

The Factors Affecting Dam Safety and Seepage Control Measures

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Abstract. Dam plays an important role in the development of economy, measurement of flooding, human life and property safety. If dam broken occurs, it could cause massive damage and casualties. Seepage is one of the main problems that influence the dam safety. Therefore, it's significant to study the dam safety and seepage control measurements. This research focuses on the factors that affecting dam safety and evaluate the seepage fold control methods. Results show that the influence factors of dam safety include geological condition, overtopping, human factors and dam structure. They affect dam safety by causing geological hazards like flood or reducing the dam's ability to withstand these disasters. Seepage prevention and control is effective to alleviate dam safety problems. There are some methods such as concrete impermeable panel, concrete impermeable wall and improvement of dam body. Different measures are applied in different kinds of dam and have specific features.

Keywords: Dam, Flood, Dam Safety, Seepage Control.

1. Introduction

The number of Chinese reservoirs is the largest in the world, which is more than 87000. With 500G m³ total storage capacity, 500G m³ annual water supply and 4.8×10¹¹ hm² irrigation area, they protected 310 million people, 3.2 cropland and hundreds of large and medium-sized cities from flood damage [1]. The hydroelectric power and irrigation functions of dams are significant for economic development and population growth, especially in arid and semi-arid areas [2]. However, most Chinese dams were built from the 1950s to the 1970s, and they have some safety hazards due to the background of the times [3]. Low flood control standards and poor dam quality have led to some reservoirs becoming dangerous reservoirs. The potential hazards of dam failure are destructive, usually causing a lot of casualties, damaging the environment, and threatening people's property safety [4]. For example, The Banqiao Reservoir dam in Henan province, China, along with 63 other dams, failed in 1975, killing 171,000 people. They destroyed the homelands of millions and are seen to be the largest dam breach in history. In 1993, the dam of the Gouhou Reservoir in Qinghai Province collapsed, with 288 dead and 40 missing, with a direct economic loss of 153 million yuan [5]. Therefore, investigating and researching dam safety is significant to loss reduction and dam management.

There are some factors leading to dam safety problems. For example, specific geological conditions that are prone to geological hazards and difficult to deal with heavy rainfall are one of the factors causing the dam break [6]. In addition, overtopping is considered as the most common cause factor of dam failure [7]. The dam structure affected by seepage could lead to erosion and increase the risk of dam failure. Moreover, construction and management are also important factors to influence the dam safety [9]. It seems that the seepage is one of the main causes of dam failure hence it's essential to explore the seepage control measures to solve the safety problems of dams. Additionally, concrete impermeable panel, concrete impermeable wall and improving the seepage prevention of dam body are widely applied in the dam seepage control, which is important to dam safety. However, few articles consider multi-aspects about the dam failure and seepage control measures. This article focuses on the influence factors of dam failure and analyzes the seepage control measurements.

2. Influencing factors of dam break

The factors affecting dam safety are complex and diverse. Understanding the mechanism of risk factors and making reasonable prediction and prevention are significant in dam safety management and risk reduction. It seems that the factors could be divided into external factors such as geological condition, overtopping, and human factors, and internal factor like dam structure that could lead to the seepage problem to influence dam safety.

2.1 Geological Condition

Specific geological conditions have a huge impact on dam safety because they are sometimes accompanied by geological disasters.

Topography is one of the geological factors affecting dam safety. If a dam is built in a mountainous environment where the terrain is undulating and the river flows fast, it will form confluence problem with strong impact force and has great potential to cause debris flow. It could further cause damage to the dam body and lead to dam break [6].

In addition, climate is also an important factor because of the significance of flooding to dam safety. Some dams built in areas with heavy rain, especially in areas where rainfall is not evenly distributed in time and space like southwestern China, are more threatened by flooding than dams built in area where annual precipitation is almost distributed equally [10].

Soil properties and river sediment properties also have an impact on dam safety [6]. In some areas, loose soil easily causes soil erosion and heavy rainfall carries these soils sediment into rivers. This might lead to silting within the dam, greatly reducing the dam's flood discharge capacity and safety.

2.2 Overtopping

One third of dam failures are connected with flooding overtopping [1]. Overtopping is that the overtop of the standard water level, which is water flows over the crest of a dam, caused by irregular movement of waves. Moreover, flooding overtopping is a phenomenon in which heavy rain causes the water to surge and spill over the top of the dam. It is accompanied by a large amount of flood and strong impact force that the dam body cannot support and resulting in dam break. In China, a lot of overtopping happens because those dams were built at a time when flood control standards and engineering quality were not enough for today's flood control needs. For example, about 46.6 percent of the quantity of dam (1147 dams) in China were threatened by flooding overtopping from the 1950s to the 1990s [11].

