THE HYDRAULIC PERFORMANCE OF ORIENTED SPUR DIKE IMPLEMENTATION IN OPEN CHANNEL

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ABSTRACT

River training is a process involving construction of structures across or along a river. The most common types of these training structures are groins. They are mainly used for bank protection against erosion and for channel rehabilitation and maintenance. The present study aims for simulating and predicting the flow pattern around non-submerged single groin. A two-dimensional hydrodynamic model was developed. The model was physically verified by using experimental results of a proposed physical model. The verification was carried out to assure the validity of the developed mathematical model. Specific runs were conducted to achieve this verification. The model simulation was focused on the study of velocity in the longitudinal and transverse directions. In addition, the lengths of separating and reattachment points were also investigated. Two effective parameters were tested through twelve runs conducted by the model. The first was the contraction ratio which is defined as the groin length to channel width (L/B). Four contraction ratios of 0.1, 0.15, 0.2, and 0.30 were used. The second was the groin orientation angle; three orientation angles were tested to define three types of groins. Angle 60 degree defines repelling groin type which was pointing to the upstream direction or opposite to flow direction. Angle 90 degree is defining the straight groin or the groin perpendicular to flow direction. Angle of 120 degree defines the attracting type groin which was pointing to the downstream direction similar to flow direction. A finite element mesh was designed for measuring purposes. The measurements covered about 48 grid points interpreted to four horizontal lines (A, B, C, and D) and 12 vertical cross sections from 1 to 12. The study cases represent several concluding remarks. For the reattachment length, it was found that all tested contraction ratios indicated resemble trend. The angle represented repelling groins had longer reattachment lengths if compared to the same angles of attracting ones. Furthermore, the straight groin gave the longest reattachment lengths. The contraction ratio of 0.1 was too short to show noticeable effect on the reattachment length. For the separation point length, the results show that all contraction ratios have similar trend and inversely proportional to the orientation angle. All attracting angles don't form any separation point length. Similar findings for contraction ratio of 0.1 on separation point length were observed for repelling groins.

There is a clear similarity between the longitudinal velocity for repelling and attracting type groins, the similarity is found between angle 60^o for repelling, and 120^o for attracting respectively with slight more or less increase in the maximum velocities. The study recommended that, the repelling type groin of 60^o orientation angle with 0.2 contraction ratio can be used for the best upstream and downstream bank protection. The orientation angle of 90 degree with the contraction ratio of 0.3 resulted the highest values of maximum and minimum longitudinal velocities. Therefore, the straight groin type can be designed for sediment removal and evacuation in front of critical zones and infrastructures. The study recommended that this work should be repeated using a series of spurs in order to be able to create a checklist for spurs for different functions.

Keywords: Oriented Spur dike, mathematical model, velocity components, separation and reattachment point lengths

INTRODUCTION

The existence of human kind is highly related to rivers as they are the main source of fresh water. The river systems as a part of our nature need to be mastered and trained to gain the optimum use of them. This is done through human interference by planning, design, and implementation. Spur dikes are the most common river training works used to regulate rivers as they proved different functions all over the world. They have been recognized as hydraulic structures extending outward from the bank of stream for the purpose of deflecting or attracting the flow. The main functions of groins are:

1- To protect the bank against erosion.
2 - To reduce the velocity of flow along river banks owing to their roughness.
3- To enhance aquatic habitat by creating stable pools in unstable streams.
4- To sustain channel for navigation and sediment control.
5- To establish well defined channel in wide braided rivers.
6- To control flow into or out of a bend through meandering channel.

This research simulated the hydraulic performance of implementing a single oriented groin on open channel flow. The groin effective working area was defined through the investigation of reattachment and separation lengths. Moreover, the velocity components in X and Y directions were qualitatively and quantitatively determined. A two dimensional finite element mathematical model was developed to achieve the study objectives (Molinas and Hafez 2000).

MATHEMATICAL MODEL

The differential governing equations are written in the Cartesian X-Y coordinates, where the X-direction is in the main flow direction and Y-direction is in the lateral direction. The most complete equations of motion for a viscous fluid are known as

Reynolds average equations (Navier-Stokes equations). It is assumed that the fluid is incompressible and follows a Newtonian shear stress law whereby viscous force is linearly related to rate of strain. For two-dimensional steady incompressible flows, the flow hydrodynamics governing equations are the equation for conservation of mass and the equations for conservation of momentum. Conservation of mass equation takes the form of the continuity equation while Newton's equations of motion in two dimensions express the conservation of momentum. The continuity equation is given as:

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0 \tag{1}$$

The momentum equation in the longitudinal (X) direction is:

$$U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} = -\frac{1}{\rho}\frac{\partial P}{\partial X} + \frac{\partial}{\partial X}\left(2\nu_e\frac{\partial U}{\partial X}\right) + \frac{\partial}{\partial Y}\left(\nu_e\left(\frac{\partial U}{\partial Y} + \frac{\partial V}{\partial X}\right)\right) + F_X + \left(\frac{\partial}{\partial z}\left(\frac{\tau_{fx}}{\rho}\right)\right)_{z=H} \tag{2}$$

The momentum equation in the lateral (Y) direction is:

$$U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y} = -\frac{1}{\rho}\frac{\partial P}{\partial Y} + \frac{\partial}{\partial X}\left(\nu_e\left(\frac{\partial U}{\partial Y} + \frac{\partial V}{\partial X}\right)\right) + \frac{\partial}{\partial Y}\left(2\nu_e\frac{\partial V}{\partial Y}\right) + F_Y + \left(\frac{\partial}{\partial z}\left(\frac{\tau_{fy}}{\rho}\right)\right)_{z=H} \tag{3}$$

Where U = Longitudinal surface velocity, V = Transverse surface velocity, P = Mean pressure, ν_e = Kinematics eddy viscosity, F_x = Body force in X direction, F_y = Body force in Y direction, g = Gravity acceleration, θ = Average water surface slope, ρ = Fluid density, τ_{fx} = Turbulent frictional stresses in X-direction, τ_{fy} = Turbulent frictional stresses in Y-direction.

