https://doi.org/10.31713/m1314

UTILIZATION OF OVERBURDEN QUATERNARY ROCKS TO CREATE SOIL CUSHIONS FOR STRUCTURES

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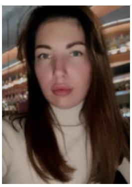

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Abstract

The article presents data on scientific and technical support of the construction of an embankment with an area of 1.9 million m^2 and a thickness of 4-6 m for the facilities of an electrometallurgical plant in the city of Horishni Plavni, Poltava region of Ukraine. The paper presents the results of comprehensive laboratory and

field studies of physical and mechanical parameters of compacted overburden of low-cohesion rocks, mainly sands, and their mixtures, and determines the influence of technological factors on the variation of these values. These rocks were formed as a result of the construction of quarries at the Yeristovo and Lavrykivka iron quartzite deposits. Practical possibilities of utilization of overburdened Quaternary low-cohesive rocks and their mixtures as a material for soil cushions of structures have been proved. Optimal methods of compaction of low-cohesive rocks using the vibration mode of rollers have been developed. The influence of technological parameters of compaction on the scatter of random variables of physical and mechanical characteristics of the soil cushion material was also determined. A certain inconsistency of the normative approach to quality control of compaction of overburden of low-cohesive rocks (standard laboratory test of Proctor) during the construction of pillows by modern mechanisms was established. The correct laws of distribution for random values of physical and mechanical properties of compacted low-cohesion overburden of quarries as a material of artificial foundations of structures have been substantiated by the tested methods of mathematical statistics.
Keywords: iron quartzite deposit, quarry, overburdened Quaternary low-cohesion rock, compaction, soil cushion, dispersion analysis.

Introduction

Geotechnical engineers are forced to use flooded areas and sites composed of weak soils for modern facilities for various purposes [1]. Under these difficult conditions, artificial massifs with better geotechnical properties are a reliable and economical solution [2-4]. These design and technological solutions are enshrined in building codes [5].

In particular, the world geotechnical practice has already accumulated a very significant positive experience in the construction of geomasses by compacting soils and their mixtures. For example: artificial islands on the shelf territories, including international airports (Kansai, Chubu, Makao airports, Palm Island, World, Perl-Qatar, etc.) [6-8]; dams (Orovill, Serr-Ponson, etc.) and dams [9]; port hydraulic structures; embankments of transport facilities [10, 11]; soil (sand) pillows, in particular for oil storage facilities [12, 13], and other critical structures [14, 15]; embankments for planning large areas [16-18], etc.

On the other hand, there is an urgent environmental and economic problem of utilization of mining and processing industry waste, including overburden generated by quarrying [18-20].

That's, it makes sense to assess the possibility of using overburden and their mixtures as geomass materials to reduce the cost of soil cushions.

1. Purpose and objectives of the study

The aim of the work is to prove the practical possibility of utilizing overburdened Quaternary low-cohesion rocks and their mixtures as a material for ground cushions of structures. For this purpose, in particular, the following tasks were set:

- to substantiate the optimal method of compaction of overburden of low-cohesive rocks and their mixtures using the vibratory mode of rollers. To evaluate the influence of technological parameters of compaction on the spread of random variables of physical and mechanical characteristics of these rocks;
- to conduct comprehensive laboratory and field studies of the physical and mechanical properties of compacted overburden of low-cohesion rocks and experimentally obtain statistical data on the spread of these characteristics;
- to verify the compliance of the regulatory approach to quality control of overburden compaction of low-cohesion rocks during the construction of pillows with modern mechanisms. To study the influence of technological parameters on soil characteristics.

2. Methods of research of overburden compaction

The experiment was conducted at a site for an electrometallurgical plant near the town of Horishni Plavni in Poltava Region. Alluvial sandy loam, loam, and sand lie on its surface, and the thickness of weak soils in some places reaches 2.5 meters. The area is flooded.

Therefore, the project for the preparation of the 1.9 million m^2 area included the removal of the soil and vegetation layer and the construction of a 4-5 m thick sand cushion by layer-by-layer compaction with self-propelled vibratory cam rollers or smooth and trailed pneumatic rollers. To strengthen the foundation for the embankment, the waterlogged and flooded massif was cut through with drainage trenches with a cross section of 1×1.5 m with a step of 3 m, which were filled with granite rubble.

The material for the artificial massif was Quaternary sands, which are overburden from the Yeristovo and Lavrykovo iron quartzite quarries. The rocks were delivered to the site by dump trucks, leveled by bulldozers or graders, brought to optimum moisture content, and rolled.

The area for the embankment was divided into 58 borrow pits with an area of 16,000-20,000 m^2. Due to the weak subsoil, the first layer of the cushion was compacted with pneumatic rollers. Its thickness ranged from 0.4 to 0.8 meters. Subsequent layers with a thickness of 0.3-0.6 m were compacted mainly with self-propelled rollers in a vibratory mode of operation, but in some grips - in a static mode.

