Experimental Study of Local Scour around Single Spur Dike in an Open Channel

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Abstract - *Spur dikes are hydraulic structures that project from the bank of a stream at some angle to the main flow direction. By changing the opening ratios, there is a great change in the scour hole pattern around the spur dike. The present study focuses on the effects of the opening ratio on the scour hole, depth, width and length around spur dike for the different flow conditions and angles of inclination with the flow direction. In the present study a series of laboratory experiments were conducted with three different opening ratios 0.82, 0.85 and 0.88 at three different angle of inclination 60°, 80° and 90° with the flow direction for different flow conditions. All the tests were held under live bed scour condition using a horizontal bed consisted of non-uniform sandy soil (D_{50}= 0.49 mm). From the experimental results graphical relationships were established between different relative scour parameters with Froude number at different opening ratios. From the graphical relationships it was observed that all the relative scour parameters increase with increase of Froude number. It was also observed that with the decrease in opening ratio there is increase in scour hole depth, length and width and on the other hand these parameters decrease with the decrease in angle of inclination of spur dike.*

Key Words: Froude Number, Opening ratio, Sandy Soil, Scour, Spur Dike.

1. INTRODUCTION

Spur dikes are the hydraulic structures that are widely used to protect the eroding banks of stream. They are projected at some angle to the main flow direction having one end on the bank of a stream and the other end projecting into the river current. They are mainly used for two purposes such as river training and erosion protection of the riverbank. With respect to river training, the primary objective is to improve the navigability of a river by providing a sufficient depth of flow and a desirable channel alignment. With respect to erosion protection, spur dikes can be designed to protect both straight reaches and channel bends. They also serve to increase the sediment transport rate through the diked reach, which decreases channel dredging costs. Compared with other methods, such as revetments, spur dikes are among the most economical structures that may be used for riverbank erosion protection [1].

Normally the effective length of spur or groyne should not exceed 1/5th of width of the flow in the case of single channel. In case of wide, shallow and braided rivers, the protrusion of the groyne in the deep channel should not exceed 1/5th of the width of the channel on which the groyne is proposed excluding the length over the bank [2].

Ezzeldin et al. (2007) conducted a series of experiment to investigate the characteristics of the scour hole around a single spur-dike installed in a straight flume and to investigate the relation between the dimensions of the scour hole and between non-dimensional parameters describing the flow ratio, and angle of flow attack. They found that the all of the scour parameters increase with the increase of the Froude number with a linear trend.

Masjedi et al. (2010) conducted an experiment to study scour and flow pattern around a T-shape spur dike located in a 180 degree channel bend. The study was conducted using in a 180 degree laboratory flume bend. They found that the characteristics of the scour hole have been shown to be affected by the shape of spur dike in the bend and Froude number. By increasing the Froude number, the scour increases.

Vaghefi et al. (2012) studied the geometry of the scour hole and topography of the bed around a T-shaped unsubmerged spur dike located in a 90° bend. They found that when the spur dike is located at sections 30° or 45°, the height of the sediment deposition ridge is higher than when the spur dike is located at sections 60° or 75° and the location of maximum scour depth is at the upstream side of the spur dike and at the distance of 10–20% of the spur dike length.

Elsaiad A A and Elnikhely E. A. (2016) conducted an experiment in a straight rectangular flume with a non-submerged spur dike. The effect of spur dike angled at 90°, 55°, 40° and 25° was studied. The experimental results of the model indicated that the relative maximum depth of scour is highly dependent on the spur dike inclination angle with channel wall.

2. OBJECTIVES OF THE STUDY

1. To study the scour and deposition pattern due to a single spur dike for various geometric arrangements i.e., spur dike length, inclination of the spur dike with the flow direction and subjected to various discharge conditions.

2. To investigate the effect of opening ratio and effect of spur dike alignment angle on scour characteristics around single spur dike for different flow conditions.

