Article no. 16

THE CIVIL ENGINEERING JOURNAL 1-2022

EFFECT OF VARIOUS GROINS IN SERIES ON CHANNEL BED MORPHOLOGY: AN EXPERIMENTAL INVESTIGATION

Mohammed Alauddin, Rokshana Pervin and Md. Zakir Hasan

Department of Civil Engineering, Dhaka University of Engineering & Technology, Gazipur, Bangladesh, mauddin@duet.ac.bd

ABSTRACT

The alluvial rivers of Bangladesh being unstable keep changing their main course, bank lines, and so on. Groins are extensively used worldwide for shore protection from erosion, river navigation, and beach reclamation among many others. Improving the performance of groins is a crucial issue around the glove. Experimental investigations under clear water scour conditions have been carried out in this research to compare the performance of different groins in order to find out the suitable design for a groin. From the experimental runs, it is revealed that the groin models having different configurations behave differently. In the case of a solid I-shaped groin, a huge scour near the groin head and irregular bed pattern develops in the channel bed while L-head and hockey-shaped groins improve the channel response a bit leading to decreased scour. Moreover, the hockey-shaped groin attracts the flow, and thus requires a close groin installation. The scour hole for a combined groin is relatively very small. As the scour endangers the stability of the groin structure, it turns out to be the most suitable one.

KEYWORDS

Bank erosion, Combined groin, Deposition, Groin, Scour, Shore protection

INTRODUCTION

Most of the lowland rivers pass through alluvium plain which is highly susceptible to erosion and deposition because of its very dynamic nature. Various river training structures are being practiced in the rivers to stabilize the river channels, among which groins are extensively used all over the world [1] to [3]. These are artificial flow deflecting structures that are employed directly or indirectly in river engineering to protect the bank from erosion, to improve the navigability of channels, and to serve many additional purposes like land reclamation, an increase of aquatic habitats, and so on. These functions are provided by means of groins both in the river and coastal engineering [4]. The groin mainly diverts the direction of flow so that the flow velocity is significantly reduced in the groin area, and thereby bank erosion is minimized. Several parameters are needed to be considered in the installation of groins including groin length, groin angle towards the approaching flow, permeable or impermeable states, submerged or non-submerged states, spacing, and number of groins, among others [5].

The construction of groin structures that impede flow causes significant changes in flow patterns, sediment transport, and bed topography. Thus, it involves in the development of strong vortices near the groin head leading to scouring around the groin. Numerous experimental and numerical studies have been done so far to examine the flow patterns induced in the vicinity of groins, morphological changes that result from the interaction among groins, and so on. Due to inherent varieties associated with the configuration of groins, flow separation and recirculating length would be greatly different posing challenges for the applications of numerical models [6]. From an investigation on the effects of groins, it was found that the increase in discharge caused an increase in the dimension of the scouring hole around the groin and an increase in the extent and thickness of sedimentation downstream of the groin [7]. Also, maximum scour depth shows an increasing trend with increasing Froude number. Through an investigation of scour-deposition mechanism around a series of spur dikes, it was concluded that the aspect ratio was a significant parameter that affected bed topography and flow behavior close to the structures [8]. A study on the flow field and bed topography being induced because of the interaction of groins of various alignments revealed that the groin modified with downstream aligned part performed better in improving navigation depth and bank protection as well [9]. From a comparison of the effect of a triangular groin with a rectangular one, it was concluded that the maximum scour hole depth and volume were smaller in the triangular spur dikes than in their rectangular counterparts [10]. An investigation on the effects of flow around a pile-group groin demonstrated that the staggered type groin functioned better compared to the in-line type in reducing flow towards the bank and turbulence around the structures [11].

The I-shaped impermeable groins are usually practiced to protect the bank from erosion. However, from this structure, the flow deviates highly from the river bank and a horizontal vortex in the recirculation zone forms that results in the local scour [12]-[15]. Thus, they cannot sustain long in many situations and cannot function properly. The L-head and hockey-shaped impermeable groins could minimize flow separation and the strong vortices near the groin tip which are responsible for a huge local scour. Although the permeable groins can allow flow through the structure which could eliminate the strong return currents, fully permeable groins cannot properly deflect the flow. Also, the flow near the bank occurs which could affect the bank if it is associated with the oblique flow. A combined groin (a combination of both permeable and impermeable parts in a groin structure) with an impermeable part near the bank could improve the flow field through a gradual deceleration of flow velocity towards the bank and develops a stagnant flow region near the bank line and thereby minimizes scour near groins [16]. In the present research, attempts are made to explore the effects of groin shape and groin permeability through experimental investigations. Four different groin models: I-shaped, L-head, hockey-shaped impermeable groins, and a combined groin are considered in this study. Thus, a suitable design of groins could be established whose performance would be better compared to others.

