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Definition of Tailings Consolidation Parameters to Optimize the Inwash Technology of the Tailing Dump Levee

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SUMMARY: The object of research of the present work is the tailing dump, located on the territory of Norilsk industrial region (north of Siberia). The new approach based on logistic approach using simplex-method for reception and processing of the geotechnical information is offered. In order to optimize the inwash technology of tailing dam it is necessary to determine the time of tail's consolidation. On the basis of laboratory tests the approach to definition of coefficients of filtrational and secondary consolidation of tails at an alluvium of tailing dam depending on a physical condition, density, water saturation degree, and the mathematical model to calculate the time of their consolidation has been developed. The results obtained from researches can be successfully used as a basis for constructing consolidation models of required layer tails.

KEYWORDS: logistic approach, consolidation, tailing dam, tails, time.

1 INTRODUCTION

In northern regions of Russia - the areas of large mining and metallurgical enterprises dozens of million cubic meters of different deposits have been accumulating for a long time in the tailing dumps

The tailing dams inwashing processes are produced in spring and summer, when the average daily temperature is above -5°C (Lolaev and Butygin, 2005). Based on the operating conditions of alluvial storage in permafrost, it should be noted that the increase in the annual capacity of alluvial layer may not provide its complete consolidation process during short spring-summer period (3-4 months) before freezing in winter, and thus it will reduce the stability of the structure. In order to optimize the inwash technology of tailing dam it is necessary to determine the time of tail's consolidation.

The object of research of the present work is the tailing dump, located on the territory of Norilsk industrial region (north of Siberia).

The tailing dump is the cascade type of dumps with two tailing ponds and with difference in grades of the tops of dams about 20 meters. Planned level of the top of the dam is 90 meters.

The purpose of research is to determine the optimal technological parameters of the tailing dams inwash.

2 CASE HISTORY

The climatic characteristics of Norilsk industrial region are:

- average annual temperature of the air is -9.4^{0}C;
- the maximum temperature of the air is +32^{0}C and the minimum temperature is -56^{0}C;
- the strong winds and snowfalls are observed up to 130 days a year;
- average amount of precipitations is 564.5 mm per year.

The exploitation of the disposal area has begun since 1983. The top of the dam of the pond is about 70 meters. Since 2006 the tailing dump has had the second tailing pond. The second pond is under construction now. The top of the dam of the second pond is about 50 meters. Thus the tailing dump is the cascade type of dumps with difference in grades of the tops of dams about 20 meters. Planned level of the top of the both dams is 90 meters.

The constructive characteristics of the first pond and dam are:

1. the disposal area - 4.02 sq.kms
2. the tailing dam is carried out as a persistent drainage prism from metallurgical slag:
   - prism width - 8 m
   - prism length - 8500 m
3. the capacity of disposal area - 16.7 mln. m^3
4. dam height - 39.3 m;
5. the inclination of a top drain level - 1:50
6. the inclination of a bottom slope - 1:4
7. the maximal depth of pool – 4.7 m
8. the average depth of pool – 2.5 m.

The constructive characteristics of the second pond and dam are:

1. the disposal area - 2.4 sq.kms
2. the tailing dam is carried out as a persistent drainage prism from metallurgical slag:
   - prism width - 8 m
   - prism length - 4313 m
3. the capacity of disposal area - 16.7 mln. m^3
4. the settlement term of operation - 20 years
5. dam height – 19-20 m;
6. the inclination of a top drain level - 1:50-1:100
7. the inclination of a bottom slope - 1:4-1:5
8. the maximal depth of pool – 5.2 m
9. the average depth of pool – 2.9 m.

The technology of controlled inwashing of the levee has been used since 1997. It includes the following operations:

- the construction of the retaining prism of metallurgical slag. The metal distributing slurry pipeline is laid on it;
- the construction of the ring slag fill in the beach zone at the specific distance from the axis of the distributing slurry pipeline. It retains the solid particles in the beach zone and simultaneously illuminates the water coming into the pool.

The scheme of the levee inwash is shown in Fig. 1.

