Experimental Study on Scour Model of Wujiagang Bridge Pier

Zhijing Li¹, Miner Shan¹, Jiancheng Huang¹ and Yinjun Zhou¹
¹Changjiang River Scientific Research Institute, Wuhan 430010, Hubei, China.
*Corresponding author’s e-mail: lizjketty@whu.edu.cn

Abstract: Local scouring of bridge piers is one of the main causes of structural damage and even water damage. In this study, an experimental study on scour model of Wujiagang bridge pier is carried out, the results show that the scope and depth of the pier scouring pit are closely related to the flow and water depth at the pier location, the maximum scouring depth and the scope of the scouring pit increase with the increase of unit-width discharge.

1. Introduction
The local scour of bridge pier is a catastrophic process in which the flow is blocked by bridge pier or foundation, and the sediment is taken away from the bridge pier or foundation to form scour pit near the pier or foundation[1]. The study of local scouring is mostly based on the prototype observation data combined with model tests. Wang Ruifeng et al. (2014) and Tao Jing et al. (2009) established a large scale normal physical model, based on which they predicted the shape of scour pit, the maximum local scour depth and scour pit range of pier, and verified the reasonableness of the results using formula calculations, data analysis and three-dimensional numerical simulation, respectively[2-3]; Melville and Chiew (1999) carried out an indoor clear water scouring test to study the change of local scouring pit depth over time in a uniform sand river bed on single cylindrical piers, and proposed a prediction formula for the development of local scouring depth over time based on the experimental data[4]; Lanca (2013) carried out laboratory scour tests, studied the influence of sediment roughness on the balanced scour depth, and established the evolution formula of local scour time[5]; Jin Yakun (2014) studied the scour characteristics of pier with uniform flow in different water depths under flat bed condition, and measured the flow field and scour pit. The analysis results show that the scour first appears on both sides of the pier, and gradually develops into a scour groove, and then the scour channel develops to the front and back of the pier respectively, forming a relatively complete inverted dimensional scour pit[6]; Xiao Yang (2018) used ultrasonic topographic instrument to measure the topography around the pier in the clear water scouring test. This method can carry out real-time non-contact dynamic measurement under water, which improves the accuracy of the results. It was found that the scour occurred first at the side and front of the pier, and then gradually after the pier, and the scour pits at the front and side of the pier were deeper[7]; Based on the actual situation of localized scour of bridge piers, Zhan Yizheng et al. (2006) proposed a extrude circumfluent flow pattern for localized scour of bridge piers and established a formula for calculating the depth of localized scour of bridge piers[8]; Most of the current studies focus on the causes of scour. As local scour is a process in which water starts and takes away sediment from around the pier, it is greatly affected by water depth and velocity, etc. Therefore, it is necessary to study the influence of water depth and velocity on the local scour around the pier, which has important guiding significance for ensuring the safety of bridge structure.

Wujiagang Yangtze River Bridge is located in the Yichang urban area, about 17 km from the Gezhouba hub and 6 km from the Yichang Yangtze River Highway Bridge, Wujiagang district is on the
north bank of the river, and Dianjun district is on the south bank. The design bridge length is 1845 m, the main bridge adopts 1160 m single span steel box girder suspension bridge scheme, the bridge width is 31.5 m, the two-way six lanes are adopted, the design driving speed is 80 km/h, and the estimated dynamic total investment of the project is 2.993 billion yuan. Wujiagang bridge is a river crossing bridge connecting Wujiagang district on the north bank and Dianjun district on the south bank. After the bridge is completed, it will form a traffic loop line in Yichang city with Miaozui Yangtze River Bridge on the upstream, which plays an important role in improving the traffic environment of Yichang City and promoting regional economic development. According to the engineering design scheme, the main bridge span of scheme 1 is \(2 \times 580\) m three tower steel box girder suspension bridge scheme, the north and south towers are located on the bank, and the middle tower is located in the middle of the river; in scheme 2, the main cable span is \(240 + 780 + 400\) m double tower two span suspension bridge, and the bridge tower near Wujiagang bank is located in the middle of the river. In order to study the local scour of piers with different schemes, we carried out an overall river engineering model test study.

2. Model building and validation

According to the model test tasks and requirements, the model simulation of the range of the river section from the inlet of the Yanzhi dam (bridge site upstream of about 7.7 km), down to the Dengjiaxi (bridge site downstream of about 6 km), the total length of about 13.7 km. The 1:2000 river channel topographic map, which was measured by the Three Gorges Hydrological Bureau of the Yangtze River Commission in April 2010, was used to make the model. The two banks of the map were measured to the levee and terrace platform, with an elevation of 52.2 ~ 53m. Using Zhuzhou clean coal as model sand, the weight ratio is 1.33 t/m³, and the dry bulk density is 0.62 t/m³. According to the model design theory, the scale of the model is shown in Table 1.

| Similar conditions                   | Name       | Symbol | Scale value |
|--------------------------------------|------------|--------|-------------|
| Geometry similarity                 | Plane scale| \(\lambda_L\) | 100         |
|                                      | Vertical scale| \(\lambda_H\) | 100         |
| Velocity scale                      |            | \(\lambda_V\) | 10          |
| Flow scale                          |            | \(\lambda_Q\) | 100000      |
| Particle size scale                 |            | \(\lambda_d\) | 10.5        |
| Starting velocity scale             |            | \(\lambda_{u_0}\) | 10          |
| Scale of sediment transport rate    |            | \(\lambda_{q_s}\) | 398         |
| Riverbed deformation time scale     |            | \(\lambda_t\) | 49.5        |

The topography for the model validation test is the measured topography of the river section in April 2010, and there are six water level stations along the river section at the bridge site. The model was validated on the basis of the velocity distribution of the measured cross-sectional surface velocity at the flow of 13,500 m³/s in September 2013 by the Three Gorges Hydrology Bureau of the Yangtze River Commission.

