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ARTICLE

Effect of Meander on Bridge Pier Scour

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ABSTRACT

Lots of work regarding the scour around bridge piers in straight channel have been donein the past by many researchers. Many factors which affect scour around piers such as shape of piers, size, positioning and orientation etc. have been studied in detail by them. However, similar studies in meandering channels are scanty. Very few researchers have studied the effect of angular displacement which has considerable effects of scour around bridge piers.

In this paper an attempt has been made to carry out a detailed study of angular displacement on scour. A constant diameter bridge pier of circular shape has been tested in a meandering channel bend with bend angle as 80^0. The test bed was prepared by using uniform sand having d_{50} as 0.27 mm and run was taken for a discharge of 2.5 l/s.

1. Introduction

Local scour is defined as the removal of bed materials from the vicinity of hydraulic structures such as abutments, below spillways, at upstream and downstream of causeways etc. The hydraulic failure of any structure depends upon the local scour that occurs around the structures. Specially, the main cause of bridge failure is the failure of its piers and abutments during heavy flood when water passes the piers and abutments. The basic mechanism of occurrence of local scour around the piers highly depends upon the vortex flow which develops near the obstruction site. Generally, pier scour occurs due to a complex vortex system. This system consists of a horseshoe vortex initiated from the down flow at the upstream face of the pier, wake vortices which shed from sides of the pier due to flow separation as well as boe vortex which is also called surface roller. This complex system digs the scour hole and deepens it. Flow pattern and mechanism of scour around a bridge pier have been

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studied experimentally in past by many investigators in cohesion less as well as cohesive soils.

Some of the most reliable studies were carried out in straight channel by [8,13,14,2,3,9], and many others There is little information available about the scour at bridge pier in curved channel reaches. The studies related to this context at hand are, those conducted by [5,10-12,6,1]. The main feature of a bend flow is the presence of spiral flow, and lateral sediment transport across the channel bend is observable. Particles at the surface of the flow in the bend tend to move toward the outer wall while at the bed elevation they tend to move forward the outer wall they tend to move toward the inner wall of the channel. Keeping in mind the gap, the present work has been taken up to study the effect of angular spacing i.e. presence of bend on scour and deposition pattern around the bridge pier.

2. Dimensional Analysis

The variables required to define the flow characteristics in straight and curved open channels are, velocity of flow (v), the radial spacing x, depth of flow above channel bed (y), mean sediment particle size (d_{50}), mass density of water (ρ), viscosity of water (μ), acceleration due to gravity (g), and angular displacement (θ).

Since, $d_S = f(v, , x, \theta, d_{50}, \mu, W)$ (1)

Carrying dimensional analysis following dimensionless numbers obtained. $\pi_1 = f\{\pi_2, \pi_3, \pi_4, \pi_5, \pi_6\}$ or $d_S/y = \{d_{50}/y, x/W, \theta, \rho v y/\mu, v/\sqrt{(gy}\}$ (2)

Since ranges of d50/y, ρvy/μ and v/√(gy are very small and only one size of sediment is used hence all three terms are dropped. And finally we have $d_S/y = (x/W, \theta)$. (3)

2.1 Experimental Model Description

Experiments were carried out in Advanced Post Graduate Hydraulics Laboratory, Department of Civil Engineering, Zakir Hussain College of Engineering & Technology, Aligarh Muslim University, Aligarh. The data are collected in an open horizontal rectangular sinuous (meandering/curved) channel (0.35 m wide and 0.43 m deep) made up of 0.5 mm thick tin sheet, carefully installed in an open horizontal rectangular flume (0.76 m wide and 0.60 m deep and 10.5 m long) prismatic glass walled channel with cement plastered bottom. The schematic diagram and photographic view of the experimental setup are shown in Figures 1 and 2.

The experimental channel consisted of 2.88 m long upstream and 2.11 m long downstream straight reaches. The model has a straight upstream reach of 2.88 m and a straight downstream reach of 2.1 m. In between the upstream and the downstream reach four sinuous bends having same dimensions are present. The four 80° curved channel bends were provided in series. Each bend has rectangular cross section with 0.35 m width, 0.43 m height and with 0.705 m radius of curvature at center line. The central angle of the bend is 80˚ and the central radius of the channel (Rc) is 0.705 m. The width of the experimental model is 0.35 m here Rc/W = 2.014 (Ratio of the central radius to the width of the channel). Since the ratio Rc/W is less than 3, the bend is considered as a sharp bend. A straight transition of 0.05 m is provided between each bends. The test bed was made using Ganga sand with d_{50} as 0.27 mm and sg = 1.35. The bed was properly compacted using tamping rod with equal efforts

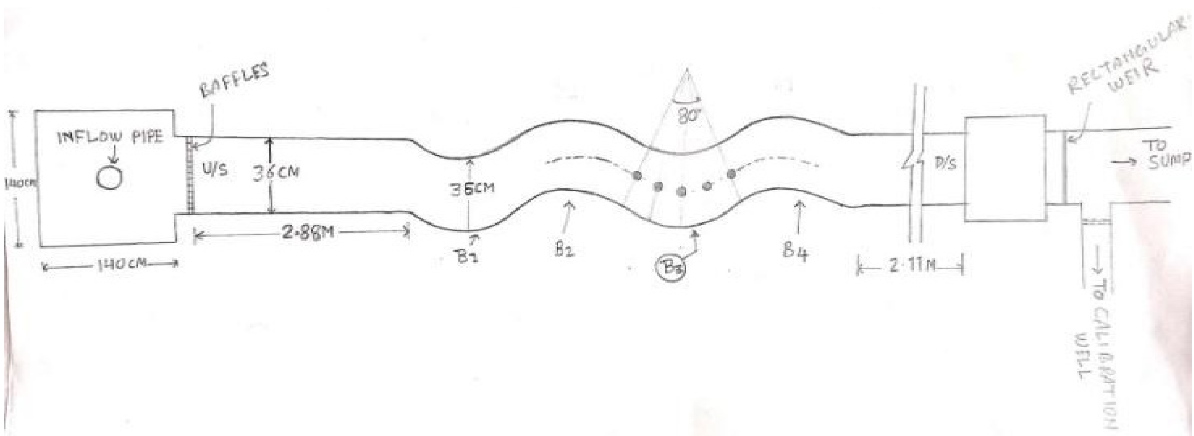

Figure 1. Schematic view of experimental channel

to make even surface with equal compacted density prior to start of run. The circular piers with diameter of5.75 cm made of G.I pipe were used for observation of scour and deposition. Predetermined locations were first decided to takethe readings as shown in Figures 3 and 4.

Figure 2. Schematic view of scour around pier used in present study

2.2 Experimental Procedure

Water is allowed to pass in the experimental channel at a constant rate from a re-circulated water supply system. After steady state condition of flow is reached, the observations for measuring the scour around bridge pier have been started. The experimental data were mainly concentrated for the 3rd Bend of meander channel as shown in Figure 2. Experimental data collected in the vicinity of pier were taken at each 20^0 interval of angular displacement in meander bend i.e 0^0, 20^0, 40^0, 60^0 and 80^0 as shown in Figure 3. To collect the experimental data at each predetermined locations of 3rd Bend of meander channel, five transverse sections as shown in Figure 4 were taken to cover the whole surrounding of pier and scour extent. Moreover, the data were also collected for local scour around pier in straight u/s reach of experimental channel and also experimental data were collected for 3rd Bend of meander channel without pier, reading were taken across the width of bend at each 20^0 interval of angular displacement, beginning from 0^0 angular displacement to 80^0. The whole above mentioned procedure were conducted for flow rate Q = 2.5 l/s.

