Estimated Monitoring Methodology for the Tailings Dam Stability

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Abstract. Tailing dumps are the dynamic man-made systems, and their operation depends on the rock mass processing volume, as well as the type of processed ores. So the problems of industrial and environmental safety, tailing dam's stability are highly relevant for the whole period of operation and require special attention. Along with the standard set of observations the methodology of the estimated monitoring includes, the tailing dam's stability calculations under changing technological parameters of exploitation, observing geometric characteristics of construction and the properties of the inwashed tails. The proposed methodology was successfully applied for the tailing dumps of the mining and non-ferrous metallurgy industrial enterprise in Norilsk industrial region (North of Siberia).

Keywords: Tailing dam · Stability · Monitoring

1 Introduction

Tailing dumps are the dynamic man-made systems, and their operation depends on the rock mass processing volume, as well as the type of processed ores. So the problems of industrial and environmental safety, tailing dam's stability are highly relevant for the whole period of operation and require special attention.

Sufficient attention has been given last years to the problem of geotechnics of mining, metallurgical wastes and tailing dams in permafrost regions [3, 8, 12, 13].

The problems of industrial and environmental safety of the tailing dumps are becoming increasingly relevant now. It is connected with the increasing amount of accidents, the increasing needs in the construction of a new tailings, the unsatisfactory condition of existing dumps and the need to increase their capacity during exploitation.

Traditionally, the calculations forecasting stability of the tailing dam are carried out in the designing stage and provide some margin of safety and stability [10]. The testing calculations are carried out only in special cases concerning any changes of exploitation technology. That is why, the problems of industrial and environmental safety of tailings, remains without permanent monitoring and therefore accidents are usually unexpected.

A. G. Correia et al. (Eds.): ICITG 2019, SSGG, pp. 644–653, 2020.
https://doi.org/10.1007/978-3-030-32029-4_54

2 Case History

Object of research of the present work is the first field of tailing dump "Lebyazhie", located on the territory of Norilsk industrial region (see Fig. 1).

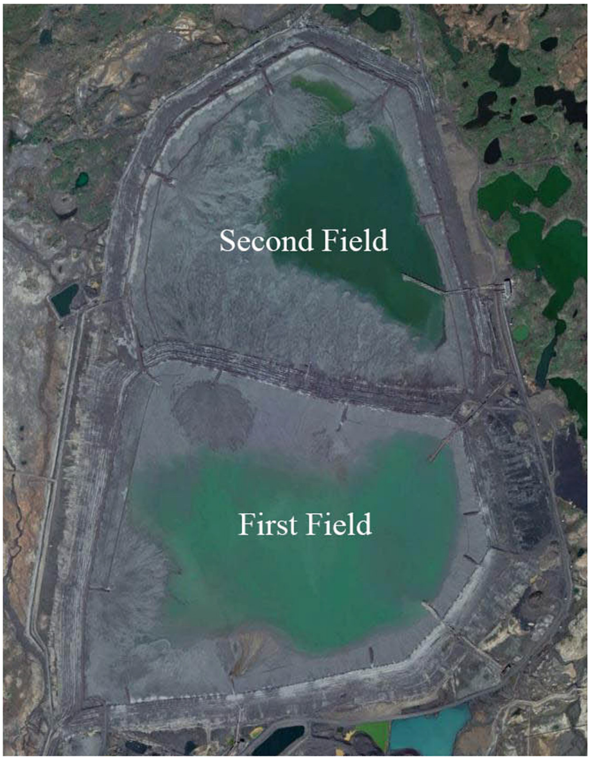

Fig. 1. Tailing dump "Lebyazhie".

The exploitation of the disposal area has begun since 1983 [9].

The basic hydraulic engineering structures include:

- pool for reception of pulp and storage of tails;
- local tailing dam;
- system of pipelines for transportation of pulp;
- system of pipelines for turnaround water supply with coastal and floating pump stations;
- spillway system.

The disposal area provides sedimentation, clarification and natural stabilization of ionic structure of turnaround water acting with tails. The clearing of water from firm phase is done with the help of gravitation method.

