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Model Tests of the Foundation Bases of Structures

Essais du Modèle du Sol de Fondation des Bâtiments

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SYNOPSIS Conditions are given for the simulation model testing of a rigid-elastic-plastic soil base. Relationships between the similarity factors are set forth for the simulation of the static state of the soil base, together with formulas for calculating the magnitudes of three similarity factors in accordance with a combination of two similarity factors whose numerical values are given. A procedure is presented for the centrifugal simulation of the bearing capacity and deformation of a two-layer soil base loaded by a rigid square foundation slab. The top layer is of sandy soil of various thicknesses and the bottom layer is of undistrubed peat. Dimensionless curves are plotted that show the dependence of the relative settlement on pressure in designing the soil bases for foundation slabs of buildings and structures. Data is given on the centrifugal simulation of the compressibility and consolidation of 56 railway embankments of dusty sand laid on low-land bogs and designed with the dynamic loads of the trains taken into account. Also presented is the dependence of the settlement of a railway embankment on the thickness of the sand and peat layers, and under various conditions. Similarity criteria for the simulation of the consolidation of a peat bed are tested. These criteria are confirmed by the experimental data.

Let us consider the conditions for the simulation model testing of a rigid-elastic-plastic soil base which is assumed to be a solid body specified by four physical constants (Geniyev, 1965 and 1966):

(1) $K\left[\frac{N}{cm^2}\right]$ - bulk (compressibility) modulus

(2) $G\left[\frac{N}{cm^2}\right]$ - shear modulus at average pressure in a deviatoric stressed state

(3) φ - dimensionless quantity analogical to the coefficient of internal friction

(4) S_{sh} - dimensionless plastic shear index.

Within the scope of the theory of small strains, used in the theory of plasticity, equations relating the strain and stress are of the form

$$K\,\Theta = P \qquad (1)$$

$$G_0 \bar{\bar{D}}_e = S\,\bar{\bar{D}}_p \qquad (2)$$

where Θ = volume strain
S = function of the stress tensor invariants proposed by Geniyev
$\bar{\bar{D}}_e$ = strain tensor
$\bar{\bar{D}}_p$ = stress tensor

$$S = 1 - f\,\frac{P}{U_p} \qquad (3)$$

where $P = \frac{P_{11}+P_{22}+P_{33}}{3}$ = average stress

$$U_p = \sqrt{\frac{1}{6}\,(P_{22}-P_{33})^2+(P_{33}-P_{11})^2+(P_{11}-P_{22})^2+6\,(P_{12}^2+P_{23}^2+P_{31}^2)}$$ = stress intensity.

After combining the equation relating the vector of small displacement u and the stresa tensor e

$$\bar{\bar{e}} = \frac{1}{2}\left[\bar{u}\,\bar{\nabla} + \left(\bar{u}\,\bar{\nabla}\right)_{conj}\right] \qquad (4)$$

with the equation of equilibrium

$$\bar{\nabla}\bar{\bar{P}} + \rho\bar{g} = 0 \qquad (5)$$

where ρ = mass of unit volume of the body
$\bar{g}$ = vector of the acceleration of gravity at the earth's surface,

we obtain a complete system of equations for determining: six components of the stress tensor, six components of the strain tensor, and three components of the displacement vector counted off from the initial unstressed state of the body.

The relationships between the similarity factors in simulating the static state of the soil base (Table 1) composed of soils with the properties of a rigid-elastic-plastic body can be derived from equations (1), (2), (3), (4) and (5).

The aforementioned system of similarity factors shows the advantages of simulation in a centrifugal machine where the length factor (ψ_r) can be taken substantially larger than for simulation in a tray and where a pressure factor (ψ_p=1) can be used, this being impermissible in tray simulation.

The centrifugal simulation of the bearing capacity and deformation of a two-layer base (Rudnitsky, 1974) loaded by a rigid square foundation slab was conducted in a machine of the Gersevanov Research Institute of Bases and Underground Structures by Senior Researcher N.Ya.Rudnitsky.Cand.Sc.(Eng.), engineer K.V.Malakhova under the supervision of D.E.Polshin, Cand.Sc.(Eng.).