3. Data Analysis, Discussion and Results

Figure 6 shows that the variation of scour and deposition across the bend from inner side of the bend to outer side (x/W = 0 to 1.0) i.e. along transverse direction for discharge Q = 2.5 l/s for various angular displacement

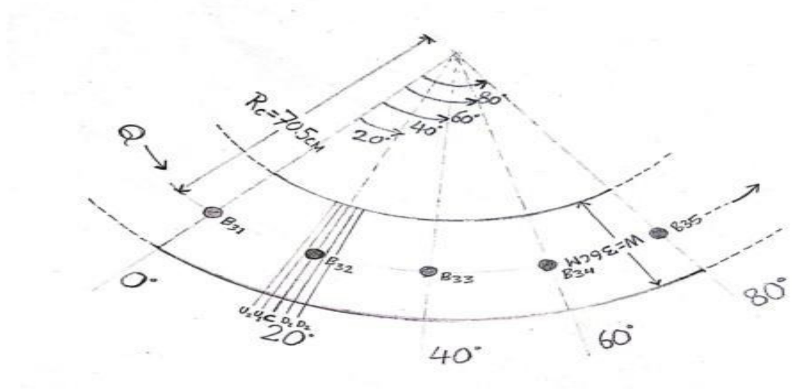

Figure 3. Schematic View of Bend - 3 (B-3) and Pier position at different angular displacement (θ).

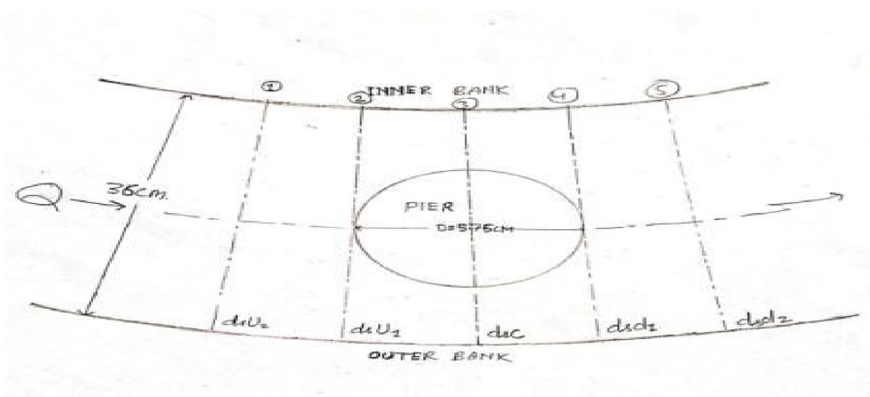

Figure 4. Showing the Centrally positioned Pier in Bend -3 of experimental

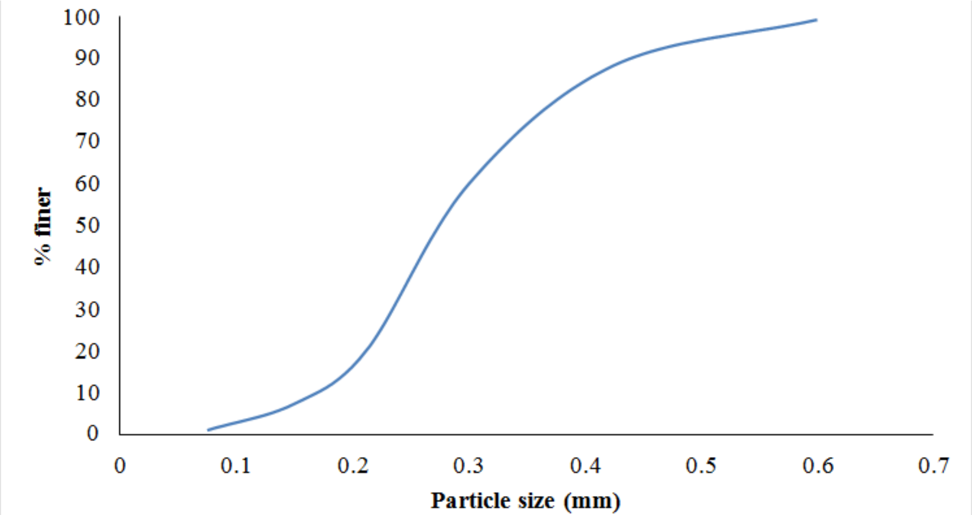

Figure 5. Particle size distribution curve

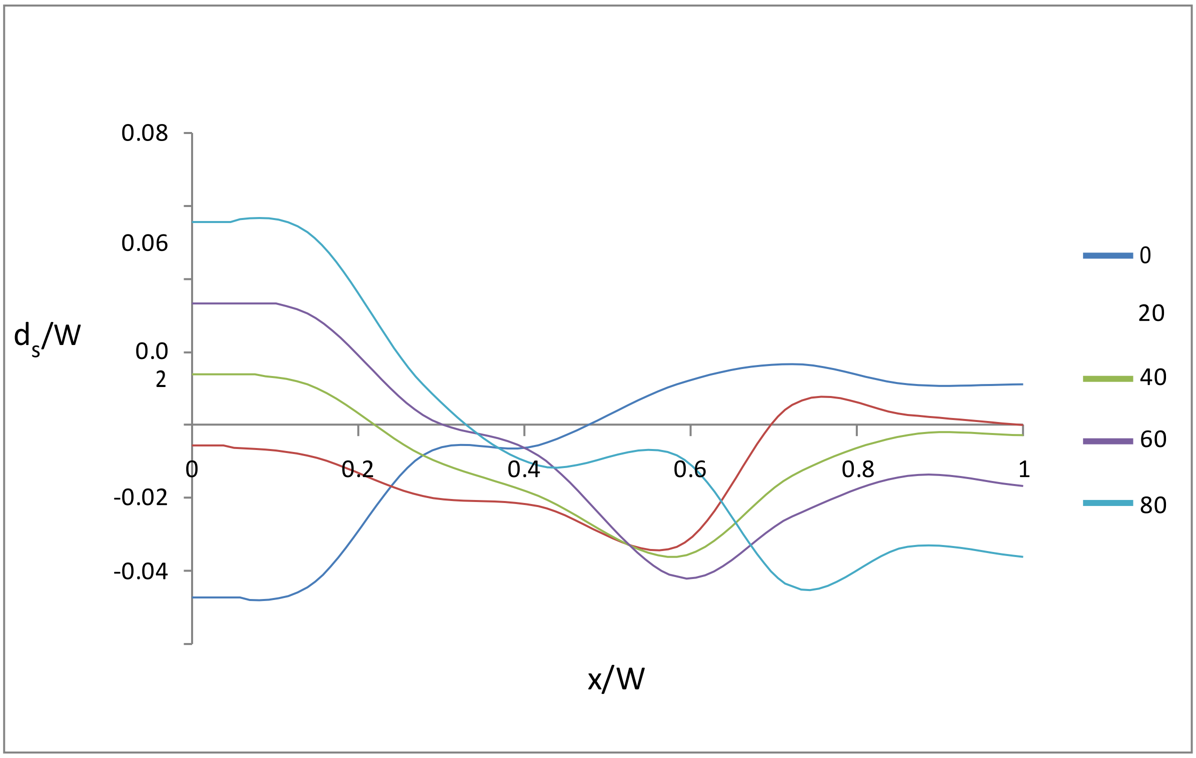

Figure 6. Variation of general scour and deposition in meander channel at different angular displacement θ for Q = 2.5 l/s

