Alignment of a Combined Groin for Flow through a Straight Open Channel

M. Alauddin, M. A. Ullah, M. Alom, M. N. Islam

***Abstract*—**The rivers in Bangladesh are highly unstable having loose boundaries, mild slope of water surface and bed, irregular siltation of huge sediment coming from upstream, among others. The groins are installed in the river bank to deflect the flowing water away from the vulnerable zones. The conventional groins are found to be unstable and ineffective. The combined groin having both impermeable and permeable components in the same structure improves the flow field to function better over others. The main goal of this study is to analyze the hydraulic characteristics induced by the combined groins of different alignments by using a 2D numerical model, iRIC Nays2DH. In this numerical simulation, the K-ε model for turbulence and Cubic Interpolation Pseudo-particle (CIP) method for advective terms are utilized. A particular flow condition is applied in the channel for all sets of groins with different alignments. The simulation results reveal that the combined groins alter the flow patterns considerably, with no significant recirculation of flow in the groin field. The effect of different alignments of groins is found somewhat different. Based on hydraulic features caused by the groins, the combined groin that aligns the permeable component towards slightly downstream performs better over others.

***Keywords*—**Combined groin, alignment, hydraulic characteristics, numerical model.

I. Introduction

BANGLADESH is at the tail end of the delta where the world's three mighty rivers – the Ganges, the Brahmaputra, and the Meghna (GBM) meet together to flow into the Bay of Bengal. The riverbank erosion problem in Bangladesh is a regular phenomenon, and it is losing more than 10000 hectares of land annually due to bank erosion [1]. As the rivers flow over the loose soil formations and become very dynamic and unstable, the development of river training and bank protection works have become urgent. There are various methods being practiced to protect riverbanks from erosion. The groin is one of the popular structures among them. By causing redirection of flow, the groins prevent the banks from the direct impact of flows. It guides the river along the desired course to reduce the concentration of flow at the point of attack [2]. An organized spur protection, stream flow controlling, sidewall scour prevention, and changing flow direction are commonly used to protect the concave bank [3].

Although numerous experimental and computational studies have been carried out to investigate the mean flow parameters around impermeable groins [4]-[7], only a few have looked at permeable situations [8]-[10]. Due to the rapid flow deviation and strong eddies near the groin's tip, an impermeable groin produces a significant scour hole, which is the principal worry about the structural stability [11]-[13], and in permeable case, the flow is not diverted rightly towards the main channel for developing navigation depth, and flow occurs near the bank [10].

The design of a combined groin having both permeable and impermeable components in the same structure has been evident to improve the flow field gradually from the groin head to the bankline, and reduce scour near the groin tip and produce a dead water zone near the bank [10]. However, there are only a few studies on the alignment of the newly developed combined groin. The present study aims at investigating the flow fields induced around the combined groins of different alignments and analyzing them so that an optimum alignment can be identified.

II. Methodology

A pre-and post-processing software, iRIC Nays2DH, is utilized in this study to simulate the flow fields in an open channel with groins. The details of the model setup and working procedures are explained in the following sections.

A. Software Used

The numerical model, iRIC Nays2DH, is a depth-averaged two-dimensional (2D) model for numerical simulation of flow and morpho-dynamics in rivers. Before applying the software in the present case, it is verified by comparing the well-accepted experimental data of Rajaratnam and Nwachukwu who investigated the flow fields and shear stress in a laboratory flume near a groin-like structure [4].

B. Model Verification

Rajaratnam and Nwachukwu [4] conducted the experiments in a straight channel with a groin-like structure placed normal to the side of the channel, i.e., 90° to the direction of flow. The simulations were performed under the same flow conditions. The initial flow velocity and water depth were $U_0 = 0.50$ m/s and $h_w = 0.189$ m, respectively.

Fig. 1 shows a comparison of bed shear stress found from the simulation with that of experiments. The comparison is made through two longitudinal sections at $y/L_g = 0.75$ and $y/L_g = 1.5$. The simulated results are not reflected rightly near the groin in the case of $y/L_g = 0.75$. It might be due to the use of depth-averaged model in accounting for the velocity gradient arising near the groin.

