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Research and Application on Seepage Detection and Repair of Anti-Seepage System for Earth-Rockfill Dam with Asphalt Concrete Core

Wei Min*, Zhou Heqing, Cui Dongdong

Changjiang Institute of Survey, Planning, Design and Research, Wuhan, China

Email address:
602716791@qq.com (Wei Min)

*Corresponding author

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Abstract: The asphalt concrete core wall has been widely used in various kinds of high dams because of its good performance of anti-seepage, deformation and rapid construction speed. In recent years, the leakage phenomena of some asphalt concrete core dams begin to occur, endangering dam safety. To determine the leakage status, location and access of the bituminous concrete core, drilling holes are arranged in the upper and lower reaches of the bituminous concrete core wall. With water as the medium, underwater sonar, color TV observation in hole, consecutive test of tracer, water level analysis in the dam body and physical detection and other methods were used for detection. Then the leakage state of asphalt concrete core wall of dam body is comprehensively analyzed and determined according to a variety of test results. At the same time, aiming at the problems existing in the direct repair of asphalt concrete core wall in the dam body, repairing project of concrete seepage cut-off wall, controlling grouting repair scheme, as well as its key control factors, construction process and technical parameter indexes were studied. Through the application of multiple engineering examples, the treatment effect was remarkable, which can provide a reference for the treatment of similar engineering problem.

Keywords: Earth-Rockfill Dam with Asphalt Concrete Core, Seepage Detection, Anti-Seepage System, Repair

1. Introduction

The use of bituminous concrete core wall to prevent seepage of earth-rock DAMS began in the 1930s, because of the asphalt concrete impervious performance is good, ability to adapt to the deformation is stronger, seismic self-healing ability is excellent, construction speed is fast, and has simple structure and so on [1], many bituminous concrete core wall DAMS have been built at home and abroad. So far, the number of asphalt concrete core wall dam that has been built and under construction is more than 100, among them, the Finstertal dam in Austria is the highest asphalt concrete core wall rockfill dam in the world, which is 149m high and the vertical height of it is 96m [2]. In the 1970 s in China started to build the asphalt concrete core wall dam, to the end of this century, has built dozens of asphalt concrete core wall dam. In the 21st century, the construction of bituminous concrete core wall rockfill DAMS in China has entered a new stage. A number of large and medium-sized reservoirs that use bituminous concrete core wall DAMS have been built successively. The characteristics of some bituminous concrete core wall DAMS in China are shown in table 1 [3].

Bituminous concrete core wall dam is generally made up of upstream dam shell, upstream transition layer, asphalt concrete core wall, downstream transition layer and downstream dam shell. The asphalt concrete core wall in the dam is very thin relative to the dam body. To improve the stress condition of the core, the transition layer is usually set on the asphalt concrete core wall and the downstream side. In addition, the construction of dam body is an extremely important and complex process. Asphalt concrete core wall has high requirements on construction technology and technical standards, and strict quality control requirements. The construction process of core wall and dam should be coordinated with each other. Since the construction of Majiagou reservoir in Chongqing in 2002, there has been obvious leakage of the dam, with the maximum leakage of 70 L/s [4]. After the completion of water storage, the dam foot leakage of Holinghe reservoir in Inner Mongolia occurred, and local water and sand production occurred, with the maximum leakage volume reaching 136.8L/s. In the process of creating Sichuan Dazhuhe reservoir and impound, downstream of the dam saturation line is higher, large amount of seepage, when water storage close to the normal level, the dam axis parallel to the downstream dam slope of dam infiltration zone, and form the local flow shape [5]; At the beginning of water storage of the bituminous concrete core rockfill dam of a reservoir in yangjiang, Guangdong, leakage occurred at the foot of the dam. With the water storage level rises, the amount of leakage increases continuously, and the maximum amount of leakage is about 710L/s. The leakage of asphalt concrete core dam often affects the normal operation of the reservoir and even endangers the safety of the dam. Therefore, it is necessary to strengthen the leakage detection and anti-seepage body repair of concrete core dam.