METHODS

Experimental setup

In this study, laboratory experiments are conducted in a straight concrete channel of dimension: 22.50 m x 1.52 m x 1.15 m with a sand bed of 0.30 m (Figure 1). Four sets of different groin models such as I-shaped (M-1), L-shape (M-2), hockey-shaped (M-3) impermeable, and a combined groin (M-4) containing six numbers in each set to install the groins in series are considered for assessing their performance. Solid groin models – I-shaped, L-shaped, and hockey-shaped groins are made with wooden planks of 2.5 cm thickness; the other combined groin is made of wooden plank for the impermeable part with 5.0 mm diameter steel sticks at different spacings of 7.0 cm@1.0 cm c/c and 11.0 cm @1.5 cm c/c for the permeable portion.

.

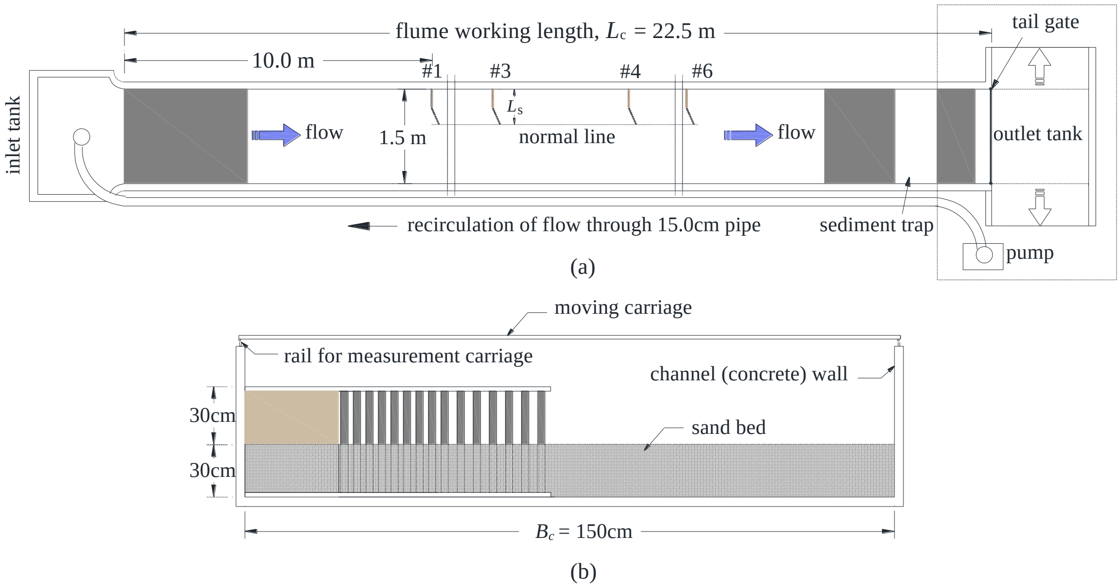

Fig. 1 – Laboratory channel: (a) Plan view; (b) Cross-section

The L-shaped and hockey-shaped solid groins are expected to improve the flow pattern compared to I-shape solid groin model. The part of a combined groin model near the main channel is made permeable to allow the flow through the structure to minimize the strong vortices near the groin head and to develop gradual deceleration of flow velocity towards the bank. The groin models used in the study are shown below (Figure 2).

