ISSN: 1687-1006 p
ISSN: 2682-3640 e

The Egyptian International Journal of Engineering Sciences and Technology

https://eijest.journals.ekb.eg/

Vol. 42 (2023) 15–22

DOI: 10.21608/eijest.2022.150217.1167

Influence of the Shape and Properties of the Bridge Pier's Nose on Scour Depth

Elsayed M. Elshahat and Eman A. Elnikhely*

Water and Water Structures Eng. Dept., Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt.

ARTICLE INFO

Article history:

Received 18 July 2022
Received in revised form 16 September 2022
Accepted 01 November 2022
Available online 01 November 2022

Keywords:

Scour
gabion nose
pier shape
pier modification
scour countermeasure

ABSTRACT

Bridge pier scouring may lead to bridge failure, and one of the major factors in minimizing scour around the pier is the shape of the pier itself. This study investigated the effects of bridge pier nose shapes (rectangular, oblong, and triangular) and nose properties (solid and gabion) on scouring around the bridge pier. A uniform bed material with a median size (d_{50} = 0.52 mm) and a standard deviation (σ_g= 2.35) was employed. The results showed that the triangular shape has more satisfactory results in reducing scour compared to other shapes of the pier. The results revealed the effectiveness of the gabion-nosed piers in decreasing the maximum scour depth, results indicated that about a 46% reduction in scour depth was obtained due to using the pier with a gabion nose for used pier models. The study results may be applied in the area of applicability for bridge pier protection design.

1. Introduction

An important and complex research subject in hydraulic engineering is local scouring around bridge piers. Local scour is one of the major factors leading to bridge failures, such as overloading, collisions, and poor maintenance. Scour may be defined as a local decrease in bed elevation around a bridge pier [1]. A scour hole is created at the bridge pier as a result of the localized scour, which exposes the pier foundation underneath the riverbed. The two main types of scour countermeasures used at bridge piers are bed armoring and flow-altering methods. Placing riprap stones on the riverbed around the bridge pier is the most popular method of armoring the riverbed [2,3]. Other armoring systems for river bed around the piers include articulating concrete blocks [4,5], gabions [5,6], concrete armour units, etc. The necessity for flow-altering countermeasures arises because bed armoring systems may not be able to reduce the local scour around bridge piers. These countermeasures vary the flow field dramatically, which reduces the axial downflow and eventually produces weaker horseshoe vortices. On the other hand, due to the lack of large quantities of riprap stones or because they are prohibitively expensive, the flow-altering methods may be more cost-effective. Flow-altering countermeasures reduce the down flow and the horseshoe vortex strength, which are the main reasons for the local scour around the bridge pier. Flow-altering countermeasures are typically divided into two categories based on the