Table 1. *Characteristics of some vertical bituminous concrete core wall DAMS in China.*

Name	Site	Height (m)	Length (m)	Thickness of core wall (cm)	Completion year
Kanerqi dam	Xinjiang	51.3	312.0	40~60	2001
Dongtang dam	Chongqing	48.0	145.5	50	2003
Majiagou dam	Chongqing	38.0	267.6	50	2002
Maopingxi dam	Hubei	104.0	1840.0	50~120	2005
Yele dam	Sichuan	125.5	411.0	60~120	2005
Nierji dam	Nenjiang	41.5	1360.0	50~70	2005
Huolin river dam	Inner Mongolia	26.1	1230.0	50	2008
Pingdi dam	Guangdong	43.4	395.0	50~80	2007
Longtoushi dam	Sichuan	58.5	365.0	50~100	2008
Dazhu river dam	Sichuan	61.0	206.0	40~70	2011

2. Leak Detection of Bituminous Concrete Core Wall Dam

The leakage of bituminous concrete core wall dam should first be analyzed for its causes, properties and location. To set up inside the dam leakage of asphalt concrete core wall, there is no single, effective and reliable detection methods and techniques, more commonly in mind, the downstream side of the layout of drilling hole on the wall, with water as medium, using underwater sonar, hole color TV observation, tracer connectivity test, analysis of the water level in the dam body and geophysical detection method, based on the results of testing and comprehensive analysis, determine the leakage situation.

2.1. Underwater Sonar Detection

Underwater sonar detection is to use the excellent conduction characteristics of sound waves in water to measure water leakage field. Underwater sonar detection is used to collect the heart wall, in the cross section of the downstream and vertical drilling core wall leakage current sound field, through analyzing seepage field mathematical model of flow velocity measurement of dam body seepage channel and its vertical distribution, combining with the parts of the leakage flow rate, core wall dam leakage strength can be partitioned defined by the plane and vertical.

2.2. Color TV Observation in Hole

In order to obtain the intuitive information, the flow direction of the leakage flow can be determined and the initial flow velocity can be estimated, so as to determine the distribution height of the leakage site. The digital TV function of the whole hole wall is used to collect the complete image information of the flow state of the leakage flow in the hole wall and the hole.

2.3. Consecutive Test of Tracer

Connect field tracer test mainly USES in the wall, the downstream hole drilling hole points of points on the tracer, downstream of the heart wall drilling hole and the toe drain observation its escape, for convenience of observation and analysis, appropriate sequence in the toe drain water point of observation point arranged in advance. Through a field tracer test results analysis to determine the flow of dam seepage flow, estimated leakage flow rate, and combined with the comprehensive analysis of the test method of achievements mentioned above determine the core wall parts and its leakage.

2.4. Analysis of Water Level in Dam

According to the dam body of all kinds of drill hole water level observation data, draw the dam water level contour map, the analysis of the core wall dam before and after the change of water level and the corresponding relationship between mainland, core wall leakage area generally formed in the upstream side close to the heart wall local land "funnel", weak leakage or leakage is not obvious, water levels have no obvious change; The lower side of the core wall is opposite, and the high water level of the end hole indicates that the place is supplied with large leakage. By analyzing the contour map of the water level before and after the core wall, we can determine the leakage location and its distribution.

2.5. Geophysical Detection

Geophysical detection can be performed by seismic imaging or acoustic testing.

The seismic image is generated by excitation of seismic waves at the top of the asphalt concrete core wall, and the seismic waves will generate a certain amount of energy when they encounter the interface in the process of propagation of the medium in the heart wall. In the heart wall when encountered in the process of media interface to produce energy of reflected wave and the reflected wave amplitude, frequency, speed information such as the difference of interface depth calculation, analysis and structure form; Sound wave test is carried out through single hole or cross-hole in the borehole of the heart wall to test the wave speed of different frequencies.

3. Anti-seepage System Repair Plan

The following difficulties exist in the direct repair of asphalt concrete core:

(1) the bituminous concrete core wall is placed inside the dam body, and the current detection method is difficult to accurately determine the specific location, distribution and status of all leakage channels of the core wall.

(2) the thin asphalt concrete core wall structure, thickness, generally within 1.0 m, if the borehole wall grouting treatment, drilling hole inclination accuracy requirement is high, the difficulty is great, slightly may break through core wall carelessly, cause damage;

(3) because it is difficult to combine asphalt concrete and grouting materials closely, grouting treatment of core wall is extremely difficult; The thermal asphalt can be applied to the top 1m depth of the core, but not to the bottom of the core.

