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SCOUR REDUCTION AROUND BRIDGE ABUTMENTS USING INDUSTRIAL BY-PRODUCTS AS A COUNTERMEASURES-AN EXPERIMENTAL APPROACH

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Abstract- Due to the three-dimensionalities of the flow and sediment movement, the scour process around bridge elements such as piers, abutments, and spur dikes is complicated. In the present study, a laboratory investigation was carried out to determine the scouring around the bridge abutment without and with countermeasures. A wooden model of bridge abutment was embedded in a sand bed under two different values of discharge. Each experimental case was run for the time duration of two hours. The result showed that scouring around bridge abutment increases by increasing the flow discharge. The maximum scouring around the bridge was observed to be 17.92cm which was 9% greater than scouring at a flow discharge of 0.016m^3/s. By providing an industrial by-product as a countermeasure, it was observed that scouring around the bridge abutment decreases compared to without placing any countermeasures but scouring increases by increasing the flow discharge. The maximum reduction in scouring around the bridge abutment was observed to be 33% for two different values of flow discharge compared to the without placing countermeasures cases. It was concluded that industrial by-products reduced scouring around the bridge abutment up to the maximum level and provided protection to the bridge abutment from failure.

Keywords- Scouring, bridge abutments, countermeasures, sand bed, flow discharge.

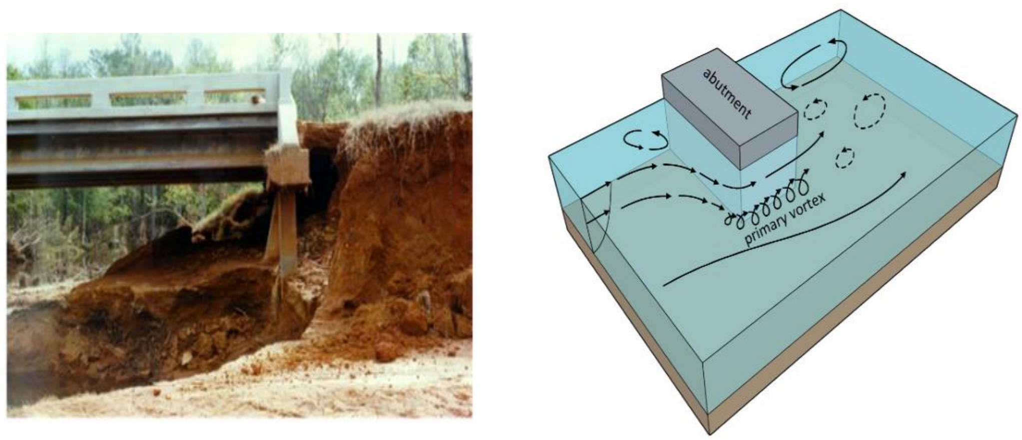
1. Introduction

The process of soil or silt being eroded or removed from around the base or foundation of a bridge is referred to as "scouring around a bridge abutment." The moving water of a river or stream, particularly during times of high-water velocity or floods, has the potential to bring about this effect. If it is not addressed, scouring has the potential to put the bridge's stability and safety at risk. Sand, gravel, and silt are examples of sediments that are typically carried by rivers. These sediments have the potential to build up around the abutments of the bridge over time. It is possible for scouring in the river as a result of the sediments being mobilized and eroded if there is an excessive sediment load or if there are changes in the sediment transport patterns of the river as shown in Figure 1.

Local scouring is an important and critical process that may occur around the piers and abutments leading to the catastrophic collapse of the bridge [1]. The process of local scour occurs in the surroundings of piers and abutments and has many similarities [2-4]. Therefore, it is necessary to assess the local scour around piers and abutments carefully and precisely. Otherwise, local scour may result in the collapse of the whole bridge structure, with the potential of a serious death toll and injuries in its aftermath [5, 6]. As the flow encounters the pier or abutment, it separates and converges downstream, forming a vortex. The downstream flow and vortices shed by the abutment may result in local scour at its upstream face [7]. The horseshoe vortex at the base of the abutment causes the scour hole to become wider and deeper as briefly presented in Figure 1 [8, 9]. It's important to note that scours can be influenced by various factors, including flow velocity, sediment characteristics, channel geometry, and structural design. Understanding the scour mechanism is crucial for designing effective countermeasures to mitigate scours and ensure the stability of bridge structures [10].

