Settlement of the base of clay soil under regime weighting

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Abstract. The aim of the article is the development of the theory of strength and deformation of clay soils under conditions of triaxial compression under combined alternating long-term static and cyclic loading. As a result of the research, new experimental data were obtained on the peculiarities of the stress-strain state of clay soils under triaxial compression under combined alternating long-term static and cyclic loading, as well as the development of base sediments of foundation models in laboratory conditions. The significance of the results obtained for the construction industry lies in the fact that experimental studies of determining the changes in the strength and deformability of clay soils under combined alternating long-term static and cyclic loading are necessary for the modernization of engineering methods for calculating sediments and the bearing capacity of foundations.

Keywords: triaxial compression, clay soils, static loading, cyclic loading, combined loading, bearing capacity, strength, specific adhesion, hardening, base settlement.

1 Introduction

Until today, one of the fundamental tasks in the design, which must also be taken into account during the operation of buildings and structures under the influence of static and cyclic loads [1-2], is the assessment of the bearing capacity and prediction of precipitation of the sub-foundations, taking into account changes in the physical and mechanical characteristics of soils with a combined alternating long-static and cyclic loading [3-8].

Therefore, the experimental studies conducted to determine the changes in the strength and deformability of clay soils under combined alternating long-term static and cyclic loading in volumetric trays are necessary for the modernization of engineering methods for calculating sediments and the bearing capacity of foundations [9-14], since knowledge of the nature of soils, the conditions of their formation and changes in the future existence, their natural composition and structure strongly affects their physical and mechanical characteristics and gives the possibility to assess correctly their strength and deformation properties during design and during the operation of buildings and structures [15-20].

2 Materials and methods

For an experimental study of the stress-strain state of a clay base under a slab foundation under combined alternating long-term static and cyclic loading in laboratory conditions, stamp-shaped tray tests of a clay soil of a disturbed structure with the following physical and mechanical characteristics were carried out: $\gamma=19.4$ kN/m$^3$, $W=23\%$, $W_l=40.1\%$, $W_p=22.8\%$, $I_p=17.3\%$, $I_l=0.012$, $e=0.81$, $S_e=0.73$.

The experimental studies consisted of several stages, which had their own methodological features and, to one degree or another, influenced the final result:

1. Development of a test procedure.
2. Production of prototypes.
3. The manufacture of resistance strain gauges.
4. Model loading and load control during the experiment.
5. Measurement of deflections, deformations, and settlement of the model.
6. Processing of test results.

To establish the dependence of vertical displacements in the soil on the time of the load, on the applied cyclic loads, to determine the deformations of the soil mass at the base of the slab foundation and in the array surrounding with short-term static, long-static, cyclic and combined alternating long-time static and cyclic external loads, the tests were carried out by the methods of static pressing loads and cyclic loads.

Experimental studies were carried out in a tray with dimensions of 1000×1000×1000 mm at the laboratory of Kazan State University of Architecture and Engineering. The strain readings were taken using the ASM-4 Automatic Strain Meter.

In the experiments, the load on the base was transmitted through the construction of a rigid frame using a hydraulic jack.

In experiments, the load was transmitted through the construction of a rigid frame, using a hydraulic jack. A reinforced concrete slab is adopted as a model of a slab foundation. Measurements of the vertical displacements of the slab foundation model were carried out by dial indicators. The appearance of the experimental plant is shown in figure 1. The loading diagram of the clay base and plate dimensions is shown in figure 2.

To measure stresses in the soil mass of the stamp base, soil pressure sensors were placed. Schematic diagram of the location of the sensors in the soil base are shown in figure 3.

Figure 1. The appearance of the experimental plant.
3 Results
Based on the results of experimental studies performed in a volumetric laboratory tray, graphs of changes in the settlement of the slab foundation model were constructed (figures 4-8) under combined alternating long-term static and cyclic loading, on which it is shown that deformations with different intensities developed on each load block under consideration during the entire test, and the intensity of their development depended on the coordinate of the point in question.

Figure 2. Scheme of loading a clay base:
1 – soil base; 2 – tray;
3 – model of slab foundation (stamp);
4 – dial indicator; 5 – frame for mounting indicators of the watch type; 6 – a bendometer.

Figure 3. The layout of the sensors in the soil base:
1 – soil massif; 2 – volume tray;
3 – stamp 250×250×40 mm;
4 – indicators of the sentry type;
5 – a frame for installing indicators;
6 – deflection meter; 7 – soil sensors.

Figure 4. The development graph of the slab model of the slab foundation under combined alternating long-term static and cyclic loading (experiment № 1).
Analyzing the results of experimental studies of clay soil under combined alternating long-term static and cyclic loading, it is clear that there is a change in all deformation and strength parameters of clay soil. Let us consider the changes in the vertical deformation of experiment No. 1 (figures 4, 5). First, the vertical static load (block 1) was applied to the sample in steps up to $\sigma_{\text{max}} = 100$ kPa. Each stage of loading was maintained for 15 minutes according to the test program, where after static loading the sediment of the base was 4.05 cm.

