UNIVERSITY OF TECHNOLOGY SYDNEY

Introducing, Examining and Optimising Flow Diversion Structure as an Innovative Countermeasure against Local Scour around Bridge Piers

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Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of Associate Professor Hadi Khabbaz

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Mohsen Ranjbar-Zahedani declare that this thesis, is submitted in fulfilment of the requirements for the award of PhD degree, in the School of Civil and Environmental Engineering, Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Signature: Production Note: Signature removed prior to publication.

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Sincerely dedicated to

my wonderful wife

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List of Publications

- ### Journal Papers

1. **Ranjbar-Zahedani, M**., Keshavarzi, A., Khabbaz, H. & Ball, J. 2018, 'Protecting bridge pier against local scour using flow diversion structure', *Proceedings of the Institution of Civil Engineers-Water Management*, vol. 171, No. 5, pp. 271-280.

2. **Ranjbar-Zahedani M**, Keshavarzi A, Khabbaz H, & Ball J., 'Optimising Triangular Prism Flow Diversion Structure as an Effective Local Scour Countermeasure around a Pier'. Accepted for publication in the Journal of Hydraulic Research.

- ### Peer-Reviewed Conference Papers

3. **Ranjbar-Zahedani, M**., Keshavarzi, A. & Khabbaz, H. 2017, 'Control of local scour at vicinity of bridge piers using flow diversion structure', *Proceedings of the 37th IAHR World Congress*, Kuala Lumpur, Malaysia.

4. **Ranjbar-Zahedani, M**., Keshavarzi, A., Khabbaz, H., & Ball, J. 2019, 'Submerged flow diversion structure as an effective countermeasure to protect bridge piers from scour', *9h Australian Small Bridges Conference*,Gold Coast, Australia.

5. **Ranjbar-Zahedani, M**., Keshavarzi, A., Khabbaz, H., & Ball, J. 2019, 'Flow structures around a circular bridge pier with a submerged prism at upstream', *Proceedings of the 4th World Congress on Civil, Structural, and Environmental Engineering (CSEE'19)*, Rome, Italy

- ### Other Papers, Not Directly Related, to this Study

6. Keshavarzi, A., Shrestha, C.K., **Ranjbar-Zahedani, M**., Ball, J. & Khabbaz, H. 2017, 'Experimental study of flow structure around two in-line bridge piers', *Proceedings of the Institution of Civil Engineers - Water Management*, vol. 171, No. 6, pp. 311-327.

7. Keshavarzi, A., Shrestha, C.K., Melville, B., Khabbaz, H., **Ranjbar-Zahedani, M**. & Ball, J. 2018, 'Estimation of maximum scour depths at upstream of front and rear piers for two in-line circular columns', *Environmental Fluid Mechanics*, vol. 18, no. 2, pp. 537-50

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Abstract

Previous studies have shown that local scour around bridge piers and abutments is a common cause of waterway bridge failures, and around 60% of bridge collapses are due to this phenomenon. To control and reduce local scour, different engineering methods have been proposed by the researchers which can be classified into two distinct categories, including (i) armouring devices, which is a conventional way, and (ii) flow-altering devices. Armouring devices such as riprap is placed around a pier to armour the riverbed grains against shear stresses and reduces the local scour. However, riprap layers often fail to protect bridges during floods because it cannot be stable to withstand the high approaching stream velocities. The second category is flow-altering devices that change the flow field around the bridge piers in a manner that reduces the potential for erosion.

In this study, a new flow-altering device named flow diversion structure (FDS) has been introduced and experimentally examined and optimised. Different criteria were considered to select the shape of this FDS including diverting streamlines from the vicinity of pier, creating a relatively wide wake region behind the FDS, and having a low amount of local scour around itself. Theoretically, by comparison different shapes according to the above criteria, triangular prism was recognised as a proper shape. The effectiveness of this innovative countermeasure was examined through a wide-ranging series of experimental studies. Firstly, a number of preliminary laboratory tests were conducted to prove whether proposed FDS can reduce the local scour around a circular bridge pier. An introductory FDS was built with a lateral base of 0.2D, longitudinal base of 0.5D (where D is the pier diameter), and full-depth (unsubmerged) height. Seven tests were conducted for situations of a single pier and a single pier plus the FDS, which was installed at six alternative locations upstream of the pier (namely d/D = 0.5, 1.0, 1.5, 2.0, 2.5 and 3.5, where d is the clear distance between the pier and FDS). All tests were conducted under steady state and clear-water scour conditions. After achieving the equilibrium bed condition, the bed profile was measured, and the maximum scour depth and volume of the scour hole were determined for each experimental test. In addition, to determine the influence of the FDS on the flow field upstream of the pier, the velocity components were measured by an Acoustic Doppler Velocimetry (ADV). Analysis of the results indicated that the proposed FDS could change both the magnitude and direction of the velocity components upstream of the pier, and consequently reduce the scour depth around the pier

up to 38%. Besides, the clear distance between the pier and the FDS affected the performance of this new countermeasure.

Secondly, to optimise the dimensions of FDS including the lateral base (B), longitudinal base (L), and height (H), and its clear distance from the upstream face of a circular pier (d), different FDS dimensions and locations were examined experimentally. Taguchi's method, which is an efficient statistical approach to design experimental tests, was employed here to determine the parameter combination to minimise the numbers of alternative tests. Therefore, 27 FDSs were tested to find the optimum size and installation location of the FDS. An advanced technology of 3-D printing was employed to build accurate physical models. At the end of each test, to measure the topography of the scoured bed a precise 3-D scanner was used. Similar to the preliminary tests, these experiments were also conducted in a steady flow and under clear water scour conditions. However, the hydraulic conditions were adjusted in such a way to produce almost maximum possible local scour. After achieving equilibrium condition, the scour hole was scanned, and the maximum scour depth and the volume of the scour hole were extracted from the 3-D model for each experimental test. The outcomes clearly demonstrated that the best lateral base, longitudinal base, and height of FDS were equals to 0.4D, 0.6D, and 0.25y (where y is the water depth), respectively. Furthermore, the best clear distance between FDS and the pier is approximately between 1D and 1.5D. In the optimum situation, the scour depth and the volume of the scour hole around the pier reduced by 40% and 60%, respectively.

Finally, to find out how the optimised FDS affected the flow field around a circular pier, an experimental study of flow field was conducted using a Particle Image Velocimetry (PIV) system. All tests were conducted under fixed bed condition with no sediment. The optimised FDS was installed at the best location upstream of the pier (d/D = 1.5), and the velocity components were measured at five vertical planes (i.e., Y/D = 0, 1, 2, 3 and 4, where Y is the transverse direction). A similar test was carried out with only a single pier as a control test. The PIV images, collected during the individual experiments, were processed to determine the streamwise (u) and vertical (w) velocity components. A code was developed using MATLAB software to calculate the turbulence characteristics of the flow. Analysis of the results indicated that the optimised FDS significantly affected the flow field and changed the complicated vortices systems, including down-flow, horseshoe vortex, and wake vortex around the pier. Consequently, the pier-scour was significantly reduced by the substantial changes in the flow field. This novel device is a simple and easy option for mitigating local scour around the piers supporting existing and new bridges.