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LOCAL SCOUR AROUND NON-SUBMERGED BELL MOUTH GROIN

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Abstract

Groins are the most popular techniques for riverbank stabilization that are constructed along the channel bank to locally change river conditions, thereby creating a flow condition that promotes navigability and diverts the flow away from the bank. The scour around groin head play a very important for their performance. No systematic experiments have been conducted to study the scour around bell mouth groin. An experimental study was undertaken in a 45.6m long and 2.45m wide laboratory water basin to investigate the local scour around a non-submerged bell-mouth groin structure. A total number of 12 test runs were performed for different flow conditions. Three different discharges and four different angles with non-submerged groin condition were considered in the present study. Therefore, Twelve tests were conducted of which six had a water depth of 14 cm and the rest six had a flow depth of 18 cm. All tests were conducted for 8 hours duration in clear water condition. In order to avoid the ripple formation, the coarse sand with d_{50} = 0.75 mm was selected as bed material. Scour depth for 90^o angled groin was observed to be the maximum and for 135^o it was the minimum. The time to reach maximum scour depth was found to vary with discharge and angle of attack. The study also revealed that maximum scour depth and deposition pattern changed for the case of different test runs. Scour depth varied with velocity variation of flow, and an increasing tendency of scour depth has been observed with increasing flow intensity. Maximum scour depth shows an increasing trend with increasing Froude number.

Key Words : Local Scour,Non-Submerged Groin, Bell Mouth Groin

1. Introduction

Groins are structures constructed in rivers to maintain a suitable measure for bank protection and flood control. Recently groins have been received more attention from the standpoint of ecosystem. The design, location, orientation and length of groins are very important subjects for the hydraulic engineers in the field. Basically, it is important to have a clear picture of scour phenomenon around these structures in order to be able to make a safe and economic design. Also, hydraulic conditions such as velocity, water depth, bed shape, and bed material around groins are so diverse to provide the ecosystem with suitable habitat. The development and magnitude of local scour for different angle of attacks are still undefined, though local scour is of utmost importance to the design of any type of groin. The foundation should be able to sustain the maximum scour depth around the mouth of groin. In Bangladesh, failure of bell mouth groin often occurred due to excessive scouring. From the engineering point of view, one is always interested in determining the potential scour so that the provision can be made in design and construction (Chang, 1988). The engineer is often called to design bank protection and conveyance channels that must maintain stability while subject to scour. Groins are structures that are constructed along the channel bank to locally change river conditions, thereby creating a flow condition that promotes navigability and diverts the flow away from the bank. As one of the most popular techniques for riverbank stabilization, groins have already been enjoyed a wide use in a number of riverbank stabilization projects and with a strong tendency to increase its applicability (Shields et al., 1995).

Over the past several years, there has been a rapid expansion of literatures concerning groins under clear water scour condition in both laboratory experiment and numerical simulation (Rahman and Muramoto 1999, Ishigaki and Baba 2004, Zhang 2005, Raudkivi and Ettema 1977); Live-bed scour around spurdykes (Zhang et al. 2005); Local scour formulae around piers and groins (Anawaruzzaman 1998, Islam et al. 2002); River course stabilization by groin like structures (Khaleduzzaman 2004); River bank stabilization in a bend by groin (Hossain 1981, Khan 1983, Sarker 2001); velocity distribution in groin fields (Muto et al. 2005); Exchange process between river & its groin fields (Uijttewaal et al. 2001) etc. Hasan (2003) investigated the local scour at the toe of protected embankment. Kabir (2007) investigated the scour reduction technique and flow pattern around abutment using bottom vanes. Khatun (2001) conducted an experiment on local scour around bridge pier using cohesive and non-cohesive bed materials and established an empirical relationship to estimate local scour. Rahman et al. (2001, 2002) investigated flow field and scouring around piers and abutments.

From the foregoing discussion it is apparent that most of the above studies were concerned with pier, embankment, abutment, groin and spur-dikes mainly for assessment of local scour which is very frequently used in Bangladesh. But the development of scientific guiding principles for the bell mouth groin design is yet not fully explained. The reason is that bell mouth groin is typical in the India subcontinent including Bangladesh. The flow structure and scour development around bell mouth groin is of great interest for the design of riverbank stabilization projects in Bangladesh. In the present study, which is exploratory and experimental in nature, the scour around the single groin is investigated for submerged condition.

Groins are classified according to the method and material of construction, i.e. permeable and impermeable. The permeable and impermeable are self explanatory are differentiated by the ability of the construction material to transmit flow. Permeable groin slow down the current while impermeable groins deflect the current. Permeable groins are most effective on alluvial streams with considerable bed load and high sediment concentration, which favour rapid deposition around the groins. Groins vary depending on their action on the stream flow. They may be classified as attracting, deflecting or repelling groins. Groins may be further classified according to their appearance of plan. Straight groin is set at some angle from the bank and has a head to provide extra volume and area for scour protection at the outer end. T-head groin has a straight shank with a rectangular guide vane at the outer end. The angle at the bank is normally 90 degree. L-head groin or wing or trail groins have larger sediment deposits between groins, less scour at their head, provide greater protection to the banks and are more effective in channelization for navigation when the length closes 45 to 65 percent of the gap between the groins. Hockey shape groins have scour holes that are more extensive in area than the T-shape groins and do not appear to have any advantages over the other shapes (Richardson et al., 1975). Straight groin with pier head was designed and executed to dig and stabilize artificial pools for salmon and trout migration and fishing.

In some locations groins are constructed higher than the high water level, which are called non-submerged groin. In other locations groins are submerged under the water surface. In rivers with unsteady flow conditions, groins can serve as non-submerged in ordinary state or submerged during flood. The area behind the groin is either a dead zone during non-submerged conditions or a slow flow zone during submerged flow conditions. Most of previous investigators published experimental data on the various aspects of the local scour around emerged spur dikes. In their experiments, they have used flow depths that were less than the height of the spur-dike model, (Ahmed 1953; Liu et al. 1961; Garde et al. 1961; Laursen 1963; and Gill 1972).Recent studies have included Rajaratnam and

Nwachukwu (1983), Melville (1992). Many prototype spur dikes, however, were designed to regularly consider overtopping flow, submerged condition. A few studies were presented for submerged groin, such as the study of Kuhnle et al. (1999), Kuhnle et al. (2002). In the present study an attempt has been made to investigate the scour around submerged bell mouth groin by varying discharge and angle.

2. Dimensional Analysis Approach

Dimensional analysis is a mathematical technique which makes use of the study of dimensions as an aid to the solution of several engineering problem. Each physical phenomenon can be expressed by an equation, composed of variable (or physical quantities) which may be dimensional and non-dimensional quantities. Dimensional analysis helps in determining a systematic arrangement of the variables in the physical relationship and combining dimensional variables to form non-dimensional parameters. An attempt has been made to establish relationship between maximum scour around the head of bell mouth groin and various parameters that affect scour. Non-dimensional parameters that control predominantly the scour effects were developed using Rayleigh method. For this, the Rayleigh method has been used for dimensional analysis. The variables considered are the scour depth (h_s), water depth (y), groin angle of attack (α), the approach flow velocity (V_a) and acceleration due to gravity (g). But the groin angle of attack (α) is not a physical dimension and it was not considered in the dimensional analysis.