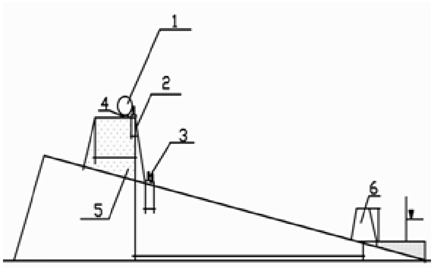

Figure 1. The scheme of the levee inwash
1. distributive slurry pipeline; 2. geotextile anti-filtration screen; 3. load; 4. slag prism; 5. retaining prism of a dam; 6 . slurry collecting slag prism

The developed technology of the dam

inwash takes into consideration the height of a dam inwashed for one cycle and as a whole for a year, the width of the inwash front, the quantity of the inwashed tails, operations schedule etc. The inwash is made by sections of 900-1200 m in width, after formation of a layer of tails with the capacity of ≈0,5 m, hydraulic fill section is left for "rest" (10-15 days). The given way of an inwash provides an advance growth of a dam. The beach sectoring for the determination of the volume of the inwashed tails and the sequence of the sections inwash of tailing dump are presented in Fig. 2. (Lolaev et al., 2010)

The schedule of the inwash works is made for the whole year. This, in its turn, has allowed to design the duration of the dam operation until achievement of its design elevation.

During the inwash process and the subsequent consolidation the values of physical and mechanical properties of the filled-up grounds are being established.

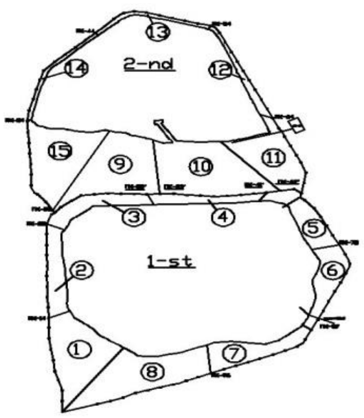

Figure 2. The Beach sectoring

3. METHODOLOGY

3.1. Logistic Approach to the Optimization of the Inwash Technology

The increase in expenses at warehousing of waste of the mining industry demands scientific justification of optimization of schemes of their transportation and warehousing.

The concept of logistics is based on rational management of different types of streams: material, service, financial, information:

raw materials → delivery process → transfer→ → distribution → sale

In relation to the largest mining enterprises and questions of transportation and warehousing of their waste the schematic logistic diagram of streams can be presented as follows:

mining enterprises → concentrating production → hydrotransport system → distributive slurry pipeline → store of waste

The made breakdown on blocks of the transport scheme of industrial complex rather close similarity to the classical logistic scheme. Thus, it is established that application of logistic approach expediently for the solution of problems of determination of technological parameters of the inwash technology (Akopov et al., 2013)

For the purpose of determination of technological parameters of construction of the store of waste of the enterprise, for the received scheme statement of a transport task in the form of systems of the equations (1), (2) is carried out:

$$\begin{cases} x_{11} + x_{12} + \ldots + x_{1\,15} = a_1; \\ x_{21} + x_{22} + \ldots + x_{2\,15} = a_2; \\ x_{31} + x_{32} + \ldots + x_{3\,15} = a_3 . \end{cases} \tag{1}$$

$$\begin{cases} x_{11} + x_{22} + x_{m1} = b_1; \\ x_{12} + x_{22} + x_{m2} = b_2; \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ x_{1\,15} + x_{2\,15} + x_{3\,15} = b_{15} . \end{cases} \tag{2}$$

where a_i – "suppliers" of waste; b_i – "consumers" (warehousing sites) of waste.

Considering the requirements of ecological safety meaning warehousing in the store of all volume of developed waste = the transport task is the closed or usual model type.

$$\sum_{i=1}^{3} a_i = \sum_{j=1}^{15} b_j \tag{3}$$

Criterion function of a task is presented in a look:

$$T = \sum_{i=1}^{n} \frac{S_{1i} \cdot h_1}{q} + \sum_{k=1}^{n} \frac{S_{2k} \cdot h_2}{q} \tag{4}$$

where, i – quantity of sectors of the first field; k – sectors of the second field; S_{1i}- the area of the i- sector of the 1-st pond of the tailing dump; S_{2k}- the area of the k-sector of the 2-nd pond; h_1- the height of inwash on the 1-st pond; h_2 – the height of inwash on the 2-nd pond; q- the day volume of waste arriving on warehousing; 180 - the duration of the inwash period in summer time in the days, defined from climatic conditions of the region.