3. EXPERIMENTAL SETUP

All the experimental works for the present study were planned and carried out in the Hydraulics Laboratory of Department of Civil Engineering, Assam Engineering College, Guwahati. A re-circulating 20 m long and 0.96 m wide concrete channel with sediment bed was used to carry out the experiments. All the tests were held under live bed scour condition using a horizontal bed consisted of non-uniform sandy soil (D_{50}= 0.49 mm). The spurs were made up of wood. The channel was provided with three different capacity pump of 10 HP, (10+5=15) HP and (10+5+7.5=22.5) HP. In the present study three single spurs of length 17.5 cm, 14.5 cm and 11.5 cm were used. Each spur was laid at an angle of 60°, 80° and 90° and for each position of the spur; experimental runs were carried out at three different flow conditions i.e, at Froude number, F_r = 0.63 (Q = 0.0225 m^3s^{-1}), F_r = 0.96 (Q = 0.0585 m^3s^{-1}) and F_r = 1.29 (Q = 0.11 m^3s^{-1}). The runs were carried out over a period of 3 to 4 hours and after that the scour depth was measured. Experimental details of present study have been given in table 1.

Table 1: Different Flow Parameters

Q(m^3s^{-1})	V(ms^{-1})	q (m^2s^{-1})	y (m)	F_r
0.0225	0.45	0.02	0.052	0.63
0.0585	0.82	0.06	0.074	0.96
0.11	1.23	0.11	0.093	1.29

4. EXPERIMENTAL RESULTS

4.1 Scour Pattern around Single Spur Dike

To study the scour pattern around spur dikes, a set of experiments was conducted involving three model spur dikes having lengths of 17.5 cm, 14.5 cm and 11.5 cm. Each model spur dike was laid at three different positions i.e, at angles of 60°, 80° and 90° with the flow direction. The scour pattern around spur dike for each position was studied at three Froude number, F_r = 0.63 (Q = 0.0225 m^3s^{-1}), F_r = 0.96 (Q = 0.0585 m^3s^{-1}) and F_r = 1.29 (Q = 0.11 m^3s^{-1}). The scour patterns around the spur dikes are shown from chart 1 to chart 9. It was observed that the scour hole upstream of the spur was conical in shape, whereas at the downstream it was elongated and had a shallower shape. The maximum scour depth occurs at upstream side, near nose of spur dike and erosive sediment was deposited at downstream side of the spur dikes.

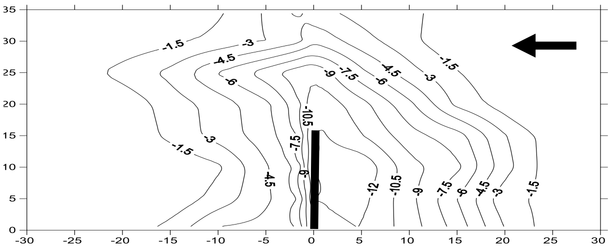

Chart 1: Scour Pattern around single spur with θ=90° (Deflecting Groyne) (F_r = 0.63, Q=0.0225 m^3s^{-1})

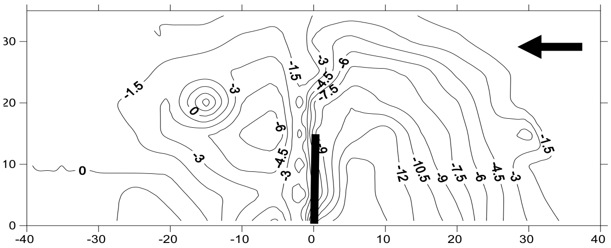

Chart 2: Scour Pattern around single spur with θ=90° (Deflecting Groyne) (F_r = 0.96, Q=0.0585 m^3s^{-1})

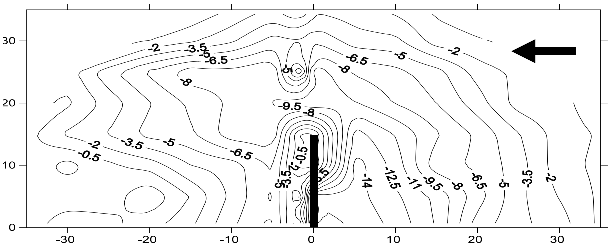

Chart 3: Scour Pattern around single spur with θ=90° (Deflecting Groyne) (F_r = 1.29, Q=0.11 m^3s^{-1})

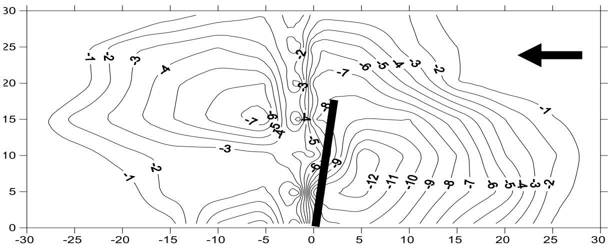

Chart 4: Scour Pattern around single spur with θ=80° (Repelling Groyne) (F_r = 0.63, Q= 0.0225 m^3s^{-1})

