Flexible flow deflectors against local scour at bridge piers

Huishu Li¹, Huang Li¹, Peng Jin¹* and Yuanping Yang²

¹College of Civil Engineering, Tongji University, Shanghai, China
²Zhejiang Institute of Hydraulics and Estuary, Hangzhou, China

*Corresponding author e-mail: 365607268@qq.com

Abstract. In order to explore the potential application of flexible flow deflector in engineering, experiments were conducted to study the countermeasures against bridge pier protection. A three-deflector structure was proposed to improve the efficiency of reducing scouring depth at bridge piers, including one body and two wings. The performance of the proposed three-deflector structure was subjected to some preliminary laboratory tests, and satisfactory results were obtained.

1. Introduction

In engineering, local scouring is continuous around piers and abutments of bridges in rivers, which forms scouring pits around bridge foundation and results to reduce the burial depth of bridge.

In study of bridge’s scouring, physical model test can help researchers better understand the scour’s impact with different factors. Scholars have carried out many scouring tests to study different contents about the scour around piers, which mainly were divided into three aspects. First, some studies were concerned about eddy current test on foundation, like Baker [1], Sumer [2], Zhao [3, 4], Lu [5], and Veerappadevaru [6]. Secondly, some researchers conducted experimental studies on influencing factors of scouring depth, like Ataieashtiani [7], Li [8], and Zhao [9]. In the third aspect, some experimental studies were carried on scouring process characteristics and pit morphology, like Liu [10] and Xie [11]. The results obtained from these studies could be in agreement with those obtained from empirical formulas or semi-empirical and semi-theoretical formulas, which also provided some scientific basis for engineering.

Based on the studies about the scour, many scholars studied the application of scour protection measures to reduce the depth of scour pits around the bridge foundation. Among the scouring protection measures, study on engineering measures of body protection is one of the usual methods, like riprap protection [12], enlarging pier foundation protection [13, 14] and other measures [15, 16]. These methods obtain well results in preventing local scour of bridge foundation. However, the above-mentioned engineering measures were protection measures of the rigid structures.

In this paper, the application of a soft diversion device, flexible flow deflector proposed by Xie [17-20], was studied to protect bridge pier against local scour. The flexible flow deflector is an underwater structure for flow pattern modification (like Figure 1), composed of a bottom beam, a flexible curtain, and a floating tube. The bottom beam serves as a foundation for the whole structure and can be made of reinforced concrete, geotextile tube, or other heavy materials. The flexible curtain is a geotextile sheet that is attached to the beam on the bottom edge and the floating tube is attached on the upper edge. The floating tube is a light or inflatable structure manufactured with materials like foamed plastic. When the flexible flow deflector is deployed in a steady current, the upper edge of the curtain is extended upward and inclines to the downstream side due to the buoyancy of the floating
tube and the flow drag force. The flexible curtain can guide the flow and change the movement trajectory of water or sediment to achieve the functions of induced siltation of beach land and river regulation. The parameters of the flexible flow deflector are shown in Figure 2.

![Figure 1. The flexible flow deflector.](image1)

Model tests were conducted to study the application of the flexible flow deflector in bridge pier protection against local scour in this paper. The tests were carried out in the flume of Zhejiang Institute of Hydraulics and Estuary. The flume has a length of 42 m, a width of 4.3 m, and a height of 1.0 m. The picture of the flume is shown in Figure 3. Water flow was constant in one direction in this test. The test section of the flume was a mobile bed area with a length of 2 m, a width of 4 m, and a depth of 15 cm. This test used a probe fixed by a movable steel rail to measure the topography after scouring, which can obtain the erosion and deposition changes accurately. The sand used for the test is yellow-gray sand, which is non-sticky, non-plastic, and excellent in selection. It contains a small amount of silt at 0.35%, gravel at 0.03%. The median diameter of the sand is 0.33 mm, and the gradation is shown in Figure 3. The density of the sand at room temperature is 2.6 g/cm³.