**Figure 5.** Fragments of the graph of the development of the settlement of the slab foundation model under combined alternating long-term static and cyclic loading (experiment № 1).
After 1 block of static loading, we go to block 2 by cyclic loading, where the maximum vertical stress is $\sigma_{\text{max}} = 100 \text{ kPa}$. For the entire 2 cyclic loading unit, 500 cycles were performed, where the total settlement of the base was 5.78 cm.

Further, during the transition from the block by cyclic loading (block 2) to the block with a long-term static load (block 3), at the moment of changing the loading mode, the settlement of the base did not change, only after 30 minutes the draft increased slightly by 0.02 cm and the total draft was 5.80 (see Block 3 with long-term static loading lasted 1 day, where the settlement of the base increased by 0.21 cm and the total settlement of the base was 5.99 cm).

During the transition from the long-term static loading unit (block 3) to cyclic loading (block 4) at the moment of changing the loading mode, the base sediment does not change up to 3 loading cycles, and after that, the vertical deformations increased on the 4 loading cycle (figures 4, 5) by 0.03 cm. For the entire 4 block of cyclic loading, another 500 cycles were performed, where the draft of the base increased by 0.83 cm and the total draft of the base was 6.82 cm.

Then again, when switching from the block with cyclic loading (block 4) to the block with a long-term static load (block 5), at the moment of changing the loading mode, the settlement of the base did not change, only after 50 minutes the draft increased slightly by 0.01 cm and the total draft was 6.83 cm. Block 5 with long-term static loading lasted 1 day, where the base sediment increased by 0.23 cm and the total base sediment was 7.05 cm.

During the transition from the long-term static loading unit (block 5) to cyclic loading (block 6), at the moment of changing the loading mode of the base sediment, up to 2 loading cycles do not change, and after that, the vertical deformations increased by 3 loading cycles (figures 4, 5) by 0.01 cm. For the entire 6 unit of cyclic loading, another 1200 cycles were performed, where the base draft increased by 0.51 cm and the total base draft was 7.56 cm.

Then again, when switching from a block with cyclic loading (block 6) to a block with a long-term static load (block 7), at the moment of changing the loading mode, the settlement of the base did not change, only after 50 minutes the draft increased slightly by 0.01 cm and the total draft was 5.57 cm (figure 4). Block 7 with long-term static loading lasted 1 day, where the base settlement increased by 0.08 cm and the total base settlement was 7.64 cm.

During the transition from the long-term static loading unit (block 7) to cyclic loading (block 8), at the moment of changing the loading mode of the base sediment, up to 5 loading cycles do not change, and after that, after the 5th loading cycle (figures 4, 5), the vertical deformations increased 0.02 cm. For the entire 8 block of cyclic loading, another 1400 cycles were performed, where the draft of the base increased by 0.36 cm and the total draft of the base was 8.00 cm.

Then again, when switching from a block with cyclic loading (block 6) to a block with a long-term static load (block 7), at the moment of changing the loading mode, the settlement of the base did not change, only after 50 minutes the draft increased slightly by 0.01 cm and the total draft was 5.57 cm (figure 4). Block 7 with long-term static loading lasted 1 day, where the base settlement increased by 0.08 cm and the total base settlement was 7.64 cm.
entire 8 block of cyclic loading, another 1400 cycles were performed, where the draft of the base increased by 0.36 cm and the total draft of the base was 8.00 cm.

Further, when switching to blocks with cyclic loading, an increase in the strain accumulation rate is observed. It should be noted that the accumulation of general deformations occurs mainly due to the plastic (inelastic) component. Elastic deformations within loading blocks practically do not change (figures 4, 5).

Also, according to the obtained indications of soil sensors located in the clay base massif (figure 3) of the slab foundation model, strain diagrams were constructed for each loading stage (figure 6).

![Figure 6. Diagrams of deformations under the model of a slab foundation with combined alternating long-term static and cyclic loading (experiment № 1).](image)

As can be seen from the diagrams (figure 6), deformations in all soil zones change as the number of cyclic loads increases and the duration of exposure of the test specimen under prolonged static loading increases. It should be noted that the greatest increase in stress occurs under the model of a slab foundation under the action of cyclic loads.

Consider the changes in the vertical deformation of experiment № 2 (figures 7, 8). First, a vertical static load (block 1) was applied to the sample in steps up to $\sigma_{\text{max}} = 100$ kPa.
Each stage of loading was maintained for 15 minutes according to the test program, where after static loading the sediment of the base was 3.37 cm. After 1 block of static loading, go to block 2 by cyclic loading, where the maximum vertical stress is $\sigma_{\text{max}} = 100$ kPa. Under the action of cyclic loads, within each block, there was an increase in settlement of the base. Deformations with different intensities developed throughout the test. The most intensive development of deformations occurred in block 2 in the initial period of loading (up to 1000 cycles). For the entire 2 cyclic loading block, 1000 cycles were performed, where the base settlement increased by 2.12 cm and the total base settlement was 5.49 cm.

