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Effect of Discharge and Sand Bed Variations on scouring depth at a Groin of Rivers Having 180° Bend

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ABSTRACT

Groins are commonly used at the river bends for controlling erosion along the banks and protecting the adjacent infrastructure. Groins are designed to divert river flows towards its axis, thus reducing stream pressures leading to enhanced protection of river banks. The new flow pattern, however, entails the inherent risk of disturbing the established river regime leading to scouring around the groin. This research was undertaken to investigate the effect of variations of discharges and sand beds on scouring depth at a groin using an experimental flume having a 180 degree bend. The laboratory experimental program used three sands with different median grain sizes, i.e, 0.41, 0.95, 1.6 mm, and three discharge values of 20, 24, and 30 l/s. Whereas, the groin was aligned at 90 degree position, with width of 8 cm. The results pertaining to the effects of discharge and sand median grain size on maximum scour depth were analyzed in the light of previous published data. The results further substantiated that an increase in discharge or decrease in sand median grain size causes an increase in the dimensions of scouring hole around the groin. It is also observed that increasing the discharge or decreasing the sand median grain size leads to increase in the extent and thickness of sedimentation downstream of the groin. This paper shows that, maximum scour depth shows an increasing trend with increasing Froude number.The results are represented by curves and equations to facilitate determination of the maximum scour depth for various discharge and sand bed conditions.

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INTRODUCTION

Hydraulic structures, such as groins, pile dikes, splitting dikes, etc, have been constructed in natural rivers to improve the stability of channels against bank or bed erosions by reducing flow velocities or changing flow direction. Off these methods, the use of groins are considered the most effective methods for preservation of rivers against erosion and devastation caused by water flows.

Groins are designed and constructed to harness the river course, especially along the bends. One of the major challenges posed at the river bends is the secondary flows accompanied by the erosion of river banks, whereas construction of groin is considered as a remedial intervention (Ahmed, M., 1953). These structures are extended from the river banks into the main flow stream causing regional flow contraction (Oliveto, G. *et al* 2002). These structures, designed and constructed either singly or in series, divert the flows thus protecting the walls from degradation. Whereas, generation of recirculation flow downstream will cause gradual sedimentation around the main banks which in the long term will protect and preserve the natural river wall (Gill, M.A., 1972, Petersen, M.S., 1986). One of the main reasons for constructing the groins is the scouring impact around these structures, which necessitate the study of the important parameters which could protect the banks from degradation. Various studies have been conducted by researchers on scouring phenomenon around the groin in straight rivers (Grade, R.J., *et al*, 1961, Lacey, R.W., *et al*, 2004).

The effects of groins on stable beaches and the coastal changes for various groin parameters were studied using a three-dimensional physical model. It was observed that effect of the groins on the beach was similar for different wave angles (α=20°, α=5°) and for the fixed groin spacing, (Price WA.*et al* 1968). Experimental investigations were carried out to study the effects of series of three groins on shore evolution and proposed a numerical model (GENESIS) and concluded that this model was in good agreement with the study of the physical model (Hanson H. *et al* 1991). A field study about groins at three sites, using aerial photographs of groin fields were carried out. Dimensionless parameters that determined whether the groins are “long” or

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"short", and "high" or "low" are given. Long term and seasonal variations were investigated by plotting the dimensionless groin variables as a function of time and season. He proposed the variable of dimensionless groins spacing for all investigated region (Webb RS.1994). The effects of groins on shore, using a 3D physical model were studied. The tests were carried out at two different wave basins with the beach length of 8 and 28 m. A straight beach in the absence of groins was tested for each set of variables, and then one or two impermeable surface piercing groins with different lengths were installed and tested (Badici P. 1994). A numerical model to simulate the short-term temporal changes in shoreline position due to a structure interrupting the long shore sediment transport was proposed. The impacts of the groin-type construction and under water trench of arbitrary orientation relative to the shore are investigated and tested the model using the laboratory data (Leont'yev I.O.1997).

