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Deformation of clay soils under regime long-term static loading

Déformation des sols argileux sous un régime de charge statique à long terme

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ABSTRACT: This article deals with the study of the features of deformation of clayey soil samples under regime block long-term static loading under laboratory conditions. A peculiarity of this regime is the alternation of the active static loading block (stage of static load application) with the block of long-term static loading (stage of long exposure under load). This regime loading simulates stages of erection of a building and further deformation of the base under operational loads. The tests were carried out in a triaxial compression device with rigid punches. Clay soils are chosen as the most sensitive to the "time" factor. It is established that the strength of the sample and its volume deformations increase depending on the duration of the loading unit and the average normal stress. The improvement in the mechanical properties of the investigated soil in the compacted zones was recorded in comparison with the initial values obtained after the sample was prepared before the tests began. This fact indicates that the strength parameters of the soil: the specific cohesion and the angle of internal friction are not constant values and depend significantly on the loading regime and the time factor, while these characteristics vary both within the characteristic compacted and decompressed zones, and in the integral volume. The established effect of the loading regime makes it possible to reliably regimel the behavior of the soil foundation base during stage-by-stage a building erection.

RÉSUMÉ: Cet article traite de l’étude des caractéristiques de déformation d’échantillons de sol argileux soumis à un régime bloquant les charges statiques à long terme dans des conditions de laboratoire. Une particularité de ce régime est l'alternance du bloc de chargement statique actif (étape d'application de la charge statique) avec le bloc de chargement statique à long terme (étape d'exposition longue sous charge). Ce régime de chargement simule les étapes de l'édification d'un bâtiment et la déformation ultérieure de la base sous des charges opérationnelles. Les essais ont été réalisés dans un dispositif de compression triaxiale à poinçons rigides. Les sols argileux sont choisis comme le facteur le plus sensible au facteur temps. Il est établi que la résistance de l'échantillon et ses déformations volumiques augmentent en fonction de la durée de l'unité de chargement et de la contrainte normale moyenne. L'amélioration des propriétés mécaniques du sol étudié dans les zones compactées a été enregistrée en comparaison avec les valeurs initiales obtenues après la préparation de l'échantillon avant le début des tests. Ce fait indique que les paramètres de résistance du sol: la cohésion spécifique et l'angle de frottement interne ne sont pas des valeurs constantes et dépendent significativement du régime de chargement et du facteur temps, alors que ces caractéristiques varient à la fois dans les zones compactées et décompressées caractéristiques, et dans le volume intégral. L'effet établi du régime de chargement permet de modéliser de manière fiable le comportement de la fondation de sol lors de la construction étape par étape du bâtiment.

Keywords: clay soil, regime loading, dilatancy, triaxial compression, deviator

1 INTRODUCTION

During the construction of buildings and structures, works are carried out by tiers or bays, in which case the base is exposed to regime long-term static loads. Especially sensitive to such loads are clay soils (Ter-Martirosyan, 2014, Mirsayapov ,2011). However, in the existing calculation methods for determining the deformations of soil foundations, the construction sequence is not considered, i.e. it is believed that the object arises "in one step" and all 100% of the load from the structure is applied to the base immediately. Besides, the effect of time on changes in the strength and deformation characteristics of the soil is not counted in the process of determining base settlements as well as the phenomenon of dilatancy (Mirsayapov, 2011, 2016). Due to the neglect of these factors, there is a significant discrepancy between the calculated and the observed values of the base settlements of newly erected buildings (Mirsayapov, 2011).

According to aforementioned, stress-strain state of clay soils depends on the history of previous loads and to obtain more reliable results of the predicted settlements during determining the deformation characteristics of the soil base, it is necessary to consider the regime of its loading.