Many hydraulic researchers have investigated the challenge of local scouring experimentally under various flow conditions. Numerous methods have been proposed and implemented based on research aiming to minimize local scours around the piers and abutments [11]. There are two categories of countermeasure techniques around the abutments for local scour: bed surface armoring and flow modification [12-14]. Bed surface armoring techniques use hard materials like riprap stones, gabions, cable-tied blocks, concrete mats, or bags to protect the bed surface materials from flow-induced destabilization and scour. The flow modification techniques either prevent the scour-inducing mechanism or shift the scour hole away from the abutment's vicinity [15]. They are spur dike, parallel-wall, or collar and hooked-collar applications on abutments used as countermeasures against abutment scour in open-channel flow scenarios [16].

Previous literature shows that different researchers proposed countermeasures for scour reduction around bridge abutments, but their proposed solution is not economical and cost-effective. Therefore, in the present study, the objective was to investigate the scour reduction under different flow discharges and to investigate the maximum scour around the bridge abutment. The present study mainly focuses on scour reduction around bridge abutments by using industrial by-products such as bricks, and ceramic material to provide economical and better countermeasures.



(a) (b)

Figure 1. (a) bridge abutment failure caused by scouring (b) schematic figure of scouring pattern around bridge abutment

2. Experimental Procedures

Experiments were performed in an open channel placed in the water resources engineering laboratory of the Civil Engineering Department of the University of Engineering and Technology Taxila. The channel has a length of *20 meters*, width of *0.96 meters*, and height of *1 meter* respectively as shown in *Figure 2a*. Flow was supplied to the channel from the underground tank through the pump. The channel flow was measured by using a compound rectangular trapezoidal sharp-crested weir provided at the end of the channel. Such discharge was permitted so that bed shear stress does not exceed the threshold. The whole study was carried out using a bed of uniform sand that has an average diameter of 'd50' = 0.51 mm. The geometric standard deviation of the particle size distribution $\sigma g = (d_{84}/d_{16})^{0.5}$ was 1.74, here d_{84} and d_{16} represent that the sediment sizes were finer at *84%* and *16%* respectively. The mean grain size of sand is d_{50}=0.51 mm. The tests were performed at two different discharges (i.e., *0.016* m^3/s, *0.022* m^3/s). To fulfill the short-abutment criteria i.e., $La/Yc \leq 1$, the flow depth of *12cm* was used in all these experiments against *14 cm* abutment length as shown in *Figure 2b* and *Figure 2c* shows the scour depth and scour pattern around the bridge abutment. Flow conditions for each experimental case are summarized in *Table 1*.

Table 1. Hydraulics condition experiment

Discharge (m^3/s)	Flow depth (cm)	Median Grain Size
Q	Ym	(d_{50}) (cm)
0.016	12	0.051
0.022	12	0.051

3. Research Methodology

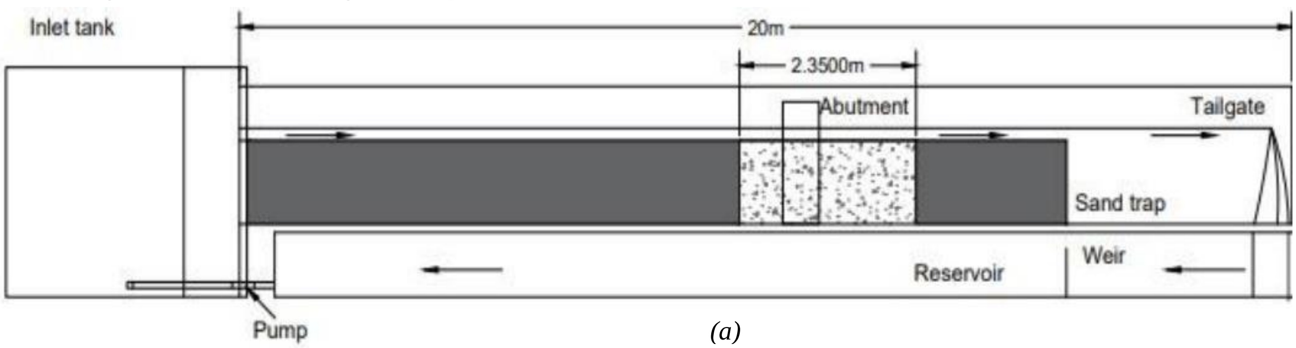
All the experiments were carried out in clear water conditions. To confirm fully established velocity profiles, a vertical-wall abutment was positioned in the last one-third of the sediment bed region of the experiment portion [17]. To measure the value of discharges at the end of the channel a trapezoidal sharp-crested weir was positioned with the help of the equation obtained by [18].

