Third International Conference on Geotextiles, 1986, Vienna, Austria

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AN INSTANT ROAD OF STEEL REINFORCED GEOTEXTILE

UN REVETEMENT DE ROUTE PRET A L'EMPLOI COMPOSE D'UN GEOTEXTILE RENFORCE D'ACIER

STRASSENBELAG MIT EINEM STAHLBEWEHRTEN GEWEBE

The accessibility of boggy terrains with low bearing capacity for heavy trucks is a problem, in particular when a relatively quick or semi-permanent solution is required. This contribution deals with a steel reinforced polypropylene woven geotextile with strength of 2 MN/m' and 0.8 MN/m' in longitudinal direction and cross direction respectively. This so-called Mammoth-Mat serves as an instant road without additional aggregate. Membrane and plate bending action are discussed. Model tests and calculations are calibrated with prototype tests. It is shown that the instant road can be used successfully on subsoils with c_u > 30-50 kN/m² at an axle load of 100 kN. On very poor soils the instant road is to be anchored in length direction.

Der Zugang zu sumpfigen Gelände für Lastkraftwagen stellt eind Problem da. Dies gi lt ins besondere für zeitliche Lösungen, die in kurzer Zeit realisiert sein müssen. Dieser Beitrag behandelt die Anwendung eines stahlbewehrten Polypropylengewebes mit eine Festigkeit von 2 MN/m und 0.8 MN/m in Quer- bzw. Längsrichtung.
Diese sogenannte Mammoth-Matte dient als Strassenbelag ohne Zuschläge. Das Membran und Biegetragverhalten werden diskutiert.
Darüberhinaus werden Berechnungen an Hand der Versuche calibriert.
Es wird gezeigt, dass dieser Belag erfolgreich auf Böden mit c_u > 30-50 kN/m² bei Achslasten bis zu 100 kN verwendet werden kann. Auf noch schlechterem Untergrund kann der Belag zusätzlich in Längsrichtung verspannt werden.

1. INTRODUCTION

The bearing capacity of very soft or boggy terrains does not suffice for heavy loaded trucks with an axle load of, say, 100 kN.
Yet, the accessibility of such poor soils is often required. If there is a need for instantaneous or semi-permanent accessibility, for example in a construction area, classical road foundation profiles do not offer a feasible solution.
Therefore a special steel reinforced geotextile has been developed by Robusta, The Netherlands. This so-called Mammoth-Mat acts as an instant road without additional aggregate layers. During operations it supplies an access to poorly bearing soils for trucks with an axle load of 100 kN. In the following the mechanisms involved and the dimensioning will be discussed.
The development included model tests and prototype tests in order to obtain a practically useful design based on a fundamental approach. The idea is more generally applicable to geotextiles in a soil-geotextile-aggregate system.
The general idea of the instant road is a woven geotextile of black, UV-stabilized polypropylene reinforced with
- 80 galvanized steelwire ropes per meter in length direction
- in cross direction 7 prestressing rods ⌀ 15.7 mm per meter for soils with c_u > 50-60 kN/m² (type A) or
- in cross direction 10 suspension springwire bars ⌀ 13 mm per meter for soils with c_u > 30-50 kN/m² (type B).

2. FUNCTIONING OF THE MAT

The load-spreading capacity of the Mammoth-Mat depends on two functions:
- beam-action by the stifness of the rods
- membrane-action by the tensile strength of the rods

The stiffness of the rods causes a beam-function, that is always there, regardless of the terrain formation or the rutting.
The membrane action is caused by the fact that the mat is tensioned as soon as it follows the deformation of the subsoil. The vertical components of the membrane-tension cause the spreading of the load. This tensioning or membrane action can only exist if the horizontal components of the tension force can be absorbed. That is to say when the mat has been anchored. Because the Mammoth-Mat is not covered with an aggregate layer, as is usual in geotextile reinforcement, there is no anchoring effect. The only possible anchoring points are the wheels of the truck. The mat is thus tensioned between the wheels. The mat, however, is not tensioned in cross direction only, but also in length direction, when the soil underneath the wheels is deforming. Because, in front of the truck there is no anchoring in length direction, the mat will be pulled into the rut. The mat is rippled. Caused by this effect the membrane action in length direction, also between front and back axles of the truck, will be less at each successive passage of the vehicle. Furthermore, the rods in front of the truck will be pulled somewhat into the rut that is left by the previous passage, caused by tension in the length direction. If the rods are very stiff, this is favourable, because the load will be spread to an area in front of the truck and the more, the deeper the rut is. This means that the rutting will be less at each successive passage.
If, however, the rod has no stiffness at all, the rods in front of the truck will be pulled into the existing rut