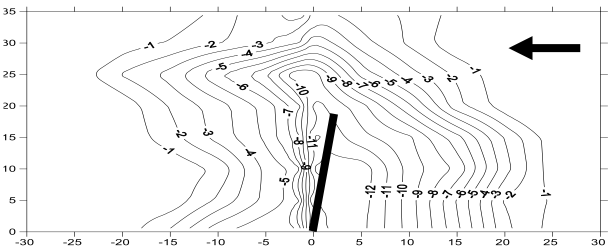

Chart5: Scour Pattern around single spur with θ=80° (Repelling Groyne) (F_r = 0.96, Q=0.0585 m^3s^{-1})

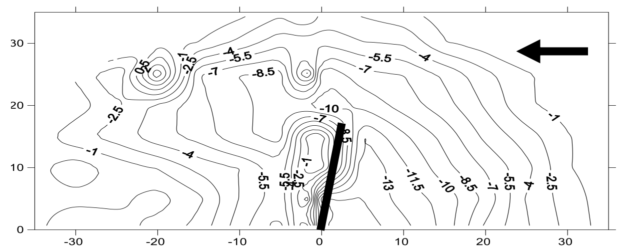

Chart 6: Scour Pattern around single spur with θ=80° (Repelling Groyne) (F_r = 1.29, Q=0.11 m^3s^{-1})

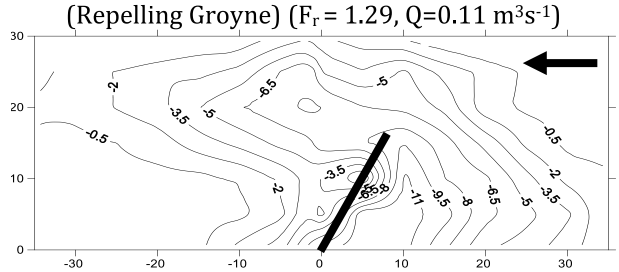

Chart 7: Scour Pattern around single spur with θ=60° (Repelling Groyne) (F_r = 0.63, Q=0.0225 m^3s^{-1})

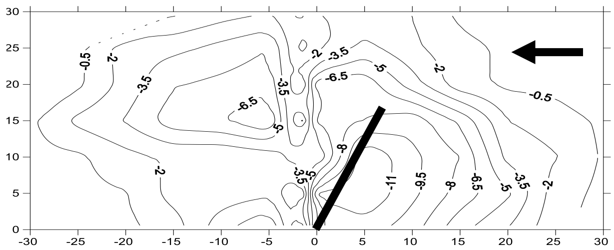

Chart 8: Scour Pattern around single spur with θ=60° (Repelling Groyne) (F_r = 0.96, Q=0.0585 m^3s^{-1})

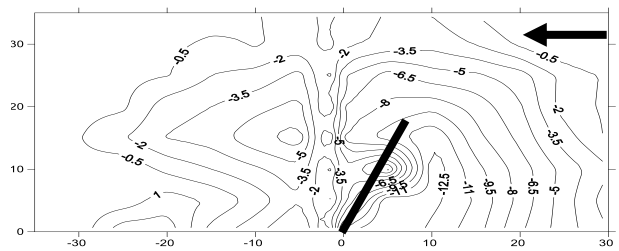

Chart 9: Scour Pattern around single spur with θ=60° (Repelling Groyne) (F_r = 1.29, Q=0.11 m^3s^{-1})

4.2 Effect of Opening Ratio on Scour Pattern:

Opening ratio is defined as the ratio of difference between width of the channel and length of spur dike (B-L) to the width of the channel (B). By changing the opening ratio, there is a great change in the scour pattern around the spur dike. If the length of a spur is too long then it may direct the river current to the opposite bank which will cause damage to the opposite bank during flood and if the length of a spur is too short, it may cause erosion of the near bank. The lengths of the spur taken in the present study were 17.5 cm, 14.5 cm and 11.5 cm and so the opening ratios are namely 0.82, 0.85 and 0.88. In the present study the effects of the opening ratios on the scour hole, depth and length investigated for the different flow conditions and angles of inclination with the flow direction. From the experimental results for different opening ratios the relationship between Froude number (F_r) and different relative scour parameters h_s/L, L_{us}/L, L_{ds}/L, w/L are presented in chart 10 to chart 21 for different angle of inclination with the flow direction. It can be noticed that all the scour parameters increase as Froude number (F_r) increases. From the graphical relationships it can also be observed that with the decrease in opening ratio, the scour hole depth, length and width increases. In other words, decrease in opening ratio results in increase in all the scour parameters.