Thereby, in laboratory conditions at the Department of Bases, Foundations, Dynamics of Structures and Engineering Geology at KSUAE, experimental studies have been carried out on the process of deforming samples of clay soils with the impaired structure under regime block long-static loading. A feature of this test regime was the alternation of active static loading blocks (stages of static load application) with blocks of long-term static loading (stages of long exposure under the load). The specified loading regime allowed to imitate the process of erection of a building by tiers and further deformation of bases under operational loads. The tests were carried out in a three-axis compression device with rigid stamps. Clay soils were selected as the most sensitive to the “time” factor.

2 EXPERIMENTAL STUDIES

The main feature of silty-clay soils of the natural composition is their considerable heterogeneity due to randomly located pores, voids and inclusions. In order to reduce the influence of this factor, the test samples were prepared from clay soil of a broken structure, according to the methodology developed at the department. The samples had the following parameters: moisture W = 0,23; liquid limit (the moisture content at which the soil passes from plastic state to liquid state) W_L = 0,401; moisture at the border of rolling W_P = 0,228; plastic index I_p = 0,173.

The tests were carried out in a three-axis compression device with rigid stamps in two regimes (Figure 1), which are described below. At the stage of comprehensive compression σ_m = 80 kPa was applied to the sample, then there was a deviator loading unit, which was replaced by a block of long-term static loading, after that the sample was again subjected to an increase in vertical load. Under conditions of regime 1, the duration of each block of long-term static loading was twenty-four hours, and for regime 2 it was forty-eight hours.

In order to identify the influence of the considered loading regimes on the deformation of the soil, a short-term three-axis loading of the sample was carried out according to the “crush” scheme. The results of this test were taken as “reference” static tests corresponding to the conditional instantaneous loading.

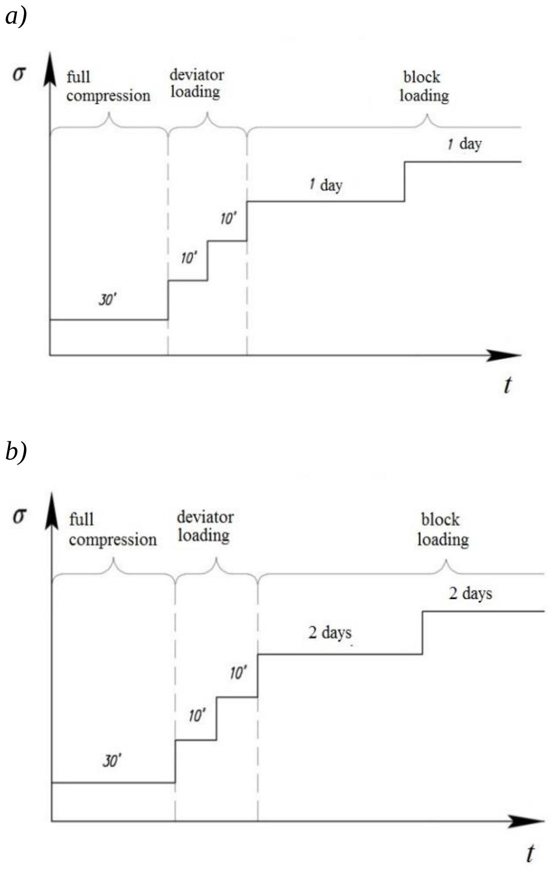

Figure 1. Regimes of loading: a – regime 1, б – regime 2

According to the results of experimental studies, we plotted the graphs of the development of relative vertical deformations in time during the whole test (Figure 2), graphs of the development of volume deformations (Figure 3), soil creep standard (Figure 4). The resulting graphical dependencies (Figures 2-4) illustrate that sample deformation are increasing throughout the test, regardless of the loading regime.

At the initial stage of the process of loading clay soil, we can see the intensive development of vertical deformations, accompanied by damping of horizontal deformations. At the stage of long exposure under load, depending on the loading regime, this process stops, the growth speed of vertical deformations slows down, while the structure of the soil is compacted due to the restoration of water-colloidal and structural bonds, a transition to a linear creep zone is observed.