The constructive characteristics of dam are:

1. the disposal area - 4.02 kms^2;
2. the length of the tailing dam - 8.1 kms;
3. the tailing dam is carried out as a persistent drainage prism from metallurgical slag:
   – the width of a prism - 8 m;
   – the length of a prism - 8500 m.
4. the capacity of disposal area - 16.7 mln. m^3;
5. the settlement term of operation - 20 years;
6. the height of dam - 39.3 m;
7. the inclination of a top drain level - 1:50;
8. the inclination of a bottom slope - 1:4;
9. the maximal depth of pool - 4.7 m;
10. the average depth of pool - 2.5 m.

As a result of mutual research-and-production investigations the technology of controlled inwashing of the levee was designed [11]. 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 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 it clearing the water coming into the pool.

The scheme of the levee inwash is shown in Fig. 2.

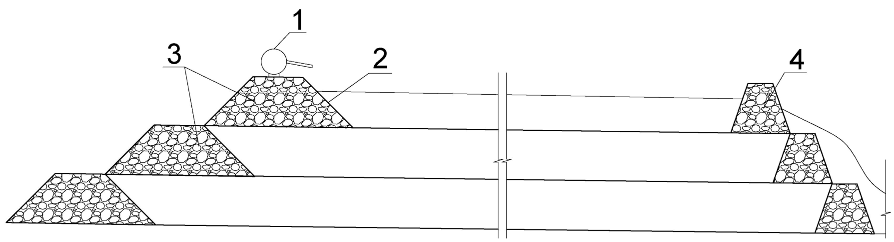

Fig. 2. The scheme of the levee inwash: 1. distributive slurry pipeline; 2. geotextile anti-filtration screen; 3. a retaining slag prism of a dam; 4. slurry collecting slag prism.

Functions of a slurry collecting prism in operation of an inwash are the following:

- placing of prism on various distances from distributive slurry pipeline allows regulating intensity of an inwash;
- slurry collecting prism promotes more intensive consolidation of hydraulic fill tails and increase of stability of a dam;
- it allows operating of bottom contour formation in pond zone that is rather an important factor that provides winter storing of tails under ice;

- it promotes more intensive frost penetration in an inwash massif that raises its static and filtration stability and in that way provides environmental safety of the tailing dump;
- it carries out reinforcing a body of a levee function.

On a backslope of a dam an impervious screen from geotextiles is being placed. The inwash is made by sections of 800–1000 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 already for the first years has provided an advance growth of a dam.

3 Methodology

Carried out complex researches allows to formulate a methodology of the estimated monitoring for the tailing dam's stability The algorithm is shown in Fig. 3.

Along with the standard set of observations the methodology of the estimated monitoring includes, the tailing dam's stability calculations under changing technological parameters of exploitation, observing geometric characteristics of construction and the properties of the inwashed tails.

The technique includes a number of successive operations.

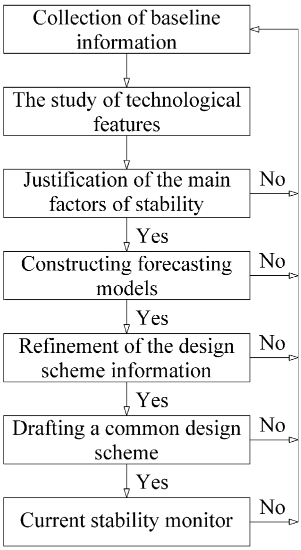

Fig. 3. Algorithm of the methodology of the estimated monitoring for the tailing dam stability.

At the first stage after receiving the research data on the structure and the properties of the composing inwashed soils, the preliminary calculations for the most typical cross-section and average values of physical and mechanical properties are conducted. The result is accepted as the baseline.

As the initial data for the calculation should be used the following materials [4]:

- geology, geocryological and hydrogeological conditions, physical and mechanical properties of natural and artificial soils taken according to engineering studies, research and direct definitions and observations in the field and laboratory conditions;
- geometrical parameters of structures defined by the direct geodetic works [2];

At the second stage while changing the values of soils characteristics towards increase and decrease was investigated the influence of the physico-mechanical properties of soils to the construction stability.

At the third stage, the influence on the tailing dam's stability of the design parameters of height of dam and of angle of the foundations under constant values of physical and mechanical properties are tested.