Table-2: Variation of Relative Scour Parameter with Froude Number (F_r) for different opening ratios

θ	α	F_r	h_s/L	L_{us}/L	L_{ds}/L	w/L
60°	0.82	0.63	0.27	0.59	0.49	0.63
		0.96	0.43	0.89	0.75	0.95
		1.29	0.62	1.18	1.02	1.28
	0.85	0.63	0.23	0.54	0.43	0.58
		0.96	0.37	0.84	0.69	0.89
		1.29	0.58	1.12	0.91	1.23
	0.88	0.63	0.18	0.48	0.36	0.53
		0.96	0.33	0.78	0.63	0.83
		1.29	0.53	1.04	0.86	1.17
80°	0.82	0.63	0.36	0.71	0.58	0.73
		0.96	0.58	1.07	0.89	1.09
		1.29	0.81	1.41	1.19	1.44
	0.85	0.63	0.32	0.66	0.52	0.69
		0.96	0.53	1.01	0.84	1.03
		1.29	0.76	1.33	1.08	1.38
	0.88	0.63	0.28	0.61	0.47	0.63
		0.96	0.48	0.92	0.78	0.93
		1.29	0.71	1.28	0.99	1.32
90°	0.82	0.63	0.47	0.79	0.67	0.82
		0.96	0.73	1.19	1.01	1.23
		1.29	0.98	1.57	1.34	1.64
	0.85	0.63	0.42	0.72	0.63	0.77
		0.96	0.69	1.13	0.92	1.17
		1.29	0.92	1.52	1.27	1.59
	0.88	0.63	0.37	0.67	0.59	0.72
		0.96	0.63	1.02	0.87	0.93
		1.29	0.86	1.46	1.22	1.53

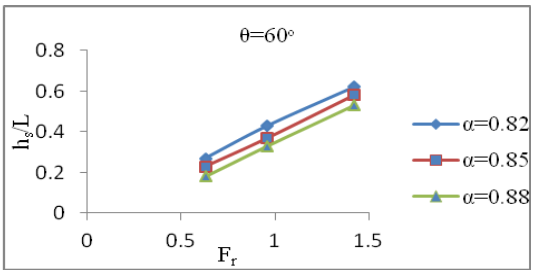

Chart -10: Relative Maximum Scour Depth (h_s/L) vs Froude Number (F_r) (θ=60°)

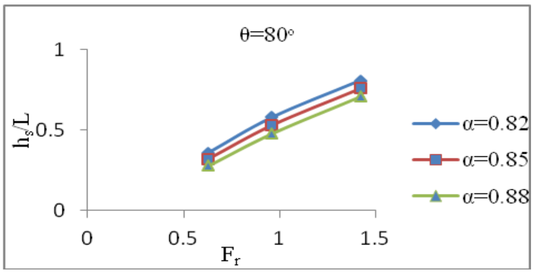

Chart -11: Relative Maximum Scour Depth (h_s/L) vs Froude Number (F_r) (θ=80°)

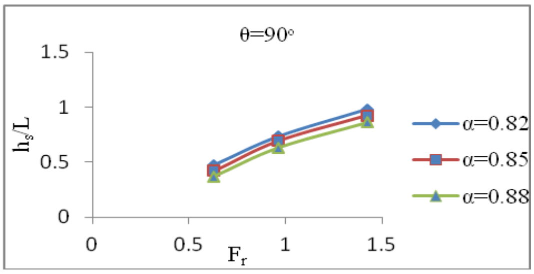

Chart -12: Relative Maximum Scour Depth (h_s/L) vs Froude Number (F_r) (θ=90°)

