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NIEUWENHUIS J.D.
Rijkswaterstaat, State Road Laboratory, Delft, NL

Membranes and the bearing capacity of roadbases
Membranes et portance des couches de fondation des routes

Résumé

Un modèle mécanique simple du comportement d'une membrane intercalée entre fondation et sous-sol est développé. Par ce modèle le fonctionnement de diverses nappes textiles sous charges des roues peut être estimé. Le sous-sol est remplacé par des ressorts. Le coëfficient du ressort est déterminé au moyen des essais spéciaux de plaque.

Il résulte que le sous-sol doit être très faible et compressible pour justifier l'emploi persistant des nappes. Mais l'application temporaire, quand le sol est bien mouillé, peut être profitable.

Si l'augmentation de la force portante d'une fondation par la résistance mécanique de la nappe sousjacente apparaît une fonction désirable des membranes, l'effort de recherche doit être concentré à la permanence de cette résistance. La résistance au poinçonnement et le blocage de la déchirure apparaîtront des propriétés essentielles à garantir le fonctionnement prolongé des nappes textiles sous fondations.

Membranes and the bearing capacity of road-bases.

1. Introduction

One of the relatively frequent applications of membranes (wovens and non-wovens) is their insertion between the subsoil and roadbase during the construction of tertiary and temporary roads and rural roads. The application of membranes is believed to improve the bearing capacity of the subsoil, to improve the quality of the subbase by keeping the base materials together due to friction between the membrane and base material, to improve the quality of the subbase by preventing the subsoil from penetrating into the roadbase. In the last case the roadbase is assumed to maintain its drainage capacity and to remain insusceptible to frost-action. In view of the wide variation of non-wovens and wovens that are put on the road construction market research into the performance of those products is necessary and is done, indeed, as is witnessed by the papers of this Conference. The results of this research, of course, should be applied to develop technical specifications for the use of membranes in road construction.

The primary task of the author is the supervision of road construction and the contents of this paper form an introduction to the development of specifications for the application of membranes under roadbases. To that end one assumed function of membranes, i.e. improvement of the bearing capacity of the subsoil, is investigated by a simple mechanical model. The obtained calculation results, combined with those from special plate bearing tests, are not believed to describe the behaviour of the subsoil-membrane-roadbase system correctly. In the author's opinion, however, they show what may be expected from a membrane. In particular they show how bad (weak, compressible) a subsoil must be to profit by the contribution of an inserted membrane. Besides the importance of the stress-strain relation of membranes can be demonstrated.

2. Description of the contribution of a membrane

1) The membrane absorbs stresses in its own plane only (no flexural rigidity).
2) The membrane rests without friction upon the subsoil (horizontal force S in the membrane is constant).
3) Consequently the vertical reaction produced by the membrane equals $S\,\frac{dy}{dx}$ (figure 1). y(x) is the shape of the loaded membrane.

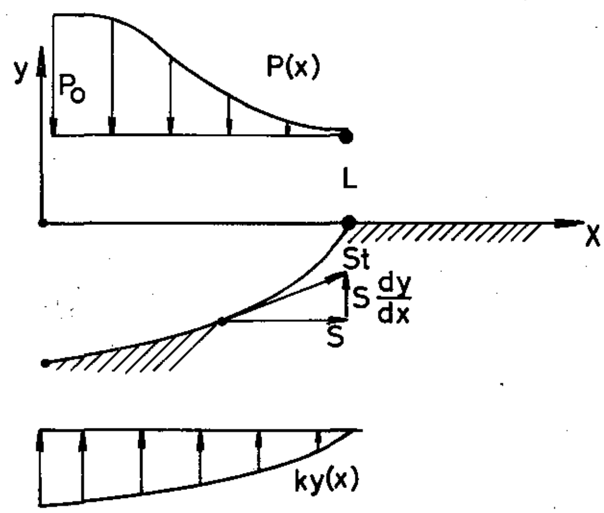

figure 1

4) The vertical traction forces p(x) exerted upon the membrane coincide with the stress distribution transferred through the roadbase.
5) According to 4, the load upon the roadbase, i.e. a wheel load, is substituted by a strip loading (state of plane strain).
6) The stress-strain relation of the subsoil is described by a coefficient of subgrade reaction k. The ratio of the resistance q(x) of the subsoil and the deformation y(x) satisfies:

$q(x) = k.y(x)$.

7) Only vertical equilibrium is respected by the solution to be presented. Horizontal equilibrium is disregarded.

Vertical equilibrium of the system shown in figure 1 is described as follows:

$$p(x) + ky - S\frac{d^2y}{dx^2} = 0, \qquad (1)$$

in which $p(x)$ is a stress and S is a load per unit length of the membrane.