Let, $h_s = f(V, y, g)$ (1)

or, $h_s = f(V)^a (y)^b (g)^c$

Where a,b,c are dimensional constant. Applying dimensions of the variables, the equation (1) can be written as

$$L = f\ (LT^{-1})^a\ (L)^a\ (LT^{-2})^b = f\ (L)^{a+b+c}\ (T)^{-a-2c}$$

And solving for a,b, c, we get

$$h_s = f(V)^{-2c}(y)^{1+c}(g)^c$$

$$or\ \frac{h_s}{y} = f\left(\frac{gy}{V^2}\right)^c = f\left(\frac{1}{F_r^2}\right)^c$$

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

$$\frac{h_s}{y} = f\left(\frac{1}{F_r^2}\right) \quad (2)$$

Equation (2) shows that the relative scour depth (h_s/y) is a function of Froude number (F_r).

3. Experimental Procedures

The experiments have been carried out in a wide straight flume which is 45.60 m long, 2.45m wide and having a depth of 1m. The flume has a re-circulating water supply system with pre-pump storage pool, measuring devices, tail gates and stilling basin etc. The water passed through an approach upstream reservoir provided with a series of baffles. These baffles distributed the flow uniformly over the entire width of the flume and also helped in dissipating the excess energy of flow. The sand bed had a thickness of 30 cm. The sand used in the experiments reported herein has mean size of d_{50}= 0.75 mm and standard deviation of σ_g= 1.94. The groin models used in the study were fabricated by wood. The groin model was bell mouth type. The groin was positioned with different angle of inclination of $\theta = 60^o$, 90^o, 135^o and 150^o with the downstream. Before the beginning of each run the sand bed was leveled corresponds to Z=0. Three different discharges were considered in the present study. Total 12 (twelve) tests were conducted with non-submerged condition of which 6 (six) had a water depth of 14 cm and the rest six had a flow depth of 18 cm. To obtain a specific discharge, water level was maintained by adjusting the tailgate on downstream. The water discharge has been measured on a routine basis at half hour intervals by sharp-crested Rehbock weir located at the re-circulating canal. The discharge has been calculated from reading of point gauge in the adjacent stilling basin using the following equation.

$$Q = \frac{2}{3} C_d L_{weir} \sqrt{2g} (\Delta H)^{\frac{3}{2}} \quad (3)$$

The free flow has been ensured only at the downstream weir and coefficient of discharge (C_d) has been calculated to be 0.6.

3.1 Scour measuring technique

The changes in the bed topography around the groin were measured with the help of the bed level measuring instrument. Each run was ended after getting equilibrium state for local scour (8 hours). Details of selected experimental runs are given in Table 1. Each test was designated by certain notations. For example, test no.1 is designated by NS11, it means that the test were conducted at a discharge of 170 l/s, non-submerged condition with the groin placed at 150^o angle in direction towards downstream. All others tests have been similarly designated.
Scour data have been collected forming grids in the selected area around bell mouth groin on the dry bed. In one test run, 1225 scour data have been collected hence for 12 test runs total scour data was 14700.

Table 1. Experimental program

Test No.	Angle of inclination (anti-clockwise) degree	Froude number (F_r)	Discharge, Q (lit/sec)	Water depth, y (cm)
NS11	150	0.423	170	14
NS12		0.373	150	
NS13		0.323	130	
NS21	135	0.290	170	18
NS22		0.256	150	
NS23		0.222	130	
NS31	90	0.423	170	14
NS32		0.373	150	

NS33		0.323	130	
NS41	60	0.290	170	18
NS42		0.256	150	
NS43		0.222	130	

3.2 Velocity measurement

Flow velocity measurements were obtained by using programmable electromagnetic velocity meter (P-EMS) consisting of a 50 mm-diameter probe and a control unit, mounted on a movable measuring carriage. The sensor of this instrument measured two dimensional velocity field. Water depths were measured at one-hour intervals by the help of a point-gauge mounted on a wooden frame.

3.3 Co-ordinate system

A Cartesian co-ordinate system has been chosen and used during the experimentation in the flume as shown in Fig. 1(Self explnatory).

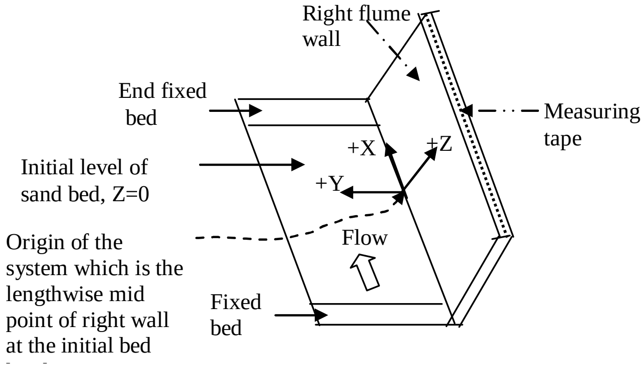
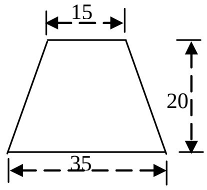


Fig.1. Coordinate system used in the experiment

3.4 Bell mouth groin dimensions

Groin was installed on the bed surface with a width of 32.5 cm, is tapering vertically and the top width was lowered to 12.5 cm, shown as (Section 1-1 in Fig. 2). The height of groin above the bed surface is 20 cm and below the bed level was 40 cm. The top diameter at head of the groin is 15 cm and at the base on the bed level is 35 cm, shown as (Section 2-2 in Fig. 2). Shank and head slope is 2V:1H. The base of the groin at the bed level is extended up to 103.5 (63.5+40) cm towards the channel middle perpendicular to the right wall.



Cross section 2-2

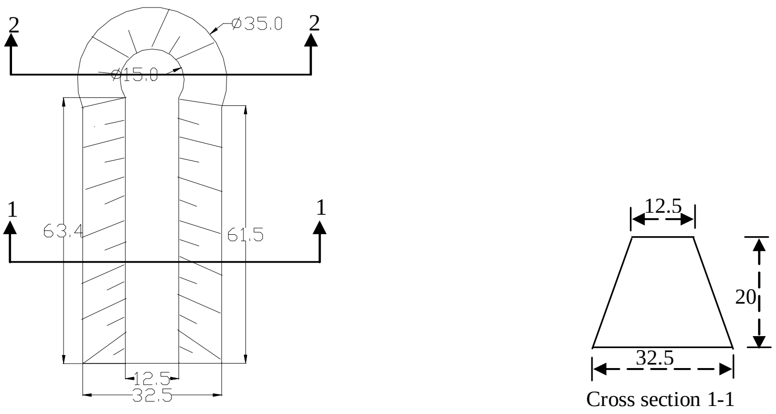


Fig.2**.** Bell mouth groin dimension above the bed level (all the dimensions are in cm)

3.5 Orientations of groin

Four types of bell mouth groin orientation were considered in the present study. These were 150^o, 135^o, 90^o and 60^o angles from the right bank of the channel (counter clockwise direction). Figures 3, 4, 5 and 6 shown the orientations and dimensions of the groin angled at 150^o, 135^o, 90^o and 60^o respectively.