(θ). Here x is the normal distance measured from inner bank towards outer bank. W be the total width of the channel. It is clear from this graph that the scour and deposition both depend upon angular displacement (θ). As θ increases the scour decrease and deposition of bed material increases attaining a maximum value for $\theta = 80^0$ on inner bank of bend (x/W = 0.0). It is also found that at outer bank of bend (x/W = 1.0), this phenomenon is just reverse. And in between two banks where x/W = 0.2 to 0.8, the scour is considerable in comparison to deposition.

Figure 7 shows the variation of scour and deposition across the width of the meandering channel at different θ, for discharge Q = 2.5 l/s. along inner wall. It can be seen from the Fig.6 that at $\theta = 0^0$, there is scour and it reduced at $\theta = 20^0$, as θ (40^0, 60^0, 80^0) values increases the scour reduces and deposition increase at inner wall. It can also be seen from the Fig.7 that at $\theta = 0^0$ there is deposition and as θ increases from $\theta = 20^0$ to $\theta = 80^0$, the deposition reduces as a result of the

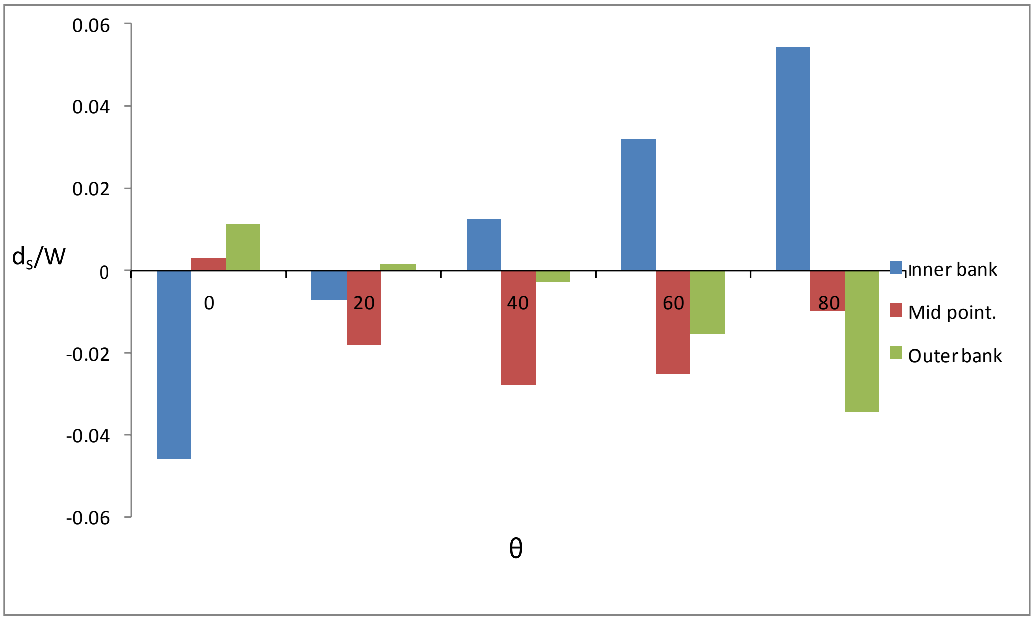

Figure 7. Variation of general scour and deposition in meander channel at different angular displacement θ for Q = 2.5 l/s.

Variation of Scour along different sections and Angular Displacement (θ) for Q = 2.5 l/S

Figures 8 and 9 show the variation of scour depth along transverse direction at $\theta = 0^0$ for a discharge of Q = 2.5 l/s. The various colored lines shows the scour variation along five transverse sections; such as centre line (dsC), u/s section-1(dsU1), u/s section-2 (dsU2), d/s section-1 (dsD1) and d/s section-2 (dsD2). It is clear from these plots that for x/W from 0 to 0.2 there is scour at $\theta = 0^0$; this value is increasing at all section from x/W = 0.2 to 0.8. After that i.e. near to outer bank there is deposition.

Table 1. Showing the values of scour at different locations

G.R Position	Initial B.L.	Final bed level (G.R) at diff. sections (cm)					ds (cm)				
(cm)	(cm)	dsC	dsU1	dsU2	dsD1	dsD2	dsC	dsU1	dsU2	dsD1	dsD2
0	68	68.9	68.8	68.7	70	70.2	0.9	0.8	0.7	2	2.2
5	68	68.6	68.6	68.6	68.7	70	0.6	0.6	0.6	0.7	2
10	68	66	66.6	67.9	66.4	67	-2	-1.4	-0.1	-1.6	-1
15	68	63.9	64	66	64.5	65.5	-4.1	-4	-2	-3.5	-2.5
21	68	64.6	64.7	65.6	65.8	67.6	-3.4	-3.3	-2.4	-2.2	-0.4
25	68	66.9	66.5	66.1	67.4	68.1	-1.1	-1.5	-1.9	-0.6	0.1
30	68	67.3	67	66.9	67.9	67.6	-0.7	-1	-1.1	-0.1	-0.4
35	68	67.3	67.6	67.6	67.8	67.7	-0.7	-0.4	-0.4	-0.2	-0.3

Pier position at angular displacement, θ=60°
Initial bed level gauge reading (G.R), Yb = 68.0cm
Discharge, Q = 2.5l/s
Depth of water flowing, y = 3.375cm
Width of channel, W = 35cm
B.L= Bed Level
G.R = Gauge reading
ds(cm), scour depth

