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Experimental Investigation of the Effects of Slotted Cone-Shaped Piers on Scour Reduction Due to Steady Flows

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Local scouring at bridge piers can be regarded as one of the main reasons for bridge collapses at river crossings. Bridge failure can cause severe damages and can result in serious injury or death. Hence, the investigation of the control of scouring at bridge piers plays an important role in bridge design. The main aim of this study was to evaluate the effectiveness of the slotted conical-shaped piers in reducing local scour when compared with a circular-shaped pier. Two sets of experimental tests were carried out under clear water conditions for the duration of eight hours and with relatively uniform sediments. For the first set, the model piers with different lateral slopes were tested, and the experimental results showed that the maximum scour depth was mainly reduced by a decrease in the lateral slope of the model piers. With the mildest lateral slope angle of 78.69° the maximum scour depth was reduced by as much as 32%. In addition, the combination of the slotted and conical shape could further reduce the maximum scour depth by up to 55%. Thus, the experimental results showed that the combination of the slotted and conical shape can be regarded as a very effective countermeasure tool against local scouring at bridge piers.

INTRODUCTION

There are many reports about the failure of bridges around the world due to the scouring process. These reports clearly show the motivation of this study of scouring and any possibility of scour reduction. The used methods of controlling the scour around bridge piers can be divided into two categories including direct and indirect methods. The first methods may be achieved by the increase in the streambed resistance. This is usually done by placing a riprap layer around the bridge piers (Worman, 1989; Yoon et al., 1995; Chiew, 2008). Indirect methods, however, can be achieved by changing the flow pattern around the piers. These methods may be done, for instance, by the use of a collar around the pier or alternatively by the use of a slot within the pier. Another method in the second category is to use a section of variable depth.

Application of Cone-Shaped Structure with Respect to Side Slope

Sumer et al. (1994) measured the bed shear stress for a cone-shaped structure to observe the influence of the side slope on the shear stress amplification. They found that the overall effect of the side slope in front of the cone-shaped structure was the reduction of the bed shear stress. Sumer and Fredsoe (1997) measured scour around a cone-shaped structure in a follow-up study. The results revealed that the scour mainly decreases through the reduction of the side slope. The scour-reduction efficiency of conical piers has already been established by Sumer and Fredsoe (2002) and confirmed numerically by Besharati and Hakimzadeh (2008). However, the projected area (the blockage ratio) of the conical piers was reduced when compared with that of the cylindrical piers. This reduction was due to the decrease in the lateral slopes in the structures at both the experimental and numerical model piers.

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Application of Slot

The main performance of a slot as a flow-altering countermeasure depends on its location within the pier. When the slot is placed near the bed, the downflow is diverted through the slot opening rather than being driven into the sand bed. Thus, this reduces the horseshoe vortex intensity. When a slot is placed near the surface of the flow, near-surface water is allowed to pass through the slot opening, which effectively lowers the flow depth and the downflow at the nose of the pier (Chiew, 1992). In his experimental research, the effects of a slot, a collar, and a combination of both in reducing the depth of local scour around a pier were investigated. He finally concluded that the combination of a collar and a slot could be a suitable substitute for the use of riprap as a countermeasure for local scour at bridge piers. Thus, his results suggested that this combination was capable of eliminating scour altogether. In this regard, Grimaldi et al. (2009) studied the effectiveness of a combined countermeasure composed of a slot and a downstream bed sill.

For the current study, the scour-reduction efficiency of the slotted conical piers with different diameters on the bed and water surface (i.e., with different lateral structural slopes) and with similar projected areas were investigated through a number of laboratory experiments. The results were then compared with those for the reference circular-shaped pier. Also, since the projected areas of the model piers were equal with a constant cross-sectional area of the flow, the blockage ratios would then be alike. Therefore, one of the main differences between this study and previous studies is related to the blockage ratio that is assumed to be constant. As can be seen in the schematic sketch shown in Fig. 1, for the studies undertaken by Sumer and Fredsoe (1997) the diameters of the cone-shaped model piers on the bed were constant. Therefore, the projected area and blockage ratio of the conical pier decreased compared to the similar parameters of the cylindrical pier. Obviously, through the decrease in the lateral slope of the pier, the scour depth was tentatively reduced due to the reduction of the blockage ratio.

However, for this study the cone-shaped model piers were designed so that the projected area and consequently the blockage