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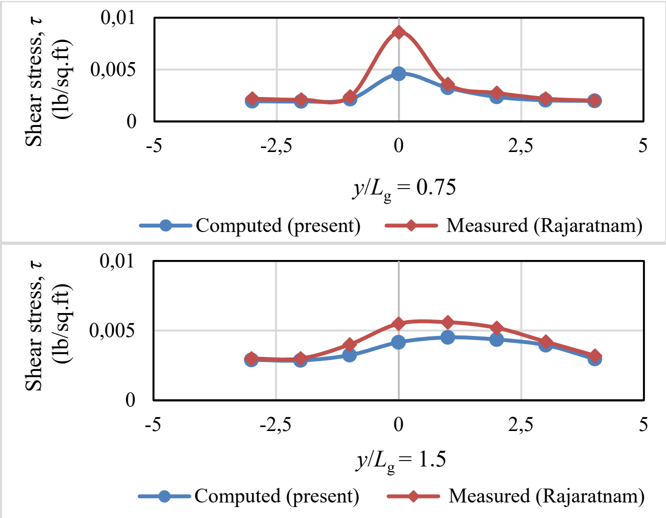

Fig. 1 Comparison of bed shear stress of computed results with the previous study

Fig. 2k shows the comparison of velocity profile of computed results with that of experimental results. Here the simulated results slightly vary from the experimental ones.

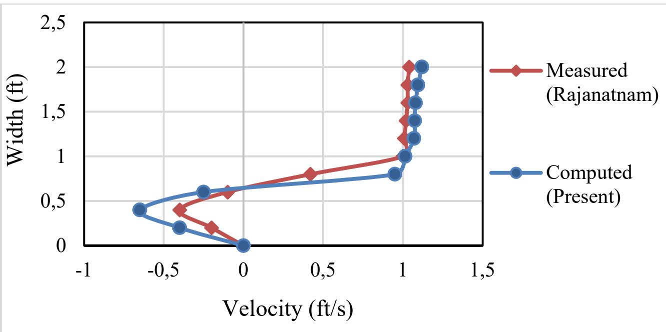

Fig. 2 Comparison of velocity profile with the experimental results

C. Model Setup

A straight channel of laboratory scale with 20.0 m length and 1.5 m width, and four different alignments of combined groins are considered in the present study. The groin models are combined (combination of impermeable and permeable parts) in nature. In each of the combined groin models, first one-third part is made impermeable and placed normal to the bankline, and the rest part is permeable and is aligned at different angles: 90°, 67.5°, 45°, and 22.5° with the flow. These are denoted hereafter as M-1, M-2, M-3, and M-4, respectively. The details of channel and groin models are presented in Table I.

A certain flow condition with a constant discharge of 0.03 m^3/s is maintained for all the groin cases. A uniform depth of flow of 0.1 m is considered in the channel for simulation of flow with groins of different alignments.

D. Simulation Procedure

The numerical simulations for flow the channel with four different sets of groin conditions are done with the numerical model as follows.

TABLE I
CHANNEL AND GROIN PARAMETERS

Channel	
Length of the channel	20.0 m
Width of the channel	1.5 m
Depth of the channel	1.0 m
Groin	
Projected length of each groin, L_g	0.45 m
Impermeable portion	0.15 m
Permeable portion (projected)	0.30 m
Number of groins in a series	6
Position of the first groin from u/s	8.0 m
c/c distance between groins, S (= $3L_g$)	1.35 m

First, the channel as per the dimension and calculation grid are created. In this calculation grid, the obstacle cells are defined at some particular locations to consider these as groins maintaining the groin parameters mentioned in Table I. After that, the calculation condition is defined and applied to the model for computation of flow fields. A constant discharge at upstream and a constant depth with zero velocity gradients at downstream are given as boundary conditions. The simulations are done for all the cases, and the calculated results are extracted for further analysis. A nonlinear K-ε model is used to predict the turbulent flow field by capturing the anisotropic turbulence. The CIP method is used for advection terms. The basic equations are discretized as fully explicit forms and are solved successively with the time increment step by step. It is solved using an iterative procedure at each time step.

III. SIMULATION RESULTS

A. Re-attachment Length

Fig. 3 shows the streamlines induced due to the groins for all the cases – 90°, 67.5°, 45°, and 22.5°. The flow passes through the permeable portion of the combined groins so that the strong vortex and flow recirculation is reduced near the groin head and at its downstream. We can see that the re-attachment length increases with the increase of the angle of alignment of the groins. In the case of groins placed at an angle of 90° and 67.5° with the flow, the flow is coming back in their downstream area after a certain distance. For the cases of smaller angles, i.e., 22.5° and 45° with the flow, the flow diversion is less than in the cases of larger angles.