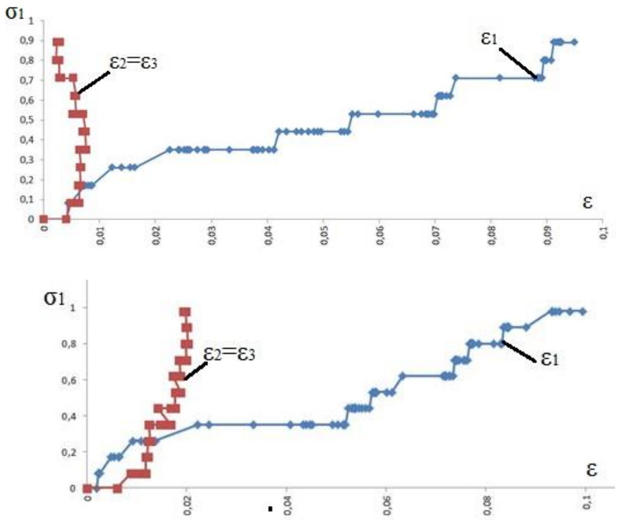

Figure 2. Graph of developing relative deformations under conditions of regime loading: regime 1 (upper), regime 2 (bottom)

On the graph of developing relative vertical deformations within each block of long-term static loading (Figure 2), an intense increase in deformations is observed at the time of application of the load with subsequent attenuation of creep deformations. Speeds of deformations developments in each block of loading are not similar. This is due to the compaction of the soil in the integral volume of the sample under rigid punches on the first blocks of loading, the formation of compacted zones and zones of maximum equilibrium between them in subsequent blocks. A similar deformation mechanism has been described in studies (Mirsayapov, 2016, 2017).

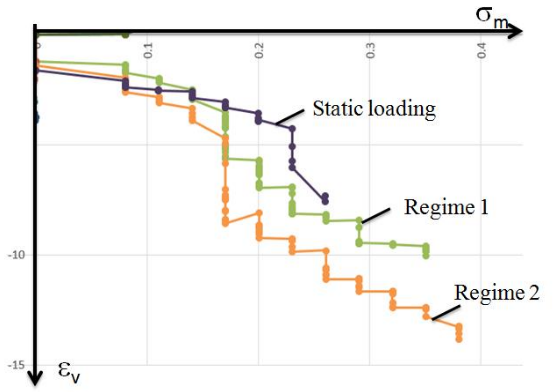

Figure 3. Graphs of relative volumetric strain development under conditions of short- and long-term regime loadings

When comparing the graphs (Figure 3) of relative volumetric strain developments of the soil samples, which were tested under the considered loading conditions, with a “reference” sample destroyed under static short-term three-axis loading, it was established that volumetric strains of the sample increase depending on the duration of the block loading: thus, in regime 1, the soil strength at the time of destruction is 35% more than in the “reference” test, and an increase in the duration of the static loading unit to forty-eight hours resulted in 1.46 times increase in strength. With the load recorded at the destruction of the “reference” sample, the volumetric strain in the conditions of the first loading regime was 115% and 88% of the limiting values obtained during short-term static tests and exposure for twenty-four hours, respectively. And under conditions of regime 2, volumetric deformations increased by 31% relative to the “reference” tests, which amounted to 74% of the limiting values of volumetric strains when sample №2 was destroyed. It was revealed that with an increase in the exposure time of the sample under static loading regime, the proportion of shear deformations increases (Figure 4).

Summary diagram of creep soil (Figure4) allowed to trace the pattern of deformation development at constant values of average normal stresses σ_m. Soil deformations (volume and shear) were developing throughout the test at different speeds in different load blocks depending on the level of the stress deviator σ_1-σ_3. The most intensive increase in strain is fixed on the first static load block in regime 1 with a deviator value of 90 kPa. In subsequent blocks, a decrease in the strain rate was observed. Under conditions of regime 2, the sample’s strain rate increased after the deviator exceeded the value equal to $\sigma_1=3\sigma_3$.

