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Laboratory and In-Situ Testing and Physical Modelling of the Tailing Dump Capacity Increasing in a Mode of Operation

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SUMMARY: The main objective of this paper is to develop special techniques of increasing of the capacity of the tailing dump and its operation period and make laboratory and in-situ investigations of these techniques. A complex of modeling laboratory and in-situ tests was used for predicting the stability of the tailing dam. Modeling laboratory tests were carried out on the specially designed installation which permit to establish the regularities of distribution of tails on a beach in the course of an alluvium, to determinate of their physico-mechanical properties and to establish the regularities of their changes in process of consolidation, dehydration etc. The results of in situ tests showed good correlation with the results of laboratory tests The complex of the carried out researches has allowed theoretically and practically to substantiate a number of directions of effective and safe operation of the tailing dump for the next period

KEYWORDS: tailing dump, dam, modeling, inwash technology.

1 INTRODUCTION

Exploitation period of the tailing dump is calculated for 15-20 years, thus building of the new store begins on much earlier than the previous will be filled. Hence new stores are being erected with an interval of 15 years. That involves the big economic losses as it is necessary to support the efficiency of everyone. The problem of capacity increasing of operating tailing dumps becomes more and more urgent because it decreases the total cost of new store construction (Lolaev et al, 2004).

The object of research of the present work is the tailing dump, located on the territory of Norilsk industrial region (north of Siberia). The exploitation of the disposal area has begun since 1983 with the purpose of warehousing of tails from concentrating mill and organization of system of turnaround water supply.

At the end of the 90-th years of last century, in connection with the changes in technological processes of concentrating mill, reduction of volumes of processing of ores and complexities in transportation of tails, the northern part of a tailing dump practically was not raised, that has resulted in considerable reduction of capacity of the pool. Thus the problem of its capacity increasing was very important (Lolaev and Butygin, 2005)..

Taking into account the fact, that stability of tailing dam must be provided, the main objective of this paper is to develop special techniques of increasing of the capacity of the tailing dump and its operation period and make laboratory and in-situ investigations of these techniques.

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 maximum speed of wind is 40 m/sec;
- winds with speed above 15 m/sec are observed during 90 days;
- 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 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 front of an inwash, the quantity of the inwashed tails, operations schedule etc. (Lolaev et al, 2010).

During the inwash process the inwashed sectors were adopted about 900-1200 m in length and the subsequent consolidation the values of physical and mechanical properties of the filled-up grounds are being established.

The beach sectoring for the determination of the volume of the inwashed tails is presented in Fig. 1.

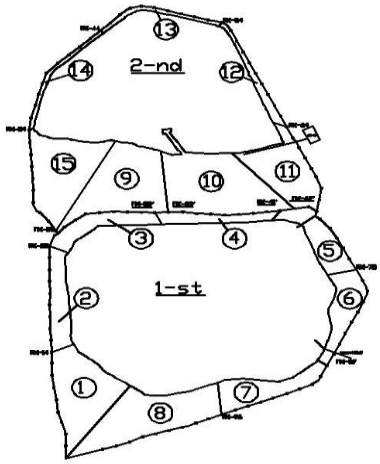


Figure 1. The Beach Sectoring

3 TEST RESULTS AND DISCUSSION

Taking into account the fact, that stability of tailing dam must be provided, the changes of the dam stability coefficient during the working life are carried out. The obtained results are included in a database and can be replenished in the course of reception of new data about the structure of the inwashed body or about the physical and mechanical properties of tails composing it.

The calculation were carried out by means of program UniFos.

The program UniFos is a part of UWay complex and is intended for calculations of stability of soil constructions. It is written in object-oriented language C++ with usage of optimising compiler Borland C++ Borland International v.5.02 with library OWL usage v.5.0 (Vlasov et al. 2003)

As a design the section (on the picket line 34) in which will be the most intensively change the settings that mostly affect on stability was chosen.

The basic value of the stability coefficient was adopted equal to 1.55 for this section (Fig.2).

