The Technique for Zoning by the Soil Strata Mechanical Stability Degree

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Abstract. The safety of buildings and structures largely depends on the bearing capacity of soil foundations. Structurally unstable dispersed soils with unstable water-colloidal bonds are widespread in Russia, therefore, the issue of evaluating the mechanical stability of dispersed soils is relevant. The authors have developed a technique for zoning by the soil strata mechanical stability degree, the approbation of which is exemplified by a large construction site being designed. The deformation modulus has been used as the main criterion. The technique involves a series of sequential logical operations outlined herein. On the experimental site, areas with a low, medium, and high stability degree of the soil stratum and its engineering-geologic elements (EGE) have been identified. For sites with a low stability degree, recommendations for their development are given.

1. Introduction

The most important condition for the sustainable development of any zone is ensuring the safety of buildings and structures, which largely depends on the bearing capacity of soil strata. Their ability to withstand external mechanical loads and reliability as the foundations of buildings and structures is determined by the nature of structural bonds. In dispersed soils, extremely unstable mechanical structural, molecular, electrostatic, magnetic, ion-electrostatic, and capillary bonds prevail [1]. They are easily destroyed by water. Therefore, an increase in the groundwater level during the construction and operation of structures located on dispersed rock masses is extremely dangerous and may lead to a significant decrease in soil strength and subsequent emergency deformations of the structures up to their destruction.

This paper describes the technique for zoning urban areas by the soil strata mechanical stability degree exemplified by a large (5 hectare) site designed by the Eco-Complex for the Management of Production and Domestic Wastes with a 4 & 5 hazard class waste disposal facility located near the eastern border of the Kirovskaya village of Kagalnitsky district of the Rostov region [2].

As a criterion for the soil strata resistance to mechanical stresses, the general deformation module has been chosen, which is a well-known soil deformation indicator used in the building and structure design calculations. It is a coefficient of proportionality between the stress applied to the soil and the general deformations (elastic and residual) caused by this stress [1]. Based on the values of this indicator, we have calculated the stability coefficient proposed by S.I. Pakhomov and A.M.
Monyushko, which is used to quantify the resistance of the geological terrain components to one or another impact [3]. Since the soil watering is accompanied by a decrease in the deformation modulus and a consequential deterioration of the system condition, the stability coefficient is defined as the ratio of the soil deformation moduli in the water-saturated and natural states:

$$K_c = \frac{E_{ws}}{E_n},$$

where $E_{ws}$ is the soil deformation module in a water-saturated state, $E_n$ is the soil deformation module in a natural state, i.e. before exposure.

2. Characteristic of the object being studied

In geomorphological terms, the site being studied is located within the Azov-Kuban Lowland in the interfluve area between the valleys of the Don and Kupalnik rivers. The site relief is flat with a slight slope in a south-westerly direction. Absolute elevations vary from 76.20 to 82.78 m. The rocks composing the territory of the site being designed are confined to the Cenozoic sedimentary complex, which is represented by diluvial loams of the Quaternary Period ($Q_{3-4}$) [2]. According to the GOST 25100-2011 classification, the site soils are related to the class of dispersed, the subclass of cohesive, the type of sedimentary, the subtype of aeolian-diluvial, the variety of mineral, and the sub-variety of clayey ones [4]. As a result of the analysis of the spatial variability of particular physical and mechanical soil indicators determined by laboratory techniques, two engineering-geological elements (EGE) have been identified:

- EGE-1 - silty clay loam, hard, high-plastic when watered, non-saline, without admixture of organic substances, non-swelling, average-subsiding,
- EGE-2 - silty clay loam, hard, non-saline, without admixture of organic substances, non-swelling, non-subsiding. The penetrated thickness of the Quaternary diluvial deposits is 14.1 to 29.6 m. From the surface, they are covered with vegetable ground and topsoil with a thickness of 0.4 to 0.9 m.

According to the hydrogeological zoning scheme of the Rostov region, the area of the survey belongs to the Azov-Kuban artesian basin [2]. When drilling wells during the low-flow period in October 2019, groundwaters were penetrated at depths from 10.70 to 23.80 m. The aquifer is formed by atmospheric precipitation, water-bearing rocks are loams of the upper Quaternary period. During the facility construction, the natural surface water runoff will be disturbed, and significant areas of the site will be paved, which will form a screen from atmospheric precipitation and meltwater. During operation, leaks from water utilities are possible. The experience of construction at such sites shows that the rise of groundwater up to the level of the buried parts of buildings and structures is inevitable. The landfill territory is characterized by the highest geotechnical category III [5].

3. Research techniques

The geotechnical data of the site have been obtained based on the geotechnical surveys performed by Engineering Surveys LLC in 2019 [2]. The site has been studied using field techniques, field trials, and laboratory soil tests performed in compliance with the state standard requirements and included determining physical, deformation, and strength properties, as well as the particle size distribution of clayey soils [6-10]. A total of 600 monoliths from 40 technical wells have been investigated.

