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Full Length Research Paper

Effect of groin geometry on scouring of sandy river beds having 180° Bend

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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 groin geometry, represented in its length and angle of inclination, on scouring of sand bed using an experimental flume having a 180° bend. The laboratory experimental program modeled groins of four different lengths, that is, 2, 4, 6, and 8 cm, with angles of inclinations of 30, 60, 90, and 120°. Whereas, aggregation of natural sand with a median grain size, d_{50} = 1.6 mm was used as material of the flume bed, with discharge of 30 lit/s. The results pertaining to the effects of groin geometry on maximum scour depth were analyzed in the light of previous published data. 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. The results are represented by curves and equations to facilitate determination of the maximum scour depth for various groin geometry conditions.

Key words: Groin, river erosion, scour depth, groin geometry, groin length, groin inclination.

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 uses 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, 1953). These structures are extended from the river banks into the main flow stream causing regional flow contraction (Oliveto and Hager, 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, 1972; Petersen, 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 et al., 1961; Lacey 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

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Table 1. The experimental prgram.

Run	Run number	Width ratio (%)	Angle (α) (°)
Incipient velocity test	1	20	90
Balance time test	1	20	90
Part I	1	5	90
	2	10	
	3	15	
	4	20	
Part II	1	20	30
	2	20	60
	3	20	90
	4	20	120

effect of the groins on the beach was similar for different wave angles (α=20°, α=5°) and for the fixed groin spacing, (Price and Tomlinson, 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 and Kraus, 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 "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, 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 et al., 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, 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.

This paper presents the results of a study undertaken to determine the effects of groin geometry, representing in groin length and its inclination angle, on the sand bed scouring of a river having 180° bend.

EXPERIMENTATION

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, flow discharge and characteristics of bed materials, whereas the groin length and inclination were considered as variables. Ten experiments were carried out to study the effect of groin geometry on the maximum scouring depth (Table 1).

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

$$\frac{d_{\max}}{d_{50}} = f(L, \alpha) \tag{1}$$

Where: $d_{\max}$ = Maximum scouring depth at equilibrium, d_{50} = Sand median grain size (1.6 mm), L = Groin length, α = Groin inclination angle

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° 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 Figure 1. The ultrasonic flow meter is used to measure the flow discharge, whereas the velocity is measured by electromagnetic meters. The discharge was constant for all experiments with a value of 30 l/s. The material used for the bed of flume was granulated sand having a median grain size of 1.6 mm.

Donnat (1995) recommends the maximum groin length between 10 to 20% of the channel width. This paper used groin lengths of 2, 4, 6, and 8 cm, for inclination angle of 90° and used the inclination angles of 30, 60, 90, and 120° for the groin of 8 cm length.

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

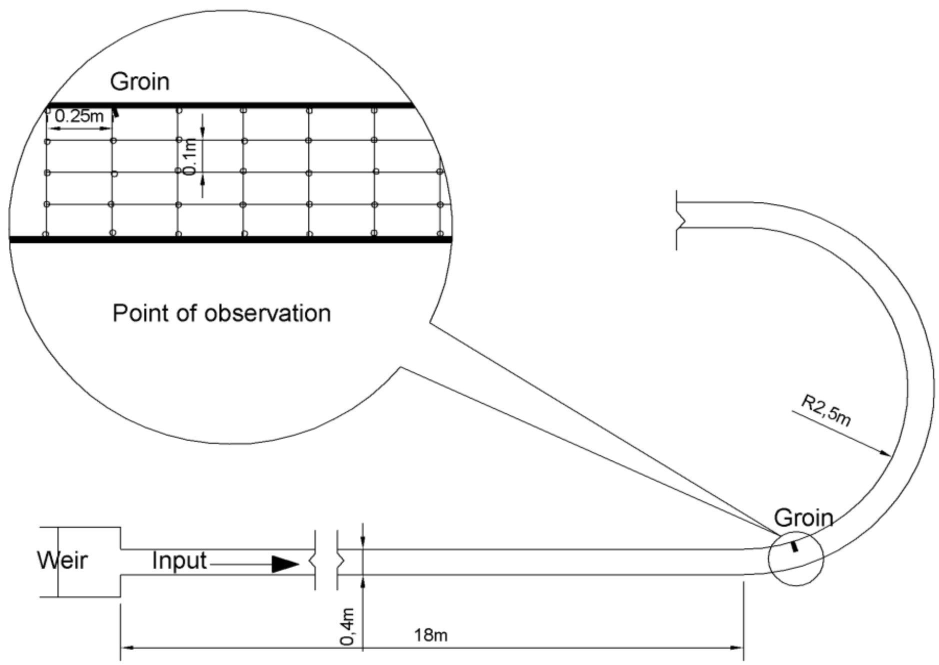

Figure 1. The laboratory layout of the experimental flume.