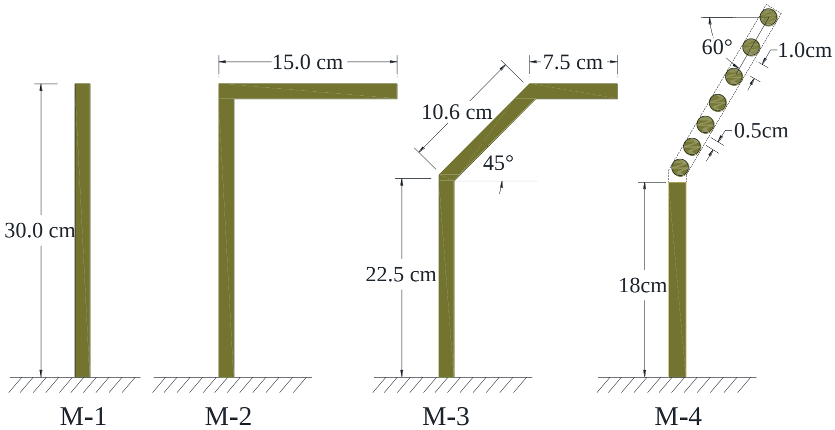

Fig. 2 – Groin models

The channel bed is prepared with fine sand with a thickness of about 30.0 cm. First, the sand is washed to remove silt and clay from this, and then this is placed on the channel bed and is levelled with a wooden scraper. A certain flow condition is considered in the study, and it was maintained the same for all the cases. The experiments are conducted under clear-water scour conditions. This scour occurs when the bed materials are not in motion before the control section. This condition is initiated in the channel when the shear stress being induced by the water flow does not exceed the critical shear stress of the bed material, and this is established after some trials. The depth of flow in the channel with the groins is kept constant. It is kept around 10.0 cm in the channel. This depth is controlled and adjusted by the tailgate set at the end of the channel. The discharge is measured by the flowmeter (0.03 m3/s) and the depth of flow in the channel is maintained the same for all the cases in the study.

DOI 10.14311/CEJ.2022.01.0016

Four different sets of groin models with six models in each set are utilized in the study and their effects on the channel being examined. The first model of each set is installed at a distance of 10.0 m from the upstream end, and the rest five models are placed at an interval of twice their length. The channel bed is carefully levelled using a wooden scraper to ensure surface regularities along the channel bed in order to consider this as the initial condition. The models are embedded in the sand bed so that 30.0 cm of its height goes under the sand bed.

Working procedure

In the beginning, the flow of water is run at a very low speed and allowed to enter the main channel slowly only to wet the sand bed, and after draining, the bed level is measured with a point gauge to find the initial bed level. Next, the flow is allowed to enter the channel gradually and the flow is increased by a check valve mounted in the discharge pipe to adjust the required flow. For each experiment, the flow runs up to 2.0 hours, till the depth of the scour hole near the first model does not increase, i.e., the equilibrium state is reached. Then, the flow is stopped and the channel bed is drained out before measuring the elevations of the final bed.

The effects of four different sets of groin models on the channel bed are evaluated based on scour-deposition patterns. In order to know the scour and deposition in the channel bed, the bed levels are measured before and after each experimental run with a point gauge. The bed level before each of the experimental runs, i.e., the initial bed level is measured at 10.0 cm grid points along both transverse and longitudinal directions in the groin area. However, after the experiments, this is measured at 5.0 cm intervals in the longitudinal direction and 2.5 cm intervals in the transverse direction to get the uneven condition of the surface well. In almost all the cases, the scour occurs at the end of the groin head in the impermeable groin cases, and at the end of the impermeable part in the case of a combined groin, where the magnitude of scouring varies with the different models. The maximum deposition is, however, observed immediately in the downstream of the scour hole in these experiments under clear water-scour conditions. Besides, erosion occurs in the main channel in different ways due to the diverted flow from the models. The channel showing the bed with four different groin sets before and after the experimental runs is shown in Figure 3.

(a) M-1

Fig. 3 – Initial bed (left) and final bed (right) with four different groin models

(b) M-2

(c) M-3

(d) M-4

Fig. 3 – Initial bed (left) and final bed (right) with four different groin models: (a) M-1, (b) M-2, (3) M-3, (4) M-4

DATA ANALYSIS

The bed level data of both the initial bed and final bed for each set of groin models are taken before and after the experimental runs. The change in bed level (Δz) is calculated to determine the effect of groins on channel bed, and bed profiles along transverse and longitudinal directions are determined. These analyses have been explained in the following sections.

Changes in bed topography

From the measured data of initial and final bed elevations, variation in the bed level due to the groins is calculated by taking their difference. The depth of scour near the groin head, and average deposition in the groin field are obtained from the bed level variation. Also, the changes in bed level due to the groins are recognized in the channel after the groin field which vary from one model to another. The bed topographies due to the various groins are shown in the following figures (Figures 4-7).