*Corresponding author. Tel: +2-01004818733
E-mail address : emanaly_99@yahoo.com

attachments and shapes of the countermeasures: (a) pier attachments and pier modifications; and (b) bed attachments. There are many types of pier modifications, some of which are mentioned as follows: slot in a pier[7,8], plate attached to a pier as a collar [9,10], threaded pier [11], splitter plate [11,12] internal connecting tubes [13,14], sacrificial piles [15,16] , openings through pier [13,17], bed sills [18,19], jet injection from the piers body [20], pier group [21], roughened pier [22] and caisson [23] are relevant. However, in the field, drilling holes through piers may weaken the piers; some countermeasures attached to piers may obstruct navigational needs; or the existing piers may not be compatible with the new jet injection through the pier. Jet injection through the pier requires permanent pumping units, and their performance must be tested in live-bed conditions. To improve the effectiveness of these countermeasures, they can also be used together [24]. **Mostafa** [25] conducted an experimental investigation into the scour surrounding a single pile and various pile group configurations exposed to currents and waves. According to the experiment's results, a pile group's scour depth is greater than a single pile's, depending on how the piles are arranged and the distance between them. The effect of geo-bags and collars on local scour around bridge piles was investigated [26]. According to the findings, using a geo-bag and a collar together significantly reduced scour for the front and rear piles, respectively. The effectiveness of using slots and roughening elements as a countermeasure for scour on the bridge abutment was investigated [27]. They mentioned that scour reductions were obtained for such attachments and recommended doing an extensive study to identify the effective design guidelines. In order to reduce the effects of local scour near a bridge abutment, **Elnikhely** [15] examined the effect of using a protection pile upstream of the bridge abutment. The results showed that using a pile upstream of the abutment reduced the maximum scour depth by about 41%. **Abouzeid et al.** [28] investigated the flow variation and local scour around a single pier, as well as the interactive effects between bridge piers, using a numerical model (3D flow model). According to the results, the circular pier produced the lowest scour depth and the rectangular pier produced the highest scour depth for both single and double pier cases. For the purpose of reducing local scour around bridge piers, **Mohammed et al.** [29] conducted an experimental study using collars around piers, current deflectors, and upstream sacrificial piles. It was observed that the local scour depth was reduced by 90% as a result of the combination of collars around piers, current deflectors, and sacrificial piles upstream of the piers. **Kumar et al.** [30] investigated the effectiveness of slots with various lengths and attack angles for reducing the scour around the bridge pier. They concluded that a slot can significantly reduce scour, especially if it extends into the bed, but that if the approaching flow has a high obliquity with respect to the slot, the slot is effectively worthless. **Najafzadeh et al.** [31] used the group method of data handling to calculate the scour depth of piles exposed to waves. They noted that the scouring process around the piles could be predicted using the group method of data handling. According to **Najafzadeh et al.** [32] , the group method of data handling (GMDH) application has resulted in a much better prediction of scour depth than that achieved using traditional equations. In an experimental study, **Najafzadeh and Barani** [33] investigated the effects of initial moisture content , flow depth, current velocity, undrained shear strength clay percentage, and clay percentage on scouring around a bridge pier. They pointed out the importance of saturated and unsaturated conditions in predicting scour depth. The neuro-fuzzy based group method of data handling network was used to predict the scour process at pile groups [34,35]. In comparison to empirical equations, the group method of data handling models based on neuro-fuzzy models showed a significantly higher accuracy in scour.

Rasuol et al.[36] investigated the impact of cables on local scouring of bridge piers using experimental study and ANN, and NFIS algorithms. Based on the results, by increasing the cable diameter, the initial and final scouring depth can be reduced. **Sharp and Tate** [37] investigated experimentally the feasibility of pier nose extensions to reduce local scour around bridge piers. They mentioned that the pier extensions reduced the local pier scour by 53% compared with the existing pier configuration without extensions.

The present study aims to study the effect of pier nose properties on scour around the bridge pier, A new flow-altering countermeasure is used to minimize the scour around the bridge pier by using gabion noses (with equal particle diameter) to the surface of the upstream pier nose.

2. Experimental Set-Up:

2.1. Laboratory Flume

In the Hydraulic lab at the Faculty of Engineering, Zagazig University, Egypt, experiments were carried out in a rectangular recirculating flume. The rectangular re-circulating flume having a 0.4 m width, a 4 m length, and a 0.2 m depth has a maximum discharge of 5 L/s, and the used flume is shown in Figure 1. For the discharge measurement, an orifice meter is used, which is fitted on the delivery pipe of a centrifugal pump. The equation of the orifice for measuring the discharge is Q (L/s) = $1.4383*(H)^{0.5}$, where H is the difference in elevation of the mercury in the tube (H in cm). To avoid the scour in the initial stages, water was filled from downstream at a very slow rate, and then the flow rate was adjusted by a control valve and the flow was re-circulated. The valve is operated gently without disturbing the bed surface until the desired depth of flow is obtained. And further, to obtain the required depth of flow, the tail gate is operated. The water surface and the scour depth are measured using a point gauge, which is sensitive to an extent of 0.1 mm.

Figure 1: Laboratory Flume.

