REGULARITIES OF SWELLING AND COLLAPSING DEFORMATION OF CLAYEY SOILS

REGULARITES DES DEFORMATIONS DU GONFLEMENT ET D'AFFAISSEMENT DES TERRAINS ARGILEUX

ЗАКОНОМЕРНОСТИ ДЕФОРМАЦИЙ НАБУХАНИЯ И ПРОСАДКИ ГЛИНИСТЫХ ГРУНТОВ

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SYNOPSIS. In this paper the regularities of two types of deformations of structurally unstable clayey soils - swelling and collapsing - are considered. The factors influencing the deformations of these soils and character of soil mass deformations accuring under the collapsing and swelling processes are shown. In particular, zones of deformations over the depth, character of surface uplift or subsidence, and so on were considered. On the basis of the regularities studied, the method of calculation of uplift and subsidence of surface and foundations is suggested herein. The possibility of appearing of swelling and collapsing processes under conditions of change of surface moisture and thermal conditions and surface "shielding" is noted.

Principal regularities of swelling and collapsing of the structurally-unstable clayey soils which, when the moisture content insreases, change in volume, have been revealed in the long-term investigations conducted at the Scientific Research Institute for Foundations and Underground Structures. The clayey soils, depending upon the nature and magnitude of change of their volume, are classified into swelling, collapsible, collapsible swelling and usual soils (Fig. I). The swelling soils being in a stressed state caused by the soil dead weight and external load, increase in volume when the moisture content increases and collapsible soils, under these conditions, are compacted.

The swelling of the clayey soils is conditioned by the moisture increase and by the wedging pressure arising in water films and resulting from the sorptive, osmotic and capillary effects (E.A.Sorochan,I968). On the basis of the experimental investigations the value of the wedging pressure ρ_p depending on the value of the relative swelling δ has been determined:

$$\rho_p = \rho_{ss} e^{-\psi\delta} + \rho_e \left[1 - \delta' e^{\alpha\delta(1-\delta')}\right]; \quad \text{(I)}$$

where: ρ_{ss} - structural cohesion of natural soil under swelling conditions;

ρ_e - swelling pressure, numerically equal to the external load at which the swelling deformations are absent;

$\delta' = \frac{\delta}{\delta_o}$; δ_o - relative swelling of a sample without load;

ψ; α - factors which take into account the changes of structural cohesion and swelling pressure.

In the collapsible soils, due to their high porosity the intrapore swelling mainly takes place during the wetting process, and the wedging action of the water films weakens the bonds between the soil particles and an additional compaction, i.e. collapsing appears.

The increase of density, quantity of clayey particles and exchange capacity causes the increase of the swelling value and decrease of collapsing. When the natural moisture content increases the swelling and collapsing are decreased. There are some critical values of density: the minimum value of density, under which the swelling is possible, should exceed 0.9 - I.0 ton per cu m

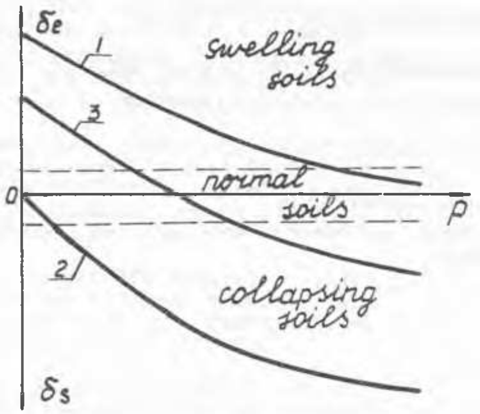

Fig. I. Relationship between the relative swelling and collapse deformations and the soil load. I- swelling soils; 2- collapsible soils; 3- swelling-collapsible soil.

and the maximum magnitude of the clay density, at which the collapsing is possible ranges from I.50 to I.60 tons per cu m.

When the soil is wetted with the sulphuric acid solutions, the swelling is conditioned not only by the moisture increase but also by formation of "new compounds" in the form of sulphates. This kind of swelling is termed conventionally as "chemical swelling". The value of swelling and swelling pressure both increase linearly as the concentration of the solution increases if the 20 per cent sulphuric acid solution is used for wetting, these values exceed 5-I0 times the values, obtained at wetting with water. The collapsing, when soils are wetted with the sulphuric acid solution, also increases.

For swelling and collapsible soils the critical or initial values of pressure and density exist in pairs at which the deformations of swelling and collapsing occur. The soil swelling occurs only in the cases when the effective pressure σ_z is less than the swelling pressure P_e and the natural moisture content is less than the swelling moisture W_e. The soil collapsing occurs on conditions that the effective pressure on the soil exceeds the initial collapse pressure P_s, and the moisture content of the soil exceeds the initial (critical) moisture content W_s.

The swelling pressure, initial collapse pressure, as well as the swelling moisture content and initial (critical) moisture content depend mainly upon the soil density and strength of its structural bonds, quantity of clayey particles, and so on.

Swelling and collapse deformations of clayey soil mass caused by the external load and by the soil dead weight as well occur only within the definite zones (Fig. 2).