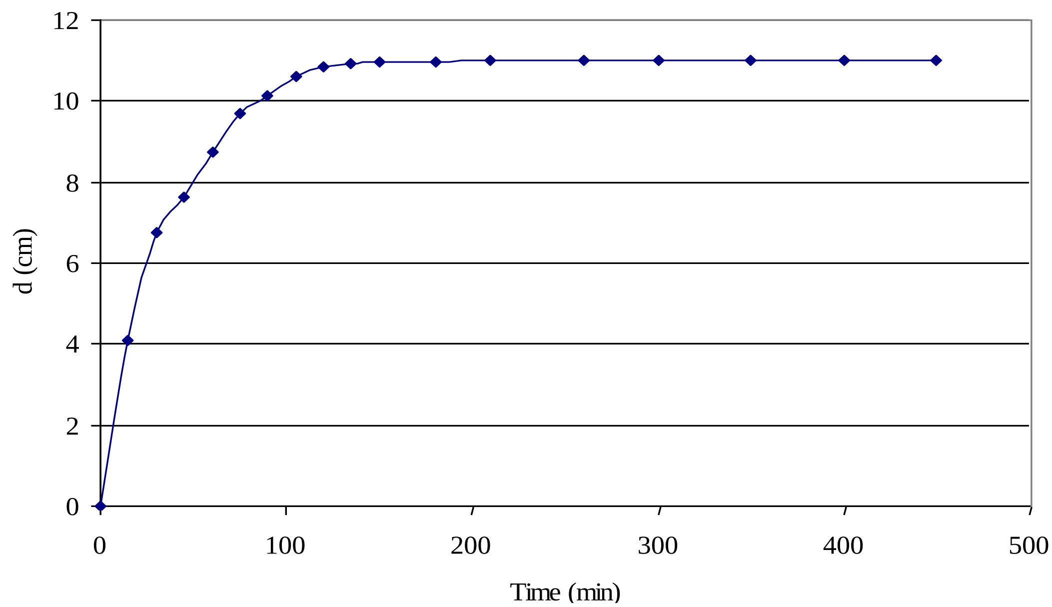

Figure 2. Curve for balance time (groin 8 cm and 90° groin inclination angle).

considered the point where any study of scour must begin. Therefore, an experiment was carried out to estimate the incipient velocity V_s of the used sand. It was found to have a value of 0.30 m/s (Vanoni et al., 1966).

Another experiment was designed and conducted for 7.5 h period, with discharge of 30 lit/s, at 90° angle and with a groin length of 8 cm until equilibrium was attained. The scouring depth was measured at 15 min intervals for the first 2.5 h, followed by 30 min intervals. According to Figure 2, 86% of the final scouring took place within the first 120 min. In view of the foregoing, a two-hour 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