Zupeng and Syunsuke (2009) studied experimentally the flow field with non-overflow groins in a straight rigid-boundary channel and the characteristics of the flow with groins positioned in stagger. The experiment showed that the maximum velocity appeared at the downstream from a groin for the two-fifths of the distance between groins, and reattachment points appeared at the downstream for the four-fifths of the distance between groins. M.J. Uddin *et al* (2011) revealed that maximum scour depth and deposition pattern changed for the case of different test runs. Scour depth varied with velocity variation of flow, and an increasing tendency of scour depth has been observed with increasing flow intensity.

Mahmoud R. *et al* (2012) carried out experiments to investigate the effect of groin geometry, represented in its length and angle of inclination, on scouring of sand bed using an experimental flume having a 180 degree bend. The laboratory experimental program modeled groins of four different lengths, i.e, 2, 4, 6, and 8 cm, with angles of inclinations of 30^o, 60^o, 90^o, and 120^o. The results further substantiated that an increase in length or inclination of groin causes a corresponding increase in the dimensions of scouring hole around it. It is also observed that increasing the groin length or its inclination leads to increase in the extent and thickness of sedimentation downstream of the groin.

This paper presents the results of a study undertaken to determine the effects of variations in discharge and sand bed on the sand bed scouring at groin of a river having 180^o bend.

MATERIALS AND METHODS

Research shows that the scouring phenomenon around the groin structure can be influenced by channel geometry, groin characteristics, bed material and hydraulic characteristics. This paper assumes the parameters for channel geometry, groin length and inclination, whereas the flow discharge and characteristics of bed materials were considered as variables. Twelve experiments were carried out to study the effect of the variation of the discharge and sand bed median grain size values on the maximum scouring depth as follows:-

Table 1: The experimental Program:

Run	Run No.	Median Grain Size d_{50} (mm)	Flow Discharge Q (l/s)
Incipient Velocity Tests	1	0.41	-
	2	0.95	-
	3	1.6	-
Time Progress of the Maximum Scour Depth d_{max}, and Longitudinal and Latitudinal Sand Profiles	1	1.6	20
	2	1.6	24
	3	1.6	30
	4	0.95	20
	5	0.95	24
	1	0.95	30
	2	0.41	20
	3	0.41	24
	4	0.41	30

For the above considerations, the relation to investigate the effect of the groin length and inclination on scouring is provided as follows:

$$d_{\max} = f(v, y, d_{50}, g) \quad (1)$$

Where:

$d_{\max}$ = Maximum scouring depth at equilibrium

d_{50} = Sand median grain size (1.6 mm)

v = Flow velocity

y = Flow depth

g = acceleration due to gravity

The final form of the non-dimensional functional relationship can be obtained

$$\frac{d_{max}}{d_{50}} = f\left(\frac{\sqrt{g\,y}}{v}\right) = f\left(\frac{1}{F_r}\right) \tag{2}$$

Equation (2) shows that the relative scour depth (d_{max}/d_{50}) is a function of Froude number (Fr).

The experiments were carried out in a flume in the laboratory of Hydraulics Research Institute, National Water Research Center Cairo, Egypt. The flume is a curvature glass flume with 180^o angle with a radius of 2.50 m. The flume has a length of 40 m, width of 0.40 m, and a 0.60 m depth as shown in Fig. 1. The ultrasonic flow meter is used to measure the flow discharge, whereas the velocity is measured by electromagnetic meters. The groin width and its inclination, were constant for all experiments with a values of 8cm, and 90^o respectively. Donnat (1995) recommends the maximum groin length between 10 - 20% of the channel width.

This paper used granulated sands having median grain sizes of 0.41, 0.95, and 1.6 mm and used flow discharges of 20, 24, and 30 l/s.