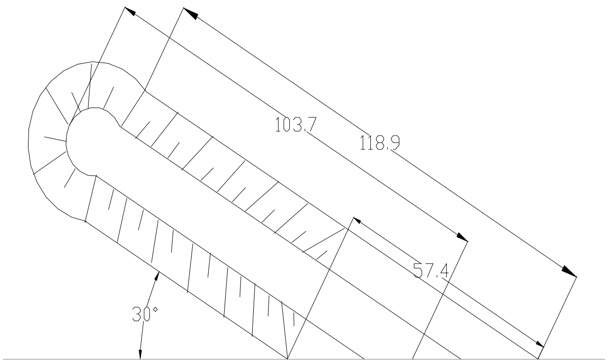


Fig.3. Groin at 150^o angle with right bank

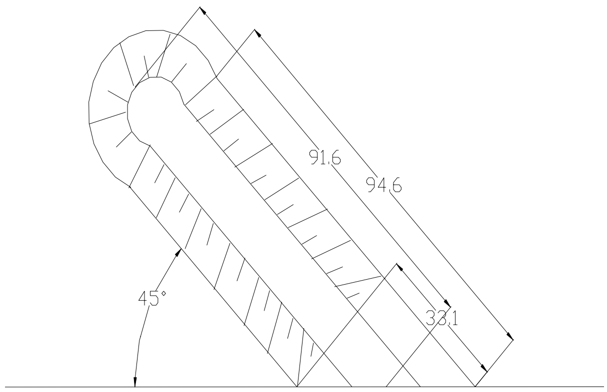
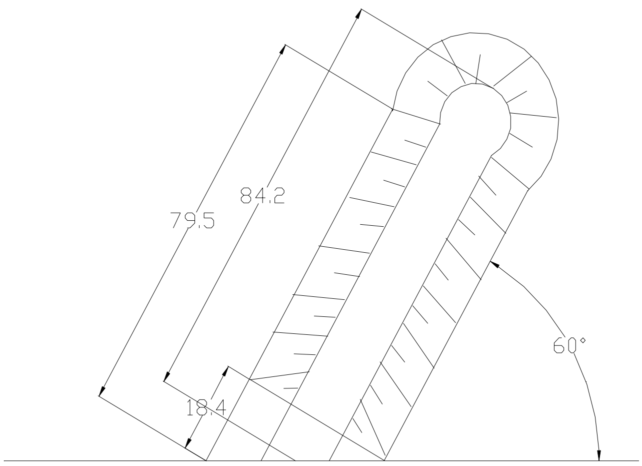


Fig.4. Groin at 135^o angle with right bank



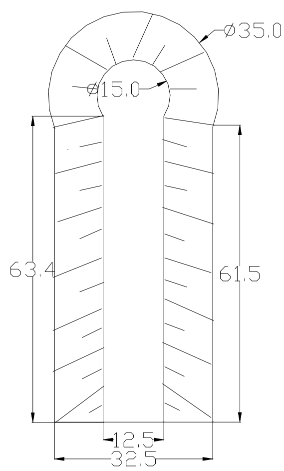


Fig.5. Groin at 60^{o} angle with right bank Fig. 6. Groin at 90^{o} angle with right bank

4. Result and Discussion

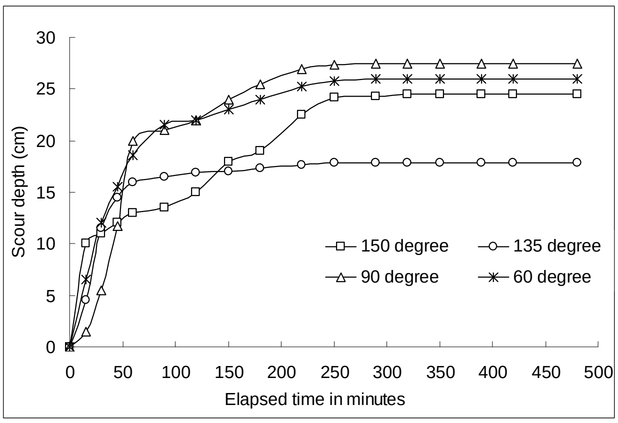
4.1 Temporal variation of scour and equilibrium scour depth

Scour depth in clear water regime increases logarithmically with time upto limiting depth at equilibrium (Melville and Chiew, 1997). But in live bed regime, equilibrium depth is reached quickly. Equilibrium scour depth has been observed at the defined location on the head of the bell mouth groin with the interval of half an hour. The defined location of the equilibrium scour depth are for 150^{o} angle, X=-70 cm and Y=90 cm; for 135^{o} angle X=-40 cm and Y=90 cm; for 90^{o} angle, X=-30 cm and Y=100 cm; for 60^{o} angle X=0 cm and Y=100 cm. Figures 7~9 show the temporal variation of scour depth and attaiment of equilibrium scour for different discharges with different orientation of groins. For the entire 12 runs scour depth for 90 degree angle has been observed to be maximum and for 135 degree is minimum. It may be caused for 90º angle flow velocity directly hit on the head of the groin and vortex created around the head of the groin. These scour measurements with an interval of half an hour have been continued until the equilibrium has reached. In all most cases it has been observed that the equilibrium scour has reached after a minimum of 4 to 4.5 hours of running. This equilibrium time has varied with discharge and angle of attack.

4.2 Scour and deposition contour map

2-D scour contour map indicating local scour around bell mouth groin for variable discharge are presented Figure 19-30 represents scour maps for angles 150º, 135º, 90º and 60º respectively. With higher discharge scour hole slope is found steeper. Scour line intensity decreases with decreasing discharges and becomes flatter for lower discharge. In general scour hole slope is steepest around the head of the structure and gradually decreases sidewise. Slope of scour hole around head of bell mouth groin is more uniform for higher discharge than that of lower discharge.

Mostly it is observed that scour hole has maximum extent around head of the structure for higher discharge and decreases gradually with decreasing discharge. Sediment deposition is found nearer to rear face of structure for lower discharge where as sediment is deposited slightly downstream for higher discharge.



