# Stability Analysis on Dam Banks of the Jiangjia Control Project in the Jinan Yellow River

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**Abstract.** Many dam banks of the Yellow River downstream control projects have not been reinforced due to the limitation of project scale and investment, which is a hidden danger affecting flood control safety. Based on the field survey of the dam banks of the Jiangjia Control Project, the stability was analyzed for the dam banks of the project, and suggestions were made for reinforcement of the dam banks of control projects. The results showed that the outer slope ratio was designed to be 1: 1.5 for the dam bank of the Jiangjia Control Project. However, the current minimal slope ratio was 1: 1.2, which was less than the design value. 94.7% of the slope ratio did not meet the standard. The maximal thickness of the flat stone body was 0.2 m, which was much less than the design value of 1.11 m. The flat stone body was thin. 81.25% of the weight did not meet the standard. The percentage of missing flat stone bodies was 81% in the estimated section, and the stability of the dam bank was significantly reduced for the control project. Thus, the results can provide technical support for the comprehensive management of the Yellow River in Jinan.

**Keywords:** Yellow River, Jiangjia, control project, dam bank, stability analysis

## 1 Introduction

Since the tenth Five-year Plan of China, the Yellow Conservancy Commission in accordance with the “priority” to some key by slipping dangerous work of the important dam pallets were raised and reinforced, the important dam stacks of the nodal projects planned for the treatment line were rock-throwing reinforced, greatly improving the overall flood resistance of the river training project. However, restricted by the scale of the project and investment, no reinforcement has been arranged for some dam stacks of dangerous works and control guide projects that do not rely on slips or rivers. The problems of insufficient height, steep slope of root stones, shallow depth and


D. Li et al. (eds.), *Proceedings of the 2023 9th International Conference on Architectural, Civil and Hydraulic Engineering (ICACHE 2023)*, Advances in Engineering Research 228,
https://doi.org/10.2991/978-94-6463-336-8_20

poor stability of these dam stacks have not been solved [1]. The main types of flat stone slope protection in the lower Yellow River regulation project are loose-throw stone slope protection, buckled stone slope protection, dry stone slope protection, and slurry stone slope protection. A flat stone is the protective barrier of the Yellow River's dangerous work and control guide project. Thus, its distribution status and solid condition are directly related to the safety of the river regulation projects.

Some scholars have conducted relevant studies on the quality assessment of the dam bank of the control guide project. Tang Youquan (1998) used the average gradation and median weight as the key indicators for the evaluation of stone-throwing and evaluated the quality of the stone-throwing slope of Daguan Dam [2]. Jiang Suyang et al. (2001) carried out an analysis of the calculation of the downstream Yellow River embankment dyke and its construction technology characteristics, focusing on the stability of the embankment and calculating the slope, thickness, diameter, and root stone diameter and weight of the flat stone, and discussing the construction technology requirements of the dyke [3]. Wang Li et al. (2013) summarized the methods used for testing the quality of physical works based on many years of experience in testing and evaluating the quality of Yangtze dry embankments [4], combined with relevant regulations and specifications, design documents, and the actual working conditions of the project and proposed a system of indicators for testing and evaluating the quality of physical works of Yangtze dry embankments, which includes the testing methods, testing contents and evaluation indicators of slope protection works. Dave, N. et al. (2017) used aerial images from 1993 to 2016 to analyze the effectiveness of bank stability measures on the Cedar River in Nebraska [5]. Some scholars also carry out experimental research and mechanism analysis of control engineering. Specifically, Xu H. et al. (2023) established formulas for calculating the maximum local scour depth of a submerged control project dam bank and the distance between the submerged dam bank and the dam axis [6]. Hu J. et al. (2023) studied the effect of riverbed scour under unsteady water flow and analyzed the spatial characteristics of scour holes in rock-throwing berms [7]. The model test shows that the 170 m long low-top breakwater connected to the north bank at an angle of 45 degrees and the 25 m long south side short spur scheme has the best effect of wave attenuation by Lin, L. et al. (2015) [8]. Farshad, R. et al. (2022) studied the maximal scour depth of dams in diagonal arrangement and its main influencing factors [9]. Han, X. et al. (2018) developed a three-dimensional numerical model to study the flow characteristics of the double ding-da of the Yangtze River during flooding [10]. However, there is a lack of data to support the comprehensive management of the lower reaches of the Yellow River, and there is an urgent need to carry out a safety assessment of the dam banks of the Yellow River Control Project.

