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Determination of Water-Saturated Tailings Compaction Characteristics During Geotechnical Massif Formation

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Abstract. The research focuses on the tailing dump, which is located in the Norilsk industrial region's (Northern Siberia) territory. The difficulty of precisely calculating the period of tailings consolidation presented itself to the authors while they conducted research on improving the technological parameters of the tailings alluvium. Without resolving this issue, it is impossible to improve the technology of the tailings alluvium. In order to assure safety and efficiency at all phases of construction and to strengthen the stability of the examined tailings, a sophisticated set of model tests and calculations was conducted. This work provided the foundation for modifying the work techniques. The method for defining the maximum density at the optimum humidity, when the formation of a geotechnical massif at the tailing dam's inwash occurs, has been devised on the basis of laboratory testing. The findings from study may be effectively used as the foundation for building tailing dams.

Keywords. Consolidation, tailing dump, tailings, compaction, optimum moisture content, maximum density

1. Introduction

The extraction and enrichment of ores is defined by the extraction and processing of massive amounts of rock. Modern technology allows just a portion of the removed rock mass to be used, with the remainder accumulating as man-made waste; The existence of the problem of safe and efficient operation of tailings is due to: lack of sufficient knowledge about engineering and geological processes occurring in the foundations and bodies of structures; isolation during operation from the complex of dynamically changing engineering and geological characteristics of the object and the natural environment; insufficiently developed system of stability forecasts in the array formation mode; imperfection of methods for determining the main characteristics that ensure the stability of structures and interpreting their results.

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In the nearby regions, there are now many accidents occurring and the ecology is in a poor situation. Infractions of the natural topography, soil temperature conditions, contamination of surface waterways, loss of flora, etc. were only a few examples of how the tailing dump's negative effects on the environment were manifested due to its operation and the enclosing dam's lack of stability [1].

It is possible to anticipate and actively manage the stability of the structure in instances of changes in the volume of mineral raw materials and storage site conditions thanks to the design and optimization of the technological parameters of the geotechnical massif evolving during its exploitation.

The foundation of the solution approach in this case should be the management of technical parameters in the construction of a technogenic deposit that ensures the stability of the structure [2, 3].

2. Case History

The current study's research topic is a tailing dump that is situated on the territory of the Norilsk industrial region. Since 1984, the dumping area has been used for various purposes. Determining the maximum density at the optimum humidity at which a geotechnical massif is formed at the inwash of the tailing dam is crucial given the impact of density on the dam stability factor.

As is well known, the consolidation process is conditionally divided into two phases: primary or filtration consolidation and secondary consolidation, due to creep of the soil skeleton, taking into account the nature of the processes that cause compaction of water-saturated soils in different periods of time [4].

The consolidation curves built in the coordinates of displacement (s) - logarithm of time (lg t) or empirically by the instant of full pore pressure dispersion determine when the filtration consolidation stage is finished. The ratio of filtration and rheological processes in the process of soil consolidation varies depending on the density, humidity, peculiarities of the soil structure, and the amount of stress acting on them [5].

3. Test Results and Discussion

At the first stage of testing, 15 series of samples were formed.

The physical and mechanical properties of the tested samples are the following:

- Humidity range was taken from from 4 to 32 % and the corresponding density from 1,01 g/cm^3 to 1,94 g/cm^3;
- Soil particle density was determined to be equal ρ_s=2.63, g/cm3;
- Void ratio varied from 0.74 to 1.76;
- The index of soil fluidity was also calculated, which, at a low degree of saturation, was less than zero and the state of the soil was solid, and starting from a water saturation of 28%, the soil turned into a plastic state [6, 7, 8].

It should be noted that according to the results of determining the tailings moisture content at the yield boundary of 32.4% and the moisture content at the rolling boundary of 27.2% (plasticity index Ip=5.2), it was found that their properties are closest to sandy loam.

The method of determining the critical moisture value of the alluvial layer of the forming technogenic massif consists in modeling the consolidation process in reality and obtaining the optimal humidity at which the consolidation occurred and the process of dusting or weathering of the main layer has not yet begun.

The traditional compaction method, which entails consistently raising the soil's humidity while compacting soil samples to determine how the density of dry soil depends on humidity, was taken into consideration for this purpose [9] on a standard soil compaction device (figure 1).

