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Analysis of Tailings Pond Collapse Accidents and Research on Prevention and Control Measures

Ruirui Yu

School of Safety & Science Engineering, Henan Polytechnic University, Jiaozuo 454003, China

Abstract

How to solve the relationship between mines and the environment is a new problem facing the mining industry in the 21st century, while at the same time tailings ponds, as artificial sources of danger with high potential energy, are extremely prone to damage to the environment and cause huge losses to people's property. Tailings ponds are extremely destructive, destroying buildings and farmland along the dumping route and posing a huge risk to the safety of mining operations. As a major manifestation of tailings pond disasters, it is imperative to analyse the risk of tailings pond failures in mines. The first step is to analyse the causes and mechanisms of tailings pond failures at home and abroad, and to summarise the basic patterns of tailings pond failures. In order to avoid the occurrence of tailings pond dam failure accidents, the basic rules of tailings pond dam failure are summarized and corresponding measures are proposed to prevent tailings pond dam failure accidents.

Keywords

Tailings Pond; Dam Failure; Prevention and Control Measures.

1. Introduction

A tailings pond is a place to store tailings by damming the valley or enclosing the land, and it is built specifically to solve the problem of piling tailings generated by the production process of mines. According to preliminary statistics, by the end of June 2008, there were 8,541 tailings ponds in China, of which 44 were second-class ponds, 182 were third-class ponds, 928 were fourth-class ponds, 6,484 were fifth-class ponds and 903 were unknown tailings ponds. There were 4,318 tailings ponds issued with production safety permits, accounting for 50.6% of the total. Among them, 5972 tailings ponds have more detailed data, 3372 tailings ponds have been determined to be safe and 2784 are not. The number of tailings ponds that have been determined to be safe accounts for about 39.4% of the total number of tailings ponds, and through investigation and analysis, China's tailings ponds account for about 63% of normal operation, while dangerous ponds, dangerous ponds and dangerous sick ponds account for about 37%. From this proportion, it is easy to see that less than 70% of the tailings ponds in China are in normal operation [1]. From the above data, we can see that the safety operation of tailings ponds, which account for a significant proportion of the total, is a cause for concern and is equivalent to a time bomb that does not know when it will explode and, in the event of an accident, will destroy downstream infrastructure and a large amount of farmland, causing irreparable damage. As an important part of the tailings pond accidents, it has become an urgent problem for scholars at home and abroad to implement risk identification for tailings ponds according to the existing knowledge, and to reduce the occurrence of tailings pond accidents as much as possible according to local conditions.

With the continuous progress and development of the mining industry, the construction of tailings storage has a long history, the earliest foreign tailings is Brent tailings dam was built in 1830 [2]. Since the establishment of tailings ponds, tailings dam failure accidents have been frequent. Many

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foreign experts have carefully analysed the causes of tailings dam failures, and a common method is disaster risk assessment, which includes relevant elements of disaster evaluation. The main purpose of disaster risk management is to transform the previous disaster relief situation into a more scientific and planned disaster prevention and avoidance on to minimise the losses caused by disasters as far as possible. In recent years, scholars at home and abroad have used hazard analysis, risk assessment and sensitivity analysis to evaluate disaster risk in the context of accidents such as tailings dam failures. However, this method still has many limitations and is not able to adequately assess. In terms of disaster losses, Chinese scholar Wei Qingzhao has established indicators of disaster losses, which are mainly divided into two categories, attribute indicators and monetary indicators. The former refers mainly to the injuries suffered by people and the length of time the disaster lasted, while the latter refers to the economic losses caused by the accident, the funds spent on relief and the money spent on post-disaster repairs. Zhao Axing has also established a corresponding classification for disaster relief and other support. On this issue of tailings pond dam stability, China is relatively late in its development, and today commonly uses knowledge from the field of geomechanics to analyse, and does not yet have its own system. In 1989, Chen Qingsheng proposed a method for predicting the impact of sand flow on the downstream after a dam failure, and the results of his analysis were consistent with reality. In addition, Dai Xinyong et al. designed a tailings pond disaster management system to make a systematic prediction of the possibility and consequences of a dam failure, and this method can be used for tailings pond safety management to avoid tailings pond accidents [3]. M. T. Zandarina et al. studied the role of capillary water in the stability of tailings dams, and applied the problem of low permeability coefficient and very slow decline of infiltration line for storm tailings dams by applying The fluid-solid coupled finite element formulation was used to simulate the response of the dam and found that the stability of the dam strongly depends on the capillary phenomenon and gave the suggestion that capillary water measurement should be added to the standard monitoring program of tailings dams. experiments by G.E. Vaezi et al. applied fractal geometry to the change of structure after tailings dewatering, which can be used to improve the consolidation and deposition of fine tailings in tailings ponds, greatly increasing the stability of tailings ponds. Most foreign scholars have used numerical simulations and field experimental research methods to analyse the causes of tailings dam failure, concluding that the failure is mainly caused by seismic liquefaction, diffuse dams, seepage, etc.; the analysis methods are mostly finite element method and limit equilibrium method, and the research content is mainly seepage law, seismic performance, displacement and deformation, stress-strain state, etc. S.K. Kim [4] used the slope sliding evolution theory to establish T.E. Martin proposed comprehensive improvement measures for the management of existing tailings ponds, including improvement of dam construction methods, water storage methods, and local to whole[5,6].

