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Investigation of Scour Reduction at Downstream Side Flushing Causeway- An Experimental Approach

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Abstract. Scouring poses a significant threat to the causeway, potentially resulting in its damage or complete failure. The force of fast-moving water acts upon the foundation, sweeping away sediment that otherwise stabilizes the causeway. In the current investigation, scour at downstream side of flushing causeway (with no vent) under four different conditions and glass sided open channel. A wooden model of causeway with different elevation above sand bed (D_{50}) was placed for different four conditions. A total of 36 cases were performed in the laboratory to investigate scour. The result shows that scours at the downstream side of the causeway increase with increase in the Froude number (0.16-33). The maximum scour was observed at causeway elevation of 6cm above sand bed and Froude number 0.33. It was observed that scour at the downstream side of causeway reduced by providing riprap and vegetation as a countermeasure. Scour depth at the downstream side of the causeway reduced up to 40% for 6cm elevation of causeway above bed level and 25% for 6cm elevation of causeway above bed level when vegetation was used as a countermeasure. It was concluded that countermeasures such as riprap, and vegetation reduced scour depth at the downstream side causeway up to significance level.

Keywords. Scouring, flushing causeway, Froude, riprap, vegetation

1. Introduction

Installing a hydraulic or marine structure in water with current or waves increases the potential for localized sediment movement and promotes scour [1]. One of the main threats to the integrity of structures is scouring, and scour prevention drives up the price of hydraulic and marine structures significantly. Numerous reviews of the studies of bridge piers [2,3], offshore monopiles [4,5], and spur dikes in bending rivers [6] have been reported. Previously research has been undertaken to examine local scour surrounding hydraulic and marine structures. Approaches for scour preservation and the reconstruction of different structures have additionally been recently explored [7-9]. There are several publications that present foundational information [10,11], results of previous studies [1], develop formulas, and directions [12-14] for scouring.

Due to their outstanding effectiveness and the rapidly expanding capacity of technology for substantial numerical simulations, computational methods have been employed more and more in the investigation of scours around hydraulics structures. It

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is hard to guarantee every commonality in a controlled study on scouring because local scouring includes complicated interactions between sand, water circulation, and structures. Scaling impact leads to inaccuracies in small-scale laboratory investigations [15-18].

Causeway [21] is a paved submerged infrastructure that has or does not have apertures (vents) which enable floodwaters to move around and/or over it. Consideration needs to be exercised when proposing a causeway to bridge an expanse of water that has shallow beds and a moderate yet continuous discharge [21]. [22] depicts a portion across a simple bed-level roadway designed for optimum velocity of water of less than 2m/sec and minimal traffic. Adding block revetment should be used to safeguard causeway foundations upstream as well as downstream of the flood [19]. Scour and sedimentation are events of nature that take place whenever a waterway or stream's flow is hindered by any impediment [20]. Whenever the openings of venting roadways become either completely or partially clogged with sediment as a result of significant sediment scour and accumulation. This condition is common when roadways are built wherever watercourse bends [20].

Causeways serve two purposes, i.e., passing river water and to cater the traffic demand simultaneously. Generally, two types of causeways flushing and vented are common practice in Asia. A causeway is a road or railroad crossing of an enormous quantity of water or swamp habitats that is elevated on a berm. Causeways primarily perform two purposes. For beginnings, it allows typical dry season flow of a river/stream flowing by means of culverts (vents) beneath the highway, as well as frequent flooding to travel across the culverts and along the roadway. Some causeways may be only accessible at low tide, and the line between causeways and tunnels could get mixed up whenever flood-relief culverts are included into the construction. A causeway, on the other hand, is stabilized mostly by soil or stone, although a walkway or bridge is sustained principally by independent foundations or supports.

The erosive action of the water undermines the causeway's structural integrity, making it susceptible to collapse. Preventative measures must be taken to reduce the effects of scouring and safeguard the causeway's stability, ensuring its long-term safety. This study focuses on experimental investigations, allowing for a more comprehensive understanding of scour processes and their impacts on the stability and safety of causeways. The research objectives are (1) Investigation of scour at downstream of causeway under different flow conditions. (2) Investigation of scour reduction at downstream of causeway using countermeasures. (3) Comparison of scouring at downstream of causeway without and with countermeasures.