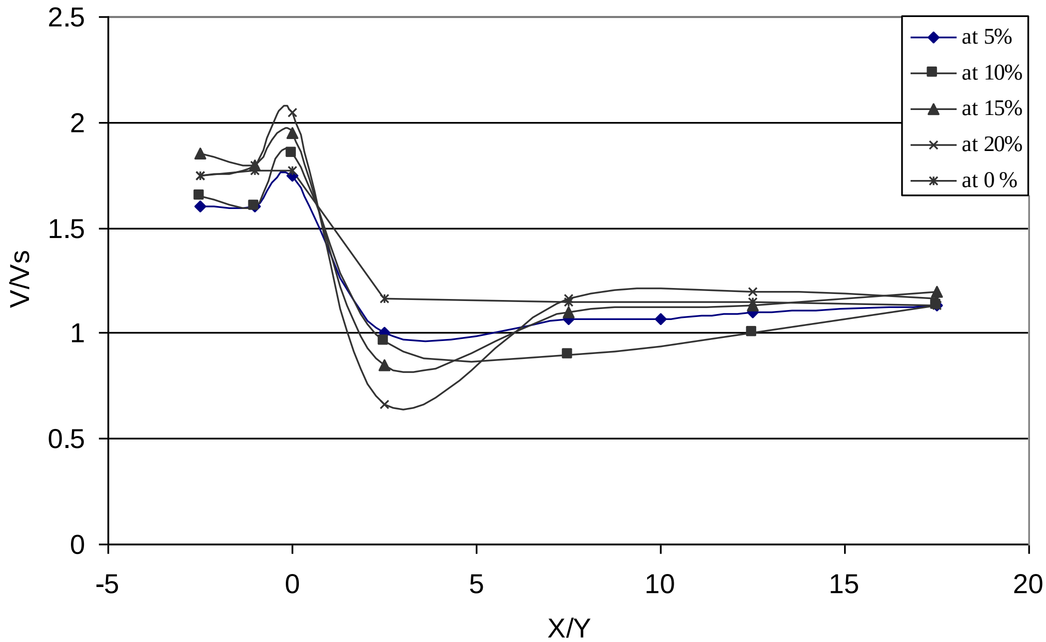

Figure 3. Longitudinal velocity distributions for different groin lengths (α = 90°).

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 reached 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 groin lengths and the groin angles of inclinations.

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.

RESULTS AND DISCUSSION

The results are presented in two main parts; the first part deals with measuring of velocity distributions for each experiment, while the second part investigates the scouring in the sand bed.

Part I: Velocity distribution around the groin

The flow velocities were measured at 60% depth of flow in all the experiments. For changing the groin lengths at 90° inclination angle, it was observed that increasing the groin length results in increasing the velocity. This means that an increase of 50% in the groin length (from 4 to 6 cm) there will be a 5.41% increase in the velocity at the groin. Results further showed that by a 33.33% increase in the groin length (from 6 to 8 cm) there will be a corresponding increase of 5.13% in the velocity at the groin nose. This was again observed when the groin length was increased by 100% (from 4 to 8 cm), the velocity at the groin increased by 10.81%. These observations are recorded in Figure 3, which shows that the velocity ratio below one does not cause scouring in sand bed.

On the other hand, for changing the groin of 8 cm length inclination, it was found that the velocity at the groin nose increases as the groin angle of inclination increases. This means that increasing 50% in the groin angle of inclination (from 60 to 90°), there will be a 6% increase in the velocity at the groin. Results further showed that by a 33.33% increase in the groin angle of inclination (from 90 to 120°) there will be an increase of 9.5% in the velocity at the groin nose. These observations were repeated when the groin angle of inclination was increased by 100% (from 60 to 120°) the velocity at the groin increased by 16%. Figure 4 shows these velocity distributions.

Part II: Scouring of sand bed due to groin

Incipient motion versus scouring was studied with respect to steady open channel flow. The scouring process begins as the flow velocity is greater than the incipient velocity V_s, that is, the ratio $\frac{V}{V_s} > 1$. It was found that the

