Investigation of Deformation Properties of Composite Soils on the Igdantine (with Inclusions) Models

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Abstract. The article presents the results of experimental studies of the deformation properties of composite soils on igdantine models with inclusions confirming the possibility of studying the soil deformability using the simulation. The influence of the fragment shape and location in composite soil samples on their deformation properties is considered.

1. Introduction

Natural and artificial bases of buildings and structures are in many cases made of the heterogeneous soil this is in accordance with the State Standard GOST 25100-2011 “Soils. Classification” a mixture of dispersed soils in two varieties: coarse-clastic and silty-clay soils. Silt-clay soil, in terms of the inclusions presented, has two varieties – the clay soils with pebbles or detritus and the clay-pebble (detrital) or gravel (grussy). Thus, the clastic-clay soils combine three varieties of dispersed soils of both natural composition and filled one.

At the meeting of the DalNIIS Scientific &Technical Council (Russian Academy of Architecture and Construction Science), it was suggested to replace the old name of coarse-clastic soils with silty-clay aggregate and silty-clay soils with coarse-grained inclusions with a new short name - composite soils.

The qualitative behavior of heterogeneous soil grounds under load, as confirmed by studies conducted under the guidance of Professor S.V. Ukhov [1] at the MISI, corresponds to the mechanics of composite materials. In this regard, the new name of coarse-clastic soils with silty-clay aggregate and silty-clay soils with coarse-clastic inclusions being a base of buildings or used in fillings and other earthworks as well as used in testing these soils in the laboratory and semi-natural conditions, - composite soils - does not contradict the properties of these soils. But at the same time the composite dispersed soils are classified as per GOST 25100-2011.

Comprehensive studies of the relationship between physical properties and the strength and deformation characteristics of composite soils were conducted by DalNIIS under the guidance of Professor V.I. Fedorov in 1968-1989 [2-5].

The aim was to study the influence of the physical and mechanical properties of composite soil components on the soil strength and deformation characteristics, in general, i.e. to determine the dependence of the quantity, type and condition of the clay component and the amount and mechanical
strength of fragments. Much attention was paid to study a physical nature of the phenomena determining the strength and deformation properties of composite soils [6].

2. Conducted research

Studies of composite soils were carried out in a large ground tray (semi-natural tests) as well as on models of clastic-clay mixtures and igdantine with various inclusions.

The investigations were resulted to determine the general patterns of composite soils physical properties influence on their strength and deformation characteristics and Tables of standard values $C$, $\varphi$ and $E$ were developed for composite soils containing very strong fragments [7].

Studies conducted by DalNIIS in 2013–2014 [8] using the results of 41 plate load tests of composite soils were resulted to reconfirm the quantitative relationships between the physical properties of the composite soil components and their strength and deformation characteristics; to estimate the convergence of the table values for composite soils characteristics and the findings of field trials; to update the tables of standard values of $C$, $\varphi$ and $E$ for the composite soils containing the fragments of different strength and roundedness. But the effect of roundedness on the deformation properties of composite soils has not been established due to lack of such data in the field plate load test materials.

Besides DalNIIS, the physical and mechanical properties of clastic-clay soils were studied at Institute of Water Supply, Drainage, Hydraulic Structures and Engineering Hydrogeology (VODGEO), Institute Hydropyject, Tbilisi Scientific Research Institute of Facilities and Hydropower Engineering, Russian National Scientific Research Institute of Hydraulic Engineering. There are known works prepared by Ya.I. Zhureka (the compression properties of detrital soils), G.V. Kulchitsky (the compressibility of eluvial coarse-clastic soils), T.P. Kudekov and R.T. Akhmetov (the influence of heterogeneity of rock soils on their physical and mechanical properties), N.Ya. Khalitov (influence of pit-run fines properties on deformation of cohesive soils with large-grained inclusions), E.M. Dobrov, V.A. Lyubchenko and others (strength, compression and subsidence properties of coarse-clastic soils for the purposes of their use in road construction and construction of banks). Currently, special attention is paid to study the coarse-clastic soils to be used in hydrotechnical construction, aimed to improve the geotechnical control over degree of compaction for these soils [9-11].