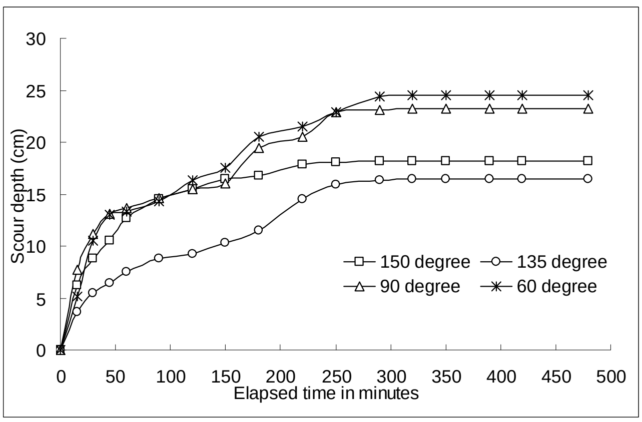


Fig.7. Variation of scour depth with time (Q=170 lit/s) Fig.8. Variation of scour depth with time

(Q=150 lit/s)

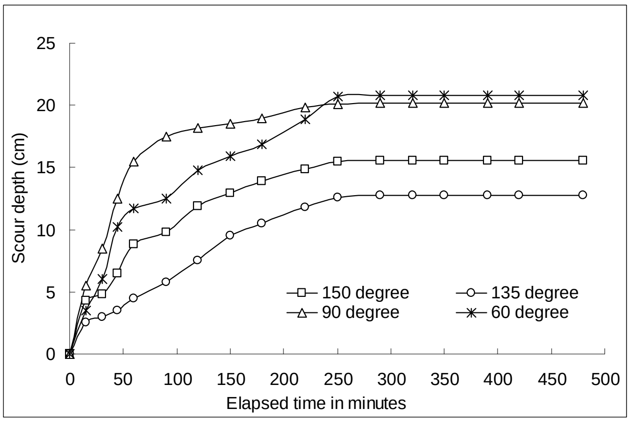


Fig.9. Variation of scour depth with time (Q=130 lit/s)

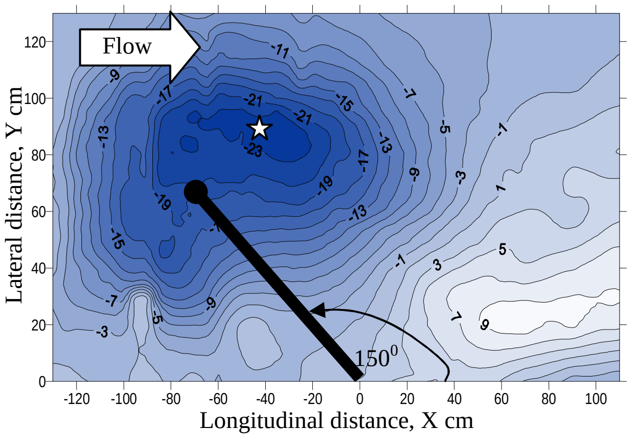


Fig.10. Final bed contour for test no.NS11

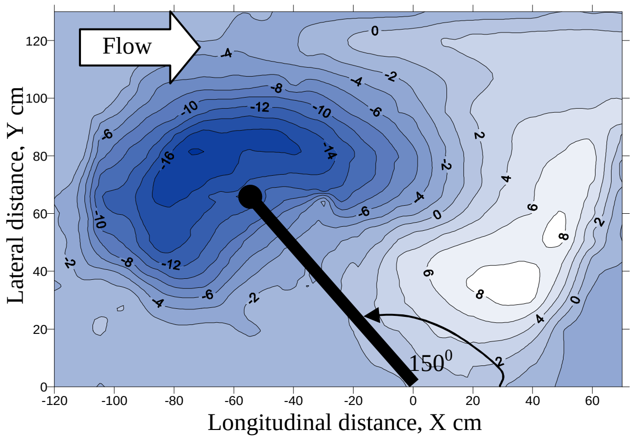
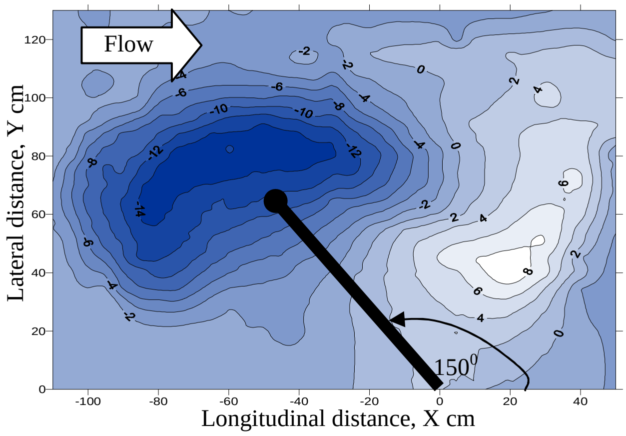