The flowchart was developed for the offered technique and the calculation program of the inwash technological parameters with use of a standard Microsoft Office Excel package was conducted and instructions for its use were provided.

3.2. Definition of Tailings Consolidation Parameters

In the course of carrying out of researches for optimization of technological parameters of an alluvium tailing dam the authors have faced with the problem of exact definition of time of consolidation of tails - the major factor of optimization of the inwash technology of the tailing dam.

Taking into account the character of the processes causing consolidation of water-saturated soils during the various periods of time, consolidation process conditionally differentiates on two phases; primary or filtrational and secondary, caused by creep of a skeleton of a ground. Time of end of a stage of filtrational consolidation is established on compression curved lines constructed in co-ordinates moving (s) - time logarithm (lg t), or experimentally on the moment of full dispersion of a pore pressure. The ratio of filtration and reologic phenomena in the process of consolidation of soils are various depending on density, moisture content, structure of soils and value of loads operating on them (Recommendation...,1989, Tsytovich and Ter-Martirosian, 1981).

For an establishment of the dependence of density of a skeleton of the soil from its moisture content it is necessary to make a series of separate tests on consolidation of soil with consecutive increase in its moisture content (GOST…,2002). The quantity of separate tests should be not less than six, and sufficient for revealing of a peak value of density of a skeleton of a ground. When the increase of moisture content at the subsequent two, three consolidation tests leads to consecutive reduction of values of density of the condensed soil samples the definition of the maximum density of a skeleton of soil is considered finished tests, (GOST…,2002).

Tests were carried on the automated test complex «ASIS» (Fig. 3) which is intended for carrying out of mechanical tests of natural and industrial building materials at various sorts of a stress condition and loading paths. Special software ASIS is applied to management of test process. The Software exercises in the automated mode administration of test process, recording and transfer of results of test to other software packages for the further processing, http://npp-geotek.ru.

Figure 3. A test complex "ASIS

The received test results were processed by the method of Kazagrande, (Recommendation...,1989, GOST…,2010). The definition of parametres of filtrational consolidation on the method of Kazagrande are found at processing of compression curves. The time of the beginning of a filtrational stage of consolidation, the deformations corresponding of 100 % and 50 % of primary consolidation, and also time corresponding of 50 % of primary consolidation, are determined on a laboratory test curved line.

The factor of filtrational consolidation C_v, cm^2/min ($cm^2/year$), is calculated by the equation:

$$C_v = \frac{T_{50} h^2}{t_{50}} \quad (5)$$

Where T_{50} – the factor (time factor), corresponding to degree of the consolidation 0,5, equal 0,197;

h – the height of the sample (average between initial height and height after compression test), cm. At a double sided filtration the height equal h/2 is accepted;

t_{50} - time corresponding of 50 % to primary compression, minutes

The factor of secondary consolidation Cα is defined on the tangent of the angle between a linear piece of a curved line on a stage of secondary consolidation and a straight line, parallel to the x-axis by the equation:

$$C_\alpha = tg\alpha = \frac{\varepsilon(t_2) - \varepsilon(t_1)}{lg(t_2) - lg(t_1)} \quad (6)$$

where ε (t_2) and ε (t_1) - values of deformation of the sample on the secondary consolidation stage;

t_1 and t_2 - time corresponding to deformations ε (t_1) and ε (t_2), minute (Recommendation...,1989, GOST…,2010).

To describe mathematically dependence of the y (consolidation factor) from the factors on experimental data, it is necessary to construct regression model type y=F (x_1, x_2... x_k)

Despite all variety of empirical formulas we have the analytical dependence, which was widely adopted. It is the equation of regress in the form of the multinomials (polynom) located on ascending degrees of the studied factor and simultaneously linear to all factors. Such formula looks like:

$$y = f(x) = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_k x_k \quad (7)$$

where b_0, b_1, b_2, …, b_k − the factors which are subject to definition, (Baraz, 2005).

