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Influence of Gravel Beds on Erosion of Sand by Submerged Jets

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Abstract: This paper shows experimentally effect of gravel beds to reduce erosion of soil downstream of submerged hydraulic jumps by using a physical model, gravel beds are employed downstream of radial gate to dissipate the energy and to control the erodibility of cohesionless soils. Two different types of gravel were considered, natural particle with graded grain sizes, and non-uniform big grain sizes, a state of smooth bed was included to estimate the influence of gravel beds on the scour hole dimensions. A preliminary comparison of the incipient motion values shows that granular soils downstream gravel bed have a smaller free surface flow erosion than the granular soils downstream smooth bed. Additional comparison of the experimental data incipient motion criteria also suggests that decrease void ratio for gravel bed leads to minimize erosion the soil. The gravel beds reduce the maximum scour hole by rate from 47% to 66% in comparing with the smooth bed.

Keywords: Gravel beds; smooth bed; submerged hydraulic jump; void ratio; erosion holes

INTRODUCTION

Erosion of sand, silt, and other materials, which often occurs downstream of hydraulic structures, is of considerable importance and complicated, as excessive scour may endanger the stability of these structures, and it has frequently been modeled as erosion by jets. Many studies have been performed to examine the erosion of cohesionless materials by submerged jets, where the tailwater depth is large, including those of Rajaratnam, and Mazurek [1], Aderibigbe and Rajaratnam [2], Mih and Kabir [3], and Westrich and Kobus [4].

It is clear that the erosion properties of a scour hole produced by a submerged jet set at a large height of the jet above the soil bed is different from the scour produced when the jet is close to the bed.

Scour downstream a hydraulic jump has been studied by some researchers such as El-Abd [5], Rice and Kadavy [6], Catakli [7], and Novak [8]. In the early stages, the scour holes develop rapidly and progresses toward an asymptotic stage beyond which the scour profile does not change significantly with time and reaches an balance state. Some of researches have been conducted with rough beds. But, most of these researches are related to formation of free jumps over smooth stilling basins and few studies of submerged jumps on gravel stilling basins and the effect of roughness elements on local scour process.

The complete protection against scour is too expensive. So, the maximum scour depth and slope of the scour hole have to be predicted to reduce the risk of failure. There are many formulas for scour following hydraulic jump in a stilling basin such as developed by Ibrahim *et al.*, [9], Ali *et al*., [10], El-Gamal [11], Aytac and Gunal [12], Dargahi [13], Uymaz [14], Shalash [15], and Schoklitsch [16].

It is considered that the tailwater depth is yet another important variable for scour by submerged jets. This experimental study constitutes an extension of the previous work on submerged jets and considers the case of erosion of cohesionless sand beds by submerged hydraulic jumps when the constant tailwater.

EXPERIMENTAL PROCEDURES

The experiments were carried out in the hydraulic Laboratory in Benha Faculty of Engineering, Benha University, Egypt. Recirculating flume used in this experimental study is a closed recirculating system, which is 15 m in length, 40 cm wide, and 50 cm depth. Ground tank with a capacity 20 m^3 of water supplied the flow to the flume at a constant rate which could be controlled by a gate valve, and an ultrasonic flow-meter in the supply pipe was used to measure the flow rate. The channel bed was roughened using two different types of gravel; natural gravels with graded grain sizes,

and non-uniform big grain sizes shown in Figure-1. The length of the roughened bed was limited to 90 cm. The roughness elements were kept to the full width of the flume.

Fig-1: The gravel beds used downstream the radial gate.

The testes also included a smooth floor without roughened to represent the reference case. In all cases, the rear reach of the channel downstream the basin is filled with a 30-cm layer of sand, in order to represent the movable soil. All tests were carried out with a radial gate under submerged flow condition.

Steady state hydraulic parameters including upstream water depth, supercritical depth, tail water 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 [17]. 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 [17].

In this paper, in order to reach the main aim of this study, a total of 60 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 25 mm x 25 mm was used to survey the sand topography.

RESULTS AND DISCUSSION

The movement of the sand bed just downstream the gravel 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 two centimeters along the centerline to get a maximum scour depth.

Fig-2 describe the relation between Froude numbers Fr_1, with relative depth of scour d_s/y_1. From this figures, it was found that, the scour hole depth increases as the Froude number increases; the scour hole depth increases as the gate opening decreases. The scour hole depth downstream gravel beds decreases as the void ratio of gravel decreases. The scour depth at graded grain sizes, and big grain sizes gravels decreases by average percentage of 47%, and 66% respectively in comparison with the scour depth of smooth apron.

