

**ARTICLE**

**Effects of Spur Dyke's Orientation on Bed Variation in Channel Bend**

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**ABSTRACT**

Spur dykes also known as Groynes are often used to either divert or attract the flow from the main structure to safeguard their life. Those structures may be bridge piers, abutments or any similar hydraulics structures. Spur dykes are also used to save the cutting of banks on concave side of stream. Lots of work have been done in recent past on spur dykes by many investigators in which various hydraulic and geometrical parameters of spur dykes such as discharge, sediment size, flow velocity, shear stress, spur dykes shape, size and submergence etc. are studied in detail. But mostly all the studies were pointed out in straight open channels. Very few studies were done in curved channel and only their similar effects were studied. In present thesis main emphasis is given to study the effect of orientation and location of spur dykes in meandering channel on the bed of downstream side. In the present study experimental work has been carried out in 80° bend and constant discharge ( $Q = 4.5$  l/s) is allowed to pass in channel without spur dyke. It is found that maximum scouring occurs at angular displacement  $\theta = 60^\circ$  to  $80^\circ$  in the vicinity of outer bank. To minimize this scouring, spur dyke has been installed at angular displacement  $\theta = 20^\circ$ ,  $40^\circ$  &  $60^\circ$  by changing the dyke angle  $\alpha = 60^\circ$ ,  $90^\circ$  &  $120^\circ$  respectively. It is found that scouring at  $\theta = 60^\circ$  is reduced by installing spur dyke at angular displacement  $\theta = 40^\circ$  which is oriented at  $\alpha = 60^\circ$  and scouring at  $\theta = 80^\circ$  is reduced by installing spur dyke at angular displacement  $\theta = 60^\circ$  which is oriented at  $\alpha = 60^\circ$ .

**1. Introduction**

Spur dykes or Groynes are hydraulic structures that project from the bank of streams or rivers at some angle or perpendicular to the main flow direction. They are used for two purposes, namely 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. Spur dykes also serve to increase the sediment transport rate through the dyked reach, which decreases channel dredging costs. With respect to erosion protection, spur dykes can be designed to protect both straight reaches and channel bends.

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Compared with other methods, such as revetments, spur dykes are among the most economical structures that may be used for riverbank erosion protection.

Spur dikes have been used extensively in all parts of the world as river training structures to enhance navigation, improve flood control and protect erodible banks. Spur dike can be defined as an elongated obstruction having one end on the bank of a stream and the other end projecting into the current. It may be permeable, allowing water to pass through it at a reduced velocity; or it may be impermeable, completely blocking the current. Spur dikes may be constructed of permanent material such as masonry, concrete, or earth and stone; semi-permanent material such as steel or timber sheet piling, gabions or timber fencing or temporary material such as weighted brushwood fascines. Spur dikes may be built at right angles to the bank or current, or angled upstream or downstream. The effect of the spur dike is to reduce the current along the stream bank, thereby reducing the erosive capability of the stream and in some cases inducing sedimentation between dykes.

Few investigators carried out extensive work on flow behavior and scour around spur dykes in straight as well as curved reach of meandering channel. Amongst those are Garde et al. (1961) [7], Gill (1972) [8], Zaghoul et al. (1982) [9], Elawady, et al. (2001) [13], Kuhnle et al. (2002) [10], Zhang (2005) [12], Vaghefi et al. (2009) [16], Zhang et al. (2009) [5], Masjedi et al. (2010) [15], Yossef (2010) [3], Zhang et al. (2012) [2], Parashar et al. (2014) [14], Przedwojski (2015) [6], Pandey et al. (2017) [1], Karki et al. (2018) [4] etc. After reviewing their work it is concluded that lot of work on spur dyke have been done. But the effect of spur dyke's orientation on bed variation is not available in literature.

This report is concerned with the use of impermeable spur dikes as a bank protection technique in a concave bend of a meandering stream. Although the use of spur dikes is extensive, no definitive hydraulic design criteria have been developed. Design continues to be based primarily on experience and judgment within specific geographical areas. This is primarily due to the wide range of variables affecting the performance of the spur dikes and the varying importance of these variables with specific applications. Parameters affecting spur dike design include width, depth, velocity, sinuosity of the channel, size and transportation rate of the bed material, cohesiveness of the bank, length, width, crest profile, orientation angle and spacing of the spur dikes.

