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Design of a Temporary Road Structure with the Use of a Textile Membrane

Conception d'une piste avec membrane textile

Field and laboratory studies have shown that a textile membrane has a considerable influence on a stressed-strained state of the system "soft soil-granular" and allowed to propose design schemes of the system for wheel load, these schemes being adopted depending upon specific properties of the soft soil.

The design schemes take into account the formation and propagation of ruts on the soft soil due to consolidation high compressible soils (peat soils) or due squeezing out low compressible soft soils. Possible decrease in the strength of some soils under the action of repeated loadings is also taken into consideration.

Les essais en laboratoires et in situ ont montré que la membrane textile influe d'une manière importante sur l'état contrainte-déformation du système sol mou- matériau granulaire et ont permis de proposer des schémas de calcul par rapport aux charges de roue prises en considération selon les particularités des propriétés du sol mou.

Au dimensionnement des schémas ont tient compte des conditions de formation et de développement des ornières en sol mou du fait de la consolidation des sols très compressibles (la tourbe) ou de l'extrusion des sols mous minéraux peu compressibles. On prend en considération également la possibilité de réduction de la résistance des sols sous l'influence des charges répétées.

The use of synthetic materials with low moduli holds the greatest promise for construction of various types of access and temporary roads over soft soils. These roads are of special importance for economic development of highly swamped areas in West Siberia.

A problem of temporary road design is in practice a design for minimum thickness. A structure of the temporary road consists of a fill-up soil layer of h_f thickness laid over geotextile spread on the surface of weak soil mass.

When designing a road structure of such type the principal aim is to determine a required minimum thickness of the fill-up soil layer h_f in order to provide the passage of vehicles over the soil. Here the designation of the textile membrane is to allow the construction of embankment of minimum thickness (0.3 to 0.8m).

The following considerations may be used as the basis for minimum thickness design.

If the material of fill-up layer has a sufficient strength and low compressibility at given loading parameters, then the successful performance of the structure considered will be dependent only on conditions of the weak soil performance at the bottom of fill-up layer. In this connection, of interest are, first of all, two possible processes which are as follows:

- lowering the strength of weak soil for the reason that the tangential stresses due to the external loading exceed the shear resistance of the weak soil;
- development of the process of weak soil consolidation under the action of compressive stresses.

As the result of the first process there occurs more or less gradual lateral squeezing-out of the weak soil to the outside from under the loaded area. It is evident that with increase in the number of wheel passages a rut will appear, which may be referred to as a rut of squeezing-out.

As the result of the second process a rut of consolidation, which is of different nature, may develop. The latter is characteristic of the high compressible soils (peats, etc.).

It is obvious that for adequate performance of a structure the depth of the rut of either nature should not exceed some allowable value taking into account the condition of vehicle passage.

If at the boundary of the fill-up layer and weak soil mass there is a membrane of the tension-resistant material, the behaviour of the structure will change, i.e. under certain conditions the membrane will act so as to restrain development of the rut of either nature.

Strain pattern analysis of the structure based on observation on models with transparent membrane has allowed to propose as a first approximation a design scheme to estimate quantitively the effect of textile membrane.

The main point of the scheme is as follows (Fig.1).

When a load P_o is applied to the surface of structure at the level of the membrane location there appear normal stresses P_z which are uniformly distributed over the area of a circle of diameter $D_1 = D_o \sqrt{k}$ where k is a coefficient of stress distribution taken in accordance with the known solutions of the theory of linearly deformed media.

Under the action of these stresses there occurs settlement of the area AB by value S. Due to high normal stresses and, hence, high friction forces there is no sliding of the membrane at this section, i.e. there is joint movement of the soil and geotextile, and the latter is not involved in work.

At the same time outside of the area AB the friction forces initially are conditioned only by stresses from the dead weight of fill-up layer (q) and therefore they are small. Because of this at some length l_d sliding of the membrane in soil occurs, and this results in the membrane tension.

Force Q applied to the membrane at point b resolves into component P tending to stretch the membrane and component N (manifested in friction) which will hinder tension as well as the friction forces due to dead weight q will.

The value l_d may be found from the condition of shear equilibrium:

$$P = N\, f_{l.s} + 2\, q\, l\, p\, f_{av.} \tag{1}$$

where $f_{l.s.}$ = friction coefficient between the lower surface of membrane and the soil;

$f_{av.}$ = average friction coefficient between the soil and the upper or lower surface of membrane.

