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Gabion basket for reducing scour around a rectangular bridge pier

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***Abstract-* Riprap, a slit inside the pier, a number of piles located in front of a pier, collars, and other strategies have all been used to control scouring around bridge piers. In this study, a new alternative countermeasure for reducing scour around the rectangular bridge pier was investigated. A gabion basket —a stone basket attached to the upstream face of the pier—was investigated experimentally for reducing scouring depth around the bridge pier as a countermeasure in a clear-water condition. For estimating the efficiency of using the stone basket as a countermeasure for reducing scour, the scour findings of the pier with no modifications were used as a basis for comparison. The findings indicate that the pier using a stone basket significantly reduced the scour depth. According to the findings, the pier with a stone basket size of dg/B = 0.3 lowered the depth of scouring to 57%, and the best relative length of the stone basket was Lg/B = 0.5. Based on the experimental findings, a formula for predicting scour depth at rectangular bridge piers was developed. The results of this study may be used in the field of application for bridge pier protection design.**

***Keywords-* Scour, rectangular pier, gabion, stone basket, scour countermeasure.**

I. INTRODUCTION

The problem of scouring around bridge piers and abutments is an important issue in hydraulic engineering. Localised scouring, in addition to overloading, collisions, and a lack of maintenance, is one of the main reasons for bridge failure.[1]. Bed armouring and flow-altering countermeasures are the two main types of engineering techniques used for dealing with scour at bridge piers. The placement of riprap stones on riverbeds around bridge piers is the most widely used bed armouring technique [2], [3]. There are many types of bed armoring to reduce scouring around the piers, such as articulating concrete blocks [4], [5], gabions [5]–[8], concrete armor units, etc. Additionally, when riprap stones are either excessively expensive or not readily available in sufficient quantities, flow-altering devices might be more cost-effective. The main contributors to local scour are down flow and the horseshoe vortex, which are diminished by flow-altering countermeasures. Flow-altering devices are often divided into two groups based on how they are attached and how they are designed: pier attachment and its modification, and bed attachment. There are various types of pier attachments and their modifications, such as: slot in a pier [9]–[14], collar plate attached to a pier [15], [16], threaded pier [17], splitter plate [17], [18], internal connecting tubes [19], [20], sacrificial piles (e.g.) [21]–[24], openings through pier [19], [25], bed sills [10], [26], jet injection from the piers body [27], pier group [28], roughened pier [29], and caisson [30] are relevant. Stones of various sizes are placed inside wire-mesh baskets called gabions. Gabions come in a variety of shapes, sizes, and applications, such as box gabions, gabion mattresses, and sack gabions. Although gabions are currently employed as pier attachments to reduce the maximum scour depth, their effectiveness in minimizing bridge pier scour has received minimal research. Yoon [31] studied the utilization of gabions filled with stone for Protecting the bridge piers and found that as the length-to-thickness ratio increased, gabion stability increased up to the limiting factor L/t = 3. According to Lagasse et al. [32], gabion mattresses operate best as a pier scour countermeasure when they are extended in all directions by at least twice the width of the pier. According to Parker et al. [5], a geotextile filter also increases mattress stability. According to Pagliara et al. [33], higher debris loads can be harmful to gabion mattresses, suggesting that debris accumulation could reduce gabion's efficiency. Although gabions are currently used in construction, there is a shortage of research on their ability to reduce scour on bridge piers. With global warming predicted to reach 1.5°C between 2030 and 2052 [34], severe droughts and floods may occur as a result of this. Severe rainfall in both summer and winter might cause flash floods in the UK in the future [35], which might cause scouring at bridge piers, resulting in enormous economic losses and fatalities not only during the peak of the flooding but also when the flow recedes [36]. Craswell and Akib [37] investigated the effectiveness of gabion mattresses filled with different materials—stone, clothes, and plastic—in a laboratory experiment using a bridge pier embedded in a flume channel protected by gabion mattresses. The findings show that stone-filled gabions are the most effective at decreasing bridge pier scour. However, using recycled clothing as a gabion filler in construction projects could show to be an acceptable option, perhaps resulting in lower construction costs and more sustainability. The concept of employing a stone-filled basket as a scour countermeasure came from studies that employed wire gabion as bed armoring for hydraulic structures to disperse more energy and reduce downstream scouring. The aim of this study is to investigate the effectiveness of using a basket filled with uniform-sized stones fixed on the upstream face of piers as a new flow-altering countermeasure designed to minimize pier scour.

