Research and Application of Feeding-hoisting Equipment for Sealing Leakage in Concentrated Inlets of Earth-rock Dams

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Abstract. In response to the needs of emergency concentrated leakage sealing technologies in earth-rock dams, this study focuses on research and application of feeding-hoisting tank technology for sealing leakage at the inlets. The findings indicate that the equipment offering functions like liquid level monitoring, GPS positioning, automatic material discharge, and wireless control. Field applications reveal that the sealing rates of two centralized leakage pipelines are 88.8% and 100%, while the sealing rates of two gravel leakage channels were 86.6% and 81.4%. The research findings effectively address the need for emergency leakage sealing technology in earth-rock dam embankments, which improve emergency response efficiency and promote construction mechanization in the field.

Keywords: Earth-rock dams; Leakage sealing; Feeding-hoisting equipment.

1 Introduction

There are currently over 98,000 reservoirs and dams in China, with approximately 50,000 small-scale earthen dams[1]. Additionally, the total length of flood control embankments exceeds 410,000 kilometers. These hydraulic structures are integral parts of flood control systems and serve as crucial safety barriers against floods.

However, piping is a significant hazard in earthen dams and often leads to landslides or breaches during flood seasons. During the 1998 Yangtze River flood[2,3], there were 6,100 recorded levee failures, including 3,233 cases of piping. Based on the French project database[4], 46% of the 371 piping-induced dam-break accidents are attributed to concentrated seepage, indicating that concentrated seepage leads to a high risk of piping in earth-rock dams.

Conducting research on the emergency repair of concentrated seepage in earth-rock dams is important to ensure the safety of engineering projects[5,6]. Currently, the leakage

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sealing measures for water-facing surfaces of earth-rock dams involve artificial riprap, laying waterproof cloth, filling cotton blanket or grass. The machinery used includes ships, conveying pumps, etc. These methods are too traditional, and the construction efficiency is low, which is difficult to meet the needs of rescue[7]. Polymer grouting is a new anti-seepage technology[8], but it is only suitable for plugging leakage channels.

Therefore, this study addresses the issue of concentrated leakage in earth-rock dams by developing feeding-hoisting tank and its application technology for sealing leakage at the inlets. The technology has been applied to real earth-rock dam projects. Results indicate that it can meet the emergency sealing requirements as well as enhancing the efficiency of risk response and mechanization in construction.

2 Development Process and Results

2.1 Structural design and technical indexes

Based on the needing of sealing leakage technology in concentrated inlets of earth-rock dams, the final structural technical plan, illustrate in Fig. 1, is designed based on automation application, precise material discharge and suitability for the working environment. The design of feeding-hoisting Equipment mainly rely on air transport and feeding. Compared with the traditional manual delivery or pumping method, it has the advantages of intelligence, flexibility and efficiency, and avoidance of underwater interference.

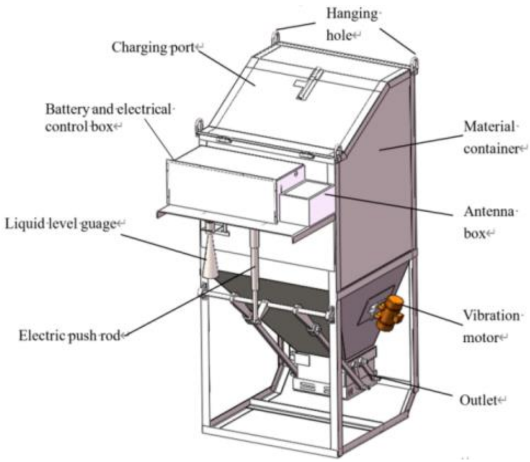

Fig. 1. Structural diagram of automatic feeding hoist equipment

The control system is the most important part of the hoist feeding system[9], which is based on a PLC for central control. It enables functions such as liquid level monitoring, GPS positioning, automatic feeding, and wireless control. The main components of the system consist of a material container, a feeding mechanism, and associated elements like the tank body, switch door mechanism, electric push rod driving device, control box, liquid level gauge, vibration motor and so on. In automatic operation mode, the program initiates the movement of the electric push rod based on equipment positioning information, resulting in the opening of the discharge outlet through the connecting rod.

