BRIDGE PIER SCOUR REDUCTION INVESTIGATION USING DIFFERENT VEGETATION ELEMENTS AS COUNTERMEASURE

[a] Sajjad Hussain*, [b] Naeem Ejaz, [c] Sheraz Hussain

a: Department of Civil Engineering, UET, Taxila, Pakistan, ziadbacha001@gmail.com
b: Department of Civil Engineering, UET, Taxila, Pakistan, naeem.ejaz@uettaxila.edu.pk
c: Department of Civil Engineering, UET, Taxila, Pakistan, sheraalvi212@gmail.com
*Corresponding authore: Email ID: sh389633@gmail.com

Abstract- Due to climate change extreme weather conditions like increased heat, droughts, glaciers melting affected the natural ecosystem of our country. Flash floods mostly occurred in hilly areas of Pakistan. Scouring occurs when the flow of water around bridge piers erodes the bed material, potentially undermining the foundation of the structure. To mitigate this problem, various countermeasures have been proposed and studied. This research investigates the effectiveness of different vegetation elements as countermeasures for reducing bridge pier scour. The study comprises a comprehensive examination of two types of rigid vegetation, including wooden and steel cylinders around bridge pier in experimental flume setups. These cylinders were of circular cross-section and were installed upstream of the bridge pier, which is of circular shape. The aspect ratio (AR-ratio of width to length) of wooden and steel cylinders and the spacing between the cylinders (G/d) were changed against two different flow conditions (where G is spacing between each cylinder and d is the diameter of each cylinder). Theexperiments were conducted under sub critical flow conditions i.e at Froude number 0.136 and 0.187. The results showed that by decreasing the aspect ratio of cylinders, scourhole reduces effectively. The denser arrangement of cylinders obstructs the flow and results in a greater reduction of scouring on the bridge pier. Maximum scour reduction atpier is 71.7% by using vegetation cylinders of 7.46 aspect ratio and G/d ratio of 0.71. Thus, vegetation significantly contributes to scour reduction on the bridge pier. Hence, sacrificial piles with a denser arrangement are recommended for scour reduction at pier facing high river flow.

Keywords- Scouring, pier, vegetation cylinders, clear water condition, scour countermeasure.

1 Introduction

Bridge structures play a vital role in facilitating transportation networks, connecting communities, and fostering economic development. However, bridges located in waterways are susceptible to a critical issue known as bridge pier scour, which poses a significant threat to their integrity and safety. Scouring occurs when the flow of water around bridge piers erodes the bed material, potentially leading to the undermining of the bridge foundation and compromising its structural stability.As climate change and extreme weather events intensify, the risk of bridge pier scour becomes even more pronounced, necessitating innovative and sustainable solutions to address this challenge. (Kho et al., 1997)

Various countermeasures have been proposed and implemented to mitigate bridge pier scour, ranging from traditional hard engineering structures to more environmentally friendly and ecologically sensitive approaches. Among these alternative methods, the use of vegetation elements as scour-mitigating measures has gained increasing attention in recent years.

Vegetation, with its natural adaptability and root systems, can potentially provide a sustainable and environmentally beneficial solution to reduce the scouring effects around bridge piers (Breusers et al., 1977). This research aims to investigate the effectiveness of different vegetation elements as countermeasures for bridge pier scour reduction. The study involves a comprehensive examination of various vegetation types, including live plants, woody debris, and synthetic materials, to assess their potential in stabilizing the riverbed and impeding the erosive flow of wateraround bridge piers. By strategically deploying vegetation in experimental flume setups that simulate real-world hydraulicconditions, the performance of each vegetation element will be evaluated through systematic measurements of scour parameters (Khosronejad et al., 2012). The successful implementation of vegetation-based countermeasures offers multiple benefits beyond scour reduction. Vegetation elements can enhance ecological habitats, foster biodiversity, and improve water quality by filtering pollutants.Moreover, they are generally more cost-effective and sustainable compared to conventional hard engineering structures, which often involve significant maintenance and environmental trade-offs (DATYE & RAO, 1974).