For the stress distribution $p(x)$ a distribution approaching the bell-shaped Boussinesq solution is chosen. Simpler solutions, e.g. a homogeneous and a triangular distribution have been investigated but these are not reproduced here. The point load P is substituted by $q\pi a^2$, in which q is the mean vertical stress and a the radius of the contact area of the wheel and roadbase. The vertical stress at a depth $y = 2a$ (interface roadbase-membrane), according to Boussinesq, is introduced as a strip loading $p(x)$:

$$p(x) = \frac{12q}{(\frac{x^2}{a^2} + 4)^{5/2}} \approx \frac{p_o}{\cosh(\alpha\frac{x}{a})}. \qquad (2)$$

The Boussinesq solution in the second member of (2) is replaced by the third member for more easy integration of (1). p_o equals $p(o)$ and α is an arbitrary constant introduced to obtain a good approximation of Boussinesq's formula.

For easy calculation x and y are replaced by dimensionless variables $\frac{x}{a}$ and $\frac{y}{a}$, henceforth called x and y. Eq (1) thus becomes:

$$\frac{p_o}{\cosh(\alpha x)} + k'y - S'\frac{d^2y}{dx^2} = 0, \qquad (3)$$

with $k' = k.a$ and $S' = \frac{S}{a}$.

The solution obtained for (3) is:

$$y = \frac{p_o}{\alpha\lambda S'}\left[\left\{f(x,\gamma) + C_1\right\} e^{\lambda x} - \left\{g(x,\gamma) + C_2\right\} e^{-\lambda x}\right], \qquad (4)$$

$$\frac{dy}{dx} = \frac{p_o}{\alpha S'}\left[\left\{f(x,\gamma) + C_1\right\} e^{\lambda x} + \left\{g(x,\gamma) + C_2\right\} e^{-\lambda x}\right], \qquad (5)$$

with $\lambda = \sqrt{\frac{k'}{S'}}$, C_1 and C_2 arbitrary constants,

$$f(x,\gamma) = -\int_1^{e^{-\alpha x}} \frac{u^\gamma}{u^2 + 1}\, du;$$

$$g(x,\gamma) = \int_o^{e^{\alpha x}} \frac{u^\gamma}{u^2 + 1}\, du; \quad \gamma = \frac{\lambda}{\alpha}.$$

The auxiliary functions f and g from (4) and (5) were calculated numerically.

The deflection y of the membrane strictly becomes zero for x approaching infinity. Here we equalize y to zero for $x = L = 8a$, introducing a very small error. Hence we have the boundary conditions $y(x = L) = 0$ and $\frac{dy}{dx}(x = 0) = 0$ ($x = 0$ coincides with the centre of the loaded membrane). C_1 and C_2 then satisfy:

$$\left.\begin{aligned} C_2 &= \frac{\{f(L,\gamma) - g(o,\gamma)\} e^{\lambda L} - g(L,\gamma)e^{-\lambda L}}{e^{\lambda L} + e^{-\lambda L}} \\ C_1 &= -g(o,\gamma) - C_2 \end{aligned}\right\} \qquad (6)$$

To determine the problem of stresses and strains in the membrane completely we need another equation in which the unknown stress S' from (4) and (5) is related to the stiffness E of the membrane. The membrane is assumed to be linear elastic. The arc length of a line, for instance a stretched and deflected membrane is described by

$$J(L) = \int_o^L \sqrt{1 + (\frac{dy}{dx})^2}\, dx = L + u(x = L), \qquad (7)$$

with L: original length of the membrane, $u(x = L)$ elongation in $x = L$ due to the deflection. The tensile stress S_t in the plane of the membrane is linearly dependent on the strain $\frac{du}{dx}$:

$$S_t = S\sqrt{1 + (\frac{dy}{dx})^2} = E\frac{du}{dx}$$ or, after integration,

$$u(x = L) = \frac{S}{E} \int_0^L \sqrt{1 + (\frac{dy}{dx})^2}\, dx = \frac{S}{E} J(L). \quad (8)$$

By equating (7) and (8) we obtain:

$$\frac{S}{E} J(L) = J(L) - L. \quad (9)$$

For easy calculation J(L) is approached by

$$J(L) = L + \tfrac{1}{2} \int_0^L (\frac{dy}{dx})^2 dx.$$

For the employment of (9) in our previous calculations S is replaced by S' and E by $E' = \frac{E}{a}$. Equation (9) is combined with (4) and (5) to obtain S', E', y, etc. This is done numerically.

In the next paragraphs the results of the calculation are discussed.