The correlation analysis allows to draw a conclusion on interrelation between pairs of the data (x) and (y), and the regression analysis is used for forecasting of one variable (y) on the basis of another (x).

At moisture content in limits from 4 % to 32 % and density in limits from 1 g/cm3 to 1.94 g/cm3 it is possible to predict time for which there will be a consolidation. For calculation of time of consolidation, the equation has been received:

$$t = \frac{F}{C_v} \times \frac{h}{h - s} \quad (8)$$

where t - time of consolidation, min; F – cross-sectional area of the ring, cm^2; C_v – consolidation factor, cm^2/min; h - initial height of a layer, cm; h_k - final height of a layer, cm; s - moving, cm.

4. TEST RESULTS AND DISCUSSION

On available samples of tails 15 series of samples of the set moisture content and density for carrying out of the further trials have been generated. At planning out of quantity of experiments the methods of probability theory and the mathematical statistics were used. The least number of parallel experiments N is defined under the formula:

$$N = \frac{S}{P} \times Z_\alpha^2 \quad (9)$$

Where Z_α^2 quantile of the normal distribution, corresponding to value of reliability α and established under the table value of functions of Laplace, (GOST…,2010); S - the distribution standard; P - the accepted accuracy of definition of an average.

At reliability α =0,9 and accuracy P=0,05 minimum necessary quantity of parallel experiments at which the average quadratic error will be within accuracy of an average arithmetic, is equal to three (Pustylnik, 1968). The given conclusion has been taken as a principle definitions of quantity of tests at the set parametres of experiment.

Physical properties of the tested samples are presented in Table 1.

Table 1. Physical properties of samples

№ exp	Humidity W, %	Density ρ, g/cm^3	Soil particle density ρ_s, g/cm^3	Void ratio e	The degree of saturation S_r	Flow index I_L	Variety in terms of yield
1	4	1,05	2,63	1,60	0,07	< 0	Solid
2	6	1,01	2,63	1,76	0,09	< 0	Solid
3	8	1,09	2,63	1,61	0,13	< 0	Solid
4	10	1,12	2,63	1,58	0,17	< 0	Solid
5	12	1,16	2,63	1,54	0,21	< 0	Solid
6	14	1,18	2,63	1,54	0,24	< 0	Solid
7	16	1,12	2,63	1,72	0,24	< 0	Solid
8	18	1,15	2,63	1,70	0,28	< 0	Solid
9	20	1,34	2,63	1,36	0,39	< 0	Solid
10	22	1,3	2,63	1,47	0,39	< 0	Solid
11	24	1,44	2,63	1,26	0,50	< 0	Solid
12	26	1,51	2,63	1,19	0,57	< 0	Solid
13	28	1,94	2,63	0,74	1,00	0,15	Plastic
14	30	1,87	2,63	0,83	0,95	0,54	Plastic
15	32	1,87	2,63	0,86	0,98	0,92	Plastic

The schedule of dependence of density of a skeleton from moisture content of the tested tails shows that the maximum density of tails is equal to 2 g/cm3 at moisture content of 20 %, at moisture content of 26 % and above the density practically does not change (Fig. 4). The bulk density is in turn equal to 0,89 g/cm3

Also borders of plastic properties of tails have been defined. Moisture content on liquidity border corresponds to value of 32,4 %, and moisture content on rolling border - 27,2 %.

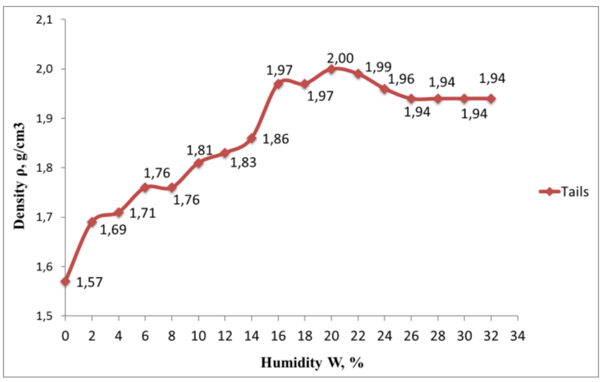

Figure 4. The schedule of dependence of density of a skeleton from humidity of tails.