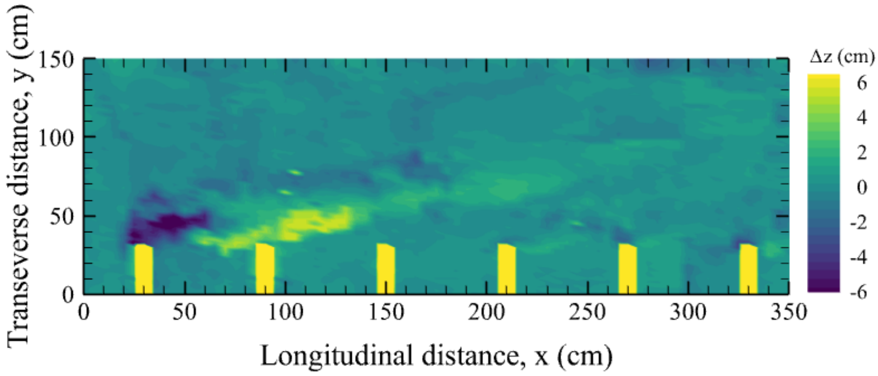

Fig. 4 – Model M-1 induced bed topography

The area of scour hole near the first groin model is more pronounced in the case of Model M-1 (Figure 4), and this is followed by siltation in the immediate downstream area. The sediments from the first scour hole have mainly accumulated here and cannot be transported downstream under the present flow conditions. However, the local scour is not visible in the next four groins downstream. But the scour near the groin is observed in the last groin as the flow is back on the same side where the groins are installed. This solid groin gives obstruction to flow fully causing a huge deviation of the flow that leads to flow separation and formation of strong eddies. Because the size and depth of scour hole near the first groin head are much higher. Also, the effect of the flow across the channel is wider and it is not even. The flow being obstructed by the solid groin does not follow a certain direction, and erosion in the channel bed is observed irregularly.

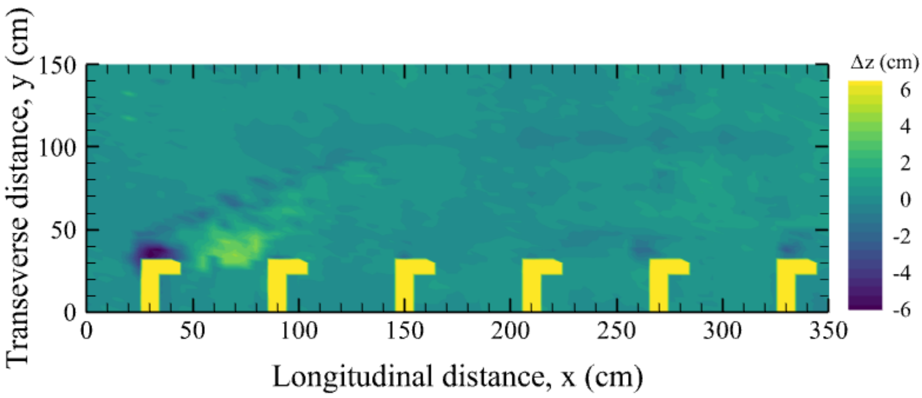

Fig. 5 – Model M-2 induced bed topography

The area of the scour hole in the L-head groin (Figure 5) is not as large as that is found in the solid straight groin. However, in this case, also more scours occur near the first groin compared to the downstream ones. Silt has accumulated in the downstream area of the scour hole in proportion to the first scour hole. The eroded area in the channel bed is influenced by the groins regular. Although the effect of this groin has gone quite far to the other side, it is still regular. As the water returns to the groin side, a little scour can be found near the groin of the downstream end which may be due to the reflected flow from the other bank.

