River Engineering Model Experiment Study on Sediment Problems at The Water Intake of Central Yunnan Water Diversion Project

Xiaoxue Wang *, Zhijing Li, Junfeng Han, Dazhi Li

Yangtze River Scientific Research Institute, Wuhan 430010, China

* 2503613509@qq.com

Abstract. The Central Yunnan Water Diversion Project is an important national livelihood project. In order to ensure the stability and safety of the project diversion, this paper adopts the river engineering model experiment to study the water flow conditions and sedimentation characteristics of the diversion intake and explore the optimization of the engineering arrangement based on prototype observation, investigation and riverbed evolution analysis. The experimental results prove that the two programs have less influence on the river situation and flood control of the intake, which can meet the stability and safety of the project. Based on the experimental results, this paper proposes specific optimization measures. In the diversion channel layout, shape optimization should minimize the length of the bend section, reduce its curvature; scheduling optimization should focus on the study of the left and right slot gate scheduling program, regulating the flow rate distribution. This is of general significance in solving the sedimentation problem.

Keywords: Water diversion project; River engineering model experiment; Sedimentation

1 Introduction

The physical model of river engineering can forecast the flow and sediment movement law, sand discharge characteristics, scour pattern, and river potential change of the river channel under natural conditions and after the construction of hydraulic buildings[1], which is an important way to study the evolution of riverbed scour and siltation. It also plays an indispensable role in the application of waterway improvement engineering and scientific research. On the one hand, the key to the river engineering model test is how to accomplish the speedy and accurate measurement of riverbed scouring patterns and changes in sediment scouring and siltation[2]. Many academics have conducted related study on this topic. Zhao Xueyi[3] analyzed the channel scour and siltation law of small and medium-sized river improvement projects based on physical modeling experiments, combined with different water inflows. Zhang Hui[4] et al. provided practical

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_50

support for the study of the changing law of the river channel before and after the construction of the bridge, based on the analysis of the evolution of the river bed and river engineering model tests. Based on the response mechanism of siltation, Zhu Boyuan[5] et al. studied the difference in siltation between upstream and downstream sections of the tidal channel hydrodynamic interface. Takahiro[6] collected experimental data through hydraulic model tests over a rigid bed to assume that flash flood/debris flow occurs in the upstream reach. On the other hand, early river engineering model test inevitably exists a certain degree of human error, with the development of computer information, automatic control theory and other related fields of technology, river engineering model test measurement and control level also continues to develop and progress[7]. Specific research findings are listed below. Jian[8] et al. studied the layout scheme of the Tianwan Nuclear Power Plant through hydraulic modeling experiments, which provided a reference for the remediation of uneven water flow distribution. Li Shunchao[9] et al. combined the normal river engineering physical model test and the self-propelled boat model test to study and analyze the channel improvement technology of curved branching river sections in mountainous rivers. Alihossein[10] et al. combined CFD-DEM coupled modeling and hydraulic modeling experiments to provide a good tool for analyzing sediment transport in downspouts. Nafia[11] et al. combined hydraulic modeling and remote sensing techniques to provide creative approaches to solving flooding problems in arid regions.

This engineering design is to select the Datong township water intake point program upstream of Shigu township among many water source points. However, how to ensure the stability and safety of the water intake point and prevent the siltation of the mouth gate is still an urgent problem to be solved. This is of great importance for the further promotion of the livelihood project.

2 Modeling Principles

2.1 Water Flow Motion Similarity

The main tool of this study is the river engineering model test. Since the project reach is a mountainous river with abundant sediment inflow, a moving bed model test was used to study sediment scour in the diversion channel and the Jinsha River near the mouth gate. The model similarity design includes the similarity of water flow movement and the similarity of sediment movement. The specific water flow movement similarity conditions are as follows:

a. Water flow continuous similarity

$$\alpha_Q = \alpha_l \alpha_h \alpha_v \tag{1}$$

b. Gravity similarity

$$\alpha_v = \alpha_h^{1/2} \tag{2}$$

c. Resistance similarity

$$\alpha_n = \frac{\alpha_h^{2/3}}{\alpha_l^{1/2}} \tag{3}$$

Where: α_Q、α_l、α_h、α_v、α_n are the flow scale, plane scale, vertical scale, flow rate scale, and roughness scale, respectively.