The dam banks were taken as an example for the Jiangjia Control Project of the Yellow River in Jinan, Shandong Province. Several indexes were evaluated based on field inspection such as slope ratio, thickness, and quality of the outer slope of the dam bank, and recommendations were made on the amount of missing tandem stone and reinforcement of the control project. It will provide technical support for the comprehensive management of the lower reaches of the Yellow River.

## 2 Project overview

Jiangjia Control Project is located on the right bank of the Yellow River, west of Jiangjia Village, Huanghe Town. The corresponding embankment pile number is 74+484 to 77+961, the project length is 3477 m, the retaining length of 2875.1 m, and the existing dam bank has 30 sections, including 25 sections of stacks, retaining five sections, all are for messy stone structure. The project was built in 1950. The top of the dam bank and the elevation of the dam base are all below the flood control standard in 2000. The project was built in an emergency. The prepared stone is seriously inadequate and the foundation is shallow with the river trough gradually brushing deeper in recent years. Thus, it increases the possibility of dangerous situations occurring when the foundation is brushed. Since the transfer of water and sand, the downstream river trough gradually brushes deep undercut, the height of the dam surface formed by the rescue has not been applied to the current depth of the river trough, resulting in the constant slow sinking of the slope surface in recent years, pulling thin the thickness of the dam surface root stone, since the transfer of water and sand, small risks occur from time to time for the Jiangjia Control Project, it becomes one of the important risk points of the Zhangqiu Bureau of flood control and rescue. At present, the stone body of the Jiangjia Control Project is thin, the top of the stone is cracked, the stone body is dormant in many places, the resistance to danger is low, and the engineering appearance is poor.

## 3 Testing content and methods

To comprehensively assess the safety state of the planned river training project, tests were carried out on the external dimensions, section thickness, regional block quality, and description of defects of the tambourine body. The external dimensions of the rock (rock elevation, slope, top width, wrapping length) were measured, at least 2 measurements for each dam stack and additional measurements for defective areas; We took a typical section of a dangerous dam, measured and counted the thickness of the typical rock section and the regional block quality distribution, checked and reflected the cracking and stinging state of the rock body. The thickness of the flat stone body and the measurement of the flat stone body were carried out based on a random selection of 10% of the number of dam stacks for each project, ensuring that there is no less than one project per site.

## 4 Field test results and analysis

From 14 July 2019 to 16 July 2019, the outer dimensions of dams 1 to 21 of the Jiangjia Control Project, a total of 21 dams, were inspected, and their external defect characteristics were checked, and the section thickness of two dams and their block quality were extracted and measured. The results of the outer dimensions inspection are shown in Table 1. The thickness and quality of the flat stone are shown in Table 2.

The 1985 national elevation system was used for the elevation in the inspection table. The maximal thickness of the typical section was 0.2 m, which was much less than the design value of 1 m.

