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Mechanical behaviour of membranes in road foundations
Le comportement mécanique des membranes sous les couches de base des routes.

RÉSUMÉ

Cet article traite deux situations différentes, où des membranes peuvent être appliquées comme renforcement en la construction des routes. Il est indiqué succinctement de quelle façon on peut introduire au calcul habituel d'équilibe la contribution d'une membrane à la stabilité d'un remblais, par exemple pour une autoroute.
A part, une méthode est développée pour de procurer une idée des tensions et des déformations des membranes sous des couches portantes relativement minces, par exemple pour des voies de chantier.
Suivant les résultats obtenus ainsi, conclusion est faite que les membranes ne seront utiles que dans des sols relativement mauvais.

INTRODUCTION

Some years ago the idea has arisen to use the tensile forces in membranes for the reinforcement of road constructions. As the stresses in the membranes are induced by the deformations of the soil, these stresses and deformations should be studied in relation with each other.
Two different situations, in which membranes can be applied in road constructions, will be considered. Firstly, the improvement of the stability of embankments, for instance for motorways, is dealt with. Secondly, a method to investigate membranes underneath thin road foundations, for instance for temporary roads, is developed.

CONTRIBUTION TO THE STABILITY OF EMBANKMENTS

To investigate the contribution of membranes to the stability of embankments some field tests were carried out in the Netherlands (Zevenhoven, RW 12). In these cases the embankments were applied on membranes spread out on the ground surface.
Stability computations for these cases were carried out with the aid of a computer programme developed by our Laboratory for the usual stability problems (without membranes).
This programme is based on an infinite long cylindrical surface of sliding.

In the stability calculation the membrane is replaced by a thin cohesive layer. For the computation of the cohesion in this layer the stress in the membrane is considered as a force (per unit length of the slip cylinder), tangent to the surface of sliding and resisting to the sliding movement (see fig. 1).

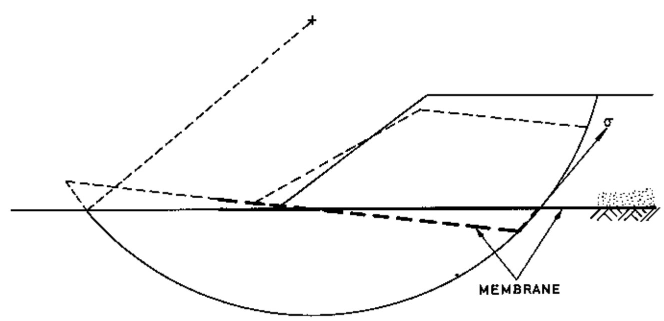

Fig. 1: Model for the calculation of the contribution of a membrane to the stability of an embankment

For a given stress in the membrane the cohesion is depending on the cosine of the angle of intersection between the slip circle and the membrane. Because of this the most probable slip circle is selected after some preliminary calculations.
The stresses in the membrane are induced by the deformations of the soft layers caused by the applied loads. Before the forming of a surface of sliding the membrane is "prestressed" by horizontal deformations of the soft layers due to the difference in stresses between the loaded and unloaded

areas. When a surface of sliding is formed the membrane is stressed additionally due to the differences in deformation on both sides of the sliding plane.
Deformations along the surface of sliding of some centimeters at the utmost are thought acceptable, as otherwise the shearing resistance of the soft layers will be reduced in a too large extent.
Calculated in the described manner the improvement of the stability factor can be computed at 5 or 10% for the membranes used in the tests mentioned above.

For further details is referred to the papers "Fabrics below sand embankments over weak soils...." by A.C. Maagdenberg and "Armature de traction en tissu Stabilenka...." by W.J. Volman, L.J. Krekt and P. Risseeuw.

STRESSES IN A MEMBRANE UNDERNEATH A THIN ROAD FOUNDATION

Nowadays membranes are applied underneath rather thin layers of aggregate, such as are used, for instance, for temporary roads, in an increasing extent. In the following the bearing capacity of the weak subsoil underneath this type of road foundation is considered by means of bearing capacity factors (Prandtl, Reissner) to obtain an idea of the stresses and deformations of the membranes. The calculation is carried out according to a very simplified model (see fig. 2).

