Use corrugated beds to improvement downstream local scour Characteristics

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ABSTRACT:

Local scour downstream of radial gates in Non-erodible beds by using a physical model, corrugated beds are employed downstream of hydraulic structures to dissipate the energy and to control the downstream scouring. Several experiments were performed in which beds were considered at four different aprons with corrugation heights of 22, 29, and 41 mm in open channels with zero slope. This paper experimentally explored the effect of the height of corrugation elements on the scour geometry downstream of submerged hydraulic jumps. A case of smooth apron was included to estimate the influence of corrugation types on the scour hole dimensions. Obtained results were analyzed and graphically presented and the scour profiles were drawn in dimensionless forms. The results indicated that as the scour hole increases as the submergence ratio increases, the corrugated beds reduce the scour hole by rate from 27% to 50% in comparing with the scour hole of smooth bed.

Keywords: Corrugated beds, submerged hydraulic jump; submergence ratio; corrugation heights; scour holes.

1-INTRODUCTION:

Local downstream scour one of the important and complicated problems facing many of irrigation works, such as gates, weirs, regulators, and dams, which are built crossing the flow of open channels. It is important to study the characteristics of scour, that occurs downstream of irrigation structures to protect them from failure. Scour downstream a hydraulic jump has been studied by many researchers such as Novak (1961), Catakli (1973), Pillai (1989), Rice and Kadavy (1993), Hoffmans (1998) and El-Abd (2002). The scour holes develop rapidly in the early stages and progresses toward an asymptotic stage beyond which the scour profile does not change significantly with time and reaches an equilibrium state.

Many of researches have been conducted with different shapes of corrugated beds. But, most of these researches are related to formation of free jumps over smooth stilling basins and few studies in the case of submerged jumps on corrugated stilling basins and the effect of corrugation shape on local scour process. The first study on hydraulic jump over rough bed were carried out by Rajaratnam (1968), and this study was mentioned that, the length of jump over rough bed is smaller than the length over smooth bed. Some different corrugated shapes beds have been proposed studied by Ead and Rajaratnam (2002), Farhad Izadjoo and Shafai (2005), Ead S. A. (2007), Zedan et al. (2010) and Ali et al. (2014).

Zidan et al. (2010) experimentally studied the effects of different shapes of corrugated beds on the corresponding scour downstream free hydraulic jumps, it was found that the spaced triangular corrugated bed is the best shape for the scour hole reduction. Ali et al. (2014) installed corrugated aprons to minimize the scour downstream heading-up structures in the presence of submerged hydraulic jumps. They believed that employing spaced triangular corrugated beds are minimized the scour hole geometry. Radial gates are preferred over vertical sluice gates for several next advantages. Produce lower flow disturbance, they require smaller hoisting force, have easier operation, and provide better discharge, Sehgal (1996). The flow through radial gates is classified as either free flowing or submerged depending upon the tail water depth and the size of the gate opening. Little researches can be found in the literature about submerged and free radial gates such as Buyalski (1983), Clemmens et al. (2003), Bijankhan et al. (2011), Ali et al. (2015), Abdelhaleem (2017).

The review of the previous available published researches showed that the corrugated beds can effectively decrease the length of the jump. It thus can reduce the cost of stilling basins downstream of heading-up structures.

The present study is aiming to extend the previous studies by investigating experimentally the effect of U-shaped corrugated beds at downstream of submerged radial gate on the local scour. The submerged flow condition is the most common in Egypt, so, laboratory experiments were carried out using U-shaped corrugated beds downstream of radial gate under submerged flow condition produced by radial gate.

2- DIMENSIONAL ANALYSIS

The depth of scour downstream of submerged hydraulic jump can be expressed as a function of the following independent variables:

$$d_s = f(\mu, \rho, g, x, L_b, d_{50}, k_s, y_1, y_2, y_3, y_t, v_1, L_j, S) \quad (1)$$

Where: d_s is the depth of scour at distance x, μ is the dynamic viscosity of water, ρ is the density of water, g is the acceleration gravity, x is the distance from end L_b to any point in movable bed, L_b is the length of bed, d_{50} is the mean size of movable bed material, k_s is the corrugation height, y_1 is the water depth under gate, y_2 is the sequent depth of submerged hydraulic jump, y_3 is the backup water depth downstream of the radial gate, y_t is the tailwater depth, v_1 is the mean velocity under gate, L_j is the length of submerged hydraulic jump, and S is the submergence factor.