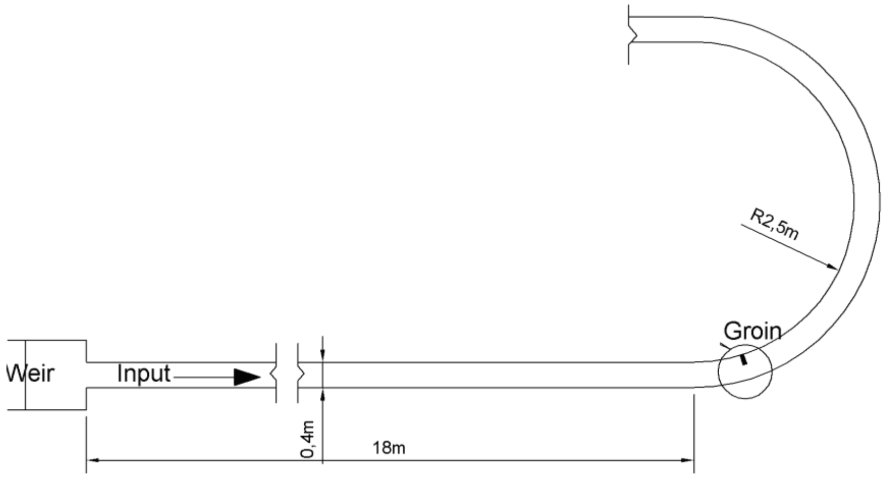

Fig. 1: The laboratory Layout of the experimental flume

The scouring of bed particles adjacent to an obstacle occurs when velocities and accelerations of water particles cause hydrodynamic forces sufficient to overcome gravity, and hence cause the bed particles to move. When the bed particles begin to tip from their angle of repose, it is defined as incipient motion and is considered the point where any study of scour must begin. Therefore, an experiment was carried out to estimate the incipient velocities v_s of the used sands.

Another experiment was designed and conducted for 7.5 hours period, with discharge of 30 l/s, and sand bed median grain size of 1.6 mm until equilibrium was attained. The scouring depth was measured at 15 minutes intervals for the first 2.5 hours, followed by 30 minutes intervals. As shown later, 86% of the final scouring took place within the first 120 minutes. In view of the foregoing, two-hours period was allocated for the experiment.

The experimentation study followed the sequence which started with the installation of the groin. The bed load sediments were scattered uniformly in the longitudinal and lateral directions. Prior to the operation of the pump, the end gate was closed and clear water was allowed to enter the channel gradually. After ensuring that the moisture was distributed evenly in the sediments, the pump was operated with a low discharge rate. This was gradually increased to reach an appropriate level. With the simultaneous regulation of the flow tap and downstream gate, the appropriate discharge was reached at a flow depth of 13 cm. After two hours the pump was switched off and the water trapped in the system was gradually drained in order to prevent any effects on the topography of the channel bed. The bed configuration around the groin was surveyed for different sand beds and discharges

In all experiments, the flow discharges and flow depths were adjusted such that immediately vortex formed around the groin and scour began with high speed. With the formation of scour holes, deposits eroded from the hole were moved downstream. The velocity distribution and the consequent scour hole formed in the case of all experiments were observed clearly.

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RESULTS AND DISCUSSIONS

The experimental results for all the tests are given in table and dimensionless curves. The results show the effect of the flow discharge and the sand bed median grain size variations on the scouring depth at a 90^o positioned groin in a river having 180^o bend.

3-1. Incipient Velocities for the Used Sand Beds:

Experiments were carried out to determine the incipient motion for each sand bed. The obtained incipient velocities are found to be consistent with Hjulstrom curve (1939). The incipient velocity, (v_s) for the three sand beds are given in Table (2).

Table 2: Incipient Velocities for the Used Sand Beds:

Sand median grain size, $d_{50}\,(mm)$	0.41	0.95	1.6
Incipient velocity, $v_s\,(cm/s)$	27.2	24.67	23.22

3-2. Temporal variation of scour and equilibrium scour depth:

Scour depth in clear water regime increases logarithmically with time up to limiting depth at equilibrium (Melville and Chiew, 1997). But in live bed regime, equilibrium depth is reached quickly. Experiments were also directed towards the investigation of scour development with time. Fig. (2 and 3) show the temporal variation of scour depth, d and attainment of equilibrium scour for different discharges with different sand beds. It is noticed that, the maximum scouring depth, d_{max}, increases as the median grain size d_{50} of the sand bed gets finer. For example, for flow discharge of 30 l/s, the maximum scouring depth increases from 13.8 to 16.48 cm when the sand bed median grain size decreases from 0.95 to 0.41 mm, i.e. decreasing 131 % in the sand bed median grain size results in increasing 19.4 % in the maximum scouring depth. It is found, that the maximum scouring depth