Taking into account that an average tensile force in membrane is

$$P_{av.} = \frac{P}{2} \tag{2}$$

and hence the tension of the membrane is

$$\Delta = \frac{P}{2E_{fab}} \cdot l_d \tag{3}$$

as well as geometric relation between $l_{d.}$ and $+l_d$ it is not difficult to obtain formula connecting value P and settlement S:

$$S = \frac{P\left[\sqrt{\frac{P_{tex}}{2E_{tex}}\left(\frac{P}{2E_{tex}} + 2\right)} - f_{e.s.}\right]}{2g \cdot f_{AV}} \tag{4}$$

where $E_{tex.}$ = geotextile tensile modulus (N/cm). Then considering relation between P and Q and replacing the unit force Q (per unit of membrane operational width) by the stamp unit load, an expression may be obtained to determine the value of stamp load (P_{tex}) which is compensated by forces appearing in the geotextile at tension:

$$P_{tex} = \frac{4P}{D_o \cdot \sqrt{K}} \sqrt{1 + \frac{1}{\frac{P}{2E_{tex}}\left(\frac{P}{2E_{tex}} + 2\right)}} \tag{5}$$

Formulae (4) and (5) allow to establish relation between $P_{tex.}$ and settlement S. In practice these relationships may be used by means of monograms the example of which is given in Fig. 2. At specified $E_{tex.}$, $f_{av.}$, $f_{l.s.}$, q, D_o and a specified (allowable) value of settlement S the monogram permits to determine the magnitude of that portion of the load on stamp that is accepted by the geotextile due to its tension and friction against the soil.

Thus, as it follows from the above, the designation of the textile membrane is in that it removes a port of stresses arising from the external loading and acting at the surface of weak soil mass, thus reducing the stresses by value of $P_{tex.}$

With the above in mind, structural design may be done by the following way:

1. Design in respect of squeezing-out rut development is reduced to checking the condition:

$$P_z^o \leq P_{cz} + K P_{tex} \tag{6}$$

where P_z^o = vertical normal stresses from the external load and the dead weight of ill-up soil acting at the level of membrane location;

P_{cr} = critical load on weak soil.

Value $P_{cr.}$ can be determined by means of solutions according to the limit equilibrium theory using the relationship of the following kind:

$$P_{cz.} = M_1 D_1 \gamma_\omega + M_2 \gamma_f h_f + M_3 C \tag{7}$$

where M_1, M_2, and M_3 = functions of the angle of internal friction for weak soil;

γ_ω and C = unit weight and cohesion of weak soil;

γ_f and h_f = unit weight and depth of fill-up layer

Value $P_{tex.}$ is evaluated from Eqs. (4) and (5) at $S = S_{allow.}$

2. Design in respect of consolidation rut development, is reduced to the check of the condition:

$$S_{des.} \leq S_{allow.} \tag{8}$$

A design depth of the consolidation rut may be estimated from the relationship:

$$S_{des} = \frac{P_z \cdot D_1 \cdot U_c}{E_\omega} = \frac{P_o \cdot D_o \sqrt{K} \cdot U_c}{E_\omega} \tag{9}$$

where: P_z, D_1, P_o, D_o = values according to Fig. 1;

E_w = modulus of deformation of weak soil;

U_c = coefficient less than one taking into account an actual degree of consolidation that may be reached during structure life (For peats it is often assumed to be 0.6).

In some cases a depth of the rut due to squeezing out the plastic soil from under the wheel should be well below an allowable value according to the condition of vehicle passage. This is the case with soils in which the squeezing-out leads to a sharp drop of strength and progressive rutting as well as with temporary roads when the requirements to carriageway evenness are increased.

As practice and experiment (1) show, when placed at the contact of granular material and weak soil, geotextile, even having not high geotextile tensile modulus (uniaxial tension) - of the order of 10 kH/m, can substantially ffect rut development under the multiple load application (Fig. 3). This is explained by improving the conditions of weak soil performance near the contact surface with fill-up material. Stabilizing effect of the geotextile membrane can be represented, as a first approximation, in terms of reduction of of tangential stresses in the weak soil due to provision of a smooth contact in the two-layered semi-space loaded with circular stamp.

The condition of limit equilibrium in soil as determined under the centre of stamp, is as follows:

$$\frac{1}{2\cos\varphi_w}\left[(\sigma_1-\sigma_3)-(\sigma_1+\sigma_3)\sin\varphi_w\right] \leq C_w \qquad (10)$$

where: σ_1 and σ_3 = the highest and lowest principal normal stresses φ_w and C_W - angle of internal friction and cohesion of weak soil.

