Study of Effect of Riprap Diameter Size on Instability Depth Around Bridge Abutment with Arched Wall at River Bend

1Mehdi Nirobakhsh, 2Alireza Masjedi, 3Ali Assareh

ABSTRACT
Scouring is defined as the waterways erosion of the bed and sides because of crossing water flows, as bed erosion in downstream of hydraulic structures because of flow high intensity, and as bed erosion because of the creation of local turbulent flows. Because of the intensity of the secondary flows in this part of the river, noting the subject of erosion and sedimentation and rendering suitable solutions for its controlling in the arches is highly important. Among the simple and economic methods of protecting the bridge abutment against scouring is the usage of riprap coverage. The aim of this research is to study the impact of riprap diameter size on the instability depth. To do the experiments, a flume with 180 degree arch from Plexiglas was used. Experiments were performed in clear water conditions using two types of ripraps with two densities with four diameter sizes around abutment with arched wall located in 70 degrees from arch with four discharges. Experiments started from upstream flow depth and by decreasing the flow depth and by movement of the first riprap the movement threshold depth was recorded and by the ripraps group movement the failure threshold depth was recorded. The results obtained from experiments show that in stable density and discharge, the instability depth decreases in both movement and failure thresholds by increasing the riprap diameter.

KEY WORDS: Movement threshold, Riprap, Instability depth, Bridge abutment.

INTRODUCTION
Scouring is defined as the waterways erosion of the bed and sides because of crossing water flows, as bed erosion in downstream of hydraulic structures because of flow high intensity, and as bed erosion because of the creation of local turbulent flows. Water crossing beside the abutment and digging the bottom and deepening the river bed in torrential times is one of the fundamental factors in destroying and scouring of bridges. Direct touch of water flow with the bridge wing walls causes the increase of longitudinal slope because of its scouring. Thus, when rivers alluvial bed in the nose of bridge abutment confronts the flow, hydrostatic difference in upstream and downstream of wing wall becomes one of the factors in production of circular and vortical turbulent flow around it and the influences will appear as vacuolate and deep erosion especially at the end of the nose of upstream wing wall. In other words, after bridge construction, because of the placement of bridge piers and abutments in the way of river flow, a series of variations occur in the flow. Because of placement in the way of water flow, bridge abutment acts as a barrier and causes change in flow direction at the collision site with abutment and development of vortical flow. These vortices in turn deracinate materials around abutment, then these materials are carried by river flow toward downstream which this act finally causes the development of scouring hole at abutment placement. Figure 1 shows the flow model around bridge abutment.

Because of having special model of flow, river arch has always been under the care of hydraulic engineers. By entering the flow in the arch the centrifugal force affects it, which this force is variable parallel to the arch radius and also in the course of depth variations because of speed variations. The existing centrifugal force in the bend creates transverse slope in water surface which lifts the water level in the outer arch and decreases the depth in the inner arch. This phenomenon creates side pressure gradient inside the section. When the mentioned
pressure gradient overcomes centrifugal force, a flow in lateral side is formed inside the section which is called secondary flow. Due to this flow, particles in water surface move toward the outer wall and the particles in the bottom move toward inner wall.

![Fig. 1: Flow in around bridge abutment.](image)

Unger and Hager (2006) introduced three different mechanisms of sliding, subsurface destruction and rolling for the riprap around bridge pillars, among them just sliding and subsurface destruction were observed in the riprap around abutments.

Cardoso and Christiana (2009) performed experiments in a rectangular channel with sand bed and with four different wall lengths, three different riprap sizes and two different sand types. The aim of this research was to design a riprap cover for confrontation with erosion near bridge upright walls under clear water conditions. These researchers took the riprap size needed for protection of the wall as a function of Froude number and the ratio of wall length to the flow depth.

Simarro et al. (2011) performed experiments in a rectangular laboratory flume with four sizes of riprap under 7% slope. Results showed that the distance between bridge abutments has a slight effect on size of riprap.

Salemi et al. (2015) performed experiments in a laboratory flume made of Plaxiglass with 180 degree bend to investigate the effect of spur dike length on riprap stability. These experiments were conducted using various lengths of spur dike along with surrounding ripraps. Ripraps with three densities and diameters were used in a constant flow rate and clean water conditions. In each experiment, flow depth was measured at two states of motion threshold and failure threshold and then desired relations were calculated based on these obtained data. Results indicated that by increasing Froude number and relative diameter of riprap particles, stability number of particles reduced at these two states.

Nirobaksh et al. (2015) performed experiments in a laboratory flume with 180 degree arch, using three types of ripraps with three densities and four diameter sizes and with 4 discharges in one location in around bridge abutment with arched wall. Experiments started from upstream flow depth and by decreasing the flow depth and by movement of the first riprap the movement threshold depth was recorded and by the ripraps group movement the failure threshold depth was recorded. The results obtained from diagrams show that in each density the aggregates stability decreases by increasing the ripraps relative diameter, in both movement threshold and fracture threshold.