At the fourth stage, the changes of physico-mechanical properties of inwashed soils during alluvion and subsequent consolidation are tested. It is recommended to study the physical and mechanical characteristics by micro structural analysis and modeling.

At the final stage the multivariate calculations of dam's stability are conducted using all installed above patterns. 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 [14].

The results are recorded in the database and can be replaced in the process of getting new data on the structure. Estimated maintenance of the tailing dam stability is comparing with the information obtained as a result of standard monitoring of hydraulic structures safety of with the existing database. And if, at least, one of the parameters will vary from the normalized values, the calibration calculations must be carried out and engineering activities must be designed to eliminate deviations.

Thus, the idea of the estimated monitoring of the stability of hydrotechnical constructions is presented as a permanent model quickly check the State of buildings when changing technology exploitation properties of alluvial soils, height of structures, the length of the beach, the water level in the body of the enclosing constructions, etc.

4 Test Results

The developed method of estimated performance monitoring the stability of tailing dam was tested and implemented in a number of design decisions. [5] for the tailing dumps of the mining and non-ferrous metallurgy industrial enterprise in Norilsk industrial region (North of Siberia).

The results of calculations used for zoning and to visualize the state of the tailings of tailing dump "Lebyazhie". Normally the legend to the map serves as a table, in which different colors marked valid, invalid, and above the permissible values safety factor of sustainability as indicated in Table 1 [1].

Table 1. The legend to the map of the tailing dump stability.

Combination of loads and effects	Class of Structure			
	I	II	III	IV
Basic				
Above the allowable (Stable)	>1,3	>1,2	>1,15	>1,1
Allowable (Boundary)	1,3-1,25	1,2-1,15	1,15-1,1	1,1-1,05
Invalid (Unstable)	<1,25	<1,15	<1,1	<1,05
Special				
Above the allowable (Stable)	>1,1	>1,1	>1,05	>1,05
Allowable (Boundary)	1,1-1,05	1,1-1,05	1,05	1,05
Invalid (Unstable)	<1,05	<1,05	<1,05	<1,05

The scheme is represented as a cartographic model with dedicated it clearing blocks by color the status of the tailing dam stability (see Fig. 4).

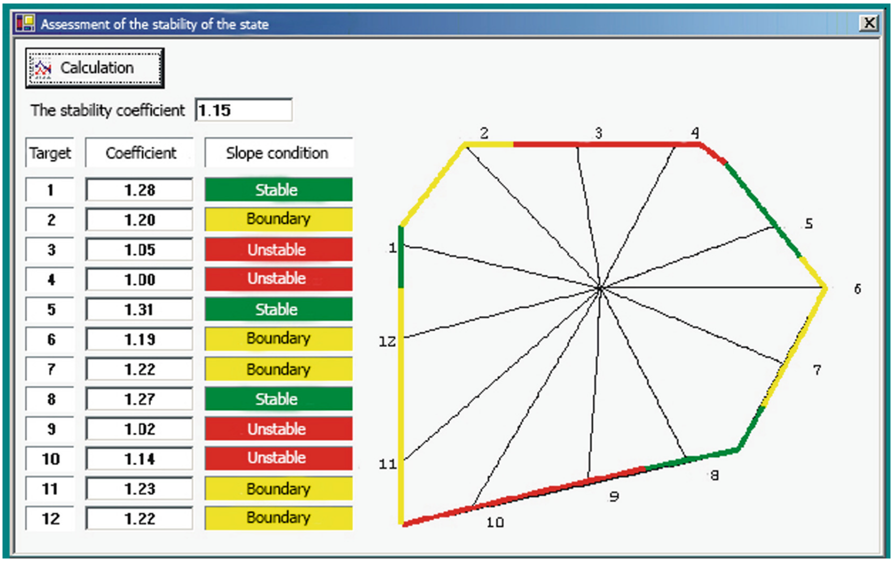

Fig. 4. Tailing dam "Lebyazhie" stability monitoring.

According to the results of calculations it is established:

- plots along areas 1, 5 and 8 are in a steady state – slope condition is stable;
- plots along areas 2, 6, 7, 11 and 12 should be operated with careful observance of the requirements of the project for the operation of the tailing dump – slope condition is boundary;
- dam sites along cross-sections 3, 4, 9, and 10 need urgent measures to increase the bearing capacity of the dam – slope condition is unstable.