2.2 Similar Sediment Movement

Jinsha River and water diversion project channel bed deformation to suspended sediment movement is dominated by suspended mass, suspended mass in the process of suspension with the water flow, by gravity and turbulence diffusion, need to meet the sediment settlement similar requirements, taking into account the water diversion project channel siltation is the focus of the study, therefore, suspended sediment should first meet the similar requirements of the settlement, and then to meet the similarity of the starting and so on. The specific similarity conditions are as follows:
a. Settlement similarity

$$\alpha_\omega = \alpha_V \tag{4}$$

$$\alpha_d = \left(\frac{\alpha_\omega}{\alpha_{r_s - r}}\right)^{1/2} \tag{5}$$

b. Starting similarity

$$\alpha_{v_0} = \alpha_v \tag{6}$$

c. Similarity of water flow holding sand force

$$\alpha_s = \alpha_{s_*} = \frac{\alpha_{r_s}}{\alpha_{r_s - r}} \tag{7}$$

d. Similarity of riverbed deformation

$$\alpha_{t_1} = \frac{\alpha_L \alpha_{\gamma_0}}{\alpha_V \alpha_S} \tag{8}$$

Where: α_ω、α_d、α_{r_s}、$\alpha_{r_s - r}$ are the sedimentation velocity scale, grain size scale, sediment bulk weight scale, and sediment floating bulk weight scale, respectively; α_{v_0}、α_s、α_{s_*} are the starting flow velocity scale, sand content scale, and current sand holding force scale, respectively; α_{t_1}、α_{γ_0} are the suspending mass flushing and siltation time scale and the sediment dry weight scale, respectively.

3 Experimental Design

The model sand for the dynamic bed model experiment is selected from Zhuzhou fine coal with good similarity of sedimentation; its capacity is 1.33 t/m^3, and its dry capacity is 0.62 t/m^3. The model is based on the simulation of suspended matter movement, and its time scale is adopted as the control scale of the model experiment. According to the purpose of experimental research and site conditions, and concerning the previous model test results and experience in the upper reaches of the Yangtze River, it is determined that the model is normal, with the planar scale L=80 and the vertical scale H=80. Other model ratios are calculated from equations (1)-(8) above. To ensure the reliability and accuracy of the study, a normal model was used for the tests. The model simulation of the river section from the Fork of the Bay down to Maanshan has a total length of about 5.5 km, using the measured 1:5000 waterway topographic map modeling. The model layout is shown in Figure 1.

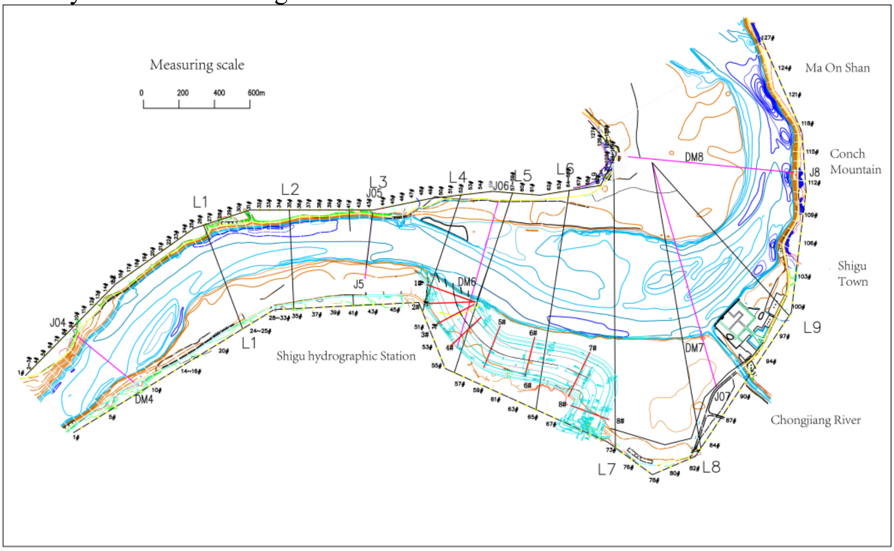

Fig. 1. River situation and river engineering model layout of the Jinsha River Shigu Diversion Project river section

The long diversion channel and short diversion channel programs adopted in the trial are arranged as follows:

Program 1 (long diversion channel program): diversion channel length of 1255m, along the right bank of the Jinsha River, Datong village downstream of the river bank flat roughly "∽" type arrangement, along the diversion of the mouth of the uniform arrangement of 5 channel walls, sedimentation ponds import and export are set up to stop sand cans, connecting the section of the length of 287 m. This program selected three typical test years, the arrangement of eight sections to observe diversion channel siltation characteristics, the observation of sediment grain size and gradation carried by the water flow in the pumping station inlet and 6# section in the middle of the diversion channel, and the observation of sand content in the diversion channel inlet section (0.4h), the 6# section (0.4h), and the pumping station gate section (0.5h).

Program 2 (short diversion channel program): diversion channel length of 728.53m, along the right bank of the Jinsha River, Datong Village, downstream of the river bank flat roughly straight layout, along the diversion gate uniformly arranged 5 channel wall, sedimentation pond inlet set sand barriers can be set up at the end of the 6-hole sand barriers are set up to connect the section of the length of 70 m. This program selects three typical test years, the layout of the diversion channel to observe the characteristics of siltation in the 6 cross sections, and the sand grain size of the cross-section. This program selects three typical test years: the layout of the diversion channel to observe the characteristics of siltation in the 6 sections, the observation of sand grain size in the section set up in the pump outlet (pump station gate section) (0.4h), the 6# section (0.5h), and the pump station gate section (0.5h). The sediment grain size observation section is set up at the water pump outlet (water depth 0.1～0.3h), and the sand content observation is set up at the diversion channel inlet and the water pump inlet.