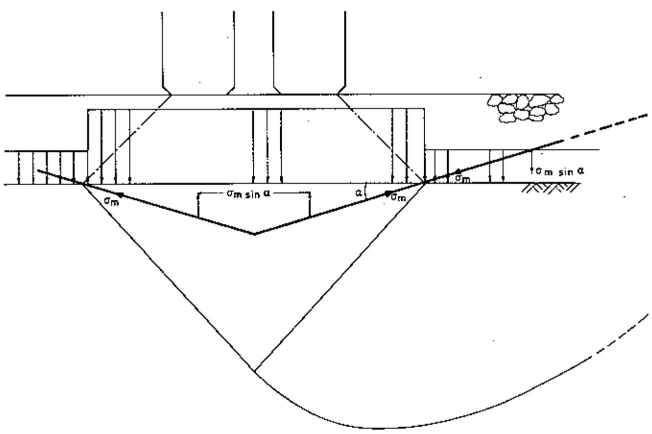

Fig. 2: Model for the calculation of the bearing capacity of the subsoil underneath a layer of aggregate with a membrane

The wheelloads are supposed to be distributed evenly in the layer of aggregate. For the case without a membrane the bearing capacity of the subsoil is calculated according to the formula:

$$p = n\left[V_p p_b + V_c c + V_b \gamma B\right] \qquad .....(1)$$

If the bearing capacity of the subsoil is insufficient the membrane will be stressed due to the deformations of the subsoil. Ruts will be formed. The vertical component of the stress in the membrane will carry a part of the distributed wheelload on one hand and will act as an additional overburden pressure on the other hand (see fig. 2).
Eq. (1) is then for the case with a membrane modified as follows:

$$p - \sigma_m \sin\alpha = n\left[V_p(p_b + \sigma_m \sin\alpha) + V_c c + V_b \gamma B\right] \qquad .....(2)$$

- p = evenly distributed load on subsoil caused by wheelloads and layer of aggregate (road foundation)
- p_b = overburden pressure caused by layer of aggregate
- σ_m = average stress in the membrane
- V_p, V_c, V_b = bearing capacity factors depending on (ϕ = angle of internal friction)
- α = angle over which the membrane is rotated (see figs. 2 and 3)
- B = width of the loaded area
- c = cohesion of subsoil
- γ = average unit weight of subsoil
- n = shape factor - analogous to Terzaghi and Peck, as the loaded area is not infinite long. (But n = 1.3, according to Dutch experiences for B = L.)

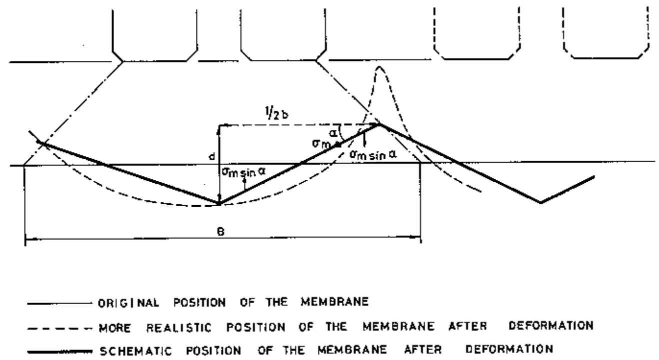

Fig. 3: Deformations of a membrane underneath a layer of aggregate

The following simplifying assumptions are made:

- only the loads of the wheels on one side of both axes are considered. The influence of the other wheels is disregarded;
- the loads of the wheels are considered as static loads. The wheelloads are supposed to be distributed evenly in the layer of aggregate with an angle of 45°;
- the loaded part of the road foundation is supposed to act like a slab;
- settlements due to consolidation are neglected;
- it is supposed that a membrane will not be arched, but will become a broken but straight plane (figs. 2 and 3);
- friction between membrane and aggregate and between membrane and subsoil is not taken into account;
- stresses in the membrane are averaged;
- creep in the membrane is neglected;
- tensile strength of the turf, which can be quite considerable, is disregarded;
- capillary forces in the subsoil above groundwater table are not taken into account.

To restrick the possible number of parameters the following values are chosen:

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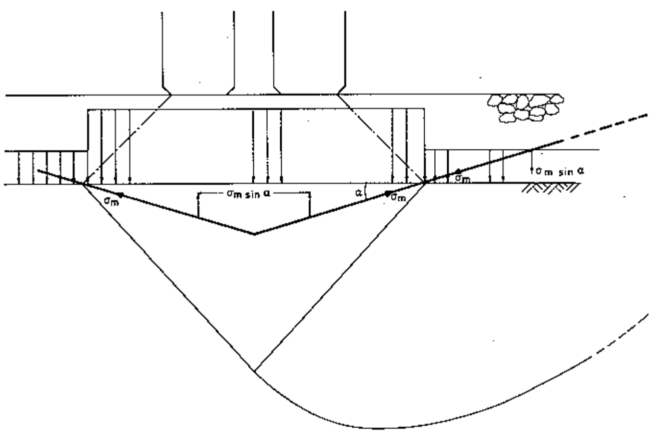