It is revealed that to each value of moisture content of tails there is a certain range of change of density corresponds. Moisture content indicator on border of liquidity and ranges of change of density of tails became the base for spacing definition (moisture content from 4 % to 32 %) changes of investigated parametres.

The compression curves for the tail samples with specified moisture content and density are shown in Fig.5

From data in Fig.5 we can see that the behaviour of tails at different moisture content and density remains invariable. It testifies that the given factor of consolidation can be applied to definition of consolidation characteristics of tails that considerably will reduce labour input.

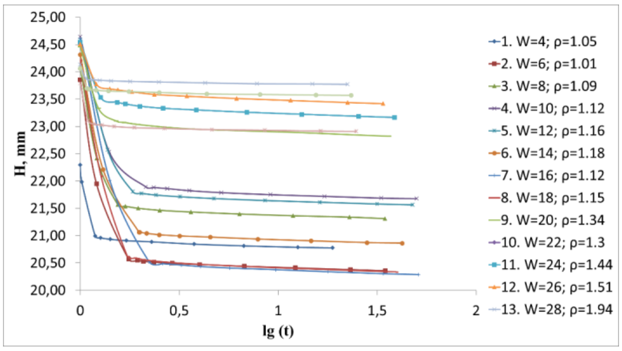

Figure 5. Compression curves for the tail samples with specified moisture content and density

The time, required for consolidation of the layer and also the description of the process of the sample deformation in height h depending on its deformation properties were defined by the equation (8). The results are presented in Table 2.

Table 2. The time of the layer consolidation

№ exp	Filtrational consolidation coefficient C_v, cm^2/min	Time, min	The coefficient of secondary consolidation C_α, cm^2/min	Time, days
1	6,89	10,38	0,0083	6,01
2	3,90	18,69	0,0117	4,34
3	5,80	12,03	0,0112	4,32
4	2,81	24,41	0,0090	5,27
5	5,36	12,86	0,0102	4,67
6	5,21	13,66	0,0091	5,43
7	5,22	14,02	0,0114	4,48
8	5,17	14,14	0,0125	4,07
9	5,92	10,99	0,0132	3,43
10	5,41	12,63	0,0141	3,37
11	5,52	11,61	0,0124	3,59
12	6,54	9,70	0,0124	3,55
13	17,16	3,64	0,0022	19,87
14	12,32	5,26	0,0045	9,90
15	15,23	4,14	0,0035	12,61

5. CONCLUSIONS

Application of the simplex-method in using of the logistic approach to the optimisation of the inwash technology has showed it effectiveness and allows to:

- achieve the increase in the stability coefficient of the dam and of the construction as a whole during its working life,
- raise the level of the industrial and environmental safety,
- provide the achievement to the design elevation of the levels of the ridges of the first and of the second field dams simultaneously.

That will permit to provide the required capacity for warehousing of the tails for the whole working life without building of new stores

The results of laboratory experiments permit to do some conclusions:

- The received results of consolidation of tails (a Fig. 4) show that their maximum density makes 2 g/sm3 and is reached at moisture content of 20 %.
- Compression curves (Fig. 8) show that the behaviour of tails at different moisture content and density remains invariable. It testifies that the given factor of consolidation can be applied to definition of the consolidation characteristics of tails that considerably will reduce labour input.
- As a result of the F-test the value of F_{calc}. is equal = 46,999 for factor of filtrational consolidation C_v and F_{calc}. = 26,654 for factor of secondary consolidation $C_{\alpha.}$ Taking into account that both of these values more than tabular F_{tabl}. (0,05; 2; 12) =3,885, it is possible to confirm that regression models are significant and can be used for a prediction of values of a dependent variable y at all values of independent variables x_1 and x_2 within values of y observed at experiment.
- The formula (8) allows to define the time (Tab.2), required on consolidation of the layer, and also allows to describe process of the sample deformation in height h depending on its deformation properties.

The results obtained from researches can be successfully used as a basis for constructing consolidation models of required layer tails.

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