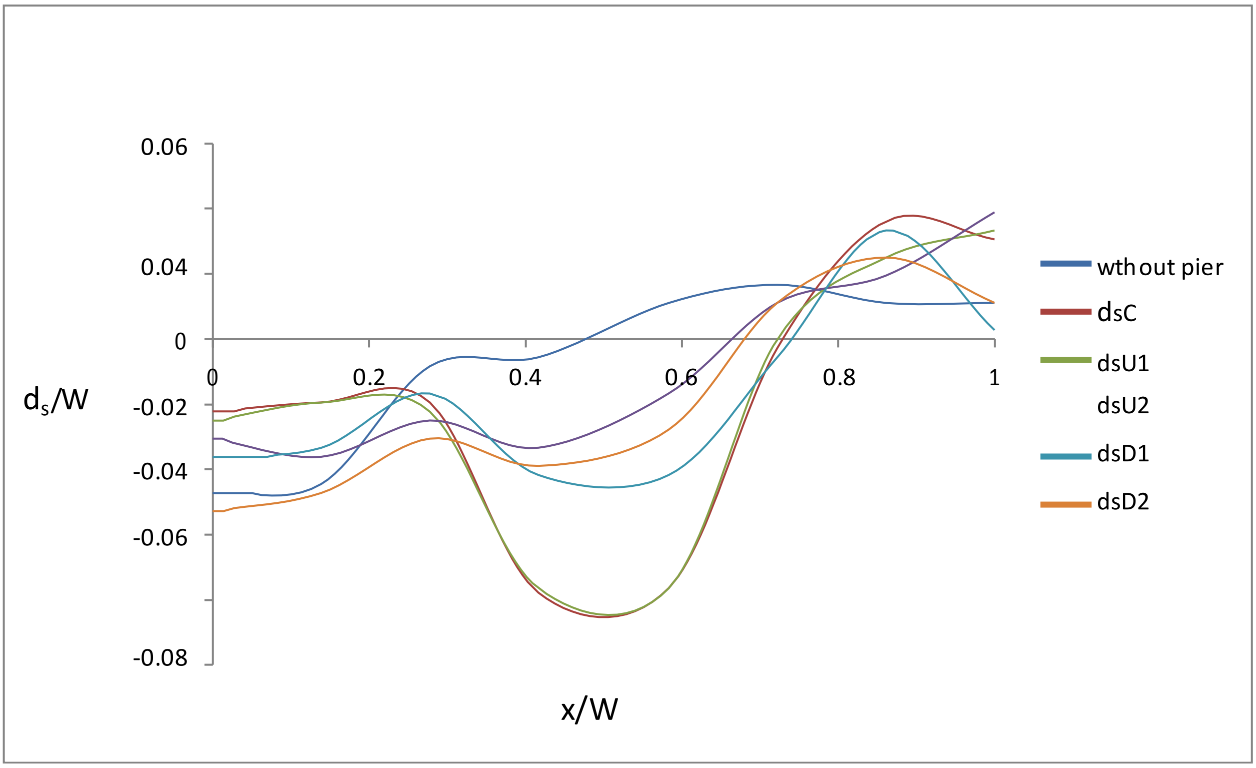

Figure 8. Variation of scour along different sections at θ = 0° for Q = 2.5 l/s

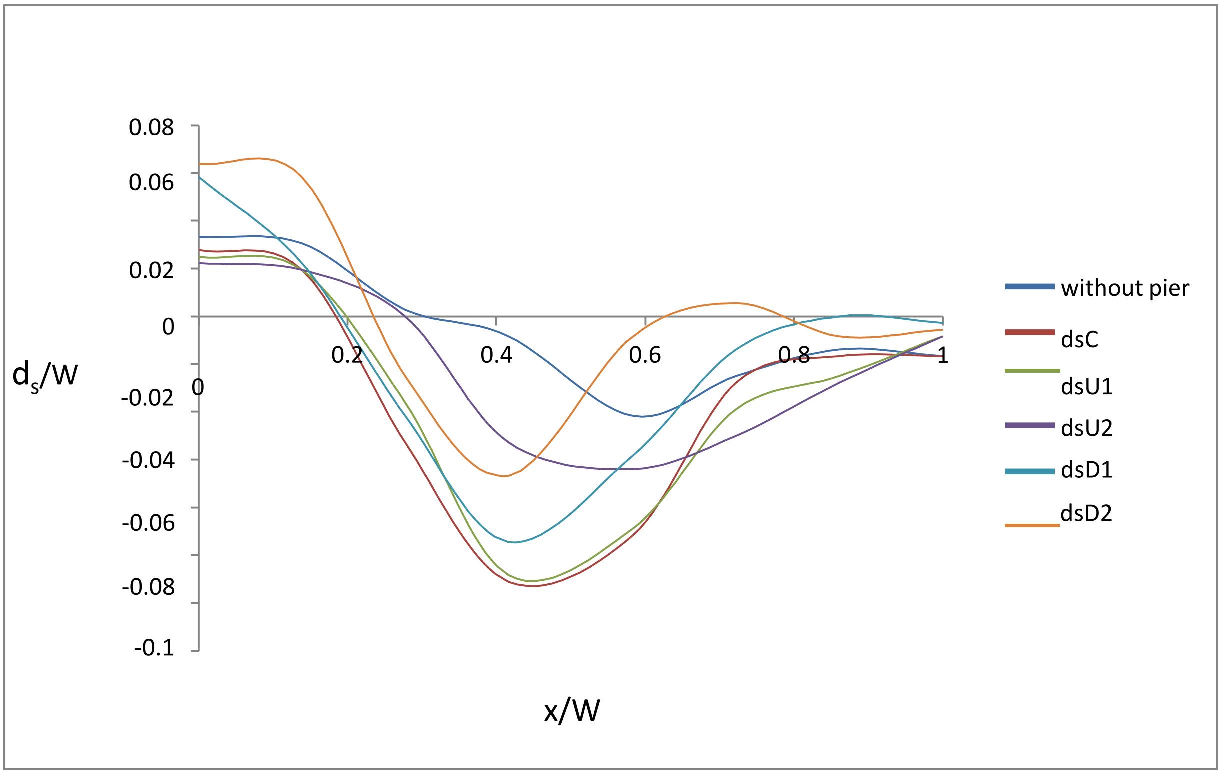

Figure 9. Variation of scour along different sections at θ = 60° for Q = 2.5 l/s

Variation of Scour and Deposition along Various Sections at Different Angular Displacement (θ) and Discharges

Figure 10 shows the variation of scour along transverse direction for discharge Q = 2.5 l/s at various angular displacement θ. It is clear from this two graph that at inner bank scour decreases gradually with θ values, then start increasing gradually and attained peak values in the vicinity of pier (x/W = 0.42 to 0.58). Further as x/W increases towards outer bank, scour start decreasing gradually and deposition start toward outer bank. It is also clear from the graph, the maximum scour occur for 60^0 displacement. However the scour values are almost equal for $\theta = 40^0$ and 60^0.

Variation of Scour and Deposition along Various Sections at Different Angular Displacement (θ) and Discharges

Figure 12 shows the variation of scour/deposition at the centre line section for two discharges i.e Q = 2.5 l/s and Q = 4.5 l/s at various angular displacement. It is found that it depends on discharge (flow rate). As discharge is increasing, the scour increases. Also it is clear that as displacement increases gradually for 0^0 to 80^0, the scour increases slowly up to 60^0 after that start decreasing gradually. This pattern was obtained for both Q values. Similar trend of variation have been found for the remaining sections (dsU1, dsU2, dsD1, dsD2) not shown here.

