Journal of Civil Engineering and Urban Planning (2023)
Clausius Scientific Press, Canada

DOI: 10.23977/jceup.2023.050702
ISSN 2616-3969 Vol. 5 Num. 7

Research on Grouting Reinforcement Construction Technology of Reservoirs in Water Conservancy Project Construction

Li Yu[1,a,*], Gaoyang Sui[2,b]

[1]*Jinan Hydrological Centre, Jinan, Shandong, China*
[2]*Shadnong Survey and Design Institute of Water Conservancy Co, Ltd, Jinan, Shandong, China*
[a]*423636050@qq.com*, [b]*1273912720@qq.com*
[*]*Corresponding author*

Keywords: Water Conservancy Project Construction, Reservoir Grouting Reinforcement, Construction Technology, Specific Discharge Reduction

Abstract: In order to improve the service life of reservoirs and reduce the risks associated with their use in water conservancy projects, this study focuses on the curtain grouting reinforcement construction technology applied in the construction of reservoirs in a specific region. The physical and mechanical properties of the geological conditions of the dam foundation site of the reservoir are analyzed, taking into account factors such as construction period, cost, and desired treatment effects. The curtain grouting reinforcement technology is adopted, which involves five steps: drilling, flushing, hydraulic testing, grouting and sealing, and special case handling, to reinforce the leakage of the reservoir. The reliability of the reinforced anti-seepage measures is analyzed using finite element models. The experimental results show that the construction results of each step meet the construction standards. The permeability coefficients at different locations are within the allowable range of 8.9×10-6cm/s, and the results of the specific discharge of the soil layers are smaller than the allowable decrease in specific discharge. The construction effect meets the reinforcement requirements.

1. Introduction

Reservoirs are hydraulic engineering structures used for flood control, water storage, and water flow regulation. Their main functions include irrigation, power generation, flood control, and more. They can be classified into small, medium, and large-scale reservoirs based on their size [1]. During the construction of reservoirs, it is important to ensure the impermeability of the dam and other components, in order to reduce the infiltration of groundwater and minimize its impact on the performance of the dam [2]. Therefore, the grouting reinforcement method is widely applied in reservoir construction. This method involves injecting a cementitious grout into natural or artificially formed cracks or voids, using means such as air pressure or hydraulic pressure [3]. The purpose is to consolidate loose soil structures and enhance the dam's physical performance by providing it with certain strength and impermeability. Grouting reinforcement generally includes filling grouting, permeation grouting, injection grouting, and rotary grouting [4]. To analyze the construction effectiveness of grouting reinforcement in reservoir projects in detail, this article takes a specific reservoir project in a certain region as an example and conducts relevant research.

2. Grouting Reinforcement Construction Technology for Reservoirs

2.1. Project Overview

In order to study the construction effectiveness of grouting reinforcement technology in reservoir projects, the article focuses on the construction of a reservoir project in a specific region and conducts relevant analysis. The total design capacity of this reservoir project is 3.3 million cubic meters, and it is a small reservoir that integrates multiple functions such as flood control, irrigation, and power generation. The designed dam height of the reservoir is 41.64 meters, with a dam crest length of 150 meters, a width of 5 meters, and the controlled catchment area above the reservoir dam site is close to 20 square kilometers.

During the construction of the reservoir dam, the foundation base is composed of weakly weathered basalt. Under the erosion of rainwater, significant seepage phenomena occur in various positions such as the dam body, dam shoulder, and contact zone, resulting in multiple locations with seepage, primarily infiltration and jetting. This directly impacts the engineering quality of the dam and affects the normal functioning of the reservoir [5]. The physical and mechanical properties of the dam foundation rock mass were determined through sampling tests, and the details of the rock's physical and mechanical properties at the dam site is shown in Table 1.

Details of the Physical and Mechanical Properties Parameters of Table 1 Dam Site Rocks.