This system enables automatic material feeding and closure of discharge doors. Wireless control allows for convenient operation, with the control box installed above the tank body to meet waterproof requirements. The material discharge process can be smooth and precise for sealing of the feeding point. Furthermore, the vibration motors are installed on both sides of the lower part of the tank body to prevent blockage at the discharge outlet. A liquid level gauge and GPS positioning device are also used for tracking the distance and orientation from the tank body to the water surface. In remote manual control mode, users can monitor real-time GPS positioning and liquid level through the remote control handle. Once the equipment reaches the designated location, users can control the electric push rod and vibration motors using the remote control handle.

The feeding hopper has a capacity of 1 m^3. The system is powered by a 24 V 95 AH lithium battery. The electric push rod operates at 24V DC with a thrust of 1800N and a speed of 10 mm/s. The main technical indexes include a remote control distance of 250 m, a distance of tank body to the water surface of 0 ~ 70 m, a range measurement accuracy of ±20 mm, and lifespan of electric push rod of not less than 10,000 times.

2.2 Design of automatic control systems

The Siemens S7-1200 series PLC is adopted as the controller due to its stability, real-time performance, adaptability to harsh working environments, and ease of maintenance. The control system communicates wirelessly with the supervisory control system, receiving tasks and controlling the automatic material discharging based on user-defined parameters and sensor signals.

The control system, centered around the PLC, serves as real-time liquid level monitoring, GPS-based automatic system positioning, automatic and safe material discharging, and remote wireless real-time control. Ultrahigh frequency water level radar is used to collect water level data. The data is then transmitted to the PLC control system through the 485 communication protocol, enabling wireless remote real-time liquid level distance measurement technology.

The system is designed to incorporate a coordinated function between GPS positioning and remote control of material discharge direction. The GPS positioning establishes the equipment's location, while the operator sets the parameters for the theoretical discharge direction, specifically the leak point on the earth-rock dams. Once the tank reaches the designated position, automatic discharge can be initiated remotely, ensuring a protective mechanism for the remote-controlled automatic material discharge. The system controls the opening and closing of the discharge valve and employs vibration motors automatically for enhanced efficiency and safety. 433 wireless communication platform is established based on high-performance chips and efficient GFSK modulation, which leading to a reliable remote control by wireless controller.

3 On-site engineering demonstration application

3.1 Project background

A model of an earth-rock dam with scale of 1:5 was constructed to serve as a demonstration dam. with a top width of 3.0 m, height of 3 m, length of 10 m and slopes of 1:2 (upstream) and 1:3 (downstream). The dam was constructed by clay and filled in layers (0.25~0.3 m per layer) with compacting by rolling.

Based on the real leakage situation observed in the earth-rock dam and the need for engineering demonstration of leakage sealing, two concentrated leakage pipes and two sand-gravel leakage channels were installed inside the dam. Two concentrated leakage pipes, designated as Pipe 1 (with a 6 cm diameter) and Pipe 2 (with a 10 cm diameter), were simulated using polyvinyl chloride (PVC) pipes. These pipes were arranged in a straight line located below the upstream water level, with their inlet and outlet sections positioned 1.5 m away from the right and left bank walls of the dam. The height of these pipes was 0.5 m above the bottom of the embankment. The downstream outlet was equipped with a control valve.

