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Minimizing scour around bridge pile using holes

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Abstract Driven by the importance of bridges, researchers are currently undergoing profound paradigm to implement piles to reduce the scour due to the erosive action of flowing water. This research aimed to investigate the minimization of the scour hole around a bridge pile, experimentally. Perforated piles with holes with different orientations were tested, a sacrificial pile and perforated sacrificial pile were placed at the upstream. Measurements were performed, analyzed and presented. Empirical equations were formulated to evaluate the scour parameters. The results indicated that about 89% reduction in scour depth was obtained due to using the combination of pile with hole angle of 45° and a perforated sacrificial pile with hole angle of 45° and hole diameter equals 0.43 of the pile diameter. The results of this study may be used in the field of application for the purpose of bridge pile protection design.

1. Introduction

The harmful effect of local scour around bridge piers and abutments can induce high maintenance costs or even bridge collapse resulting in the disturbance of traffic and possibly human losses. Literature was reviewed in the field of scour around piles of bridges. Many articles, papers and reports were collected, investigated and comprehended. Based on this review, it was apparent that many researchers investigated scour, as follows: Refs. [1,2] reported that investigated bridges' failure around the world is due to scouring. Therefore, there is an extensive research on bridge scour ranging from theoretical analyses, laboratory experiments, and numerical modeling. Deng and Cai [3] presented a comprehensive review of the up-to-date works on scour at bridge piers and abutments. Different techniques and instruments developed for bridge scour monitoring were presented. Various mitigation countermeasures developed for bridge scour were discussed. Mostafa [4] presented the results of an experimental study of scour around single pile and different configurations of pile groups exposed to waves and currents. It was documented that the scour depth for case of pile group is generally greater than that for the case of single pile depending on the group configuration and gap between piles. Akib et al. [5] tested the use of collars and geo-bags for reducing local scour around bridge piles. The results indicated that using a combination of a steel collar and a geo-bag yielded the most significant scour reduction for the front and rear piles, respectively. Akib et al. [6] presented an experimental study on the scouring mechanism at semi-integral bridge piers. The results specified that the scour development with respect to time was greater for higher flow

Abbreviations: GMDH, group method of data handling; NF-GMDH, neuro-fuzzy group method of data handling; S.P., sacrificial pile.
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Notations

B	clear flume width (L)	T	time at maximum scouring (T)
D	pile diameter (L)	x_p	sacrificial pile position (L)
d_1	hole diameter of bridge pile (L)	y_t	tail water depth (L)
d	sacrificial pile diameter (L)	θ	hole angle of pile (–)
d_2	hole diameter of sacrificial pile (L)	α	hole angle of the sacrificial pile (–)
d_s	maximum scour depth (L)	θ_r	hole angle of pile in radiant degree (–)
d_{smax}	maximum scour depth for no hole case (L)	α_r	hole angle of the sacrificial pile in radiant degree (–)
F_t	tail Froude number (–)		

depth and bigger flow discharge at semi-integral bridges. Refs. [7–10] investigated the equilibrium scour depth. They documented that it increased with the approach flow depth around piers at semi-integral bridges where scour around bridge piers was numerically simulated. Abouzeid et al. [11] investigated the flow and local scour variation around single pier and the interaction effect between bridge piers using 3D flow model. It was noticed that the maximum scour depth for circular pier is less than that for rectangular one for both single and double pier cases. Mohamed et al. [12] applied different methods of scour countermeasures to minimize local scour around multi-vents bridge supports experimentally. It was found that using collar around piers, current deflectors and sacrificial pile upstream piers reduced local scour depth by 90%. Elnikhely [13] studied the effect of using a protective pile installed upstream a bridge abutment for reducing the effects of local scour around it. It was found that using a pile upstream the abutment provided a reduction in the maximum scour depth by about 41%. Many researchers investigated the reduction of local scour around bridge pier by implementing a collar around the pier and riprap [14–17] and by using a slot through the pier [18–20]. Kurmar et al. [21] studied the efficiency of slots with different lengths and angles of attack. It was concluded that a slot can be effective in reducing scour, particularly if it extends into the bed, and that the slot is practically ineffective if the approach flow has a high obliquity with respect to the slot. Najafzadeh et al. [22] presented new application of group method of data handling (GMDH) to predict scour depth around a vertical pier in cohesive soils. It was found that, the GMDH has produced quite better scour depth prediction than those obtained using traditional equations. Najafzadeh et al. [23] used the GMDH to predict pile scour depth exposed to waves. It is noticed that, the GMDH produced the best realization of the inductive approach to predict the complexity of the scour process. Najafzadeh and Barani [24] investigated experimentally, the effect of current velocity, flow depth, initial moisture content, clay percentage and undrained shear strength on scour around a bridge pier. It was found that, saturated and unsaturated conditions are significant factors in predicting scour depth. Najafzadeh and Azamathulla [25] and Najafzadeh [26] utilized the neuro-fuzzy based group method of data handling (NF-GMDH) network to predict the scour process at pile groups. The NF-GMDH models indicated quite higher accuracy of scour prediction compared with the empirical equations.

In terms of the importance of protecting bridges against failure, this research was started. It aims to consider the effects of piles with holes with different orientations (i.e. 0°, 90° and 45° in the flow direction) under clear-water conditions. The research also aims to investigate the effect of perforated pile with sacrificial pile at the upstream.

2. Dimensional analysis

A dimensional analysis was carried out. The analysis considered variables were as follows:

d_s = the maximum scour depth
d_{smax} = maximum scour depth for no hole case
D = the diameter of the pile
F_t = the tail Froude number
y_t = the tail water depth
d_1 = the diameter of the hole of the perforated pile
B = the width of flume
T = time at maximum scouring
θ = the oblique angle of the hole in the horizontal plan
d = the diameter of the sacrificial pile
d_2 = the diameter of the hole of the perforated sacrificial pile
α = the oblique angle of the hole of the perforated sacrificial pile in the horizontal plan, Fig. 1.

The functional relationship for the maximum relative scour depth $\frac{d_s}{D}$ was as follows:

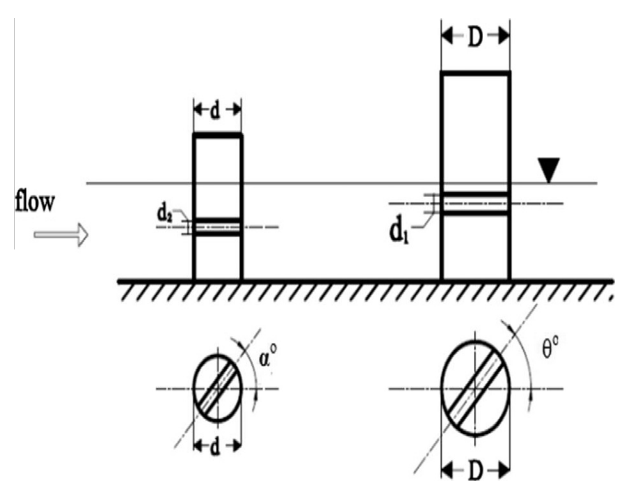

Figure 1 Schematic diagram of the experimental model.