Fig.11. Final bed contour for test no.NS12



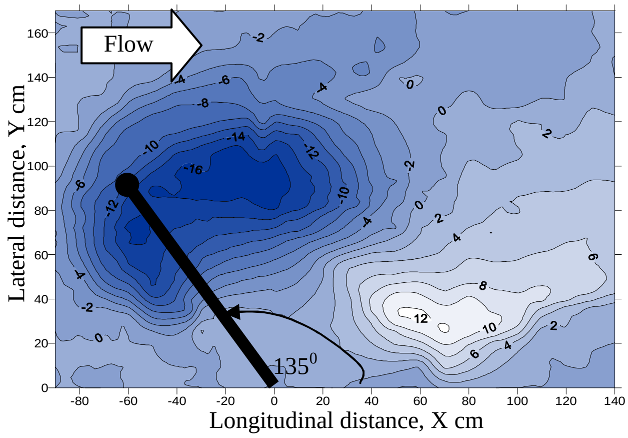


Fig.12. Final bed contour for test no.NS13

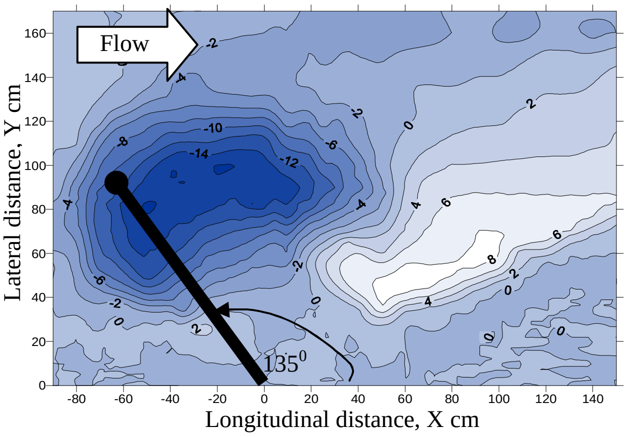


Fig.13. Final bed contour for test no.NS21

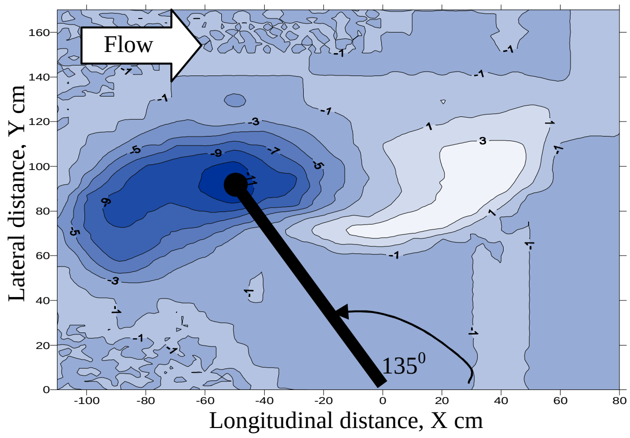
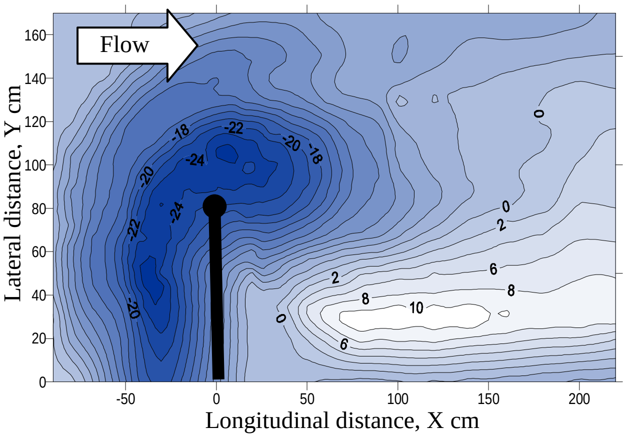


Fig.14. Final bed contour for test no.NS22

Fig.15. Final bed contour for test no.NS23



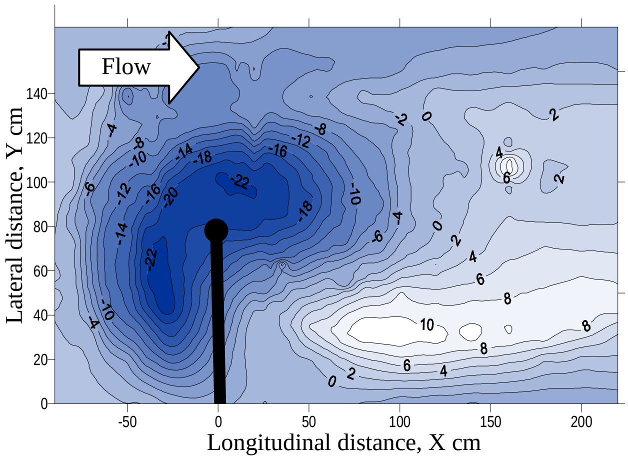
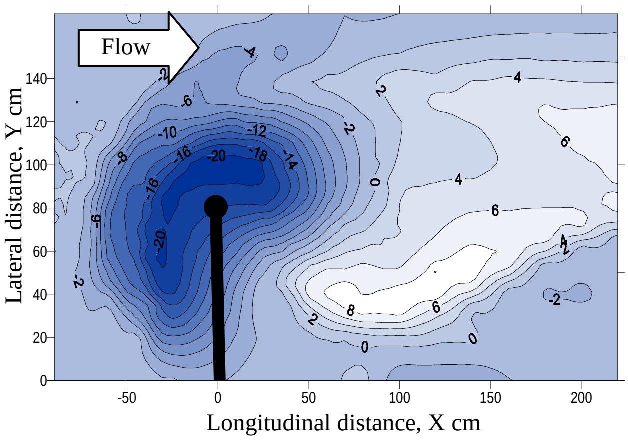


Fig.16. Final bed contour for test no.NS31

Fig.17. Final bed contour for test no.NS32



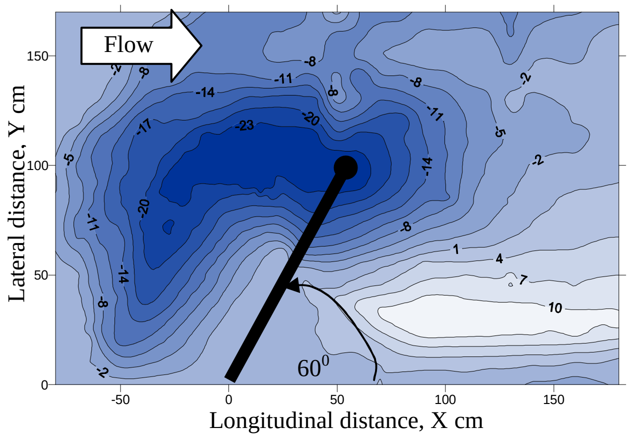
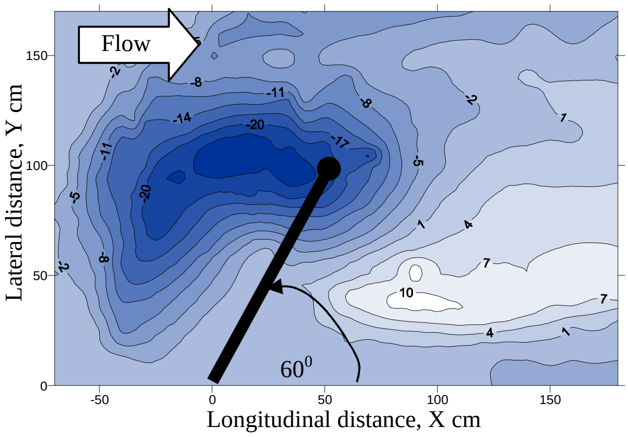


Fig.18. Final bed contour for test no.NS33 Fig.19. Final bed contour for test no.NS41



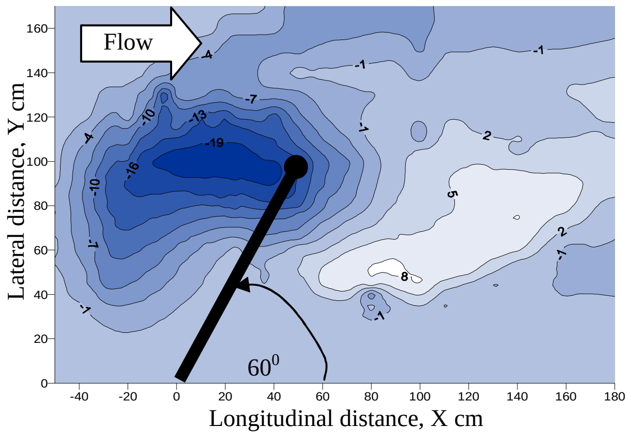


Fig.20. Final bed contour for test no.NS42 Fig.21. Final bed contour for test no.NS43