## Dimensional analysis

The variables required to define the scour and deposition

(river bed variation) in straight and curved open channels are velocity of flow ( $v$ ), depth of flow above channel bed ( $y$ ), mean sediment particle size ( $d_{50}$ ), mass density of water ( $\rho$ ), mass density of solid ( $\rho_s$ ), viscosity of water ( $\mu$ ), acceleration due to gravity ( $g$ ), and angular displacement ( $\theta$ ). Using Buckingham Pie's method following dimensionless number have been found.

$$d_s = f \{v, \rho, y, \theta, d_{50}, \mu, g, b, t, \alpha, \rho_s, w\} \quad (1)$$

Now, from Equ.(1)

$$d_s/w = \Pi_1$$

So we can write all Pie terms

$$\Pi_1 = f(\Pi_2, \Pi_3, \Pi_4, \Pi_5, \Pi_6, \Pi_7, \Pi_8, \Pi_9, \Pi_{10})$$

$$\text{Therefore } d_s/w = f(\rho_s/\rho, y/w, b/w, t/w, \alpha, \theta, d_{50}/w, \rho v w/\mu, v/\sqrt{g w}) \quad (2)$$

Since only one dyke of constant size, shape is used so  $b/w$  &  $t/w$  both are constant hence both parameter are dropped. Also discharge was constant so  $y/w$ ,  $\rho v w/\mu$  (Reynolds No.) and  $v/\sqrt{g w}$  (Froude no.) all were dropped. Thus finally two were left therefore it can be concluded that  $d_s/w$  is a function of angular displacement and spur dike angle.

$$d_s/w = f(\theta, \alpha) \quad (3)$$

Now, using above dimensionless parameters all data analysis were carried out and graphs were plotted to investigate the actual effect of spur dyke's orientation & location on bed variation in curved channel.

## 2. Experimental Setup and Procedure

Experiments were conducted in the Advanced Post Graduate Hydraulics Laboratory, Department of Civil Engineering, Zakir Hussain College of Engineering & Technology, Aligarh Muslim University, Aligarh.

### 2.1 Flume

The data are collected in an open horizontal rectangular sinuous (meandering/curved) channel (0.35m wide and 0.43m deep) made up of 0.5mm thick tin sheet, carefully installed in an open horizontal rectangular flume (0.76m wide and 0.60m deep and 10.5m long) prismatic glass walled channel with cement plastered bottom. In channel, bed is prepared by 0.22m height of sand throughout the channel. Schematic diagram and photographic view of the experimental setup are shown in Figures 1, 2 and 3. The model has a straight upstream reach of 2.88m and a straight downstream reach of 2.1m. In between the upstream and the downstream reach two sinuous bends having the 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 each bend is  $80^\circ$  and the central radius of the channel ( $R_c$ ) is 0.705 m. The width of the experimental model is 0.35 m here  $R_c/W = 2.014$  (Ratio of the central radius to the width of the channel). Since the ratio  $R_c/W$  is less than 3, the bend is considered as a sharp bend. A straight transition of 0.05 m is provided between each bends.