Applying the π theorem with ρ, g, and y_1, as repeating variables, Eq. (1) can be written in dimensionless form as following;

$$d_s/y_1 = (Fr_1, R_e, \frac{d_{50}}{y_1}, \frac{k_s}{y_1}, S, \frac{y_2}{y_1}, \frac{y_3}{y_1}, \frac{y_t}{y_1}, \frac{L_j}{y_1}, \frac{L_b}{y_1}, \frac{x}{y_1})$$
$$(2)$$

In which R_e is the Reynolds number, Fr_1 is the Froude number under gate. Because of d_{50}, μ, ρ, and θ are constants so, can be ignored. Hence, Eq. (2) is reduced to

$$d_s/y_1 = (Fr_1, \frac{k_s}{y_1}, \frac{x}{y_1}, S)$$

(3)

3- EXPERIMENTAL SET-UP

The experimental works were carried out at the hydraulics and irrigation laboratory of the Benha Faculty of Engineering, Benha University, Egypt. Measurements were conducted in a zero slope flume with smooth concrete bed and Plexiglas walls. The flume

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has a length of 15.0 m, width of 0.4 m, and height of 0.6 m. It has an adjustable tailgate at the downstream end to control the submerged flow condition. At the middle, a radial gate was installed. The radial gate was made of steel with sharp edge seal of 4.0 mm thickness. For all experiments, the radial gate radius was 470 mm, the trunnion-pin height was 230 mm, and the gate width was 400 mm. The discharge was measured with a magnetic flowmeter and a digital point gauge with an accuracy of ±0.1 mm was used to measure scour depths.

The experimental work was carried out using spaced corrugated beds (U-shaped) with different heights of (22, 29, and 41 mm) downstream the radial gate to simulate the corrugation elements, as shown in Fig. 1.

Fig. 1 the different materials used downstream the radial gate, and the jump over corrugated bed.

The testes also included a smooth floor without corrugation to represent the reference case. In all cases, the constant length of stilling basin 120 cm and the rear reach of the channel downstream the basin is filled with a 30-cm layer of sand with d50

= 0.37 mm, in order to represent the mobile bed. All tests were carried out with a radial gate under submerged flow condition; this hydraulic condition was quantified by applying the formula of Bijankhan et al. (2011) on smooth basins.

Steady state hydraulic parameters including upstream water depth, supercritical depth, tailwater depth, backup water depth, and discharge were measured with different gate openings. The upstream and tailwater depths, y_o and y_t were measured at distances 3.0 m upstream and 5.0 m downstream of the gate, respectively. These distances were always far away from any zone of water surface turbulence. y_1 was measured at a distance of 1.15 times the gate opening downstream the gate lip, this is the approximate location according to, Chow (1959). In this study, the submergence factor is defined as $S = (y_t - y_2)/y_2$, where y_2 is the subcritical sequent depth for a submerged jump corresponding to the supercritical depth of y_1, computed by the illustrious Belanger equation, Chow (1959).

In this paper, in order to reach the main aim of this study, a total of 180 tests were performed. For each run, after the desired water depth and the discharge were achieved, the running time of the test was started. For comparison purposes, duration of four hours was maintained. At the end of every test the flume was slowly drained and the geometry of the scour hole was measured. A grid of 2.0 cm x 2.0 cm was used to survey the bed topography.

4- ANALYSIS AND DISCUSSION
4.1 Scour profile

The movement of the bed material just downstream the bed was measured after each test run. The depth and length of the scouring hole was measured. The scour profile was measured using a point gauge with accuracy ± 0.1mm. The scoured bed was measured each five centimeters along the centerline.