2.2. Pier Models

As shown in Figures 2, six piers of different shapes and nose properties of equal width were used as pier models, since it was recommended by **Chiew and Melville** [38] that the pier width should be less than 10% of the flume width in order to avoid the influence of the walls, which leads to contraction scour. Hence, the pier width in all cases was 4 cm. The pier models used in this study have a fixed width to length ratio of 1:4. Three of the pier models used in this study are of different shapes (rectangular, oblong, triangular) with a solid nose as shown in figure 2, and the other three models are gabion-nosed piers (rectangular, oblong, triangular) as shown in figure 2. The gabion nose length is half of the pier's width, and the gabion nose has a median grain size of 1.20 mm.

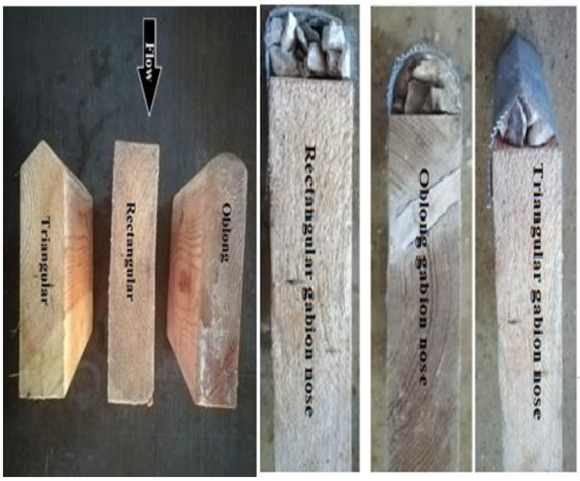

Figure 2: Piers shape models.

2.3. Bed Material

The sand bed material used in this study was analyzed by carrying out a mechanical sieve analysis test. The bed material had a geometric standard deviation of σ_g=2.35 and a median particle size (d_{50}) of 0.52 mm, as determined by the sieve analysis. The plot of the grain size distribution test is depicted in figure 3. Additionally, it is known that the grain size of the bed material has no effect on the depth of scour if the pier width to grain size ratio is greater than approximately 25 **(Melville, 1997)** [39]. This is to disregard the effect of sediment size on the depth of scour. Therefore, for this study, the ratios are approximately 72.72 for the pier width, which meets the criterion of **Melville (1997)**[39].

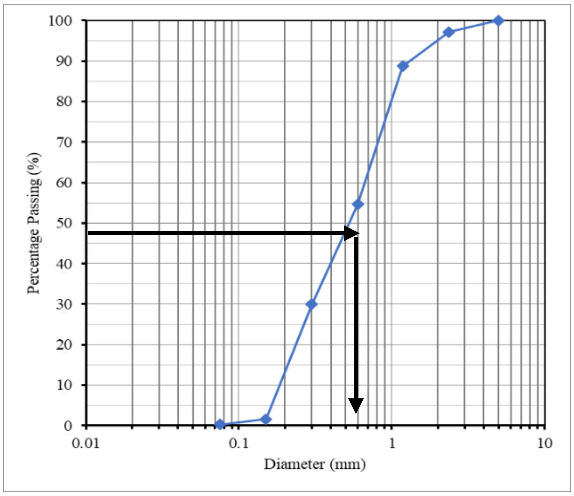

Figure 3: The grain size distribution

2.4. Experimental Procedure

All experiments were conducted in clear water under steady subcritical flow on a plain bed; no dunes or ripples were generated through the working section's upstream portion. The following process method was used:

1. Pier models were fixed vertically at the middle of their respective places within the section in use.
2. The bed of the section in use is filled with a 10 cm thick layer of sand.
3. A scraper was used to level the bed's surface, and the point gauge was also used to check the levels of the beds.
4. The working area is filled with water by hose from the downstream section of the flume, and the tail gate is raised to allow any air bubbles to percolate out of the bed, in order to avoid any initial scouring around the piers and to prevent any disturbances in the sand bed after starting pumping.
5. After starting pumping, the required water depth is obtained in the flume by gradually lowering the tail gate. This depth is checked by a point gauge, and the run is conducted over two hours.
6. Time was recorded using a stopwatch during each test, and at the end of the time, the flow was stopped by turning off the centrifugal pump.
7. To prevent any change in the scour hole, the flume drains slowly. After the sand has had time to dry, a point gauge is used to record the necessary measurements of the sand bed in all directions, including upstream, downstream, longitudinally, and transversely.
8. The steps from 1 through 7 were repeated after adjusting the sand levels, gradually altering the shape of the pier.