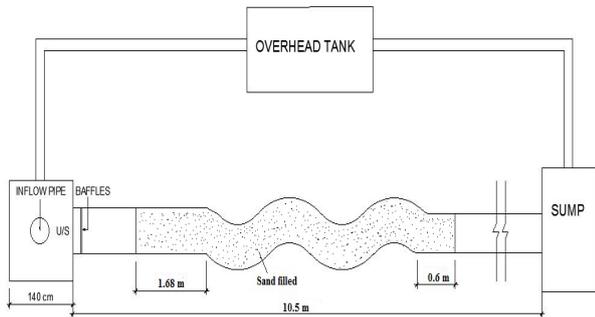


Figure 1. Schematic line diagram of bed flume

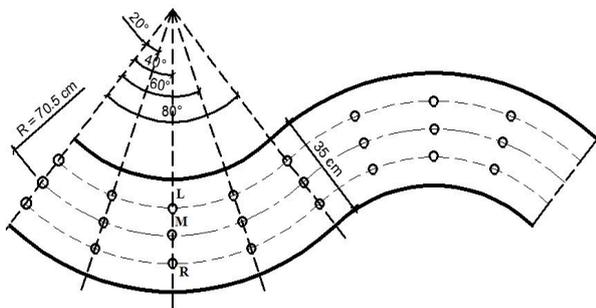


Figure 2. Schematic view of bend angle



Figure 3. Installation of spur dyke

### 2.1.1 Dyke Model

In present study spur dyke is made up of wooden sheet having width ( $b = 7.5 \text{ cm}$ ) and thickness ( $t = 1.5 \text{ cm}$ ). Spur dyke of non-submerged condition is installed one by one at three orientation ' $\alpha$ ' (measured from tangent of right

hand side of channel in clockwise direction)  $60^\circ$ ,  $90^\circ$  and  $120^\circ$  and three different locations in Bend 1 and Bend 3 separately. Bend angle and orientation of spur dyke are shown in Figure 2.

### 2.1.2 Contraction Ratio

Contraction ratio is defined as the ratio of the width of spur dyke to the width of the flume. In present study contraction ratio is 0.214 which is less than 0.25. If contraction ratio is greater than 25% with higher values of Froude number, the stability of the opposite bank will be in danger, in addition to the stability of the spur itself, which will cost a lot to protect the spur foundation and the channel banks against the scouring process.

### 2.1.3 Source of Sediment and Its Properties

Sediment size  $d_{50}$  as 0.27 mm was used for making the bed of channel.

### 2.1.4 Flow Condition

Discharge = 4.5 l/s, Flow depth = 4.5 cm, Average velocity = 0.286 m/s and Froude No. = 0.43 (Subcritical). Discharge is measured by a sharp crested calibrated rectangular weir provided at the end of downstream drain channel by recording the head on the weir with the help of point gauge (with 0.10 mm accuracy).

### 2.1.5 Calibration of Weir

A sharp crested rectangular weir provided at the end of downstream drain channel was first calibrated. Through the gate valve feeding the channel, a small discharge was allowed to pass and after obtaining the steady state flow condition, head on the weir was recorded with the help of a point gauge (with 0.10 mm accuracy) and rise in water level in the underground collecting well was recorded in three mutually perpendicular directions with the help of two theodolite simultaneously. The corresponding time for the rise mentioned above was recorded with the help of stopwatch (with 0.01 seconds least count). For each head over the weir, three sets of rises in water level and corresponding time were recorded. In this way six values of this discharge for one head were recorded for getting the best accuracy. Average value of these six observations was noted and calibration curve is plotted. Table 1 shows the data of deposition and scour for Bend 1 at  $\theta = 0^\circ$  displacement when dyke installed at location 1.

## 2.2 Experimental Procedure

Test bed was first prepared by filling the well graded

sand having  $d_{50}$  as 0.27 mm with uniform compaction method. It was first ensured that test bed is properly compacted and smoothened. When test bed is ready than a flow of amount 4.5 l/s is allowed to pass over the bed for about 3-4 hours. After that test run is stopped there was slight variation in the test bed level in straight and curved reaches. All readings along and across were taken. In second phase the spur dyke of designed shape and size was installed at a particular location and similar run was passed and again all readings were recorded. Similarly at many locations and orientations for same discharge  $Q = 4.5$  l/s run were taken and data for bed variation were collected for further analysis.

### 3. Analysis of Data and Results

#### 3.1 Bed Variation along the Longitudinal Direction without Spur Dyke

Figure 4 shows the variation of scour and deposition

along the longitudinal direction in meandering channel without installing spur dyke for  $Q = 4.5$  l/s. Maximum scouring and maximum deposition occurred at concave (outer) side and convex (inner) side respectively in the vicinity of bank. Scouring and deposition pattern at 5 cm and 30 cm are mirror image of each other. At 20 cm, scouring and deposition pattern lies in between the 5 cm and 30 cm.