$$Q_t = \frac{2}{3} C_{rd2} \sqrt{2g} \left(b'' h''^{\frac{3}{2}} \right) + \frac{2}{3} C_{rd1} \sqrt{2g} \, (2b') h'^{\frac{3}{2}} + \frac{8}{15} C_{td} \sqrt{2g} \left(\tan\frac{\theta}{2} \right) he^{5/2}$$

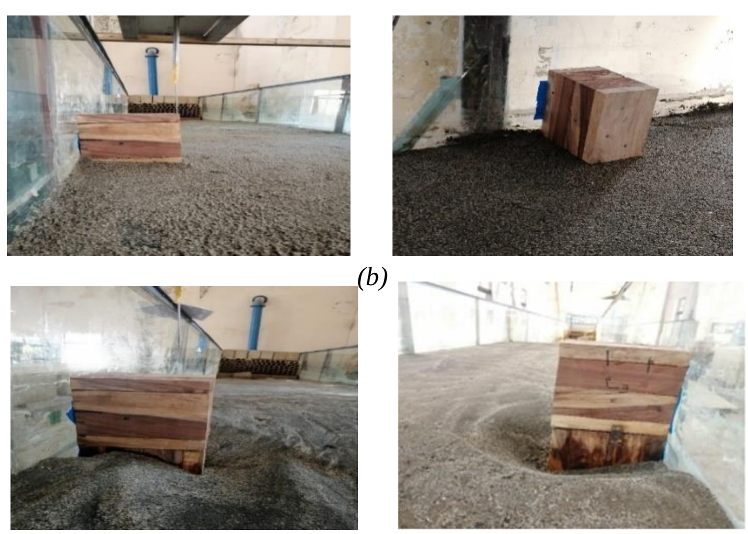
Where θ = notch angle, b = length of the weir

C_{rd}= discharge coefficient of the rectangular sharp-crested weir,

C_{td}= discharge coefficient for triangular sharp-crested weir



(a)



(b)

(c)

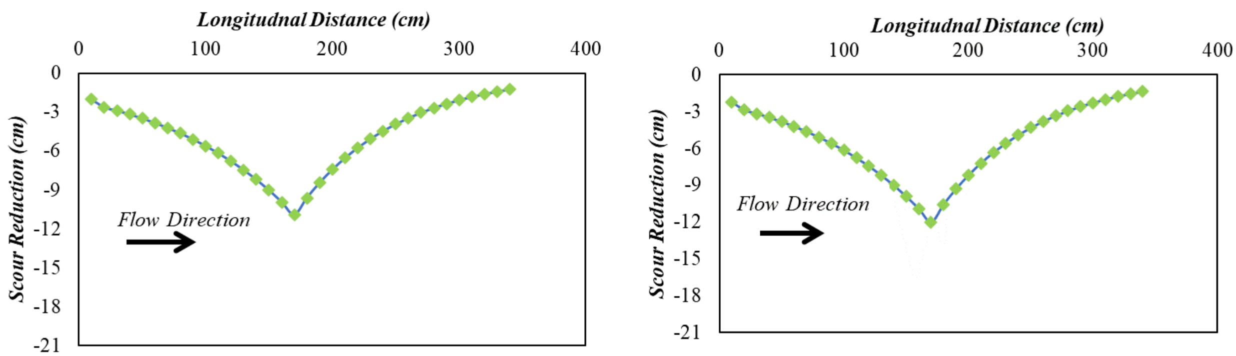
Figure 2. experimental setup of laboratory investigation (a) schematic diagram of experimental work with abutments setup (b) photograph of abutments model in a flume (c) scouring depth and pattern around abutments