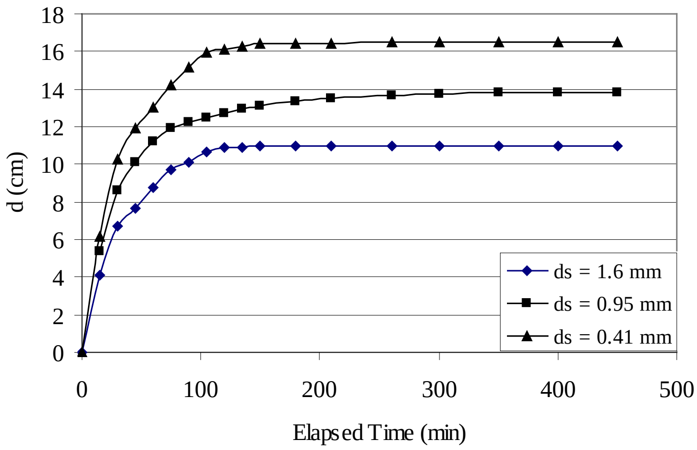

Fig. 2: Variation of scour depth with time for Q = 30 1/s

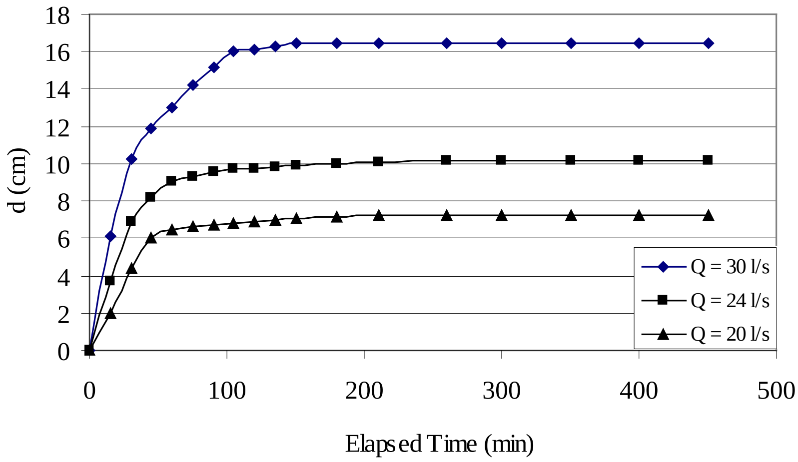

Fig. 3: Variation of scour depth with time for d_{50} = 0. 41 mm

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increases as the flow discharges increases. For instance, for sand bed median grain size of 1.6 mm, the maximum scouring depth increases from 6.7 to 11 cm due to increase in flow discharge from 24 to 30 l/s. i.e. increasing 25 % in the flow discharge leads to 64 % increasing in the maximum scouring depth. It also realized, that 86% of the final scouring took place within the first 120 minutes, and the equilibrium time to reach the maximum scour depth was found to vary with discharge.

3-3. Variation of maximum scour depth with Froude number:

This paper shows that, variations of dimensionless maximum scour depth, $\frac{d_{\max}}{d_{50}}$ with Froude number, F_r are shown in Fig. (4). From trend line of this graphical presentation, it has been found that scour depth increases at an increasing tendency with increasing Froude number. Equation (3) may be used for calculating the maximum scouring depth for a given Froude number;

$$\frac{d_{\max}}{d_{50}} = 64.157\,F_r - 209.92 \tag{3}$$

3-4. Scour and deposition:

Fig. (5) shows the comparison between maximum scour depths with maximum heights of deposition for each test run. It is found that the maximum scour depth is relatively higher than the maximum height of deposition. As discharge increases scour depth increases and more sediment deposited downstream of the groin. For the same sand bed, the scour and deposition are higher for higher discharge and vise versa. The lateral and longitudinal cross section bed profiles are drawn to compare differences in scour and deposition pattern for each test run. Fig. (6) shows the relation between the maximum scour depth and maximum deposition height for all test runs. The trend line of this graphical presentation shows the linear relationship

3-5. Cross sectional sand bed profile:

The experimental observations for the cross-sectional profiles of the sand bed scour for different discharges and sand beds, are shown in Figs. (7 and 8). In order to make dimensionless, the cross distance, X and the corresponding scour depth, d has been divided by the flume width, b and the groin width, w respectively. It was found that, the sand bed profile increases as the discharge increases. All the cross sectional sand bed profiles show the same trend for a given sand bed. A small ridge is formed at the groin followed by a steep side slope. The inclination of all the slopes are approximately equal to the corresponding angle of repose of the considered sand bed. On the other hand, the sand bed hole decreases as the sand bed median grain size increases. It was found also that, the scour hole grows such that the profiles after different time intervals have the same shape and trend.