Two sand-gravel leakage channels were constructed by gauze-wrapped gravel. These channels run through the upstream and downstream. Channel 1 was arranged in a zigzag shape below the upstream water level, it is a cross-section with diameter of 10 cm. The inlet and outlet sections were positioned 3.0 m away from the right bank wall of the dam and have a height of 1.0 m above the bottom of the dam. To simulate realistic leakage situation, a 10cm diameter PVC pipe was connected at the outlet of Channel 1 within a 0.8 m range, covered with a 5 cm thick soil layer. Channel 2, with a cross-section diameter of 15 cm, zigzagged below the upstream water level. The inlet and outlet sections were positioned 3.0 m away from the left bank wall of the dam and at a height of 1.5 m above the dam's bottom. A layer of sand soil ranging from 0.7 m to 1.4 m was placed at the outlet of Channel 2. It inclined downward by 10 cm towards the downstream and was topped with a 5 cm thick soil layer covered by geotextile fabric.

3.2 Leakage sealing task

At a water level of approximately 2.5 m, an engineering demonstration task was carried out to seal the inlets of leakage in the earth-rock dam based on the developed material feeding-hoisting equipment technology. To deal with the concentrated leakage pipes and sand-gravel leakage channels in the dam, the hoisting equipment was remotely positioned at the vertical water surface of the upstream seepage inlet by the coordinate information of the leakage points. Sealing material was then promptly deposited into each of the four seepage points to seal them one by one. In conjunction with the feeding-hoisting equipment, a shore-based crane was used. The crane's arm and rope were sufficient to position the hoisting equipment at the vertical area of the leakage point and even reach a depth of approximately 1.0 m underwater. After completing the work, the overall effectiveness of the seepage sealing was evaluated by comparing the downstream seepage flow rate before and after sealing.

3.3 Implementation process of leakage sealing

The sealing material was prepared on-site using sand and gravel, and then place in the tank, followed by battery charging, rope installation, GPS positioning, remote control of the hoisting equipment, and leakage sealing.

The detected planar coordinates of the four leakage inlet points (-6.85, 1.25), (-5.6, 2.80), (-4.80, 7.10), and (-6.85, 8.75) were entered into the wireless remote control handle for GPS positioning of the feeding-hoisting equipment. Then the remote-controlled hoisting equipment was positioned vertically above the leakage point on the water surface, and gradually descend until the discharge outlet was partially submerged. The discharge valve was turned on and the vibration-assisted discharge function was activated to enhance efficiency and ensure immediate sealing.

3.4 Downstream leakage percentage measurement

Concentrated leakage pipes

Considering the variations between two types of leakage passages, the downstream seepage volume is measured using a water meter since the concentrated leakage pipes exhibit a higher flow rate, while the triangular weir method is employed to the gravel seepage channel due to its lower water seepage volume. By comparing and analyzing the pre and post-sealing leakage volumes, the effectiveness of upstream surface leakage sealing in this project is determined.

Before the leakage, while valves of the pipe were opened to their maximum extent, allowing for the highest possible flow rate, the measured flow rates for pipeline diameters of 6 cm and 10 cm were recorded as 1933 ml/s and 3417 ml/s respectively, with corresponding flow velocities of 0.43 m/s and 0.68 m/s. However, there was a significant drop in the flow rate at the outlet of the downstream pipes after the sealing operation, the flow rates were measured to be 217 ml/s and 0 ml/s for pipeline diameters of 6cm and 10 cm after 5 minutes of sealing. The corresponding flow velocities were 0.08 m/s and 0 m/s. The sealing rates were determined to be 88.8% and 100% for the respective pipelines. This also suggests that pipeline 2 had a higher blockage rate, indicating more accurate positioning of the hoisting tank.

Sand-gravel leakage channels

In order to assess the variations in flow rate through the sand-gravel leakage channels, water level heights before and after sealing were measured at downstream right-angled triangular weir. The results demonstrate a significant reduction in flow rate through both sand-gravel leakage channels after conducting sealing work. Channel 1 experienced a decrease from 67 ml/s to 9 ml/s, representing an 86.6% reduction, while Channel 2 decreased from 86 ml/s to 16 ml/s, indicating an 81.4% reduction. These findings highlight the effectiveness of the sealing in reducing water leakage through the sand-gravel leakage channels.