Table 1

Relationships Between Similarity Factors For a Rigid-Elastic-Plastic Base

No..	Combination of two given similarity factors		Formulas for calculating the three other similarity factors		
1.	ψ_r	ψ_u	$\psi_e = \frac{\psi_u}{\psi_r}$;	$\psi_p = \frac{\psi_u}{\psi_r}$,	$\psi_g = \frac{\psi_u}{\psi_r^2}$,
2.	ψ_r	ψ_e	$\psi_u = \psi_r \cdot \psi_e$,	$\psi_p = \psi_e$;	$\psi_g = \frac{\psi_e}{\psi_r}$;
3.	ψ_r	ψ_g	$\psi_p = \psi_r \cdot \psi_g$,	$\psi_e = \psi_p \cdot \psi_g$,	$\psi_u = \psi_r^2 \cdot \psi_g$;
4.	ψ_r	ψ_p	$\psi_e = \psi_p$,	$\psi_u = \psi_r \cdot \psi_p$;	$\psi_g = \frac{\psi_e}{\psi_r}$;
5.	ψ_u	ψ_e	$\psi_r = \frac{\psi_u}{\psi_e}$;	$\psi_p = \psi_e$,	$\psi_g = \frac{\psi_e^2}{\psi_u}$;
6.	ψ_u	ψ_g	$\psi_p = \psi_u \cdot \psi_g$;	$\psi_e = \psi_u \cdot \psi_g$;	$\psi_r = \frac{1}{\psi_g}$;
7.	ψ_u	ψ_p	$\psi_e = \psi_p$;	$\psi_r = \frac{\psi_u}{\psi_e}$,	$\psi_g = \frac{\psi_e^2}{\psi_u}$;
8.	ψ_e	ψ_g	$\psi_p = \psi_e$,	$\psi_r = \frac{\psi_e}{\psi_g}$;	$\psi_u = \frac{\psi_e^2}{\psi_g}$,
9.	ψ_g	ψ_p	$\psi = \frac{\psi_p}{\psi_g}$;	$\psi_e = \psi_p$;	$\psi_u = \frac{\psi_p^2}{\psi_g}$,

where ψ_r=length factor; ψ_u=displacement factor; ψ_e=volume strain factor; ψ_g=gravitational factor.

This machine has the following specifications: effective radius of rotation-2000mm and simulation scale range - 10 to 100 (Polshin,et al, 1973).

The upper sand layer had a thickness of 33, 66 and 100mm in the various experiments and was of a medium-grade sand with a specific weight of 26.6 kN/m^3.The specific cohesion of the sand was 0.07 kgf/cm^2 and the angle of internal friction, 34°.The sand was tested to determine the specific cohesion and angle of internal friction by slow shear without previously compacting the sand.The lower layer was a peat monolith of undisturbed structure,a water content of w=350% and a thickness of 200mm.

On the basis of the given scale of simulation (15),the full-scale thicknesses of the sand layer were 0.5,1.0 and 1.5m,and that of the lower peat layer was 3.0mm for all the experiments.

The model of the foundation was a rigid square steel plate with a size of 105x105mm in the plan view and 10mm thick,corresponding to a full-scale slab 1.5x1.5m in size.A vertical uniform load was applied.The foundation model was placed on the surface of the model of the two-layer base.The experiments consisted in determining the settlement vs load relationship at steps of 0.025,0.039 0.052, 0.065,0.085,0.104 and 0.125 MPa for various thicknesses of the sand layer and a single thickness of the peat layer.

Shown in Fig.1 are combined curves of the dependence of the relative settlement of a sand pad over a peat base on the average pressure with pad thicknesses of 0.5,1.0 and 1.5m.These curves lead to the conclusion that at the same average pressure,the average settlement is reduced with an increase in pad thickness.This is an indication of the high capacity of the sand pad to distribute the pressure over the underlying layer of peat.As can be seen in Fig.1,the bearing capacity of a sand pad 1.5m thick over a layer of peat 3.0m thick is from 0.125 to 0.15 MPa at an average settlement of 12 to 18cm. For a sand pad 0.5m thick over a 3.0m layer of peat,the bearing capacity is 0.05 to 0.08 MPa with an average settlement of 15 to 25cm.The settlement of the pad itself is about 2% of its thickness and included compaction strain,bending deflection of the pad and the pressing of the sand particles into the peat.The settlement depression on the surface of a sand pad on a peat layer (Fig.1) is reduced with an increase in the pad thickness;its diameter ranges from 1.5 to 2.5 times the side of the foundation footing.