Table 1: Dam Site Rocks

Parameter Names		Numerical Values
Densityg/cm3	Particle Density	2.948
	Dry Density	2.917
Water Absorption Rate/%	Natural	0.21
	Saturated	0.3
Compressive Strength/Mpa	Natural	75.02
	Saturated	63.01
Tensile Strength/MPa	Natura	7.78
	Saturated	5.41
Elastic Modulus/Gpa	Dry	58.97
	Saturated	55.96
Poisson's Ratio		0.273
Longitudinal Wave Velocity m/s	Dry	5544
	Saturated	5793

Due to the occurrence of leakage at multiple locations in the dam body, the normal functioning of the reservoir is somewhat affected. Therefore, it is necessary to carry out anti-seepage reinforcement measures. However, in the process of treatment, considerations such as construction period, economic factors, and treatment effectiveness need to be taken into account.

2.2. Grouting Reinforcement Construction Technology

Based on the leakage situation of the reservoir project and the reinforcement requirements, the article adopts the curtain grouting reinforcement technology to address the reservoir's leakage issues. This reinforcement method has the characteristics of small construction scale, short construction period, strong adaptability, and high economic efficiency [6].

The construction technique primarily involves single-row holes, double-row holes, and triple-row holes. The construction is carried out in a sequential manner based on the principle of subdivision encryption. After each unit is completed, the construction results are inspected. The construction technique consists of multiple steps, as described in detail below:

2.2.1. Drilling

Drilling is the foundation of curtain grouting reinforcement construction. It mainly involves measuring the construction site using the grouting hole layout plan as a reference [7]. Based on this, the construction hole positions are determined and used as control points. Depending on the type of holes, such as guide holes, inspection holes, and grouting holes, appropriate drilling methods and equipment are selected, ensuring that the deviation between the construction positions and the design positions of the holes is not greater than 10cm.

Hydraulic rotary drilling machines are mainly used for drilling in this study. During the construction process, it is necessary to ensure the vertical and horizontal alignment of the drilling, and the drilling should follow the grouting sequence. The calculation formula for the deviation distance of the drilling is:

$$d = \sqrt{\left(\sum L \sin\theta \sin\alpha\right)^2 + \left(L \sin\theta \sin\alpha\right)^2} \tag{1}$$

In the equation:

represents the projected length inside the borehole.

represents the azimuth angle of the borehole deflection.

represents the inclination angle of the borehole deflection.

The allowable tolerances at the bottom of the hole are detailed is shown in Table 2.

Table 2: Details of Allowable Deviation at the Bottom of the Hole

Serial Number	Depth of Hole/m	Allowable Deviation/cm
1	20	0.25
2	30	0.50
3	40	0.50
4	50	1.15
5	60	1.50

2.2.2. Borehole flushing

After the completion of drilling, a large flow of water is used to flush the borehole. The flushing method for fractures is pressure flushing. After the backflow becomes clear, continue flushing for 10 minutes to ensure that the sediment thickness inside the borehole is less than 20 cm. The total flushing time should not exceed 30 minutes. If there are grouting holes adjacent to the drilling location within 24 hours of grouting construction, flushing is not conducted for those holes. Crack flushing is carried out immediately after the completion of flushing.

2.2.3. Water pressure test

A single-point method is used for standard water pressure testing of pilot holes and inspection holes, and a simplified water pressure test is conducted for grouting holes.

The formula for calculating the water pressure test is: Please provide the missing information for the formula:

$$q = \frac{Q}{P \times L} \tag{2}$$

n the formula:
represents permeability.
represents the final injection flow rate.
represents pressure.

2.2.4. Grouting and sealing

The grouting construction is carried out by closing the borehole, circulating within the hole, and performing segmented grouting from top to bottom. The grout is prepared uniformly by the grout plant according to the designed water-cement ratio. It is then transported to the construction site through the slurry pipeline and used for grouting after secondary modulation. To avoid leakage during grouting, the grout plug should be positioned 0.5m above the bottom of the already grouted section, and the grouting pressure should be controlled. Overpressure or underpressure conditions can both affect the grouting effect. Therefore, the calculation of grouting pressure is based on the test results of the backflow pipe pressure gauge at the borehole, aiming to obtain more accurate injection pressure. The calculation formula is:

$$P = P_0 + mD + k\gamma h \times 0.001 \times 0.1 \tag{3}$$

In the formula:
represents the initial pressure value.
represents the designed depth of the curtain.
represents the allowable pressure increase.
represents the grouting construction coefficient.
represents the unit weight of the soil.
represents the thickness of the soil mass.
The formula for determining the reading of the backflow pipe pressure gauge is:

$$P_1 = P - \gamma h \times 0.001 \times 0.1 \tag{4}$$

Based on the above formula, the grouting pressure value is determined, and the grouting construction is carried out based on this pressure value. On this basis, pressure sealing is performed and construction parameters are recorded.

