The influence of time on the bearing capacity of piles in water-saturated clay soils

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Abstract. The change in the bearing capacity of piles over time is an established fact that is carefully studied by many researchers. Depending on the type of soils and their condition, there is both a decrease (in sandy) and an increase (in clay) in the bearing capacity of piles over time. The most effective increase in bearing capacity occurs in water-saturated, clayey soils with the property of thixotropy. The results of experimental studies of soils with piles in natural conditions, carried out with different periods of their rest, are of considerable value in the study of this phenomenon. During the construction of a multi-storey residential complex in Odessa, which began in 2019, it became necessary to increase the load on the pile foundation made of prismatic piles with a length of 16 m and a cross-section of 350×350 mm. According to research in 2019, the bearing capacity of the piles was 1500 kN. In February 2021, static soil tests were carried out with the existing piles from under the grillage of the building, which was installed by 90%, while the bearing capacity of the piles was 1800 kN. Thus, for the period from July 2019 to February 2021, the bearing capacity of C160.35-11 piles at the construction site in water-saturated soils in Odessa increased from 1500 kN to 1800 kN, which is 20%.

1. Introduction
The change in load-bearing capacity of piles over time is an established fact that requires comprehensive study. Depending on the type of soil and their condition, there is a decrease (in sand) and increase (in clay) of piles bearing capacity over time. The results of experimental studies of soils by piles in natural conditions, conducted with different periods of their rest are considerably valuable in the study of this phenomenon. Unfortunately, such studies are rare.

During the construction of a multi-storey residential complex with underground parking (Figure 1), at the address: 6, Fontanskaya doroga str., Odesa there was a need to increase the load on the pile foundations of prismatic piles 16 m long and 350 mm cross section. Therefore, tests of single piles from the existing strip pile foundation were performed.

2. Analysis of recent research and publications
The analysis of works [1-4] shows that in clay soils of soft and fluid-plastic consistency, as the consolidation and thixotropic hardening, there is an increase in the bearing capacity of piles over time. In July 2019, tests of prismatic piles (Figure 2) were performed before the construction of a multi-storey residential complex with underground parking at the address: 6, Fontanskaya doroga str., Odesa. The allowable design load on piles C160.35-11 was confirmed by static tests of soils by 4 piles, the rest of which ranged from 10 to 14 days. According to these researches, the bearing capacity of the piles was 1500 kN [5].
3. The aim of the work
Conducting static testing of soils with prismatic piles on the construction of a multi-storey residential building with underground parking, which at the time of the study was built by 90%. The foundations of the building are made of prismatic reinforced concrete piles with a length of 16 m and a cross section of 350×350 mm, which were immersed in water-saturated clay soils in July 2019. The purpose of the study is to determine the bearing capacity of piles after their rest for 19 months and inclusion in the work of an existing building and compare it with the results of research in 2019, ie to establish the effect of time on bearing capacity of piles in water-saturated clay soils.

4. Research methodology
Static tests of soils with full-scale prismatic piles are performed in accordance with the requirements of DSTU (State Standards of Ukraine) BV.2.1-27:2010 (GOST 5686-94) "Piles. Determination of bearing capacity based on the results of field tests" [6], and DBN (Ukrainian building norms) B.2.1-10-09 "Bases and foundations of buildings and structures. Amendment №1" [7].

The maximum loads during the control tests were brought to 1800 kN. Axial compressive static
load on the pile was transmitted by two hydraulic jacks DGO (Jack hydraulic lightweight)-100-2. The emphasis for the jacks during the test was a pile cap, loaded with the structures of the building. The study of soils with piles was carried out according to the method of control testing. Loading was performed in steps equal to 1/10 of the maximum load, with the endurance of each stage to the conditional stabilization, which was taken as 0.1 mm per hour of observation. The first two stages were taken within 1/5 of the maximum load. Determination of pile movements during the tests was performed on two prognometers with a division value of 0.01 mm, installed on the reference system. The pressure in the system of hydraulic jacks DGO-100 during the tests was recorded by a manometer class 1.5. During the tests, the journal was kept according to the form given in the annex "Zh" of DSTU [6]. According to the results of motion measurements, the subsidence of the piles was determined, which allowed to plot the dependence of the subsidence of piles on the load in time $S = f (P, t)$ and graphs of the dependence of subsidence on the load $S = f (P)$.