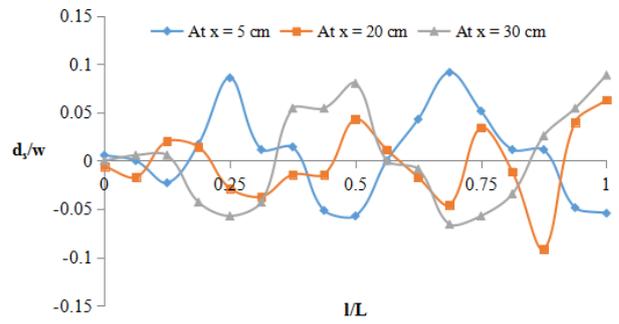


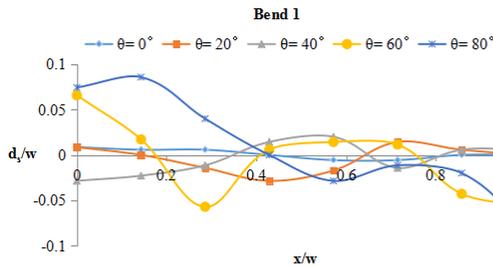
Figure 4. Bed variation along the longitudinal direction throughout the channel without spur dyke

Table 1. Data for bed variation at section  $\theta = 0^\circ$  along the transverse direction when dyke installed at location 1,  $\theta = 0^\circ$

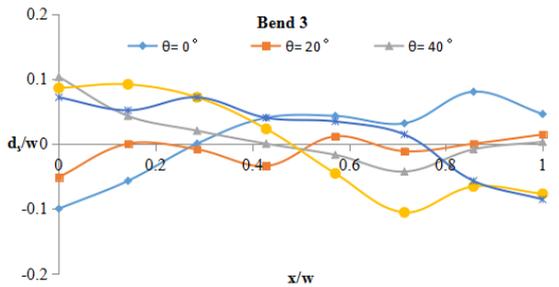
BEND 1				BEND 3			
NO SPUR DYKE							
x	ds	x/w	ds/w	x	ds	x/w	ds/w
0	0.3	0	0.008571	0	-3.5	0	-0.1
5	0.2	0.142857	0.005714	5	-2	0.142857	-0.05714
10	0.2	0.285714	0.005714	10	0	0.285714	0
15	0	0.428571	0	15	1.4	0.428571	0.04
20	-0.2	0.571429	-0.00571	20	1.5	0.571429	0.042857
25	-0.2	0.714286	-0.00571	25	1.1	0.714286	0.031429
30	0	0.857143	0	30	2.8	0.857143	0.08
35	0	1	0	35	1.6	1	0.045714
SPUR DYKE ORIENTED AT $\alpha = 90^\circ$							
x	ds	x/w	ds/w	x	ds	x/w	ds/w
0	0.6	0	0.017143	0	-0.2	0	-0.00571
5	-0.1	0.142857	-0.00286	5	-1.3	0.142857	-0.03714
10	-1	0.285714	-0.02857	10	-0.5	0.285714	-0.01429
15	-3.2	0.428571	-0.09143	15	1.4	0.428571	0.04
20	-2.1	0.571429	-0.06	20	-0.5	0.571429	-0.01429
25	-4.2	0.714286	-0.12	25	0.2	0.714286	0.005714
30	-2.2	0.857143	-0.06286	30	-0.6	0.857143	-0.01714
35	-0.9	1	-0.02571	35	0	1	0
SPUR DYKE ORIENTED AT $\alpha = 60^\circ$							
x	ds	x/w	ds/w	x	ds	x/w	ds/w
0	0.7	0	0.02	0	-3.9	0	-0.11143
5	-1.5	0.142857	-0.04286	5	-2.7	0.142857	-0.07714
10	-1	0.285714	-0.02857	10	-1.2	0.285714	-0.03429
15	-0.7	0.428571	-0.02	15	0.8	0.428571	0.022857
20	-3.6	0.571429	-0.10286	20	1.1	0.571429	0.031429
25	-3.9	0.714286	-0.11143	25	1.5	0.714286	0.042857
30	-2.1	0.857143	-0.06	30	-1.7	0.857143	-0.04857
35	-1.5	1	-0.04286	35	-2	1	-0.05714
SPUR DYKE ORIENTED AT $\alpha = 120^\circ$							
x	ds	x/w	ds/w	x	ds	x/w	ds/w
0	0	0	0	0	-3.8	0	-0.10857
5	0.2	0.142857	0.005714	5	-3	0.142857	-0.08571
10	0.1	0.285714	0.002857	10	-0.5	0.285714	-0.01429
15	-0.3	0.428571	-0.00857	15	0.3	0.428571	0.008571
20	-1.9	0.571429	-0.05429	20	1.1	0.571429	0.031429
25	-3.5	0.714286	-0.1	25	2	0.714286	0.057143
30	-2	0.857143	-0.05714	30	-0.5	0.857143	-0.01429
35	-2	1	-0.05714	35	-1.5	1	-0.04286