There are two main reasons for the flooding overtopping. The first important one is that the rainfall precipitation is larger than the dam capacity. Another is the misuse of dams. For example, people are concerned about insufficient water storage and raising the water level of the waterfront above the limit level, in which case a flood outbreak could lead to overtopping.

2.3 Dam structure

The structure of a dam includes the dam body and dam foundation. They have been impacted by the pressure from rivers and mountains for a long time, which makes the reservoir dam suffer from such as aging, rupture and structural change. These kinds of chronic damage could lead to the seepage problem, which is significant to dam safety. The problem of seepage directly reduces the function and benefit of dam storage. It can the internal structure of the dam are gradually eroded, making it difficult for the dam to withstand geological hazards such as flood. In addition, a large proportion of dams in China are earth dams, which are more vulnerable to seepage than some other dams.

3. Seepage control measures

Seepage is one of the important causes and manifestations of dam break. It is caused by changes in the structure of the dam matrix, which can weaken the risk capacity of the dam and threaten the safety of the dam. It's essential to pay attention to the seepage problem to improve the safety of dam.

There are many seepage control methods for reservoir dams. For example, concrete or reinforced concrete impermeable panel, concrete impermeable wall and improvement of the dam body seepage prevention are considered as effective prevention and control measures.

The scale and number of masonry gravity dams in developing countries continue to increase. However, many of their upstream concrete panels are threatened by aging, creaking and some other problems after long-term operation due to the large number of masonry voids inside such kinds of dams. It results in serious seepage problems that potentially damage the safety of the dam and endanger the lives of downstream residents. Earth-rock dams, most of which were built more than 40 years ago in China, have also faced various safety concerns [12]. Compared with the other two methods, concrete impermeable panel is more widely used in the seepage control of masonry gravity dams whereas dam body improvement is more widely used in earth-rock dam. In addition, different measures are often applicable to specific cases, which means they should be compared according to the cases themselves [13].

3.1 Concrete impermeable panel

The measures to prevent seepage of masonry gravity dam mainly include reconstructing the panel and repairing the original reinforced concrete panel, and the first one is widely used. There are two ways to reconstruct the panel: adding reinforced concrete panels and building new ones after removing the existing ones. Adding reinforced concrete panels on the outside of the original panels can retain part of the anti-seepage function of the original panels, and then prevent the dam body from damage. It means that the reconstruction is less difficult and costly, so it is usually used to reinforce the dam by adding reinforced concrete panels.

As for reinforced concrete panels, there are four important properties need to be considered: the stability of the panel structure, the sealing of the panel construction joint, the crack prevention of the panel, and the anti-freezing and anti-corrosion of the panel [11].

In order to ensure the stability of the panel structure, there are three methods: (1) setting the anchoring chemical bonding steel bar between the old and new panels, (2) injecting inorganic interface glue in the interface of the old and new concrete panels, (3) in the interface of the old and new concrete panels coated with inorganic glue, that can be used to balance the forces applying on the panels [11]. The vertical construction joints of the reinforced concrete panel cut through the vertical construction joints of the original dam body, and adopt a reliable sealing structure [14]. Setting up construction joints, improving material properties and panel strength are the main methods to satisfy the requirement of panel crack resistance [15]. Additives or special surface protective coatings can be used to protect the panels from freezing and corrosion. In addition, according to the environmental type of the dam, the appropriate reinforcement concrete should be selected, the maximum chloride content of concrete should be controlled, the compactness of concrete should be improved [11]. Concrete impermeable panel plays an important role in the seepage control of masonry gravity dams. This measure has applied in many reconstruction projects of dam. For example, Qingshan Reservoir in Jiangxi Province, China, concrete impermeable panel has been used to solve the seepage problems of dam foundation and dam body [16].

3.2 Concrete impermeable wall

Concrete impervious wall is a method of vertical anti-seepage measures. Compared with other vertical anti-seepage measures, it has good mechanical properties, seismic and anti-seepage performance. In addition, it has the advantages of good workability, long final setting time and low strength, good construction and easy operation. Moreover, it reduces the amount of cement used by adding clay, which means reducing construction costs while increasing the capacity of anti-seepage [17]. It's widely applied in seepage control and reinforcement of the dams such as Houqiao Reservoir in Fujian Province and Andike Reservoir in Shandong Province, China.