Table 2 Maximun scour depth with position for various cases

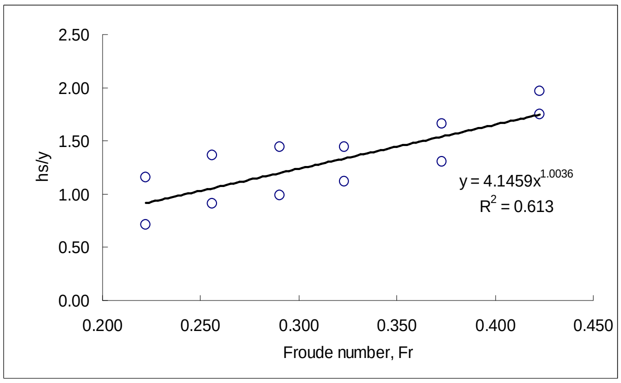
Cases no.	Maximum scour depth (cm)	Position X , Y (cm)
NS11	24.5	-35, 82.5
NS12	18.2	-75, 82.5
NS13	15.6	-45, 82.5
NS21	17.8	-10, 92.5
NS22	16.4	-50, 82.5
NS23	12.8	-50, 82.5
NS31	27.5	10, 102.5
NS32	23.2	-30, 45
NS33	20.2	-30, 82.5
NS41	26	5, 105
NS42	24.5	5, 105
NS43	20.8	-5, 100

4.2.1 Variation of maximum scour depth with Froude number

Variations of dimensionless maximum scour depth (h_s/y) with Froude number (F_r) are shown in Figure 31. From trend line of this graphical presentation, it has been found that scour depth increases at an increasing tendency with increasing Froude number.

4.2.2 Variation of relative scour depth with approach flow velocity (Va)

Variation of relative scour depth (hs/y) with approach flow velocity (Va) is shown in Figure 33. From trend line of this graphical presentation, it was found that relative scour depth increases with increasing approach flow velocity.



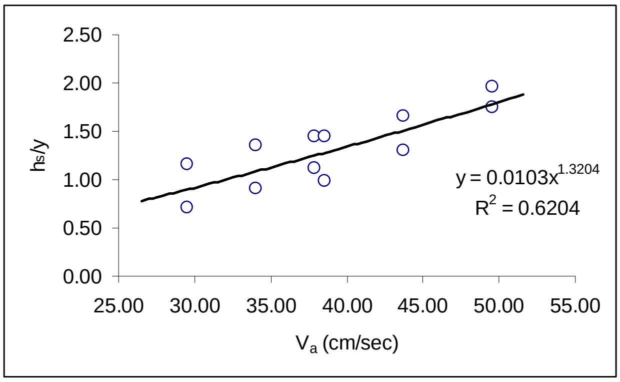
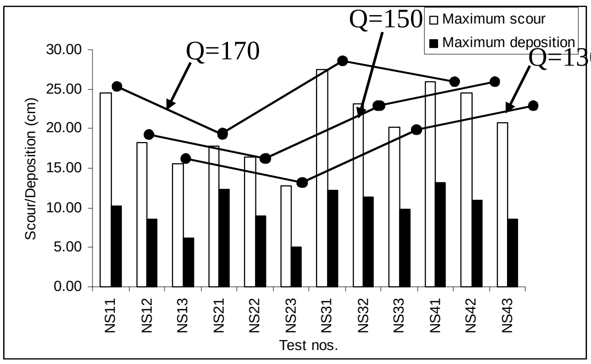


Fig.22. Variation of relative scour depth with Froude number Fig.23. Variation of relative scour depth with approach flow velocity

4.3 Scour and deposition

Figure 18 shows the comparison between maximum scour depths with maximum height of deposition for each test run. It is found that for 90^0 the scour depth is relatively higher than the maximum height of deposition. As velocity increased scour depth increases and more sediment deposited downstream of the structure. For the same angle, the scour and deposition are higher for higher discharge and viseversa. The lateral and longitudinal cross section bed profiles are drawn to compare differences in scour and deposition pattern for each test run. Figure 19 shows the relation mximum scour and maximum deposition for all test runs.The trend line of this graphical presentation shows the linear relationship.



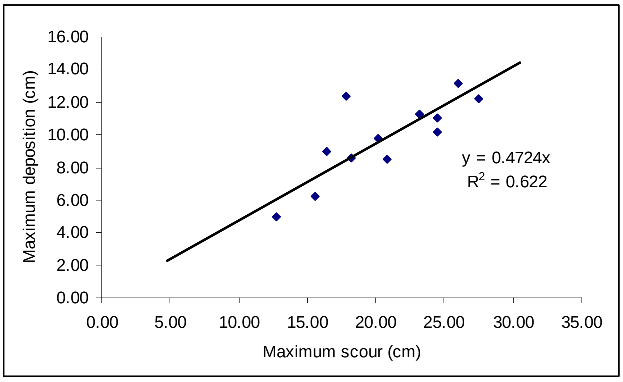
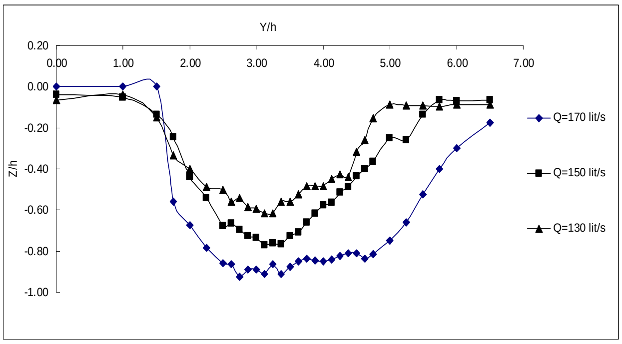


Fig.24. Scour and deposition pattern for all test runs Fig.25. Relation between maximum scour and maximum deposition

4.4 Cross sectional bed profile

The experimental observations for the cross-sectional profiles of scour & deposition for different orientations are shown in Figs. 10~13. In order to make dimensionless, the X and Y co-ordinates has been divided by the height of the bell mouth groin (h) above the bed level.

Figure 13 shows both deposition and scour around the bell mouth groin. Deposition starts at Y/h=0 and ends at Y/h=2. After 2h distance scour starts and continuing 7h distance.