II. THEORETICAL STRATEGY

The three main factors that contribute to local scour at bridge piers are the down flow in front of the pier, the horseshoe vortex that forms at the base of the pier, and the wake vortex that forms inside the scour hole [38]. It is possible to delay flow division and move the point of

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stagnation upstream of the pier by using a basket filled with stone that is installed at the face of the pier. This method generates turbulence and kinetic energy upstream of the pier. As a result of this, as shown in Figure 1, the force generated by the down flow and horseshoe vortex has been decreased and diverted away from the canal bed. According to the current investigation, piers with stone baskets have less of an impact on the bed upstream of them. As a consequence, piers with stone baskets work well as preventative measures because they reduce the scour's depth.

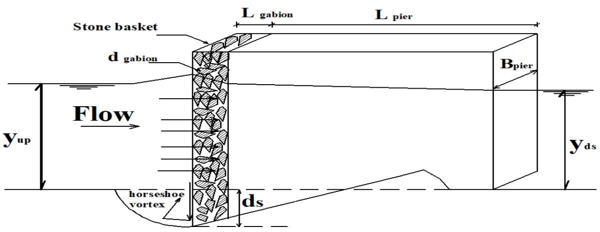

Figure 1. Sketch of the flow field and local scour at the pier with a stone basket.

III. MATERIALS AND METHODS:

1.1 Laboratory Flume

Experiments in a rectangular recirculating flume were carried out in the hydraulic lab at the Faculty of Engineering, Zagazig University, Egypt. The rectangular re-circulating flume with a width of 0.4 m, a length of 4 m, and a depth of 0.2 m has a maximum discharge of 5 L/s, as shown in Figure 2. An orifice meter installed on the delivery pipe of a centrifugal pump is used to measure discharge. To avoid scour in the early phases, water was slowly released from downstream, then the flow rate was regulated by a control valve and the flow was re-circulated. The valve is gently opened and closed without disturbing the bed surface until the required depth of flow is reached. Furthermore, the tailgate is lowered to reach the appropriate depth of flow. The water surface and scour depth are measured with a point gauge that is sensitive to 0.1 mm increments.

Figure 2. A modeled rectangular bridge pier at the considered laboratory Flume.

1.2 Pier Model

Since Chiew and Melville [39] recommended that the pier width (B) should be less than 10% of the flume width (w) to reduce the influence of the walls, which leads to contraction scour, As a result, the used rectangular pier model has dimensions of 4 cm in width, 16 cm in length, and 20 cm in height and was made from wood as shown in figure 2.

1.3 Bed Material

A coarse sand with a geometric mean size of sand (d50) equal to 0.52 mm was used. The bed sediment consisted of uniform sediment and geometric standard deviation σg=2.35. The grain size of the bed material has no effect on the depth of scour if the pier width-to-grain size ratio is more than about 25 (Melville) [40]. For the present study, the ratios are approximately 72.72, which fits the condition of (Melville) [40] and neglects the effect of sediment size on scour depth.

1.4 Gabion (Stone Basket)

Stainless steel wire mesh with an aperture of 1.2 mm was used to model a wire gabion basket with a constant width equal to the rectangular pier width (4 cm). The wire mesh was cut into varying lengths and filled with different stone sizes. The fill material of gabion was uniform stone with median particle sizes of 0.80, 1.20, 1.80, and 2.20 mm, as shown in Figure 3. The wire mesh was then bonded to the upstream face of the rectangular pier. The gabions were placed in an orderly manner such that their longitudinal axes were parallel to the direction of flow as shown in figure 1.

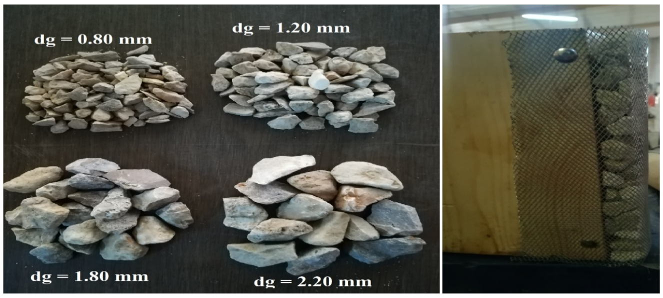

Figure 3. The fill material of the gabion basket.

