Research on the optimization analysis and monitoring elements of tailings pond

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Abstract. This paper introduces how to select the monitoring elements scientifically, normatively and reasonably from the two links of monitoring elements and installation points of tailings dam. Based on ISM theory, the monitoring elements are systematically optimized, and obtains the corresponding monitoring model. According to the monitoring technical specifications of tailings dam and the analysis of safety risk factors in the whole life cycle, the layout of monitoring points of tailings dam is optimized, and a set of reasonable layout process is summarized, which provides theoretical guidance for the safety monitoring of the tailings dam.

1. Introduction
In recent years, the country has put forward the development concept of green mines, and proposed corresponding countermeasures for the tailings selected by the mines, but only about 18.9% of the tailings are used for empty area filling and recycling of construction materials, and most of the remaining basically use tailings ponds. Pile up [1]. According to statistics, as of 2016, there are 8,870 tailings ponds in China, including 1,425 head-end pits, which is about 21.91% less than that in 2014. However, it is still one of the countries with the most tailings ponds in the world [2], of which about 44% of the tailings ponds are in the "sub-health" state (including danger, disease, overdue service, etc.) [3]. As we all know, tailings ponds are a major source of danger with huge potential energy. Once a dam breaks due to improper management, incalculable losses will occur. For this reason, how to effectively prevent tailings dam failure from the source has always been the focus of safety supervision departments and mining enterprises. Tailings monitoring can effectively manage the operation of the storage area and prevent major accidents caused by tailings dam failure, especially the design and installation of online monitoring systems, which can automatically monitor multiple status indicators under harsh conditions, which has brought many enterprises Easy management. However, the selection of elements and the location of the points in the monitoring of tailings ponds are directly related to whether the monitoring data is reliable and whether the accuracy meets the requirements. Therefore, the method and process of tailing pond monitoring element selection and point layout optimization summarized in this article have important guiding significance for the safe and efficient monitoring and management of the tailing pond.
2. Selection of monitoring elements

Each monitoring element is a small unit in the tailings pond monitoring system, and the selection of elements is directly related to whether the tailings pond safety monitoring can be effectively guaranteed. Therefore, the selection of monitoring elements must follow the principles of norms, comprehensiveness, and reasonableness. According to the requirements of the "Technical Specifications for Safety Monitoring of Tailings Ponds" (AQ2030-2010) issued by the State Administration of Security, the main contents of safety monitoring of tailings ponds are: displacement, seepage, The dry beach, reservoir water level, rainfall and other aspects, according to the construction level of the tailings pond, divided the installation requirements of different monitoring elements, as shown in Table 1.

| Monitoring content          | Tailings pond grade |
|----------------------------|---------------------|
|                            | First class | Second class | Third class | Fourth class | Fifth class |
| Displacement               | Should be set | Should be set | Should be set | Should be set | Should be set |
| Infiltration line          | Should be set | Should be set | Should be set | Should be set | Should be set |
| Reservoir water level      | Should be set | Should be set | Should be set | Should be set | Should be set |
| Dry beach                  | Should be set | Should be set | Should be set | Should be set | Should be set |
| Precipitation              | Should be set | Should be set | Should be set | Should be set | Should be set |
| Pore water pressure        | Set if necessary | Set if necessary | Set if necessary | Set if necessary | Set if necessary |
| Infiltration water         | Set if necessary | Set if necessary | Set if necessary | Set if necessary | Set if necessary |
| Turbidity                  | Set if necessary | Set if necessary | Set if necessary | Set if necessary | Set if necessary |

It can be seen from Table 1 that the technical specifications for tailings pond safety monitoring set a principle requirement for different levels of warehouse categories. Therefore, the specific tailings pond monitoring program should be specifically designed and optimized according to actual conditions.

3. Optimization of monitoring elements

From the analysis of the monitoring content, we can see that there is an interactive relationship between each monitoring element. Therefore, further optimization of monitoring elements plays an important role in the safety management of tailings ponds, and to a certain extent can promote the process of standardization of tailings pond supervision technology. Based on the Interpretative Structural Model Theory (ISM) proposed by American scholar Prof. Walfitt, using directed graphs and matrices to analyze the interaction between various elements of the system, and decomposing the entire large system into a certain number of subsystems based on software and hardware facilities Unit [4-6]. Therefore, the overall system is expressed by a multi-level hierarchical and highly hierarchical structural model from the principle of complexity to simplicity, so as to realize the simplification of complex systems.