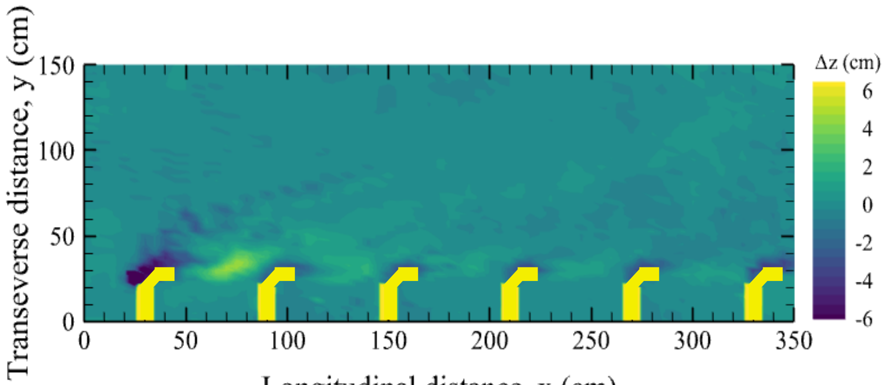

Fig. 6 – Model M-3 induced bed topography

In the case of Model M-3 (Figure 6), the hole in the first object covers a little more space than in the second. Due to its shape in the head, this groin does not deflect the flow too far. As a result, there are holes near every groin models. In this case, the main flow path passes close to the groin area. These groins do not make irregular paths, and the effect of the flow on the other side of the channel is not found at all.

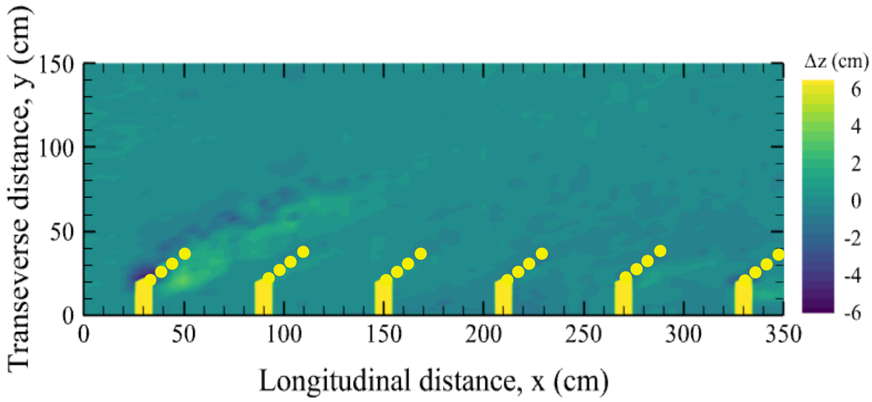

Fig. 7 – Model M-4 induced bed topography

In the case of the combined groin M-4 (Figure 7), since water can pass through the structure on the flow side, the flow is not obstructed much. As a result, the flow separation or the eddies is reduced, and scour in both area and depth is very few. When it flows through the first groin, its speed decreases and goes downstream with a low speed resulting in decreased ability to form scour in the downstream groins. So there are no scour holes near the downstream groins. There is no effect of these groins on the other side of the channel and no significant change is observed in the bed in other areas. In this case, the effect of the flow is greatly reduced.

Erosion-deposition pattern

To identify the changes in bed level, the bed profiles are taken along various sections in both longitudinal and transverse directions. Finally, the profiles found from different groin models have been compared to evaluate the effects of groin models having different shapes and configurations. The changes in bed level across the channel width at the location of the first groin are presented in the following figure (Figure 8). From the profile, bed level changes (Figure 8) are evident across the channel width for the first groin and the variation of the profiles due to the various groin models can be recognized. The highest effect can be noticed for the solid straight groin (M-1), where the local scour depth is observed that be maximum and then a relatively lesser effect can be observed in the case of the L-head groin (M-2). The scouring effect for the other two groin models (M-2 and M-3) has decreased significantly. Alignment and permeability could be attributed to the improved response in these cases. For model M-1, the scour-prone zone can be recognized from 30.0 cm (groin tip) to 70.0 cm along the transverse direction, and 10.0 cm upstream of the groin section to 35.0 cm downstream (Figure 4). For model M-2, the scour-prone zone is found from 30.0 cm (groin tip) to 47.5 cm in the transverse direction, and 7.5 cm upstream to 12.5 cm downstream from the groin location (Figure 5). However, for model M-3, this area can be seen between 30.0 cm to 40.0 cm in the transverse direction and 10.0 cm upstream to 17.5 cm downstream as affected in the inclined part (Figure 6), and for model M-4, this area is between 22.5 cm to 37.5 cm from the channel side, and 5.0 cm upstream to 10.0 cm downstream from the groin position (Figure 8).