3-6. Sand Bed profiles along the longitudinal section:

In this paper, the longitudinal sand bed profiles has been plotted to observe the change in the sand bed profile along the stream around the groin for different discharges and different sand beds. Fig. (9) shows that, for sand median grain size of 1.6 mm, the sand bed longitudinal profile increases as the discharge increases. But the longitudinal sand bed profiles decreases as the sand bed median grain size increases, for discharge of 30 l/s, as shown in Fig. (10).

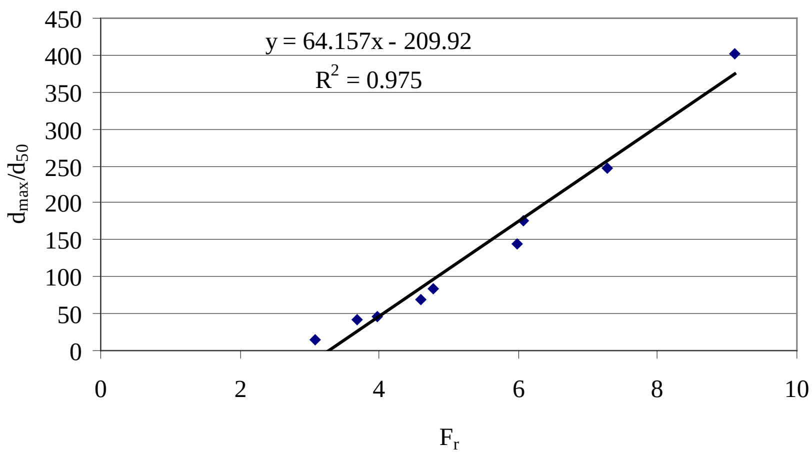

Fig. 4: Variation of the maximum scouring depth with Froude number

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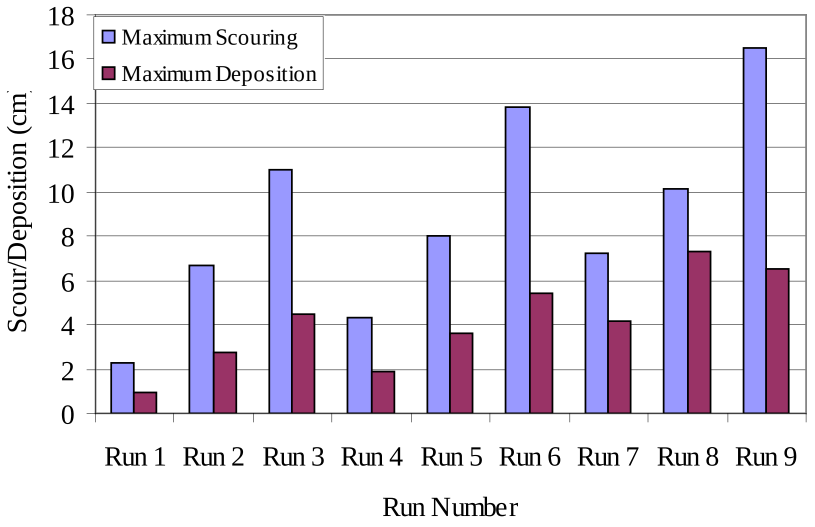