The reattachment length for different alignments of the groins is shown in Table II. Because of the permeable component of the combined groin, the reattachment of flow does not occur immediately downstream area as impermeable groins do. Here, the reattachment is considered for the flow after the impermeable part from the bankline.

TABLE II
COMPARISON OF RE-ATTACHMENT LENGTH

Angle of alignment	Re-attachment length
90°	3.52
67.5°	3.24
45°	2.06
22.5°	1.24

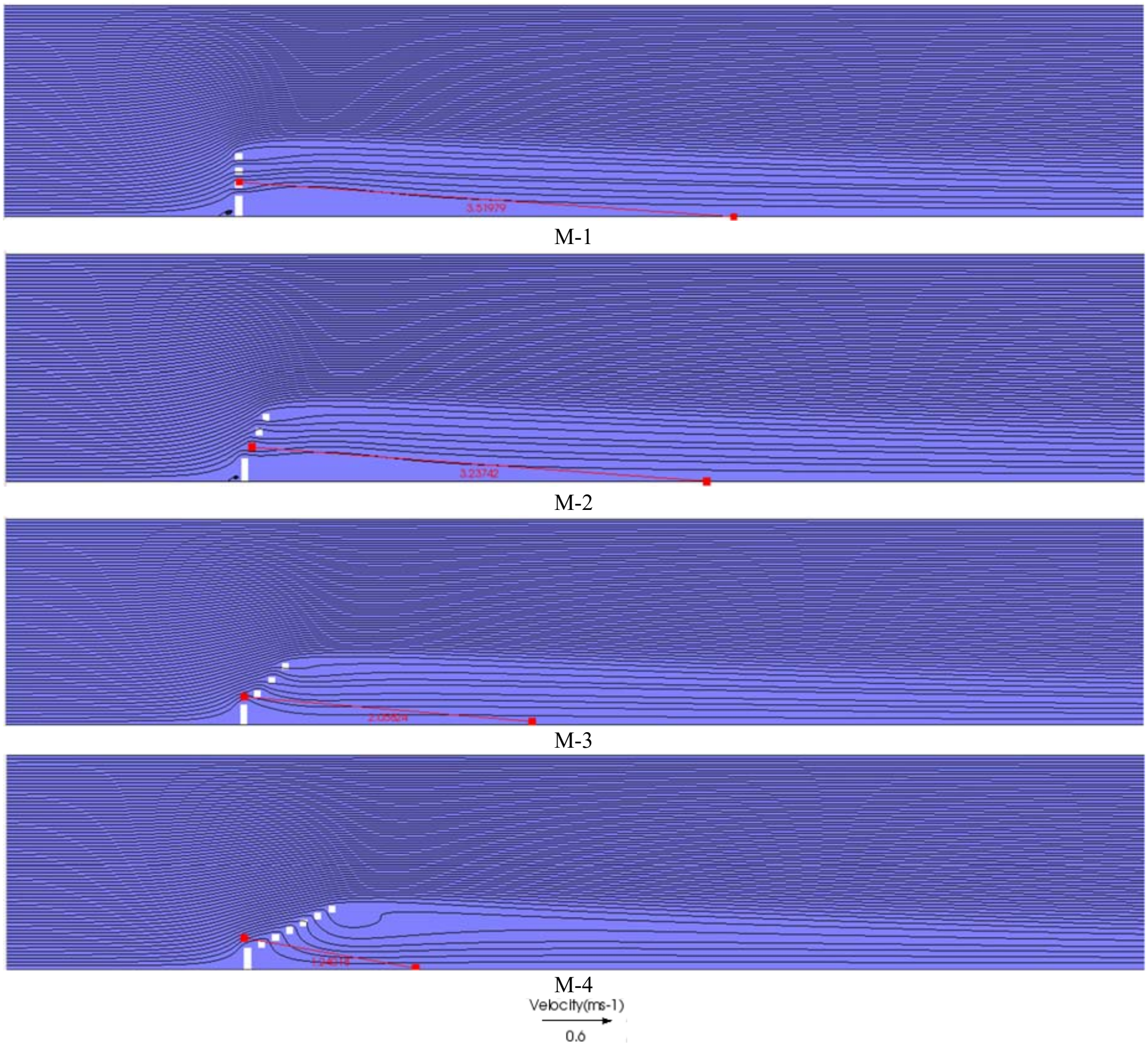

Fig. 3 Simulated streamlines around the single groin

B. Comparison of Simulated Flow Fields

Fig. 4 shows the distribution of longitudinal flow velocities along the transverse direction for different alignments of combined groins. For all the cases, the model is found to reproduce the general flow features of the flow field around the groins successfully. From the simulated results as in the figure, it can be seen that at the upstream area of the groin zone, the flow is uniform and hence the flow vectors are parallel to the bankline. However, when the flow approaches towards the groin, the flow is deviated towards the left bank being obstructed by the groins. The velocity vectors through the permeable part in cases of 90^o and 67.5^o can be recognized much higher than those for the other two cases. However, the flow velocity near the bankline, at downstream of the impermeable part of the combined groins is found much less for the cases of larger angles, 