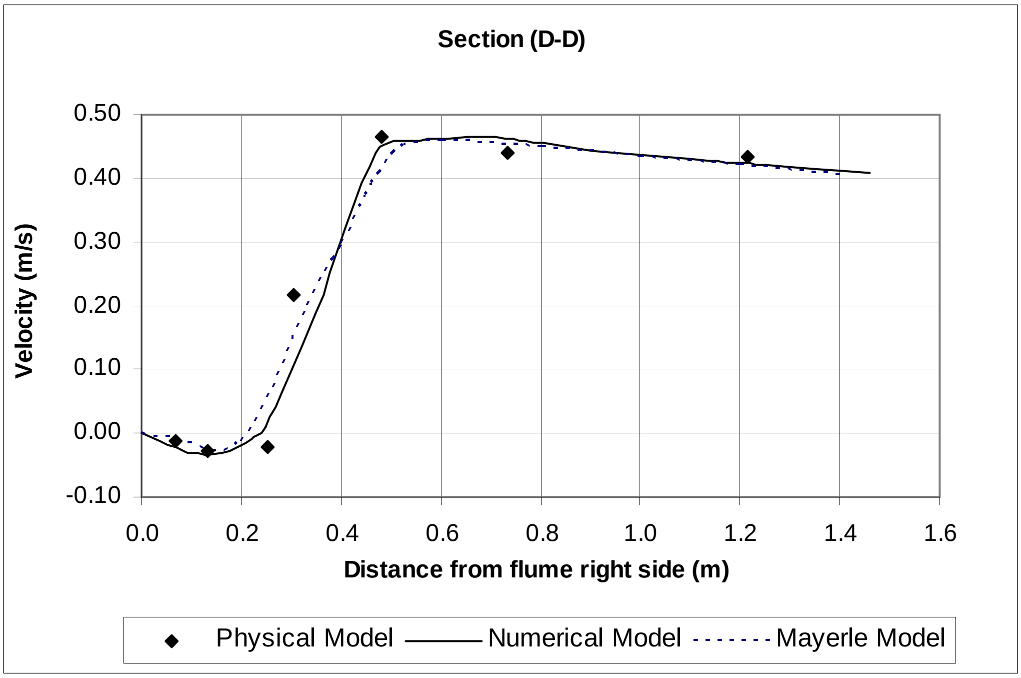
The assumptions used in the hydrodynamic model are:

- The density is assumed to be constant (Incompressible fluid).
- Steady flow conditions.
- Varying turbulent viscosity with the velocity gradient.
- Two-dimensional surface analysis.
- Free surface as a rigid lid.
- Hydrostatic pressure.
- Wind stresses are neglected.

It should be mentioned that complete details about numerical solution of the model governing equations, the boundary conditions and the working flow chart is presented in Ebraheem 2005.

TESTING MODEL VALIDITY AND VERFICATION

To verify the effectiveness of the numerical model, an experimental study to simulate the flow in the vicinity of groin is used. Similar verification is conducted by Mayerle et al., in 1995 to test the validity of three dimensional mathematical model developed by them. Figure 1 shows comparison between the developed model and the 3-D model developed by Mayerle et al. The comparison indicates two cross sections of 0.33 m (cross-section D) and 1.55 (cross-section E) respectively downstream the dike axis. The figure illustrates good agreement between the two models and the experimental data. It can be concluded that the current model proves to reproduce the experimental study in a suitable way. Therefore, it can be used to predict new and similar situations.



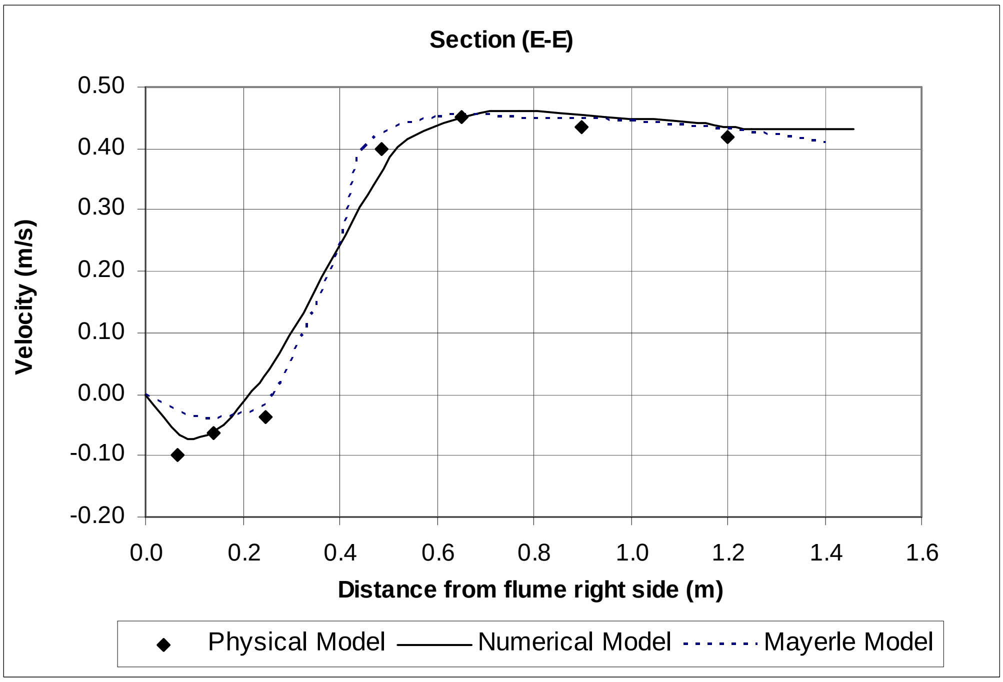


Figure 1: Testing the Validity of the Used 2-D Numerical Model

STUDY CASES

A number of cases are formulated for simulation using the mathematical model. A basic case run is conducted to represent the straight channel without any groins. This run will be used as reference to allocate the hydraulic performance of spur dike implementation in open channel. The runs names are formulated as a function of spur type, angle of orientation and contraction ratio. For example, RS_{10} is stand for repelling groin of sixty degrees orientation angle with 10% contraction ratio, and SN_{20} is stand for straight groin of ninety degrees orientation angle with 20% contraction ratio, and AS_{15} is stand for attracting groin of sixty degrees orientation angle with 15% contraction ratio. Table 1 indicates the study cases.

Table (1): The Study Cases and the Run Nominations

Run Name	L/B	Angle of Orientation	Groin Name
Basic	-----	-----	No groin
RS_{10}	0.10	60°	Repelling
RS_{15}	0.15		
RS_{20}	0.20		
RS_{30}	0.30		
SN_{10}	0.10	90°	Straight
SN_{15}	0.15		
SN_{20}	0.20		
SN_{30}	0.30		
AS_{10}	0.10	120°	Attracting
AS_{15}	0.15		
AS_{20}	0.20		
AS_{30}	0.30		

DISCUSSION OF RESULTS AND ANALYSIS

1. The Reattachment Length

It is defined as the position downstream the groin where the flow returns to its original condition before implementing the groin. This length is defined by the assist of velocity vector (arrows) on the channel plane view Figure 2 (a, b, and C).