### 3.2 Bed Variation along the Transverse Direction without Spur Dyke

Figures 5 and 6 show the bed variation along the transverse direction for Bend 1 and Bend 3 respectively at various values of angular displacement ( $\theta$ ) without spur dyke. At  $\theta = 0^\circ$  negligible scour and deposition occurred at Bend 1 but this phenomenon is not same for Bend 3 because of transition zone in Bend 1. In Bend 3, at  $\theta = 0^\circ$ , initially scouring occurred till  $1/4^{\text{th}}$  of width of channel and after which deposition start. This difference of bed pattern of Bend 1 & Bend 3 occurred till the  $\theta = 40^\circ$  and after that similarity in bed pattern begins.



**Figure 5.** Bed variation of Bend 1 along the transverse direction without spur dyke



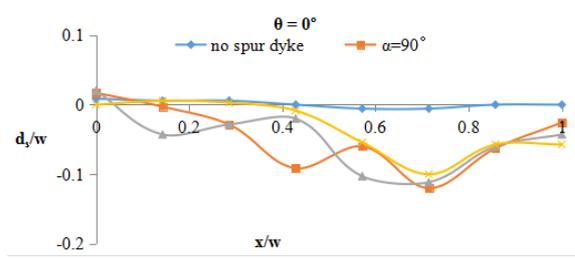
**Figure 6.** Bed variation of Bend 3 along the transverse direction without spur dyke

### 3.3 Bed Variation along the Transverse Direction of Bend-1

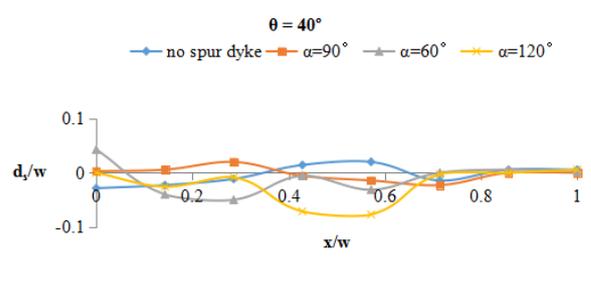
Figure 7 shows the bed variation along the transverse direction at angular displacement ( $\theta = 0^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  &  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 0^\circ$  (location 1) of Bend 1. Maximum scouring occurred near the spur dyke for all ' $\alpha$ ' but  $\alpha = 120^\circ$  gives less scouring near spur dyke in comparison to other  $\alpha = 60^\circ$  and  $90^\circ$ .

Figure 8 shows the bed variation along the transverse direction at angular displacement ( $\theta = 40^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 0^\circ$  (location 1) of Bend 1. Maximum scouring occurs at center of the channel when  $\alpha = 120^\circ$ . At  $\alpha = 90^\circ$  and without spur dyke

show almost same pattern.

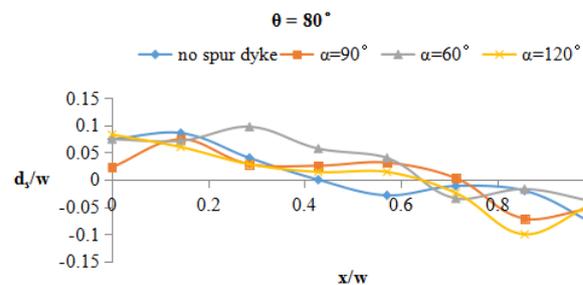


**Figure 7.** Bed variation of Bend 1 at angular displacement  $\theta = 0^\circ$  along the transverse direction when dyke installed at location 1,  $\theta = 0^\circ$



**Figure 8.** Bed variation of Bend 1 at angular displacement  $\theta = 40^\circ$  along the transverse direction when dyke installed at location 1,  $\theta = 0^\circ$

Figure 9 shows the bed variation along the transverse direction at angular displacement ( $\theta = 80^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 0^\circ$  (location 1) of Bend 1. Graphs at  $\alpha = 60^\circ, 90^\circ, 120^\circ$  and without spur dyke show almost same bed variation.