90^o and 67.5^o, and is recognized relatively higher for the smaller angled groins, 45^o and 22.5^o. The flow passes through the permeable portion and takes a turn towards the right bank. Therefore, near bank flow vectors can be recognized for the groins of smaller angles. However, a slight inclination of the permeable part of the groin with the flow, say 67.5^o can facilitate debris flow when it is significant in the river.

When the groins are placed in a series, similar results are observed except the redistribution of velocity fields occurs in the groin embayments (Fig. 5). In this case, the near-bank distribution of velocity has been modified. The increasing trend of velocity vectors at downstream near the bankline is discontinued due to the presence of subsequent groins. Also, the magnitude of velocity vectors after the groins is observed less compared to the case of a single groin. This can also be seen that the strength of flow current at the first groin field is less than that of single groin, and this strength is further reduced in the subsequent groin fields for all the groin cases. Consequently, the flow velocity after the groin head is increased in the downstream groins.

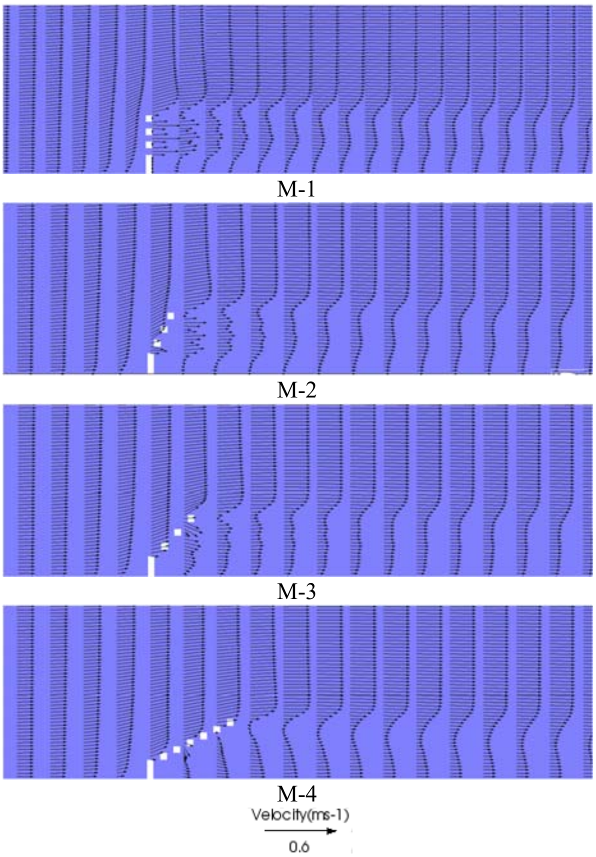

Fig. 4 Simulated velocity profiles around a single groin for four different alignments

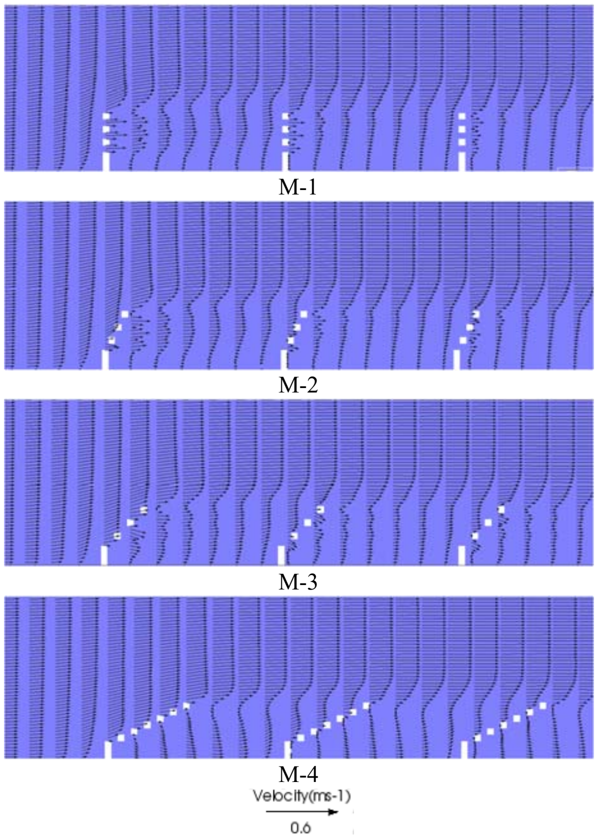

Fig. 5 Simulated velocity profiles around the groins of different alignments in a series