The stress-deformed state of a base out of coarse-clastic soils having the various particle size distribution, was estimated in article [12] using the example of tests in a specially created flat soil tray in which the movement of soil particles can be observed. Article [13] represents a method to determine the physical and mechanical properties of the aggregate for coarse-clastic soils; the soil samples with a given density were prepared at the aggregate natural humidity. Article [14] specifies the results of studies to establish the relationship between the physical and mechanical characteristics of clay soils in the south of Tomsk territory (Neogene-Quaternary sediments); the regional table of standard values of soil characteristics is made.

Soil behavior modeling is studied in some works. Paper [15] describes the results of computer simulation of soil test processes using the LS-DYNA program.

Papers [16-17] consider the mathematical and graphical modeling of sandy soil mixtures with specified physical and mechanical properties.

In DalNIIS, the composite soils was experimentally modeled using the samples in which the clay aggregate was replaced by igdantine [18 - 19].

This article presents and analyzes the experimental data which being obtained during the tests of the model igdantine samples with inclusions. The work is aimed to have a qualitative picture of influence of the fragment form (rounded or angular) on the composite soil compressibility.

Clay aggregate was replaced by igdantine due to the following reasons: the deformations of clay soil and igdantine are linearly dependent on stresses and the lateral expansion coefficients of clay soil and igdantine $\mu$ have the close values: clay soil $\mu = 0.42$, igdantine $\mu = 0.5$. 
Igdantine sample preparation and testing takes considerably less time compared to samples from composite soil. At one time not exceeding 5 days, at least 9 samples can be made and tested. One sample is tested during 10 to 20 minutes. In addition, the igdantine samples are transparent which makes it possible to observe the location of inclusions in the sample and their behavior during deformation. The theoretical basis for physical processes and phenomena modeling is a theory of similarity and dimension [20].

Igdantine is a water-glycerin jelly of gelatin. The technology of its preparation was developed by V.F. Trumbachev and N.A. Suvorov [4]. Igdantine was prepared with the same composition according to the same technology: it was poured into a metal mold consisting of 9 cells with dimensions of 40x40x40 mm. Inclusions were simultaneously or preliminarily added into these cells. After pouring, the samples were kept in a mold for 24 hours, then this mold was disassembled and the samples were lubricated with Vaseline oil. After weighing and face measuring the samples were placed in a desiccator and stored there until testing.

Samples made during one day were one series. 5 series of test samples were prepared. In each series there were five samples: one sample without inclusions and four samples having the inclusions of different types (gruss, detritus, crushed claydite and rounded claydite). Volume content of the inclusions ranged within 5.8% to 66.0%.

Gruss, detritus, crushed claydite and rounded claydite were used as inclusions for the igdantine samples. Maximum size of the fractions should not exceed 1/5 the size of the cell (40 mm) which was 7 mm. Fractions were 2-3 mm, 3-5 mm, 5-7 mm.

Samples were tested 48 hours after their preparation during one day under 18° - 19°C. The tests were carried out using the sequential loading scheme. The load increments were applied at 0.5 - 1 min intervals. The load increment was 0.625 kPa, the limit pressure was 12.9 - 14 kPa. Deformations were measured with a dial gauge having 0.01 mm accuracy. Under uniaxial compression conditions the deformation moduli were determined using the Hooke formula:

\[ E = \frac{\sigma}{\varepsilon}, \]

where \( E \) is the modulus of a sample deformation under conditions of uniaxial compression, kPa, \( \sigma \) - stress, kPa, \( \varepsilon \) - relative deformation corresponding to stress.