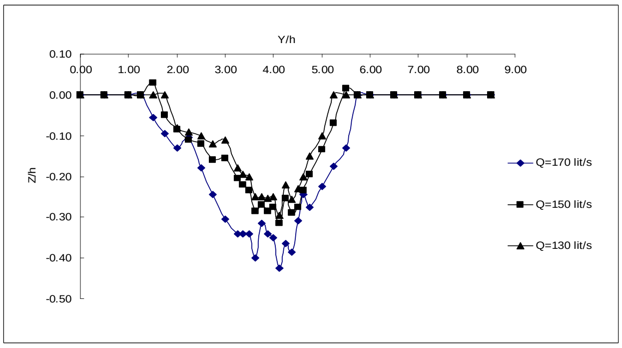
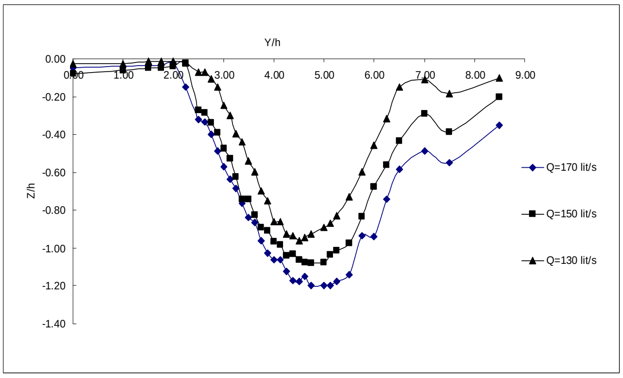


Fig.26. At X/h=-4.5 for 150^0 angle

Fig.27. A at X/h=-4 for 135^0 angle



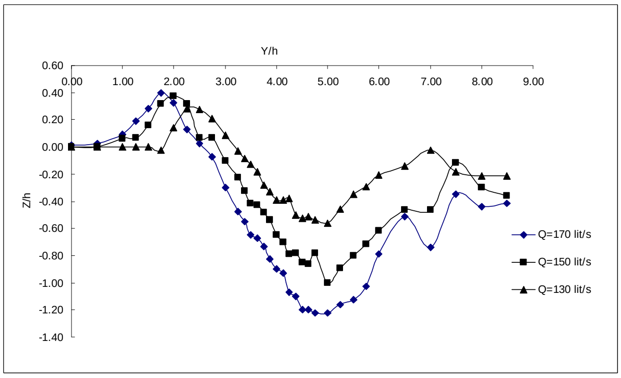


Fig. 28. At X/h=1.5 for 90^0 angle

Fig.29. **A**t X/h=3 for 60^0 angle

4.5 Bed profiles along the longitudinal section

The longitudinal bed profile has been plotted to observe the change in bed profile along the stream wise direction at the vicinity of the head of the bell mouth groin for different discharges. These have been shown in Figures 14~17. In these Figures the horizontal line corresponding to Z/h=0 represents the initial bed level.

Figure 14 shows the variation of longitudinal bed profile at Y=85cm (away from the right bank) for 150^o angle. It shows that maximum scours starts from -7h distance and end 3h distance. After 3h distance it rises above the initial bed level i.e. starts deposition. Minimum scours starts from -3.5h distance and end at X/h=0.

Figure 15 shows the variation of longitudinal bed profile at Y= 105 cm (away from the right bank) for 135o angle. It shows that maximum scours starts from -4.5h distance and end 3.5h distance. After 3.5h distance it rises above the initial bed level i.e. starts deposition. Minimum scours starts from 1h and end at 3h distance.

Figure 16 shows the variation of longitudinal bed profile at Y=100 cm (away from the right bank) for 90o angle. It shows that maximum scours starts from -5h distance and end 8h distance. After 8h distance it rises above the initial bed level i.e. starts deposition. Minimum scours starts from -1.5h distance and end at 3.5h distance.

Figure 17 shows the variation of longitudinal bed profile at Y=100 cm (away from the right bank) for 60o angle. It shows that maximum scours starts from -4h distance and end 8h distance. After 8h distance it rises above the initial bed level i.e. starts deposition. Minimum scours starts from -1h distance and end at 3h distance.

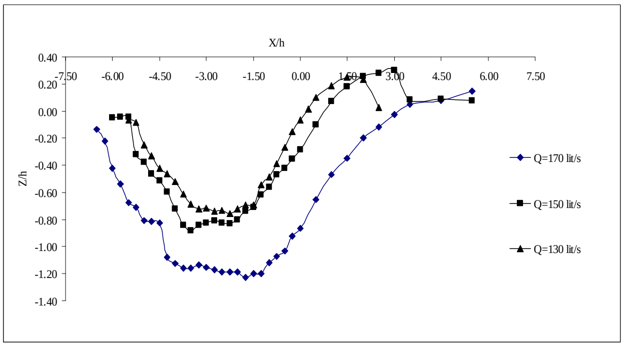


Fig.30. At Y/h=4.25 for 150^0angle

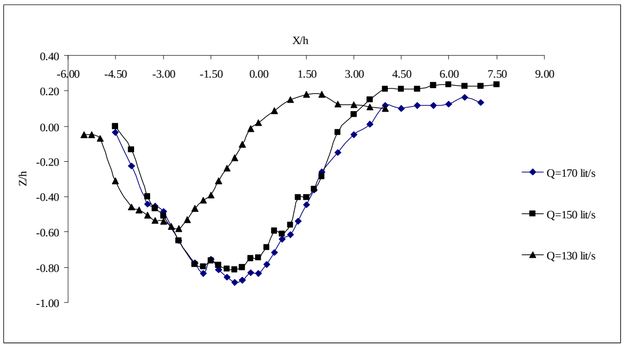


Fig.31. At Y/h=5.25 for 135^0angle

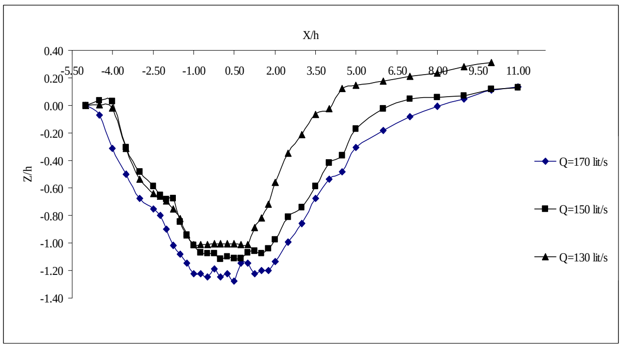


Fig.32 At Y/h=5 for 90^0 angle

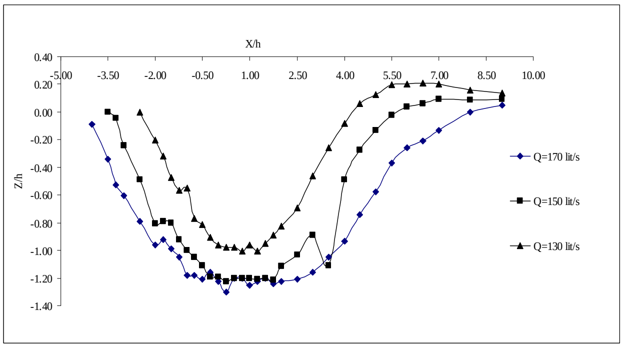


Fig.33. At Y/h=5 for 60^0 angle

5. Conclusions

Based on the detailed experimental investigation, analysis and discussion the following conclusions may be drawn:

- Equilibrium scour depth measured around the head of the bell mouth groin shows that the scour depth for 90^o angle was the maximum while for 135^o it was the minimum. The equilibrium time to reach the maximum scour depth was found to vary with discharge and angle of attack for different test runs.
- The differences between the maximum scour depth and the maximum height of deposition are relatively less.
- The longitudinal profiles along the stream wise direction at the vicinity of the head of the bell mouth groin appears that the maximum scour occurs for discharge 170 lit/sec and minimum scour occurs for discharge 130 lit/sec.
- Scour depth varied with velocity variation of flow and an increasing tendency of scour depth has been observed with increasing flow intensity. Maximum scour depth shows an increasing trend with increasing Froude number.