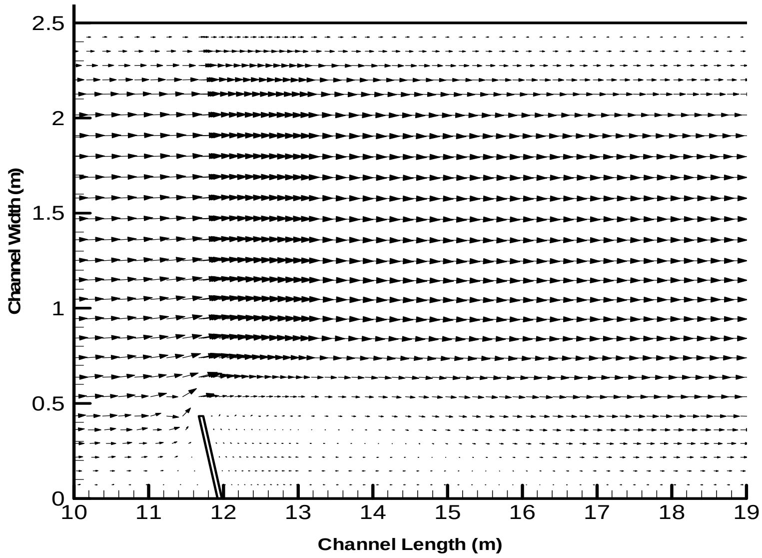


Figure 2 (a): Example of Flow Pattern around Repelling Type Groin

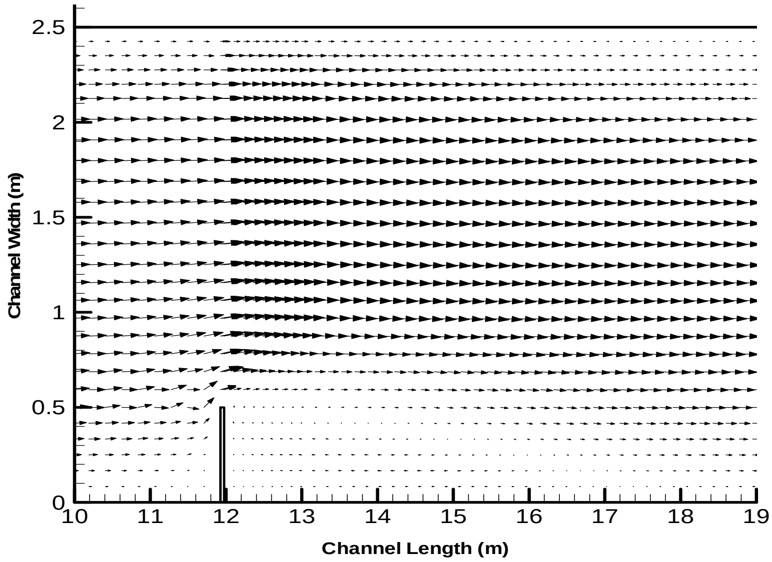


Figure 2 (b): Example of Flow Pattern around Straight Type Groin

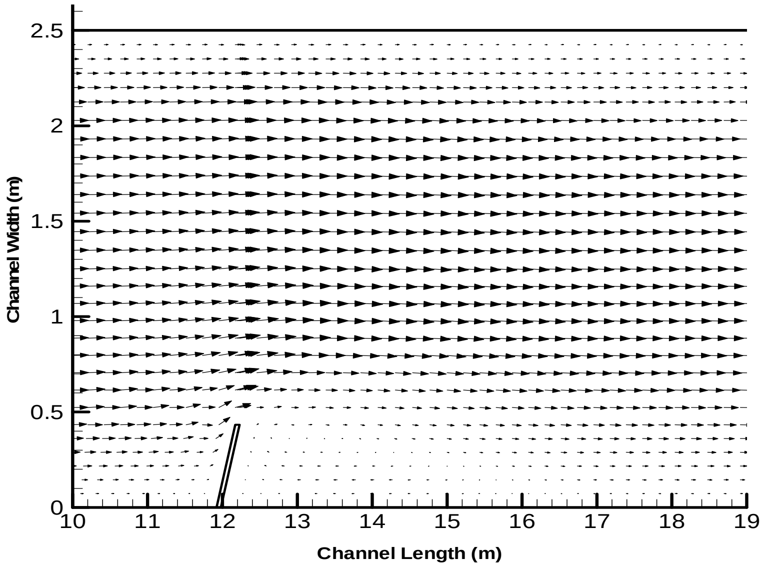


Figure 2 (c): Example of Flow Pattern around Attracting Type Groin

Figure 3 illustrates the different relationships conducted to analyze the measured reattachment length. It can notice that for each angle of orientation, the reattachment length is directly proportional to the contraction ratios. In terms of groin type, it can be concluded that the highest reattachment length is indicated by the perpendicular type. Additionally, there is very clear similarity between repelling and attracting type groins with slight increase in the reattachment length for the repelling type. Increasing the contraction ratio indicates similar trends for all used angles with peak values indicated by the straight spur of angle 90^{o}. At 0.2 contraction ratio the repelling type illustrates coincidence results if compared to attracting type. It can be summarized that reattachment length is very sensitive to groin length and the contraction ratios.