3. RESULTS AND DISCUSSION

The main objective of the experiment is to examine the minimum scour depth condition among rectangular, oblong, and triangular piers with a major focus on the time after which equilibrium scour condition is achieved. Table 1 shows the maximum scour depth at various flow depths and velocity for all pier models.

Table 1. The experiment Results

Q L/s	***y cm***	***v m/s***	***Fr***	***Max scour depth (cm) for the pier's models***					
				Rect. solid	**Oblong solid**	**Trian. solid**	**Rect. gabion**	**Oblong gabion**	**Trian. Gabion**
4.8	**4.5**	**0.267**	**0.401**	**2.4**	**2.1**	**1.3**	**1.4**	**1.1**	**0.7**
4.8	**5**	**0.24**	**0.342**	**1.6**	**1.5**	**0.8**	**0.9**	**0.7**	**0.5**
4.8	**5.5**	**0.218**	**0.297**	**1.4**	**0.8**	**0.5**	**0.6**	**0.6**	**0.3**
4.8	**6**	**0.2**	**0.26**	**1.3**	**0.6**	**0.3**	**0.5**	**0.3**	**0.1**
4.8	**7**	**0.171**	**0.206**	**0.7**	**0.4**	**0.1**	**0.3**	**0.1**	**0.1**

3.1. Effect of pier shape

The scour depth variation for different flow conditions and different pier shapes is shown in Figure 4. From the figure, it is observed that scouring is drastically reduced with the change of the pier's shapes and increases with an increase in flow velocity. These results also showed that a rectangular pier shape developed a maximum scour depth because of the upstream pier shape and corners, where a powerful horseshoe vortex system occurs. Due to its upstream shape, which only promotes a very weak vortex system, the triangular pier developed the lowest scour depth when compared to other shapes. As seen in figure 5, the triangular shape reduced the scour depth by about 46% when compared to the rectangular shape at the flow velocity V = 0.267 m/s.

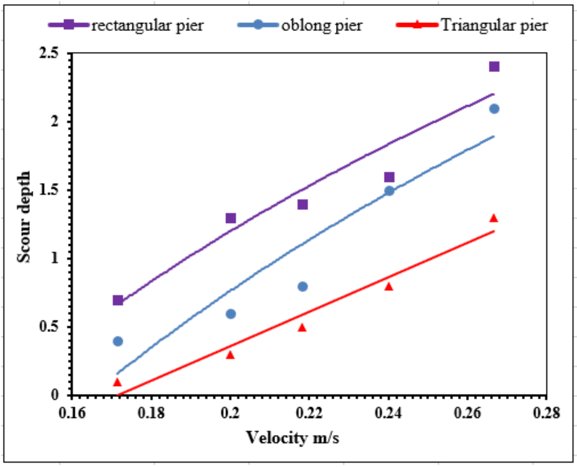

Figure 4: The relationship between velocity and scour depth of different uniform pier shapes

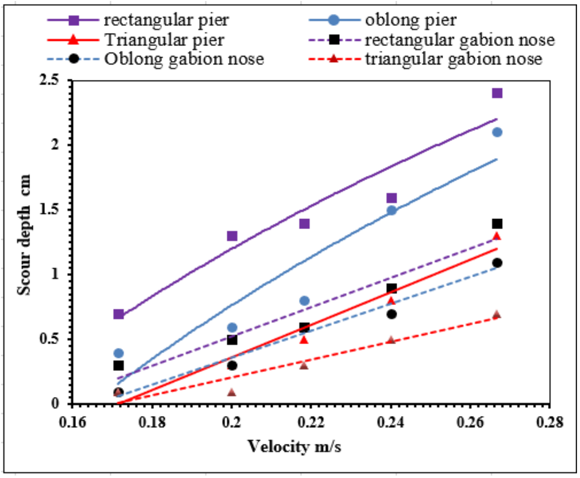

Figure 6: The relationship between velocity and scour depth of different pier models