4. Discussion of the results

The technique for zoning by the soil strata mechanical stability degree involves a series of sequential logical operations.

1. At the first stage, average values of the soil deformation modulus in the natural and water-saturated states were calculated for monoliths taken at different depths from the same well within the EGE. Then, the mechanical stability coefficient (MSC) was determined for each EGE. The results obtained for several wells, including the minimum, maximum, and average deformation modulus and mechanical stability coefficient values, are shown in Table 1.
Table 1. Results of Determining the Mechanical Stability Coefficients (MSCs) of the Differentiated Engineering-Geologic Elements (EGEs).

| Well No. | Deformation modulus, MPa at natural humidity, $E_n$ | MSC | Deformation modulus, MPa at water saturation, $E_{ws}$ | MSC |
|----------|--------------------------------------------------|-----|--------------------------------------------------|-----|
| 11       | 18.2                                             | 0.25| 14.3                                             | 11.8| 0.83 |
| 14       | 22.2                                             | 0.20| 15.3                                             | 12.3| 0.80 |
| 20       | 16.4                                             | 0.26| 16.8                                             | 13.9| 0.83 |
| 21       | 13.3                                             | 0.25| 15.3                                             | 12.3| 0.80 |
| 23       | 16.6                                             | 0.27| 21.8                                             | 15.3| 0.70 |
| 26       | 17.8                                             | 0.22| 16.8                                             | 13.1| 0.78 |
| Ranges   | 11-22.2                                          | 3-5 | 0.20-0.28                                        | 13-21.8| 10.6-16.8| 0.73-1.0 |
|         | 17.79                                            | 4.12| 0.23                                             | 16   | 13.4| 0.84 |

*Notes: in the raw ‘Ranges’, in the fraction numerator and denominator, minimum - maximum and average indicator values are specified, respectively.

2. At the second stage, the mechanical stability coefficients of the soil strata forming the geological structure of the site were determined. They were calculated as the arithmetic mean of all the EGEs identified within the site. The results were recorded in a table similar to Table 1. The nature and number of soil strata forming the massif were determined according to the V. Trofimov classification [11]. Based on the analysis of geological and lithological columns drawn by the data of drilling 102 wells, according to the classification, a single type was selected, i.e. a double-rock clayey soil stratum with a loess layer in the upper part. The minimum, average, and maximum MSC values of the soil stratum are 0.48, 0.54, and 0.61, respectively.

3. The next stage provides for a separate ranking of all EGEs and soil strata by the degree of their mechanical stability. The selected gradation ranges and their belonging to the categories offered are given in Table 2.

Table 2. Evaluating the Mechanical Stability Degree for Individual Soils (EGEs) and Soil Strata.

| Item No. | MSC range | Category          |
|----------|-----------|-------------------|
|          | EGE-1     |                   |
| 1.       | 0.20 – 0.22| Low stability     |
| 2.       | 0.23– 0.25| Average stability |
| 3.       | 0.26-0.28 | High stability    |
|          | EGE-2     |                   |
| 4.       | 0.70 – 0.80| Low stability     |
| 5.       | 0.81 – 0.88| Average stability |
| 6.       | 0.89 – 1.0 | High stability    |
|          | Soil Strata |                 |
| 7.       | 0.48 – 0.52| Low stability     |
| 8.       | 0.53 – 0.57| Average stability |
| 9.       | 0.58 – 0.61| High stability    |

At the final stage, zoning of the eco-complex being designed was performed according to the mechanical stability degree of individual EGEs forming the soil stratum and the latter itself as a separate structural unit (Figs. 1, 2, 3). Territorial elements of the high, medium, and low stability
degrees were identified. They are shown in the figures in colors as follows: blue (high), green (medium), and red (low).

![Figure 1. Zoning by the EGE-1 Soils Mechanical Stability Degree.](image1)

![Figure 2. Zoning by the EGE-2 Soils Mechanical Stability Degree.](image2)

For EGE-1, the largest fragment characterized by the high stability degree is located in the southwestern part of the landfill being designed and practically coincides with the distribution area of type I subsidence soils [12]. Two less significant areas are observed close to the border dividing the territory into type I and II subsidence soils, i.e. in the southern and eastern parts (Fig. 1). A low stability degree is confined to the zone of type II subsidence soils.

It should be noted that the southeastern part of the landfill to the border separating the soil condition types has been evaluated mainly as having a high stability degree for EGE-1 soils and the entire soil stratum. However, for the EGE-2 soils, a significant part of this area is ranked as low stable, and fragments with the high stability degree are located in the type II subsidence soil distribution zone. The exception is a small area adjacent to the western border of the tablet. Along with the aforementioned southwestern low stability zone, for EGE-2, this category areas extend in a narrow strip along the eastern and northeastern landfill borders and are observed in the southeast.

In the soil stratum, considering the peculiarities of mechanical stability of EGE-1 and EGE-2, against the background of the prevailing average stability degree of the landfill site, narrow low stability bands laying along the northwestern and southwestern borders are found.