This condition is checked for a point situated under the stamp centre; it may be written as

$$\tau_w - \tau_g \leq \frac{1}{K_N} C_w \qquad (11)$$

where: τ_w = active (not compensated by friction) part of tanential stresses in weak soil caused by temporary load;

τ_g = correction to shear stresses considering the structure dead weight; stresses induced by the latter are distributed according to hydrostatic law;

K_N = 1 + lgN = factor taking into account an increase in severity of load action under N repetitive applications

Values τ_w and τ_g may be found from the chart in Fig. 4 based on solutions according to the theory of elasticity for two-layered system with smooth contact between the layers.

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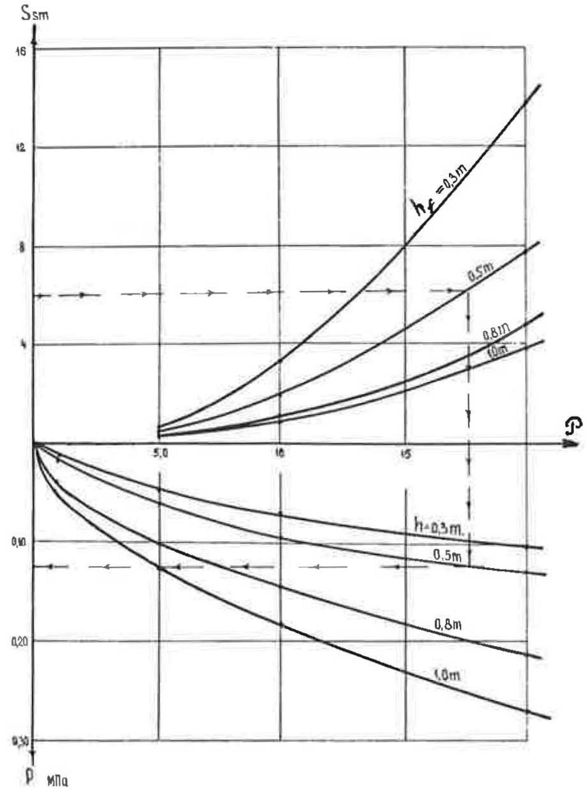

Fig. 2 Nomogram for determination of value $P_{tex.}$ at specified rut depth in weak soil (S) and various thicknesses of fill-up layer (h_f)

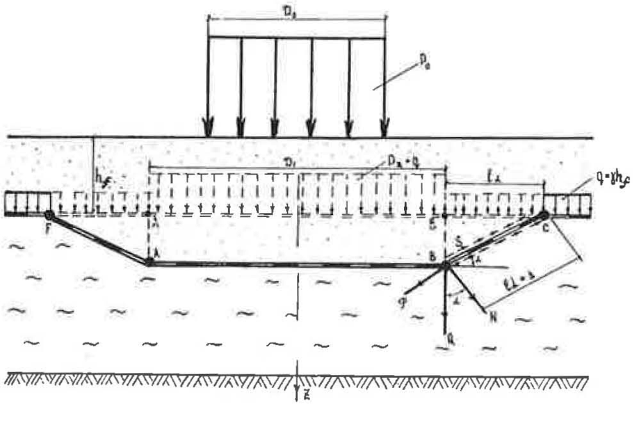

Fig. 1 Scheme of membrane performance in thin-layered structure of temporary road.

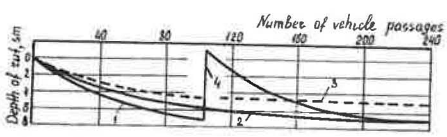

Fig. 3 Relationship between rut depth and number of load applications: 1 - gravel layer, 40 cm thick, no membrane; 2 - gravel layer 70 cm thick, no membrane; 3 - gravel layer 40 cm thick, membrane of non-woven fabric; 4 - grading operations.

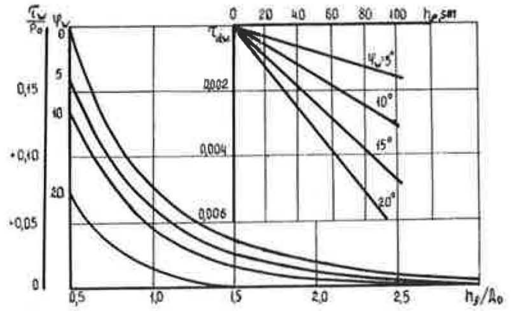

Fig. 4 Relative active shear stress τ_ω/P_0 and correction to soil dead weight $\gamma_{d\omega}$ versus thickness of granular layer h_f.