2. Material and Method

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 1a. 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 'D_{50}' = 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 four different discharges (i.e., 0.021, 0.029, 0.035, 0.043 m^3/sec). Flow conditions for each experimental case are summarized in table 1.

Table 1. Hydraulic condition of the present study.

Water Depth (m)	A(m^2)	d_{50}(mm)	U (m/s)	Discharge (m^3/s)	Fr
0.12	0.12	0.00051	0.18	0.021	0.16
0.12	0.12	0.00051	0.24	0.029	0.22
0.12	0.12	0.00051	0.29	0.035	0.27
0.12	0.12	0.00051	0.36	0.043	0.33

2.1. Model Preparation

The average size of riprap used for different purposes is riprap stone = 0.31m [24] and Eucalyptus tree is abundantly found in Pakistan and commonly required large amount of water for their growth. Therefore, it is essential to use Eucalyptus tree in a floodplain. The average height of Eucalyptus tree in a southern region of Punjab, Pakistan is between 7.6-14.6m with an average diameter of 0.11-0.33m [23]. In the current investigation, considering the above limitation a riprap of 25mm and vegetation of 7mm diameter and 12 cm height was selected at scale of 1/100. The riprap and vegetation were placed at the upstream face of the abutment to counter the scouring depth surrounding causeway (figure 1 and figure 2).

2.2. Experimental Procedure

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 [25]. 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 [26].

$$Q_t = \frac{2}{3} C_{rd2}\sqrt{2g}\left(\mathrm{b}h^{\frac{2}{3}}\right) + \frac{2}{3} C_{rd1}\sqrt{2g}(\mathrm{b})h^{\frac{3}{2}} + \frac{8}{15} C_{td}\sqrt{2g}\left(tan\frac{\theta}{2}\right) h^{\frac{5}{2}e} \tag{1}$$

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
g = gravitational acceleration, h = water head on the weir crest, he = effective head

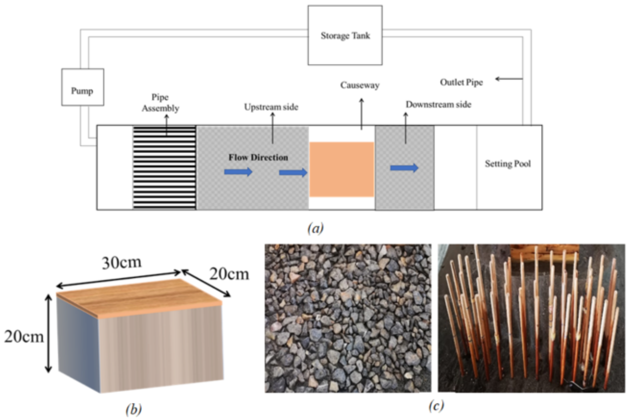

Figure 1. Experimental setup (a) Schematic diagram of laboratory investigation (b) causeway model specifications (c) Vegetation and riprap used in the study.

Figure 2. Experimental setup of model (a) causeway embedded in a sand bed (b) scouring in the vicinity of causeway (c) scouring in the vicinity of causeway when riprap used as a countermeasure (d) scour at the downstream of causeway when vegetation used as a countermeasure.

3. Results and Discussion

3.1. Scour Depth around Causeway without Countermeasures.

Each experimental case was run for duration of 120 minutes, and it was observed that scour depth around causeway was at higher rate initially and reach maximum level after some time then decreases and reached an equilibrium position. The maximum scour depth around causeway was maximum at Fr = 0.33. The maximum scour depth around causeway at Fr=0.33 was observed to be 98mm for causeway at 6cm height above level respectively. The average scour depth around causeway for the range of

Froude number from 0.16 to 0.33 was 44mm at causeway height of 6cm above bed level respectively. Figure 3a shows the scour depth around the causeway for each Froude number. Figure 3b shows the maximum scour depth for each value of Froude number. The scouring depth increases up to 6% when Froude number increases from 0.16 to 0.33.