5. The results of research
In March 2021, the builders set a task to clarify the bearing capacity of existing working piles 18 months after their immersion and construction of 90% of aboveground structures. As a result, static soil tests were performed with existing pile caps. The fragment of soil tests by a pile is presented in Figure 2. Technological piles №256, 119 in section 2 and №108, 301 in section 1 were selected for static tests. The piles are based on Engineering Geological Elements-6 (EGE-6) – brownish-brown loam, heavy, solid. The link of piles and engineering-geological section is shown in Figure 3, and physical and mechanical properties of engineering geological elements in Table. 1.

![Figure 3. Link of piles and engineering geological section.](image)

Control tests of soils by pile №279 were performed on 18.02.21, the maximum compressive load was increased to 1800 kN, while the stabilized subsidence was 7.72 mm.

Control tests of soils by pile №119 were performed on 19.02.21, the maximum compressive load was increased to 1800 kN, while the stabilized subsidence was 8.25 mm.

Control tests of soils by pile №108 were performed on 20.02.21, the maximum compressive load was increased to 1800 kN, while the stabilized subsidence was 8.73 mm.

Control tests of soils by pile №301 were performed on 22.02.21, the maximum compressive load was increased to 1800 kN, while the stabilized subsidence was 10.22 mm.

The fragment of tests of soils by a pile is given in Figure 4, and graphs of dependence between piles subsidence and vertical compressive loadings are presented in Figure 5.
Table 1. Physico-mechanical characteristics of soils.

| № EGE | Name EGE | ρs, g/cm³ | ρs,* g/cm³ | W* | Wl | Wp | φ*, ° | с*, kPa | E,* MPa |
|-------|----------|-----------|------------|-----|-----|-----|-------|---------|---------|
| 1     | Medium loess loam | 2.70  | 1.74  | 0.20  | 0.33  | 0.21  | 21  | 22  | 10  |
| 2     | Light loess loam   | 2.69  | 1.70  | 0.18  | 0.26  | 0.18  | 20  | 16  | 8   |
| 3     | Medium loess loam | 2.71  | 1.88  | 0.22  | 0.36  | 0.22  | 21  | 21  | 9   |
| 4     | Light loess loam   | 2.70  | 1.79  | 0.27  | 0.29  | 0.19  | 11  | 10  | 4   |
| 5     | Heavy loam         | 2.72  | 1.82  | 0.21  | 0.38  | 0.23  | 21  | 23  | 13  |
| 6     | Heavy loam         | 2.72  | 1.74  | 0.22  | 0.39  | 0.23  | 20  | 24  | 12  |
| 7     | Heavy loam         | 2.72  | 1.86  | 0.21  | 0.41  | 0.24  | 21  | 25  | 11  |
| 8     | Red-brown clay     | 2.73  | 1.84  | 0.22  | 0.45  | 0.27  | 19  | 45  | 16  |

*Above the line is the value for the state of natural humidity, below the line is the value for the water-saturated state.

Figure 4. Fragment of test of soils by a pile from under a pile cap.

The bearing capacity of prismatic piles according to the results of their tests by pressing load is determined by the formula:

\[
F_d = \gamma_c \times F_u / \gamma_g ,
\]

where: \( \gamma_c \) – coefficient of operation conditions, in case of pressing load \( \gamma_c = 1.0 \);

\( \gamma_g \) – soil reliability coefficient \( \gamma_g = 1.0 \);

\( F_u \) – the value of the ultimate resistance according to the results of static tests.

Thus, according to the results of tests of 4 piles in 2021 value \( F_u \) is taken equal 1800 kN [8].

The bearing capacity of prismatic piles C160.35-11 is equal to:

\[
F_d = 1.0 \times 1800 / 1.0 = 1800 \text{kN} .
\]
Figure 5. The results of soil tests by piles in 2021.

6. Conclusions
According to the results of static tests of water-saturated clay soils by prismatic piles C160.35-11 on the construction site of a multi-storey residential complex at the address: 6, Fontanskaya doroga str., Odesa, their bearing capacity during the tests in 2019 was 1500 kN, and during the tests of 2021 was 1800 kN.

Thus, for the period from July 2019 to February 2021, the bearing capacity of C160.35-11 piles in water-saturated clay soils increased from 1500 kN to 1800 kN, which is 20%.

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