Five grippers were made of a mixture of low-cohesion overburden and plastic sandy loam. The mixing of different types of rocks was performed as follows. Overburden (70-85% of the total mass) was delivered to the site. Next, sandy loam was added from the dumps formed during the drainage trenches. This mixture was then evenly leveled and mixed over the area of the bulldozer or grader.

The overburden compaction technology was tested in the field. It was found that low-cohesive overburden, when compacted in the vibration mode, reaches the design density of the soil skeleton faster if the work is performed in the following sequence. After the material of each layer was delivered and leveled, the first two passes with a roller were performed in a vibratory mode with oscillations of low frequency and amplitude. As a result, the rock particles take on a more compact position, and the massif becomes more homogeneous in density.

Compaction should be performed at the lowest possible speed of the roller (2-3 km/h). The next 2-3 passes in one trace were performed in a vibrating mode with a higher frequency and amplitude. At this stage, the soil is already dense enough for the equipment to move on it. Then, the rock was allowed to cool to the optimum moisture content and a technological break was scheduled for 2-3 hours so that the moisture was evenly distributed throughout the entire layer. After that, compaction was performed in both vibration and static mode.

To assess the physical and mechanical characteristics of the rocks and the optimal conditions for their compaction, comprehensive laboratory and field studies were carried out. Thus, the first stage included: sampling in quarries; determination in the laboratory of the optimal parameters of their compaction according to the standard Proctor test in a stationary dynamic compaction device (optimal moisture content at different shock impulses, maximum density of the rock skeleton and values of mechanical characteristics when its design degree of compaction is reached).

The second stage included: controlling the type of rock delivered to the site; fixing the type of roller; the roller's operating mode; the number of passes in one trace; and measuring the thickness of the layers on the grippers before and after compaction. In accordance with the optimal parameters obtained, the material was compacted at the test sites.

After that, the geotechnical quality control of compaction was carried out, followed by standard laboratory determination of physical and mechanical parameters of rocks. In particular, during the quality control of the embankment compaction, rock samples were taken in rings with a cross-sectional area of 40 cm^2 and a volume of 140 cm^3 from the surface or pits. The number of samples depended on the compaction area and amounted to 12-30 for each layer of the gripper.

As a result, sufficient samples of random variables (RV) of rock characteristics and technological parameters were obtained. Their size was for: moisture content w and rock skeleton density ρ_d–3000; internal friction angle φ and specific cohesion c–50; strain modulus E–1500; number of measurements of passes along one roller track – 20, number of measurements of layer thickness h–50, etc.

After screening out the so-called "outliers", the statistical series was analyzed, the correct law of distribution of random variables was selected, and its parameters were determined. The coefficient of their variation was taken as the criterion for the variability of geotechnical properties of bedrock.

3. Results of overburden compaction studies

From the analysis of the results of field and laboratory studies with a sample size of up to 3000 random variables, the following statistical data were obtained: variability of the values of the characteristics of compacted overburden and their mixtures from the variability of technological parameters of cushioning. This allowed us to make certain generalizations.

It makes sense to use waste generated as a result of open-pit mining in the mining and processing industry, in particular, overburden of low-cohesion rocks (sands and sandy loams), as a material for geotechnical massifs.

Field and laboratory studies have shown that in most cases, the actual value of the rock compaction coefficient $k_s > 1$. That is, the "standard" laboratory Proctor test does not provide a value for the maximum rock skeletal density and optimal moisture content. More accurate data was obtained using a modified Proctor test. The optimal compaction parameters for specific rocks (mixtures) and mechanisms should be determined by shock pulses that are close to the technical parameters of the seals.

Rock compaction performance significantly depends on the proximity of its moisture content to its optimum value, the thickness of the filled layer, the number of roller passes and its mode, which should be determined for each type of seal by full-scale experimental compaction. When arranging the leveling layer of cushions, it is not advisable to use the vibration mode at high groundwater levels.

The vibration mode allows to compact low-cohesive rocks in layers of 40-60 cm thick to the standard values: the first two passes should be performed with a low frequency and amplitude of oscillations at the lowest possible speed, and for subsequent passes, the frequency and amplitude should be increased.

With a decrease in the coefficients of variation of the thickness of the cushion layer and the moisture content of the rock in it, the variability of its skeletal density decreases. The most significant influence on this indicator is the type of rock and the content of impurities in it.

Therefore, statistical samples should be formed taking into account both the parameters of the mechanisms and the particle size distribution of the rock and the content of impurities in it.

The construction properties of the compacted soil mixture are not worse than those of homogeneous compacted rocks. There was an increase in the scatter of their values, and random values of the rock skeleton density of a poorly mixed mixture are characterized by the bimodality of the experimental graph of their distribution.

The technological mixing of different types of rocks and the vibration mode significantly affect the specific cohesion of compacted rocks and slightly affect their angle of internal friction; the value of the deformation modulus of the compacted material depends on the density of the rock skeleton and the pressure interval in compression tests.