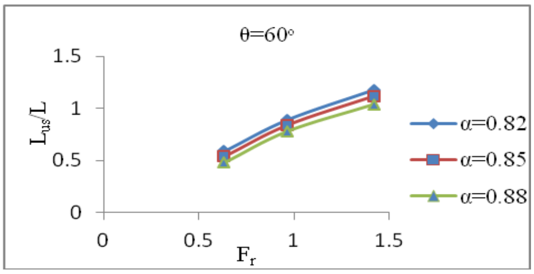

Chart -13: Relative Upstream Scour Length (L_{us}/L) vs Froude Number (F_r) (θ=60°)

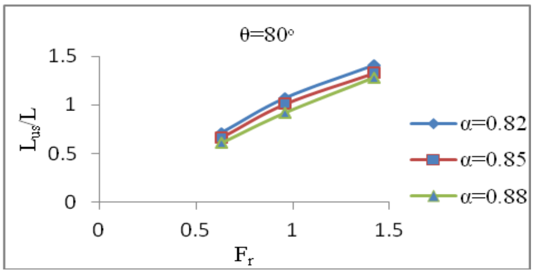

Chart -14: Relative Upstream Scour Length (L_{us}/L) vs Froude Number (F_r) (θ=80°)

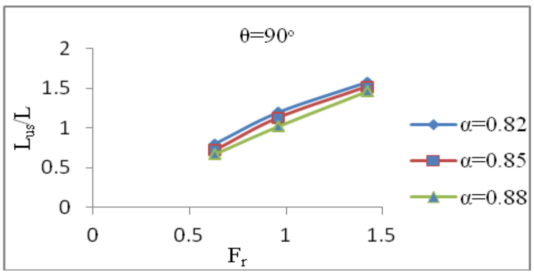

Chart -15: Relative Upstream Scour Length (L_{us}/L) vs Froude Number (F_r) (θ=90°)

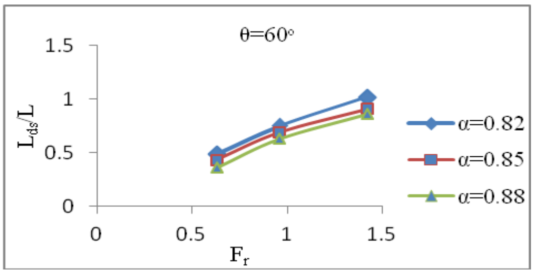

Chart -16: Relative Downstream Scour Length (L_{ds}/L) vs Froude Number (F_r) (θ=60°)

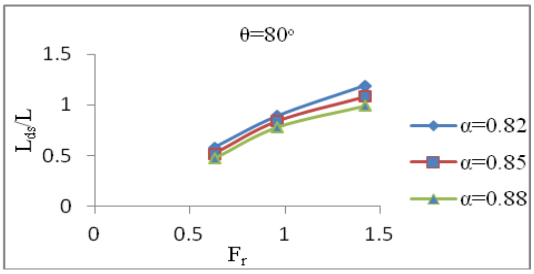

Chart -17: Relative Downstream Scour Length (L_{ds}/L) vs Froude Number (F_r) (θ=80°)

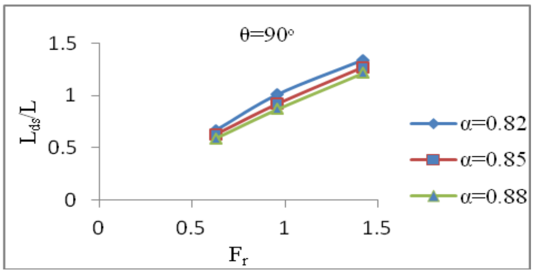

Chart -18: Relative Downstream Scour Length (L_{ds}/L) vs Froude Number (F_r) (θ=90°)

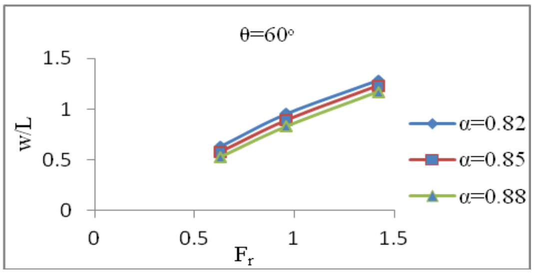

Chart -19: Relative Scour Width (w/L) vs Froude Number (F_r) (θ=60°)