2.2.5. Handling Special Conditions

During the entire grouting construction process, special conditions need to be addressed. One of them is the densification of the drilling. The primary purpose is to ensure the continuity of the curtain. The densification treatment is determined based on the actual construction conditions [8]. The details of the densification drilling carried out for this project are shown in Table 3.

Note: The translation assumes that "heavy curtain" refers to a curtain wall or similar structure. If " heavy curtain " has a different meaning or context, please provide more information for accurate translation is shown in Table 3.

Table 3: Details of Densification Drilling

Serial Number	Encryption Details
1	Connection positions of straight and oblique curtains within the same grouting cavity
2	Positions within the grouting cavity face and the range of the upper grouting cavity's slope
3	Position of the concentrated segment with high grout consumption
4	Positions where curtain grouting construction did not meet the requirements due to geological reasons

2.3. Reinforcement Reliability Calculation Model

After completing the grouting reinforcement construction of the reservoir curtain according to the above steps, the reliability of the reinforced impermeable wall was analyzed using a finite element model in this study. In the reliability analysis, the weight and density of the reinforced wall were the main factors considered [9]. In order to take into account the time-dependent nature of the impermeable wall, the reliability analysis process was transformed into random variables. The time range for reliability analysis is the analysis reference period converted to. The calculation formula for the maximum distribution of the reliability of the impermeable wall after reinforcement within is as follows:

$$F_t(x,t) = \exp\left\{-\eta t\left[1 - F_M(x)\right]\right\} \tag{5}$$

In the equation: represents the time interval parameter; represents the result of the maximum distribution of reliability.

According to the finite element calculation theory, the mean and standard deviation of the reliability of the reinforced impermeable wall are calculated, and the probability distribution parameters and are obtained using maximum likelihood estimation. At this point, the expression for is as follows:

$$F_t(x,t) = \exp\left\{-\exp\left[\frac{-(x - T_t)}{U_t}\right]\right\} \tag{6}$$

When the value is at its maximum, the stability of the reinforced impermeable wall can be determined through the safety ratio reduction method. If the permeability ratio of the reservoir dam soil layer is reduced to, and the allowable reduction ratio is, when, it indicates that the impermeable wall loses stability under the condition of water flow infiltration.

3. Experimental Results Analysis

3.1. Construction Effect Inspection

After completing the construction of the reservoir curtain grouting reinforcement technology, the construction results are first inspected. The grouting construction inspection results are shown in Table 4.

Based on the inspection results in Table 4, it can be determined that the construction results of each construction step after completing the reservoir grouting reinforcement construction meet the construction standards. Therefore, the construction quality can be guaranteed.

Table 4: Details of Grouting Construction Parameters

Inspection Content Inspection	Inspection Standard	Actual Construction Results
Grouting Hole Elevation/m	547.65~548.85	548.02
Drilling Depth/m	15.95~18.60	16.85
Concrete Thickness/m	0~0.55	0.44
Rock Penetration Depth/m	15.5~18.75	17.22
Average Length of Grouting Section/m	2.25~11.52	6.52
Number of Grouting Holes/pcs	≥300	348
Grouting Pressure/Mpa	0.42~2.31	1.61

3.2. Permeability Testing

The permeability results of three inspection holes at three positions, namely dam body, dam shoulder, and contact zone, were randomly obtained 14 days after the curtain grouting construction. The results are shown in Table 5.