Because of asphalt concrete core wall dam itself cannot directly, effectively repair, considering structure characteristics of asphalt concrete core wall dam on the distribution of the core wall leakage passage, study on seepage control system repair in the upstream side, key research setting concrete cut-off wall and control grouting scheme.

3.1. Study on Repairing Project of Concrete Seepage Cut-off Wall

In the 1950 s, the introduction of concrete cut-off wall construction technology in China, the early main use percussion drill hole, into the wall thickness of 0.8 ~ 1.0 m, 80 s introduced hydraulic grab, slot milling machine into a variety of slot method, wall depth will become more and more deep. By setting up a concrete wall upstream of the asphalt concrete wall to repair the dam system, it provides possibility to solve the problem of the wall of asphalt concrete.

3.1.1. Axis Layout of Impervious Wall

The upper side of the core wall of the dam body is provided with a transition layer, and the dam shell is filled with rockfill or slag. The concrete seepage prevention wall is installed on the upstream side of the dam core wall, and its axis layout should take into account the following factors:

(1) considering the dam shell structure, properties and transition layer thickness, cut-off axis in upstream side wall suitable location arrangement, and the wall into a trough, prevent leakgrout and collapse hole, avoid the construction wall cause adverse effect;

(2) the construction need to dismantle the top structure, forming a certain width of the construction platform to meet built blastholes slots, slag charge transportation construction requirements, its axis layout should consider to try to reduce the height of the excavation of dam;

(3) the axis of the seepage prevention wall should be arranged as close as possible to the core wall, so as to avoid the deformation and stability of upstream dam slope caused by mechanical load and the effect of channel hole mud during construction.

(4) The end of the axis of the seepage wall should be connected and closed with the original seepage prevention system of the dam.

3.1.2. Materials and Their Physical and Mechanical Indicators of the Wall

In the mid 1980s research and application of plastic concrete cut-off wall, some common understandings on its properties [6], in the 90 s before the construction of diaphragm wall concrete, and the most used for clay of already built cut-off is about 76% [7]. Considering that some local materials are used as wall materials in some projects, the properties and general applicable conditions of clay concrete and plastic concrete are listed in table 2. The seepage prevention wall is set up in the asphalt concrete core wall dam. The following factors are mainly considered in the selection of wall materials:

(1) the anti-seepage grade, durability and allowable seepage slope of the seepage prevention wall should meet the needs of seepage treatment of the dam body;

(2) the physical and mechanical indexes of the wall shall meet the requirements for safe operation of the wall under stress. Wall stiffness modulus of elasticity, the differences and the dam material, load, under the action of water in the water wall tensile stress may be produced, especially the deformation of the dam itself is not yet stable and high dam wall, should be the wall stress and strain calculation analysis, carefully to determine the wall materials and their physical and mechanical indexes.

Table 2. *General scope of application about Material properties of clay concrete and plastic concrete cut-off wall.*

Kind	Collapsed slump (cm)	Diffusion degree (cm)	Compressive strength (MPa)	Elastic Modulus (MPa)	Impermeability grade	Osmotic coefficient (cm/s)	Permissive permeability gradient	Density (t/m^3)
Clay Concrete	18~22	34~40	7~12	12000~20000	W4~W8	$\leq 8.8\times10^{-9}$	80~150	2.3~2.4
Plastic concrete	18~22	34~40	1.5~5	300~2000	-	10^{-6}~10^{-8}	50~80	2.1~2.3

3.1.3. Thickness of the Wall

The thickness of impervious wall is mainly determined according to the anti-seepage property and construction conditions of the wall. Meet the thickness of the wall permeability resistance, lower the head in the cut-off wall and wall body allows penetration ratio calculate and determine the hydraulic gradient, at the same time considering the wall deep diaphragm wall and wall curtain grouting under construction should be embedded in the wall grouting steel pipe and other factors.

3.2. Study on Controlling Grouting Repair Scheme

"The design of the asphalt concrete panel and the design of the heart wall" is required to make the transition material dense, hard, resistant to weathering, resistant to erosion, particle grading continuous, the maximum size of the maximum size of 80mm, less than 5mm, less than 5mm, less than 5mm, less than 5mm, less than 5%[2]. In view of that fine, loose and easily collapse holes of the transition material layer, the filling of the transition layer, grouting slurry, drill irrigation method, permeation coefficient of grouting curtain and permeation coefficient of the grouting curtain and the thickness of permeation are studied.