For the analytical description of the experimental distribution of random values of the physical characteristics of compacted overburden, it is advisable to use the normal distribution law. For the density of the soil skeleton of compacted mixtures, it is a polynomial exponential law. At the same time, the coefficient of variation of the soil skeleton density ranged from 2-4.4%, its moisture content from 23-36%, and the specific gravity of the rock from 4-4.6%.

The modulus of deformation of compacted rocks and their mixtures is best described by a logarithmic normal distribution law. The coefficient of variation of the deformation modulus is 33-57%.

The angle of internal friction φ and the specific cohesion c of compacted rocks and their mixtures are random vectors and are best described by a normal and logarithmically normal distribution law, respectively. The coefficient of variation of the internal friction angle was 11%, and the specific adhesion was 25%.

The distribution of random values of the specific resistance to penetration of compacted soil is best approximated by an exponential distribution law. The coefficient of variation of the values of the specific penetration resistance was 57%.

The horizontal strength of compacted overburden within the pillow is greater than the vertical strength. Thus, artificial geomasses are characterized by the above anisotropy of their mechanical characteristics.

4. Recommendations for the design of overburden pillows

By modeling the stress-strain state (SSS) of the cushions by the finite element method (FEM) using an elastic-plastic soil model with the involvement of Monte Carlo simulation, taking into account the experimentally established laws of distribution of RV physical and mechanical parameters of the overburden of the cushion, the statistical characteristics and laws of distribution of RV settlements S of the foundations were determined.

Based on the statistical analysis of the distribution of settlements of these foundation bases and their relative unevenness, the probability of their failure was obtained. In particular, it was found that the distributions of RV of the calculated and ultimate resistances of compacted rocks are correctly approximated by Gauss's normal law.

The coefficient of variation RV of the calculated resistance of compacted soil ranges from 21.8-36.3%, and the RV of the ultimate resistance - from 34.4-37.5%.

The probabilistic approach to the calculation of foundation settlements on a cushion has established the following. There is a probability of linear and nonlinear stages of deformation of the foundation when the pressure under the foundation sole does not exceed the calculated resistance of the compacted soil in the deterministic approach.

This effect is due to the heterogeneity of physical and mechanical parameters of compacted rocks and the random nature of loads and impacts on foundations.

For a multilayer cushion, the value of the coefficient of variation of settlement is less than for a single-layer cushion. The mathematical expectation of settlement is 2.4 times higher.

The decrease in the coefficient of variation of settlement for the multilayer artificial massif can be explained by the fact that this value is the result of adding up a large number of random variations in settlement in individual layers that overlap.

The coefficient of variation of settlement also increases with increasing heterogeneity of the layers. The values of this coefficient depend on both the thickness of the individual layers and the ratios of the strain moduli in them.

This coefficient increases with increasing heterogeneity of the layers. In particular, with greater compressibility of the upper layers than the underlying layers and an increase in the ratio of their strain moduli.

The method of constructing a cushion with different degrees of compaction of its layers reduces the variability of foundation settlement on it.

It is established that the probability of failure of foundations on a cushion according to the first limit state is acceptable, since the safety characteristic $\beta > 3\text{-}4$, and according to the criterion of relative unevenness of their settlements on a single-layer cushion, it reaches 10% at the limit value $(\Delta S/L)_u$=0.002 and 3% at $(\Delta S/L)_u$=0.004, but for a multilayer cushion, these values are only 0.02% and 0.0006%, respectively.

Evaluation of FEM, SSS of artificial foundations using the Ansys 11.0 software package and its subsystem Probabilistic Design with the use of the Monte Carlo method at the number of iterations of 10^4 in the probabilistic formulation shows that the analytically determined probability of the existence of linear and nonlinear stages of soil deformation correctly describes the real processes occurring in overburden cushions when they are loaded.

Conclusions

Thus, as a result of comprehensive laboratory and field studies, the possibilities of utilizing overburdened quaternary low-cohesion rocks formed as a result of quarrying iron quartzite deposits as a material for soil cushions for structures have been proved. The influence of technological factors on the scatter of random variables of physical and mechanical parameters of these compacted rocks and their mixtures is determined. It is statistically substantiated for the physical properties of the pillow rocks. The correctness of applying the normal law of distribution of mixtures - polynomial-exponential, for the deformation modulus of compacted rocks and mixtures – logarithmically normal, for the angle of internal friction – normal, for the specific adhesion - logarithmically normal, and for the specific resistance to penetration - exponential law of distribution.

Comparison of the coefficients of variation of physical and mechanical properties of compacted and natural rocks proves that when using overburden of low-cohesion rocks, waste from the mining and processing industry, they are more homogeneous in the pillow than in the natural state. Among the technological factors, the type of rock and the content of impurities in it have the greatest impact on the variability of the material properties of the new massif. The number of passes in one track and the vibration or static mode of operation of the mechanism have a smaller impact. And the smallest is the thickness of the layer before compaction.

It is proved that the optimal rock compaction parameters should be determined by pulses close to the technical characteristics of the mechanisms or natural seals. Since the standard laboratory Proctor test does not reach the maximum rock skeleton density that corresponds to the capabilities of modern seals, for example, in the vibration mode.

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