2. Tailings Pond Dam Failure Accident Pattern and Analysis

2.1 Tailings Pond Dam Failure Statistics

Since the 20th century, countries all over the world have been making rapid progress in comprehensive national power, developing their manufacturing industries and vigorously exploiting energy resources for their development needs, while at the same time neglecting the importance of tailings pond safety, resulting in a series of shocking tailings pond accidents that have brought huge losses to people. However, due to the large number of tailings ponds throughout the country and the fact that they are not easily managed by the relevant authorities, tailings pond accidents are on the rise. Table 2.1 and Table 2.2 are examples of tailings pond failures that have occurred in recent decades at home and abroad [7,8].

In the world, tailings pond accidents occur from time to time, not only bringing huge property losses and threats to people's lives, but also causing great damage to the local ecological environment, so tailings ponds are to a certain extent seriously affecting social harmony and stability. This was followed by infiltration damage, which accounted for 16%, followed by failure of flooding facilities, earthquakes, illegal mining and dam instability, which accounted for 12%. Finally, subsidence of the

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dam foundation accounts for 8% of the causes of dam failure. The three factors, human-machine-environment, were analysed as the main causes of the accident, as follows:

(1) Human factors.

One reason for tailings pond breaching accidents caused by human factors is because of human inaction. For example, the tailings pond collapse at the Silver Rock tailings pond in Loubo County on 15 August 2006 was caused by the failure of the drainage facilities, which would not have led to the tailings pond accident if people had inspected the drainage facilities before the accident and dealt with the problems identified in a timely manner. Another cause is unsafe human behaviour, mainly in the form of illegal mining. For example, the Miaolinggou iron ore tailings pond accident on 23 April 2006 was due to illegal operations by the company, which would not have occurred if the operation had been carried out in accordance with the code of practice for tailings ponds.

(2) Machine factors.

Failure in the tailings pond. There are many reasons for failures in tailings ponds, such as infiltration damage, unstable dam foundations, and malfunctioning flood discharge facilities. For example, the main cause of the tailings pond accident at the Zhenan Gold Mine on 30 April 2006 was the destabilisation of the dam which eventually led to a dam failure.

(3) Factors of the environment.

Disasters in the natural environment are mainly reflected in the occurrence of tailings pond floods and tailings pond dam failures caused by earthquakes. For example, on 28 July 1976, the tailings pond of the Tianjin ash twister dam collapsed due to damage to the dam structure caused by an earthquake, which ultimately led to the accident. In terms of flooding, the main example is the Guangdong Zijin Mining Company on 21 September 2001, where the original accident was caused by the landfall of a typhoon, resulting in a dramatic increase in rainfall and flooding of the roof.

2.2 Analysis of the Causes of Tailings Pond Failures

1. Flooding accidents

The causes of flooding accidents are complex. Statistically we can conclude that the failure of flooding facilities is also a cause of tailings pond failure, but in extreme rainfall weather if the flooding facilities are perfect, no accident will occur, so we can regard the failure of flooding facilities as a cause of flooding accidents.

Most tailings ponds in China are built on mountains, and when extreme rainfall weather is encountered, the water level in the pond will rise rapidly, which, together with the limitation of flood discharge capacity and low permeability of the dam, often causes flooding to further evolve and damage the stability of the dam [8]. Analysis of the statistical data shows that accidents in tailings ponds caused by flooding account for approximately 28% of the total accidents, which mainly include damage or problems with flood discharge facilities, poor flood discharge, insufficient flood discharge capacity and flooding. The main cause of flooding accidents occurs during the rainy season and is due to lax management, failure of management to regularly inspect flooding facilities, failure to troubleshoot problems that arise during inspections, and a lack of management ability to deal with extreme rainfall events.

2. Infiltration damage

Infiltration damage in tailings ponds has long been a hot and difficult area of mine safety research. One of the factors that determine the stability of tailings ponds is the location of the infiltration line. Extreme rainfall, flash floods and flood relief device failures often lead to a rise in the position of the infiltration line, which in turn leads to infiltration incidents. According to experts and scholars, coarse and fine tailings of different particle sizes have a higher infiltration line than coarse tailings ponds due to differences in permeability, so that there are differences in the permeability of different tailings ponds. Also prolonged heavy rainfall can increase the infiltration line of tailings ponds, while the amount of rainfall has a linear relationship with the stability of the dam [9,10].