References

[1] Anwaruzzaman, S.M. (1998). “Evaluation of Selected Local Scour Formulae Around Piers and Groynes.” M.Engg. Thesis, Department of Water Resources Engg., BUET, Dhaka.

[2] Ahmad M (1953). “Experiments on design and behavior of spur-dikes.” Proc. Int. Hydraul. Convention. : 145–159

[3] Chang, H.H. (1988). “Fluvial Processes in River Engineering.” John Wiley and Sons Inc., USA.

[4] Gill M. A. (1972). “Erosion of sand beds around spur-dikes.” J. Hydraul. Div., Am. Soc. Civ. Eng. 98: 1587–1602

[5] Garde, R. J., Subramanya, K., Nambudripad, K. D. (1961). Study of scour around spur dikes. ASCE Journal of the Hydraulics Division, 87(HY6), 23-37.

[6] Hossain, M.M. (1981). “Study of River Bank Stabilization in a Bend by Groin.” M.Sc. thesis, BUET, Dhaka, Bangladesh.

[7] Hasan, R.M.M. (2003). “Experimental Study of Local Scour at the Toe of Protected Embankment.” M.Engg. Thesis, Department of Water Resources Engg., BUET, Dhaka.

[8] Islam, G.M.T., Rahman, M.M., and Haque, M.A. (2002). “Experimental Study on Scour around Groins in a Straight Compound Channel.” IWFM, BUET, Dhaka.

[9] Ishigaki, T. and Baba, Y. (2004). “Local Scour Induced by 3D Flow around Attracting and Deflecting Groins.” Proceedings of Second International Conference on Scour and Erosion, Meritus Mandarin, Singapore: 301-308.

[10] Khan, M.A.O. (1983). “An Experimental Investigation on the Effect of Location and Projection of Single Groin in a Bend.” M.Sc. Thesis, Department of Water Resources Engg., BUET, Dhaka.

[11] Khaleduzzaman, A.T.M. (2004). “Experimental Study on River Course Stabilization and Restoration by using Groin-like Structures.” Master thesis Kyoto University, Japan.

[12] Kabir, M.A. (2007). “An Experimental Study on the Effect of Submerged Vane on Scour and Flow around Abutment.” M.Sc. Thesis, Department of Water Resources Engg., BUET, Dhaka.

[13] Khatun, F. (2001). “Experimental Study on Local Scour around Bridge Piers and Its Reduction.” M.Sc.Thesis, Department of Water Resources Engineering, BUET, Dhaka.

[14] Kuhnle, R.A., Alonso, C.V., Shields, F. D. (2002). “Local scour associated with angled spur dikes.” Journal of Hydraulic Engineering, ASCE, Vol. 128(12), pp. 1087-1093.

[15] Kuhnle, R. A.; Alonso, C.V., Shields, F.D. (1999). “Geometry of scour holes associated with 90-degree spur dikes.” J. Hydraulic Engineering. ASCE, Vol. 125 (9), p.972.

[16] Laursen E.M. (1963). “An analysis of relief bridge scour.” J. Hydraul. Div., Am. Soc. Civ. Eng. 89: 93–118

[17] Liu, M. K., Chang, F. M., Skinner, M. M. (1961). Effect of bridge construction on scour and backwater. Report No. CER60-HKL22, Department of Civil Engineering, Colorado State University, Fort Collins, Colorado.

[18] Muto, Y., Kitamura, K., Baba, Y. and Nakagawa, H. (2005). “Field Measurement of Velocity Distribution in Groin Fields with ADCP.” Annual Journal of Hydraulic Engineering, JSCE, 49.

[19] Melville, B.W. (1997). “Pier and abutment scour: integrated approach.” Journal of Hydraulic Engineering, ASCE, 123(2), 125-136.

[20] Melville, B.W. (1992). “Local Scour at Bridge Abutments.” ASCE Journal of Hydraulic Engineering, Vol. 118, No. 4, April, 1992, pg615.

[21] Rahman, M.M. and Muramoto, Y. (1999). “Prediction of Maximum Scour Depth around Spur-Dike-Like Structures.” Annual Journal of Hydraulic Engineering, JSCE, 43: 623-628.

[22] Rahman, M.M., Haque, M.A. and Alam, A.A. (2001). "Flow Field Around Piers and Abutments at the Initiation of Scouring." Proceedings of the 1st International Conference on Civil Engineering, IEB and FEISCA, Chittagong, 2-3 Nov. pp.403-410.
[23] Rahman, M.M., Haque, M.A. and Islam, M.S. (2002). "Flow and Scouring around Piers and Abutments." 13th IAHR-APD Congress, Singapore, 280-283.
[24] Raudkivi, A.J. and Ettema, R. (1977). "Effects of Sediment Gradation on Clear Water Scour." Journal of Hydraulic Engineering, ASCE, 103(10), 1209-1212.
[25] Rajaratnam N, Nwachukwu B A (1983). "Flow near groin-like structures." J. Hydraul. Eng., Am. Soc. Civ.Eng. 109: 463–480
[26] Richardson, E.V., Simons, D.B., Karaki, S., Mahmood, K., and Stevens, M.A., (1975) "Highways in river environment." Hydraulic and Environmental Design Considerations, Engineering Research Center, Colorado State University, Fort Collins, Co.
[27] Shields Jr., F.D., Cooper, C.M. and Knight S.S. (1995). " Experiment in Stream Restoration." Journal of Hydraulic Engineering, ASCE, 121(6): 494-502.
[28] Sarker, M.S.R. (2001). "Development of a Physical Model Facility and Investigation of Flow Pattern Due to Groyne on the Right Bank of Jumuna River near Kazirhat-Natibpur Area." M.Sc. Thesis, Department of Water Resources Engineering, BUET, Dhaka.
[29] Uijttewaal, W.S.J., Lehman, D., and van Mazijk, A. (2001). "Exchange Process Between a River and Its Groin Fields: Model Experiment." Journal of Hydraulic Engineering, Vol. 127, No 11, pp.122-125.
[30] Zhang, H. (2005). "Flow and Bed Evolution in Channels with Spur Dykes." Doctoral Thesis, Kyoto University, Japan.
[31] Zhang, H., Nakagawa, H., Ishigaki, T., Muto, Y., and Khaleduzzaman, A.T.M. (2005) "Flow and Bed Deformation around a series of Impermeable and Permeable Spur Dykes." Proc. of the International Conference on Monitoring, Prediction & Mitigation of Water-Related Disasters (MPMD) Jan. 12-15, Kyoto, pp.197-202.