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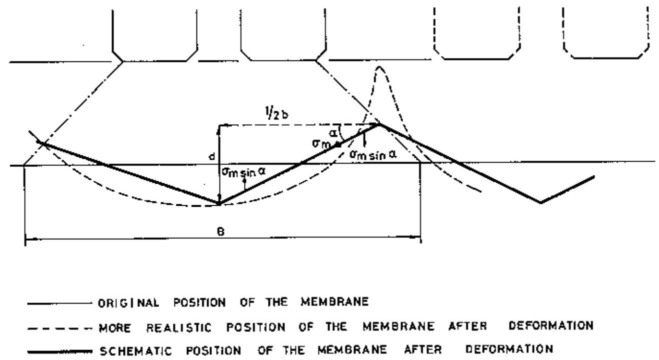

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- capillary forces in the subsoil above groundwater table are not taken into account.

To restrick the possible number of parameters the following values are chosen:

thickness of the layer of aggregate 0.4 m
unit weight of the aggregate 17 kN/m^3
unit weight of the subsoil 5 kN/m^3
(mean unit weight of dry and submerged peat; the term $V_b \gamma B$ is for small values of ϕ only slight importance)

According to VOSB 1963 (see fig. 3)

Width over both wheels	0.75 m
Length of axis	2.0 m
Distance between both axes	1.0 m
Load per axis	200 kN (Class 60)

For given wheel loads and given soil properties σ m sin α is a constant. Thus: C ....(3)

For various combinations of unconsolidated shearing resistance properties of the subsoil C can be computed according to eq. (2).

Table 1

ϕ	kN/m^2	$\sigma_m \sin \alpha$ kN/m^2
0	1	28.0
0	4	19.5
0	8	8.1
5	4	3.9
5	6	0.85

The following formulae appear from fig. 3:

$$\text{tg}\ \alpha = \frac{d}{\frac{1}{2}b} \quad .....(4)$$

and

$$\cos \alpha = \frac{1}{1 + \Sigma} \quad .....(5)$$

Also the relation:

$$E = \frac{\sigma}{\Sigma} \quad .....(6)$$

is used.

d = depth of the rut, which is twice the depth of the rut in respect of the original position of the groundlevel
b = c.o.c. distance between both ruts = 1.25 m
Σ = strain in the membrane
E = elasticity modulus

It should be remarked that the deformations of the subsoil (and membrane) as indicated in fig. 2, are not in agreement with the assumed distribution of the loads in the road foundation, although the more realistic position of the membrane as indicated in fig. 2 has been observed in practice.
The simplified deformations of the membrane are in so far theoretically correct that the downwards and upwards displaced volumes of soil are equal.
As appears from fig. 3 the actual strains in the membranes will be larger than calculated from eq. (5).

With the aid of eq. (3), (4), (5) and (6) the relation between the E-modulus of the membranes and the depth of rut for a set of given soil properties can be calculated.
This relation is drawn in fig. 4.