![Figure 2. Parameters of the flexible flow deflector.](image2)

![Figure 3. Particle grading of the sand.](image3)
2. Local scour test of bridge pier

2.1. Tests

The bridge pier used in the test is a rigid PVC pipe with a diameter of 12 cm and a height of 1 m. It was inserted into the sand at the center of the test section. The upper end was fixed to prevent the pier from tilting under water flow. The water depth was 30 cm and the flow rate was 0.27 m/s, and the scouring time was 2 hours. The test condition is shown in Table 1.

| Flow                        | Diameter of the pier (cm) | Water depth (cm) | Flow rate (m/s) | Scouring time (h) |
|-----------------------------|----------------------------|------------------|-----------------|-------------------|
| Constant in one direction   | 12                         | 30               | 0.27            | 2                 |

![Figure 4. Topography after scouring.](image)

2.2. Testing results and analysis

Figure 4 shows the topography after scouring. The topography was processed symmetrically. An area with the center of the pier as the origin, 30 cm upstream, 40 cm downstream, and 30 cm laterally on one side was selected for topographic measurement. 9 sections were measured along the lateral direction, and the distance between each section was 4 cm. The measurement results were plotted by Matlab as shown in Figure 5, where the center of the bridge pier corresponds to the coordinate origin.

As can be seen from Figure 5, the local scouring area around the pier is roughly a circular area. The center of the circular area is the center of the pier and the diameter is 3 times the diameter of the pier. The position of the maximum scouring depth is at the upstream front of the pier, and the maximum depth is 9.5 cm. The scouring index is shown in Table 2.

![Figure 5. Contour line of topography after scouring.](image)
### Table 2. Scouring index.

| The maximum scouring depth (cm) | Scouring area (cm²) | Scouring volume (cm³) | Average scouring depth (cm) |
|---------------------------------|---------------------|-----------------------|-----------------------------|
| 9.5                             | 1825                | 5665                  | 3.1                         |

### 3. Protection test of the three-deflector structure against local scour

#### 3.1. The concept of the three-deflector structure including one body and two wings

The concept of the three-deflector structure including one body and two wings was proposed for scour protection. The arrangement of the three-deflector structure is shown in Figure 6 and 7. It can be seen that a flexible flow deflector is placed far away from the pier and two symmetrically placed near the pier.

#### 3.2. Tests

The test condition is shown in Table 3. As is shown in Figure 6, the inner side of the two wings is tangent to the outer edge of the pier, and the buoy is just at the front of the pier when the curtain body is tiled. The width of the single flexible flow deflector is 24 cm, which is twice the diameter of the pier. The height of the single deflector in the straightened state is 24 cm, which is 0.8 times the water depth. The distance between the bottom of the one body and the bottom of the two wings is 7 times the diameter of the pier.

#### 3.3. Testing results and analysis

The three-dimensional topographic map and the corresponding contour map after scouring are shown in Figure 8 and 9.

It can be seen from Figure 8 and 9 that the area with severe scour is far upstream from the pier and around the three-deflector structure. And there is no phenomenon of excessive concentration of...

![Figure 6. The three-deflector structure including one body and two wings.](image6.png)

![Figure 7. Testing arrangement](image7.png)
deposition near the pier. Both scouring and silting hardly occur within the short distance of the pier. As a result of water diversion, the maximum scouring depth decreases, reaching 5.2 cm.

**Figure 8.** Topography after scouring.

**Figure 9.** Contour line of topography after scouring.

4. **Conclusions**

In this paper, the application of flexible flow deflector in bridge pier protection against local scour was studied. The following conclusions are obtained through experiments.

1. The local scouring area around the pier without protection is roughly a circular area. The center of the circular area is the center of the pier and the diameter is 3 times the diameter of the pier. The position of the maximum scouring depth is at the upstream front of the pier, and the maximum depth is 9.5 cm.

2. In the protection test of the three-deflector structure against local scour, the area with severe scour is far upstream from the pier and around the three-deflector structure. And there is no phenomenon of excessive concentration of deposition near the pier. Both scouring and silting hardly occur within the short distance of the pier. The maximum scouring depth decreases, reaching 5.2 cm.
5. Acknowledgments

This work is financially supported by the National Natural Science Foundation of China [grants 11172213 and 51479137]. The authors also acknowledge Prof. Liquan Xie’s work contributing to this article.

References

[1] C. J. Baker, The position of points of maximum and minimum shear stress upstream of cylinders mounted normal to flat plates, Journal of Wind Engineering & Industrial Aerodynamics, Vol. 18, No.3, May 1985, pp 263-274.