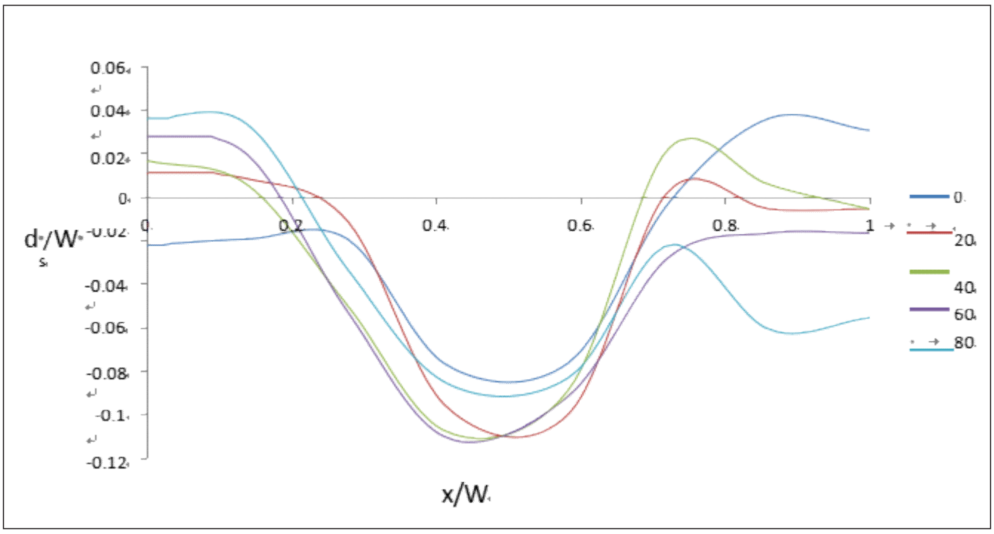

Figure 10. Variation of scour along centre line section (dsc) at different angular displacement, θ for Q = 2.5 l/s

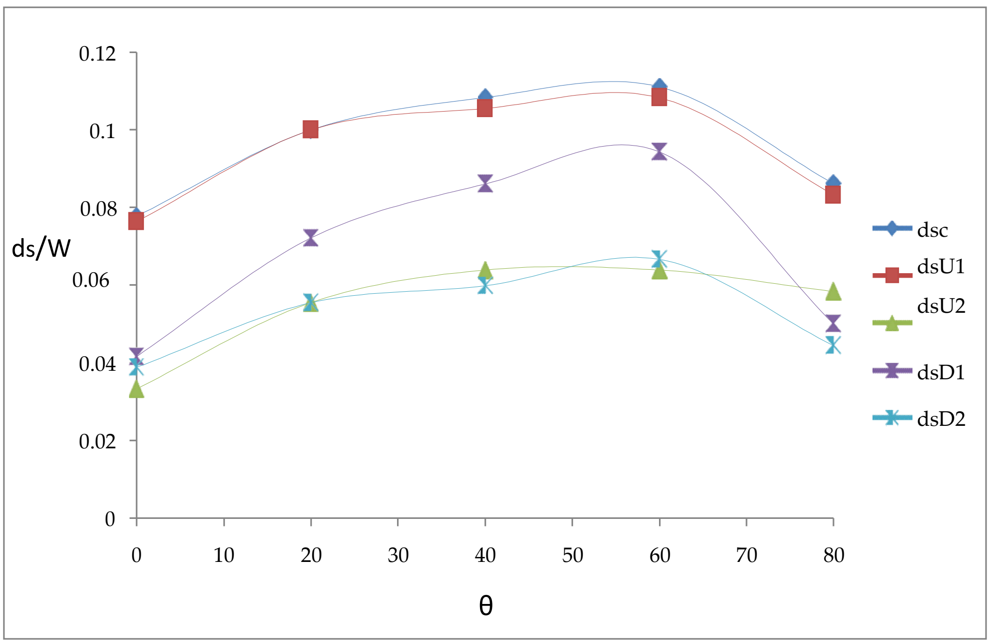

Figure 11. Variation of bridge pier scour in meander channel at different angular displacement (θ) and transverse sections for Q = 2.5 l/s.

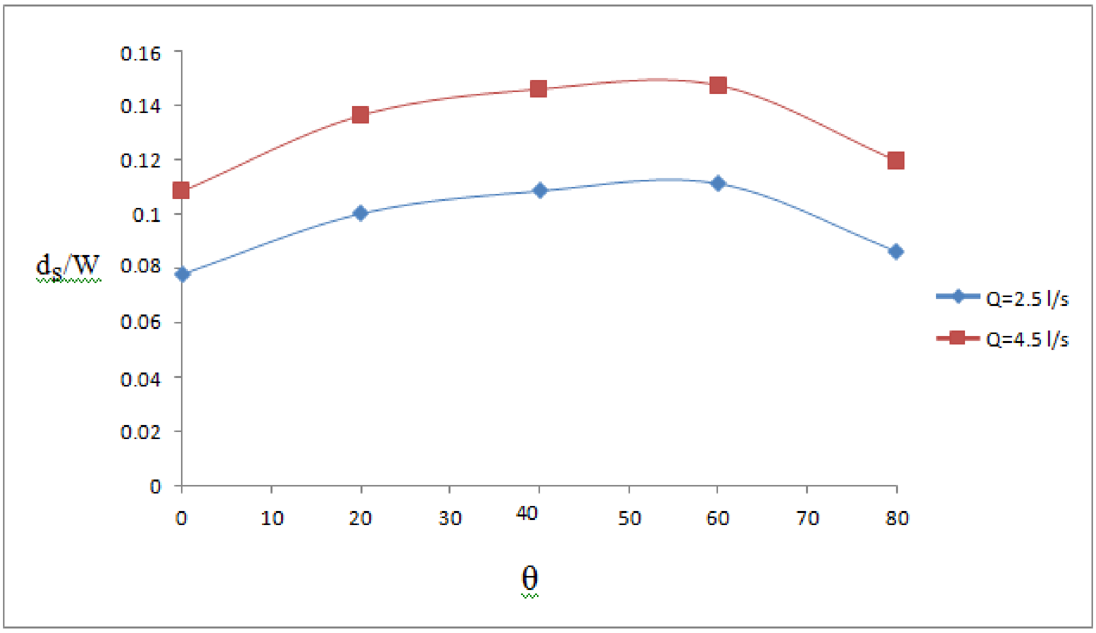

Figure 12. Variation of bridge pier scour in meander channel at different angular displacement (θ) and discharge for centre line section (dsC).

Variation of Scour and Deposition in Straight Channel and at Angular Displacement (θ) in Meander Channel for Different Discharges

Figure 13 shows the variation of scour in straight and meander portion of channel with and without pier. The graph is plotted for Q = 2.5 l/s along transverse direction for various angular displacement. It is found that without pier in meandering channel there is scouring along inner side while deposition on outer side at 0^0 displacement. When pier was installed at mid of channel scour is occurred which obtained maximum value near pier and further scour decreases towards outer bank. It is also found that at 0^0 location of pier the value of scour in meander channel is slightly less then the scour obtained in straight channel.