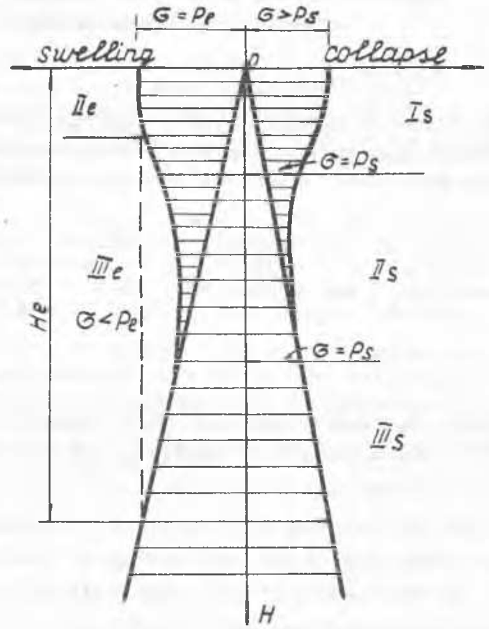

Fig. 2. Zone of swelling and collapsing in soil mass.

At the soil swelling caused by its wetting to the considerable depth, the following zones of deformations are formed:
a) compaction zone, within which $\sigma_z > P_e$;
b) neutral zone, where $\sigma_z = P_e$ and
c) zone of swelling, where $\sigma_z < P_e$. When soil is loaded by the dead weight alone, only the swelling zone is formed in the soil mass, whose lower limit is located at a depth of H, when the condition $\gamma H = P_e$ is complied with (E.A.Sorochan, 1970).

At collapsing of the foundation soil mass three characteristic zones may be distinguished: a) deformed zone within which the effective stresses σ_z are greater than the value of the initial collapse pressure P_s; b) neutral zone, where $\sigma_z \leq P_s$, and c) zone of soil collapsing caused by the dead weight of soil in which $\sigma_z > P_s$. The combination of the above listed zones depends on the dimensions of foundations, load applied to them, thickness of the collapsible soil layer and other factors (N.M.Sokolov and others, 1965).

The uplift or subsidence of the soil surface, when wetting process is going on, depends mainly on the relative swelling or relative collapsibility, thickness of the swelling or collapsible layer, depth and width of wetted area.

The magnitude of the swelling or collapsing deformations in the centre of the wetted area depends on its width (Fig.3); the magnitude of the soil surface uplift or subsidence increases as the width of the wetted area increases within certain limits, from minimum (b'_e ; b'_s) to maximum (b''_e ; b''_s), depending on the depth of wetting.

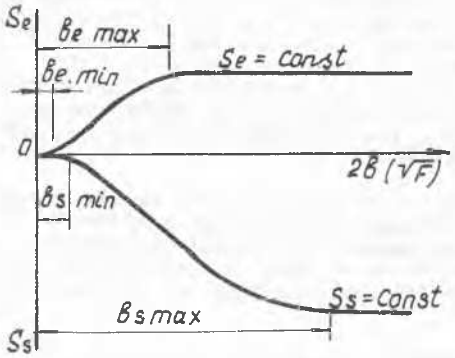

Fig. 3. Relationship between the uplift and subsidence of soil surface and the width of wetted area.

The swelling or collapsing of soils is possible both within and beyond the wetted area (Fig. 4). In the central part of the wetted area of a considerable width, the values of the uplift and subsidence of the soils are uniform and in the peripheral areas these values decrease to zero. The variations of the uplift and subsidence of the soil surface $S(x)$ in these areas may be approximated by the equation:

$$S_{(x)} = \frac{S_{max}}{2}\left(1 + \cos\frac{\pi x}{L}\right) \quad (2)$$

where: S_{max} - maximum uplift or subsidence of the surface;
L - length of the curvilinear profile of the uplift or subsidence of the soil;
x - distance to the point under consideration from the origin of the curvilinear profile.

The swelling or subsidence of the soil occuring due to dead weight causes additional horizontal pressures resulting, for the collapsible soils, in horizontal movements (Fig. 4c) developing in the curvilinear collapsible areas.

On the basis of analysis of regularities of swelling and collapse deformations the scheme of calculation of surface uplift and collapse values is suggested (Fig.3). In this calculation the interaction of wetted and unwetted zones of soil mass under conditions of swelling and collapsing, which causes the redistribution of stresses in the soil, is taken into consideration (Fig. 4d).