Fig. 5: Scour and deposition pattern for all test runs

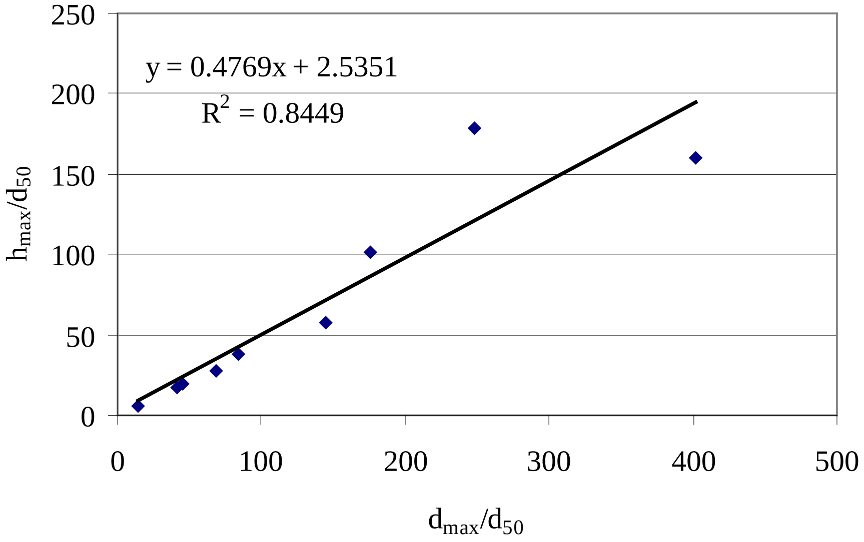

Fig. 6: Relation between maximum scour and maximum deposition

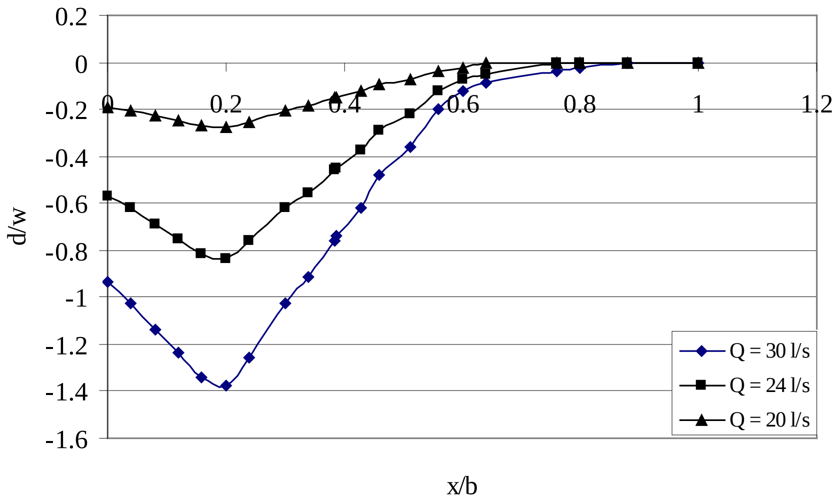

Fig. 7: Cross sectional sand bed profiles for different discharges and d_{50} = 1.6 mm

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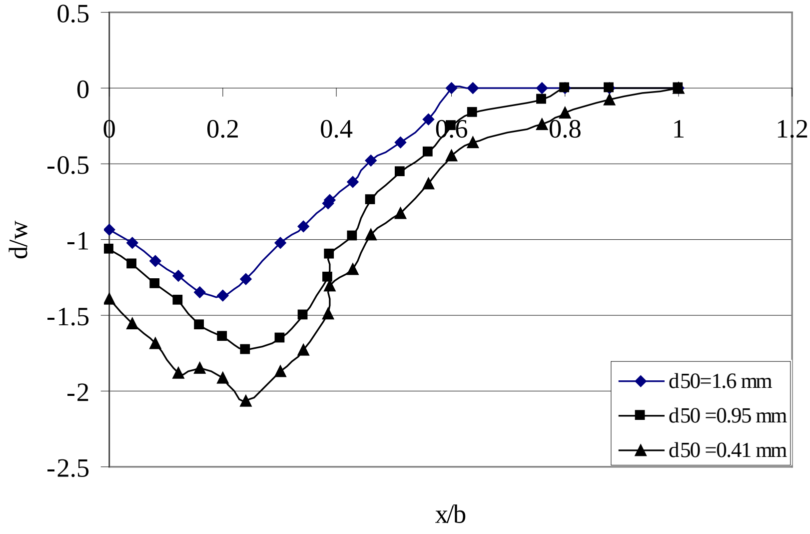

Fig. 8: Cross sectional sand bed profiles for diffent median grain sizes and Q = 301/s