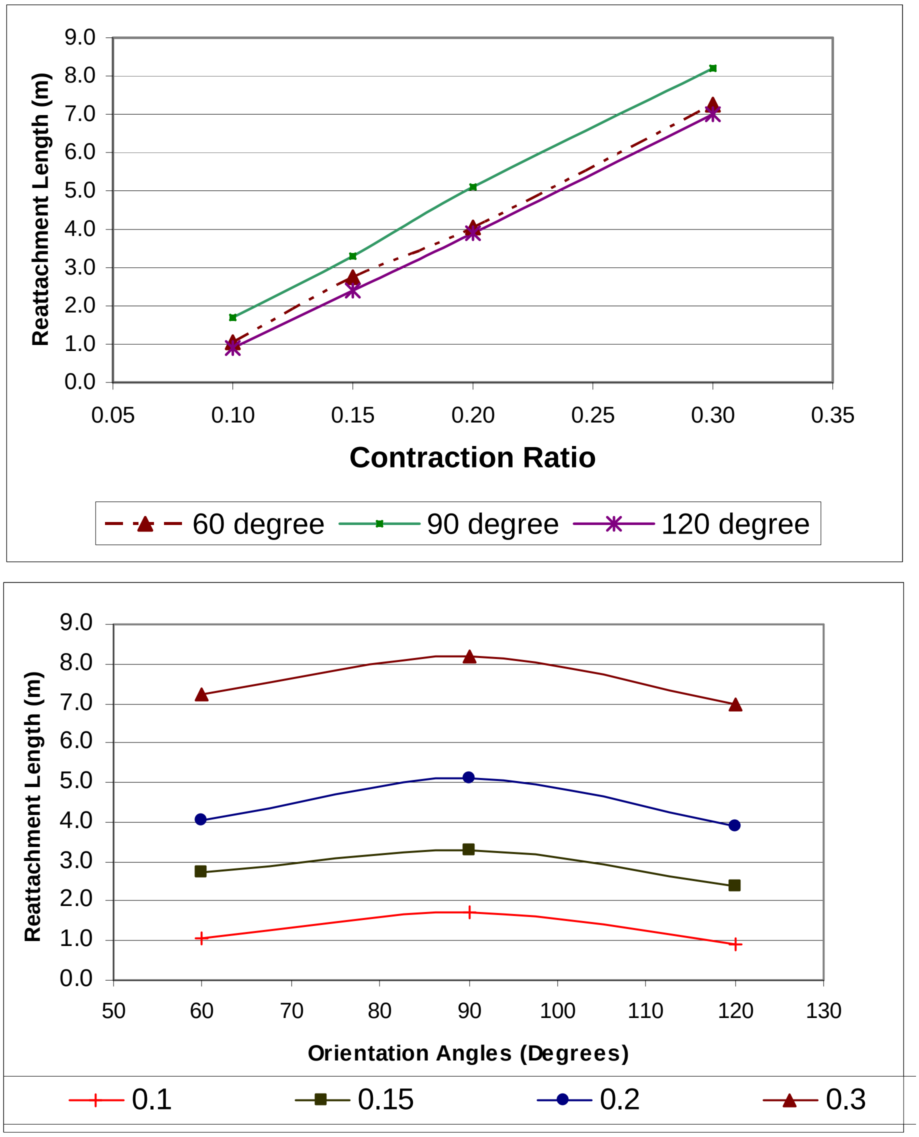


Figure 3: Relationships between Studied Parameters and the Reattachment Length

Expressing the reattachment length as a function of spur length shows that for all tested angles, the reattachment length increased gradually until reached its peak values at angle 90^o then started to decrease gradually until reached its lowest values at angle 120^o. This value is amounted to 6.8L for the straight type groin of contraction ratio of 0.1. Comparing this value to what reported by Francis, et al. in 1968 for similar situation indicates lower value as they stated 11.5L for the same case. This finding is still giving more support that the straight type groins result in highest effective working length in the downstream directions. Therefore, it can be selected for longer regulation requirements.

2. The Separation Point Length

It can be defined as the length of back eddy started upstream groin and ended somewhere upstream or in front of the groin tip. The separation point length is measured by the assist of velocity vector (arrows) on the channel plane view (see figure 2).

Figure 4 illustrates the different relationships conducted to analyze the measurement of the separation point lengths. It is evident that the attracting type groin doesn't give any separation length for the entire contraction ratios. The contraction ratio of 0.1 is too short to influence the separation length. The highest lengths are accomplished by the repelling type groin for the entire contraction ratios. Similar trend is found for the whole contraction ratios in terms of spur type and this trend is inversely proportional to the orientation angle. The percentage of increasing the length with the increased contraction ratio decreased as the angle of orientation increased. If the repelling type angle is used with contraction ratio of 0.3 it can result in longest separation point length. Therefore, this orientation is suitable for protection work. The straight groins of 90 degrees orientation give the lowest length for the separation points. It can be concluded that using the spur dike orientations and contraction ratios should be adjusted according to the length of regulation needed in the channel. If the regulation needed located in the downstream direction, the straight spur can be used. Otherwise, the repelling type can be used. Also, it is preferred to use the repelling groin of 60^o orientation angle with 0.2 contraction ratio for the best upstream and downstream bank protection.

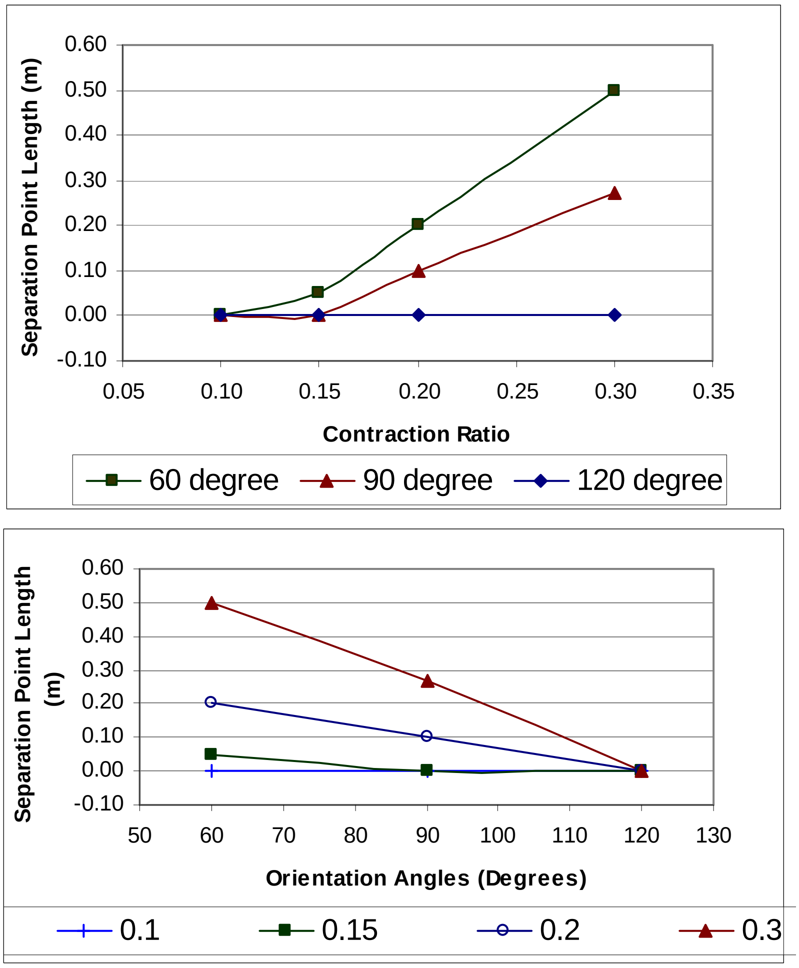


Figure 4: Relationships between Studied Parameters and the Separation Point Length