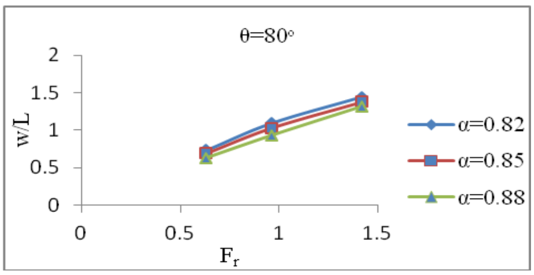

Chart -20: Relative Scour Width (w/L) vs Froude Number (F_r) (θ=80°)

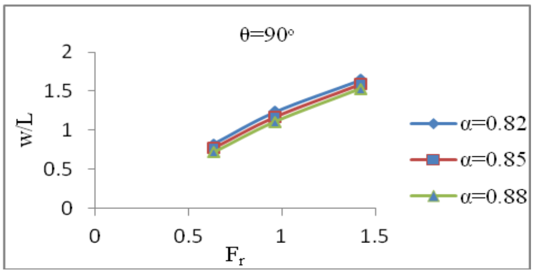

Chart -21: Relative Scour Width (w/L) vs Froude Number (F_r) (θ=90°)

4.3 Effect of Spur Dike Alignment Angle on Scour Pattern

Spur dike may be positioned facing upstream (repelling groyne), normal to flow (deflecting groyne) or facing downstream (attracting groyne). Each orientation to the flow affects the river current in a different way. The present study was limited on the case of deflecting and repelling groyne. The angle tested in this study was 60°, 80° and 90° with the flow direction for three different opening ratios namely 0.82, 0.85 and 0.88 for different flow conditions. From the experimental results for different opening ratios, the relationships between Froude number (F_r) and different relative scour parameters h_s/y, L_{us}/y, L_{ds}/y, w/y for three different spur dike alignment angles 60°, 80° and 90° with the flow direction in chart 22 to chart 33 are presented. From these relationships it can be observed that as the angle of inclination of the spur dike decreases from 90° to 60° the scour depth also decreases. In other words the scour parameters decrease with the decreases of angle of inclination.

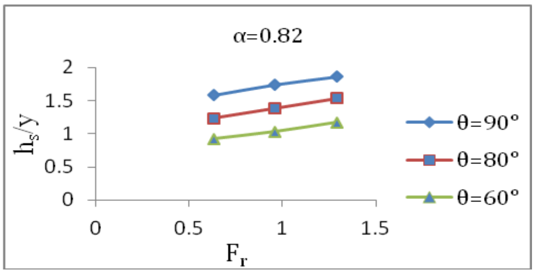

Chart-22: Relative Maximum Scour Depth (h_s/y) vs Froude Number (F_r) (α=0.82)

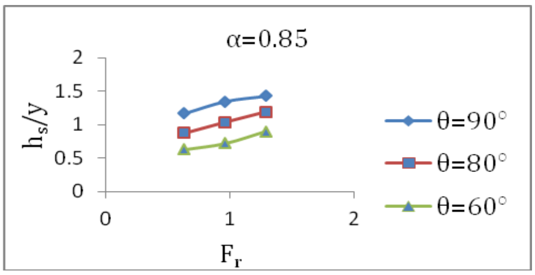

Chart-23: Relative Maximum Scour Depth (h_s/y) vs Froude Number (F_r) (α=0.85)

Table-3: Variation of Relative Scour Parameter with Froude Number (F_r) for different angle of inclination

θ	α	F_r	h_s/y	L_{us}/y	L_{ds}/y	w/y
60°	0.82	0.63	0.92	1.98	1.65	2.11
		0.96	1.03	2.11	1.78	2.26
		1.29	1.17	2.23	1.93	2.42
	0.85	0.63	0.63	1.50	1.19	1.61
		0.96	0.72	1.65	1.35	1.74
		1.29	0.90	1.74	1.42	1.91
	0.88	0.63	0.40	1.06	0.81	1.17
		0.96	0.51	1.20	0.97	1.28
		1.29	0.66	1.29	1.06	1.44
80°	0.82	0.63	1.23	2.40	1.96	2.46
		0.96	1.38	2.54	2.12	2.59
		1.29	1.53	2.65	2.24	2.71
	0.85	0.63	0.88	1.85	1.44	1.92
		0.96	1.04	1.97	1.65	2.04
		1.29	1.19	2.07	1.69	2.15
	0.88	0.63	0.61	1.35	1.04	1.38
		0.96	0.76	1.43	1.20	1.43
		1.29	0.88	1.58	1.22	1.63
90°	0.82	0.63	1.58	2.65	2.27	2.77
		0.96	1.74	2.82	2.40	2.93
		1.29	1.86	2.97	2.53	3.09
	0.85	0.63	1.17	2.02	1.75	2.15
		0.96	1.35	2.22	1.79	2.29
		1.29	1.43	2.36	1.97	2.47
	0.88	0.63	0.81	1.48	1.31	1.59
		0.96	0.97	1.58	1.35	1.72
		1.29	1.05	1.81	1.50	1.88