1.5 Experimental Procedure

A total of 35 runs were conducted, including 5 runs with an unprotected pier (a rectangular pier without a wire gabion basket) to assess the efficiency of the wire gabion basket piers on the geometry of scour pits upstream of the pier. Table 1 outlines the conditions of the experiment. After positioning a pier and gabions, a scraper was used to level the bed's surface, and the point gauge was also used to check the levels of the bed. The flume is slowly filled with water until the specified flow depth is attained with the downstream tailgate raised. Once the predetermined flow rate had been determined, the flow velocity was raised by lowering the water depth. The water depth was lowered by slowly lowering the tailgate with a steady movement and then allowing the flow for two hours. At the end of each experiment, the flume was let to dry, and a point gauge was used to record the necessary measurements of the sand bed in all directions, including upstream, downstream,

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longitudinally, and transversely. The above-noted procedure was repeated for all experiments.

Table 1. Experimental conditions

Variables	Range
Rectangular bridge pier	4 cm width , 20 cm height, and 16 cm length
Flow depths (y)	4.5, 5, 5.5 ,6, and 7 cm
Flow rate (Q)	5 L/s
Stone size (dg)	0.80, 1.20, 1.80, and 2.20 mm
Wire mesh gabion length	1, 2, and 3 cm

IV. RESULTS AND DISCUSSION

Dimensional analysis was used to develop the following relationship for maximum scour depth ds at a rectangular bridge pier with a gabion basket:

$$f\left(\frac{d_s}{B}, \frac{d_g}{B}, F = \frac{u}{\sqrt{gy}}, \frac{L_g}{B}\right) = 0 \qquad (1)$$

where ds is maximum scour depth upstream of a pier, B is pier width, F is the Froude number, u is mean flow velocity, y is flow water depth, g is acceleration due to gravity, Lg is the gabion basket length and dg is the median stone particle sizes . The dimensionless terms in Equation (1) were employed to draw the relationships to explore the effects of these parameters on the scouring characteristics.

1.6 Effect of gabion basket on maximum scour depth

Piers with a wire gabion basket were tested to explore the effect of the wire gabion basket on scour depth reduction. The maximum scour depth is located upstream of the bridge pier for a non-modified pier or in the presence of countermeasures (Tafarojnoruz et al.) [41]. The maximum depth of scour was adjacent to the pier or at a distance towards upstream. The effectiveness of the countermeasures affected where the maximum scour depth occurred. The results of scouring without wire mesh gabion are considered the reference case to evaluate the degree of scour depth reduction when gabion stone sizes are introduced. As a result, the effectiveness of the countermeasure is measured using the following formula in terms of the percentage reduction of the scour depth:

$$R_{ds}(\%) = \frac{d_{su} - d_s}{d_{su}} x100 \qquad (2)$$

Where dsu is the maximum depth of scour upstream of the unprotected pier and ds is the maximum depth of scour upstream of the protected pier with the wire gabion basket. Also, the same concept of Equation (2) was applied to determine the reduction of the maximum scour volume RVs (%).

1.7 Effect of gabion fill stone material size on the maximum scour depth

The size of the stone filling the wire mesh gabion has a direct effect on the depth of scour. A wire mesh gabion of constant dimensions (mesh length Lg = 0.5B, mesh width = B) was used to study the effect of the different stone sizes on the maximum scour depth. In this study, four different stone sizes (0.80mm, 1.20mm, 1.80 mm, and 2.20mm) were simulated as a ratio of stone size to the pier width (dg/B) = 0.20, 0.30, 0.45, and 0.50. Figure 4 shows the relationship between the relative maximum scour depths and the Froude number for different stone sizes. According to this figure, runs with unprotected piers resulted in a deeper scour for all experiments. This shows the wire mesh gabion's effectiveness in lowering the scour depth. The gabion basket of dg/B =0.30 gave the minimum value of the relative maximum scour depth. At a Froude number (F) of 0.297, Figure 5 illustrates the relationship between the relative maximum scour depth and different gabion stone sizes (dg/B). Results showed that the stone basket of dg/B = 0.30 significantly minimized the scour depth, up to 57 %.