3. Velocities

No one can deny or neglect the effect of velocity as a hydraulic parameter represents the main function of scouring and deposition actions in open channel. The velocity is measured in forty eight location points, distributed in twelve cross sections one meter horizontal spacing in between as shown in figure 5. Each cross section has four measuring points half meter vertical spacing in between. The points are representing four measuring lines in the longitudinal direction. A summary of velocity values resulted from different study runs is presented in tables 2 and 3. They illustrate the values of maximum and minimum longitudinal and transverse velocities respectively for each run together with their locations related to cross section number and line symbol.

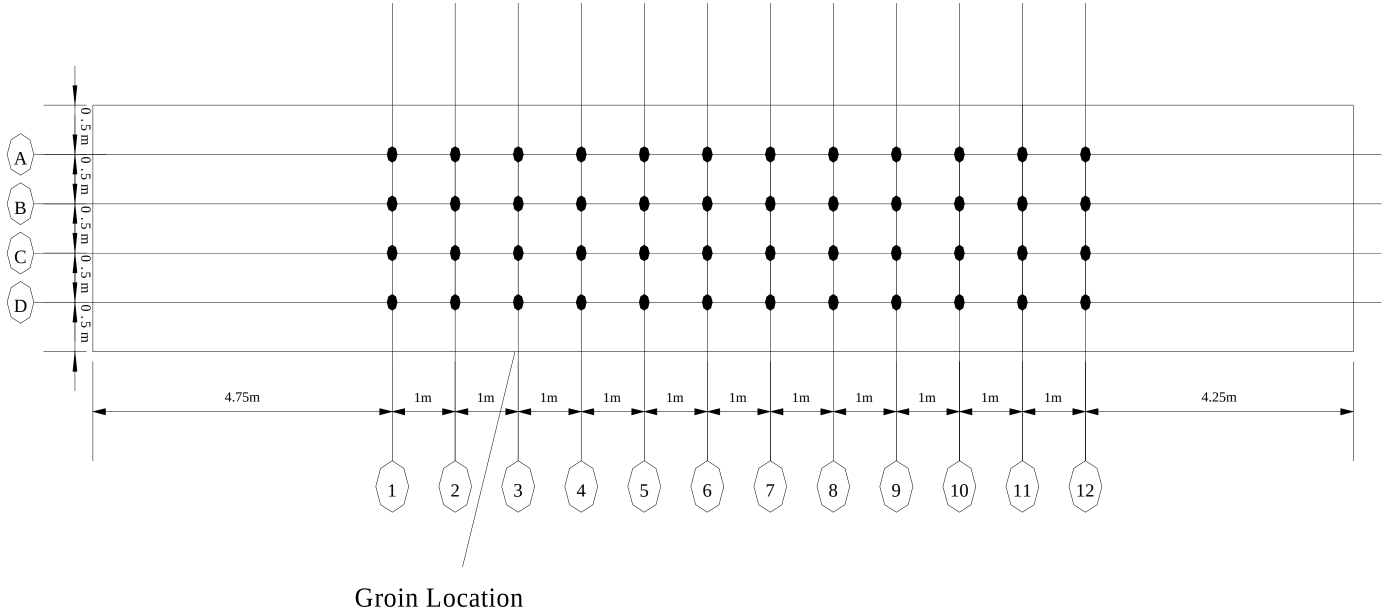


Figure 5: Locations of Velocity Measuring Points

Table 2: Maximum and Minimum Longitudinal Velocities (U) and their Locations

Run Name	L/B	Angle degree	Max. U (m/s)	Location X-Sec.	Location Line	Min. U (m/s)	Location X-Sec.	Location Line
Basic	0.00	-----	0.647	12	B	0.494	12	D
RS_{10}	0.10	60°	0.655	12	B	0.449	10	D
RS_{15}	0.15		0.694	4	C	0.424	4	D
RS_{20}	0.20		0.749	4	C	0.226	4	D
RS_{30}	0.30		0.897	5	B	-0.067	4	D
SN_{10}	0.10	90°	0.662	4	C	0.444	5	D
SN_{15}	0.15		0.726	4	C	0.251	4	D
SN_{20}	0.20		0.778	5	B	0.000	3	D
SN_{30}	0.30		0.955	6	B	-0.101	5	D
AS_{10}	0.10	120°	0.647	9	B	0.507	9	A
AS_{15}	0.15		0.697	4	C	0.438	4	D
AS_{20}	0.20		0.752	4	C	0.244	4	D
AS_{30}	0.30		0.867	6	B	-0.007	6	D

Table 3: Maximum and Minimum Transverse Velocities (V) and their Locations

Run Name	L/B	Angle Degree	Max. V (m/s)	Location X-Sec.	Location Line	Min. V (m/s)	Location X-Sec.	Location Line
Basic	0.00	-----	0.006	1	D	-0.006	1	A
RS_{10}	0.10	60°	0.030	3	D	-0.019	4	D
RS_{15}	0.15		0.057	2	D	-0.034	5	D
RS_{20}	0.20		0.133	2	D	-0.049	6	C
RS_{30}	0.30		0.137	2	C	-0.070	8	C
SN_{10}	0.10	90°	0.098	3	D	-0.025	5	D
SN_{15}	0.15		0.088	3	D	-0.039	6	C
SN_{20}	0.20		0.141	3	C	-0.058	7	C
SN_{30}	0.30		0.318	3	C	-0.083	9	C
AS_{10}	0.10	120°	0.063	3	D	-0.021	4	D
AS_{15}	0.15		0.135	3	D	-0.036	5	D
AS_{20}	0.20		0.185	3	D	-0.052	6	C
AS_{30}	0.30		0.461	3	D	-0.077	8	C