The comparison of transverse distribution of longitudinal velocity for four different alignments is also delineated in Fig. 6. The velocity vectors through the permeable part for 90° case are higher than the other cases, and it can be recognized minimum for 22.5° case, although the direction of the vectors is observed towards bankline (Fig. 4). However, a relatively smaller value of flow vectors near the groin head can be recognized for the case of smaller angles, 45°, and 22.5°, and the main flow passes near the groin head. For the case of larger angles, 90°, and 67.5°, higher values of velocity vectors can be observed to pass a little farther.

It can be mentioned here that the permeable part of the groins with smaller angles will require a larger length to project the same portion of the channel width. Thus, these will cost more than the others. The magnitudes of maximum flow velocity vectors after the groin tip and in the groin field for different alignments are summarized in Table III.

Although, the flow velocity through the voids of the permeable part can be seen higher for all the groins with relatively lower values for the groins of smaller angle, the average flow velocity in the groin field is much less than the average flow velocity of the channel (Table III). The average velocity of flow in the groin field is relatively higher for larger angle, and conversely the velocity after the groin head is higher for smaller angle.

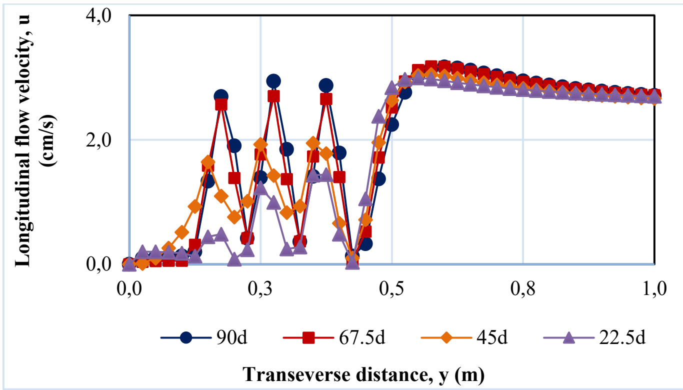

Fig. 6 Comparison of the values of simulated velocity vectors at immediate downstream of the first groin

TABLE III
FLOW VELOCITY NEAR GROIN FOR DIFFERENT ALIGNMENTS

Groin alignment	Avg. long. velocity in groin field (m/sec)	Max. long. velocity after groin tip (m/sec)	Avg. flow velocity in channel (m/sec)	Decrease in velocity in groin field (%)	Increase in velocity after groin tip (%)
90°	0.13	0.35	0.20	35	75
67.5°	0.12	0.38		40	90
45°	0.10	0.41		50	105
22.5°	0.09	0.43		55	115

IV. Conclusion

This study has given detailed information regarding the flow fields, velocity profiles, re-attachment length, and recirculation zone due to the interaction of groins of combined nature with different alignments in an open channel. From the numerical simulation, the general flow features around a groin are reproduced successfully. From the analysis of flow fields found from the simulation, the following conclusions are drawn.

a) The flow velocity is found relatively higher in the groin field for the groins with permeable part of 90° and 67.5° with the flow, and this is relatively less for the cases of 45° and 22.5° permeable components;
b) The flow vectors can be recognized to pass through the permeable part towards the bank for the cases of 45° and 22.5° permeable parts, and near bank velocity vectors are recognized; besides, their higher lengths will cost more than the other two;
c) The reattachment length increases with the increase of the angle of the permeable part; thus, the groins can be spaced high for the groins with higher angle.

Therefore, model M-2 which has a permeable part with an angle 67.5° with the flow can be recognized better as this could guide the flow efficiently when debris flow present in the river and this does not direct the flow vectors towards the bank through the permeable part. This study will help to optimize the functions of combined groins. However, the study can be extended to investigate the sediment transport, shear stress, and bed deformation due to groins of combined nature.

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