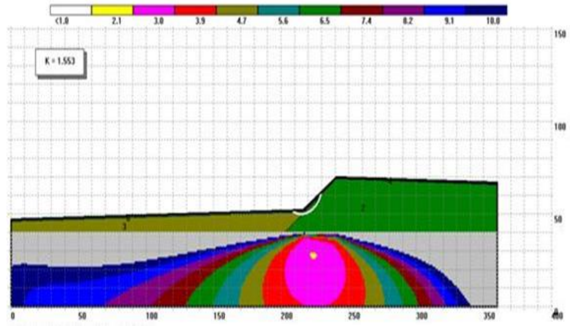


Figure 2. The basic value of the stability coefficient K_{st} = 1.55

The data obtained during the field and laboratory researches have made the reasons and production of physical model of the inwashing of tailing dump.

The general view of the laboratory-scale plant is given in Fig.3

Figure 3. General view of the laboratory-scale plant for the inwash technology modeling (Patent RU 122098)

The laboratory experiments were conducted made according to the requirements of the similarity theory criteria (Lolaev et al., 2013). The equality of Fourier numbers of nature (n-parameters of an object) and model (m-parameters of a model) was taken as conditions of similarity of model and nature

$$Fn = Fm \quad (1)$$

According to Rozovsky (1969) the correlations of geometric measurements and volumes of nature and model are in dependencies.

$$L_m / L_n = B_m / B_n = H_m / H_n \; ; \qquad (2)$$

And the timing of nature and model are in the ratio:

$$\tau_m / \tau_n = (L_m / L_n)2 \; ; \qquad (3)$$

where L, B, H- geometric measurements, V – volume, τ –time, indices m and n – indications of model and nature system.

At the known consumption of pulp in full-scale conditions (Q_P^n) and the equality of Froude criteria (Fr) on a model and in the nature, the consumption for the model must make up, Chugaev (1982):

$$Q_p^m = Q_p^n \left(\frac{1}{100}\right)^{\frac{5}{2}} = 1{,}0 \times 10^{-5} \times Q_p^n \qquad (4)$$

Test results permit to establish the regularities of distribution of tails on a beach in the course of an alluvium, to determinate of their physico-mechanical properties and to define the regularities of their changes in process of consolidation, dehydration etc.

The general view of the inwashed beach, is presented in Fig. 4.

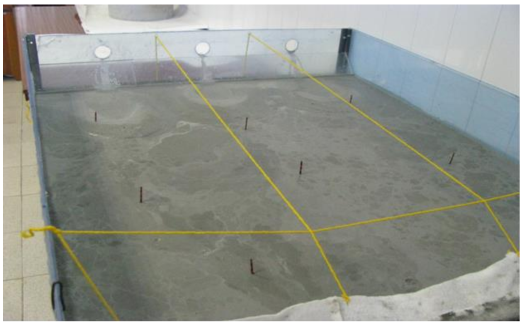


Figure 4. Gneral view of the inwashed beach

To conduct the modeling of the inwash technology in winter conditions the settings of the installation have been changed.

The table of the installation was placed in a specially-made cryogenic chamber equipped with two viewing windows. Low temperatures in the chamber were provided by liquid nitrogen (temperature -196.2 ^{o}C).

The general view of the laboratory-scale plant for modeling the inwash technology in winter conditions is given in Fig.5

Figure 5. General view of the laboratory-scale plant for modeling the inwash technology in winter conditions.

The experiments were carried out at the temperature in the camera -45 °C. The outlet temperature of pulp was +15 °C.

The experiments showed, that the freezing of the pulp before reaching the border of the beach had not occurred.

The almost uniform layer of tails was received on the beach.

The craters formed from jets of pulp and the deposition of large fraction near them had been observed.

The general view of the inwashed beach at the temperature of -45 °C, is presented in Fig. 6.

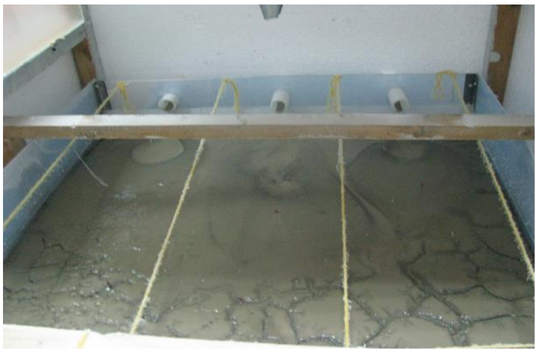


Figure 6. General view of the inwashed beach at the temperature of -45 ^{o}C .