They are confined to type II subsidence soils. The southwestern area occupied by type I subsidence soils is characterized by the high and medium mechanical stability degree. An exception is an insignificant area partially falling into the zone described.
Figure 3. Zoning by the Soil Stratum Mechanical Stability Degree.

5. Conclusion
1. The lowest mechanical stability coefficients have been obtained for the EGE-1 soils, which exhibit subsidence properties of both types I and II. Obviously, the rather low mechanical stability degree is associated with a specific property of these soils, i.e. subsidence. For EGE-1, the minimum MSC values peculiar to the areas with the low stability degree are confined to the zone of type II subsidence soils. It is known that in this type of massif, subsidence deformations develop more intensively, and soil foundations have a low bearing capacity; they are the least reliable ones, require increased attention during the construction and operation and often the use of engineering amelioration [13]. It should be noted that for EGE-1, the low, average, and high stability degree is observed with a decrease in the deformation modulus after water saturation, on average, by 78.8, 76, and 73.9 %, respectively. Thus, the greater the change in the deformation modulus, the lower the EGE-1 soil stability degree.

2. The mechanical stability coefficients of the EGE-2 soils are almost 3 times higher than those for EGE-1. The decrease in the deformation modulus for the low-stability EGE-2 soils after water saturation is also 3 times less than for the same category of the EGE-1 soils and is 24 %. For water-saturated EGE-2 soils of high and medium category, the deformation modulus has decreased by 8 %, which is 9 times less compared to the EGE-1 soils of the same categories. Obviously, such a difference is associated with the lack of subsidence properties in the EGE-2 soils. Analysis of the nature of the EGE-2 low soil stability area distribution requires additional research.

3. In general, the EGE-1 and EGE-2 soils and the entire soil stratum are characterized by an average degree of stability.

4. The mechanical stability degree of soil strata should be considered when choosing the final solution for zone planning. E.g., it is not recommended to locate buildings and structures with a significant mechanical load on soils, as well as those involving wet process cycles or dynamic and vibrational impacts in areas with a low soil strata stability degree.

5. The following should be performed in areas with the low soil strata stability degree:
- local monitoring of geological terrain components, i.e. updating data on changes in the conditions and properties of soils in the area of interaction of buildings and structures with the geological terrain,
- geotechnical control, i.e. performing geodetic measurements of settlements and deformations of the building and structure foundations, the terrain surface, and the rock strata and developing
recommendations for improving the reliability and safety of the building and structure operating conditions based on the results [5].

6. It is not recommended to arrange the foundations in soils (EGEs) with a low mechanical stability degree.

6. References

[1] Trofimov V T, Korolev V A, Voznesensky E A, Golodkovskaya G A, Vasilchuk Yu K, Ziangirov R S 2005 Ed. V T Trofimova 6th ed. Rev. And add. Soil science (M.: Publishing house of Moscow State University) 1024 p

[2] An eco-complex for handling production and consumption waste, with a waste disposal facility of 4.5 hazard class, located near the eastern border of the Kirovskaya village of the Kagalnitsky district of the Rostov region Technical report on the results of engineering and geological surveys for the preparation of project documentation 380-IGI.1 Vol 2 Engineering Survey LLC 2019 288 p

[3] Korolev V A 2007 Monitoring of geological, lithotechnical and ecological-geological systems Ed. V T Trofimova publishing house "Book House University" (M)

[4] Soils Classification GOST 25100-2011 Introduction 2013-07-01 (M.: Standartinform) 60 p

[5] 5.SP 47.13330.2016 Engineering surveys for construction Basic provisions Updated edition of SNiP 2.02.01-83* Introduction 2016-30-12 (M.: Standartinform) 170 p

[6] Soils Methods for laboratory determination of physical characteristics GOST 5180-84 Introduction 1985-01-07 (M.: Standartinform) 21 p

[7] Soils GOST 30416-2012 Laboratory tests General Provisions Enter 2013-07-01 (M.: Standartinform) 16 p

[8] Soils GOST 12248-12 Methods for laboratory determination of strength and deformability characteristics ” Introduction 2012-01-01 (M.: Standartinform) 83 p

[9] Soils GOST 23161-12 Methods for laboratory determination of subsidence characteristics Introduction 2013-07-01 (M.: Standartinform) 16 p

[10] Soils GOST 12536-14 Methods for laboratory determination of particle size (grain size) composition Introduction 2015-07-01 (M.: Standartinform) 18 p

[11] Engineering geology of Russia Volume 1 Soils of Russia: [monograph] Ed. V T Trofimova, E A Voznesensky, V A Queen (M.: KDU) 672 p

[12] SP 21.13330.2012 Buildings and structures in undermined areas and subsiding soils Updated edition of SNiP 2.01.09-91 Introduced 2013-01-01 (M.: Ministry of Regional Development of Russia) 95 p

[13] Ananiev V P, Gilman Ya D, Korobkin V I and other 1976 Loess rocks as foundations of buildings and structures (Rostov-n / D.: Publishing house of Rostov University) 216 p