**Table 1.** Results of the embodiment field verification for the control guide project of flat stone.

| No. | Building time (year) | Structure type | Flat stone type | Measured values for external dimensions | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Length (m) | Location | Top elevation (m) | Top width (m) | External slope ratio |
| 1 | 1972 | Traditional willow-stone | Scattered stones | 57 | 0+00 | 19.39 | 1.0 | 1:1.85 |
| | | | | | 0+22 | 19.41 | 1.0 | 1:1.59 |
| | | | | | 0+57 | 19.39 | 1.0 | 1:1.64 |
| 2 | 1955 | Traditional willow-stone | Scattered stones | 121 | 0+00 | 19.53 | 1.0 | 1:1.63 |
| | | | | | 0+72 | 19.54 | 1.0 | 1:1.79 |
| | | | | | 0+121 | 19.35 | 1.0 | 1:1.45 |
| 3 | 1955 | Traditional willow-stone | Scattered stones | 51 | 0+00 | 19.43 | 1.0 | 1:1.47 |
| | | | | | 0+25 | 19.40 | 1.0 | 1:1.70 |
| | | | | | 0+51 | 19.53 | 1.0 | 1:1.82 |
| 4 | 1955 | Traditional willow-stone | Scattered stones | 74 | 0+00 | 19.40 | 1.0 | 1:1.61 |
| | | | | | 0+37 | 19.30 | 1.0 | 1:1.71 |
| | | | | | 0+74 | 19.93 | 1.0 | 1:1.88 |
| 5 | 1955 | Traditional willow-stone | Scattered stones | 55 | 0+00 | 19.34 | 1.0 | 1:1.50 |
| | | | | | 0+34 | 19.48 | 1.0 | 1:1.67 |
| | | | | | 0+55 | 19.47 | 1.0 | 1:1.67 |
| 6 | 1955 | Traditional willow-stone | Scattered stones | 52 | 0+00 | 19.40 | 1.0 | 1:1.73 |
| | | | | | 0+22 | 19.57 | 1.0 | 1:1.73 |
| | | | | | 0+52 | 19.42 | 1.0 | 1:1.60 |
| 7 | 1955 | Traditional willow-stone | Scattered stones | 56 | 0+00 | 19.42 | 1.0 | 1:1.38 |
| | | | | | 0+20 | 19.33 | 1.0 | 1:1.56 |
| | | | | | 0+56 | 19.19 | 1.0 | 1:1.80 |
| 8 | 1955 | Traditional willow-stone | Scattered stones | 58 | 0+00 | 19.29 | 1.0 | 1:1.44 |
| | | | | | 0+28 | 19.43 | 1.0 | 1:1.87 |
| | | | | | 0+58 | 19.34 | 1.0 | 1:1.75 |
| 9 | 1955 | Traditional willow-stone | Scattered stones | 64 | 0+00 | 19.82 | 1.0 | 1:1.75 |
| | | | | | 0+30 | 19.82 | 1.0 | 1:1.82 |
| | | | | | 0+64 | 19.66 | 1.0 | 1:1.89 |
| 10 | 1955 | Traditional willow-stone | Scattered stones | 54 | 0+00 | 19.92 | 1.0 | 1:1.86 |
| | | | | | 0+24 | 19.92 | 1.0 | 1:1.95 |
| | | | | | 0+54 | 19.70 | 1.0 | 1:1.89 |
| 11 | 1955 | Traditional willow-stone | Scattered stones | 36 | 0+00 | 19.72 | 1.0 | 1:2.30 |
| | | | | | 0+20 | 19.74 | 1.0 | 1:2.60 |
| | | | | | 0+36 | 19.85 | 1.0 | 1:2.00 |
| 12 | 1955 | Traditional willow- | Scattered | 63 | 0+00 | 19.83 | 1.0 | 1:1.92 |
| | | | | | 0+18 | 19.81 | 1.0 | 1:2.60 |

| No. | Building time (year) | Structure type | Flat stone type | Measured values for external dimensions | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Length (m) | Location | Top elevation (m) | Top width (m) | External slope ratio |
| | | stone | stones | | 0+63 | 19.10 | 1.0 | 1:2.00 |
| 13 | 1955 | Traditional willow-stone | Scattered stones | 195 | 0+00 | 19.21 | 1.0 | 1:1.52 |
| | | | | | 0+113 | 19.40 | 1.0 | 1:1.83 |
| | | | | | 0+195 | 19.08 | 1.0 | 1:1.64 |
| 14 | 1955 | Traditional willow-stone | Scattered stones | 42 | 0+00 | 19.21 | 1.0 | 1:2.00 |
| | | | | | 0+14 | 19.15 | 1.0 | 1:2.10 |
| | | | | | 0+42 | 19.13 | / | / |
| 17 | 1951 | Soil side slopes | None | 34 | 0+00 | 18.74 | 1.0 | 1:1.92 |
| | | | | | 0+23 | 18.67 | 1.0 | 1:1.24 |
| | | | | | 0+34 | 19.59 | 1.0 | 1:1.82 |
| 18 | 1951 | Soil side slopes | The head of the dam | 40 | 0+00 | 19.34 | 1.0 | 1:1.52 |
| | | | | | 0+21 | 19.36 | 1.0 | 1:2.00 |
| | | | | | 0+40 | 19.48 | 1.0 | 1:2.00 |
| 19 | 1951 | Traditional willow-stone | Scattered stones | 31 | 0+00 | 19.51 | 0.8 | 1:2.00 |
| | | | | | 0+22 | 19.54 | 0.9 | 1:2.00 |
| | | | | | 0+31 | 19.43 | 0.8 | 1:1.93 |
| 20 | 1951 | Traditional willow-stone | Scattered stones | 50 | 0+00 | 19.15 | 0.8 | 1:1.86 |
| | | | | | 0+31 | 19.97 | 0.8 | 1:2.10 |
| | | | | | 0+50 | 19.06 | 0.8 | 1:2.00 |
| 21 | 1951 | Traditional willow-stone | Scattered stones | 51 | 0+00 | 19.12 | 1.0 | 1:1.43 |
| | | | | | 0+24 | 19.12 | 0.9 | 1:1.38 |
| | | | | | 0+51 | 19.13 | 1.0 | 1:1.10 |