Fig. 2 describe the relation between x/L_b, with relative depth of scour d_s/y_1 at different values of submergence factor S. From this figure, it was found that, the scour hole length decreases as the submergence factor decreases and depth of the scour decreases by small rate due to the reduce of the jump length. Fig. 3 shown the relation between x/L_b, with relative depth of scour d_s/y_1 at S =0.4, it's found that; The scour hole at corrugated bed decreases by average percentage of 47% in comparison with the scour depth of smooth bed. The scour hole decreases as the roughness height increases by small rate. Fig. 4 shown the relation between x/L_b, with relative depth of scour d_s/y_1 at S =0.1, it's found that; The scour hole at corrugated bed decreases by average percentage of 31% in comparison with the scour depth of smooth bed. The scour hole decreases as the roughness height increases by small rate. From Figs. 3 and 4 effect of corrugated bed at high submergence factor more than effect of corrugated bed at low submergence factor to reduce scour hole, so whenever heighten the length of submerged jump increase the effect. Fig. 5 the relationship between x/L_b, with relative depth of scour d_s/y_1 at S =0.4 and Fr_1 = 6.49, it's found that; The scour hole at corrugated bed decreases by average percentage of 48% in comparison with the scour depth of smooth bed, the effect of roughness height is not significant.

It may be concluded from these figures that, the scour hole increases as the submergence ratio increases; the scour hole increases as the Froude number increases; corrugated bed decreases the scour hole. Increasing the effect of corrugated bed at high length of submerged jump.

4.2. Scour contour

The scour contour maps downstream of smooth and corrugated beds at different cases were presented in Figs. 6, 7, and 8. It is clearly that the scour hole downstream of corrugated beds has smallest dimensions compared to the smooth bed. In which, as the discharge increases the water velocity increases through channel cross section and hence higher local scour depth will be created and vice versa.

Figures 6, 7, and 8 show of scour contour maps downstream smooth and corrugated beds. It is appeared from these figures that the maximum scour hole depth occurs at the center line of the channel width and the effect of the channel boundaries on the scour contours is very small and does not appear in contour maps.

The zone of maximum scour hole depth has a small width downstream corrugated beds and it has large width for smooth bed. It means that for the scour holes having large length, large dimensions of the zone of maximum scour hole depth are produced. It is clear that, the scour hole downstream corrugated beds is less than the scour hole downstream smooth bed because the length of the hydraulic jump at the corrugated beds is less than the smooth bed.
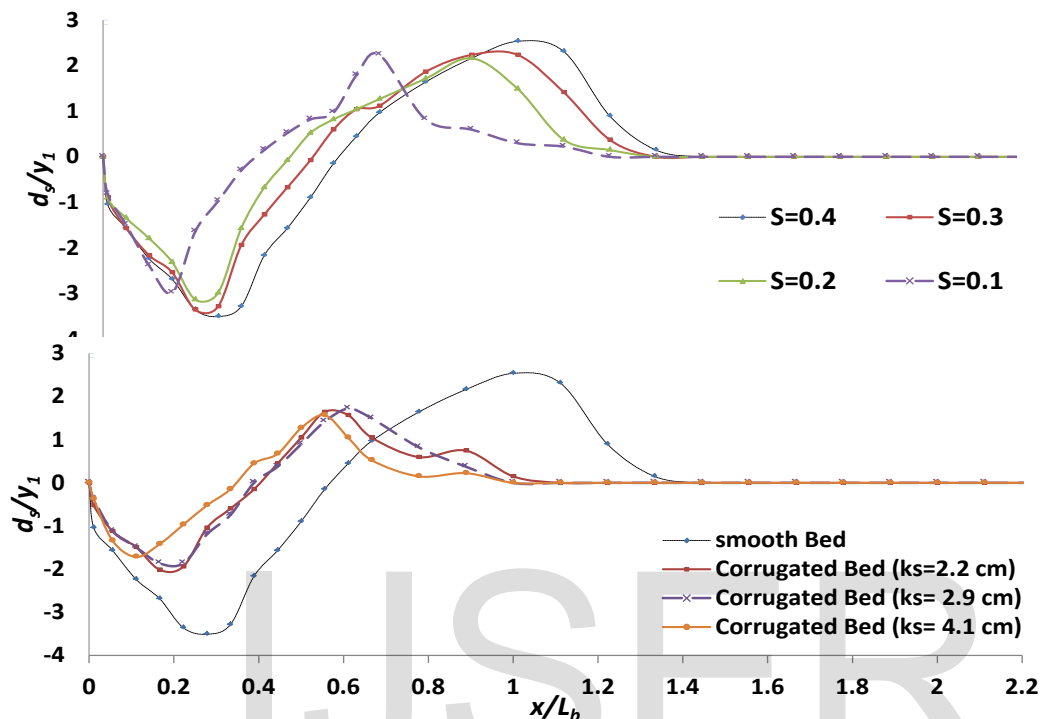