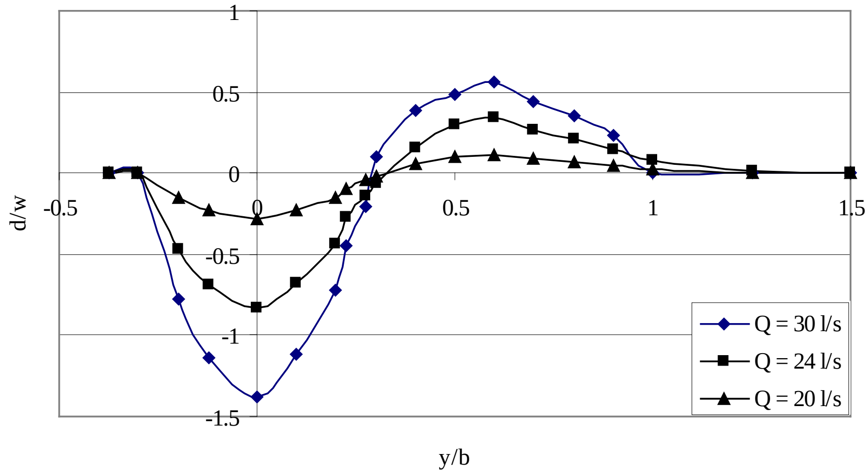

Fig. 9: Sand bed longitudinal profiles for different discharges for d_{50} = 1.6mm

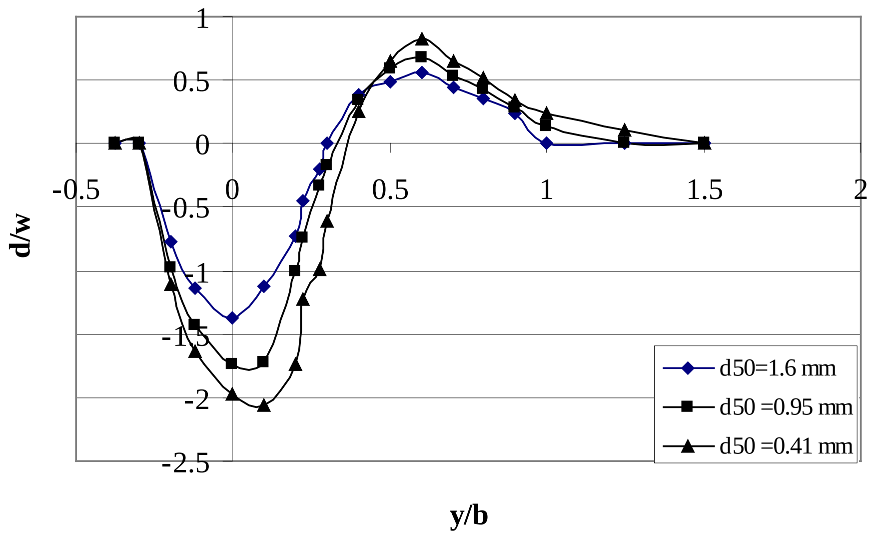

Fig. 10: longitudinal sand bed profiles for different median grain sizes and Q = 301/s

Conclusions:

This paper presents the study conducted on the effects of the flow discharge and sand bed median grain size, on the scouring of sand bed at a 90^o position groin in a river has 180^o bend. The several experiments were performed with three discharges and three sand beds. The following are the conclusions of this study:-

1- Equilibrium scour depth measured around groin shows that the scour depth in sand beds increases as the sand bed median grain size decreases.

2- The equilibrium time to reach the maximum scouring depth was found to be varied with discharge.

3- The longitudinal profiles along the stream around the groin shows that the maximum scour occurs at the groin increases as the flow discharge increases.

4- The scour hole profiles for different discharges have the same slope. Their side slope angles are almost equal the angle of repose of the corresponding sand bed.

5- The scour depth in sand bed increases with time and reaches almost equilibrium after two hours, as observed from experiments.

6- The maximum scouring depth shows an increasing trend with increasing Froude number.

7- There was also an observation pertaining to increase in the extent and height of sedimentation of sand downstream of the groin by increasing the flow discharge or decreasing the sand bed median grain size.

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