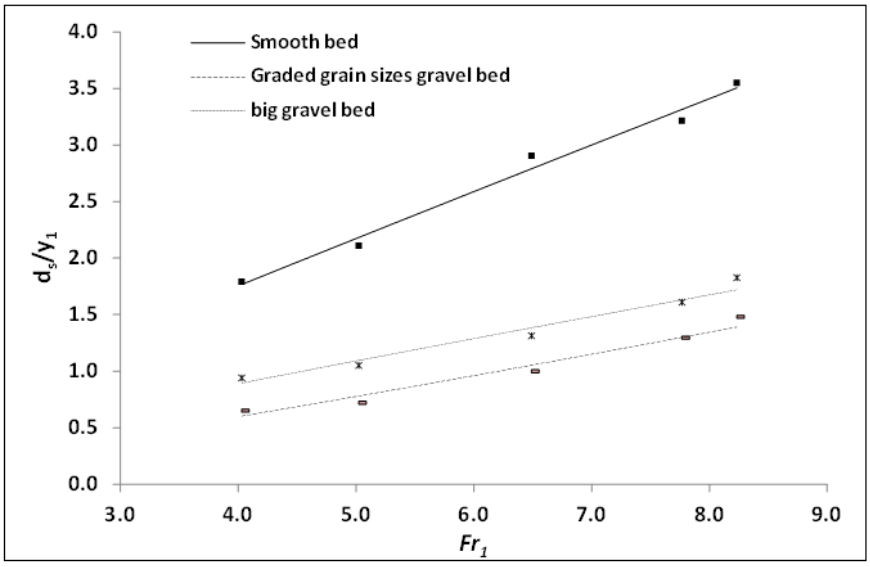

Fig-2: Relationship between observed relative scour depth (ds/y_1) with Fr_1 over smooth, and gravel beds.

The scour contour maps downstream of smooth beds, graded grain sizes, and non-uniform big grain sizes gravel beds at different cases were presented in (Fig-3, 4, 5, 6, 7 and 8). It is clearly that the scour hole downstream of gravel 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.

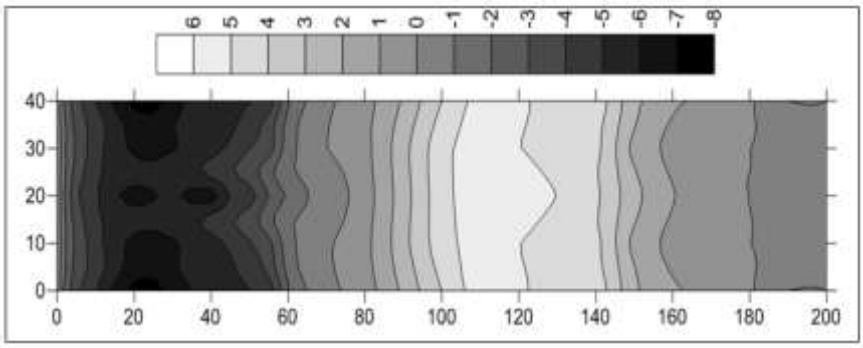

Fig-3: Scour contour map for the sand soil downstream of smooth bed at (Q = 27 lit. /sec., w = 40 mm).

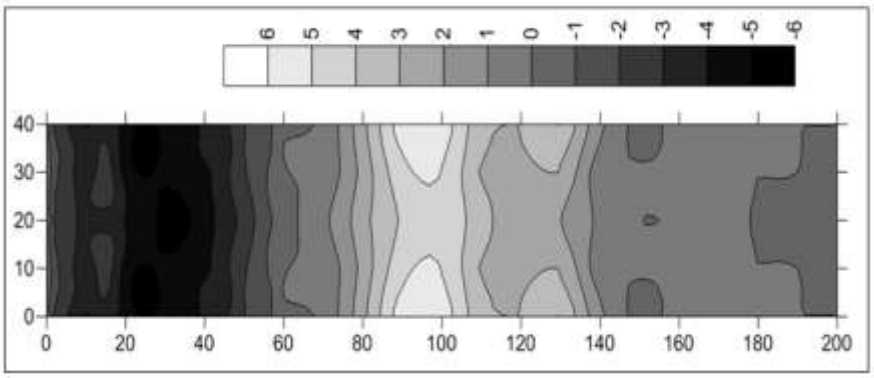

Fig-4: Scour contour map for the sand soil downstream of smooth bed at (Q = 23 lit. /sec., w = 30 mm).

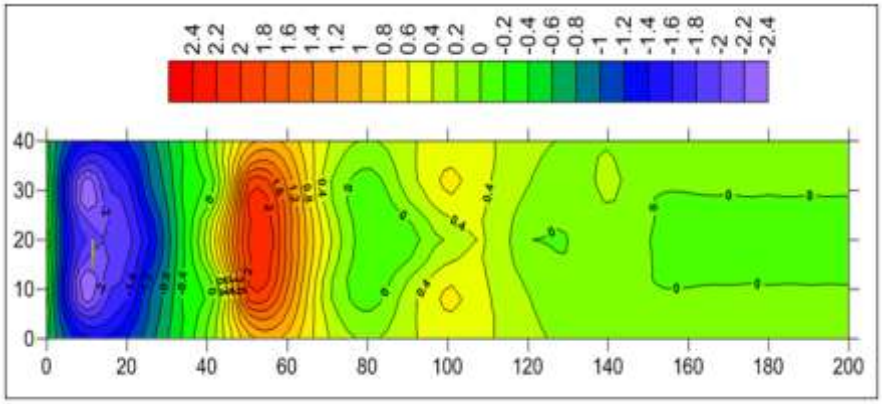

Fig-5: Scour contour map for the sand soil downstream of graded grain sizes gravel bed at (Q = 27 lit. /sec., w = 40 mm).