3.2.1. Irritability of Transition Layer

The material composition, properties, permeability and grain gradation of the upper transition material layer of the inner wall should be known first. Whether the transition material layer can accept effective grouting of a certain grouting material can be preliminarily determined by the ratio of irrigability. Moreover, different grouting slurry can be selected according to the permeability coefficient of the transition material layer [8]. The engineering practice indicates that the cement clay grout with the particle content of less than 0.1mm can be injected effectively. The grain size of ordinary Portland cement is more than d95, which is less than 80 [8]. Clay (or bentonite) has the characteristics of high fineness, high dispersibility and high stability. The addition of clay into the cement can increase the stability and irrigation of thegrout and avoid pipe plugging accidents [9].

3.2.2. Grouting Slurry

Seldom in transition layer grouting control experience both at home and abroad, our country in the 1950 s in the miyun reservoir, yuecheng reservoir engineering foundation layer for curtain grouting test and application of core wall transition layer control grouting slurry exist a certain differences with the cover layer, model layer grouting success experience, according to the characteristics of transition layer of asphalt concrete core wall dam key for plaster grout and mixture ratio of grout, stable performance research in laboratory and in-situ grouting test, put forward suitable for transition layer material mechanical performance index of the grouting slurry, see stable 3.

Table 3. *Performance indexes of paste grout and mixed stable grout.*

Kinds of grout	Performance of grout				Performance of set strength	
	Density (g/cm^3)	Syneresis rate (%)	Shear yield strength τ_0 (Pa)	Plastic viscosity η (Pa·S)	Osmotic coefficient (cm/s)	Compressive strength (MPa)
Colloidal grout	≥1.58	<5	20~35	0.1~0.3	≤1.0×10^{-6}	≥7.5
Mixed stable grout	≥1.40	<5	<20	<0.10		≥12.5

3.2.3. Drilling and Grouting

In order to improve the drilling efficiency and drilling quality, the wall protection drilling method is adopted for the characteristics of hard texture, fine particles, continuous gradation and loose gradation of the transition layer material, and easy collapse of the hole wall when drilling. In order to avoid the adverse effect of the mud skin formed by the hole wall on the control grouting of the transition material, casing wall drilling, water drilling or air washing holes are adopted to drill the hole. In case of deep stratum or large gravel, the method of percussive rotary follow - pipe drilling is adopted to facilitate construction and high efficiency. Grouting in the transition layer can be grouted by hole closed method and sleeve valve pipe method. Drilling and grouting are carried out from top to bottom in the transition layer by grouting with closed orifice, and the drilling and grouting process is carried out alternately. Every grouting is closed at the orifice, and the grouting section can be refilled with good grouting quality. Method of sleeve valve tube grouting first drilled grouting hole, hole down into a hole grouting tube (tube), between grouting pipe and wall of hole to fill in a special packing, then install double grout in the grouting pipe plug segments, grouting method of sleeve valve tube grouting holes to drill out, a continuous grouting tube in the flower, can be segmented isolation using different grouting pressure and adjust the filling grout.

3.2.4. Control Indicators of Grouting Curtain

(1) permeability coefficient of grouting curtain

The design specification for RCC earth-rock DAMS requires that the permeability coefficient of homogeneous earth DAMS shall not be greater than 1 x 10^{-4}cm/s, and that of clay core walls shall not be greater than 1 x 10^{-5}cm/s [10]. The permeability coefficient of the combined impermeable body formed by the interlayer grouting curtain and the asphalt concrete core wall can refer to the requirement of impermeability of the impermeable body of earth-rock dam. The anti-seepage effect of the grouting curtain formed in the sand and gravel material has a large relationship with the genetic conditions of the irrigated layer and the irrigated capacity. For example, the seepage coefficient of the grouting test in the gravel overburden in xiabandi reservoir in xinjiang is 1.8 x 10^{-4} ~ 1.7 x 10^{-6} cm/s. The curtain permeability coefficient of miyun reservoir is 7 * 10^{-4} ~ 6 * 10^{-5}cm/s in the sand and gravel layer [8]. It is difficult to analyze the implementation effect of similar projects in China and according to the current construction experience, the permeability coefficient of the curtain body after cement and clay grouting in the transition material layer is less than 1 * 10-5cm/s. Considering that seepage safety and seepage rate of dam body are satisfied, it is proposed that the seepage coefficient of grouting curtain body should not be greater than 5 * 10-5cm/s in the transition material layer.