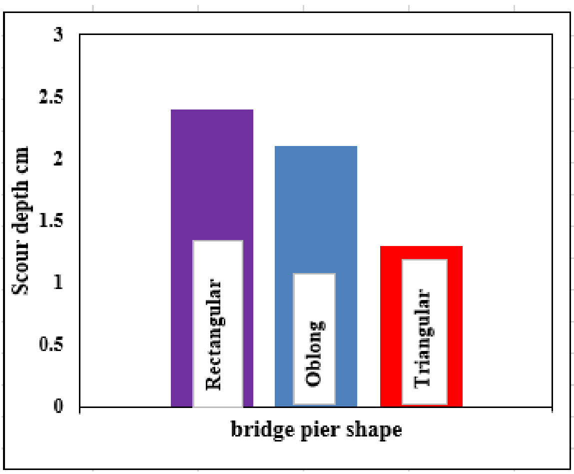

Figure 5: Scour around different bridge pier shapes for the flow velocity V = 0.267 m/s.

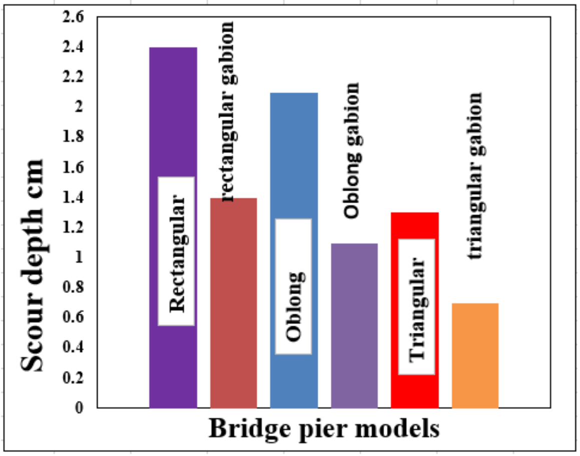

Figure 7: Scour around different bridge pier shapes and gabion noses for the flow velocity V = 0.267 m/s.

3.2. The effect of the pier with a gabion nose

Figure 6 depicts the variation in scour depth for various flow conditions and pier shapes, including gabion nose piers. From the figure, it is observed that scouring is drastically reduced with the change of the pier's shapes and the pier nose properties and increases with an increase in flow velocity. Due to the upstream pier shape and the gabion porosity, which only had a very weak vortex system, these results also showed that piers with gabion noses developed a minimum scour depth. As shown in figure 7, the gabion nose decreased the scour depth by about 50% compared to the pier without the gabion nose at the flow velocity V = 0.267 m/s.

The contour maps of bed morphology were drawn by using **The Surfer program** [40]. Figures 8 and 9 show the contour map of bed morphology around all pier models under the same experimental conditions respectively. It can be observed that the scoured region is large for rectangular pier than triangular pier. The scour depth at triangular pier is reduced by 46% than the scour depth at rectangular pier under the same experimental conditions. The diameter of scour hole is more in case of rectangular pier than triangular pier and that too for every experimental condition. However, the deposition height and deposition length at downstream of pier is also greater for rectangular pier. The scour hole region around gabion nosed pier is smaller than the pier without gabion nose.