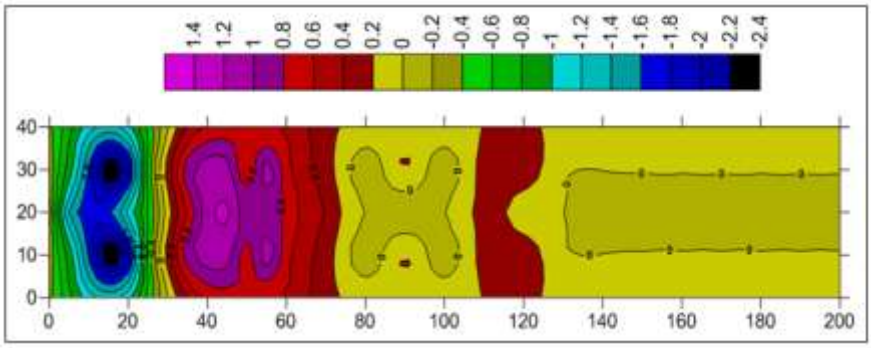

Fig-6: Scour contour map for the sand soil downstream of graded grain sizes gravel bed at (Q = 23 lit. /sec., w = 30 mm).

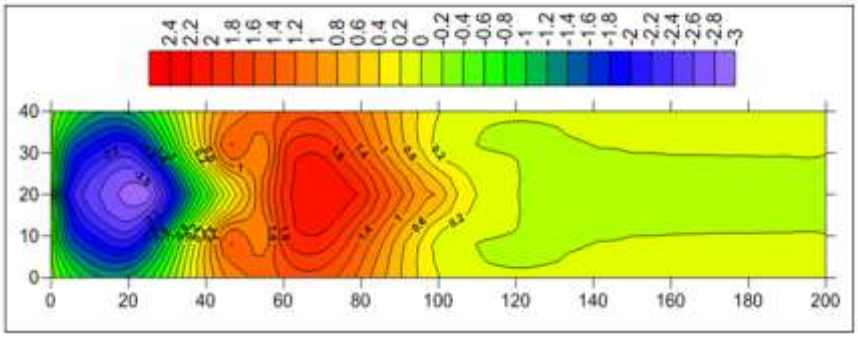

Fig-7: Scour contour map for the sand soil downstream of a big gravel bed at (Q = 27 lit. /sec., w = 40 mm).

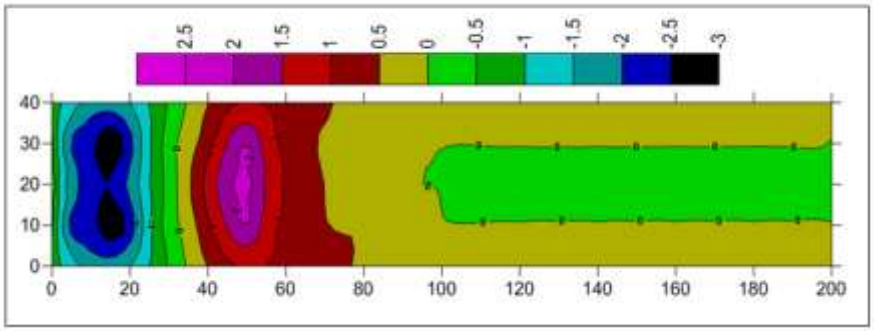

Fig-8: Scour contour map for the sand soil downstream of a big gravel bed at (Q = 23 lit. /sec., w = 30 mm).

These figures show of scour contour maps downstream smooth and gravel beds. It is appeared from these figures that the maximum scour hole depth occurs at the center line of the channel width at distance not exceed length of basin from its end and the effect of the channel boundaries on the scour contours ignored. The zone of maximum scour hole depth has a small width downstream rough 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 rough beds is less than the scour hole downstream smooth bed because increase the energy dissipation, and the length of the hydraulic jump at the gravel beds is less than the smooth bed.

CONCLUSIONS

The results of this study for erosion the soil downstream of submerged hydraulic jump over gravel beds have been presented. The discussion and analysis of the results concluded as following:

- Many parameters affect the scour properties for the same sample of sand, the most important of these parameters initial Froude number, gate opening, tailwater depth, and the martial of basin. The scour hole increases as the Froude number increases.
- The scour hole increases as the Froude number increases.
- Using gravel beds downstream of hydraulic structures is an effective engineering approach to minimize Scour holes dimensions, also economical solution.
- Gravel beds reduce the scour hole by rate from 47% to 66% in comparing with the scour hole of smooth bed.
- The rough bed (big gravel) could be considered the least for the reduction of the scour hole depth compared to graded grain sizes gravel beds, because the void ratio is high and therefore generated vortices with high velocities.
- This study were presented for a range of Froude number from 4.0 to 8.45.

NOTATION

The following symbols were used in this paper:

d_s: depth of the scour;
Fr_1: initial Froude number;
Q: flow discharge;
S: submergence factor;
w: gate opening;
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;

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