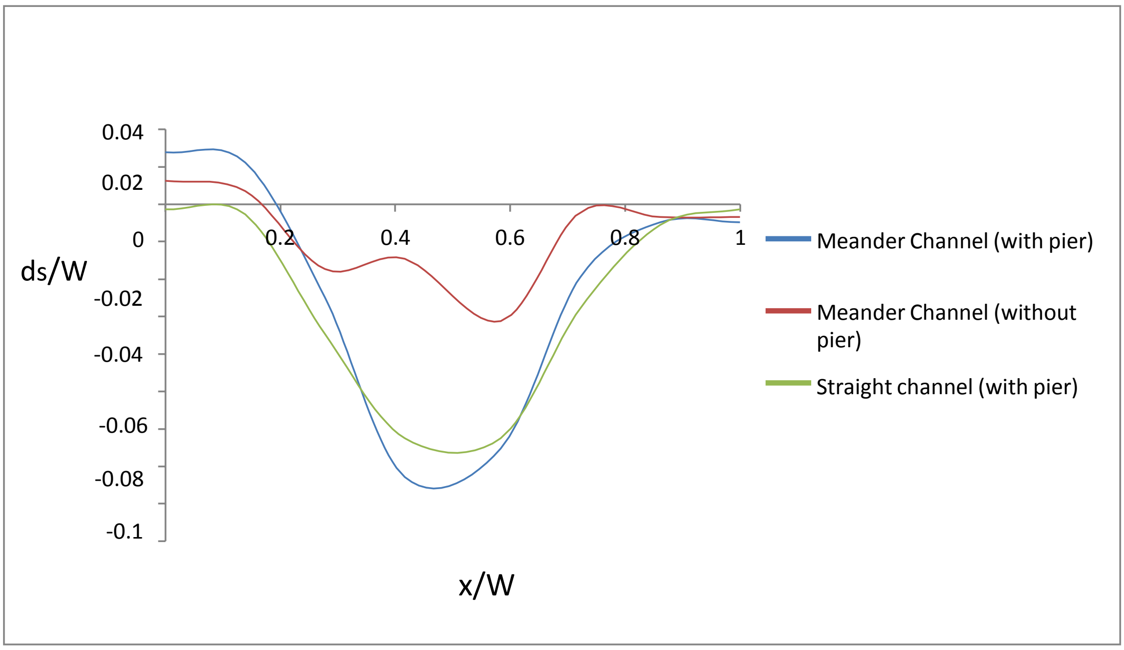

Figure 13. Variation of scour in meander channel at θ = 400 and in straight channel for Q = 2.5 l/s

Comparison of Bridge Pier Scour in Meander Channel at Different Angular Displacement (θ) to Straight Channel for Q = 2.5 l/s

Figure 14 shows the comparison of scour for two discharges at various θ values between straight and meandering channel. It is very clear from these two plots at $\theta = 0^0$ and $\theta = 80^0$, the scour is less in meandering channel in comparison to straight channel. For remaining θ values from $\theta = 20^0$ to $\theta = 60^0$, the scour is more in meandering channel in comparison to straight channel. Also itis clear that at 60^0 angular displacements the scour attains the maximum.

Transverse Variation of Scour and Deposition with Pier in Meander Channel at Different Angular Displacement (θ) for Q= 2.5 l/s

Figure 15 shows the variation scour and deposition with pier across the width of the meanderchannel at different θ, for discharge Q = 2.5 l/s. It can be seen from this graph that, at $\theta = 0^0$, there is scouring and this reduces at $\theta = 20^0$, and as θ (40^0, 60^0, 80^0) values increases the scourreduces and deposition increase at inner wall. It also can be seen from this graph that at $\theta = 0^0$, there is deposition at outer wall and as θ increases from $\theta = 20^0$ to $\theta = 80^0$ the deposition reduces as a result of the scouring increases at the outer wall. Also local scour around circular pier placed at centre of the meander channel at different angular displacement can be noticed. It can be noticed that the maximum scouring around pier is at $\theta = 60^0$ angular displacement.

Comparison of Bend Scour with and without Pier in MeanderChannel at Different Angular Displacement (θ) for Q = 2.5 l/s.

Figure 16 shows the variation of scour and deposition at inner wall with and without pier at different angular displacement θ. It is evident from the above figure, on inner wall of bend at $\theta = 0^0$, effect of scour has reduced after installing the pier at same location ($\theta = 0^0$). As θ no effect when pier increases from 0^0, the nature of scour on inner wall after installing pier is still reducing and have installed at angular displacement $\theta = 50^0$ i.e scour on inner wall is almost equal before and after installing the pier at $\theta = 50^0$ angular displacement of the bend. After $\theta = 50^0$ angular displacement of the bend, the effect of pier on deposition on inner wall at the same location is to reduce the deposition till the end of bend ($\theta = 80^0$).

Figure17 shows the variation of scour and deposition at outer wall with and without pier at different angular displacement θ. It is evident from the above figures, on outer wall of bend at $\theta = 0^0$, effect of deposition has increased after installing the pier at same location ($\theta = 0^0$). As θ increases from 0^0, the nature of deposition on outer

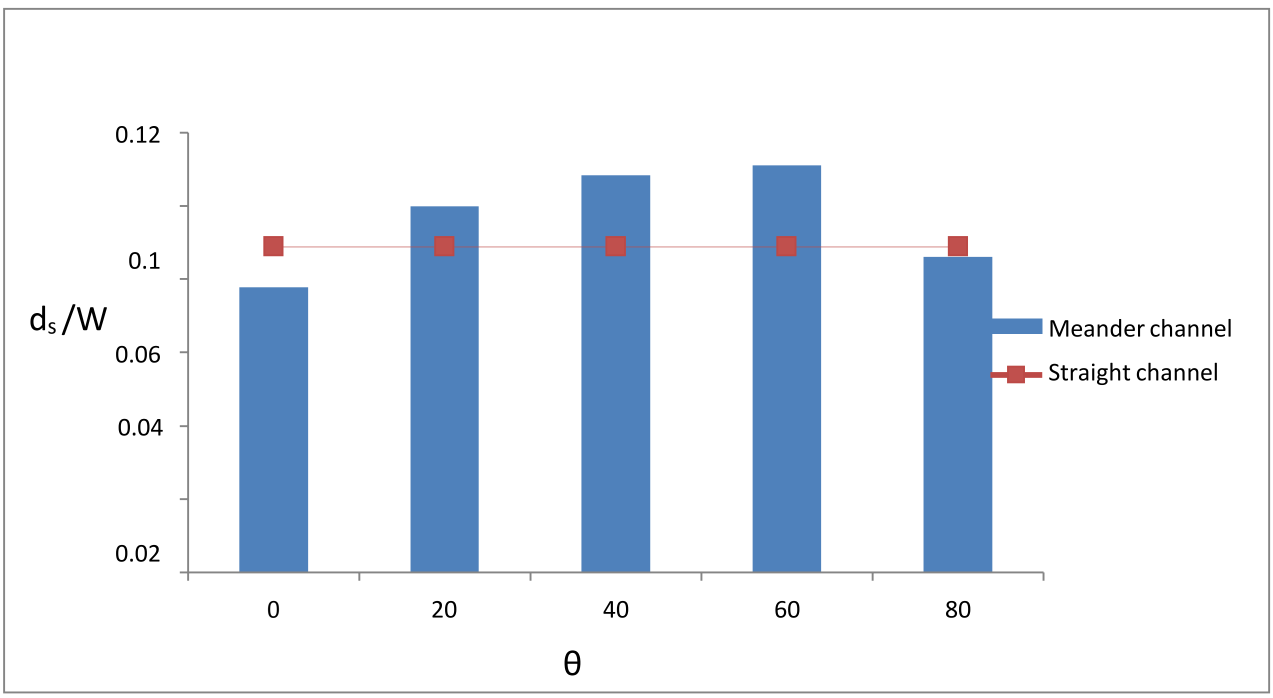

Figure 14. Comparison of bridge pier scour in meander channel at different θ to straight channel for Q = 2.5 l/s