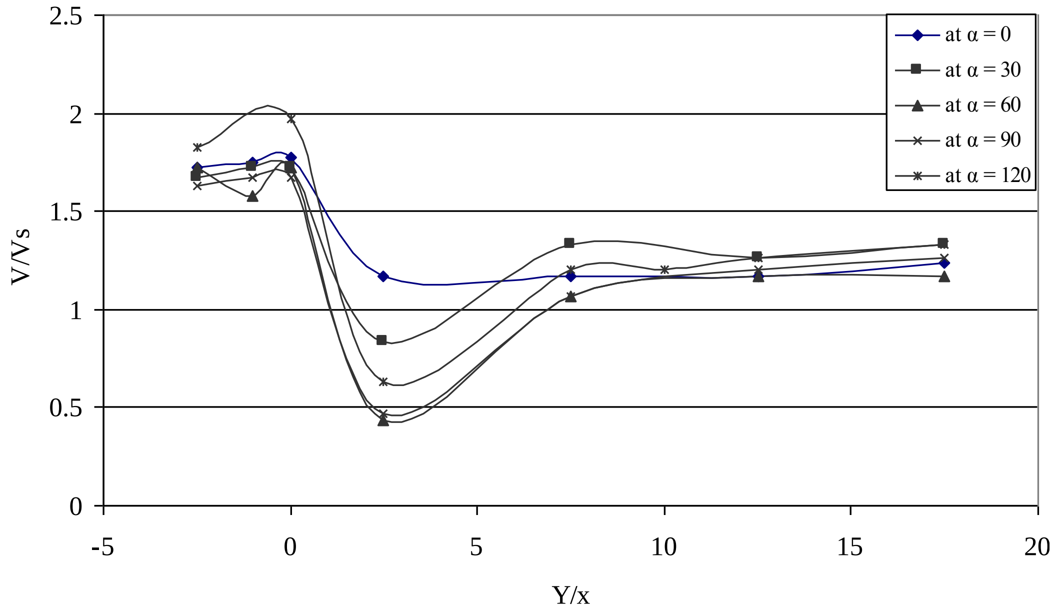

Figure 4. Variations of velocity distributions due to the 8 cm groin angle of inclination.

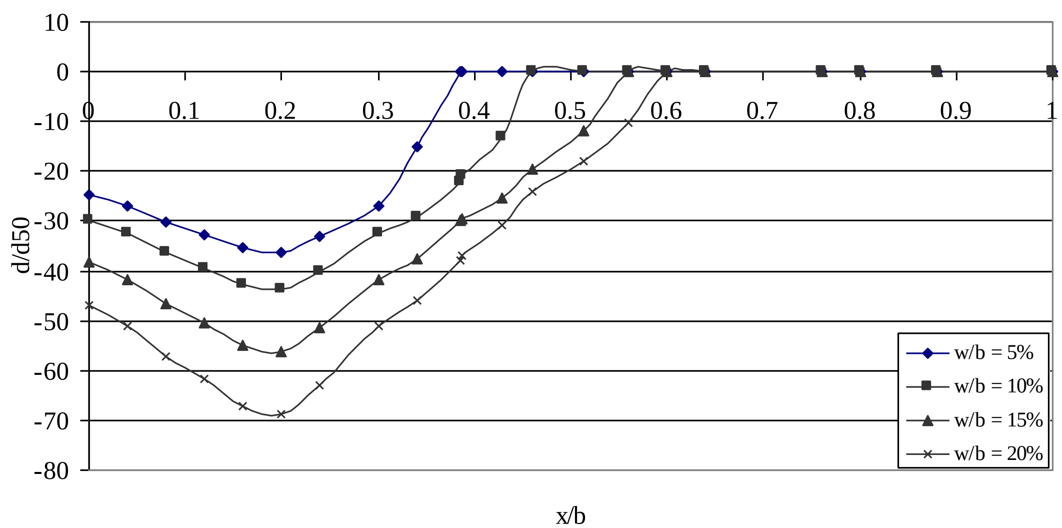

Figure 5. Latitudinal profiles of the scouring depth d, for different groin lengths (α =90°).

maximum scouring depth occurs at the groin nose and it increases as the groin length increases for 90° angle of inclination. For example, by increasing 100% in groin length (from 4 to 8 cm) the maximum scouring depth increases by 90%. Figures 5 and 6 show the longitudinal and latitudinal bed scouring profiles for different groin lengths and 90° groin angle of inclination. Figure 7 shows the comparison of the present study and Moradi's results.

The variations in the results are attributed to different discharge, that is, 28 L/s. used by Moradi et al. (2011). The maximum scouring depth may be calculated by knowing the groin length ratio for 90° groin inclination angle using the following relationship,