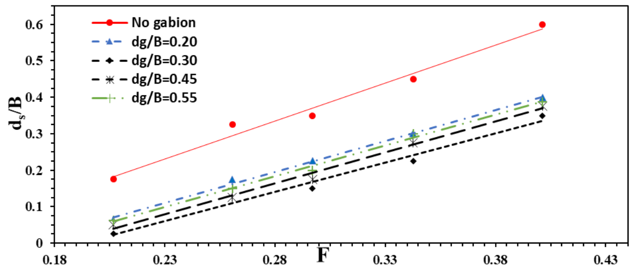

Figure 4. Relation between relative maximum scour depth (ds/B) and the Froude number for different size of the gabion stones.

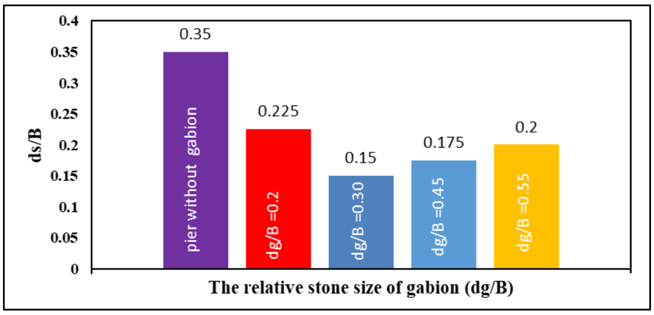

Figure 5. Relationship between the relative maximum scour depth and different gabion stone sizes (dg/B) at F =0.279.

1.8 Effect of gabion basket size on maximum scour depth

A wire mesh gabion with a constant width of B and a stone size of dg/B =0.30 was used to study the effect of the different gabion mesh lengths on the maximum scour depth. In this study, three different gabion lengths (1cm, 2cm, and 3cm) were simulated as a ratio of gabion length to the pier width (Lg/B) = 0.25, 0.50, and 0.75. Figure 6 shows the relationship between the relative maximum scour depths and the Froude number for different gabion lengths. From the

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figure, it is observed that scouring is drastically reduced with the change in the wire mesh gabion's length and increases with an increase in the Froude number. Due to the upstream gabion porosity, which only had a very weak vortex system, these results also showed that piers with gabion basket developed a minimum scour depth. At a Froude number (F) of 0.342, Figure 7 illustrates the relationship between the relative maximum scour depth and different gabion basket lengths (Lg/B). Results showed that the relative gabion basket length of Lg/B =0.50 gave the minimum value of the relative maximum scour depth.

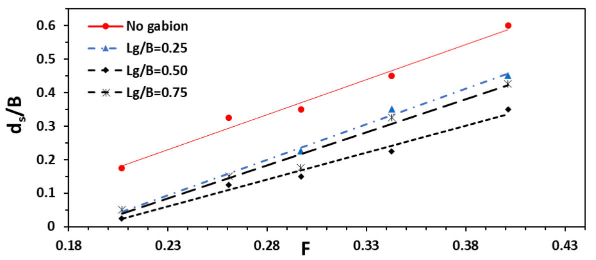

Figure 6. Relation between relative maximum scour depth (ds/B) and the Froude number for different size of the gabion stones.

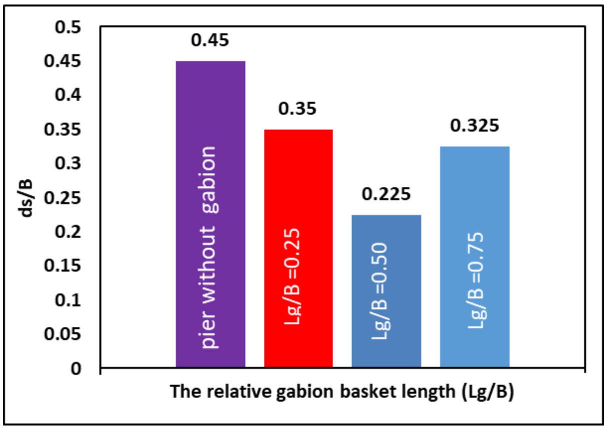

Figure 7. Relationship between the relative maximum scour depth and different gabion basket lengths (Lg/B) at F =0.342.