Let us consider the results of the simulation of the deformability of peat soil bases

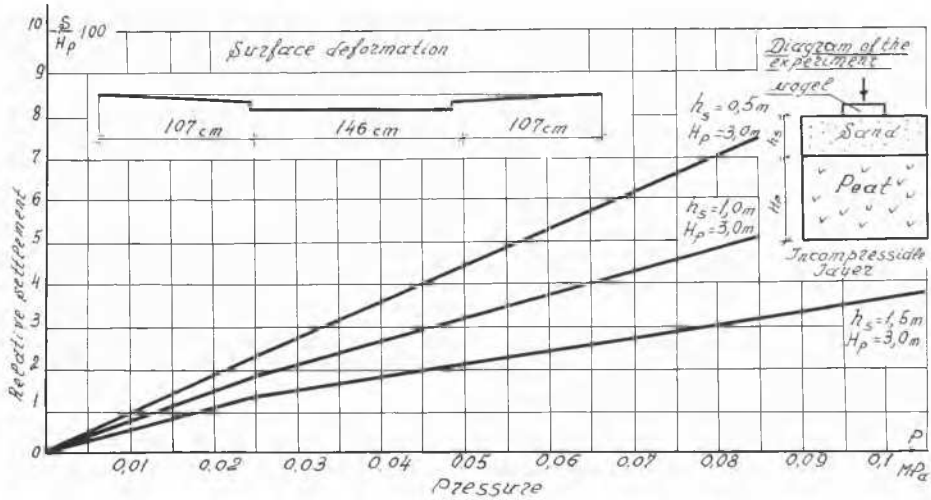


Fig.1. Curves of the realtionship $\frac{S}{H_p}100=f(P)$

subject to the action of the static weight of the embankment and dynamic train loads. This data was obtained to substantiate the posibility of employing local dusty sands for making embankments on Type 1 bogs for one of the largest railway construction sites of West Siberia.

Used for the models of the bases were low and medium water content peaty soils of forest and forest-marsh sub-types, valley peat (Shakhunyantz, 1953) and reed and sedge peat selected in the form of monolithic blocks along the route of the railway construction. The models of the embankments were made of local dusty sands.

The simulation scale n equalled 50. The transient operation period of the centrifuge was utilized to simulate the construction period according to a procedure worked out by the authors. In this procedure, the acceleration of the machine is coordinated with the rate at which the embankment is being made and at which the stresses grow in the embankment. The required increment of speed ΔN_i of the machine at the moment of time t_i is determined by formula (3) given in previous works (Yakovleva, 1968) and (Polshin, et al 1973). The models of the sand embankments were subjected to the model of a dynamic train load, transmitted to the embankments in perio-

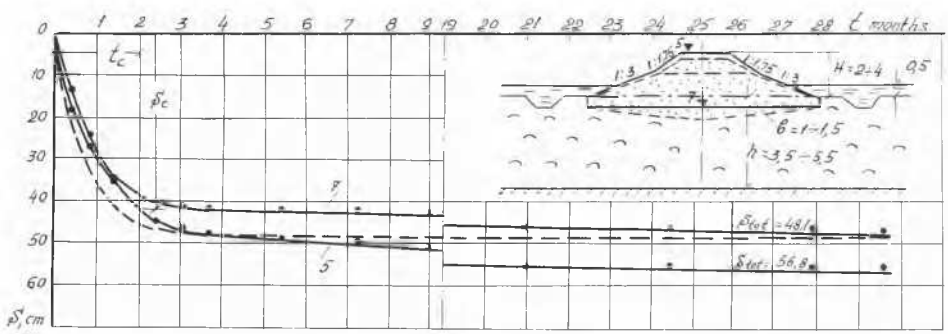
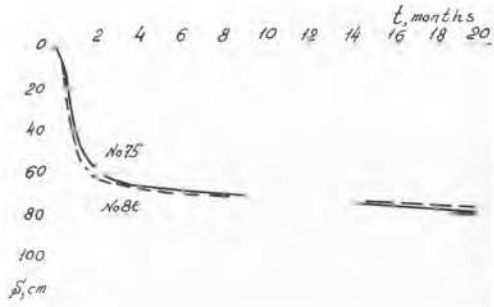


Fig.2 Curves of the relationship S=f(t) for transmitters Nos 5 and 7



$-\alpha t)$ (6)