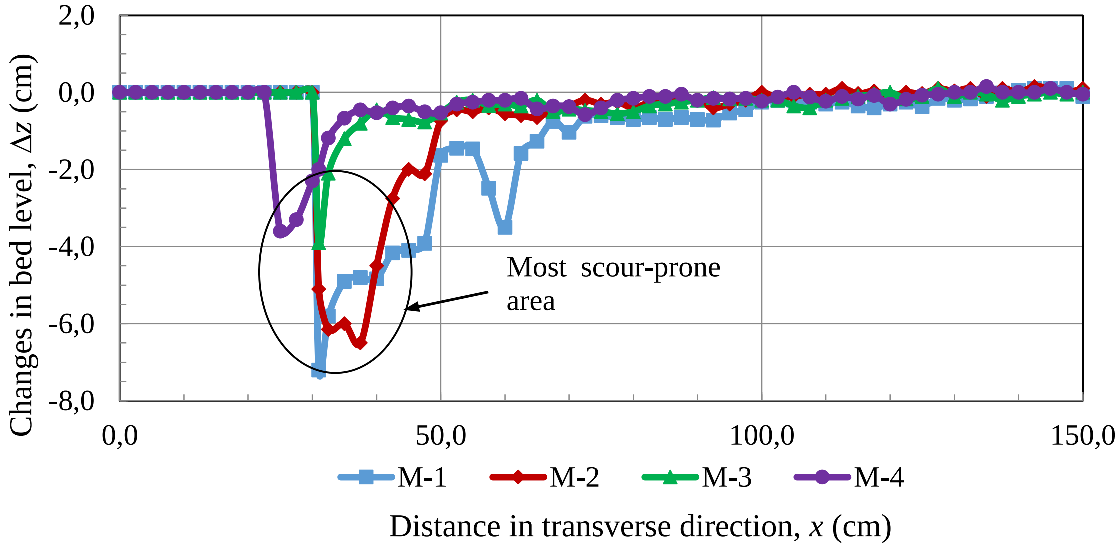

Fig. 8 – Bed level changes along the cross-section at the first groin

The maximum depth of scouring formed near the first groin-head due to various groin models is shown in the following figure (Figure 9).

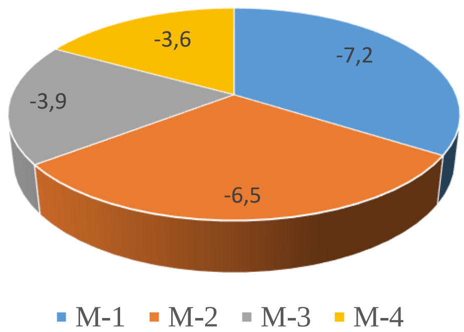

Fig. 9 – Maximum depth of scour due to various groin models

From the figure shown above, it can be found that the maximum value of scouring occurs for model M-1 and the minimum for model M-4. These values are 7.2 cm and 3.6 cm, respectively, i.e., the scour depth for the combined groin is reduced by 50%. The depth of the scour hole for M-2 is very close to that of M-1. But in the case of M-3, it is a bit more than M-4. The maximum scour depth for groin M-2 is 6.5 cm, and it is 3.9 cm for groin M-3. Also, the average depth of scour in the scour area is calculated for all the groin models. These values are 1.35 cm, 0.70 cm, 0.41cm, and 0.40 cm for the groin models of M-1, M-2, M-3, and M-4, respectively.

An average deposition in the groin field developed by various groin models is presented in the following figure (Figure 10).

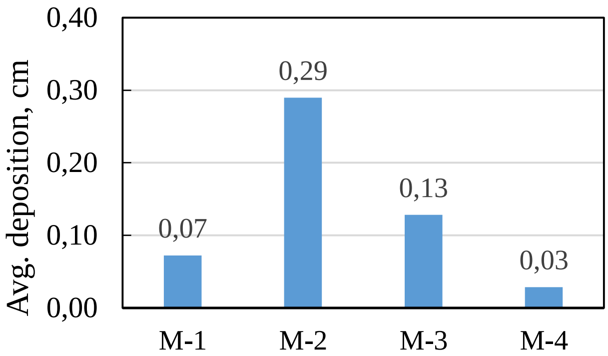

Fig. 10 – Average deposition in the groin field due to various groins

From the Figure shown above (Figure 10), the average deposition that occurs the groin field for different groin models can be observed differently. This is found maximum for the groin model M-2 and minimum is in case of M-4, and it is almost 10 times more than that of model M-4. Deposition from models M-1, M-2, M-3 and M-4 is found 0.07 cm, 0.29 cm, 0.13 cm and 0.03 cm, respectively. It is worth mentioning here that the experiments are conducted under clear water scour conditions, and even in the control area, the presence of suspended sediments is not significant. As a result, the deposition in the groin field does not truly reflect the natural flow environment as prevalent in the lowland river where the siltation of fine suspended sediment particles occurs in the slow flow zone of the groin field.