The test is based on the topographic data of 2010 and 2015, using the flow and sand transport process from May to October of each typical year: 1966 (year of abundant water and sand), 1996 (year of medium water and less sand), and 1977 (year of less water and less sand), and the siltation test is conducted for the river near Shigu Town with a length of about 1.5 km. The characteristics are shown in Table 1.

Table 1. Statistics of water and sand characteristics in typical years at Shigu Station

Typical year	Year	Drift value		Runoff	
		annual sand transfer (million tons)	average increase compared to multi-year	annual runoff volume (billion m^3)	average increase compared to multi-year
25%	1966	3253	24.2%	475	12%
50%	1996	2193	-16.3%	424	0%
75%	1977	1435	-45.2%	373	-12%

4 Results

According to the monitoring and analysis of topographic siltation in three typical test years, after the implementation of the diversion project, the Jinsha River Shiku River section siltation changes with the basic similarity of the project before the occurrence of major floods: the side of the beach and the deep channel siltation. After the flood water flows back to the trough scouring, the bed of the riverbed siltation is balanced. The two programs in each typical year in the river channel siltation changes are the same; siltation is located in the left trough of most of the 2 # section near the total amount of silt in each hydrological year. 1996 siltation is the largest, followed by 1966, and 1977 is the smallest. The thickness of siltation in each monitoring reach is shown in Tables 2 and 3.

Table 2. Typical Year-End Average Siltation Thickness at the Monitoring Section of the Diversion Channel of Program 1(m)

Typical year	Imported Shakan top	2# Right channel	2# Left channel	4# Right channel	4# Left channel	6# Right channel	6# Left channel	8# Right channel	8# Left channel
1966	0.60	2.35	2.40	2.19	2.20	1.51	1.32	0.33	0.32

1996	0.48	2.40	2.58	2.35	2.44	1.63	1.44	0.40	0.38
1977	0.22	2.18	2.21	2.03	2.08	1.42	1.33	0.33	0.32

Table 3. Typical Year-End Average Siltation Thickness at the Monitoring Section of the Diversion Channel of Program 2(m)

Typical year	Imported Shakan top	2# Right channel	Left channel	4# Right channel	Left channel	6# Right channel	Left channel	8# Right channel	Left channel
1966	0.60	2.38	2.50	2.22	2.29	1.49	1.45	2.38	2.50
1996	0.48	2.45	2.65	2.39	2.50	1.59	1.55	2.45	2.65
1977	0.22	2.30	2.34	2.10	2.12	1.37	1.36	2.30	2.34

After the implementation of the two programs, the sediment particle size gradation into the pumping station meets the design requirements (less than 0.05mm sediment sand weight is more than 95%). The sediment particle size distribution at the pump inlet of the diversion canal is shown in Table 4.

Table 4. Sediment particle size at the pumping station inlet (water depth 0.5h) in the typical year 1996 for both programs

Portal D6	Program 1			Program 2		
Water level (m)	0.05 mm	0.01 mm	D50	0.05 mm	0.01 mm	D50
1817.66	96.4%	66.9%	0.0048	95.6%	66.2%	0.0054
1819.58	96.6%	67.2%	0.0046	96.0%	66.7%	0.0052
1820.60	97.2%	67.3%	0.0044	96.2%	66.9%	0.0050
1818.76	96.5%	66.0%	0.0048	95.8%	66.5%	0.0053

According to the results of the typical annual observation test in 1996, under the test flow at all levels, the sand content in the inlet of the diversion channel of Program I is between 0.12 and 1.77 kg/m^3, the sand content in Section 6# is between 0.10 and 1.40 kg/m^3, and the sand content in the gate section of the pumping station is between 0.09 and 1.20 kg/m^3. The sand content in the inlet of the diversion channel of Program 2 is between 0.12 and 1.77 kg/m^3, and the sand content entering the pump is between 0.092 and 1.23 kg/m^3.

5 Conclusion

The test results show that after the diversion project is applied, the two systems have less influence on the river situation and flood control of the Jinsha River, which can satisfy the stability and safety of the project. The optimization of the project can start with the optimization of the diversion channel layout and the scheduling optimization: the layout of the diversion channel can minimize the length of the diversion channel bend section and improve the effect of siltation in the sedimentation pond; the scheduling can optimize the scheduling scheme of the left and right slots and play the advantages of the left and right slots under different flow rates.

Acknowledgments

This study was supported by the National Natural Science Foundation of China (Grant No. U2240226 &No. 52239007&)

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