3.1 Longitudinal Velocity

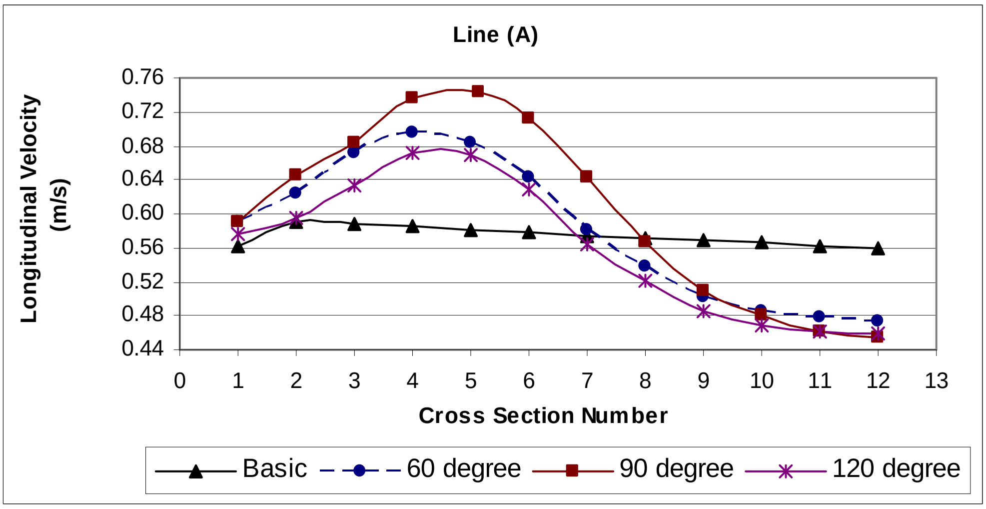
Table 2 shows that the maximum and minimum longitudinal velocity (U_{max}, and U_{min}) occurred at orientation angle of 90^0 (straight groin) with contraction ratio of 0.3. This condition gives velocity amounted to about 1 m/sec near the tip of the groin (at line B). At the same time, it is resulted in lowest velocity at the nearest line D (negative velocity) which confirms highest degree for sediment evacuation in front of the groin to produce scour in bed that extend further to reach close to the opposite bank. It also forms a long weak region of eddy velocity flow which in turn produces a high amount of deposition downstream the groin. For the same contraction ratio, the maximum longitudinal velocity is recorded for angle 90^0 of straight groin. The attracting type gives higher maximum velocity if compared to repelling type for all contraction ratios except for 0.1 and 0.3, the relation is reversed. However, the increase is not significant as it reached about one percent. For minimum longitudinal velocity the situation is reversed as the orientation angle of 90^0 indicates the minimum values for all contraction ratios. It should be noticed that the contraction ratios of 0.1 for all orientation angles indicate no effect for groin implementation for the attracting type as the maximum velocity is equal to the corresponding one of the basic case. It is concluded that all maximum longitudinal velocities occurred in the middle third of the channel (lines B, C) and all minimum longitudinal velocities occurred near the channel sides (lines A, D).

3.2 Transverse Velocity

Table 3 shows that all values of maximum transverse velocity occurred upstream groins, and most of them are near the channel side in vicinity of the groin (at line D). All values of minimum transverse velocity are occurred downstream groin and located in the first third of channel width near the groin (at lines C, D). Increasing the contraction ratio for the same angle is resulted in decreasing the minimum transverse velocities. This finding is applied to maximum transverse velocity for repelling and attracting types. It can be concluded that for channel maintenance and navigation processes it is preferred to use straight or attracting groins with contraction ratio of 0.2 and 0.3, because they are creating higher transverse velocity which is directly considered good indicator for scouring action and spiral motion. Therefore they can be used to maintain the desired depth and prevent deposition in front of pump stations.

3.3 Effects of Orientation Angles on Velocities

To test the effect of orientation angles on flow pattern, the relationships between the velocity and the orientation angles are plotted for the basic case and the simulated cases for different lines. The contraction ratio is kept constant during this investigation in order to restrict the effect on the angle of orientations. The ratio 0.2 is selected as it is considered the most effective influencing ratio as emphasized from the previous analysis. Besides, it is also recommended in many of previous studies (Attia 1996). Figure 6 shows that the entire orientation angles for line A gives the same trend for longitudinal velocities in terms of the relation shape. However the peak values are indicated by the orientation angle of 90°. Orientation angles of 60 and 120 degrees illustrate closer trend with a little bit higher values for the repelling types. This result points out that the attracting groins may be safer for the opposite bank. The maximum longitudinal velocity is located just downstream the groin. Transverse velocity for the same line confirms that all orientation angles have the same trend with some sort of horizontal shift appeared between the different angles. The straight groin still keeps the highest values for the transverse velocity.



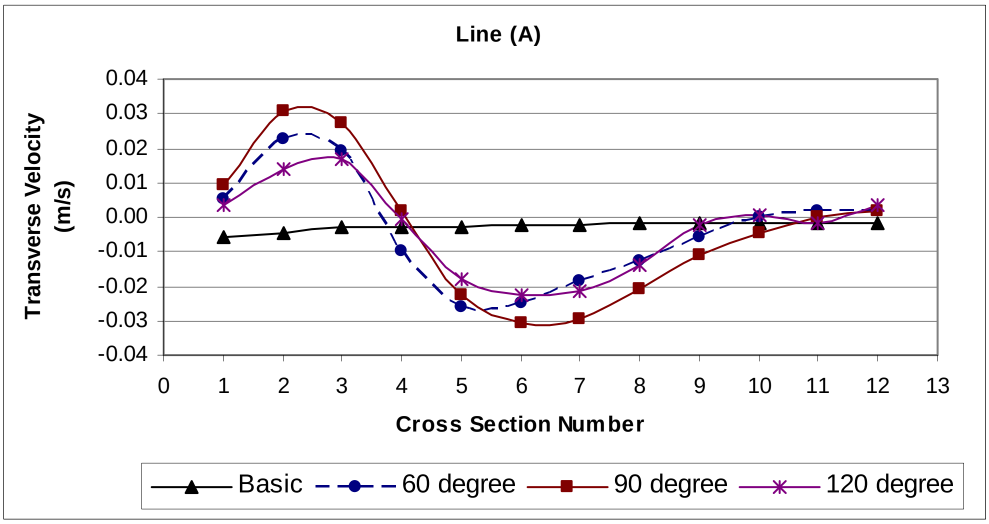


Figure 6: Longitudinal and Transverse Velocities at Line (A) for 0.2 Contraction Ratio and Different Orientation Angles

