EFFECT OF RATE OF DEFORMATION ON THE COMPRESSIBILITY OF LOESS SOILS

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S. S. Grigoryan [1, 2] has derived the basic equations of the dynamics of a soft soil for the case when the effect of rate of deformation on compressibility can be neglected. Experiments [3-5] show the suitability of this model for a theoretical study of dynamic processes in sandy soils. Subsequent investigations [6] and the data presented below make it possible to extend the region of applicability of Grigoryan's model, in certain circumstances, to soils in which the effect of rate of deformation on the stress-strain state can not be disregarded.

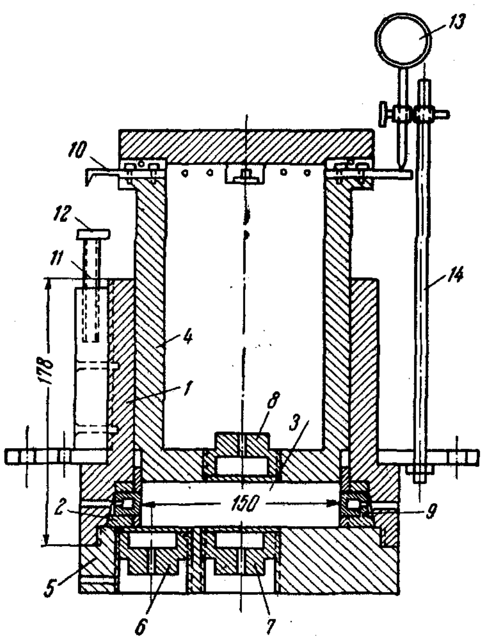


Fig. 1

This article presents the results of experiments on the effect of rate of deformation on the compressibility of loess soils and the yield condition. It is shown that, on the whole, this effect is substantial, but disappears as the rate of deformation tends to a certain critical value, so that there is a limiting form of the relations between the stresses and the deformation characteristics in which the rate of deformation is no longer represented. Obviously, there is also another limiting form corresponding to zero rate of deformation. The corresponding quantitative data are presented for loess soils. It is shown that the Mises-Schleicher yield condition [1, 2] does not depend on the rate of deformation.

1. Experimental Conditions and Method

The object of investigation was a loess soil of undisturbed structure, density γ = 1.44-1.47 g/cm^3 and moisture content w = 3-13% by weight. Soil in the form of paraffinized monolithic samples was obtained from the region of the experiments described in [6]. The samples were tested on a specially designed apparatus (Fig. 1), under conditions of static and dynamic loading. The apparatus consisted of a cylinder 1 in which the sample 3 was placed in a ring 2. The load was transmitted to the sample through a piston 4. The base of the cylinder 5 and piston 4 contained strain gauges 6, 7, 8 to measure the vertical stresses $\sigma_y(t)$. Two strain gauges 9 were built into the ring to measure the horizontal stress in the sample $\sigma_x(t)$. The displacement of the piston was measured with a cantilever-type deflectometer 10 in the form of a high-frequency cantilever arm to which strain gauges were bonded. The deflectometer rested on an extensible support 11, 12. The strain gauge readings were registered by an N-102 oscillograph across a 8ANCh-7M amplifier. The dynamic loads were applied by means of falling weights (50-200 kg). By varying the tripping height and using different kinds of cushioning it was possible to create different loading regimes for which the rate of deformation varied within the limits 4-40 sec^{-1}. For the static experiments we used the same apparatus, the displacement of the piston being measured by means of a gauge pin 13 attached to a stand 14. In these cases the rate of deformation was $1.45 \cdot 10^{-7}$ sec^{-1}.

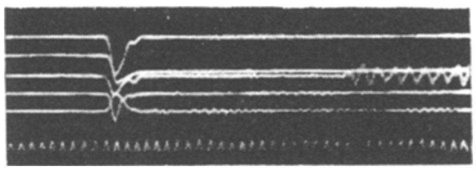


Fig. 2

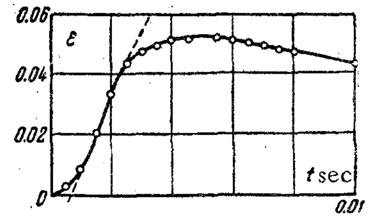
Since the height-diameter ratio of ring 2 is 1 : 5, the effect of friction forces along the walls of the ring may be neglected.