without stress distribution.
Repeated loading leads to extra rutting before the required membrane action occurs.
This means that the rutting will continue as indeed occurred on a location at Molenplaat (Netherlands) where after 11 passages the rutting was so bad, that the differential of the truck touched the Mammoth-Mat type A.
From the above it appears that on poor subsoils the membrane action is small, but the beam action of a stiff rod can be expected to be large.

3. DESIGN FORMULAE

3.1 Loads acting on the mat

In figure 1 the schematic loading diagram has been given, together with some characteristic dimensions.

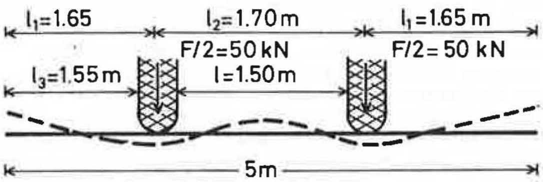

Figure 1 Cross section

In the consideration of the design formulae the part of the mat in between and outside the wheels is considered separately.
It is assumed that the mat underneath the wheel is laying horizontally and that the passive soil pressure is not very much related to the deflection of the mat. This is more or less valid for plastic soil behaviour. This is also valid if the settlement W_o of the soil is large compared to the deflection δ, which is true when the mat is used on very soft subsoils, and when a stiff rod is used. In that case the soil reaction q will be the same everywhere.
On a better subsoil or a less stiff rod ($\delta \approx W_o$) the soil reaction q will be greater close to the wheels. This causes both less deflection and moment, so that this situation is not representative.
Furthermore, the load spreads less in length direction of the mat on a relatively stiffer subsoil, which will result in a greater load q per m^1 width. This increased loading is having less effect than the abovementioned moving of the passive soil pressure towards the wheels.
The situation at the edge of the mat has been schematized in figure 2.
The moment under the wheel is:

$$M_{max} = \tfrac{1}{2}\, q_1 a_1^2 \tag{1}$$

and the deflection δ :

$$\delta = \delta_{x=a} + (l_1 - a_1)\, \phi_{x=a_1} = \frac{q_1 a_1^4}{8EI} \cdot \frac{q_1 a_1^3 (l_1 - a_1)}{6EI} \tag{2}$$

where ϕ is the angle distortion.
The maximal occuring stress σ_{max} is:

$$\sigma_{max} = \frac{M_{max}}{W} = \frac{\frac{1}{2} q_1 a_1^2}{W} \tag{3}$$

where W, I, E are the moment of resistance, moment of inertia and modulus of elasticity of the rod respectively.
For the part of the mat in between the wheels the situation has been schematized in figure 3.

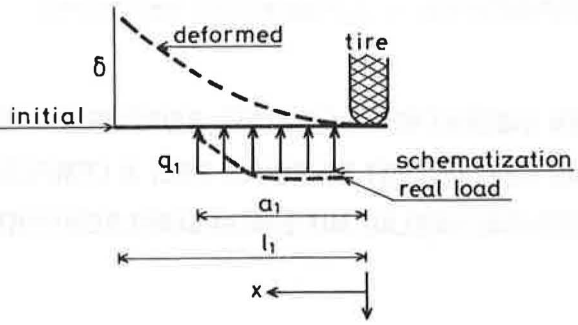

Figure 2:Schematization for the edge of the mat

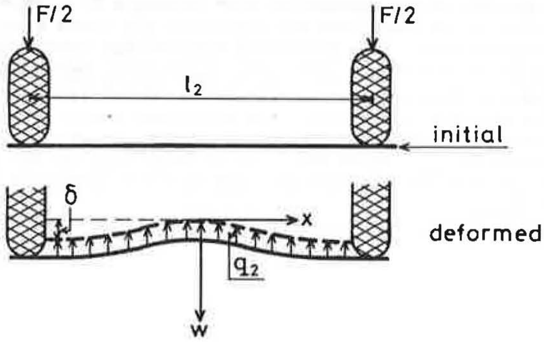

Figure 3: Schematization for the part of the mat in between the wheels

Assuming a uniform passive soil pressure q_2 the deflection w of a rod is determined by the following differential equation:

$$EI\,\frac{d^4w}{dx^4} = q_2$$

With boundary conditions

$$x = 0 : \frac{d^3w}{dx^3} = \frac{dw}{dx} = w = 0$$

$$x = \pm\frac{l_2}{2} : \frac{dw}{dx} = 0$$

This leads to the following formulae for the moment M, the deflection w and the maximal deflection δ:

$$M = -EI\,\frac{d^2w}{dx^2} = q_2\left(\frac{x^2}{2} - \frac{l_2^2}{24}\right) ; \quad M_{max} = \frac{q_2 l_2^2}{12} \tag{4}$$

$$w = \frac{q_2}{EI}\left[-\frac{x^4}{24} + \frac{(l_2^2\, x^2)}{48}\right]$$

$$\delta = w_{max} = \frac{q_2 l_2^2}{384EI} \tag{5}$$

The maximal occuring stress is:

$$\sigma_{max} = \frac{q_2 l_2^2}{12\,W} \tag{6}$$

3.2 Dimensioning of the mat

The rods have to be designed in such a way that:
- the mat is bearing over the full width
- the axle load can be 100 kN minimal
- the performance of the mat is independent from the settlement w_o in the soil
- the beam action is large in relation to the membrane action.

Bearing over the full width implies that $a_1 = l_1 = l_2 = l$. The ratio between the maximal stress at the edge σ_1 in the middle σ_2 is:

$$\frac{\sigma_1}{\sigma_2} = \frac{M_1 W}{M_2 W} = \frac{\frac{1}{2} q\ l^2}{\frac{1}{12} q\ l^2} = 6 \qquad (7)$$

Hence the stress at the edge is predominating.

Bearing over the full width means furthermore that the deflection δ at the edge must be equal to or smaller than the settlement w_o of the mat.
With (1) and (2) it follows that:

$$w_o > \delta = \frac{ql^4}{8EI} = \frac{\sigma_1 l^2}{4Er} \qquad (8)$$

in which r = radius of a round rod or tube.

From (7) and (8) it follows that:

$$rW = \frac{q\ l^4}{8\ E\delta} \qquad (9)$$

For a full cross section as in a suspension springbar $W = \frac{1}{4}\ \pi\ r^3$, so

$$r = l \sqrt[4]{\frac{q}{2\pi E\delta}} \qquad (10)$$

For the required stress at yield $\hat{\sigma}$ the demand follows from (8)

$$\hat{\sigma} > \frac{4Er\delta}{l^2} = \frac{q\ l^2}{2\ W} \qquad (11)$$

Furthermore holds $\delta < w_o$ where the settlement w_o under the spreaded traffic load is found from a soil mechanical settlement calculation.
From (10) and (11) it follows, that, if a larger deflection δ is accepted (which is very well possible in poor soils) the required diameter of the rod decreases somewhat but the required stress at yield must increase drastically.

Now suppose the bearing of the mat is limited to a part of the full width.

Under the wheels at a sufficiently great settlement w_o of the subsoil the yield stress $\hat{\sigma}$ can occur:

$$\hat{\sigma} = \frac{\frac{1}{2}\ q\ a^2}{W} \qquad (12)$$

The bearing width outside the wheels can be calculated from (12) and (6)

$$a = l\sqrt{\tfrac{1}{6}} = 0.41\ l \qquad (13)$$

The maximal admissable axle load becomes now:

$$F = q\ (l + 2a) * \frac{0.4}{0.1} = 4\ q\ (l + 2a)$$

if loading by membrane action is neglected.
The deflection $\delta_{x=a}$ is calculated with (2) and (13):

$$\delta = \frac{\hat{\sigma}\ l^2}{24Er} \qquad (14)$$

where δ follows from $\delta = w_o$, and w_o is to be calculated from a settlement consideration. In fact this condition means, that the settlement or rutting may increase till the value is reached as calculated with (14) and that with greater rutting, danger of lasting deformation of the rods exists.

Using the formulae of this chapter the mat can be designed.

