Experimental studies of the structural strength effect on the swelling of clay soils

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Abstract. The paper notes that the influence on the increase in the clay soil swelling disturbs both intra-aggregate and inter-aggregate bonds. A new technique and device for studying the “sensitivity” of swollen clay soils have been developed, which make it possible to study more accurately the swelling of clay soils in the natural state and also in the structurally disturbed one on the same sample. Studies of the swollen clay soils “sensitivity” selected from various regions of Azerbaijan have shown that with an increase in the depth of clay soils, their coefficient of structural strength influence on swelling, i.e., “sensitivity” increases significantly.

1. Introduction
Swelling is usually understood as the process of increasing the volume of clay soil when it interacts with water.

The increase in the scale of construction has shown that the swollen clay soils have a much greater development on the earth’s surface than previously supposed. As noted by (Cromko [1]; Sorochan [2]) and others, ignoring the negative properties of swollen clay soils leads to significant material damage.

The works of (Fityuş, Smith and Allman [3]; Peredalskiy and Ananjev [4]; Mustafayev [5]; Kulchitskiy and Usiyaroy [6]; Al-Homond, Bagma, Husein Malkavi and Al Bashabsheh [7]; Gabibov [8]; Day [9, 10, 11]; Noamooz, Jahangir and Masrouri [12]; Cui, Yahia-aissa and Delage [13]; Alonso, Romero, Hoffmann and Escudero [14]; Sun and Sun [15]) and others are devoted to the study of swollen clay soil stress-strain state regularities

It is well-known that as a rule, violation of natural structural bonds in clay soil leads to an increase in swelling, and often to a very significant one.

2. State of knowledge of the problem under study
In natural conditions, structural bonds are disrupted by weathering, increased pressure, recent tectonic movements, anthropogenic impact, etc.

(Schmetmann [16]) proposed the term "sensitivity" of clays to denote the phenomenon of increased swelling of clays due to the repeated repetition of significant shear deformations during mechanical grinding of clay soils. The value of this "sensitivity" is expressed by the ratio of the clay swelling indicators with disturbed (δᵣₑₚₑ) and undisturbed (δₑᵤₑ) texture, i.e.
\[ K_c = \frac{\delta_{\text{min}}}{\delta_{\text{swell}}}, \]

In this formula, \( K_c \) is the value of "sensitivity" or the coefficient of clay soil structural strength influence on soil swelling. This formula shows that when the coefficient \( K_c \) is equal to or close to unit, the structural bonds do not affect the clay soil swelling. In the work of (Snezhkin and Ziangirov [17]), it is noted that in some clays with a high strength of interaggregate bonds, the violation of the structure leads to an increase in swelling by 3-20 times. It should be noted that according to our research, the violation of interaggregate bonds also has a noticeable effect on the increase in the swelling of clay soils.

3. Development of a new technique for studying the structural strength effect on clay soil swelling

Under laboratory conditions, the change in the coefficient of clay soil structural strength ("sensitivity") influence on swelling of various swollen clay soils in Azerbaijan was studied by a refined method on an improved device (see figure 1). Unfortunately, none of the published works on the study of clays "sensitivity" mentions how the equality of the samples density in the natural and disturbed state was achieved in comparative studies.

![Device for studying the "sensitivity" of swollen clay soils](image)

**Figure 1.** Device for studying the "sensitivity" of swollen clay soils: 1 is composite ring; 2 is soil sample; 3 is cup; 4 is tray; 5 is stamp-piston; 6 is collar; 7 is clock-type indicator; 8 is water.
The improved device includes composite ring 1 with soil sample 2, cup 3, at the bottom of which permeable tray 4 is installed, stamp-piston 5 with collar 6 protruding beyond the upper edge of the ring, and clock-type indicator 7. During the test, water 8 is poured into cup 3.

As it is known, when selecting a structurally undisturbed sample into a ring, the sample receives a strictly specified cylindrical shape, defined by the selected ring size. After testing of the structurally undisturbed sample, the water is drained, the indicator and the piston are removed. Then, with the help of a special spoke, the sample is loosened in the ring, then piston 5 is again placed under pressure on the sample until its collar 6 stops at the upper edge of ring 1. Again, indicator 7 is set to zero and the soil is tested for swelling by pouring water into the cup, but in a structurally disturbed state. As can be seen on the described device, the initial density of the soil is achieved in the simplest way. The tests in both disturbed and undisturbed states are performed on the same soil sample. This allows you to increase the reliability of the "sensitivity" test results.