**Table 2.** Thickness and quality inspection results of the flat stone body.

| No. | Revealing the state of the flat stone body | | | | | |
|---|---|---|---|---|---|---|
| | | | Flat stone body | | Stone | |
| | Location | Length x width | Distance (m) | Thickness (m) | Number | Quality (kg) |
| 6 | 0+10 | 1.0m x 1.2m | 0.00 | 0.21 | 16 | 50.5, 60.1, 10.2, 18.9, 16.7, 30.2, 20.8, 19.9, 10.7, 16.9, 18.9, 20.2, 10.7, 16.6, 18.5, 5.8 |
| | | | 0.50 | 0.30 | | |
| | | | 1.00 | 0.19 | | |
| 13 | 0+30 | 0.9m x 1.0m | 0.00 | 0.20 | 11 | 20.5, 11.7, 40.6, 19.9, 17.2, 10.2, 10.1, 17.0, 5.8, 32.0, 6.2 |
| | | | 0.50 | 0.25 | | |
| | | | 1.00 | 0.20 | | |

The thickness of the tambourine body of the Jiangjia Control Project was shown in Table 3. According to the design index of the standard cross-sectional tandoori body in the Preliminary Design Report of the Lower Yellow River Flood Control Project approved by the Ministry of Water Resources, the flat stone body has an external

slope ratio of 1: 1.5 and an internal slope ratio of 1: 1.3. From Table 3, it can be seen that the slope ratio of the outer slope of the flat stone body is designed to be 1: 1.5, and the minimum slope ratio of the current situation is 1: 1.1, which is less than the design value. The maximum thickness of the typical section is 0.2 m, and the measured values are much less than the design value with a single thin flat stone body.

According to the "Notice of the Planning Bureau of the Yellow Committee on Further Clarifying the Requirements for the Design of the Yellow River Flood Control Project" (Yellow Planning [2014] No. 9)", the weight of a single block of stone for slope protection in river training projects is greater than 25 kg. The standard for the river training project is more than 25 kg. 16 pieces of stone were taken from the dam section, of which three pieces were more than 25 kg, accounting for 18.75%. 13 pieces were less than 25 kg, accounting for 81.25%.

Statistics on the slope ratio of the outer slope of the dam bank, the thickness and quality of the frank stone body of the Jiangjia Control Project, and the estimated missing amount and quality of the project stone at each location were shown in Table 4 (the design standard is 1: 1.5 for the outer slope ratio and 1: 1.3 for the inner slope ratio). Table 4 shows the estimated percentage of missing sections of the control guide project flat stone body is 81%, the quality of the flat stone body does not reach the design value, and the flood control capacity is weakened, which affects the flood control safety.