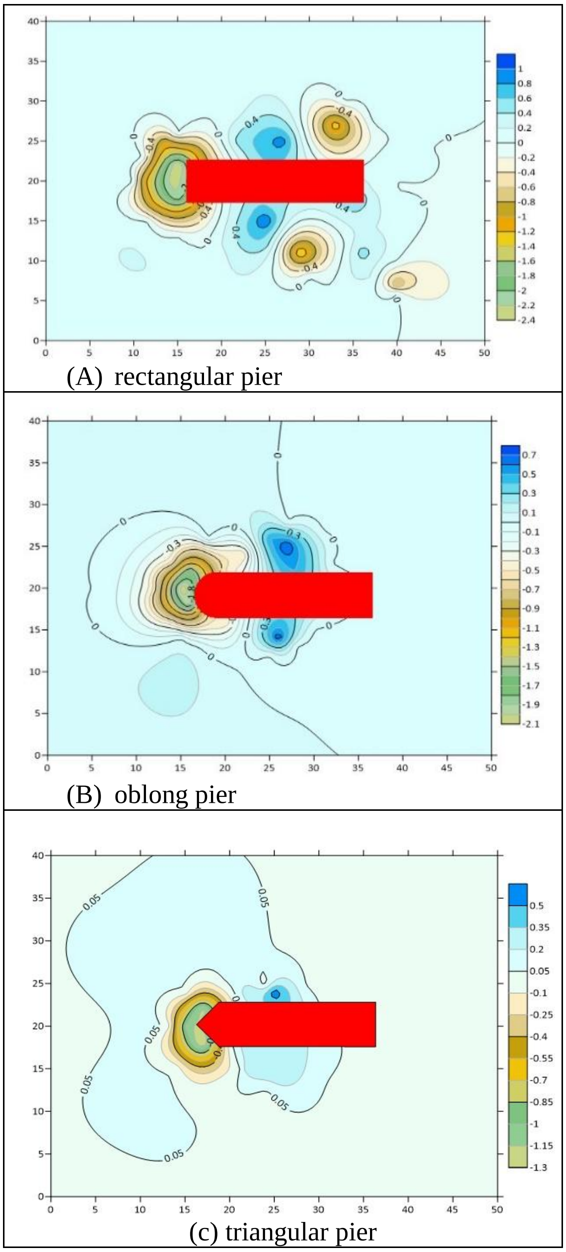

Figure 8: The contour map of bed morphology around all pier models without gabion nose for the flow velocity V = 0.267 m/s.

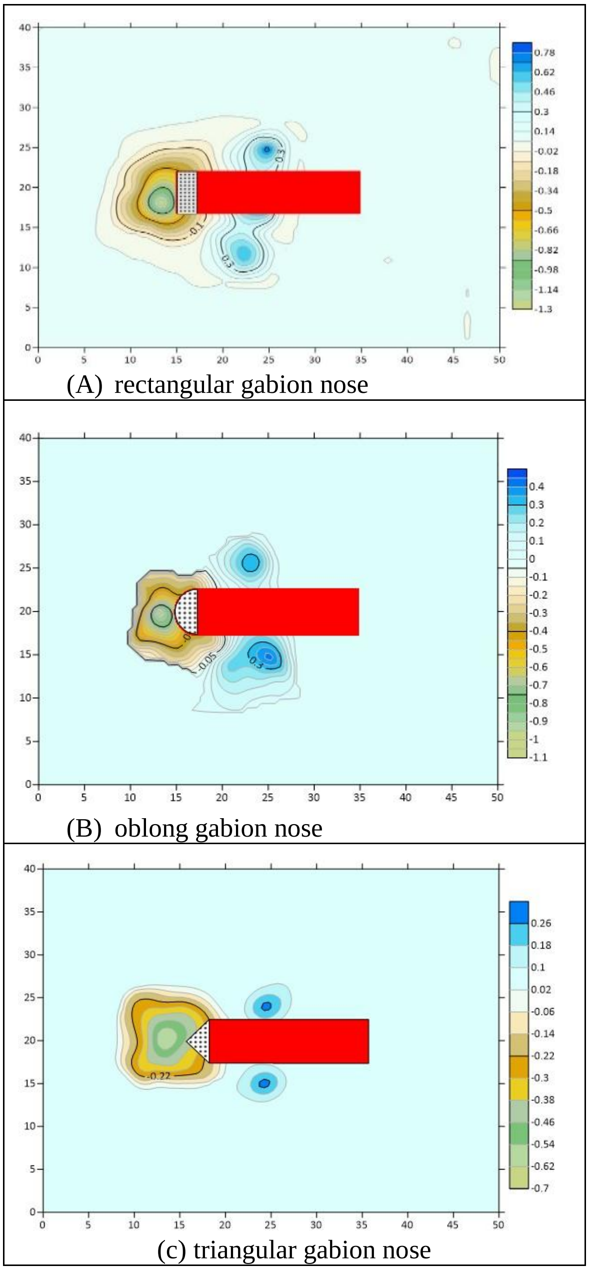

Figure 9: The contour map of bed morphology around pier model's with gabion nose for the flow velocity V = 0.267 m/s.