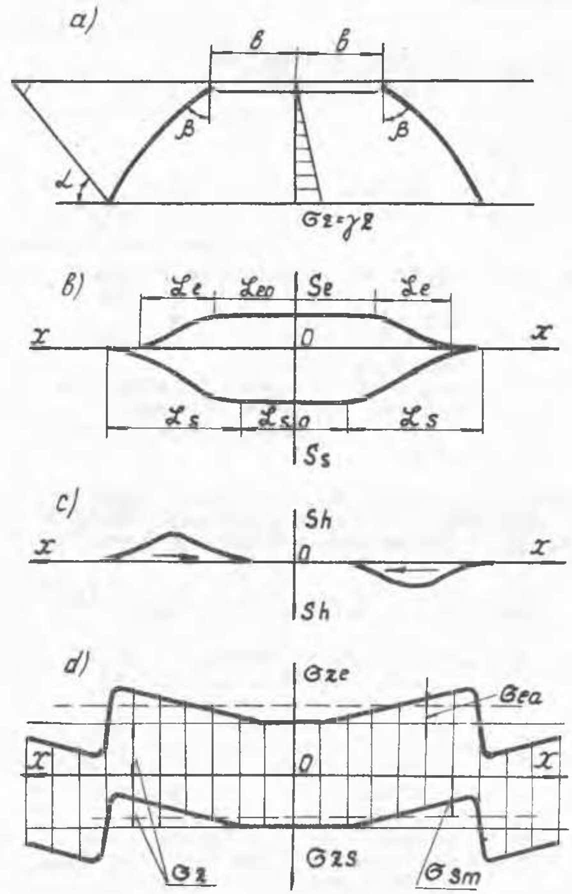

Fig. 4. Scheme for calculation of the swelling and collapsing: a) scheme of wetted soil mass; b) uplift and subsidence of soil surface; c) horizontal movements of soil surface; d) change of stress in soil mass at depth „Z" during processes of swelling and collapsing.

In case the swelling process occurs within the wetted soil mass, the additional vertical stresses arises in the soil:

$$\sigma_a = \frac{\gamma (H-y)^2 \, ctg\,\alpha \cdot \sin^2\alpha}{2b + 2(H-y)\,tg\,\beta}, \quad (3)$$

where: H - thickness of swelling zone;
y - distance from the lower boundary of the swelling zone;
α - angle of gradient of the part of soil mass at natural mois ture content, affecting the wetted soil;

b – half-width of the wetted pit.

During the collapsing of soils, the mass of wetted soil is relieved and the average vertical stresses in this case are equal to:

$$\sigma_s = \left(\gamma h_c + \frac{c}{A} - \gamma \frac{b + h_c tg\beta}{A tg\beta}\right)\left(\frac{b + h_c tg\beta}{b + z\, tg\beta}\right)^{A tg\beta} - \frac{c}{A} + \frac{\gamma z\, tg\beta + b}{A + tg\beta}; \quad (4)$$

$$A = tg\beta + (tg\varphi - tg\beta)\left[\xi + (1 - \xi)\sin^2\beta\right] \quad (5)$$

where h_c – depth of collapsible fissure, assumed to be equal to I/4 – I/2 of wetted depth z ;
c – cohesion of soil at natural moisture content;
φ – angle of internal friction at natural moisture content;
ξ – factor of lateral pressure of soil.

The uplift or subsidence value of the soil, assuming the layer uniformity over the depth, is determined from the formula:

$$S = a\int_0^{h_1} \sigma_z^{\,n}\, dz + a\int_{h_1}^{H} \sigma_{z_i}\, dz; \quad (6)$$

where: h_1 – depth, below which the additional stresses σ_a or σ_s , occur for collapsible soils this depth equals to $h_1 = h_s$;
σ_z – vertical stresses reaching the depth h_1 which are calculated without taking into account the influence of the soil, surrounding the wetted zone;
H – thickness of the swelling zone or the layer of collapsible soils.
σ_{z_i} – mean vertical stresses, determined for swelling soils with σ_a taken into account (Formula 3), and for collapsible soils from the formula (4);
$a; n$ – coefficients depending on soil properties.

The process of soil swelling or collapsing occurs not only in cases where the soils are wetted from the surface or the ground water level rises but also in cases where the wetting process is absent, the above processes are possible when the moisture content increases due to different structures built on the area under consideration and due to construction of different impermeable blankets on the soil surface. The process of moisture accumulation in the swelling soils lasts 5 to 6 years and in the collapsible soils – 3 to 4 years.

The moisture content increase in the clayey soils is predetermined by the absence of evaporation and by the action of the moisture and temperature gradients. The maximum thickness of the high moisture content zone is observed in the central part of the impervious blanket and towards the sides of the blanket the thickness decreases. In swelling soils the thickness of the high moisture content zone amounts usually to 3–5 m, and in collapsible soils the moisture content insreases over the entire depth.

Using the theories of the heat and mass transfer (A.V.Lykov, I968) and methods of hydrostatics and hydrodynamics of swelling soils, the one – dimensional problem of moisture content accumulation in soils under the water impermeable blankets and under the conditions of the moisture and temperature regime changes on the surface is considered.

The solution of this problem on the computer at different initial data allowed to obtain the numerical values of swelling soils meisture content increase with time under the impermeable blanket and on the surface.

CONCLUSIONS

I) Depending on the character and magnitude of change of volume, at moisture content increase the clayey soils are capable of collapsing and swelling deformations, which should be taken into account in construction

2) The regularities of soil mass deformations at swelling and collapsing processes of soils have been studied, and the principal factors influencing the values of these deformations have been revealed.

3) On the basis of the regularities studied methods of calculation of uplift and subsidence of surface or foundations at swelling and collapsing processes in soils are suggested.

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