Table 5: Permeability Test Results for Inspection Holes

Test Location		Standard Permeability Coefficient/ $\times 10^{-6}$cm.s	Experimental Result/ $\times 10^{-6}$cm.s
Dam Body	Hole1	≤8.9	1.42
	Hole2		2.64
	Hole3		2.55
Dam Shoulde	Hole1		1.97
	Hole2		1.22
	Hole3		3.55
Contact Zone	Hole1		4.46
	Hole2		2.98
	Hole3		4.06

Based on the inspection results in Table 5, it can be determined that after the curtain grouting reinforcement treatment at the permeable positions of the reservoir, the permeability coefficient results at different positions are within the range of 8.9×10-6 cm/s, meeting the construction application standards. Therefore, the grouting construction has good effectiveness and meets the construction requirements of the project.

3.3. Stability Analysis of Reinforcement Construction

After 14 days of curtain grouting reinforcement construction, the results of the specific discharge of each inspection hole were obtained. The obtained results were compared with the allowable specific discharge results to assess the stability of the reservoir after the curtain grouting reinforcement construction. The results are shown in Table 6. Due to space limitations, only the test results of 10 randomly selected holes are presented.

Based on the inspection results in Table 6, it can be determined that after the curtain grouting reinforcement construction, the specific discharge results of the soil layers in the inspection holes at different positions of the reservoir's impermeable wall are all smaller than the allowable specific discharge results. Therefore, the stability of the impermeable wall after the grouting construction is good, and the reliability of the construction results is high, improving the reservoir's resistance to penetration.

Table 6: Stability Results of Reinforcement Construction

Hole Number	Allowable Gradient	Actual Result
1	0.25	0.11
2		0.09
3		0.14
4		0.07
5		0.11
6		0.13
7		0.15
8		0.08
9		0.09
10		0.06

4. Conclusion

After the construction of a reservoir, leakage is prone to occur due to the impact and infiltration of water, directly affecting the normal use of the reservoir's functions. Therefore, reinforcement treatments are required. In this study, the curtain grouting reinforcement technology for reservoir construction was investigated and applied for leakage reinforcement treatment. After analyzing the construction results, it is concluded that this construction technology has good effectiveness and can effectively address leakage issues, reducing the permeability of multiple parts of the reservoir such as the dam body and improving its resistance to penetration.

References

[1] Cao, J. (2022). Application of Grouting Anti-Seepage Treatment Technology in Risk Removal and Reinforcement Construction of Reservoirs. China High-Tech and High-Tech Enterprises, 115(07), 108-109.

[2] Li, J. (2022). Research on Construction Techniques and Anti-Seepage Reinforcement Treatment of Reservoirs. Development Guidance of Building Materials, 20(24), 120-122.

[3] Zl, A., Dc, A., Rl, A., & Aa, B. (2021). Artificial Intelligence for Securing Industrial-based Cyber–physical Systems. Future Generation Computer Systems, 117, 291-298.

[4] Huang, Y. (2021). Reliability Analysis of Concrete Anti-Seepage Wall in Reservoir Reinforcement Engineering Based on High-Pressure Rotary Jet Grouting Technology. Groundwater, 43(02), 192-195.

[5] Mo, H., & Chen, Y. (2022). Application of Grouting Anti-Seepage in Risk Removal and Reinforcement Engineering of Xinchongkeng Reservoir. Science, Technology, Innovation, and Application, 12(24), 193-196.

[6] Huang, Z. (2016). Application of High-Pressure Jet Grouting Technology in Anti-Seepage Reinforcement Construction of Reservoir Dams. Building Materials and Decoration, No. 412(08), 275-276.

[7] Zhang, T. (2022). Application Study of High-Pressure Rotary Jet Anti-Seepage Wall Construction Technology in Yuanyangchi Reservoir. Gansu Water Resources and Hydropower Technology, 58(11), 60-64.

[8] Zhao, Y., Moayedi H., Bahiraei M. & Kok Foong, L. (2020). Employing TLBO and SCE for optimal prediction of the compressive strength of concrete. Smart Structures and Systems, 2020, 26(6):753-763.

[9] He, C., Liu, M., Zhang, Y., Wang, Z., Hsiang, S. M., Chen, G., and Chen, J., 2022. Exploit Social Distancing in Construction Scheduling: Visualize and Optimize Space–Time–Workforce Tradeoff. Journal of Management in Engineering, 38(4), 4022027. DOI: https://doi.org/10.1061/ (ASCE)ME.1943-5479.0001037.