Discussions

From the figures presented above, the effect of the groin models on the channel bed is quite evident. Among these, the effect of the conventionally used groins, the solid straight one (M-1) is quite irregular. For large and irregular effects, there is an effect on a distant and some important installation, and no good channels are generated in a certain direction which could not be a good arrangement for navigation either. The scour near the other bank occurs, which might not be expected in many cases. The returned and oblique flow on the bank can be more dangerous as observed in the Jamuna River [17]. Also, for larger holes nearby, its stability can be assumed to be lower. Compared to Model M-1, the effect of the flow in the M-2 has been much more regular or even. Its stability is expected to be higher with a comparatively less scour depth. By conducting the flow through the space close to the groin area, a suitable channel for navigation can be found with Model M-3. However, since the flow returns quickly with a short distance, the distance from one of the continuously placed groins to the other does not show much. As a result, the return flow can come back resulting in an attack on the bank of the river or channel for which the groins have been provided.

In the combined groin (M-4), the flow does not come back towards the bank or side where the groins are placed leading to less scour in the vicinity. However, the concentration of flow in a certain direction may not be so good. Pointing to the permeable end of the groin towards downstream may point the flow somewhat in a certain direction, although this has not been observed under the low flow conditions in the present experiments. However, this arrangement can reduce the problem of debris flow to minimize the force from the debris and also can allow debris to flow along the downstream direction. In this case, there is lesser tendency to damage any important object placed on the far or other bank, and there is less chance for returning the flow that can affect the bank where the groins are installed. So, in this case, groins can be placed far away. Having a very few scour in the vicinity of the groin head, a combined groin could increase its stability and longevity. As a result, the costs of groin implementation for the protection of the river bank from erosion can be less.

Although a deeper channel cannot be recognized rightly under the present experimental conditions, its evolution can be marked relatively uniform along the definite direction in the case of downstream aligned groins (M-3 and M-4). The deeper portion of the main channel developed for M-1 is not found uniform; while M-2 modifies the channel far better than M-1. Deposition in the groin field is not found significant in the experimental runs as the suspended sediment particles in the flow are very few, and the experiments are conducted under clear water scour conditions. The silt from the scour hole has accumulated in the downstream area as it cannot be transported under the prevailing flow conditions and available channel bed materials.

CONCLUSIONS

As the groin models with different configurations behave differently, the extent and distribution of erosion and deposition in the channel bed are different. From the changes in bed levels, i.e., erosion-deposition reflects from the channel bed due to the groins as discussed earlier and the following conclusions can be drawn.

In the case of solid I-shaped groin, as the flow is deviated, a huge, deep and large scour holes have formed near the groin structure. Also, the flow being deviated from the groin returns to the same bank get obstructed from the other bank, as recognized from the erosion and the channel that has been created is found irregular. The flow for L-head and hockey-shaped groins has improved compared to the first one as changes in bed level are found defined and regular, whereas the depth and size of scour holes near the groin have decreased. However, for the hockey-shaped groin, the flow is attracted towards the groin area, and thus groins are required to be placed closely in series. The flow has deviated slightly in the case of the combined groin as it allows flow through the structure, and flow separation is minimized resulting in a very few scour hole. As the scour endangers the stability of the groin structure, the stability of the groin can be expected to be higher in this case.

A major deposition of sediment occurs immediately in the downstream of the scour zone near the groin head. The formation of this scour hole can be attributed to the sediment deposition. The deposition measured in the groin field is found maximum for model M-2, and minimum for M-4. The deeper channel which provides navigation facilities does not show clearly in these present experiments; however, a defined path of flow towards the downstream direction is quite apparent for the downstream aligned groins (M-3 and M-4).