4. Results

4.1. Scour Depth without Countermeasures

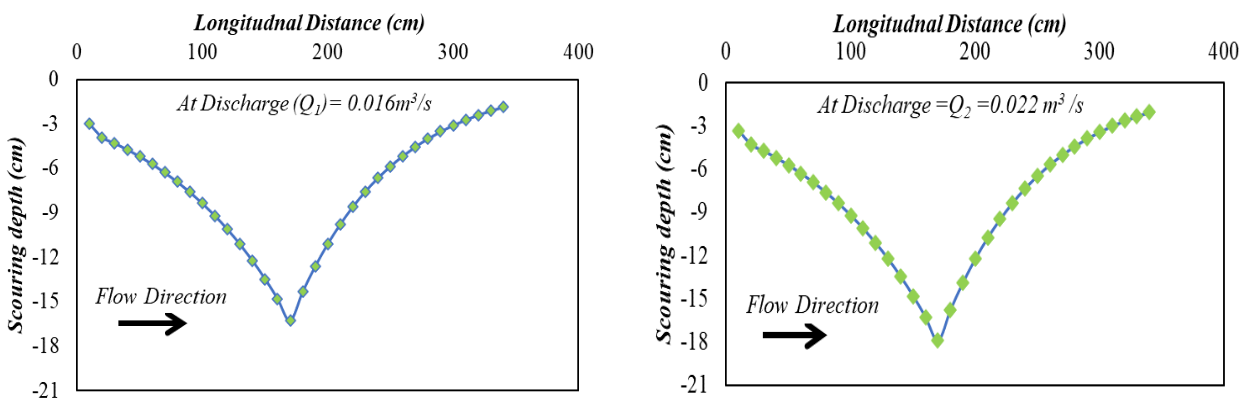
The scour depth around the bridge abutment has been determined under two different flow discharges. It was observed that scouring depth at the outer side of the bridge abutment increases by increasing the flow discharge as by increasing the discharge the flow velocity at the outer edge of the abutments increased that resulting sediment flow on the outer edge of the abutment. *Figure 3a* shows the scour around bridge abutments for flow discharge of *0.016m³/s*. The maximum scour depth underflow discharge of *0.016m³/s* was observed to be *16.29cm* as shown in *Figure 3a*.

Similarly, scouring depth around the bridge abutment underflow discharge of *0.022m³/s* was also determined. The maximum scour around the bridge abutment underflow discharge of *0.022m³/s* was observed to be *17.92cm* which was *9%* more than scour depth under the discharge of *0.016m³/s* as shown in *Figure 3b*. The results showed that by increasing the flow discharge, scour depth around bridge abutments increased by a multiple of *9%*.



(a) *(b)*

Figure 4. Scour reduction using countermeasures (a) Scour reduction under flow discharge of 0.016m³/s (b) scour reduction under flow discharge of 0.022m³/s.



(a) *(b)*

Figure 3. Scour depth around abutments without countermeasures. (a) scour depth at discharge of 0.016m³/s (b) scour depth at discharge of 0.022m³/s.

4.2. Scour Depth with Countermeasures

The present study investigates the scour reduction around bridge abutments using industrial by-products as a countermeasure. It was observed that scour depth with countermeasures decreases for two different values of flow discharge but increases by increasing flow discharge as shown in Figure 4a-b. Industrial by-products protect the bridge abutments that reduced the flow velocity around the bridge abutment resulting in a scour reduction around the bridge. The scour depth is reduced by up to *33%* for two different values of flow discharge and scour reduction increases by decreasing the intensity of flow. Hence it was found that industrial by-products are efficient for scour reduction around bridge abutments.

4.3. Implementation of Study

In Pakistan, it is common practice to come across scouring or sediment erosion, both of which have the potential to cause damage to bridge abutments. Researchers from a variety of institutions have come up with a variety of potential solutions to the problem of scouring bridge abutments in the hopes of reducing the frequency with which it occurs [12,19,20]. However, despite the fact that these preventative measures have been shown to be beneficial in lowering scour, the country's economic conditions have not been fulfilled by them. This study investigates the use of industrial by-products as a potential method for reducing the amount of scouring that occurs near bridge abutments in a way that is both cost-effective and efficient. The project will also look into ways to improve existing systems to prevent the collapse of bridge abutments.

5. Conclusions

Based on an experiment performed in the hydraulic laboratory for scour reduction around bridge abutments using industrial by-products as a countermeasure, the following conclusion has been concluded.