From the same equations also eq. (7) is derived

$$d = \frac{\frac{1}{2}b\ C(E + \sigma_m)}{\sigma_m E} \quad .....(7)$$

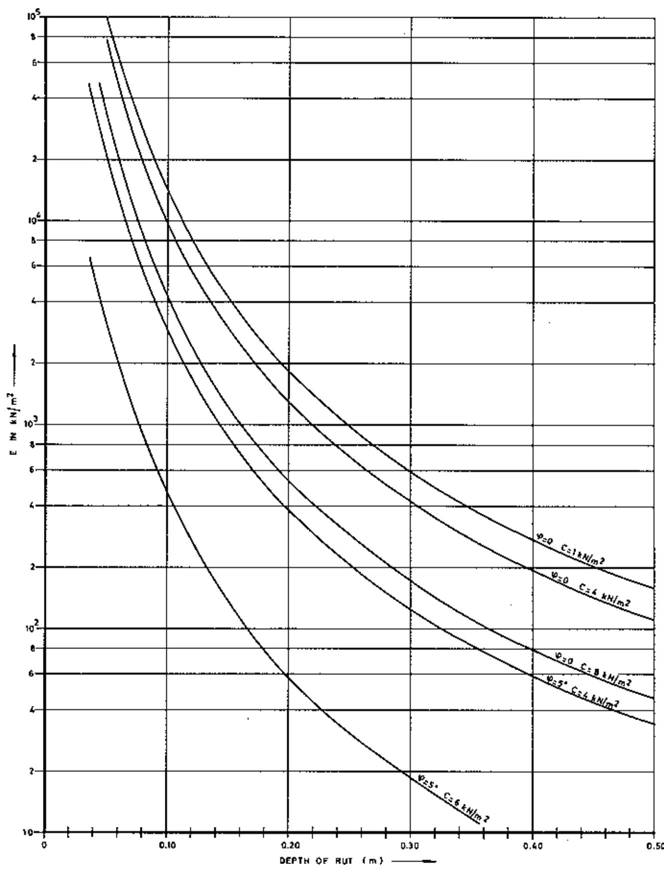

Fig. 4: Relation between depth of rut and E-modulus of the membrane

With also the E-modulus as a parameter eq. (7) indicates the relation between the depth of rut and the stress in the membrane. This relation is given in fig. 5, but for convenience sake only for some of the combinations of soil properties mentioned in table 1.

From the graphs in the figs. 4 and 5 together the stress in a membrane can be determined for the combination of a given soil and a given E-modulus of the membrane.
The usually applied membranes have E-moduli between about 50 and 200 kN/m', according to their stress-strain properties.

The graphs in fig. 4 indicate that the depth of rut in weak soils (ϕ = 0, c = 1 or 4 kN/m^2) can be larger than 0.5 m (or 0.25 m in respect of the original ground surface).
In rather firm soils (ϕ = 0, c = 8 kN/m^2 or ϕ = 5°, c = 4 kN/m^2) the ruts will be 0.25 - 0.4 m (0.1 - 0.2 m) deep. In relatively firm soils (ϕ = 5°, c = 6 kN/m^2) the ruts will be 0.15 - 0.2 m (or 0.1 m) deep.
As mentioned the strains in this model will be too small, so the indicated depth can be too pessimistic.

Assuming the determined depths to be correct it appears from the graphs in figs. 4 and 5 that the

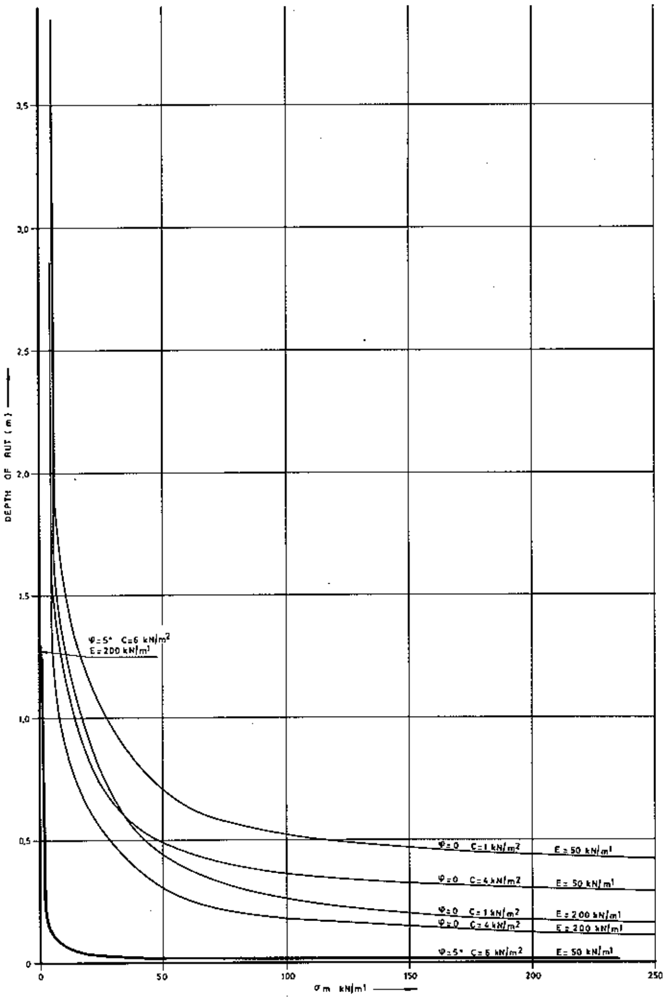

Fig. 5: Relation between depth of rut and the stress in the membrane

tensile strength in case of weak soils should be approximately 30 or 50 kN/m' at least or even larger; in case of rather firm soils about 20 to 40 kN/m' at least.
In relatively firm soils the strength of the membranes is hardly used.

CONCLUSION (thin road foundations)

Actually soils will obtain readily a slight angle of internal friction as also lateral drainage will be possible because of the limited width of the loaded area, so $\phi = 0$ is a too pessimistic assumption. Rather heavy soils, especially in case of a low groundwater table, will easily reach unconsolidated cohesions of 4 kN/m^2 or larger.
Because of this membranes can be applied successfully in case of lightweigthed soils, especially with high groundwater tables, provided their stress-strain properties will be adapted to these types of soil.

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