There are four main types of concrete impervious walls [17]. The first is the pile-column impervious wall. Its biggest application feature is to select the drilling bits with strong impact force

and large diameter to drill hole in the wall of the operation area in the construction process of anti-seepage wall. And then the mud is injected into the target hole to reinforce the target operation area. After that, the impermeable wall and the pile-column are combined in a pile-type connection to make the whole structure more stable. This construction method is mainly applied to earth dams. The second type, pile - filled concrete impervious wall, is one of the most applicable impervious wall types. In the concrete construction process, the structure mainly uses the impact force generated by the vibration process to nail the steel sheet pile prepared in advance into the foundation environment that has been built. At the same time, a section of small pipe diameter is welded next to the steel sheet pile nail nailed into the foundation. The significance of this small pipe is to facilitate the subsequent removal of steel sheet pile nail and ensure the integrity of the hole [18]. The third species is trough slab concrete impervious wall. It is mainly suitable for the construction process of conventional water conservancy and hydropower projects. Its construction method is similar to the pile-column impervious wall, but the concrete mixture is added after the internal structure of the hole is stabilized. So that the internal environment of the hole can be connected in series with the concrete structure to form a fixed whole and improve the overall strength of the structure. The last type is mud trough, which is different from the above three. First, trench digging was carried out on the foundation of the operation area followed by cleaning the surface and hole environments. The mixed mud is then injected into the hole and reinforced with concrete. Finally, the construction personnel need to backfill the trench, and the backfill material selected is consistent with the type of foundation structure [19].

3.3 Improvement of the seepage prevention of dam body

Seepage is one of the concrete manifestations of old dams with low engineering quality because of historical conditions, inadequate technology and experience [20]. High-pressure jet grouting, split grouting and curtain grouting are the three main reinforcement methods.

High-pressure jet grouting method, as shown in the Figure 1, is to use the drilling grouting pipe with special alloy nozzle down to the desired location. Next is to use high-pressure water pump or high-pressure mud pump (20 ~ 40 MPa) to water or slurry through the nozzle jet to impact and damage the soil. After that, the soil particles in the jet flow are impacted by the comprehensive action of centrifugal force and gravity, and then mixing with the slurry. In that case, soil particles and slurry are regularly rearranged according to a certain proportion and mass size. When the new slurry is solidified, a certain shape of consolidated body is formed in the soil [21]. High-pressure jetting grouting significantly improves the impermeability of earth-rock dam foundation. Moreover, it has been successfully used in some important reservoirs such as the Ta-gang Reservoir and the Three Gorges Dam [22].

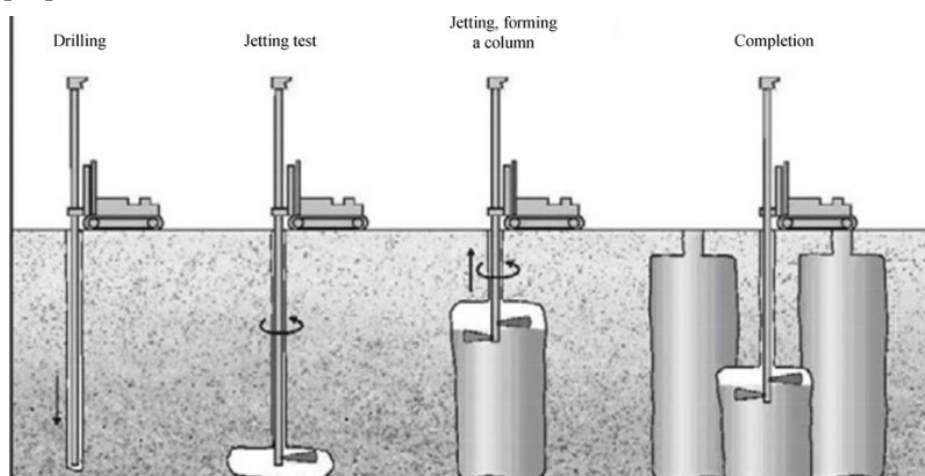


Figure 1. High-pressure jet grouting.