Monitoring the longitudinal velocity at lines (B and C) in figures 7 and 8, it can say that all tested orientation angles have the same trend and the straight groin of 90° produces the maximum values at all cross sections, and the peak values for tested orientation angles located at one meter downstream groin for both lines. It is also noticed that all tested orientation angles have longitudinal velocities greater than the basic case. For the transverse velocity, it is noticed that all tested orientation angles have alike trend in terms of having about third of the cross sections indicating higher velocity if compared to the base case and about two third of the cross sections (the right hand ones) indicating lower velocity if compared to the base case. Comparing the repelling and attracting groins of 60 and 120 degrees respectively illustrates that the repelling groin has lower values which is contrary to what observed before. In addition, the straight groin continues to have highest and lowest velocity values in terms of the range of variations. It can be concluded that the straight groin of 90° has excellent hydraulic performance in terms of velocity as the action of high velocity can result in increasing the channel depth in the middle third of channel width. Also contracting channel width by any contraction ratio will have the impact of increasing longitudinal velocity.

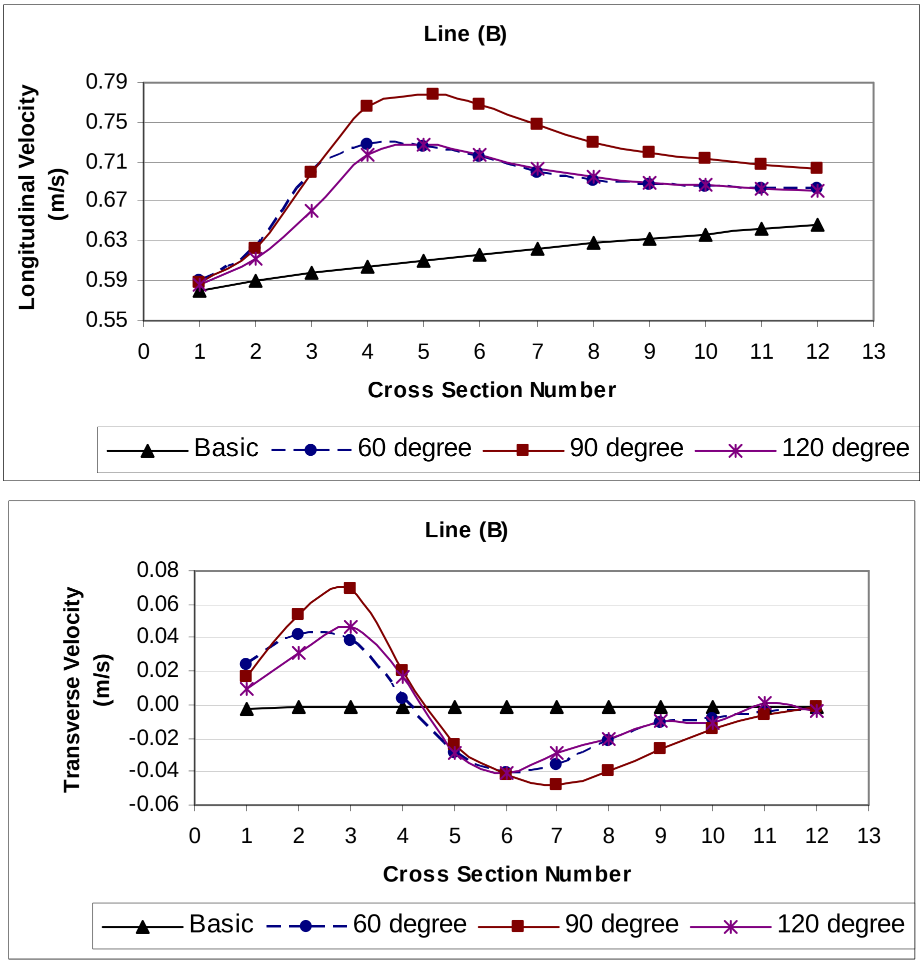
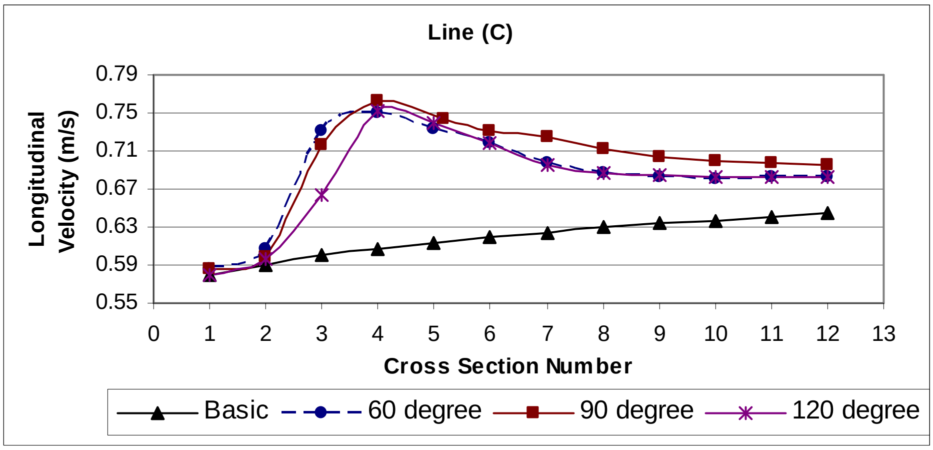


Figure 7: Longitudinal and Transverse Velocities at Line (B) for 0.2 Contraction Ratio and Different Orientation Angles