$$\frac{d_{\max}}{d_{50}} = 2.325\left(\frac{L}{b}\right) + 20.625 \qquad (2)$$

$$R^2 = 0.918$$

Where: b = the open channel bed width

There was also an observation to increase in the length

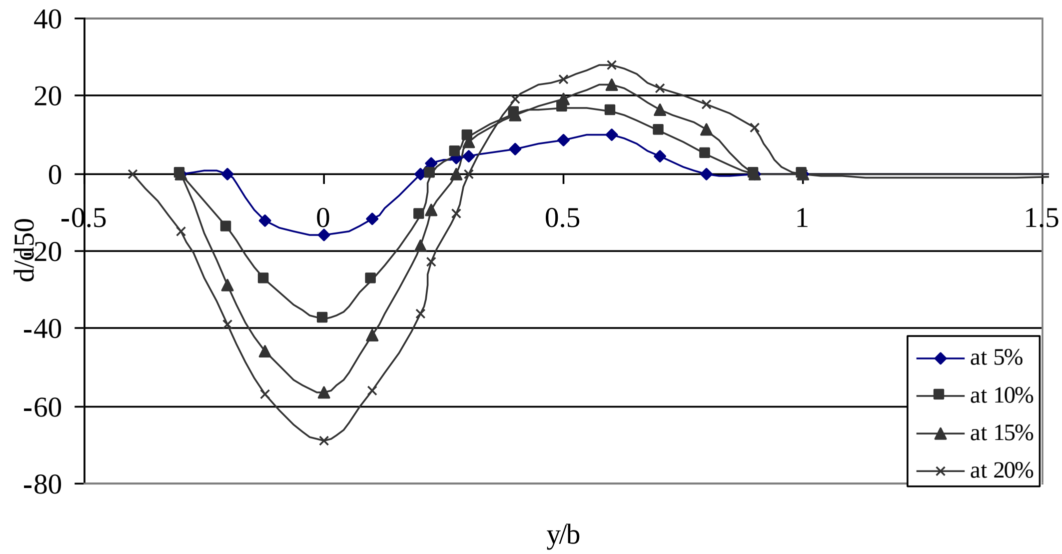

Figure 6. Longitudinal profiles of the scouring depth d, for different groin lengths (α =90°).

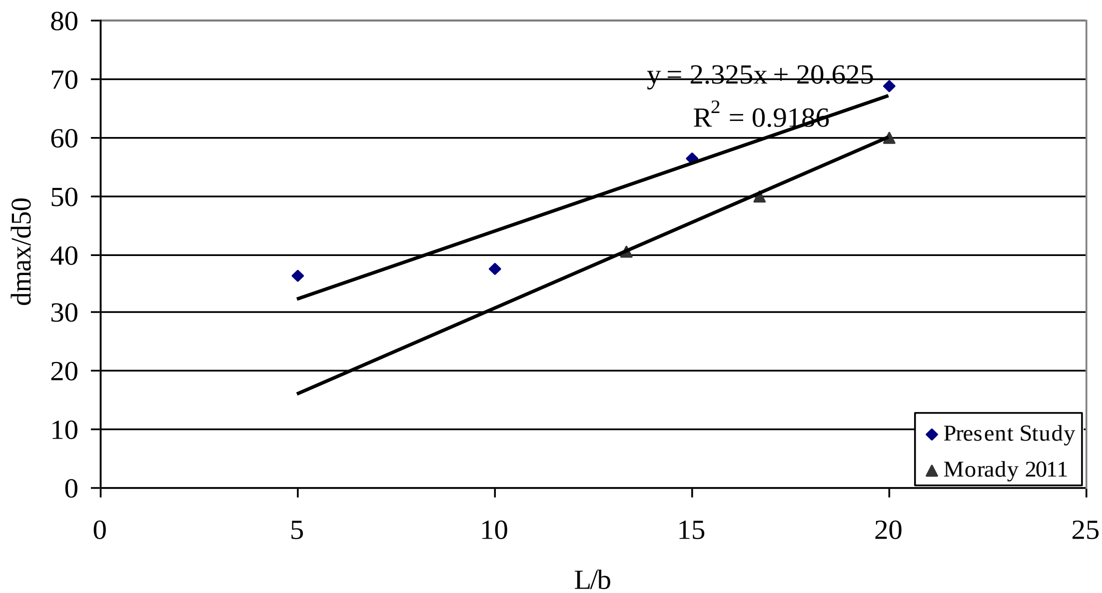

Figure 7. Comparison of present study and Moradi results for effect of groin length on the maximum scouring depth (α =90°).

and height of sedimentation of sand downstream of the groin by increasing the groin length for groin inclination angle of 90°.