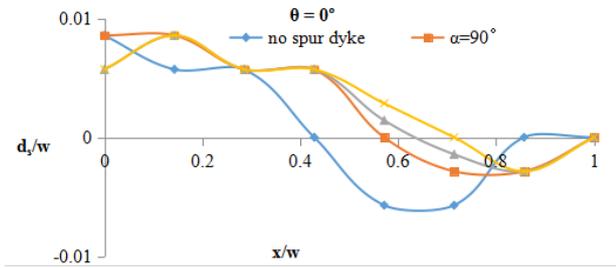


**Figure 9.** Bed variation of Bend 1 at angular displacement  $\theta = 80^\circ$  along the transverse direction when dyke installed at location 1,  $\theta = 0^\circ$

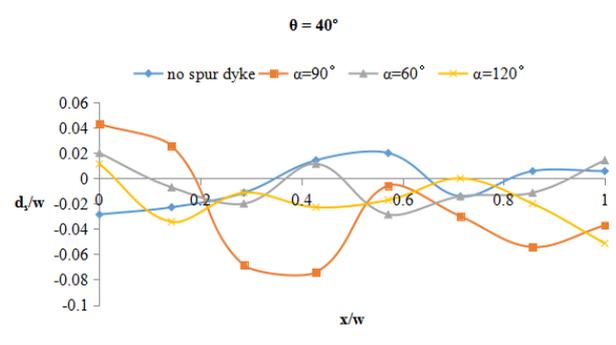
Figure 10 shows the bed variation along the transverse direction at angular displacement ( $\theta = 0^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 40^\circ$  (location 2) of Bend 1. In this figure all the graphs  $\alpha = 60^\circ, 90^\circ, 120^\circ$  and without spur dyke show the same bed variation.

Figure 11 shows the bed variation along the transverse direction at angular displacement ( $\theta = 40^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and

without spur dyke which is installed at  $\theta = 40^\circ$  (location 2) of Bend 1. This section is important for analysis because at this section spur dyke is also installed. Near the spur dyke scouring is less in comparison to when spur dyke installed at  $\theta = 0^\circ$ . So we can say at  $\theta = 40^\circ$  is the stable location for the spur dyke.

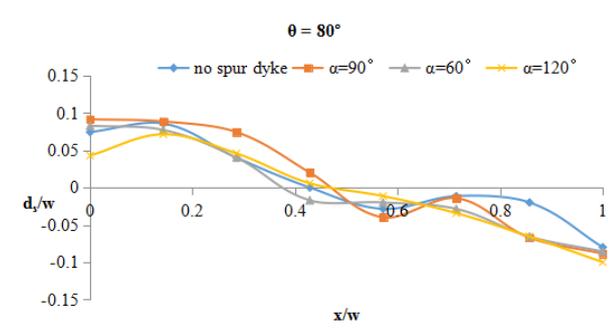


**Figure 10.** Bed variation of Bend 1 at angular displacement  $\theta = 0^\circ$  along the transverse direction when dyke installed at location 2,  $\theta = 40^\circ$



**Figure 11.** Bed variation of Bend 1, at angular displacement  $\theta = 40^\circ$  along the transverse direction when dyke installed at location 2,  $\theta = 40^\circ$

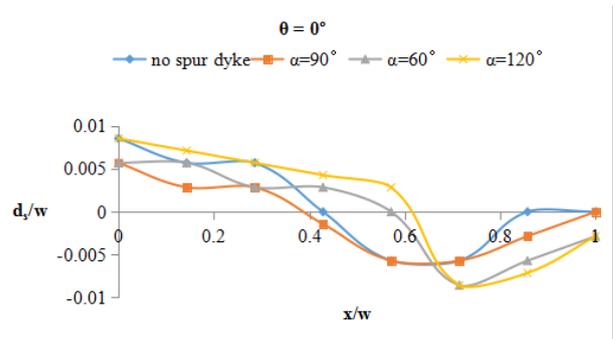
Figure 12 shows the bed variation along the transverse direction at angular displacement ( $\theta = 80^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 40^\circ$  (location 2) of Bend 1. In this figure all the graphs at  $\alpha = 60^\circ, 90^\circ, 120^\circ$  and without spur dyke shows almost same bed variation.