This investigation will contribute valuable insights into the viability of vegetation-based countermeasures for bridge pier scour reduction. By understanding the hydrodynamic and ecological interactions of different vegetation elements,engineers, and policymakers can develop practical guidelines and design strategies for incorporating vegetation-based solutions into bridge construction and maintenance practices. Ultimately, this research endeavors to promote the resilienceand longevity of bridge infrastructure while preserving and enhancing the natural environment in waterway settings. In summary, this investigation on bridge pier scour reduction using various vegetation elements as countermeasures holds the potential to revolutionize traditional scour mitigation practices. By exploring the advantages of vegetation-based solutions, it seeks to offer a more sustainable, cost-effective, and environmentally sensitive approach to safeguarding bridge infrastructure in waterways. Ultimately, the outcomes of this research can contribute to the development of resilientand ecologically responsible bridge design guidelines, fostering a harmonious coexistence between human-made structures and the natural environment. (Eni, 1967). The study conducts a comprehensive examination and comparison of effectiveness of two types of rigid vegetation, wooden and steel cylinders, in experimental flume setups. By testing and comparing different types of vegetation, the research contributes to a deeper understanding of how vegetation characteristics influence scour reduction.

2 Experimental Procedures

Experiments were conducted in the hydraulic laboratory of the Civil Engineering Department at the University of Engineering and Technology (UET), Taxila. All experiments were conducted in a rectangular channel with 20 meters long,1 meter wide, and 0.75 meters deep (Fig. 1). Transparent glass and a concrete base served as the channel's side walls and bed, respectively. Sand material was used to prepare the channel bed up to a depth of 0.30 meters, having size of d50 =

0.88 mm and relative density G=2.56. To prevent an unchanging water level in the test portion, the sand bed needs to be properly levelled. An adjustable tailgate was put at the downstream most point of the channel to manage the water level, and a flow control valve was fixed at the channel upstream to control discharge.

Figure 1: Vegetation cylinders conditions, a. steel cylinder protection, and b. wooden cylinder protection

2.1 Vegetation Cylinders Condition

In present study, wooden vegetation cylinders with an average diameter of 7mm and steel cylinders with an average diameter of 3mm are used. The G/d arrangement of the vegetation cylinders, where G denotes the distance between each cylinder in the cross-stream direction and d denotes the diameter of a cylinder. The G/d ratio indicates the density or sparsity of vegetation cylinders. for dense arrangement its value is 0.25 and for sparse arrangement its value is 2.13. The experiment was performed with three G/D conditions (2.85,1.42,0.71) and three aspect ratios (cylinders width-length ratio)(18.5,10.6,7.46). Wx and Wy represents vegetation cylinders arrangement length and width respectively.

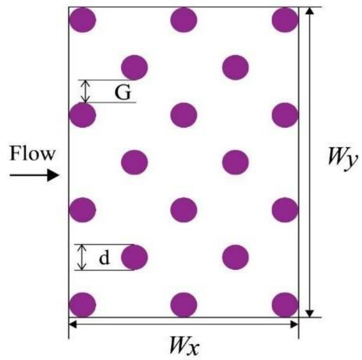

Figure 2: Vegetation cylinder conditions

3 Research Methodology

All experiments were conducted at two different discharges i.e 0.023 m³/s and 0.027 m³/s having Froude Number 0.136 and 0.187 respectively. The flow discharge was determined with a Trapezoidal weir at the end of the channel placed afterthe tailgate (Reca et al. 2006). Flow depth of 14cm was used in all lab experiments. All tests were carried out in clear water conditions at a threshold flow intensity (U/Uc) of less than 0.92, where U is the approach velocity of flow. The logarithmic format of the velocity profile was used to compute the critical velocity (Lauchlan and Melville 2001).

4 Results and Discussions

Initially the circular was tested without any protection. It was found that sediments creeping motion to downward flow started in the scour hole at the upstream tip of the pier. The effects of vegetation cylinders arrangement and their positionsfrom the circular bridge pier on the normalized maximum scour depth were studied. By performing several experiments, it was showed that aspect ratio of vegetation cylinders arrangement and their G/d ratios greatly affects the scour hole. As we reduce the aspect ratio of sacrificial piles arrangement scour hole reduces on upstream face of pier. Two flow conditionswere examined in this research. Scouring increases as we enhance the flow so at higher discharges scour reduction efficiency of vegetation cylinders reduces. The maximum scour depth around bridge pier were 55,51mm. The comparisonof Flow Depths and Efficiencies of circular pier for the different Froude Numbers (0.136,0.187) are shown in Fig .3 and Fig. 4.