[2] Sumer and B. Mutlu, 2002. The mechanics of scour in the marine environment. Singapore: World Scientific.

[3] M. Zhao, L. Cheng and Z. Zang, Experimental and Numerical Investigation of Local Scour around a Submerged Vertical Circular Cylinder in Steady Currents, Coastal Engineering, Vol.57, No.8, August 2010, pp 709-721.

[4] M. Zhao and L. Cheng, Numerical Investigation of Local Scour below a Vibrating Pipeline under Steady Currents, Coastal Engineering, Vol.57, No.4, April 2010, pp 397-406.

[5] J. Lu, Z. Shi, J. Hong, J. Lee and R. Raikar, Temporal Variation of Scour Depth at Non-uniform Cylindrical Piers, Journal of Hydraulic Engineering, Vol.137, No.1, December 2011, pp 45-56.

[6] G. Veerappadevaru and T. Gangadharaihaah, Temporal Variation of Vortex Scour Process around Caisson Piers, Journal of Hydraulic Research, Vol.50, No.2, March 2012, pp 200-207.

[7] B. Ataieashtiani and A. A. Beheshti, Experimental Investigation of Clear-Water Local Scour at Pile Groups, Journal of Hydraulic Research, Vol.132, No.1, 2006, pp 1100-1104.

[8] S. Li, Z. Chai, T. Liu and Y. Feng, Rules of Local Scour of Skewed Tower Footing, Journal of Yangtze River Scientific Research Institute, Vol.35, No.1, January 2018, pp 11-15.

[9] M. Zhao, X. Zhu, L. Cheng and B. Teng, Experimental study of local scour around subsea caissons in steady currents. Coastal Engineering, Vol.60, No.1, February 2012, pp 30-40.

[10] X. Zhang, H. Lv and B. Shen, Experimental studies on local scour mechanism of cylinder bridge piers, Hydro-Science and Engineering, No.2, April 2012, pp 34-41.

[11] L. Xie, Liang, M. Wang, H. Li, Y. Li, and T-C. Su. Horizontal Planar Scale Test of Local Scour at Submerged Monopile. Journal of Coastal Research, 2019 Special Issue, No. 93, pp 298-303.

[12] F. Lim and Y. Chiew, Parametric study of riprap failure around bridge piers, Journal of Hydraulic Research, Vol.39, No.1, February 2001, pp 61-72.

[13] A. C. Parola, S. K. Mahavadi, B. M. Brown and A. El. Khoury, Effects of Rectangular Foundation Geometry on Local Pier Scour, Journal of Hydraulic Engineering, Vol.122, No.1, January 1996, pp 35-40.

[14] D. Zhao, W. Tian and Y. Zhang, Local Scour at Piers and Protection with Apron, Journal of Xi’an Highway University, Vol.18, No.4 (b), 1998, pp 38-40.

[15] Y. Sun, P. Liu and H. Ren, Construction of six feet body protection for scouring and Permeable Pier of River Crossing Bridge, Water Resources & Hydropower of Northeast China, No.12, 2017, pp 14-16.

[16] F. Chen, Y. Chen, J. Chen and J. Zheng, Experimental study on downstream of submerged breakwater embankment with bottom protection, China Water Transportation (Science & Technology for Waterway), No.1, 2018, pp 74-79.

[17] L. Xie, W. Huang and Y. Yu, Experimental study of sediment trapping by geotextile mattress installed with sloping curtain. Geosynthetics International, 20, No. 6, pp 389–395.

[18] L. Xie, Y. Zhu, W. Huang and C. Liu, Experimental investigations of dynamic wave force on seabed around a geotextile mattress with floating curtain. Journal of Coastal Research, Special Issue, No. 73, pp 35-39.

[19] L. Xie, Y. Zhu, Y. Li and T-C. Su, Experimental study on bed pressure around geotextile mattress with sloping plate, PLOS ONE. 2019, 14(1): e0211312.

[20] L. Xie, Y. Zhu and T-C. Su, Scour Protection of Partially Embedded Pipelines Using Sloping Curtains, Journal of Hydraulic Engineering. 2019, 145(3): 04019001.