3. Experimental design

In Scheme 1, the main pylon pier in the middle of the river is close to the deep channel, and the riverbed elevation is 21.2 m; in the Scheme 2, the main pylon pier in the middle of the river is at the beach, with the riverbed elevation of 30.9 m. In the single pier scour test, the typical flow rate is 55000 m³/s (one hundred years flood flow, considering the Three Gorges reservoir scheduling) and 49361 m³/s (average flow rate of past flood peaks, considering the Three Gorges reservoir scheduling), respectively. The
The median particle size of the riverbed is 15.1 mm. The scour test of the bridge piers is mainly to study the maximum scour depth and range of the bridge piers. Therefore, sand is not needed to be added during the test. The scour time of the bridge piers is subject to the formation of stable scour pits.

### Table 2. Table of water release elements for pier scour test

| Flow rate (m³/s) | Scheme 1 | Scheme 2 |
|-----------------|----------|----------|
|                 | Velocity (m/s) | Water depth (m) | Unit-width discharge |
| 49361           | 3.15     | 28.8     | 90.7          |
| 55000           | 3.21     | 29.7     | 95.3          |

![Figure 1. Photo of fixed bed test model (scheme 1 on the left and scheme 2 on the right)](image)

### 4. Analysis of test results

The test results show that when the flow rate is 55000 m³/s, the biggest depth of the scouring pit of the main tower pier in the middle of the river in scheme one is 10.9 m, the scouring pit range is about 40 m in front of the pier, the width of each side of the pier is about 37 m, and the downstream length of the pier is about 110 m; the biggest depth of the scouring pit of the main tower pier in the middle of the river in scheme two is 8.7 m, the scouring pit range is about 32 m in front of the pier, the width of each side of the pier is about 28 m, and the downstream length of the pier is about 89 m. The maximum depth of the scour pits for each of the schemes is in the riverbed in front of the pier.

![Figure 2. Photos of pier scouring test (scheme 1 on the left and scheme 2 on the right)](image)

### Table 3. Main tower pier scour pit depth and extent table

| Flow rate (m³/s) | Scheme | Maximum pit depth (m) | Extent of flushing pit (m) |
|-----------------|--------|------------------------|---------------------------|
|                 |        | Pier front length      | Width of each side         | Pier back length |
| 49361           | 1      | 9.8                    | 35                        | 32              | 105              |
The relationship between different unit-width flow and maximum scour depth is shown in Figure 3, which shows a positive correlation, the maximum scouring depth increases with the increase of unit width flow rate, and when the unit width flow rate exceeds 90 m³/s·m, the increase speed of maximum scouring depth will increase significantly.

![Figure 3. Relationship between unit-width discharge and maximum pit depth](image)

| Unit-width discharge (m³/s) | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|----------------------------|----|----|----|----|----|----|----|
| Maximum pit depth (m)      | 8  | 8.5| 9  | 9.5| 10 | 10.5| 11  |

5. Conclusion

The results of local scour test show that the range and depth of scour pit are closely related to the kinetic energy of flow and the composition of riverbed. The maximum scour depth and the range of scour pit increase with the increase of unit width discharge. Under the condition of once-in-a-century flood discharge of 55000 m³/s, the maximum scour pit depth of the main tower pier in the river is 10.9 m, the upstream length of the scour pit is about 40 m, the width on both sides is about 37 m, and the downstream length is about 110 m; in scheme 2, the maximum scour pit depth of the main tower pier in the river is 8.7 m, the upstream length of the scour pit is about 32 m, the width of both sides is about 28 m, and the downstream length of the pier is about 89 m. The maximum scour depth of the scour pit in each scheme appears in the riverbed in front of the pier, and the larger the maximum scour depth, the larger the scope of scouring.

Acknowledgments
The research is funded by the National Key Research and Development Program of China (2016YFC0402310), and the Central Public-interest Scientific Institution Basal Research Fund (CKSF2019246/HL).

References
[1] Wang S Y, Mou L, Wei K, Qin L, Xiang Q Q. (2020) Experimental study on local scouring of cylindrical piers under different hydraulic conditions. Journal of Disaster Prevention and Mitigation Engineering, 40(03): 425-431.
[2] Wang R F, Li J, Yang Y P, Lin J, Li H Y. (2014) Experimental Study on Local Scour at Large Bridge Pier of Feiyun River. Zhejiang Hydrotechnics, 42(03): 3-6.
[3] Tao J, Zhao S W, Xu C. (2009) Study of Scoured Pit Depth at Piers of Changjiang River Bridge. World Bridges, (S1): 73-77.

[4] Melville B W, Chiew Y M. (1999) Time Scale for Local Scour at Bridge Piers. Journal of Hydraulic Engineering, 125(1): 59-65.

[5] Lanca R M, Fael C S, Maia R J. (2013) Clearwater scour at comparatively large cylindrical piers. Journal of Hydraulic Engineering, 139 (11): 1117-1125.

[6] Jin Y K. (2014) Three Dimensional Turbulent Flow Field Research in the Process of Local Scour Hole Development around bridge piers. Beijing JiaoTong University.

[7] Xiao Y, Liu J Q, Wu Z, Wen T Y. (2018) Study on scouring process around bridge pier. Journal of Sediment Research, 43(06): 67-72.

[8] Zhan Y Z, Wang J, Tan G M, Shu C W, Li W, Deng C Y. (2006) Experimental study on bridge pier local scour. Engineering Journal of Wuhan University,2006(05): 1-4+9.