The creation of an additional field considered as the geometrical way of increasing of the tailing dump volume. But it is possible to do it by technological ways too.

The different techniques have been carried out and tested in laboratory and in-situ investigations.

We will consider the results of approbation of some of them:

- the compacting of the inwashed tails
- arrangement of a secondary banking dam with the help of excavating equipment
- replacement of a retaining prism by the filter screen from a geotextiles

The first researched technology of dumps volume increasing had been used the compacting of inwashed beach zone by rollers (Fig. 7). During compaction process of tails the next rules were observed:

- The selection of the type of the roller has been carried out under the average characteristics of compacting tails.

- The compacting was made with keeping of a technological pause for two weeks, after inwashing of the next layer of tails and achieving of the optimum humidity by 15÷20 %.

- Each subsequent compacting trace of roller overlapped previous on 20÷30 sm.

- The direction of movement of road-roller has been chosen from a retaining prism of a dam to a slurry collecting slag prism.

- The number of one trace passes has been defined in dependence from the weight characteristics of the roller, initial density, humidity of tails, and from the demanded final density of tails.

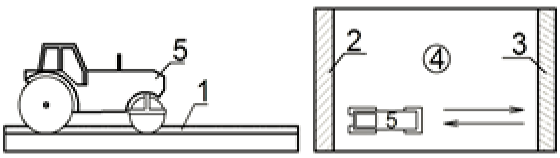


Figure 7. The scheme of the compacting process
1. compacting lay of tails; 2. a retaining prism of a dam; 3. slurry collecting slag prism; 4. a beach zone; 5. roller.

The laboratory tests (Fig.8a) show that in result of compacting it is possible to receive reserves of volume of depositing tails up to 25÷30 %.

During the process of inwash of the levee of a tailing dump in-situ compression tests of hydraulic fill tails was done by compactors (Fig.8b). Parameters of compression process depend on humidity, density, and grain-size composition of tails. Compression was carried out in two weeks after the completion of an inwash of the next sector. The use of compression allows increasing the capacity of a beach up to 30 %. Besides, due to compression, filtration factor reduction of a body of a dam is observed and value of stability factor increases.

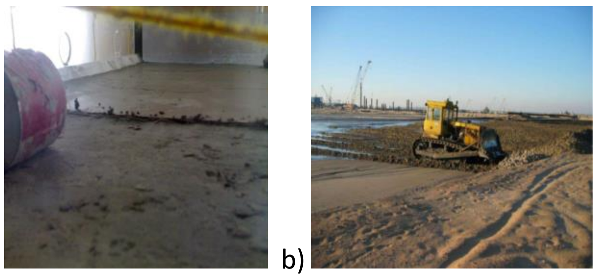
a) b)


Figure 8. Laboratory (a) and in-situ (b) tests of compacting process

Intensity of an inwash increases on the sites where the banking of a knife-edge is carried out by tails with the help of excavating equipment. The schematic circuit of banking and in-situ tests are shown in Fig. 9. Creation of a secondary river dike with the help of an excavator has shown high efficiency. Average speed of arrangement of a secondary river dike from stale tails with the help of an excavator comes to ~10-30 meters per hour. At realization of the technology with the use of banking by excavating equipment, the following operations are being occasionally excluded from the technology used now:

- Dismantling of a distributive slurry pipeline.
- Overlifting of a distributive slurry pipe-line.

Using the technology of levee embankment allows increasing its volume up to 6 %

a) b)

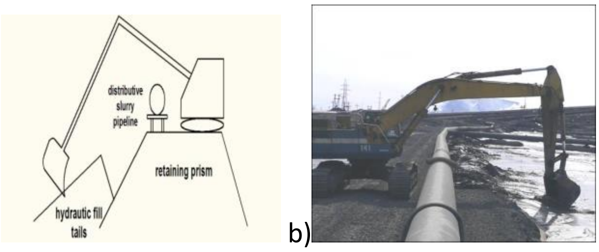


Figure 9. Arrangement of a secondary banking dam of hydraulic fill tails with the help of excavating equipment a) elementary diagram of arrangement; b) in-situ tests.

