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Review

# The effect of relative surface roughness on scour dimensions at the edge of horizontal apron

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ABSTRACT

Roughened horizontal aprons are bed covering scour countermeasures constructed downstream of stilling basins and other places where scour hole may develop. In these cases scour occurs at the edge of the apron which can lead to failure of the apron. In the present study, 24 experimental tests were carried out on four different aprons with (2, 5, 10 and 14.28 mm) roughness heights and two different bed material sizes of 0.8 and 1.4 mm under different flow conditions. The results indicated that as the roughness height of apron increases, a significant reduction in the scour depth occurs.



## 1. Introduction

One of the ways to dissipate the kinematic energy downstream of chutes, weirs and spillways is to use non-erodible horizontal aprons made of concrete or riprap. Even when concrete stilling basins are used, horizontal roughened aprons such as concrete blocks, riprap, gabions and geobags are also used at the downstream of stilling basins to control the scour downstream. Additionally, roughened horizontal aprons are common measures to control scouring around bridge piers or abutments or on the riverbed at the toe of outer bank. Although, from the hydraulic point of view, the water head above the apron and the river bed are the same, scour occurs at the edge of apron and as it deepens it can damage the apron. This is mainly because of the formation of vertical vortices due to roughness differences of two types of materials. With all the accomplishments made so far in the study of local scour, numerous evidences still indicate extensive scour in stilling basins, sliding gates, spillways, breakwaters, culverts and near bridge piers that can seriously endanger the stability of such structures.

Scouring occurs when the local shear stress of flow is less than the critical shear stress of the bed material, although the average local shear stress of bed may be less than that of the critical shear stress. This increase of the local shear stress can be attributed simply to the existence of vertical vortices and three-dimensional flow. The occurrence of such conditions downstream of aprons is due to different roughness of materials. Because of the failure of many structures due to scour, the localized scour phenomenon has been the subject of extensive investigation by many researches. Breusers (1965) investigated the time variation of scour due to the flow over and under an estuary closure structure and proposed a power law for the time variation of scour depth. Chatterjee et al. (1994) measured the time variation of scour depth downstream of an apron due to a submerged jet issuing from a sluice opening and developed empirical relationships for the time variation of scour depth and time to reach asymptotic scour depth. Balachandar and Kells (1998) investigated the time variation of scour depth in uniform sediments downstream of a relatively short apron due to a submerged jet issuing from a sluice opening to analyze the instantaneous water surface and scour profiles by applying the technique of video image analysis. Kells et al. (2001) investigated the influence of sediment gradations on the depth and area of asymptotic scour profiles that develop downstream of a short apron due to a submerged jet issuing from a sluice opening. Dey and Sarkar (2006a) estimated the scour downstream of an apron due to submerged horizontal jets. Dey and Sarkar (2006b) estimated the response of velocity and turbulence in

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submerged wall jets to abrupt changes from smooth to rough beds and its application to scour downstream of an apron. Amoudry and Liu (2009) presented a two-dimensional, two-phase granular sediment transport model with applications to scouring downstream of an apron. Hamidifar and Omid (2011) estimated the scour of non-cohesive sediments downstream of a horizontal apron.

Few studies have been carried out on the effect of bed roughness on characteristics of the scour hole. Revelli and Sorodo (2001) found that the turbulence due to the presence of the sill and some three-dimensional effects due to roughness elements are responsible for the occurrence of the scour. Hamidifar and Nasrabadi (2011) conducted experimental study to investigate the scour downstream of a roughened apron located downstream of a hydraulic jump. They carried out tests with five different roughness heights and one bed material size under different flow conditions. Their results showed that the main dimensions of the scour hole were much smaller as the apron roughness height increases. They reported a 60% reduction in scour depth for roughened bed apron compared to the smooth bed apron.

The studies mentioned in the literature above are mostly related to the scour downstream of stilling basins and horizontal aprons which is mainly attributed to the existence of vortices and water turbulence due to hydraulic jumps and inadequate dissipation of kinematic energy. However, no studies have been carried out in the literature regarding scour due to roughness difference between two beds of different roughness while having hydraulically similar conditions. Hence, this study addresses the major factors of scour on the edge of the roughened apron.

## 2. Dimensional analysis

In order to reach the purpose of this study, since a number of variables affect the scour depth downstream of an apron, firstly a non-dimensional relation was developed, by applying the Buckingham Theorem. The major variables on scour downstream of an apron are as follows (see Fig. 1):

$$d_s = f(D_{50}, y, V, \rho, \rho_s, g, \mu, \varepsilon, H, d) \quad (1)$$

where $D_{50}$=average particle size of bed materials, $d_s$=maximum scour depth, $y$=water depth, $V$=flow velocity, $\rho$=water density, $\rho_S$=sediment density, $g$=gravity acceleration, $\varepsilon$= roughness height, $\mu$=fluid dynamic viscosity, $H$=water head on apron, and $d$=apron height.

By choosing $v$, $\varepsilon$ and $\rho$ variables as repeated variables, six non-dimensional parameters can be developed. Combining these parameters and deleting the Reynolds number due to negligible viscosity in scour studies, the following non-dimensional relation was obtained:

$$d_s/\varepsilon = f(D_{50}/\varepsilon, F_r) \quad (2)$$

where $F_r$ is the densimetric Froude number of particles which is

$$F_r = \frac{V}{\sqrt{g(G_s - 1)D_{50}}}$$

in which $G_s$ is the specific gravity of river bed sediment.

### 2.1. Laboratory setup

The experiments were carried out at the hydraulic models laboratory of the Faculty of Water Science and Engineering of Shahid Chamran University of Ahwaz, Iran. Water was supplied by a centrifugal pump with a discharge of 30 l/s. The tailwater depth was determined by a gate at the end of the setup. A laser meter and a magnetic discharge meter were used to measure the scour depth and flow discharge respectively. The plan and section view of the flume are shown in Fig. 2.

### 2.2. Methodology

First, an apron with 73 cm length, 30 cm width and 10 cm height made of plexy glass was placed at a distance of 6 m from the beginning of the flume. Downstream of the flume, sediment materials were used as bed materials of 3 m long. Two types of sand with uniform grain sizes of 0.8 and 1.4 mm average diameters were used in this study. Also, 4 different roughness heights with uniform grain-sizes and average particle diameters of 2, 5, 10 and 14.28 mm were glued on the surface of the apron while each roughness was tested under three different Froude number conditions. As recommended by Wiberg and Smith (1987), for roughness due to natural sand, $D_{50}$ was used as the equivalent roughness height ($K_s$). The flow was stopped at the end of each experiment (3 h) and the bed profile was taken by a laser meter. By placing sediment materials on bed, its surface was leveled by a pressing board. Then, while the end gate of the flume was fully closed, flow entered the flume gradually to avoid sudden removal of bed sediment materials. The flow discharge was increased by opening the inflow valve to reach the desired discharge. After stabilizing the flow discharge, the flume end gate was opened gradually to reach the desired water level. These conditions were preserved steadily for three hours during which the scour depth was also recorded. At the end of each experiment the pump was turned off and the end gate was opened slowly to completely discharge water from the flume. After the water on the sand was completely drained, the bed erosion profile was taken in a 4*4 cm plexus. A total of 24 experiments were carried out. Table 1 shows the variables used in the present study.

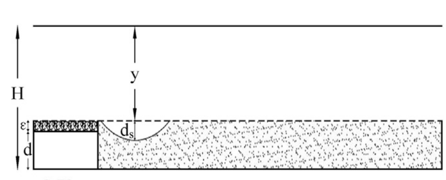


**Fig. 1.** Variables affecting scour dimensions.