Table 1 Experimental conditions using wooden cylinders

Case	**Q(m³/s)**	**h(m)**	**v(m/s)**	**AR**	**G/d**	**T(hr)**	**Ds(mm)**	**E (%)**
1	0.023	0.14	0.16	…	…	3	20.84286	0
2	0.023	0.14	0.16	18.5	2.85	3	16.88	19
3	0.023	0.14	0.16	18.5	1.42	3	16.0	23.2
4	0.023	0.14	0.16	18.5	0.71	3	14.2	31.5
5	0.023	0.14	0.16	10.6	2.85	3	15	27.8
6	0.023	0.14	0.16	10.6	1.42	3	13	37.5
7	0.023	0.14	0.16	10.6	0.71	3	10	51.9
8	0.023	0.14	0.16	7.46	2.85	3	11	47.1
9	0.023	0.14	0.16	7.46	1.42	3	7	66.3
10	0.023	0.14	0.16	7.46	0.71	3	6	71.7

Table 2 Experimental conditions using steel vegetation protection

Case	Q(m³/s)	h(m)	v(m/s)	AR	G/d	T(hr)	Ds(mm)	E (%)
11	0.023	0.14	0.16	18.5	2.85	3	17.80	14.4
12	0.023	0.14	0.16	18.5	1.42	3	16.6	20.1
13	0.023	0.14	0.16	18.5	0.71	3	14.7	30.2
14	0.023	0.14	0.16	10.6	2.85	3	15	27.8
15	0.023	0.14	0.16	10.6	1.42	3	14	32.7
16	0.023	0.14	0.16	10.6	0.71	3	11	47.1
17	0.023	0.14	0.16	7.46	2.85	3	12	61.5
18	0.023	0.14	0.16	7.46	1.42	3	8	42.3
19	0.023	0.14	0.16	7.46	0.71	3	9	66.3

The maximum scour depth (Ds) around circular bridge pier were 20.84mm and 22.91mm,respectively against Froude number 0.136 and 0.187 as shown in figure 3: a and b.

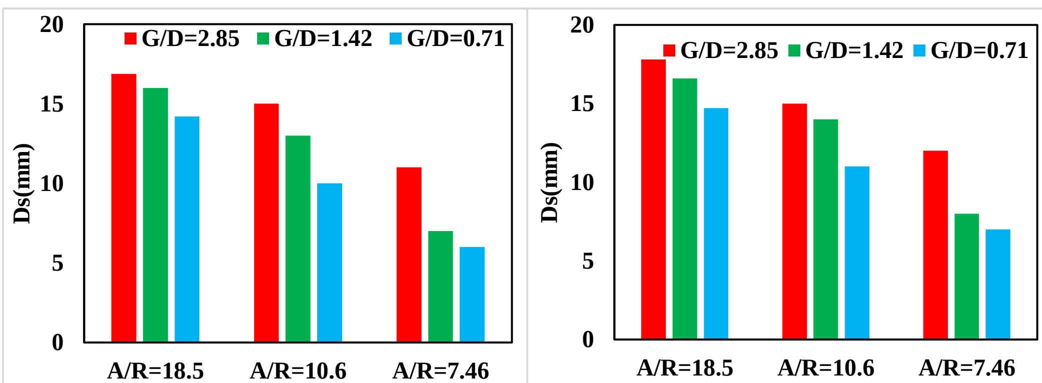

Figure 3: scour depth comparison at different aspect ratios and different G/d ratios, a. using woodencylinders, and b. using steel cylinders

The maximum scour reduction for bridge pier with wooden vegetation arranged with aspect ratio of 7.46 and G/d ratio of 0.71 is 71.7% as shown in figure 4: a

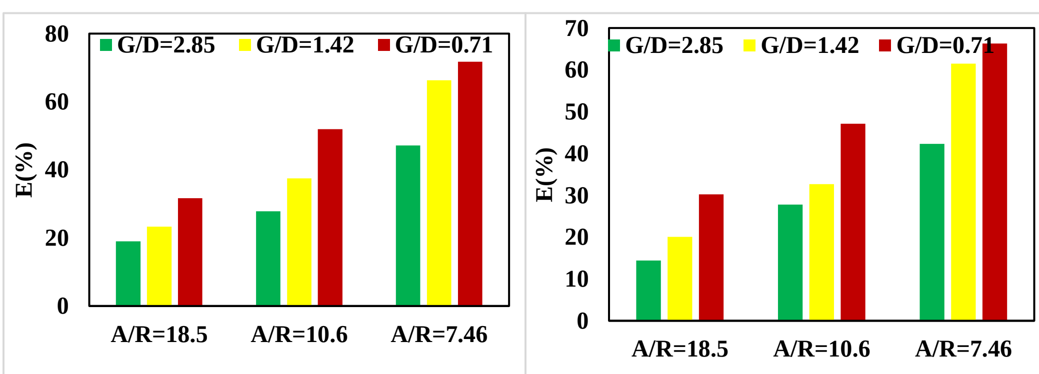

Figure 4: Scour reduction efficiency comparison at different aspect ratios and different G/d ratios, a.using wooden cylinders, b. using steel cylinders