4. Conclusions and recommendations

At bridge piers in clear water, experiments were conducted to assess the effectiveness of different pier nose properties as scour countermeasures. The gabion-nosed piers demonstrated their effectiveness in reducing maximum scour depths.

Gabion-nosed piers are recommended for existing bridges because they are a straightforward, affordable countermeasure and simple to install. Laboratory results observed that scouring is drastically reduced with the change of the pier's shapes and the pier nose properties and increases with an increase in flow velocity. Laboratory tests revealed that piers with gabion noses can reduce scouring depth by up to 46% compared to the same pier shape without gabion noses. The scour hole region around a gabion-nosed pier is smaller than the scour hole region of the pier without a gabion nose.

Before being applied in the field, this method as a scour countermeasure requires more testing in the lab to determine its effectiveness in real-world scour conditions, skewed flow, and the impact of various gabion nose heights and dimensions on other pier shapes on scour around the pier.

References

[1] Chiew Y-M. Scour protection at bridge piers. J Hydraul Eng 1992;118:1260–9.

[2] Breusers HNC, Nicollet G, Shen HW. Local scour around cylindrical piers. J Hydraul Res 1977;15:211–52.

[3] Bhalerao AR, Garde RJ. Design of Riprap for protection against scour around bridge pier. ISH J Hydraul Eng 2010;16:79–92.

[4] Escarameia M. River and channel revetments. A Des Man 1998;20:245.

[5] Parker G, Toro-Escobar C, Voigt Jr RL. Countermeasures to protect bridge piers from scour 1998.

[6] Yoon TH, Kim DH. Sack gabion as scour countermeasures at bridge piers.'. 28th Congr. IAHR, Graz, Austria, CD-Rom, 1999.

[7] Bestawy A, Eltahawy T, Alsaluli A, Almaliki A, Alqurashi M. Reduction of local scour around a bridge pier by using different shapes of pier slots and collars. Water Sci Technol Water Supply 2020;20:1006–15. https://doi.org/10.2166/ws.2020.022.

[8] Saleh H, Abozeid G, Darweesh M, Reduction of Local Scour Around Oblong Bridge Piers Using Slots. J Adv Eng Trends 2020;39:45–62. https://doi.org/10.21608/jaet.2020.75171.

[9] KIM U-Y, KIM Jon-S, AHN S-J, HAHM C-H. Scour countermeasure using additional facility in front of bridge pier. 31st IAHR Congr, Seoul, 5823–5829 2005:1289–90.

[10] Setia S. Scour protection by collar plates: A parametric study. Proc. Int. Conf. Fluv. Hydraul., 2016, p. 486–93.

[11] Dey S, Sumer BM, Fredsøe J. Control of Scour at Vertical Circular Piles. J Hydraul Eng 2006;132:270–9.

[12] Khaple S, Hanmaiahgari PR, Gaudio R, Dey S. Splitter plate as a flow-altering pier scour countermeasure. Acta Geophys 2017;65:957–75. https://doi.org/10.1007/s11600-017-0084-z.

[13] Abd El-Razek M, Abd El-Motaleb M, Bayoumy M. Scour reduction around bridge piers using internal openings through the pier. Alexandria Eng J 2003;42:241–8.

[14] El-Ghorab EAS. Reduction of scour around bridge piers using a modified method for vortex reduction. Alexandria Eng J 2013;52:467–78. https://doi.org/10.1016/j.aej.2013.04.001.

[15] EA E. Control of local scour at a bridge abutment using a protective pile. JES J Eng Sci 2014;42:956–67.

[16] Haque MA, Rahman MM, Islam GMT, Hussain MA. Scour mitigation at bridge piers using sacrificial piles. Int J Sediment Res 2007;22:49.

[17] Elnikhely EA. Minimizing scour around bridge pile using holes. Ain Shams Eng J 2017;8:499–506. https://doi.org/10.1016/j.asej.2016.06.016.