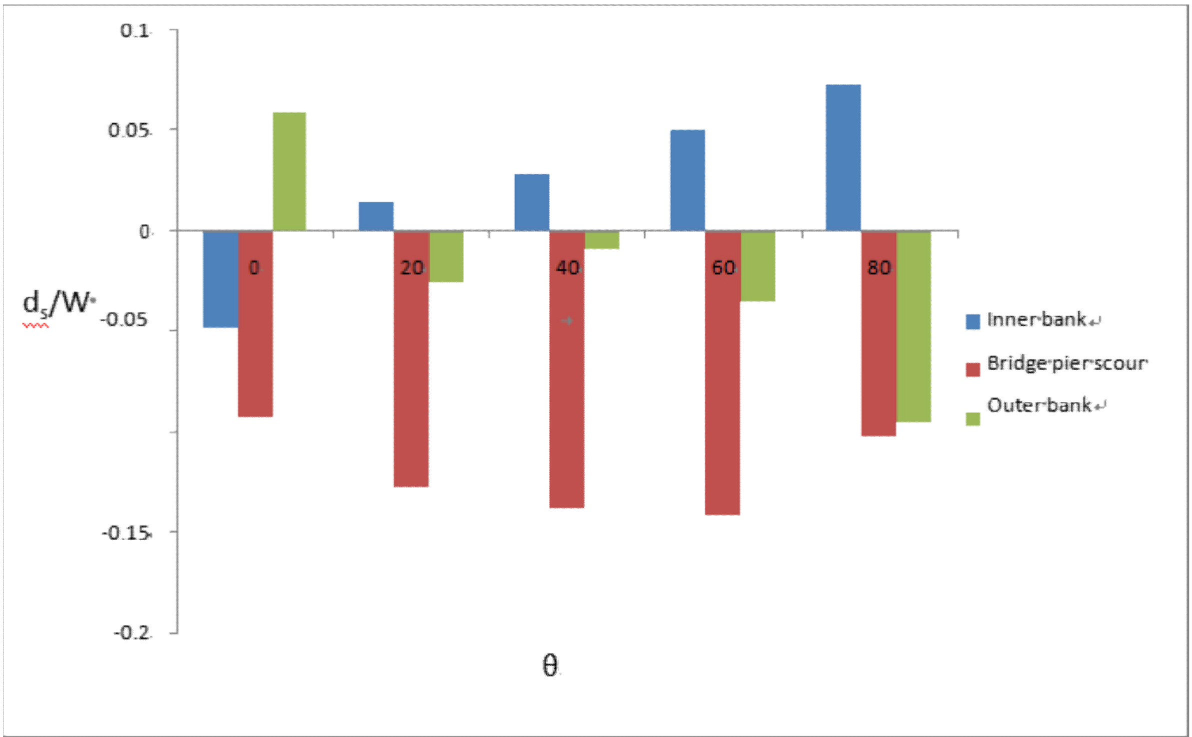

Figure 15. Transverse variation of scour with pier in meander channel at different θ for Q = 2.5 l/s

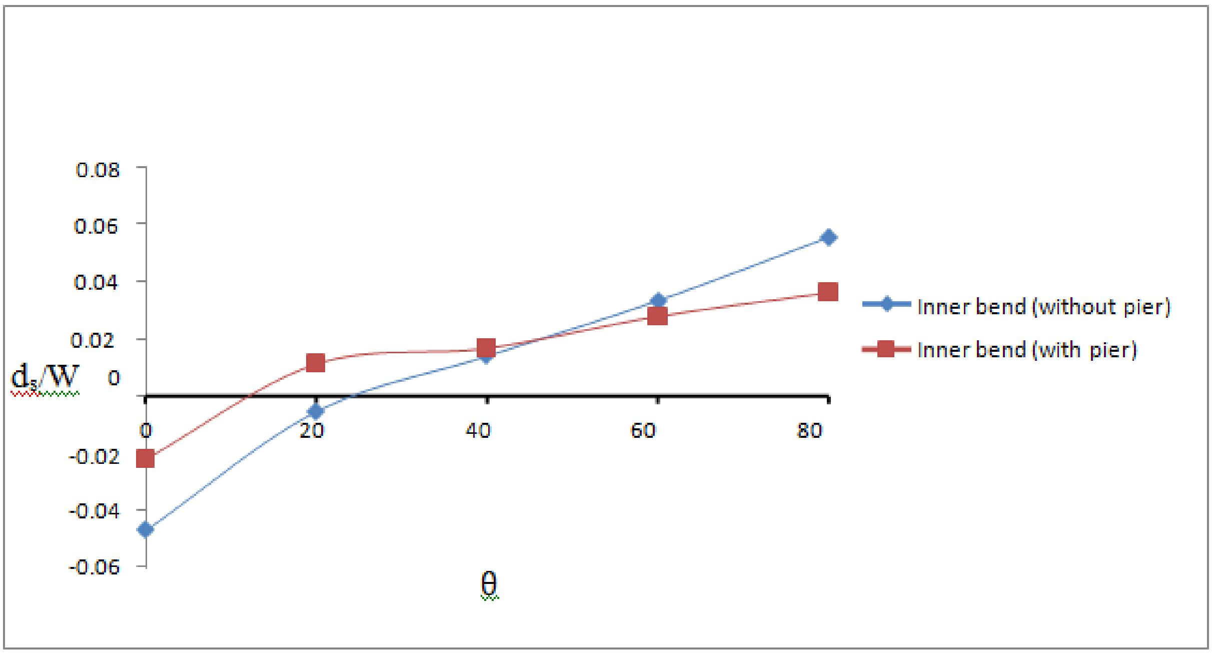

Figure 16. Comparison of bend scour with and without pier in meanderchannel at different **θ** for Q = 2.5 l/s

wall after installing pier is reducing up to 20^0 and have no effect when pier installed between angular displacement θ = 40^0 and θ = 50^0 i.e scour on outer wall is almost equal before and after installing the pier between angular displacement θ = 40^0 and θ = 50^0 of the bend. After θ = 50^0 angular displacement of the bend, the effect of pier on scouring on outer wall at the same location is to increase the scouring till the end of bend (θ = 80^0).