Another of the ways of increase in capacity of the tailing dump is replacement of a retaining prism by the geosynthetic-reinforced soil filter screen from a geotextiles (Fig. 10). The use of screens from membrane structures is known in the construction of hydraulic structures, Chanson (1998). However, as demonstrated by the experiment conducted on painted tailing dump, screen application on such sites is ineffective due to its volatility when strong wind loads. In this regard, the replacement of the secondary dam was proposed from the nonwoven geotextile sleeve using tails as the backfill , Tatsuoka et al. (1997), Kachi et al. (2010).

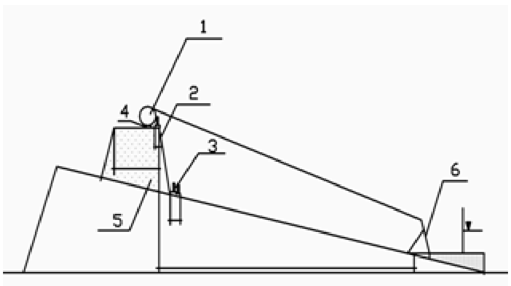


Figure 10. Replacement of a retaining prism by the filter screen from a geotextiles

1. distributive slurry pipeline; 2. geotextile anti-filtration screen; 3. load; 4. slag prism; 5. retaining prism of a dam; 6. filter screen from a geotextile.

This system is characterized by the following features:

• the use of polymer geogrid reinforcement for tails to provide good interlock with the layers.

• the use of a composite of nonwoven and woven geotextiles for saturated tails to facilitate their deposit in the dam's body, water drainage and tensile reinforcement of the dam's slope of the backfill.

• the use of relatively short reinforcement.

• the use of low-quality on-site tails as the backfill, if necessary.

During further construction of dams geosynthetic-reinforced soil layer with a wrap-around tails-filled sleeves instead of slag prism is constructed and placed at the shoulder of each layer. To test the feasibility of the application of this method was carried out laboratory and in-situ tests (Fig. 11).

a) b)

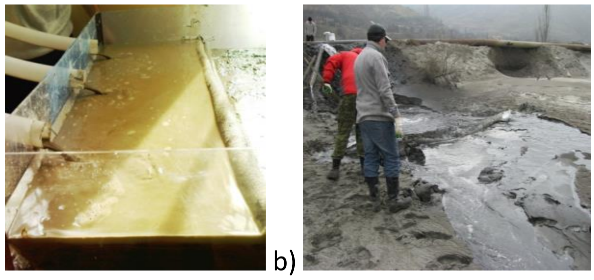


Figure 11. Laboratory (a) and in-situ (b) tests of filter screen from a geotextiles

Test results show that:

- the solid phase of the pulp populates geotextiles sleeves of and the water is filtered through the sleeve.
- The tails-filled geotextiles sleeve completely fulfilled its function: solid phase of the pulp deposited on the beach and liquid phase filtrated through the screen in the tailings pond.

As a result of the use of this technology provides increasing usable tailing dump volume approximately by 6-8 %, and lowering the metallurgical slag input and labour coefficient. The given method was tested and has shown its efficiency.

CONCLUSIONS

The results of laboratory and in-situ experiments have shown the effectiveness of the offered technological ways of increasing in capacity of the tailing dump.

• Using of the technology of controlled inwashing of the levee allows to lift its top to a mark 70m and in the long term up to 90m.

• The optimisation of the inwash technology has allowed: to achieve the increase in the stability coefficient of the dam and of the construction as a whole during its working life, to raise the level of the industrial and environmental safety,

• Creation of the second pond will allow to increase the volume of the tailing dump up to 70 % from originally planned.

• Using the technology of levee embankment allows to increase its volume up to 6 %.

• The compaction of the beach zone of the tailing dump allows to increase it volume up to 30 %.

• Application of geotextile screens instead of retaining prisms allows to increase the tailing dump volume up to 8 %.

Thus, the complex of the carried out laboratory and in-situ researches has allowed theoretically and practically to substantiate a number of directions of effective and safe operation of the tailing dump for the next twenty years.

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