1.9 Effect of wire mesh gabion on volume of the scour hole

Golden Software (SURFER) was used to create contours for all experiments based on a survey of the bed topography around the rectangular pier. Figure 8 through figure 14 depicts the contours of some selected runs at the same conditions (F= 0.40) for different stone sizes and gabion lengths. According to these figures, the effect of wire-mesh gabion piers on the scour depths is very clear. A pier with a wire mesh gabion decreases the scour depth upstream of the pier. This is because the wire mesh gabion's porosity decreases the down flow to the movable bed around the pier.

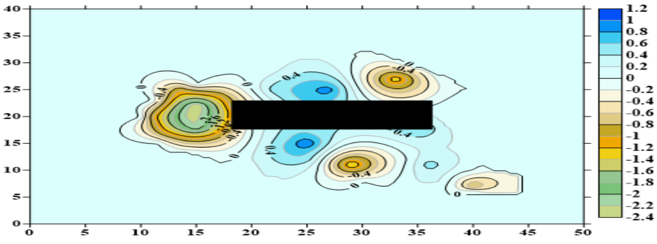

Figure 8. The contour map of bed morphology around the rectangular pier at F = 0.40.

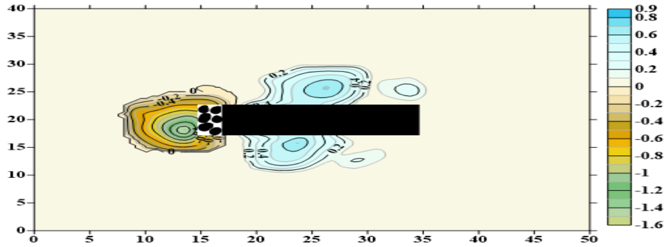

Figure 9. The contour map of bed morphology around the rectangular pier with gabion basket of (dg/B) =0.20 at F = 0.40.

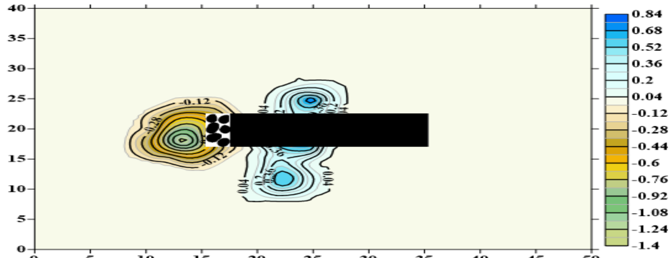

Figure 10. The contour map of bed morphology around the rectangular pier with gabion basket of (dg/B) =0.30 at F = 0.40.

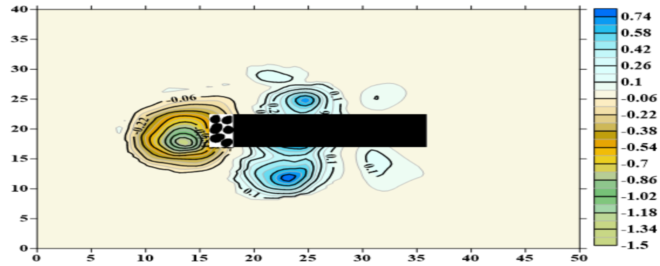

Figure 11. The contour map of bed morphology around the rectangular pier with gabion basket of (dg/B) =0.45 at F = 0.40.

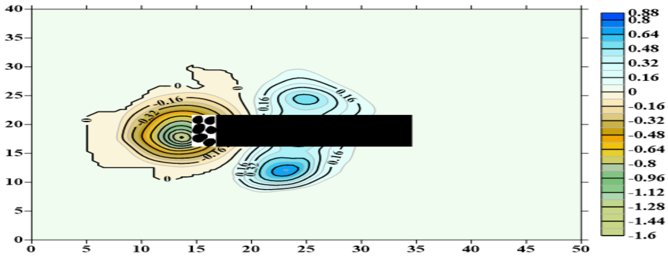

Figure 12. The contour map of bed morphology around the rectangular pier with gabion basket of (dg/B) =0.55 at F = 0.40.