Most of the performed studies are related to the direct path and the results of these researches cannot be used for structures constructed in river bend. In this research, effect of riprap diameter size on instability depth around bridge abutment with arched wall at 180 degree bend in the conditions of movement threshold and riprap breakage was investigated.

**MATERIALS AND METHODS**

Experiments were done in a flume located at hydraulic laboratory of Islamic Azad University of Ahvaz. Experiments were performed in a Plaxiglass flume with 180 degree bend, central radius of $R = 2.8$ m and width of $B = 0.6$ m. Relative curvature of bend ($R/B$) was equal to 4.67 which is classified as a moderate bend. The straight inlet channel 9.1 m in length is connected to a channel with a 180 degree bend. This curved channel is connected to the flow control gate and the outlet tank by another straight channel 5.5 m in length (Fig. 2).

According to Chiew and Melville (1987) constriction should not be more than 10 percent of channel width. In these experiments, an abutment with an arched wall and 38 cm length was used. According to Rudkivi and
Ettema (1983) to avoid the formation of riprap, particles average diameter should be more than 0.7 mm. Also, to delete the effect of sediments non-uniformity on scouring, particles standard deviation should be less than 1.3. Regarding these points, a layer of river natural sands with average diameter of 1.59 mm and standard deviation coefficient of 1.29 was selected and used in a surface with approximate thickness of 15 cm for the execution of experiments.

Selection of minimum and maximum size of riprap pieces was done with regard to experimental limitations. Applied ripraps in this research were from rounded-corner natural materials with 1.7 and 2.1 densities and particle average diameters of 4.76, 9.52, 12.7 and 19.1 mm (Table 1). Based on the studies of Melville et al. (2007), the arrangement of riprap around abutment was taken as rectangular and counterbalanced with bed materials. Moreover, according to the rendered criteria by Melville et al. (2007), the thickness of riprap layer was selected as twice of riprap average diameter. Figure 3 shows the abutment and riprap around it in flume.

<table>
<thead>
<tr>
<th>Riprap special density</th>
<th>Average size of riprap particles D50</th>
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<tbody>
<tr>
<td>1.7</td>
<td>4.76, 9.52, 12.7, 19.1</td>
</tr>
<tr>
<td>2.1</td>
<td>9.52, 12.7, 19.1</td>
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To determine riprap area around abutment, the experiment of balance time was done for 12 hours to investigate maximal dimensions of scouring hole around abutment without placement of riprap around abutment. Experiment was performed in conditions where abutment was placed in a layer of sand with the thickness of 15 cm and in 70° of bend, for maximum discharge of 27 liter per second, in flow depth of 12 cm.

At the beginning of every experiment with moving cart, channel bed was placed under flat fixed slope and riprap with the thickness of 2D50 around abutment counterbalanced with bed sediments in the area in which scouring was created. Channel terminal valve was closed and by launching pump, the flow was slowly guided through channel. Applied discharge in this research were 17, 20, 23 and 27 Lit/s. After regulation of the desired discharge, the flow depth was slowly decreased in 15 minute periods by downstream valve and the flow conditions were kept stable for some time so that the effect of water depth decrease is equalized along flume. After assurance about stability of flow depth, the movement manner of riprap materials was investigated visually. In all experiments, every particle movement including vibration, continual movement and minimal movement was registered. To avoid roughness effects, Oliveto and Hager (2002) suggested water depth to be more than 20 mm. In all performed experiments, water depth was more than 20 mm. When the first riprap movement was observed, flow depth was written as movement threshold depth and when ripraps started to move collectively, flow depth was written as fracture threshold depth. At the end of each experiment, the pump was
shut down and the terminal valve opened to slowly drain off water in channel and to make no impact on bed topography.

**RESULTS AND DISCUSSION**

In all experiments after the regulation of discharge, flow depth was measured in both movement (ytc) and failure thresholds (ytf). Figures 4 and 5 show the figures of the effect of riprap diameter size on instability depth (yt) in respectively two densities of 1.7 and 1.2 and in four discharges of 17, 20, 23 and 27 liters per second in both movement and failure thresholds. Instability depth is the depth in which movement and failure thresholds occur. Results from diagrams indicate that in each density, for a stable discharge, by increasing the riprap diameter size the instability depth decreases in movement and failure thresholds and by increasing the discharge, instability depth increases in movement and failure thresholds. In other words, in stable density and discharge, because of being heavier the bigger size riprap shows more stability in lower depths in comparison with smaller size riprap. For any stable size of riprap diameter, by increasing discharge, the necessary ford depth for movement and failure thresholds of riprap particles increase and for a stable discharge, by decreasing the ford depth, riprap diameter size which is located in movement and failure thresholds increase.

**Fig. 4:** Effect of riprap diameter size on instability depth in failure threshold in 1.7 density.

**Fig. 5:** Effect of riprap diameter size on instability depth in failure threshold in 2.1 density.

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**REFERENCES**