The effect of groin inclination angle on the sand bed scouring was also studied. An increase in the groin angle of inclination results into increase in the maximum scouring depth at the groin. For example, 100% increase in groin inclination angle (from 60 to 120°) results in 33% increasing in the maximum scouring depth for the 8 cm groin. Longitudinal and transverse bed scouring profiles for different groin angles and 8 cm groin are shown in Figures 8 and 9. The maximum scouring depth may be determined using the following relationship for 8 cm groin for different groin angles.

$$\frac{d_{\max}}{d_{50}} = 0.3104\,\alpha + 45.938 \qquad (3)$$

Whereas, $R^2 = 0.985$

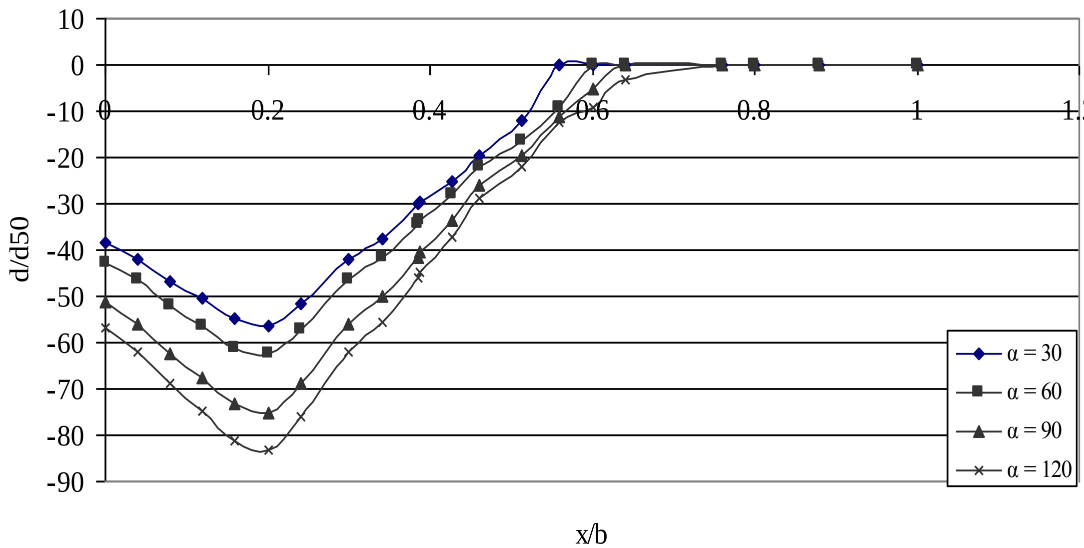

Figure 8. Transverse profiles of 8 cm - groin for different inclination angle.

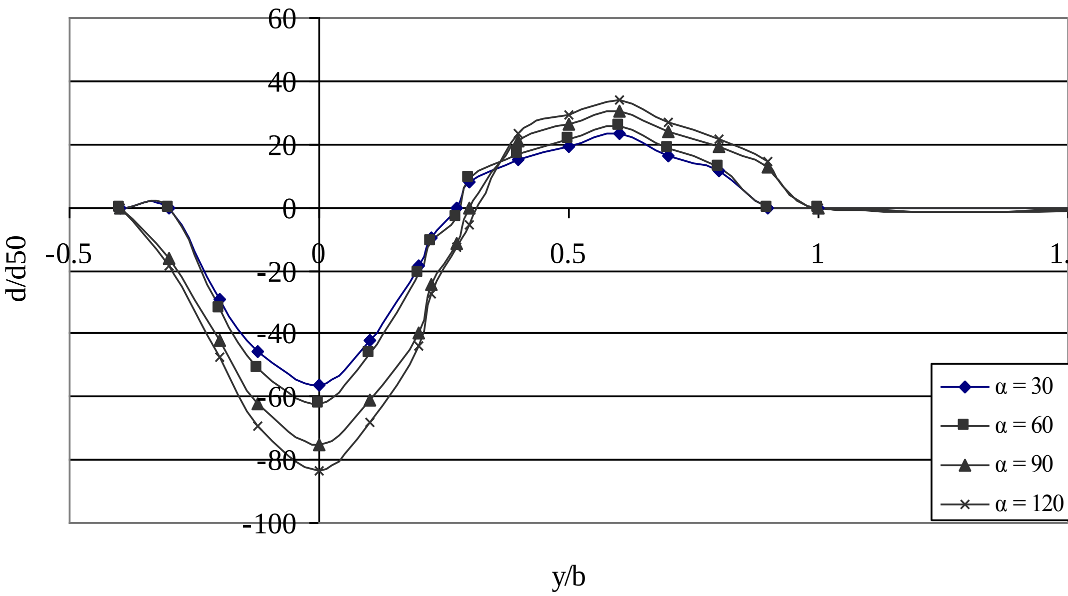

Figure 9. Longitudinal profiles for different the 8 cm groin inclination angle.

