(2) ----, "SHELL Pavement Design Manual", Shell Int. Petr. Company Ltd, London, 1978.