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3. Earthquake damage

The issue of seismic safety has been the focus of research by tailings pond scholars because of the randomness of the time of occurrence and the uncertainty of the location of earthquakes. The first is to ensure the seismic level of tailings ponds, which is mainly determined in China according to the Safety Technical Regulations for Tailings Ponds (AQ2006-2005), where tailings ponds are located in areas with seismic strength of 7 degrees or less using the upstream method of dam construction, and above 7 degrees using the midline method or the upstream method to build [11,12]. As most of the dams in China are built using the upstream method, the seismic performance is poor and the safety of the tailings ponds cannot be determined in the event of an earthquake.

The cause of tailings pond failures due to earthquakes is the liquefaction of the tailings. The main factors affecting tailings liquefaction are the shape, size, composition and arrangement of the mineral sand particles, the depth of embedment of the infiltration line and the seismic intensity. Because the dam structure is not compacted during construction, earthquakes often result in an increase in inter-pore pressure and liquefaction of the tailings pond when the pressure threshold is reached [13,14]. When liquefaction occurs in a tailings pond, a large number of pore spaces are formed, which can lead to local collapse. At the same time, earthquakes can also cause an increase in the slip force of the tailings pond dam, resulting in the displacement of the dam and the destruction of the stability and overall structure of the dam.

4. Safety management

Safety management is one of the decisive factors in the safety of tailings ponds, from tailings pond design, construction and later use, and in our statistics on the causes of tailings pond failures illegal mining we can attribute to safety management. If managers can strictly comply with safety management regulations at all stages of tailings storage, then accidents will be avoided to the greatest extent possible.

(1) Hazards in the survey phase

The preliminary survey includes site selection and analysis of the geology and astronomical location of the area to prevent the above factors from causing harm and causing landslides, dam deformation and water seepage in the tailings pond. In addition, the quality of the tailings pile dams and sediment banks is examined to determine the strength of stability.

(2) Hazards in the planning stage

The hazards of the design phase depend mainly on the designer, mainly in terms of whether the designer has prepared the required materials in the preparation phase, whether the tailings pond and the basic design and construction are in line with national standards, whether the design is realistic and not on paper, and whether the basic information about the construction site, such as the water level in the pond area and the depth of the infiltration line, is fully grasped.

(3) Hazards of the construction process

The quality of construction is directly related to the quality of the tailings storage. In this process, the problems are mainly incomplete cleaning of the initial dam construction, uneven density of the dam, improper design of the backfilter layer, and dam materials not used according to standards. In addition flood drains have strengths that are not up to standard, and later use can cause blocks to fall off, fracture or even evolve into collapse.

(4) Hazards in use

1. negligence of managers and tailings pond workers themselves.

2. failure to implement safety funding.

3. failure to designate contingency plans to deal with emergencies.

4. lack of technical information for managers.

5. the presence of unscrupulous elements in the reservoir area to interfere artificially.

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3. Tailings Pond Failure Prevention and Control Measures

Through the construction of a tailings pond collapse accident tree and the analysis of typical tailings pond collapse accidents, the conclusions drawn are analysed and countermeasures to prevent and control tailings ponds are proposed.

3.1 Natural Disasters

Natural disasters are often random and uncertain, so tailings pond managers should play it safe, pay attention to extreme rainfall and do a good job of preventing seismic hazards, make contingency plans in advance, and not take any chances with the occurrence of accidents. To minimise the possibility of an accident, the relevant manager is required to understand in advance the natural climatic conditions, underground structure, engineering conditions and rock characteristics of the reservoir area.

When dealing with extreme rainfall and snowfall, decisions should not be based on the historical weather conditions of the area in previous years, and vigilance should not be relaxed because the area in which it is located has a low level of precipitation. Even if the probability of extreme weather occurring is low, managers should make appropriate contingency plans and be prepared to deal with extreme rainfall to prevent flooding, mudslides and landslides caused by excessive rainfall from causing secondary damage to the reservoir area and causing dam failure accidents. Due to the limitation of technical reasons, the time of earthquake occurrence cannot be predicted in advance, which requires that the mine should communicate with the local seismic department regularly to understand the latest crustal activities and make corresponding emergency and evacuation plans to minimize the damage as much as possible [15,16].

3.2 Tailings Pond Operation Working Conditions

How to ensure that tailings ponds are operated in such a way as to minimise the probability of accidents requires strict compliance with the appropriate norms in the operation process to achieve safe production.

1. the tailings storage manager regularly checks the storage capacity.

2. when carrying out mine release operations, the location and manner of release should be planned to achieve an even distribution, while the water release elevation should be appropriate to prevent scouring of the dam and destabilisation of the dam.