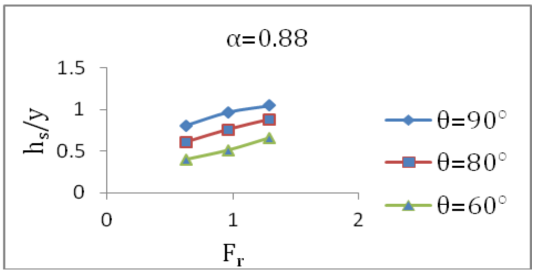

Chart-24: Relative Maximum Scour Depth (h_s/y) vs Froude Number (F_r) (α=0.88)

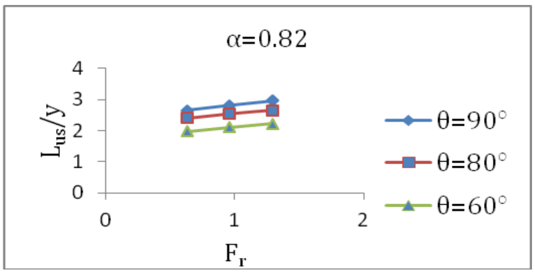

Chart 25: Relative Length of Scour U/S the Spur Dike (L_{us}/y)) vs Froude Number (F_r) (α=0.82)

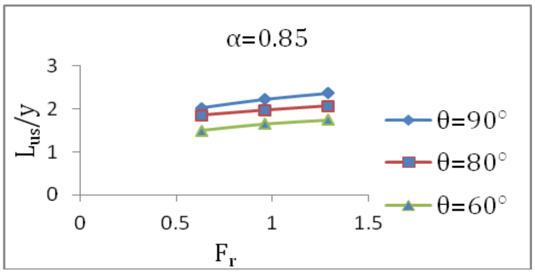

Chart 26: Relative Length of Scour U/S the Spur Dike (L_{us}/y) vs Froude Number (F_r) (α=0.85)

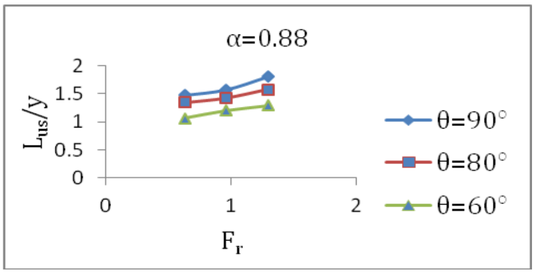

Chart 27: Relative Length of Scour U/S the Spur Dike (L_{us}/y) vs Froude Number (F_r) (α=0.88)

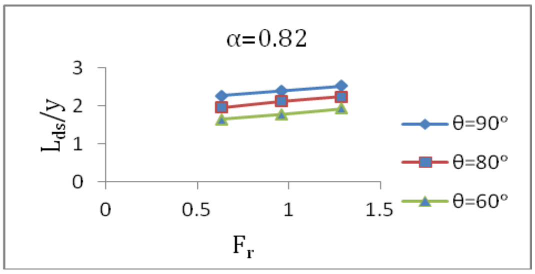

Chart 28: Relative Length of Scour D/S the Spur Dike (L_{ds}/y) vs Froude Number (F_r) (α=0.82)

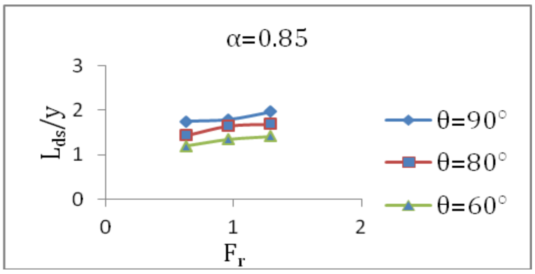

Chart 29: Relative Length of Scour D/S the Spur Dike (L_{ds}/y) vs Froude Number (F_r) (α=0.85)