Despite the igdantine samples having been prepared using the same technology and the same composition, its physical properties turned out to be different: igdantine density being varied within 1,130 to 1,165 g/cm³. The value range was 0.035 g/cm³.

To confirm these data reliability, the variation coefficients \( V \) were determined for igdantine density and deformation moduli \( E \).

3. Results
The obtained results are presented in Table 1. The variation coefficients \( V \) were 1.0% and 2.8%, respectively. As to the rules of statistics, if the variation coefficient is below 10% then the degree of data dispersion is considered to be insignificant. Therefore, the analysis of the actual test data for igdantine samples will be valid.

| Characteristics      | Sample series | Variation coefficient, \( V, \% \) |
|----------------------|---------------|-----------------------------------|
|                      | 1  | 2  | 3  | 4  | 5  | 6  |
| Density, g/cm³       | 1,145 | 1,130 | 1,140 | 1,165 | 1,150 | 1,01 |
| Mod. of deformation, kPa | 72  | 99  | 80  | 84  | 105 | 2.80 |
4. Conclusion
We should note that the composition of igdantine samples with natural stone inclusions are heterogeneous as follows: the stone density (gruss - 2.71 g/cm$^3$, detritus - 2.52 g/cm$^3$) is more than twice the igdantine density. Therefore, the picture of their compressibility may be unreliable.

Table 2. Actual moduli of deformation $E_\phi$, kPa of igdantine samples with inclusions under uniaxial compression.

| Type of inclusions | Volume content of inclusions $P_{2v}$, %, and actual modulus of deformation $E_\phi$, kPa |
|--------------------|------------------------------------------------------------------------------------------|
| Gruss              | $P_{2v}$ 0 5.8 11.9 17.7 23.8 30.0 35.2 41.2 47.8 52.9 59.1 |
|                    | $E_\phi$ 88.0 100 110 124 167 193 465 439 1758 2413 2637 |
| Detritus           | $P_{2v}$ 0 6.5 13.2 20.0 26.7 34.0 40.0 46.5 53.9 60.0 66.0 |
|                    | $E_\phi$ 88.0 99.0 105 116 166 203 439 395 1582 3955 1280 |
| Crushed claydite   | $P_{2v}$ 0 5.8 11.6 17.6 23.1 29.7 35.2 40.5 45.0 51.8 57.6 |
|                    | $E_\phi$ 88.0 125 119 144 182 208 545 465 990 1977 2157 |
| Rounded claydite   | $P_{2v}$ 0 6.5 12.6 19.3 26.0 32.1 37.8 44.8 51.7 57.9 63.7 |
|                    | $E_\phi$ 88.0 132 116 157 220 264 377 688 1551 1432 3439 |

Igdantine samples with claydite inclusions: the inclusion density (crushed claydite - 1.49 g/cm$^3$, rounded claydite - 1.03 g/cm$^3$) is close to the igdantine density; the samples have uniform composition. These tests results are analyzed in Table 3 for the given values $P_{2v}$.

Table 3. Moduli of deformation for igdantine samples with claydite inclusions for the given values of $P_{2v}$.

| Type of inclusions | Content of inclusions, $P_{2v}$, % |
|--------------------|-------------------------------------|
|                    | 20 25 30 35 40 45 50 55 60          |
| Crushed claydite   | 124 173 271 430 684 1010 1404 1939 2667 |
| Rounded claydite   | 191 176 191 264 418 686 1091 1668 2433 |

Table 3 shows the deformation moduli of igdantine samples with crushed claydite inclusions significantly to exceed the deformation moduli of igdantine samples with rounded claydite. And if we return to the igdantine samples with natural stone inclusions, we see, despite the marked heterogeneity, the igdantine samples with gruss showed the less compressibility than samples with detritus.

Analysis of the test results showed that the roundedness of inclusions during compression reduces a friction both between fragments and the aggregate, and between the fragments themselves, when a frame is formed, due to which the compressibility of samples with rounded fragments increases.
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