Figure 2 shows an oscillogram of the variation of stresses and displacements with time obtained for a loess soil with γ = 1.44 g/cm^3, w = 12.4% on the impact testing machine described. The first trace (from the top) relates to the stress $\sigma_y(t)$ recorded by the piston strain gauge 8, the second shows the displacement of the piston upon impact u(t), the third and fifth correspond to the stresses $\sigma_y(t)$ recorded by the edge 6 and central 7 strain gauges in the base of the apparatus, and the fourth to the stress $\sigma_x(t)$ recorded by the lateral strain gauge 9. The time divisions are 0.002 sec.

In view of the uniformity of deformation along the diameter of the ring, we have

$$\varepsilon(t) = u(t) / l_0 . \tag{1.1}$$

Here ε is the deformation of the sample, u(t) is the displacement of the piston, and l_0 is the original height of the sample.



In this case $\dot{\varepsilon} = d\varepsilon/dt$ is given by

$$\dot{\varepsilon} = \frac{1}{l_0}\frac{du(t)}{dt} . \tag{1. 2}$$

Thus, from the oscillograms we can, at any moment, obtain data on the stresses $\sigma_y(t)$ and $\sigma_x(t)$, the displacements u(t), the strains $\varepsilon(t)$, and the deformation rated $\dot{\varepsilon}(t)$.

Figure 3 shows a graph of $\varepsilon(t)$ plotted from the experimental data. Clearly, in the given experiment for $0.0010 \le \varepsilon \le 0.0025$ the value of $\dot{\varepsilon}$ varies little and $\dot{\varepsilon} \approx 25.3\ \mathrm{sec}^{-1}$; during unloading the rate of deformation is again almost constant at $\dot{\varepsilon} \approx 2\ \mathrm{sec}^{-1}$. This enables one to plot a stress-strain diagram $\sigma_y - \varepsilon$ for loading at $\dot{\varepsilon}$ = const and to construct the yield condition

$$T = F(p), \quad T = \sqrt{6J_2}, \quad p = -{}^1/_3(\sigma_y + 2\sigma_x),$$

where p is the mean hydrostatic pressure, J_2 is the second invariant of the stress tensor deviator

$$J_2 = {}^1/_2 S_{ij}S_{ij}, \quad S_{ij} = \sigma_{ij} + \delta_{ij}p, \quad (i, j = 1, 2, 3).$$

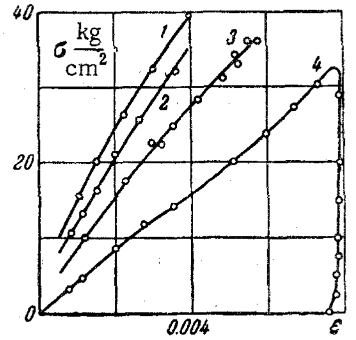


Fig. 4

σ_{ij} are the stress tensor components.

For the conditions of the experiments

$$\sigma_{ij} = 0 \quad \text{for} \quad i \neq j,$$
$$\sigma_{11} \equiv \sigma_y, \quad \sigma_{22} = \sigma_{33} \equiv \sigma_x, \; J_2 = {}^1/_3(\sigma_y - \sigma_x)^2.$$

2. Results of Experiments and Discussion

Figures 4 and 5 show the experimental relations $\sigma_y(\varepsilon)$ obtained for different, but constant for the given curve, val values $\dot{\varepsilon}$ = const. The curves in Fig. 4 correspond to a soil with γ = 1. 44-1. 47 g/cm^3, w = 3. 4-3. 6% and to the following four values of $\dot{\varepsilon}$: 1) 16. 0 sec^{-1}, 2) 11. 0 sec^{-1}, 3) 4. 0 sec^{-1}, 4) $1.4 \cdot 10^{-7}\ \mathrm{sec}^{-1}$. The curves in Fig. 5 correspond to a soil with moisture content w = 12-13% and the following values of $\dot{\varepsilon}$: 1) 24. 3 sec^{-1}, 2) 13. 3 sec^{-1}, 3) $1.4 \cdot 10^{-7}\ \mathrm{sec}^{-1}$. In Fig. 5 the triangles show the results of investigations of the compressibility of the same loess soil starting from the relations at the shock front obtained experimentally in [6].