3. The contribution of a membrane to the bearing capacity of the subsoil

Let us select the reduction of the central deflection $y(x = 0) = Y_o$ of the subsoil due to the presence of a membrane as a criterion for the improvement of the bearing capacity. The deflection Y_{oz} of the subsoil in absence of a membrane is simply calculated by

$$Y_{oz} = \frac{-p_o}{k}$$

with p_o = the stress in the centre and k = the coefficient of subgrade reaction of the subsoil. Y_o in presence of a membrane is calculated with the aid of (4). The ratio Y_o/Y_{oz}, the maximum tensile stress S_t and the maximum strain ε_t for several values of k enter table 1. The figures were obtained for a wheel load characterized by a contact pressure of 8 kgf/cm^2 and a contact area πa^2; the thickness of the roadbase is 2a cm. Of course, the results of par. 2 can be applied to various wheel loads and various roadbase thicknesses.

	Y_o/Y_{oz} %	S_t kgf/cm'	ε_t %
k = 0.03	43	34	8
	55	18	18
	63	12	30
	70	9	47
	72	8	54
	80	6	99
k = 0.06	55	28	4
	63	17	6
	72	10	10
	80	6	17
k = 0.10	63	25	2
	72	14	3
	80	8	5

table 1

The figures in table 1 suggest that membranes may improve the bearing capacity of the subsoil, especially of very bad subsoils characterized by coefficients of subgrade reaction equal to or smaller than 0.06 kgf/cm^3. Membranes, wovens as well as non-wovens, which can resist tensile stresses exceeding, for example, 15 kgf/cm' at acceptable (not too large) strains do exist. At the same time we must be aware that the maximum vertical stresses in a soil described by a coefficient of subgrade reaction decrease at the same rate as Y_o/Y_{oz}. Hence, the introduction of a membrane reduces the deflections as well as the maximum stresses of the subsoil and thus contributes to its bearing capacity. In figure 2 the effect of a few woven and non-woven membranes is illustrated. It is clear that a relatively stiff woven membrane, contributes more to the bearing capacity than a ductile non-woven, but it