It can be concluded that the demonstration work has made excellent progress in effectively sealing leaks. The implementation of feeding-hoisting equipment at the upstream inlet has demonstrated its adaptability to different challenging conditions. It has shown high construction efficiency and achieved a successful sealing effect. This solution meets the emergency response needs and enhances the level of equipment utilization in on-site construction.

The above research shows that the demonstration work is successful, and the technology has been used to instantaneously block different types of leakage inlets, and efficient engineering results have been achieved. The research results meet the needs of emergency rescue, improve the mechanization level of on-site construction, ensure the engineering safety of earth-rock dams, and have significant technical, economic and social benefits in flood control and disaster reduction.

4 Conclusion

A feeding-hoisting equipment and techniques are developed for effectively sealing leak inlets. The feeding-hoisting equipment combines technologies as precise liquid level monitoring, GPS system positioning, rapid material feeding, remote wireless real-time control and so on, thus it features functions including liquid level monitoring, GPS positioning, automatic material feeding, wireless control and so on. It effectively meets the emergency sealing needs for leakages in earth-rock dams. In on-site engineering demonstrations, the leakage sealing operation conducted at the upstream inlet achieved sealing rates of 88.8% and 100% for two concentrated leakage pipelines, and sealing rates of 86.6% and 81.4% for two sand-gravel leakage channels, indicating that the construction efficiency is high, and the sealing effect is excellent. In the future, further research work can be carried out to expand the application scenarios and scope from the aspects of new plugging materials, the scale of lifting tanks and the way of empty lifting.

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References

1. Hunter L E, Powers M H. (2008) Geophysical investigations of earthen dams: An overview. In: Symposium on the Application of Geophysics to Engineering and Environmental Problems 2008. Society of Exploration Geophysicists, pp: 1083-1096. https: //doi. org/ 10. 4133/ 1.2963216.
2. Zong Y, Chen X. (2000) The 1998 flood on the Yangtze, China. Natural Hazards, 22: 165-184. https://doi.org/10.1023/A:1008119805106.
3. Cui H, Lu Q, Chen J, et al. (2021) Causes analysis of typical piping dangers of main levees of Yangtze River and countermeasures. Express Water Resources & Hydropower Information, 42(01):54-58. https://doi.org/10.15974/j.cnki.slsdkb.2021.01.010.

4. Fry J J. (2016) Lessons on internal erosion in embankment dams from failures and physical models. In: Proc., 8th Int. Conf. on Scour and Erosion (ICSE8), pp. 41-58. https://www.researchgate.net/publication/313803802_Lessons_on_internal_erosion_in_embankment_dams_from_failures_and_physical_models.
5. Torabi Haghighi A, Tuomela A, Hekmatzadeh A A. (2020) Assessing the efficiency of seepage control measures in earthfill dams. Geotechnical and Geological Engineering, 38: 5667-5680. https://doi.org/10.1007/s10706-020-01371-w.
6. Lee J Y, Choi Y K, Kim H S, et al. (2005) Hydrologic characteristics of a large rockfill dam: Implications for water leakage. Engineering Geology, 80(1-2): 43-59. https: //doi. org/ 10. 1016/j.enggeo.2005.03.002.
7. Wang Y S, Liu S H. (2005) Treatment for a fully weathered rock dam foundation. Engineering geology, 77(1-2): 115-126. https://doi.org/10.1016/j.enggeo.2004.08.006.
8. Wang Y, Han M, Li B, et al. (2022) Stability evaluation of earth-rock dam reinforcement with new permeable polymer based on reliability method. Construction and Building Materials, 320:126294. https://doi.org/10.1016/j.conbuildmat.2021.126294.
9. Luo A N, Liu H P, Song H X et al. (2006) Hoist technology of a new agile naval gun shell-feeding system. Journal of Harbin Institute of Technology (English Edition), 5(2):55-59. https://www.cqvip.com/QK/71135X/201107/22621656.html.