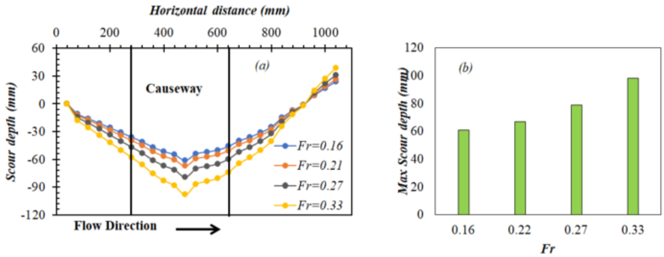

Figure 3. Scour depth around causeway without countermeasure (a) scour pattern at downstream of causeway (b) maximum scour depth at different Froude number.

3.2. Scour Depth around the Causeway with Riprap.

In the second phase of experimentation causeway was tested with countermeasures (riprap) under four different flow condition (Fr = 0.16-0.33). During each experimental trial it was observed that the scour depth around causeway increases by increasing the Froude number. Each experimental case was run for duration of 120 minutes, and it was observed that scour depth around causeway was at higher rate initially and reach maximum level after some time then decreases and reached an equilibrium position. The maximum scour depth around causeway was maximum at Fr = 0.33. The maximum scour depth around causeway at Fr=0.33 was observed to be 68mm for 6cm elevations of causeway above bed level. Figure 4 shows the scour depth around causeway for each experimental case of causeway elevation. Scour reduction around a causeway was observed when riprap was used as a countermeasure, and it was observed that scour depth around causeway reduced up to 40% for 6cm height of causeway above bed level.

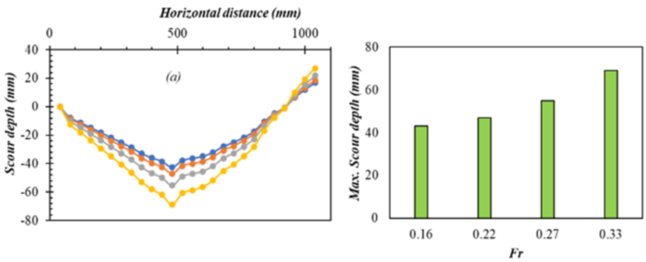

Figure 4. Scour depth around causeway with countermeasure (a) scour pattern at downstream of causeway with riprap (b) maximum scour depth at different Froude number with riprap.

3.3. Scour Depth around Causeway with Vegetation.

The maximum scour depth around causeway was maximum at Fr = 0.33. The maximum scour depth around causeway at Fr=0.33 was observed to be 85mm for causeway elevations above bed level at 6cm. Scour reduction around a causeway was observed when vegetation was used as a countermeasure, and it was observed that scour depth around causeway reduced up to 25% for 6cm height of causeway above bed level. Figure 5 shows the scour depth around causeway for each experimental case of scouring around causeway.

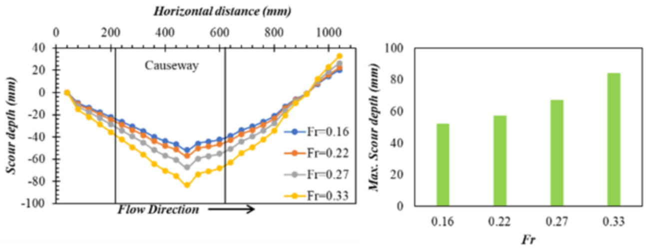

Figure 5. Scour depth around causeway with countermeasure (a) scour pattern at downstream of causeway with vegetation (b) maximum scour depth at different Froude number with vegetation.

4. Conclusions

The conclusion of this experimental study is as follows.

a) By riprap and vegetation as a countermeasure around causeway, it was observed that scour depth reduced up to significant level.
b) Scour depth around causeway was observed to be increases by increasing the Froude number from *0.16* to *0.33* and maximum scour depth was observed when Froude number reached to *0.33*.
c) Using riprap as a countermeasure, it was observed that scour depth decreased compared to without countermeasures case. The maximum reduction of scour depth was observed to be 40% for 6cm height of causeway when riprap was used as a countermeasure.
d) Using vegetation as a countermeasure, it was observed that scour depth decreased compared to without countermeasures case. The maximum reduction of scour depth was observed to be 25% for 6cm height of causeway above bed level.
e) The current research concluded that using riprap and vegetation have two significances when used as a countermeasure. First, they reduced scour depth around causeway up to a significant level and secondly, compared to other countermeasures, riprap and vegetation are economical.

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