(2) allowable penetration ratio and thickness of grouting curtain

The cement clay grouting of the gravel and gravel cover layer allows the penetration ratio to drop from 3 to 6, that of miyun reservoir and yue cheng reservoir is 6.0, that of France is 8.3, and that of India is 10.0 [8]. The upper transition layer of the core wall is made of gravel or gravel, and the allowable permeability drop of grout forming curtain is 6 ~ 10. The grouting curtain body and the bituminous concrete core wall form a joint impermeable body, whose thickness can be determined according to the difference between the upper and lower water heads of the impermeable body and its allowable permeability drop.

4. Engineering Application Examples and Effects

The majiagou reservoir dam in chongqing is a bituminous concrete core rockfill dam with a maximum height of 38.0m, a dam with a length of 267m, and an artificial limestone transition material of 2m thick on the bituminous concrete core wall and the downstream side, with a maximum grain size of 80mm. At the beginning of reservoir impoundment, there was obvious leakage in the dam, which increased with the increase of reservoir water level, and the maximum leakage was about 70L/s. Various methods were used to detect the core wall of the dam body, and the results showed that there were local passageways in the core wall of bituminous concrete. Through research and demonstration, the anti-seepage system of the dam body was restored by using clay concrete anti-seepage wall with a wall thickness of 60cm in the upstream transitional material of the heart wall. Construction commenced in May 2008, and the inspection was completed at the end of December of the same year. The leakage volume after the repair and treatment of the anti-seepage system was about 5.2L/s.

The dam of dachuhe reservoir in sichuan province is a bituminous concrete core stone slag dam with a maximum height of 61.0m and a maximum length of 206m on the dam roof. The asphalt concrete core wall and the downstream side are respectively installed with a thickness of 3.0m transition layer. The dam was completed in July 2011. When the water storage was close to the normal water level, the downstream slope of the dam appeared the flood belt of the parallel dam axis and formed the local flow pattern. The project started in April 2014 and was completed in the middle of June of the same year. After the repair and treatment of the anti-seepage system of the dam body, the reservoir has been running normally with water storage and about 1.4L/s leakage of the dam foot.

The dam of a reservoir in Yangjiang of Guangdong province is a rockfill dam with asphalt concrete core wall, the highest dam is 43.4m high. Asphalt concrete core wall, the downstream side set two thick 3.0 m Ⅰ and Ⅱ transition, transition Ⅰ design maximum particle size of 80 mm, particle content is more than 20% less than 5 mm, continuous gradation, porosity is less than 20%, the transition material Ⅱ design maximum particle size of 150 mm, less than 5 mm particle content is more than 20%, continuous gradation, porosity is less than 22%, dam shell adopts the block stone filling. At the beginning of the construction of the dam, there was leakage at the foot of the dam, and the maximum leakage was about 710L/s. Through drilling holes in the core wall of the dam crest and the downstream transition layer, the distribution of the leakage channel of the core wall is determined by the comprehensive test results by means of hole color TV observation, tracer connection test, water level observation and water injection test. The experimental study of indoor slurry and field grouting demonstrated and determined the scheme of controlling grouting to repair the dam anti-seepage system in the transition material layer. The construction started in September 2013 and was completed in January 2015, with a total drilling and filling amount of about 55,600 m. After the treatment, the reservoir successfully filled water to the normal water level, and the leakage of dam foot dropped to 6L/s, it is a remarkable result.

5. Conclusion

Some of the finished bituminous concrete core DAMS in China appear leakage, which affects the normal function of reservoirs. As the concrete location, distribution, quantity and state of the passageway of the asphalt concrete core cannot be accurately measured, and it is difficult to directly repair the core itself, the concrete seepage cut-off wall or control grouting repair scheme is adopted to repair the impervious system. This paper summarizes the method of detecting the leakage of asphalt concrete core wall, the scheme of anti-seepage system repair and its influencing factors, and summarizes several engineering application examples and their effects, which can provide a reference for similar engineering repair.

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