5 Conclusions

Following conclusions can be drawn from the conducted study:

1. The Scouring depth around the bridge pier increases by increasing Froude Number in clear water condition. At Froude number 0.136 scour depth is 20.84 while at Froude number 0.187 its value is 22.91.
2. The scour depth of bridge pier is decreased by providing vegetation. At Froude number 0.136 without vegetationscour depth value is 20.84mm but it is reduced to 16.88mm by providing vegetation protection. Same is the caseat Froude number 0.187, 22.91 without vegetation and 18.55 with vegetation protection.
3. The maximum scour depth reduction for bridge pier with wooden vegetation arranged with aspect ratio of 7.46 and G/d ratio of 0.71 is 71.7 %.
4. Vegetation with lower G/d ratio (denser arrangement) greatly reduces scour around bridge pier. At 2.85 G/d ratioscour depth is 16.88mm and 14.0mm at G/d ratio 0.71.
5. By performing several experiments, it was found that wooden cylinder vegetation has greater scour reduction than steel cylinders due to greater roughness coefficient.

6 Limitations of the Study

- The experiments are conducted in a controlled laboratory flume setup. While laboratory experiments provide valuable insights into the behavior of different vegetation elements, the results may not fully represent the complexities and variations present in real-world field conditions, especially in a river or stream with natural sediment transport and flow dynamics.
- The scouring process in natural rivers often involves a mixture of sediment sizes. In my research, the bed materialused in the flume setup might have been of uniform size, which could influence the scouring process differently than heterogeneous sediment found in real-world rivers.
- My research focused on a single pier setup, and the effectiveness of the vegetation elements for multiple piers orbridge structures in different geometric arrangements remains unexplored. Real-world bridges often have multiple piers, and the interaction between vegetation and multiple piers could differ from the single pier case.

Acknowledgment

I want to thank my advisor Professor Dr. Naeem Ejaz for his wise counsel, suggestions, and remarks. I also want to thankthe UET Taxila department of civil engineering for providing me with the research space I required to complete my study.

References

[1] Breusers, H. N. C., Nicollet, G., & Shen, H. W. (1977). Erosion locale autour des piles cylindriques. Journal *of Hydraulic Research*, *15*(3), 211–252. https://doi.org/10.1080/00221687709499645

[2] DATYE, K. R., & RAO, N. S. V. (1974). *Scour Around Bridge Piers. (DECEMBER 27-28, 1974)*, 37–41.

[3] Eni. (1967). *Angewandte Chemie International Edition, 6(11), 951–952., Mi*, 5–24.

[4] Kho, K. A. I. T. Z. E., Valentine, E., & Glendinning, S. (1997). an Experimental Study of Local Scour Around Circular Bridge Piers in Cohesive Soils. *Civil Engineering*, 1–8.

[5] Khosronejad, A., Kang, S., & Sotiropoulos, F. (2012). Experimental and computational investigation of local scour around bridge piers. *Advances in Water Resources*, *37*, 73–85. https://doi.org/10.1016/j.advwatres.2011.09.013

[6] Lind, L., Nilsson, C., Polvi, L. E., & Weber, C. (2014). The role of ice dynamics in shaping vegetation in flowing waters. Biological Reviews, 89(4), 791-804.

[7] Nabaei, S. F., Afzalimehr, H., Sui, J., Kumar, B., & Nabaei, S. H. (2021). Investigation of the effect of vegetation on flow structures and turbulence anisotropy around semi-elliptical abutment. Water, 13(21), 3108.

[8] Miyab, N. M., Fazloula, R., Heidarpour, M., Kavian, A., & Rodrigo-Comino, J. (2022). Experimental Design of Nature-Based-Solution Considering the Interactions between Submerged Vegetation and Pile Group on the Structure of the River Flow on Sand Beds. Water, 14(15), 2382.