A general relationship was established based on the two sets of results. By using Equation 4, the maximum scouring depth at the groin nose for given groin length and its angle of inclination that is, the groin geometry, may be estimated, as shown in Figure 10.

$$\frac{d_{\max}}{d_{50}} = 0.0222\ \alpha\ \frac{L}{b} + 30.29 \qquad (4)$$

$$R^2 = 0.785$$

It was also observed that there was increase in the extent and height of sedimentation of sand downstream of the groin by increasing the 8 cm groin inclination angle.

Conclusions

This paper presents the study conducted on the effects of groin geometry, represented in its length and angle of inclination, on the velocity distribution through open channel and scouring of sand bed. Several experiments

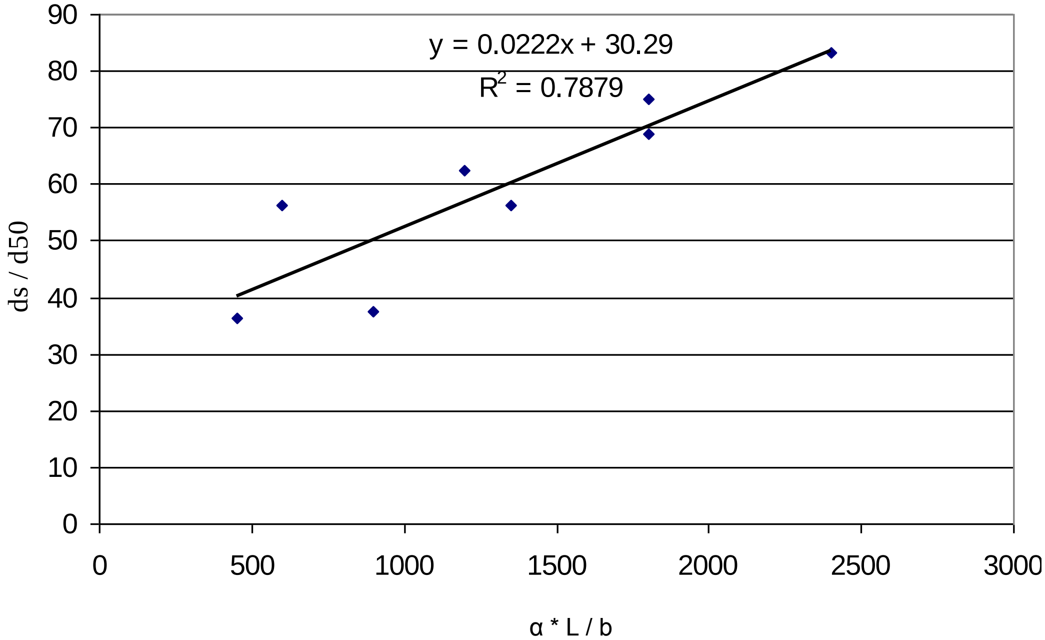

Figure 10. Effect of the 8 cm- groin angle of inclination on the maximum scouring depth.

were performed with groins of different width ratio and various angles of inclination. The following are the conclusions of this study:

1. For a given groin inclination angle, the velocity values at the groin increases as the groin length increases.
2. For a given length of the groin, increasing the groin angle of inclination results in increasing the velocity values at the groin nose.
3. The maximum scouring depth increases as the groin length increases for a given groin angle.
4. As the groin angle increases, the maximum scouring depth increases at the groin nose for a given groin length.
5. The groin length versus maximum scouring depth relation has the same trend as observed by Moradi's results.
6. The study established models that can be used to estimate the maximum scouring depth at the groin nose for known groin length and inclination angle.
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 groin length or its inclination.

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