Fig. 3 Scour profiles downstream of corrugated beds at Fr = 8.23, and S = 0.4
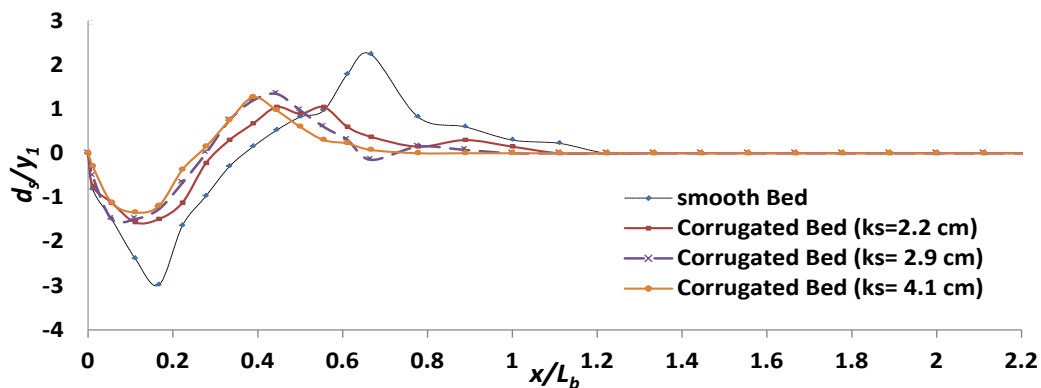
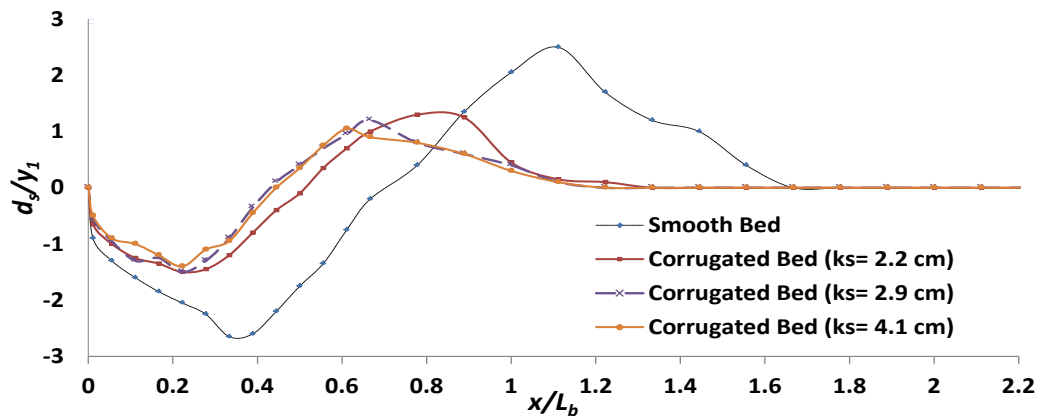Fig. 4 Scour profiles downstream of corrugated beds at Fr = 8.23, and S = 0.