Variation of Scour with Angular Displacement (θ) for Various Investigations

Figure 18 shows the variation of scour with angular displacement (θ) for studied by various in vestigators. It is clear from this graph that as θ increases, the scour

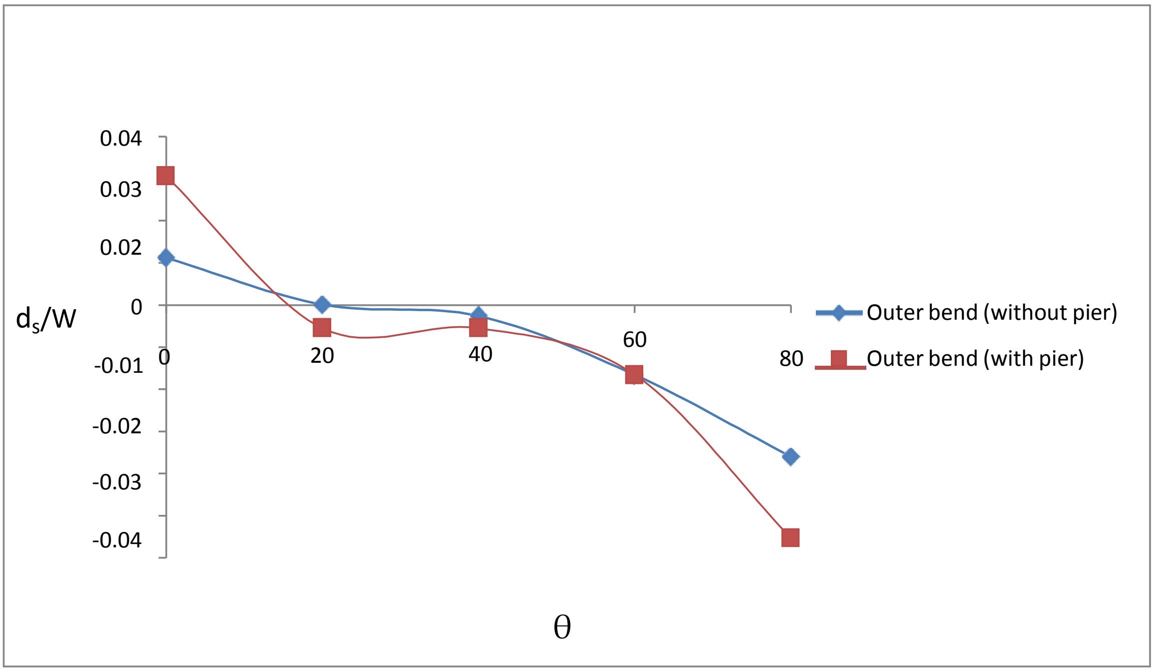

Figure 17. Comparison of bend scour with and without pier in meander channel at different θ for Q = 2.5 l/s

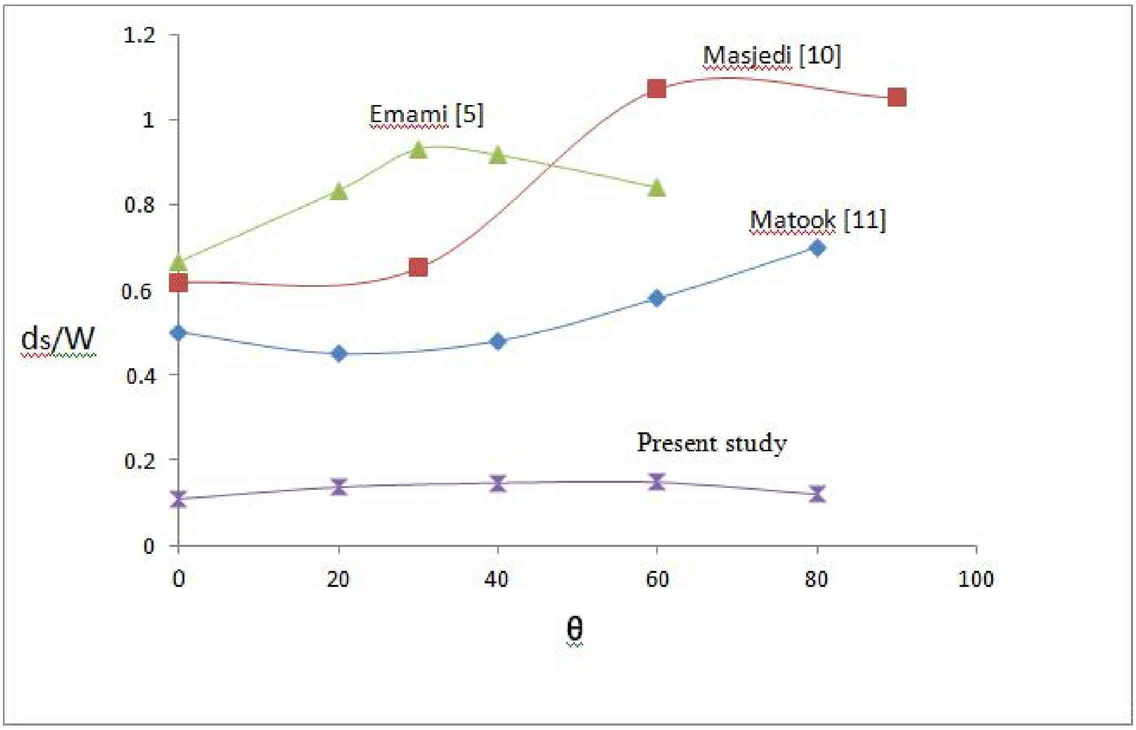

Figure 18. Show the variation of local scour studied by various investigators

depth also increases in all the studies and reaches up to maximum for θ varying from 40^0 to 60^0. This value is maximum at θ = 30-35° in the study of Emami. At θ = 60^0 the scour is maximum. Almost in all studies except Matook. One can emphasize that at θ = 60°, the scour will always be maximum as obtained by most of the investigators. The discrepancy in the various graphs (lines) may be attributed to sediment sizes and other hydraulic parameters such as discharge, pier locations, orientation etc.

4. Conclusions

Following conclusions have been drawn from the present study:

1) It is found that the scour depends on flow rate i.e higher scour hole depth at higher discharge.

2) It is also found that the maximum scour is at 60^0 angular displacement.

3) Similar trend of scour are obtained at all five sections (dsC, dsU_1, dsU_2, dsD_1, dsD_2).

4) At $\theta = 0^0$ and $\theta = 80^0$, the value of scour around pier is less in meandering channel in comparison to straight channel.

5) However, for all other θ values i.e. from $\theta = 20^0$ to $\theta = 60^0$ the bridge pier scour in meander channel is more than in straight channel.

6) The effect of pier on bend scour at inner bank of the bend in comparison to bend scour on inner bank of bend when there is no pier in channel is to reduce the scouring between $\theta = 0^0$ to $\theta = 20^0$ angular displacement and there is no effect closer to $\theta = 50^0$, then as value of θ increases up to $\theta = 80^0$, the effect of pier is to reduce the deposition on inner bank.

7) The effect of pier on bend scour at outer bank of the bend in comparison to bend scour on outer bank of bend when there is no pier in channel has increased the deposition at $\theta = 0^0$ then deposition start reducing. There is no effect on scour at $\theta = 40^0$, then as value of θ increases from $\theta = 40^0$ up to $\theta = 80^0$, the effect of pier has increase the bend scouring at outer bank and maximum bend scour was found at $\theta = 80^0$.

8) It is found that the as θ increases, the scour depth also increases in all studies and reaches up to maximum for θ varying from 40^0 to 60^0. At $\theta = 60^0$, the scour is maximum. All graphs are not matching because their hydraulic and sediment sizes were different.

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