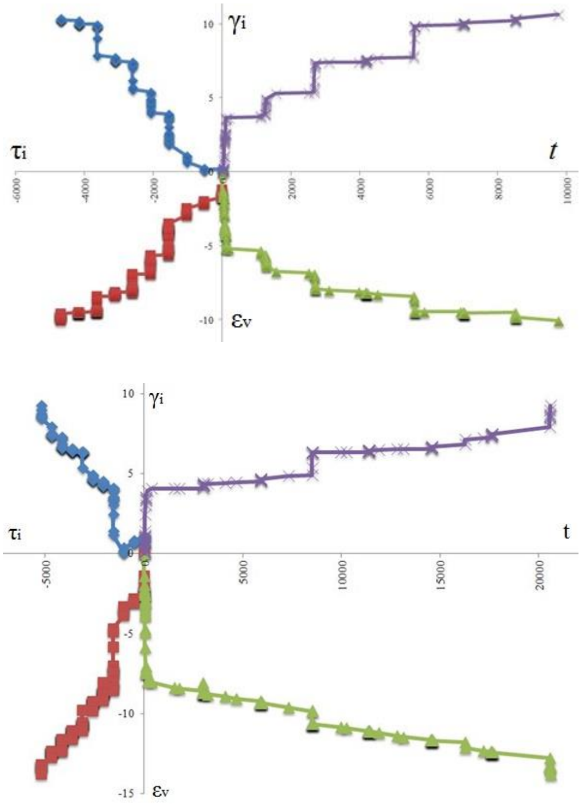

Figure 4. Summary diagram of creep: regime 1 (upper), regime 2 (bottom)

As already noted, the maximum growth rates of the sample’s relative vertical deformations were accompanied by the phenomenon of positive dilatancy (Figure 2), when not only the absence of horizontal deformations was recorded, but also their decrease, which is associated with the displacement of compacted soil pyramids formed at the side faces by vertical compacted pyramids. Described deformation pattern of samples was observed in the first 30 minutes after an increase of the deviator, then the vertical deformation increment slowed and the growth of horizontal deformations began. The probability of the manifestation of dilatancy processes substantially depended on the level of average normal stresses in the sample and the history of its previous loading. At the moment of the destruction of the sample, the sample's vertical deformation had a continuous character, and the development of horizontal deformations had a negative sign.

3 CONCLUSIONS

As a result of experimental studies, it was established:

The development of clay sample's deformations with a damaged structure under conditions of three-axis compression depends on the loading regime: the longer the block of long static loading lasts, the greater the proportion of creep deformations.

Linear, volumetric and shear deformations are developing throughout the test with different intensities. The strain rate depends on the level of average normal stresses in the sample and the history of the preceding loading.

4 REFERENCES

Ter-Martirosyan, Z.G., Ter-Martirosyan, A.Z., Sobolev, Ye.S. 2014. Creep and vibrocreep of soils. *Future directions of the theory and practice of rheology and soil mechanics: Proceedings, XIVth Intern. Symp. on the Soils Rheology* (Eds: Mirsayapov, I.T., Koroleva, I.V.), 8-23. Publisher KSUAE, Kazan.

Mirsayapov, I.T., Koroleva, I.V. 2011. Prediction of deformation of the foundation with the long-term non-linear deformation of soil, *Base, foundation and soil mechanics* **4**, 16–23.

Mirsayapov, I.T., Koroleva, I.V. 2016. Strength and deformability of clay soil under different triaxial load regimes that consider crack formation, *Soil Mechanics and Foundation Engineering* **53(1)**, 5–11.

Mirsayapov, I.T., Koroleva, I.V. 2017. Features of deformation of clay soils during loading of regime, *Izvestiya KGASU* **4**, 193–198.