Then, when switching from a block with cyclic loading (block 2) to a block with a long-term static load (block 3) at the moment of changing the loading mode $\sigma_{\text{max}} = 50$ kPa, the value of the base settlement decreased by 0.03 cm and the total base settlement was 5.46 cm, then within 50 minutes, the precipitation did not change, only after 50 minutes did the precipitate increase slightly by 0.01 cm and the total base sediment was 5.47 cm. Block 3 with long-term static loading lasted 1 day, where the base sediment increased by 0.10 cm and total base settlement 5.59 cm.

During the transition from the long-term static loading unit (block 3) to cyclic loading (block 4) at the moment of changing the loading mode, the base settlement value increased by 0.03 cm and the total base settlement was 5.62 cm. Deformations up to 5 loading cycles do not change, and then, on the 6th loading cycle (figures 7, 8), the base sludge increased by 0.02 cm. The most intense development of deformations occurred up to 500 cycles and the total base sludge was 6.60 cm. For the entire 4 block of cyclic loading, 1000 cycles were performed where the base sediment increased by 1.23 cm and a total base of sludge was 6.82 cm.

Then, when switching from a block with cyclic loading (block 4) to a block with a long-term static load (block 5) at the moment of changing the loading mode $\sigma_{\text{max}} = 50$ kPa, the value of the base settlement decreased by 0.03 cm and the total base settlement was 6.79 cm, then within 50 minutes, the precipitation did not change, only after 50 minutes the precipitate increased slightly by 0.01 cm and the total base sediment was 5.80 cm. Block 5 with long-term static loading lasted 1 day, where the base sediment increased by 0.06 cm and total base settlement 6.88 cm.

During the transition from the long-term static loading unit (block 5) to cyclic loading (block 6) at the moment of changing the loading mode, the base draft value increased by 0.04 cm and the total base draft was 6.92 cm. Deformations up to 6 loading cycles do not change, and then on the 10th cycle of loading.
the base sludge increased by 0.01 cm and the total base sludge was 6.93 cm. The most intensive development of deformations occurred up to 480 cycles and the total base sludge was 7.67 cm. For the entire 6 block of cyclic loading, 1500 cycles of a base sediment increased by 1.03 cm and a total base precipitate was 7.91 cm.

Figure 8. Fragments of the graph of the development of the settlement of the slab foundation model under combined alternating long-term static and cyclic loading (experiment № 2).
Then, when switching from a block with cyclic loading (block 6) to a block with a long-term static load (block 7) at the moment of changing the loading mode $\sigma_{\text{max}} = 50$ kPa, the value of the base settlement decreased by 0.03 cm and the total base settlement was 7.89 cm, then within 70 minutes, the precipitation did not change, only after 70 minutes the precipitate increased slightly by 0.01 cm and the total base sediment was 7.90 cm. Block 7 with long-term static loading lasted 1 day, where the base sediment increased by 0.08 cm and total base settlement 7.99 cm.

During the transition from the long-term static loading unit (block 7) to cyclic loading (block 8) at the moment of changing the loading mode, the base settlement value increased by 0.02 cm and the total base settlement was 8.01 cm. Deformations up to 5 loading cycles are not changed, and then on the 10th cycle of loading, the base sludge increased by 0.02 cm and the total base sludge was 8.03 cm. For the entire 6 block of cyclic loading 2200 cycles were performed, where the base sludge increased by 0.51 cm and the total base sludge was 8.50 cm.

4 Discussions

Based on the analysis of the results of experimental studies, the following conclusions can be drawn:

1. The nature of the deformations development in blocks with a long-acting static load under combined alternating long-term static and cyclic loading depends on the duration of the cyclic load in the previous block and the duration of the loading block under consideration. Thus, during the transition from cyclic loading to a block with a long-term static load at the moment of changing the loading mode, a slight decrease in draft occurs by 0.01-0.02 cm due to the elastic component and deformation are stabilized. Then, as the holding time under a long static load increases, deformations further increase by 0.05-0.3 cm. When switching from a long-static loading unit to cyclic loading, depending on the loading mode, at the moment of changing the mode, the base settlement increases by 0.01-0.03 cm. Further, depending on the number of applied cyclic loads, the sediment increases by 0.5-2.3 cm. The most intensive development of deformations occurs in the first loading blocks, i.e. during cyclic loading, development was observed up to 1000 cycles, with prolonged static loading up to 3 days.

2. Giving the nature of the deformations development in blocks, two characteristic cases must be taken into account when:
   - first, long-term static $\sigma_1 (t)$ loading acts, and then cyclic loading;
   - first, the cyclic load $\sigma_1 (N)$ acts, and then long-term static loading.

   In the first case, the total durability increases compared to when cyclic loading is carried out with a stress value of $\sigma_1 (N)$. This is associated with an increase in the effective surface of the energy of soil destruction at the first stage of loading due to the restoration and increase of coagulation bonds [21-22].

   In the second case, the decrease in strength during the transition to a block with a long static load will be extremely slow. This is explained by the “delay effect” of fatigue cracks in the planes of limiting equilibrium in the calculated soil volume [21-22].

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