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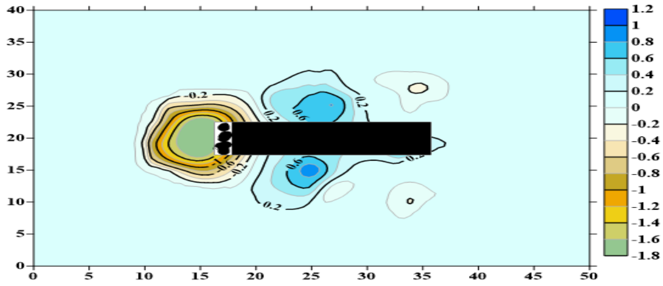

Figure 13. The contour map of bed morphology around the rectangular pier with gabion basket of (dg/B) =0.55 and (Lg/B) = 0.25 at F = 0.40.

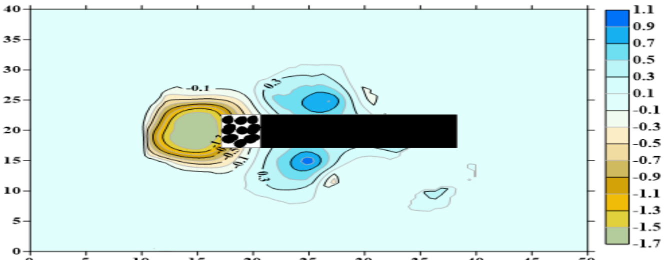

Figure 14. The contour map of bed morphology around the rectangular pier with gabion basket of (dg/B) =0.55 and (Lg/B) = 0.75 at F = 0.40.

1.10 Developed formula for maximum scour depth

The following equation was proposed for predicting the maximum scouring depth for a wire mesh gabion pier using experimental data and the dimensionless variables from Equation (1):

$$\frac{d_s}{B} = 1.84(F) - 0.16\left(\frac{d_g}{B}\right) - 0.15\left(\frac{L_g}{B}\right) - 0.203 \quad (2)$$

The maximum scour depths for piers with a wire mesh gabion are predicted by Equation (2) because the scour depth is a crucial factor in the construction of bridges. The proposed equation is valid for $0.20 \leq F \leq 0.40$, $0.2 \leq dg/B \leq 0.55$, and $0.25 \leq Lg/B \leq 0.75$. Therefore, it is not advised to apply this equation outside of the parameters shown above. The accompanying errors for computing the maximum depths using Equation (2) were consistent and did not exceed 4%. A comparison of the data generated using Equation (2) and the measured data is shown in Figure 15. They showed a strong association with one another, and the findings of this equation are accurate to within 5%.

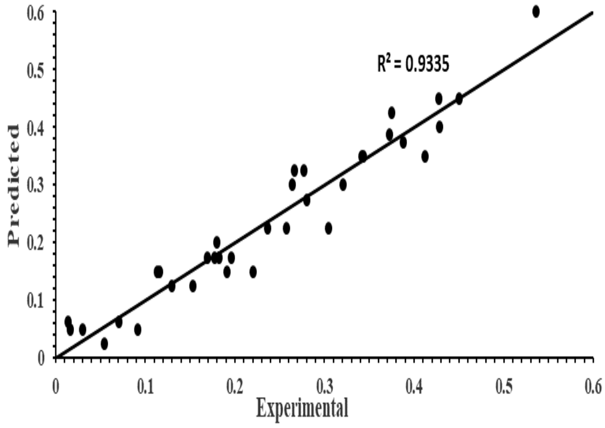

Figure 15. Comparison of the predicted values of Equation (2) with the observed values of ds/B for pier with wire mesh gabions.

V. Conclusions

On rectangular bridge piers in clear water, experiments were conducted to investigate the efficiency of the wire-mesh gabion placed on the upstream edge of the piers as a scour countermeasure. The wire mesh gabion showed its effectiveness in minimizing the maximum scour depths. From a practical point of view, wire mesh gabion is preferable as they are a simple, economical countermeasure and are easy to install on existing bridges. Laboratory observations revealed that piers with wire mesh gabions can significantly reduce the scouring depth by up to 50%. A consistent empirical formula was developed to estimate maximum scour depths for piers with wire mesh gabion. Before being implemented in the field, this method as a scour countermeasure requires additional evaluation in the laboratory in order to investigate its effectiveness in live scour conditions with skewed flow and to evaluate the impact of different wire mesh gabion heights along with different pier shapes on bed level downstream of the pier.

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Conflicts of Interest: The authors should explicitly declare if there is a conflict of interest.

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