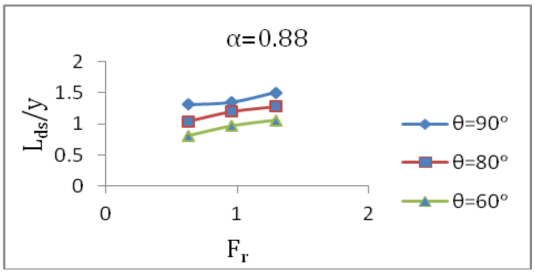

Chart 30: Relative Length of Scour D/S the Spur Dike (L_{ds}/y) vs Froude Number (F_r) (α=0.88)

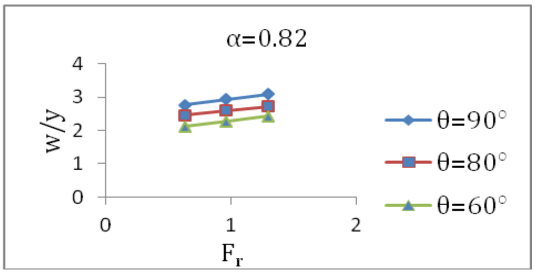

Chart 31: Relative Width of Scour Depth (w/y) vs Froude Number (F_r) (α=0.82)

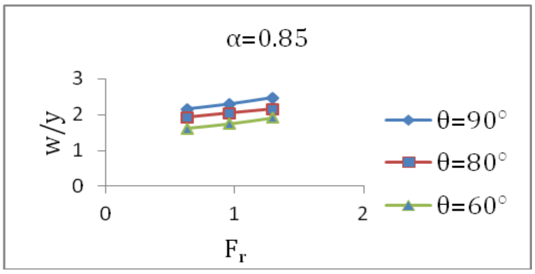

Chart 32: Relative Width of Scour Depth (w/y) vs Froude Number (F_r) (α=0.85)

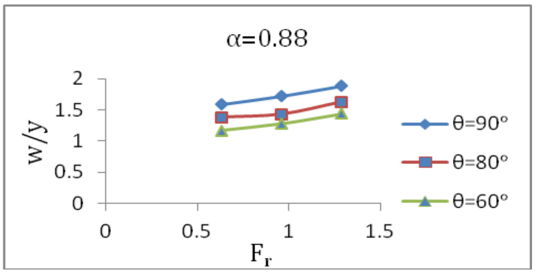

Chart 33: Relative Width of Scour Depth (w/y) vs Froude Number (F_r) (α=0.88)

5 CONCLUSIONS

The results of several long durations scour laboratory experiments around spur dike were presented in this study to investigate the characteristics of scour hole around a single spur dike installed in a straight open channel. The results of these experimental tests were analyzed and discussed and the following conclusions could be drawn from the present study:

1. The maximum scour depth occurs at upstream side, near nose of spur dike and erosive sediment was deposited at downstream side for both the spur dikes.

2. All scour parameters Relative Maximum Scour Depth (h_s/L), Relative Length of Scour U/S the Spur Dike (L_{us}/L), Relative Length of Scour D/S the Spur Dike (L_{ds}/L), Relative Width of Scour depth (w/L) increase with the increase of the Froude Number F_r for different opening ratios.

3. Other conditions remaining the same, all the relative scour parameters increase with the decrease in opening ratio.

4. All scour parameters Relative Maximum Scour Depth (h_s/y), Relative Length of Scour U/S the Spur Dike (L_{us}/y), Relative Length of Scour D/S the Spur Dike (L_{ds}/y), Relative Width of Scour depth (w/y) increase with the increase of the Froude Number F_r for different angle of inclinations.

5. For the same opening ratio and flow conditions, the scour depth has been found to be minimum when the angle of inclination is 60°.

NOTATIONS

F_r	Froude Number
h_s	Maximum Scour Depth
L_{us}	Scour Hole Length U/S the Spur Dike
L_{ds}	Scour Hole Length D/S the Spur Dike
w	Width of Scour Hole
y	Flow Depth
θ	Angle of Spur Dike with Flow Direction
q	Discharge per unit width
L	Effective length of spur dike
D_{50}	Median Grain Size
α	Opening Ratio
V	Velocity

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