3.1. Explain the structure model matrix order division

According to the definition of ISM theory, the relationship between each element in the system is represented by numerical values, and the matrix composed of all numerical values is the adjacency matrix. Assuming that there are n elements in the entire system, namely S1, S2, S3, ... Sn, then the establishment of the adjacency correlation matrix A between the elements can be expressed as:

\[ a_{ij} = \left\{ \begin{array}{ll}
1, & S_i \text{ has an influence on } S_j \\
0, & S_i \text{ has no effect on } S_j 
\end{array} \right. \]  \tag{1}

\[ A = \begin{bmatrix}
a_{ij}
\end{bmatrix} \]  \tag{2}

Use the identity matrix I and the adjacent correlation matrix A to perform the matrix sum operation, and then perform the matrix and further power operations until the requirements of the following formula are met:

\[ M = (A + I)^{n+1} = (A + I)^* \times \cdots \times (A + I) \times (A + I) \]  \tag{3}
M = (A + I)^n is called the reachable matrix. If the reachable matrix element mij = 1, it means that there is a direct or indirect way of reaching from Si to Sj, that is, Si has direct or indirect to Sj. Impact.

According to the main indicators of the monitoring elements of the tailings dam, the surface displacement, internal displacement, displacement near the dam body, infiltration line, seepage flow, seepage outside the dam, dry shoal length, dry shoal height, dry slope slope, reservoir water level, Rainfall, pore water pressure and other 12 monitoring factors, denoted as S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, and get the adjacent correlation matrix A, obtained by power operation Reachable matrix M:

\[
A = \begin{bmatrix}
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 0 & 1
1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
0 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
0 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\Rightarrow M =
\begin{bmatrix}
1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1
1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1
1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1
1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1
1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1
1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1
1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1
1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1
\end{bmatrix}
\]

Therefore, according to the set arithmetic of reachable matrix, six monitoring elements S1, S2, S4, S7, S10, and S11 are obtained as key direct index points.

3.2. Establishment of monitoring element system

Based on the theoretical analysis of the explanatory structure, the theoretical model of the ISM is obtained by dividing the order of the matrix. Based on the direct index points of the theoretical model of ISM, the slope displacement, seepage, dry beach, hydrology and daily inspections are comprehensively analyzed, and the monitoring element analysis system is established to provide guidance for the selection of the tailings reservoir monitoring system points, such as Figure 1.

![Figure 1. Optimizing monitoring element model based on ISM theory](image-url)
4. Optimization of monitoring points

4.1. Layout of monitoring points based on specifications

It can be seen from the monitoring location layout regulations in the “Technical Specifications for Safety Monitoring of Tailings Reservoir” (AQ2030-2010) that the specifications are in principle for the layout of the cross section and the location of the distribution point. Depends on the level of the dam, the construction method of the dam, the structure of the dam body, the geological conditions of the tailings pond, etc. It is generally set at the maximum dam height section and other terrain conditions are complex, the number of sections is generally 1 to 3, and 1-3 monitoring vertical lines are arranged for each section; however, only general requirements are given in terms of the location of points (distance and number of points). For example, the distance between monitoring points in the vertical line should be based on the height, structure, The material, construction method and quality are determined. The general distance is 2 ~ 10 m, and each monitoring vertical line is arranged with 3 ~ 15 points.

The location of the measurement points in the monitoring of tailings ponds is the key point and the key point. However, the specifications only give general principle requirements. Due to the complexity of the tailings pond monitoring system, it is not enough for the actual application of tailings pond monitoring. Therefore, it is necessary to optimize the layout in combination with the tailings pond risk to supplement the actual monitoring point layout.

The initial dam of a tailings dam is a permeable rockfill dam with a total storage capacity of 47.811 million m$^3$ and an effective storage capacity of 33.468 million m$^3$. The initial height of the top of the dam is 460 meters and the length of the dam is about 150 meters. The tailings accumulation dam is a sub-dam that is continuously heightened with tailings above the initial dam crest. The average slope ratio of the tailings accumulation dam is 1: 4. At present, the accumulation dam has a dam height of 35 meters and the top of the dam is +496 meters. A total of 7 phases have been built, each with a height of 5 meters and a top width of 5 meters. The tailings pond is pre-programmed in the second-phase online monitoring and monitoring project of the + 480m ~ + 490m two-stage accumulation sub-dam, and the following point layout requirements are adopted for the top of its sub-dam:

1) Arrange 4 artificial monitoring points for dam displacement and 4 GPS monitoring points for dam surface displacement;
2) Compatible with the original 4 infiltration line monitoring points, and then add 4 additional infiltration line monitoring points;
3) Two internal displacement monitoring points are arranged, and one fixed inclinometer is arranged in each monitoring point.

It can be seen from the plan that the tailings pond only puts forward the relevant location requirements in accordance with the "Technical Specifications for Safety Monitoring of Tailings pond" (AQ2030-2010), and does not take into account the problems arising in the first-phase monitoring system. The analysis and optimization also neglected the interactive factors of the relevant risks in the early stage, in operation, late stage of operation and the entire life cycle of the tailings pond.