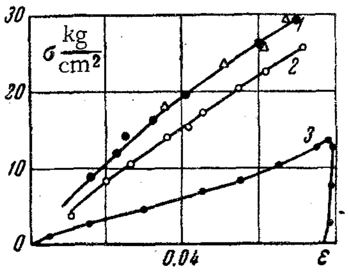


Fig. 5

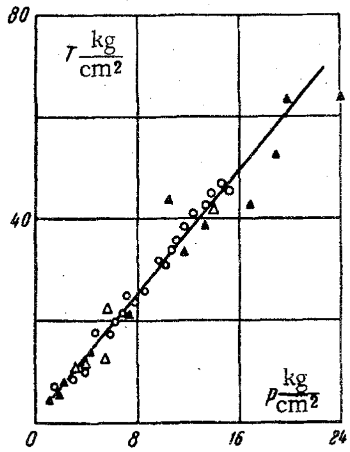


Fig. 6

The agreement of these data with curve 3 (Fig. 5) indicates that for the given soil as $\dot{\varepsilon}$ increases from the critical value $\dot{\varepsilon}_*$ = 24. 3 sec^{-1} to $\dot{\varepsilon} \to \infty$ (at the shock front) there is no further decrease in deformation at σ_y = const.

Analysis of the data points to the importance of the effect of the rate of deformation on the compressibility of loess soils: with variation of $\dot{\varepsilon}$ from 24. 3 to $1.45 \cdot 10^{-7}\ \mathrm{sec}^{-1}$ the deformations at constant stress increased by 2-3 times. Note that in our experiments we observed two limiting positions of the $\sigma_y(\varepsilon)$ diagram at $\dot{\varepsilon}$ = const – a lower corresponding to static loading (curve 4, Fig. 4, and curve 3, Fig. 5) and an upper corresponding to $\dot{\varepsilon} \geq 24.3\ \mathrm{sec}^{-1}$ (curve 1, Fig. 5). The latter may be called the "limiting dynamic compression diagram."

Simultaneous measurement of all the stress tensor components enabled us to clarify the question of the effect of rate of deformation on the yield condition previously adopted for soft soils in the form of a Mises-Schleicher condition [1, 2] and verified experimentally under explosion conditions [3-6].

In Fig. 6 we have plotted the quantities

$$T = \sqrt{2}(\sigma_y - \sigma_x), \qquad p = -{}^1/_3\,(\sigma_y + 2\sigma_x)$$

for different $\dot{\varepsilon}$. The circles correspond to $\dot{\varepsilon} = 4.0\ \mathrm{sec}^{-1}$, the triangles to $\dot{\varepsilon} = 16.0\ \mathrm{sec}^{-1}$. The solid triangles correspond to loading, the open ones to unloading. Analysis of the data shows that in the investigated range of values of $\dot{\varepsilon}$ a yield condition of the type

$$J_2 = {}^1/_6\,F^2(p)$$
$$F(p) = kp + b \qquad (k,\ b = \mathrm{const}) \tag{2.1}$$

does not depend on $\dot{\varepsilon}$ either during loading or during unloading.

Thus, on the basis of data on uniaxial compression we can construct $f(\theta)$ diagrams for $\dot{\theta} = \dot{\varepsilon} = \mathrm{const}$ in accordance with the formula

$$p = -\frac{\sigma_y(\varepsilon) + {}^1/_3\sqrt{2}\,b}{1 + {}^1/_3\sqrt{2}\,k} \equiv f(\theta), \qquad \dot{\theta} = \mathrm{const} \tag{2.2}$$

where θ is the cubical contraction of the soil.

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