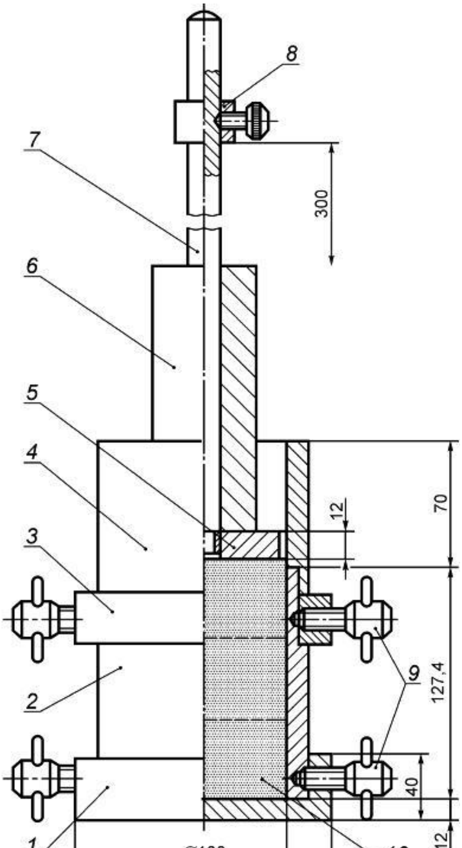

Figure 1. Schematic diagram of the SOYUZDORNII device for standard soil compaction. 1-pallet; 2-split form; 3-clamping ring; 4-nozzle; 5-anvil; 6-load weighing 2.5 kg; 7-guide rod; 8-limiting ring; 9-clamping screws; 10-soil sample.

The number of consecutive tests of the soil with an increase in its humidity was equal to six. This number of tests is sufficient to determine the maximum density value

The method assumes that in the soil sample, when its humidity increases sequentially, particles will be rearranged, and, consequently, the density values after each test will not be linear, and for several parallel tests, the density values at the same humidity will be different.

The test results are presented as a graph (figure 2).

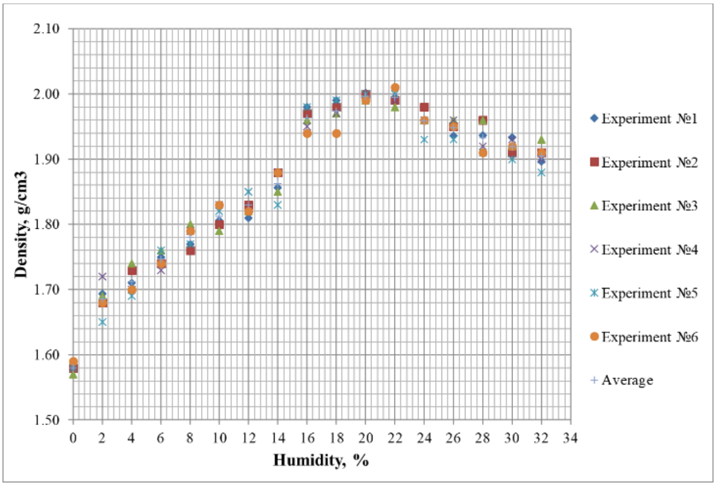

Figure 2. Maximum tail density in parallel tests.

The value of the optimal humidity here corresponds to w=20%, and the maximum density is 2 g/cm^3.

However, in real life, the process of consolidation occurs differently and it should be taken into account that during the reclamation of the next layer, all excess water passes down and flows into the pond, and it is necessary to identify the moment when it will be possible to reclamate the top layer and not miss the beginning of dusting.

The second method is a simulation of the process of filling the pores with water without disturbing the structure of the solid fraction. The maximum density of the solid fraction in the dry state practically does not differ when passing from one parallel test to another. This value is equal to ρ_0 =1.58 g/cm^3.

Since all the water flows into the pond, the behavior of the layer was modeled from the dry state with increase in humidity.

The tests were performed on a device for simulating pore filling with water (figure 3).

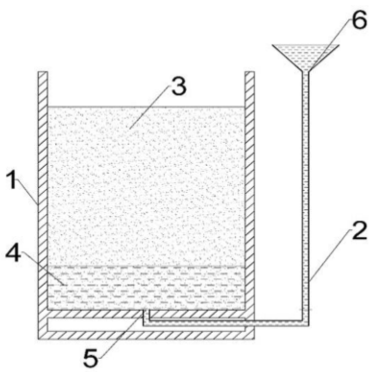

Figure 3. Device for modeling the filling of pores with water: 1 - vessel, 2 - glass tube with fissions, 3 - compacted solid fraction to maximum density in dry condition, 4 - water, 5 - paper filter, 6 – funnel.