3. the minimum dry beach length in the reservoir area should meet the actual situation and comply with the relevant national standards.

4. ensure that the spillway tower and its associated tunnels are functioning properly and are monitored in real time.

5. The drainage system is regularly inspected to prevent blockage of the drainage pipes, and any cracks or deformations in the pipes are repaired in a timely manner to ensure that the tailings pond can be drained during rainfall events and to avoid landslides.

6. design the dam body in accordance with the relevant national specifications, regularly clean the siltation in front of the dam, prevent the dip line from being raised, and ensure the stability of the dam body.

7. Check and eliminate sand leakage and pipe surges caused by poor foundation contact treatment, permeation damage of the backfilter layer and cracks in the culvert pipe.

8. regularly inspect cracks in the dam body to prevent sand leakage and pipe surges caused by cracks in the dam body.

9. check for transverse cracks in the dam body using appropriate technical means.

10. enhance the operational capacity of the out-of-bank drainage system to ensure safety during extreme rainfall events.

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11. Establish a real time monitoring system for the dam body to monitor it 24 hours a day to deal with possible cracks, displacements etc.

12. take technical measures to prevent tailings from being too fine or unevenly graded during damming.

13. monitor the blind trench of the dam to prevent problems in the blind areas of the dam, the main content of the monitoring is the amount of water quality and seepage, if the water quality in the reservoir area becomes worse or the amount of water decreased, we must find out the cause of the occurrence, and deal with it properly, timely repair blind trench blocking, to ensure that the pre-buried seepage facilities materials work well during the service life.

14. Establish appropriate wave prevention measures and check the effectiveness of wave release.

3.3 Safety Management

Tailings pond management is a vital part of tailings pond safety. The day-to-day management of tailings ponds includes the technical level of the enterprise itself, safety inspection and supervision as well as safe production and maintenance. This requires tailings pond managers and employees to comply with the Tailings Pond Safety Management Regulations for operation, and at the same time be able to develop production management regulations that are in line with their own enterprise and have their own characteristics, depending on their own situation. The management of tailings ponds is divided into three main bodies, namely the enterprise management body, the tailings pond team and the tailings workers, and the following are the respective responsibilities of each of the three bodies.

(i) Enterprise management bodies

1. strictly comply with the relevant laws, regulations, documents and technical specifications on the operation of tailings ponds, such as the Mine Safety Law of the People's Republic of China, the Regulations on the Safe Management of Tailings Ponds, the Regulations on the Management of Tailings Facilities in Metallurgical Mines, etc. formulated by the State.

2. plan the work of the tailings pond well, which can be divided into months and years, for long-term planning, and try to reach the target.

3. be able to develop various emergency plans for different disaster situations and organise regular drills for staff.

4. Establish a sound data management department, which is mainly responsible for collecting various parameters of tailings pond operation. The parameters will be analysed, counted and stored.

5. A tailings pond rescue department is established to deal with emergencies as soon as they arise and to minimise losses.

6. Conduct regular safety inspections of the tailings pond to eliminate potential safety hazards; at the same time, do not conceal any major safety hazards that have occurred from the relevant authorities, and seek assistance from the safety management and local government if necessary.

7. To improve the vocational and technical skills of the tailings storage staff, training may be organised on a regular basis to enhance operational capabilities.

(ii) Tailings pond workshop

1. carry out the documents and tasks issued by the state or the head of the enterprise carefully to achieve safe production.

2. to do 24-hour monitoring of the tailings pond and make relevant records, and to do the safety inspection of the day.

3. be able to comply with the working system of the tailings pond and at the same time take stock of the work process and actively respond to the camera on areas that need improvement.

4. make co-ordinated arrangements in accordance with the safety production plan drawn up for the tailings pond and deal with the relationship between tailings discharge, conveyance and grading.

(iii) Tailings workers

1. Complete the work tasks assigned by the team leader in a quality and quantity manner.

2. Comply with the "Regulations on Safety Operation Qualification Assessment for Special Operators in Mines" (Ministry of Labour 1996 No. 35) when carrying out operations, and that their own operations are in accordance with technical specifications.

3. report and discourage activities that endanger the safety of the tailings pond when they can be detected in a timely manner during daily dam inspections.

4. When a disaster is found, it should be reported in time and measures can be taken to nip it in the bud if conditions permit. Through the actual situation of one's frontline work, one should respond to higher authorities about some unreasonable areas and form safety management regulations with one's own characteristics.

4. Conclusion

As a major safety accident hazard source, the safety of tailings ponds has always been a hot spot for tailings pond research scholars to explore, and finding an efficient and reasonable method is the key to solving safe mining and establishing an environmentally friendly mine.

In this paper, we analyse the relationship between the causes of tailings pond failures by counting a number of tailings pond failure accidents. The study also proposes preventive and control measures to reduce the occurrence of tailings dam failures.

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