In these areas (3, 4, 9, 10), various methods must be applied to prevent an accident.

It is possible to do by technological ways. We will consider the results of approbation of some of them [6, 7].

Intensity of the inwash process increases on the sites where the secondary coating of tails of the beach area at a distance of 5 m were carried out by tails with the help of excavating equipment. The schematic circuit of banking is shown in Fig. 5.

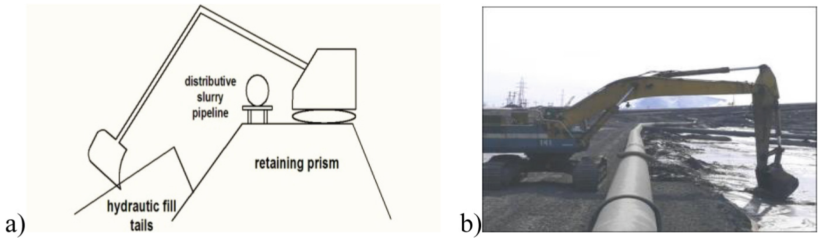

Fig. 5. Arrangement of a secondary banking dam of hydraulic fill tails with the help of excavating equipment: (a) elementary diagram of arrangement; (b) in-situ tests.

This allows to form an additional embankment dam, which in turn leads to a change of:

- geometric parameters of the dam with an increase in the size of the dam along the top;
- processes of consolidation of inwashed tailings, their acceleration and natural improvement of the dam base.

Creation of a secondary dam with the help of an excavator has shown high efficiency.

Average speed of arrangement of a secondary dam from stale tails with the help of an excavator comes to ~10–30 m 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 pipeline.

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

The next technological way of compression process and dumps volume increasing has been used by compacting of inwashed beach zone by rollers (see Fig. 6).

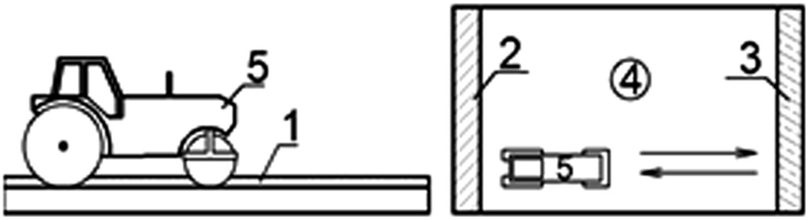

Fig. 6. The scheme of the compacting process: 1. compacting lay of tails; 2. a retaining prism of a dam; 3. slurry collecting slag prism; 4. a beach zone; 5. roller.

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 $15 \div 20\%$.
- Each subsequent compacting trace of roller overlaped previous on $20 \div 30$ 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;

As a result of compacting it is possible to receive reserves of volume of depositing tails up to $25 \div 30\%$.

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.

The results of the obtained data were compared with the results of the basic version of the calculation of the stability of the structure. They show the dynamics of changes in the properties of soils, which effects on the stability coefficient, proving the legitimacy of the technology application (see Table 2).

Thus the approach on accident factors allow for monitoring construction in the process of exploitation and to take urgent measures in hazardous areas surrounding the tailings dam.

Table 2. Comparative results of the tailing dam stability calculation.

№ of site	k_{st} value, before applying the proposed technology	k_{st} value, after applying the proposed technology
3	1,05	1,28
4	1,00	1,26
9	1,02	1,31
10	1,14	1,43

5 Conclusions

Thus, the practical application of the developed method of estimated monitoring for the tailing dam stability has demonstrated high reliability of the results obtained confirmed the actual load-bearing tailings dam "Lebyazhie".

This approach to the impact on accident factors makes it possible to monitor the structure during operation and to take emergency measures in the hazardous zones of the tailings dam. This makes it possible to calculate the magnitude of the prevented damage in the event of an accident due to the loss of stability of the dam or hydrodynamic accident.

Program complex UniFos FEM package has been applied to the dam's stability condition calculation on the basis of finite elements.

Carried out calculations permit to forecast the stability of tailing dam and has formed the basis for alteration of work technique that has provided in its turn, safe and effective execution phase.

Thus, 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 years.

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