1. The scour depth around bridge abutments increases by increasing the flow discharge and the maximum scour depth was observed to be 17.92cm.
2. The maximum scour around the bridge abutment underflow discharge of $0.016m^3/s$ was observed to be 16.29cm.
3. Scour depth underflow discharge of $0.022m^3/s$ was observed to be 9 percent more than scour depth underflow discharge of $0.016m^3/s$.
4. The scour depth was reduced up to 33% when the industrial product is provided as a countermeasure around the bridge abutment which reduced the flow velocity around the abutment.
5. The results concluded that using industrial by-products as countermeasures would be economical and should be implemented in developing countries.

References

[1] Bestawy, A., et al., Reduction of local scour around a bridge pier by using different shapes of pier slots and collars. Water Supply, 2020. 20(3): p. 1006-1015.
[2] Chiew, Y.-M., Scour and scour countermeasures at bridge sites. Transactions of Tianjin University, 2008. 14(4): p. 289-295.
[3] Singh, N.B., T.T. Devi, and B. Kumar, The local scour around bridge piers—a review of remedial techniques. ISH Journal of Hydraulic Engineering, 2022. 28(sup1): p. 527-540.
[4] Chiew, Y.-M., Scour and scour countermeasures at bridge sites. Transactions of Tianjin University, 2008. 14: p. 289-295.
[5] Al-Shukur, A.-H.K. and Z.H. Obeid, Experimental study of bridge pier shape to minimize local scour. International Journal of Civil Engineering and Technology, 2016. 7(1): p. 162-171.
[6] Jahangirzadeh, A., et al., Experimental and numerical investigation of the effect of different shapes of collars on the reduction of scour around a single bridge pier. PloS one, 2014. 9(6): p. e98592.
[7] Kothyari, U.C., R.C.J. Garde, and K.G. Ranga Raju, Temporal variation of scour around circular bridge piers. Journal of Hydraulic Engineering, 1992. 118(8): p. 1091-1106.
[8] Kumar, V., K.G.R. Raju, and N. Vittal, Reduction of local scour around bridge piers using slots and collars. Journal of hydraulic engineering, 1999. 125(12): p. 1302-1305.
[9] Dey, S. and R.V. Raikar, Characteristics of horseshoe vortex in developing scour holes at piers. Journal of Hydraulic Engineering, 2007. 133(4): p. 399-413.
[10] Melville, B.W. and S.E. Coleman, Bridge scour. 2000: Water Resources Publication.

[11] Hong-Wu, T., et al., Protection of bridge piers against scouring with tetrahedral frames. International Journal of Sediment Research, 2009. 24(4): p. 385-399.

[12] Farooq, R. and A.R. Ghumman, Impact assessment of pier shape and modifications on scouring around bridge pier. Water, 2019. 11(9): p. 1761.

[13] Alabi, P.D., Time development of local scour at a bridge pier fitted with a collar. 2006, University of Saskatchewan.

[14] Osroush, M., S.A. Hosseini, and A.A. Kamanbedast, Countermeasures against local scouring around bridge abutments: combined system of collar and slot. Iranian Journal of Science and Technology, Transactions of Civil Engineering, 2021. 45: p. 11-25.

[15] Tafarojnoruz, A., R. Gaudio, and S. Dey, Flow-altering countermeasures against scour at bridge piers: a review. Journal of hydraulic research, 2010. 48(4): p. 441-452.

[16] Karami, H., et al., Protective spur dike for scour mitigation of existing spur dikes. Journal of hydraulic research, 2011. 49(6): p. 809-813.

[17] M. Vaghefi, M. Akbari, and A. R. Fiouz, "An experimental study of mean and turbulent flow in a 180-degree sharp open channel bend: Secondary flow and bed shear stress," KSCE Journal of Civil Engineering, vol. 20, no. 4, pp. 1582-1593, 2016.

[18] Martinez, J., Reca, J., Morillas, M.T., and Lopez, J.G (2005) "Design and calibration of a compound sharp-crested weir", Journal of Hydraulic Engineering, Vol. 131, No. 2, pp.112-116.

[19] Farooq, R., et al., *Optimal octagonal hooked collar countermeasure to reduce scour around a single bridge pier.* Periodica Polytechnica Civil Engineering, 2020. **64**(4): p. 1026-1037.

[20] Farooq, R., et al., *Effects of hooked-collar on the local scour around a lenticular bridge pier.* International Journal of Sediment Research, 2023. **38**(1): p. 1-11.