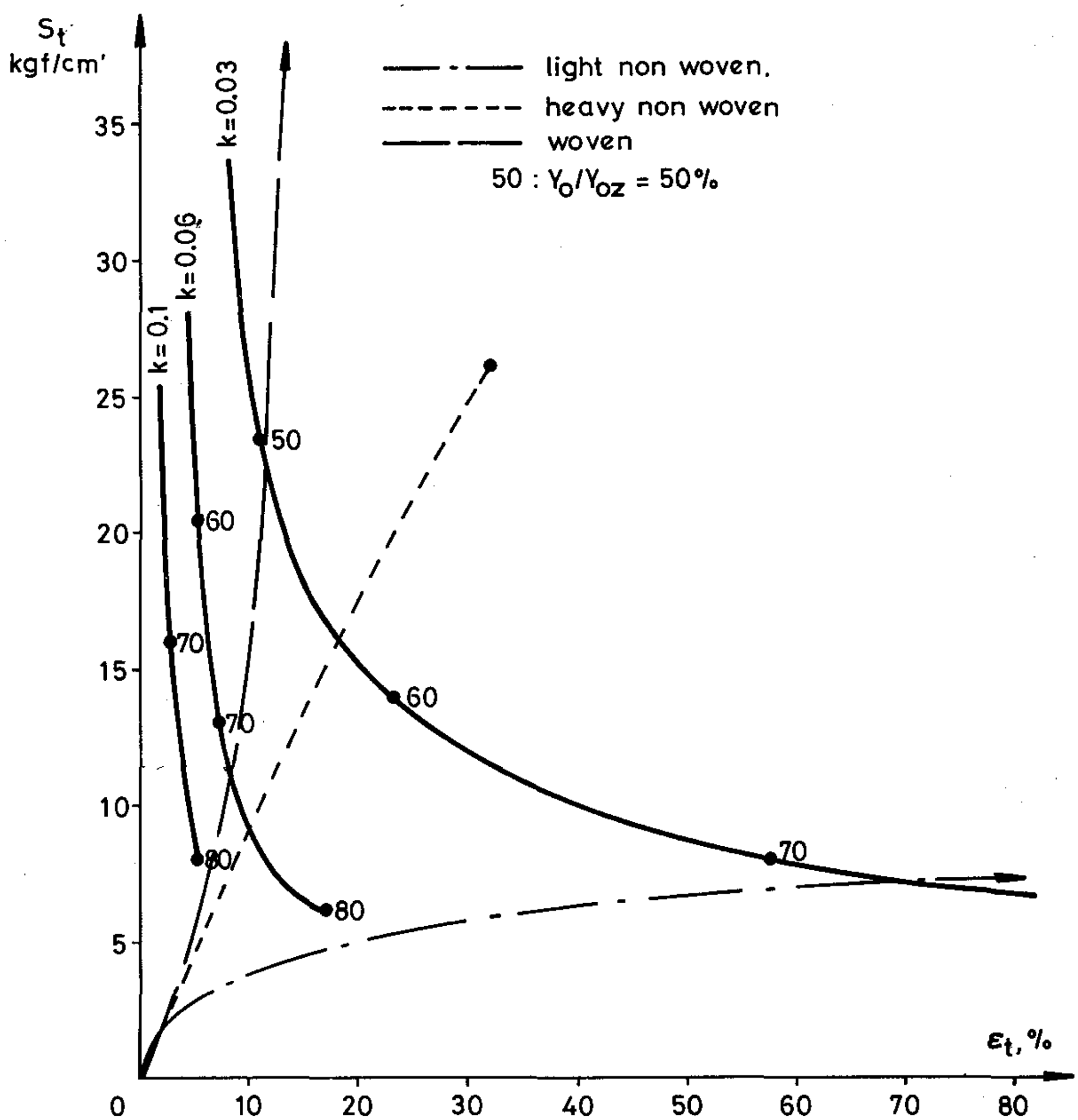

figure 2

is clear too that the woven has to be very strong to perform its function.

4. Reconaissance of the subsoil

In the preceding paragraphs the problem of applicability of membranes was transferred to the problem of determining the bearing capacity of a (compressible) subsoil. At this moment the State Road Laboratory tries to solve this problem. We try to simulate the effect of repeated wheel loads (due to the transport of materials over the roadbase) by repeated plate bearing tests upon the subsoil up to a vertical pressure level equal to the stress transferred through the roadbase. The total deflection due to these tests is used for estimating the coefficient of subgrade reaction. The coefficient is corrected for the expected total number of load repetitions and for the loaded area, which is larger than the area of the plate. Both corrections tend to reduce the coefficient. In a slow test the ultimate bearing capacity is investigated. If this value is smaller than the expected vertical stress, than of course the insertion of a suitable membrane is needed. In figure 3 the "ultimate bearing capacity" obtained from a plate bearing test is marked with an asterisk. If desired the

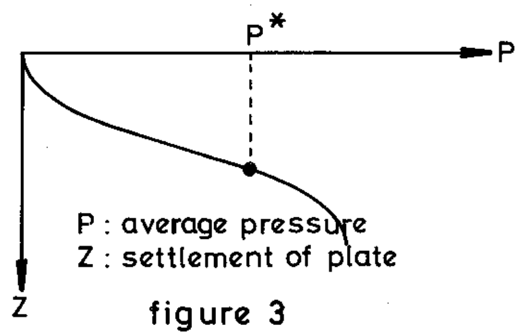

figure 3

subsoil may be thoroughly wetted to investigate its behavious in bad weather conditions.

Up to now the result of these investigations is such that, even in Holland, the subsoil often is not bad enough to justify the permanent use of a membrane. Temporary (local) use, when the subsoil is deteriorated by rain or thaw, however is, often justified.

5. Conclusions

A simple model for describing the behaviour of a membrane under roadbases of small roads under construction was developed. In the model only vertical equilibrium is respected, the load transferred through the roadbase is derived from the Boussinesq solution, the soil is replaced by a system of springs and the membrane is assumed to behave linear elastic. This model was developed to estimate the applicability of membranes to improve the bearing capacity of the subsoil. Rather roughly the model may also be used to judge the suitability of particular products put on the market.

From the results it is concluded that several existing membranes, both wovens and non-wovens, may be applied to improve the bearing capacity of the subsoil. Reconnaissance of some Dutch subsoils by means of special plate bearing tests showed that the soil must be very bad indeed to justify the permanent use of membranes. Temporary (local) use, however, during bad weather conditions, is often profitable.

Improvement of the bearing capacity is one of the possible functions of membranes, other functions, such as the separation of roadbase and subsoil, may be more important. Several papers presented during this conference report about these other functions, and I hope our papers together will throw light upon the relative importance of the assumed functions of membranes under roadbases. Contributing to the development of technical specifications for the use of membranes is the primary aim of this paper, as stated in the introduction. If improvement of the bearing capacity of the subsoil simply by the mechanical strength of membranes appears to be an important function, then a lot of optimation work has to be done, both by soil scientists and by textile specialists. Development of suitable stress-strain relations of membranes was already mentioned. Moreover, membranes should retain their strength when angular rock fragments of the roadbase are pressed in and through the membrane under a passing wheel. Hence, the resistance to perforation must be sufficient and if holes are formed the subsequent crack propagation has to be stopped by fibre or tissue rearrangement. In the Netherlands Enka Research and Soil Mechanics Laboratory Delft perform research into these and related problems.