As the suspended sediment particles are not significantly present in the channel environment and the experiments are carried out under clear-water scour conditions, the deposition in the groin field does not properly show up. Therefore, when it comes to the question of stability, the combined groin shows better performance than others in terms of minimum scour near the groin tip.

ACKNOWLEDGEMENTS

This research was supported by University Grants Commission (UGC) under the Ministry of Education, Bangladesh through CASR, DUET. We would like to express our deepest appreciation for the generous support.

REFERENCES

[1] Richardson E.V., Stevens M.A. and Simons D.B., 1975. “The design of spurs for river training.” In XVIth, IAHR congress (pp. 382–388). Sao Paulo, Brazil.

[2] Pandey M., Ahmad Z., and Sharma P.K., 2018. “Scour around impermeable spur dikes: A review.” ISH J. Hydraul. Eng., 24(1), 25–44. doi:10.1080/09715010.2017.1342571

[3] Pandey M., Valyrakis M., Qi M., Sharma A. and Lodhi A.S., 2020b. “Experimental assessment and prediction of temporal scour depth around a spur dike.” Int. J. Sediment Res. doi:10.1016/j.ijsrc. 2020.03.015

[4] Sarveram H., Shamsai A. and Banihashemi M.A., 2012. Two-dimensional simulation of flow pattern around a groyne using semi-implicit semi-Lagrangian method. International Journal of Physical Sciences. 7, 2775-2783.

[5] J Kang H. Yeo S.K. and Ji U., 2011. Permeability effects of single groin on flow characteristics, Journal of Hydraulic Research. 49:6, 728-735.

[6] Quanhong L. and Pengzhi L., 2007. Numerical Simulation of Recirculating Flow Near a Groyne, The 2nd International Conference on Marine Research and Transportation, Ischia, Naples, Italy. 61-68.

[7] Mahmoud R. Eltoukhy and Neveen B.A., 2012. Effect of Groin Geometry on Scouring of Sandy River Beds Having 180o Bend, Civil Engineering Research Magazine, Al-Azhar University. 34(3): 880-892.

[8] Fukuoka S, Nakagawa N., Sumi T. and Zhang H., 2013. Advances in River Sediment Research; Taylor & Francis Group: London, UK.

[9] Alauddin M. and Tsujimoto T., 2012. Optimum configuration of groynes for stabilization of alluvial rivers with fine sediment. International Journal of Sediment Research (Elsevier publishing), Vol. 27, No. 2, pp. 158–167.

[10] Bahrami-Yarahmadi M, Pagliara S., Yabarehpour E. and Najafi N., 2020. Study of Scour and Flow Patterns around Triangular-Shaped Spur Dikes. KSCE J Civ Eng. 2020; 24(11), 3279–3288.

[11] Ettema R., Muste M., 2004. Scale effects in flume experiments on flow around a spur dike in flatbed channel. Journal of Hydraulic Engineering 130(7):635-646, DOI: 10.1061/(ASCE)0733-9429(2004)130:7(635)

[12] Duan J.G., 2009. Mean flow and turbulence around a laboratory spur dike. Journal of Hydraulic Engineering 135(10):803-811, DOI: 10.1061/(ASCE)HY.1943-7900.0000077

[13] Jeon J., Lee J.Y., Kang S., 2018. Experimental investigation of three dimensional flow structure and turbulent flow mechanisms around a nonsubmerged spur dike with a low length-to-depth ratio. Water Resources Research 54:3530-3556, DOI: 10.1029/2017WR021582

[14] Koutrouveli T.I., Dimas A.A., Fourniotis N.Th., Demetracopoulos A.C., 2019. Groyne spacing role on the effective control of wall shear stress in open-channel flow. Journal of Hydraulic Research 57(2):167- 182, DOI: 10.1080/00221686.2018.1478895

[15] Safie and Tominaga, 2020. Effects of pile arrangement on the flow around a pile-group groyne. JSCE. 8, 207-220.

[16] Alauddin M., Tashiro T. and Tsujimoto T., 2011. Experimental investigation of channel responses against different configurations of groynes, Advances in River Engineering, JSCE, vol.17, 335-340.

[17] Uddin M.N. and Rahman M.M., 2012. Flow and erosion at a bend in the braided Jamuna River. International Journal of Sediment Research. 27(4), 498–509.