**Table 3.** The thickness of the tambourine body of the Jiangjia Control Project.

| Dam number and location | Flat stone external slope ratio | Flat stone inner slope ratio | Distance from the top of the slope (m) | Design value (m) | Measured values (m) |
|---|---|---|---|---|---|
| 6 | 1:1.5 | 1:1.3 | 0.00 | 1.02 | 0.205 |
| | | | 0.50 | 1.03 | 0.302 |
| | | | 1.00 | 1.02 | 0.185 |

**Table 4.** Table of rock deficiencies on the dam bank of the Jiangjia Control Project.

| No. | Dimensions | | | | | Design stone volume ($m^3$) | Missing percentage (%) | Amount of stone missing ($m^3$) |
|---|---|---|---|---|---|---|---|---|
| | Wrap length (m) | Height difference (m) | Slope ratio | Wide at the top of flat stone (m) | Wide underneath of flat stone (m) | | | |
| 1 | 57.00 | 3.12 | Outer slopes 1:1.50 Inner Slope 1:1.30 | 1.00 | 1.35 | 208.96 | 81 | 169.26 |
| 2 | 121.00 | | | 1.00 | 1.35 | 443.59 | | 359.30 |
| 3 | 51.00 | | | 1.00 | 1.35 | 186.97 | | 151.44 |
| 4 | 74.00 | | | 1.00 | 1.35 | 271.28 | | 219.74 |
| 5 | 55.00 | | | 1.00 | 1.35 | 201.63 | | 163.32 |
| 6 | 52.00 | | | 1.00 | 1.35 | 190.63 | | 154.41 |
| 7 | 56.00 | | | 1.00 | 1.35 | 205.30 | | 166.29 |
| 8 | 58.00 | | | 1.00 | 1.35 | 212.63 | | 172.23 |
| 9 | 64.00 | | | 1.00 | 1.35 | 234.62 | | 190.05 |

| | | | | | |
|---|---|---|---|---|---|
| 10 | 54.00 | 1.00 | 1.35 | 197.96 | 160.35 |
| 11 | 36.00 | 1.00 | 1.35 | 131.98 | 106.90 |
| 12 | 63.00 | 1.00 | 1.35 | 230.96 | 187.08 |
| 13 | 195.00 | 1.00 | 1.35 | 714.87 | 579.04 |
| 14 | 42.00 | 1.00 | 1.35 | 153.97 | 124.72 |
| 17 | 34.00 | 1.00 | 1.35 | 124.64 | 100.96 |
| 18 | 40.00 | 1.00 | 1.35 | 146.64 | 118.78 |
| 19 | 31.00 | 1.00 | 1.35 | 113.65 | 92.05 |
| 20 | 50.00 | 1.00 | 1.35 | 183.30 | 148.47 |
| 21 | 51.00 | 1.00 | 1.35 | 186.97 | 151.44 |
| Total | | | | | 3515.84 |

## 5 Conclusions

Field inspection showed that the slope ratio of the outer slope of the dams of the Jiangjia Control Project was 1: 1.5, but the minimal slope ratio of the current situation was 1: 1.2, which was less than the design value, and the slope ratio was 94.7%; The maximal thickness of the flat stone body was 0.4 m, which was much less than the design value of 1.11 m and the flat stone body was thin; 81.25% of the weight of the sampled flat stone blocks did not meet the standard. The percentage of the missing flat stone body in the estimated section was 81%.

According to the results of the dam bank stability analysis of the Jiangjia Control Project, it is necessary to design and treat the reinforcement of the dam bank of the Jiangjia Control Project to improve the flood control capacity of the project, because of the thinness of the flat stone body, the unevenness of the flat stone body, the serious local weathering of the flat stone and the absence of the flat stone body in some sections of the dam.

As only 10% of the results of each dam stack were randomly selected for evaluation, it is recommended that the frequency of sampling be further increased to improve the accuracy of accounting for the number of stone cubes in the flat stone body and to better provide scientific and technological support for project design and management.

## Acknowledgments

This work was supported by the Science and technology support project of Henan Xinhua Wuyue Pumped Storage Power Generation Co., Ltd (No. XHKY2022-01, XHKY2021-04); Engineering Research Service Item of the Henan Section of the River Diversion Project from the Yangtze River to Huai River (No. HNYJJH/JS/FWKY-2021001); Opening Foundation of Technical Research Center on Levee Safety Disaster Prevention, MWR of China in 2019 (No. 2019006).

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