Split grouting takes advantage of the rule that the minimum principal stress surface of the dam body is consistent with the direction of the dam axis. Based on the principle of soil hydraulic splitting,

holes are arranged along the dam axis. Under the grouting pressure, appropriate grout is used as the energy carrier to split the dam body in a controlled way and form a certain thickness grout anti-seepage consolidation body in the dam body. At the same time, all the cracks, caves and other hidden dangers can be filled with dense slurry. This measure not only play the role of anti-seepage, but also strengthen the dam body with low cost. Shanjiao Reservoir in Guangdong Province, China, used this measure to enhance the dam's impermeability [23].

The curtain grouting, as shown in the Figure2, needs to be carried out after the completion of drilling and washing. In the process of perfusion, the water is also pressed out of the hole and the grout gradually fills up the original space when the grout enters the dam body due to the perfusion pressure. When the grouting fluid completely fills the hole, it fuses into a solid state at the bottom, which has a good anti-seepage effect. Although it has good anti-seepage effect and low cost, it has higher technical requirements for survey, design and construction [12]. The zhoujiaying reservoir in Liaoning Province, China uses this method to reinforce the dam body [12].

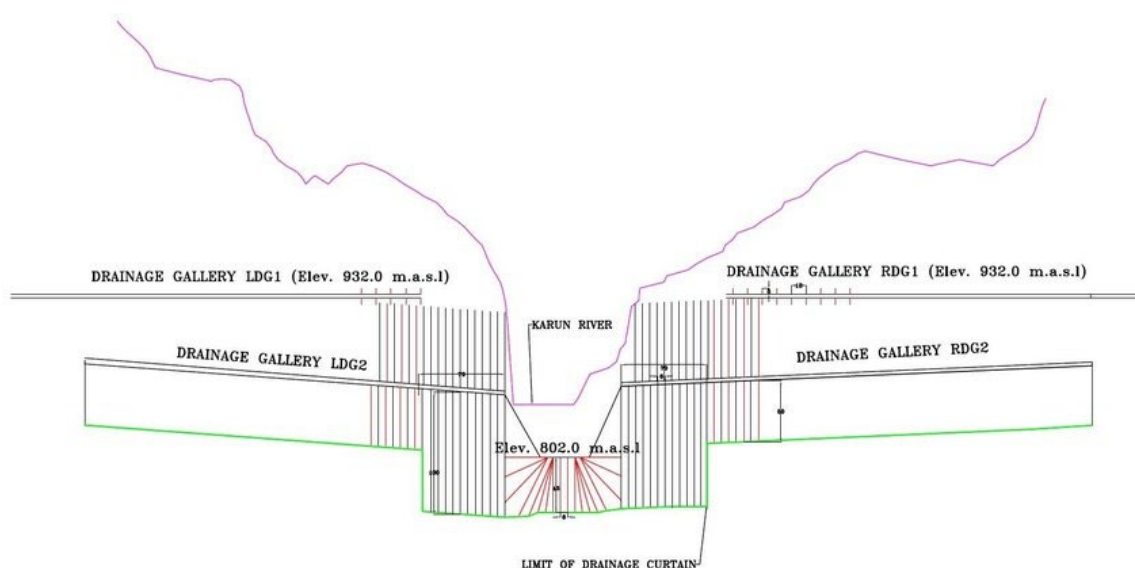


Figure 2. The Cross-sectional view of the grout curtain system [24]

4. Conclusion

This article analyzes the influence factors of dam safety and the flood control measurements. Geological conditions are connected with geological disasters and affect the safety of dams. Unfavorable terrain and climate can lead to flood, debris flow and other disasters whereas poor soil properties can cause silting. Overtopping accounts for the majority of the causes of dam failure. It's difficult to dam to support the impact force and water pressure brought by flood overtopping. The high rainfall precipitation and the human misuse of dam can lead to flood overtopping. Additionally, the aging, fracture and some problems of dam structure result in seepage problem, which corrode dam body and reduce the flood control capacity of dams. To prevent and control seepage problem, concrete impermeable panels and concrete impermeable wall are significant to improve the dam safety by adding, rebuilding or repairing the seepage control parts outside the dam. Compare with other measurements, these two methods have lower cost and better anti-seepage effect. Another possibility is to improve the seepage prevention of dam body. It mainly concludes high-pressure jet grouting, split grouting and curtain grouting. High-pressure jet grouting is more widely applied while split grouting cost much lower. These three measurements can improve the impermeability of dam body. However, curtain grouting requires more specialized personnel and technical requirements to complete the pre-construction preparation work. Although lots of technology and measurements can be used in dam safety, there is no absolutely safety of dam. More attention should be paid on the problem in the future.

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