When the humidity *w* increases, the pores are filled with water and, accordingly, the density increases (table 1). While filling the pores with water, the position of the upper border of the tails in the device does not change. And when the value *w*=20% is reached, water appears on the surface, and the solid fraction at this moment has a maximum density of p = 1.99 g/cm^3 since all the pores are filled with water.

Table 1. Received density values in modeling (average for 6 tests).

Water, %	Density ρ, g/cm^3	Water, %	Density ρ, g/cm^3
0	1,58	18	1,94
2	1,61	**20**	**1,99**
4	1,65	22	1,94
6	1,68	24	1,89
8	1,72	26	1,85
10	1,76	28	1,81
12	1,80	30	1,77
14	1,84	32	1,73
16	1,89	-	-

When the amount of water increases further, the density decreases due to an increase in volume (figure 4). Using a standard soil compaction device, such a real process cannot be simulated.

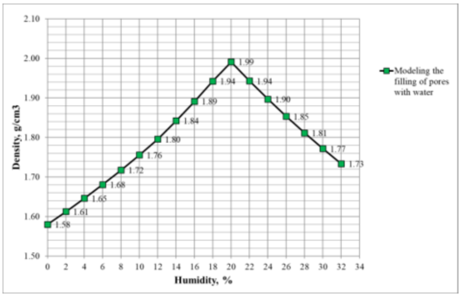

Figure 4. Simulation of the process of filling water pores.

The third method (calculated) assumes that the solid fraction has a maximum density in the dry state of ρ_0 =1.58 g/cm^3. The true density according to the results of laboratory tests is ρs =2.63 g/cm^3.

Find the porosity by the formula:

$$n = 1 - \frac{\rho_0}{\rho_s} \tag{1}$$

Here

$$n = 1 - \frac{1{,}58}{2{,}63} = 0{,}399$$

Air and water will occupy the pores.

Next, we find the maximum density, that is, the state in which all the pores will be filled with water:

$$\rho_{\max} = \rho_0 + n \cdot \rho_в \tag{2}$$

Where $\rho_в$ is the water density equal 1 g/cm^3
From here,

$$\rho_{\max} = 1{,}58 + 0{,}399 \cdot 1 = 1{,}98 г / см^3$$

Then determine the optimal humidity at maximum density:

$$w_{onm} = \frac{n \cdot \rho_в}{\rho_{\max}} \cdot 100\% \tag{3}$$

From here,

$$w_{onm} = \frac{0{,}399 \cdot 1}{1{,}98} \cdot 100\,\% = 20{,}2\%$$

Experimental, theoretical and practical data, performed in three different ways, show that the alluvium can be completed when the solid fraction reaches the optimal humidity of 20% for tailings from the tailings storage facility (figure 5), after which the next layer can be alluvied. This state corresponds to the densest laying of particles of approximately the same size, when they are laid most densely under their own weight.

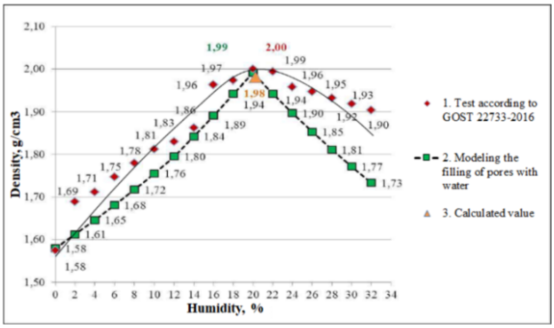

Figure 5. The results of determining the critical humidity of tails in three ways.

4. Conclusion

A series of experiments on the study tailing dump object permitted the following:

- To establish criteria that ensure the tailing dump enclosing dam's stability;
- It is revealed that the process of consolidation of the solid fraction in the alluvium geotechnical massif ends with the sludge of maximum density, and

under the alluvium of the new layer must reach a solid fraction humidity of 20%, which corresponds to the densest packing of particles of approximately the same size, when all the pores are filled with liquid, under the action of its own weight

The complex of model tests and calculations carried out created the basis for changing the methods of work, which ensured safety and efficiency at all stages of construction and made it possible to increase the stability of the studied tailings.

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Competing Interests

The authors declare no conflict of interests.

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