[18] Chiew Y, Lim S. Protection of bridge piers using a sacrificial sill. Proc. Inst. Civ. Eng. Marit. Eng., vol. 156, Thomas Telford Ltd; 2003, p. 53–62.

[19] Grimaldi C, Gaudio R, Calomino F, Cardoso AH. Countermeasures against local scouring at bridge piers: slot and combined system of slot and bed sill. J Hydraul Eng 2009;135:425–31.

[20] Soltani-Gerdefaramarzi S, Afzalimehr H, Chiew Y-M, Lai JS. Jets to control scour around circular bridge piers. Can J Civ Eng 2013;40:204–12.

[21] Vittal N, Kothyari UC, Haghighat M. Clear-water scour around bridge pier group. J Hydraul Eng 1994;120:1309–18.

[22] Abdelhaleem FSF. Roughened bridge piers as a scour countermeasure under clear water conditions. ISH J Hydraul Eng 2019;25:94–103. https://doi.org/10.1080/09715010.2017.1420498.

[23] Jones JS, Kilgore RT, Mistichelli MP. Effects of footing location on bridge pier scour. J Hydraul Eng 1992;118:280–90.

[24] Tafarojnoruz A, Gaudio R, Calomino F. Evaluation of Flow-Altering Countermeasures against Bridge Pier Scour. J Hydraul Eng 2012;138:297–305. https://doi.org/10.1061/(asce)hy.1943-7900.0000512.

[25] Mostafa YE, Agamy AF. Scour around single pile and pile groups subjected to waves and currents. Int J Eng Sci Technol 2011;3:8160–78.

[26] Akib S, Liana Mamat N, Basser H, Jahangirzadeh A. Reducing local scouring at bridge piles using collars and geobags. Sci World J 2014;2014.

[27] Radice A, Lauva O. On flow-altering countermeasures for scour at vertical-wall abutment. Arch Hydro-Engineering Environ Mech 2012;59:137–53.

[28] Abouzeid G, I Mohamed H, M Ali S. 3-D numerical simulation of flow and clear water scour by interaction between bridge piers. JES J Eng Sci 2007;35:891–907.

[29] Mohammed YA, Saleh YK, Ali A-AM. Experimental investigation of local scour around multi-vents bridge piers. Alexandria Eng J 2015;54:197–203.

[30] Kumar V, Raju KGR, Vittal N. Reduction of local scour around bridge piers using slots and collars. J Hydraul Eng 1999;125:1302–5.

[31] Najafzadeh M, Barani G-A, Hessami-Kermani M-R. Group method of data handling to predict scour depth around vertical piles under regular waves. Sci Iran 2013;20:406–13.

[32] Najafzadeh M, Barani G-A, Azamathulla HM. GMDH to predict scour depth around a pier in cohesive soils. Appl Ocean Res 2013;40:35–41.

[33] Najafzadeh M, Barani G-A. Experimental study of local scour around a vertical pier in cohesive soils. Sci Iran 2014;21:241–50.

[34] Najafzadeh M, Azamathulla HM. Neuro-fuzzy GMDH to predict the scour pile groups due to waves. J Comput Civ Eng 2015;29:4014068.

[35] Najafzadeh M. Neuro-fuzzy GMDH systems based evolutionary algorithms to predict scour pile groups in clear water conditions. Ocean Eng 2015;99:85–94.

[36] Daneshfaraz R, Abam M, Heidarpour M, Abbasi S, Seifollahi M, Abraham J. The impact of cables on local scouring of bridge piers using experimental study and ANN,

ANFIS algorithms. Water Supply 2022;22:1075–93.
[37] Sharp JA, McAlpin TO. Case Study: Experimental Investigation into the Feasibility of Pier Nose Extensions to Reduce Local Scour around Bridge Piers. J Hydraul Eng 2022;148:5021010.
[38] Chiew Y-M, Melville BW. Local scour around bridge piers. J Hydraul Res 1987;25:15–26.
[39] Melville BW. Pier and abutment scour: integrated approach. J Hydraul Eng 1997;123:125–36.
[40] SURFER n.d. https://www.goldensoftware.com/products/surfer.