4. CALCULATIONS

The design formulae of chapter 3 will be used for calculations on two different rods, viz.:
- the 7-strand prestressing rod, as used in the type A Mammoth-Mat
- suspension springwire bar ϕ 13 mm, with very high admissable tensile force (type B Mammoth-Mat)

Table 1: Material properties

type of rod or bar \ material properties	σyield kN/m²	EI kN/m²	W m³
prestressing rod ϕ 15.7 mm	$1060*10^3$	0.052	$96*10^{-9}$
suspension spring-wire bar ϕ 13 mm	$1700*10^3$	0.302	$216*10^{-9}$

Loading

The loading on the mat is due to the axle load and to the bearing capacity of the subsoil. As described in chapter 3 the dimensioning can be done in two ways:
a. With a mat that bears over the full width
b. With a mat that raises at the edges and therefore only bears partly outside the wheels

With a truck weight of 300 kN and an axle load of 100 kN this means a surface pressure of 50 kN/m² in case a, assuming a longitudinal bearing length of 0.4 m.
In case b the bearing width is 1.82 l = 1.82*1.70 = 3.10 m.
The surface pressure here is 80 kN/m².

Taking into account a distance of 0.1 m between the rods the loading q per rod is:
case a. 5 kN/m^1; case b. 8 kN/m^1.

Another condition is that the calculated surface load can be taken by the subsoil. With a traffic loading on a cohesive soil the failure bearing capacity ≈ 5 c_u and the deformation bearing capacity ≈ 3 c_u (c_u = undrained shear strength). The deformation bearing capacity is used for a greater number of passages. This means that the mat in case a can be used on soils with a $c_u \geqslant 17$ kN/m² and in case b on soils with $c_u \geqslant 27$ kN/m². This is a very poor to poor soil condition. With even poorer soils, i.e. weak mud with a c_u = 5 to 10 kN/m², spreading of the load in length direction through membrane action must be mobilized. It is preferred to anchor the mat in length direction.

Mat with prestressing rod ϕ 15.7 mm

This rod has a relatively high strength, but is very flexible. With the use of the formulae from chapter 3 it can be deduced, that the mat at high axle loads will raise at the edges. The mat does not bear over the full width (case b).
The loading that can be taken by bending is only 5 % of the total loading. The rest of the loading has to be taken by the membrane action.
Initially this is possible, especially because of the flexibility of the rod, but after repeated loading the membrane action disappears, since the mat is pulled into the rut.

Mat with suspension springwire bar ϕ 13 mm

This bar has an extremely high strength and is still rather flexible. The loading that can be taken by bending is 1.525 kN/m^1, which is about 20 % of the total loading. Here also bearing over the full width of the mat is impossible and also bearing of the full loading is impossible, because the bar is not thick and/or strong enough.

The deflection in the middle is here 0.11 mm and the lift-up at the edges 0.15 m with an overall settlement of 0.04 m.
The mat can be driven on with trucks of 60 kN, or about 100 kN, taking into account some membrane action.
With these low truck weights the mat can still be used on subsoils with a c_u = 5 kN/m², which is pure mud.
It can be said that for this mat type flexibility and strength are reasonably balanced.

5. CONCLUSIONS

The accessibility of very soft soils for trucks with axle loads up to 100 kN can be realized by an instant road of steel reinforced geotextile.
Such steel reinforced geotextiles are unrolled relatively easily and can be used several times on different locations, provided that only minor plastic deformations occur.
Two types of reinforcement have been investigated in the Mammoth-Mat:
- prestressing rods ϕ 15.7 mm, type A
- suspension springwire bars ϕ 13 mm, type B

Type A can be used successfully with 100 kN axle loads on subsoils with c_u > 50-60 kN/m². In this case load spreading by the mat of 2-4 times the tyre width and some rutting do occur to mobilize sufficient bearing capacity.
With poorer subsoils the axle load must be limited.
As an indication it can be said that using this type of Mammoth-Mat it is possible to drive over poorer subsoils than when using low pressure tyres.
Type B can be used with axle loads of 100 kN on subsoils with a c_u > 30-50 kN/m².
On poorer subsoils the axle load must be limited.
On very poor subsoils it is recommended to anchor the mats in length direction.
Best effect is obtained when flexibility and stiffness of the mat are such, that bearing over the full width of the mat is realized.