4.2. Arrangement of monitoring points based on full life cycle risk analysis

The risks involved in the tailings pond safety monitoring system include not only the safety of the tailings pond but also the overall system risk. The study of the safety risk of the tailings pond can provide a direct basis for the arrangement of measurement points of the monitoring system, and whether the analysis will be thoroughly related to the monitoring cost of the mining enterprise. To a certain extent, the safety monitoring system is not a measure and tool for risk reduction, but a real-time monitoring and timely detection of hidden risks, and then take corresponding effective measures for specific risks to reduce the overall system risk.

In the risk identification, analysis and prevention of tailings ponds, starting from a specific period in the past, it is rarely considered to link the four stages of the entire life cycle of the tailings pond (exploration and design, construction, operation, closure). According to the analysis, the whole life cycle
of the risk factors is not fundamentally recognized, so the safe operation of the tailings pond cannot be fully guaranteed [7].

(1) Survey and design stage
The survey and design of the tailings pond is a key part of its life cycle, and its quality depends on the business level and design scheme (such as flood control level and earthquake resistance level) of the design unit of the tailings pond. Considering natural factors, the geological structure, seismic intensity, bad climate and other geological hazard risks such as debris flow, landslides and other locations of the tailings dam are the objective influencing factors for the subsequent online monitoring site layout.

(2) Construction stage
During the construction of the tailings pond, it is mainly to carry out construction operations on the initial dam, auxiliary dam, flood discharge facilities, monitoring facilities, etc. The construction quality directly determines whether the tailings pond is operating with disease. It is difficult for these engineering structures to have potential safety hazard Eliminate in later operations. Therefore, the risk identification at this stage should be comprehensive and systematic to provide a strong guarantee for the subsequent operation.

(3) Operation stage
The operating cycle of tailings ponds is generally long, some up to 100 years. As the service life increases, tailings pile up more and more, and the risk factors continue to change. Therefore, it is more holistic and systematic to identify risks for the point arrangement of the monitoring system. Comprehensively consider the risks caused by factors such as the height of the accumulation dam, the physical and mechanical properties of the tailings, the length of the dry shoal, the depth of the infiltration line, the water level of the reservoir, the particle grading, the natural sediment density, and the integrity index of the drainage facility. Environmental factors such as water catchment area and seismic intensity affect the location of the tailings pond online monitoring system.

(4) Closing stage
After the tailings dam is closed, it does not mean that there are no hidden dangers. Long-term weathering and erosion will make the slope of the sedimentary beach flat and reduce the flood resistance of the tailings pond. Therefore, monitoring of tailings ponds can also be properly considered during the closure phase, but since tailings are no longer discharged and accumulated, the location of monitoring sensors can be arranged according to specific conditions.

According to the identification and analysis of the risk factors of the entire life cycle of the tailings pond, the following point optimization measures are proposed:
(A) Establish a full life cycle risk indicator system for tailings ponds and divide different risk indicator levels;
(B) Determine the layout parameters such as the key position and number of sensor points according to the risk index level;
(C) Based on the full life cycle, the network topology is used to optimize the layout.

4.3. Optimization process of monitoring point layout
The safety monitoring design of the tailings pond is based on relevant technical regulations and norms, and combined with the safety risk analysis of the tailings pond monitoring system and the data of the tailings pond design, construction, daily maintenance, etc. to optimize the deployment. To better improve the operation performance of the safety monitoring system, the specific monitoring point layout optimization process is shown in Figure 2.
5. Conclusion
At present, there are still a considerable number of tailings ponds in the unconventional operation stage. The tailings ponds have a large volume and high potential energy, which is a major danger source. Once a dam breaks, it will cause incalculable casualties and difficult repairs in the surrounding and downstream areas. Ecological destruction. The monitoring of tailings ponds plays an important role in improving the safety and effective management of tailings ponds and preventing major accidents caused by tailings dam failure.

The selection of monitoring elements and the arrangement of monitoring points in the tailings pond are two important links in the installation and operation of the monitoring system. If any link is selected or improperly arranged, it will directly affect the monitoring results. Therefore, the monitoring elements should not only be selected reasonably according to the rules and regulations of the safety monitoring technology of the tailings pond, but more importantly, they should be designed and optimized according to the actual working conditions in the reservoir area. The method has important application value; the layout of the monitoring points must first meet the relevant regulations of the monitoring technology of the tailings pond, and at the same time, it must be analyzed and optimized in detail in conjunction with the actual risk factors of the tailings pond to improve the reliability and accuracy of the monitoring data.

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