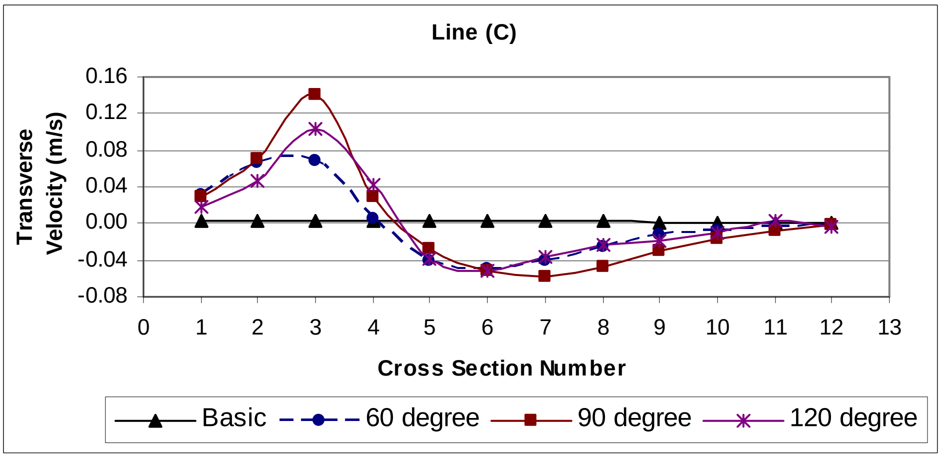
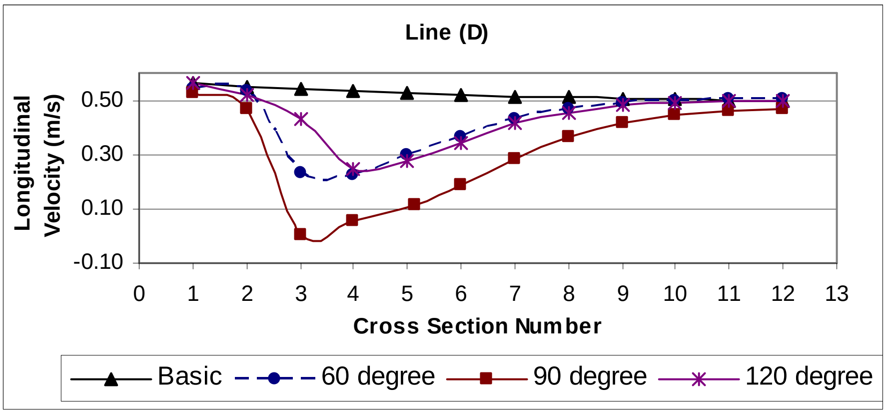


Figure 8: Longitudinal and Transverse Velocities of Line (C) for 0.2 Contraction Ratio and Different Orientation Angles

Figure 9 shows the longitudinal and transverse velocities for line (D) which is considered the nearest line to the groin location. The figure shows that the longitudinal velocities for all tested orientation angles show resemble trend and all indicate lower values if compared to the basic case without groins. The straight groin is the most effective in terms of decreasing the longitudinal velocity followed by repelling types and the attracting type groin comes at the end. The three types demonstrate horizontal budge in terms of the peak value locations.

Transverse velocity for the same line, confirms that both repelling and attracting groins have the same trend which is opposite to the trend of the straight groin. However, the three types unify the trend again downstream the groin location. The attracting groin of angle 120° has the maximum value at groin tip, and the straight groin has the minimum transverse velocity upstream the groin.



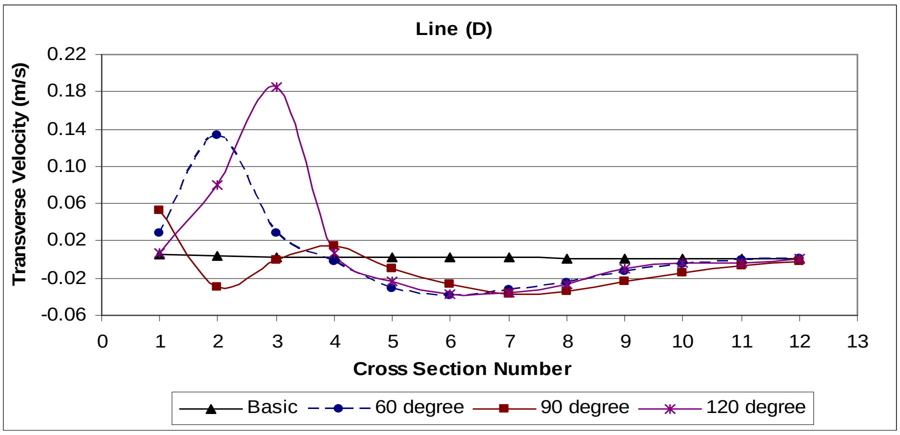


Figure 9: Longitudinal and Transverse Velocities of Line (D) for 0.2 Contraction Ratio and Different Orientation Angles

It can be concluded that there is no significant difference in transverse velocity between repelling and attracting groin of same orientation angle upstream and downstream respectively. Also, the repelling groin of 60° can be used for both upstream and downstream bank protection and the attracting groin of 120° can be used for deposition downstream only and the straight groin of 90° can be used effectively to increase the channel depth for navigation processes.

CONCLUSIONS AND RECOMMENDATIONS

The study cases represent several concluding remarks and points. The conclusions are emphasizing the effect of groin installation on the entire tested parameters. For the reattachment length it can be concluded that for all orientation angles, the contraction ratio of 0.1 is too short to show effective influence on the reattachment length, for all contraction ratios. The straight groin of 90^{o} orientation angle has the longest reattachment length. All contraction ratios of repelling type groins have longer reattachment length than the corresponding angles of attracting groins. The contraction ratios for the same angles confirm proportional relation between the reattachment length and groin length. The attracting groin types don't form any upstream back eddy flow and 0.1 contractions is two short to formulate any separation length and this valid and applied to maximum velocity as well. It is found that the maximum velocity is very close to the corresponding basic case velocity. Angle 60^o with 0.2-contraction ratio is considered the best case for the purposes of bank protection and sedimentation processes for both upstream and downstream. All maximum longitudinal velocities are located in the middle third of the channel and all minimum longitudinal velocities are located near the channel sides. All values of the maximum transverse velocity are located upstream groin and all values of minimum transverse velocity are located downstream groin. As long as the contraction ratio increases for constant angle, the maximum longitudinal velocity increases and the minimum longitudinal velocity decreases. The attracting groin of 120° has the maximum transverse velocity for all tested contraction ratios except for 0.1; the attracting groin of 120° with 0.2 contraction ratio is considered the most suitable groin to protect sedimentation in front of intakes of pump stations. The study recommended that similar study should be conducted using a series of spurs rather than single type. A checklist should be created after simulating more cases to define the suitability of each type to the channel desired improving process.

List of Symbols

The following symbols are used in this paper:
U = Longitudinal surface velocity
V = Transverse surface velocity
P = Mean pressure
ν_e = Kinematics eddy viscosity
F_x = Body force in X direction = g sin θ
F_y = Body force in Y direction = 0.0
g = Gravity acceleration
θ = Average water surface slope
ρ = Fluid density
τ_{fx} = Turbulent frictional stresses in X-direction
τ_{fy} = Turbulent frictional stresses in Y-direction

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