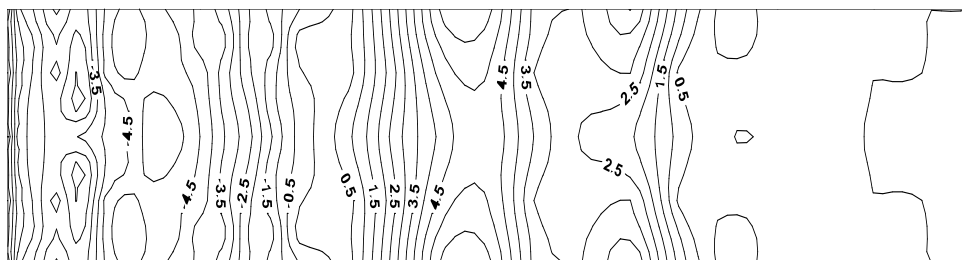Fig. 5 Scour profiles downstream of corrugated beds at Fr = 6.49, and S = 0.4

Fig. 6 Scour contour map downstream of smooth bed at (Fr = 6.49, S = 0.3).

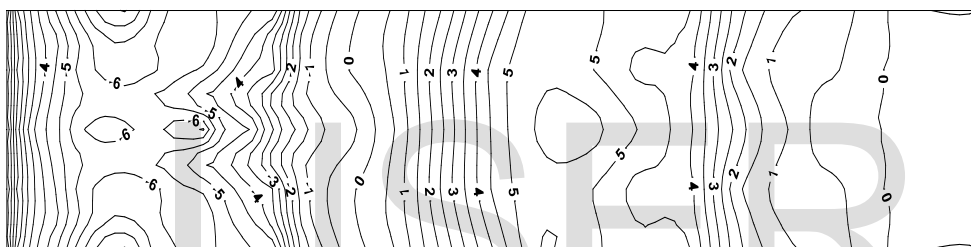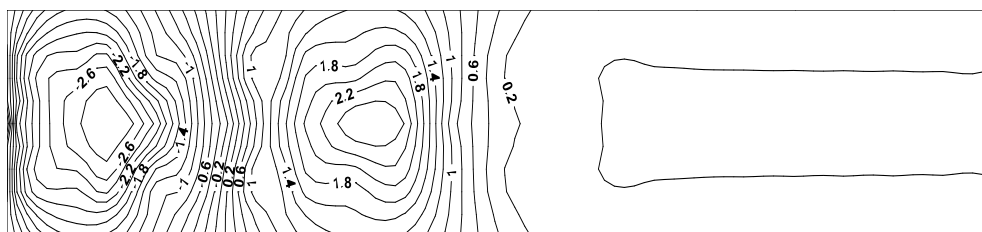Fig. 7 Scour contour map downstream of smooth bed at (Fr = 5.02, S = 0.4).

Fig. 8 Scour contour map downstream of corrugated bed at (Fr = 6.49, S = 0.3, k_s=2.2 cm).

5. CONCLUSIONS

The results of the experimental study for the local scour downstream of submerged hydraulic jump over smooth, and corrugated beds have been presented. The discussion and analysis of the results concluded as following:

- Using corrugated beds downstream of hydraulic structures is an effective engineering approach to minimize Scour holes dimensions.

- Many parameters affect the scour properties for the same sample of sand, the most important of these parameters initial Froude number, submergence ratio and the relative corrugation height. The scour hole increases as the submergence ratio increases.
- The scour hole increases as the Froude number increases.
- Corrugation beds reduce the scour hole by rate from 27% to 50% in comparing with the scour hole of smooth bed.
- Increasing the effect of corrugated bed at high length of submerged jump.

- This study were presented for a range of Froude number from 5.02 to 8.23.

5. ACKNOWLEDGMENTS:

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7. NOTATION

The following symbols were used in this paper:

a: gate trunnion-pin height;

d_s: depth of the scour;

d_{50}: mean size of bed material;

Fr_1: initial Froude number;

k_s: corrugation height;

L_b: length of stilling basin;

L_j: length of submerged hydraulic jump;

Q: flow discharge;

r: radius of the radial gate;

S: submergence factor;

v_1: the mean velocity under gate;

w: gate opening;

x: the distance from end L_b to any point in movable bed

y_o: upstream water depth;

y_1: water depth at vena contracta;

y_2: sequent depth of submerged hydraulic jump;

y_3: backup water depth downstream of the gate;

y_t: tailwater depth;

δ: contraction coefficient.

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