4. Experimental study of the structural strength influence on clay soil swelling in certain regions of Azerbaijan

The samples of swollen clay soils from the Vilyashchay hydroelectric complex facilities (south of Azerbaijan) and the village of Shirvan (near the city of Sumgait, Azerbaijan) were examined for structural strength ("sensitivity") (see table 1).

As can be seen from table 1, the "sensitivity" of Vilyashchay clays to swelling varies from 1.025 to 2.252 increasing with depth. Apparently, this is due to an increase in the degree of weathering from the depth to the mass surface.

Table 1. Results of testing clay soils in the village of Vilyashchaysky for "sensitivity" to swelling.

| Sampling depth, m | Free swelling in an undisturbed state, $\delta_{\text{undis}}$, % | Free swelling in a disturbed state, $\delta_{\text{dis}}$, % | Sensitivity of clay soils to swelling $K_c$ |
|------------------|-------------------------------------------------|-------------------------------------------------|-----------------------------------|
| 0.5              | 8.0                                             | 8.2                                             | 1.025                             |
| 1.0              | 10.3                                            | 12.1                                            | 1.175                             |
| 1.5              | 10.8                                            | 13.2                                            | 1.222                             |
| 2.0              | 22.3                                            | 30.1                                            | 1.350                             |
| 2.5              | 24.5                                            | 43.6                                            | 1.780                             |
| 3.0              | 23.0                                            | 51.8                                            | 2.252                             |

Figure 2 shows a curve of changes in the value of the Vilyashchay clays sensitivity to swelling with the depth of occurrence. This dependence has the pattern of a broken line, although it can be averaged as a linear function.

Table 2 shows the results of testing clay soils in the village of Shirvan on "sensitivity" to swelling.

Table 2 shows that the sensitivity of clay soils in the village of Shirvan to swelling ranges from 1.033 to 2.207. In general, the increase in sensitivity in depth is visible, but it is not as clearly expressed as in the Vilyashchay clays.
Figure 2. Curve of changes in the value of the Vilyashchay clays sensitivity to swelling with the depth of occurrence.

Table 2. Results of testing clay soils in the village of Shirvan for "sensitivity" to swelling.

| Sampling depth, m | Free swelling in an undisturbed state, $\delta_{\text{undist}}$, % | Free swelling in a disturbed state, $\delta_{\text{dist}}$, % | Sensitivity of clay soils to swelling $K_c$ |
|------------------|-------------------------------------------------|-------------------------------------------------|----------------------------------|
| 1.0              | 3.0                                             | 3.1                                             | 1.033                            |
| 2.0              | 10.8                                            | 12.5                                            | 1.157                            |
| 3.0              | 12.4                                            | 18.2                                            | 1.469                            |
| 4.0              | 12.1                                            | 22.5                                            | 1.860                            |
| 5.0              | 16.7                                            | 24.1                                            | 1.443                            |
| 6.0              | 21.0                                            | 31.8                                            | 1.515                            |
| 7.0              | 20.4                                            | 43.2                                            | 2.112                            |
| 8.0              | 28.1                                            | 48.1                                            | 1.715                            |
| 9.0              | 24.1                                            | 53.2                                            | 2.207                            |
| 10.0             | 26.9                                            | 55.8                                            | 2.075                            |
Figure 3. Graph of changes in the “sensitivity” of the Shirvan village clay soils to swelling with depth.

Figure 3 shows a graph of changes in the “sensitivity” of clay soils in the village of Shirvan to swelling with the depth of occurrence. On average, this dependence can be represented as a linear function. As can be seen from the graph this dependence, as in the case of the Vilyashchay clays, has the pattern of a broken straight line up to a depth of 4.0 m. Further with depth, the graph does not correspond that pattern.

5. Conclusion
1. According to our research, the increase in the swelling of clay soils was greatly influenced by the disturbance of not only intra-aggregate bonds, but inter-aggregate bonds, as well.
2. A new technique and device for studying the "sensitivity" of swollen clay soils were developed, which made it possible to study more accurately the swelling of clay soil both in a natural and structurally disturbed state on the same sample, thus helping to increase the accuracy of the test results obtained.
3. Studies of the "sensitivity" of swollen clay soils selected from various regions of Azerbaijan showed that with an increase in the depth of clay soils, their coefficient of influence of structural strength on swelling, i.e., "sensitivity" significantly increased.

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