**Figure 12.** Bed variation of Bend 1 at angular displacement  $\theta = 80^\circ$  along the transverse direction when dyke installed at location 2,  $\theta = 40^\circ$

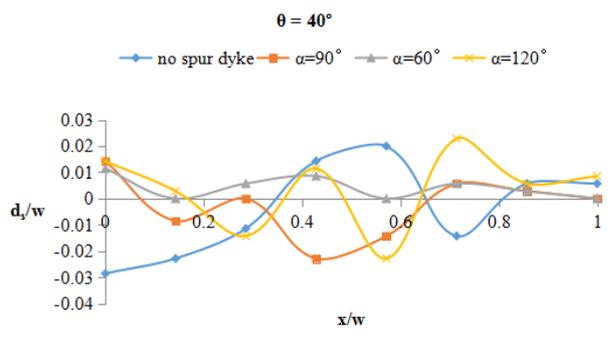
Figure 13 shows the bed variation along the transverse

direction at angular displacement ( $\theta = 0^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 60^\circ$  (location 3) of Bend 1. In Figure 13, all the graphs at  $\alpha = 60^\circ, 90^\circ, 120^\circ$  and without spur dyke shows almost same bed variation.



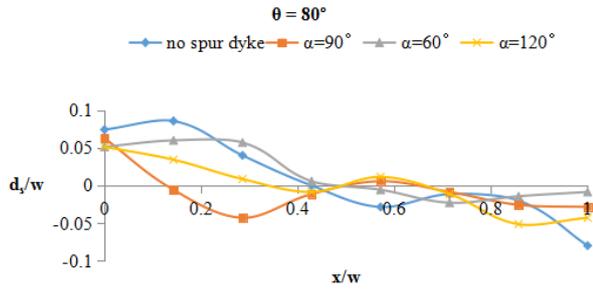
**Figure 13.** Bed variation of Bend 1 at angular displacement  $\theta = 0^\circ$  along the transverse direction when dyke installed at location 3,  $\theta = 60^\circ$

Figure 14 shows the bed variation along the transverse direction at angular displacement ( $\theta = 40^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 60^\circ$  (location 3) of Bend 1. In this graph at  $\alpha = 60^\circ$  shows the less deposition and less scouring in comparison to other graph.

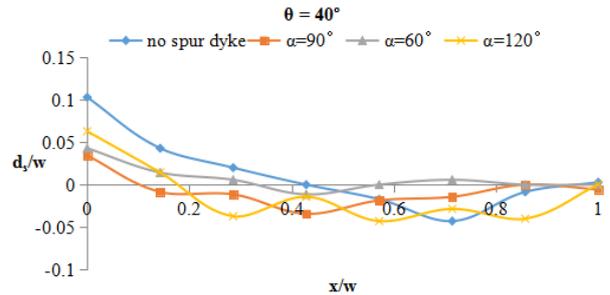


**Figure 14.** Bed variation of Bend 1 at angular displacement  $\theta = 40^\circ$  along the transverse direction when dyke installed at location 3,  $\theta = 60^\circ$

Figure 15 shows the bed variation along the transverse direction at angular displacement ( $\theta = 80^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 60^\circ$  (location 3) of Bend 1. In this figure, graph of without spur dyke shows maximum scouring near concave (outer) side of bank. This scouring is minimized by installing spur dyke at  $\alpha = 60^\circ$  and  $90^\circ$  but  $\alpha = 120^\circ$  dose not minimize scouring. Maximum scouring is minimized by  $\alpha = 60^\circ$  in comparison to  $\alpha = 90^\circ$ .



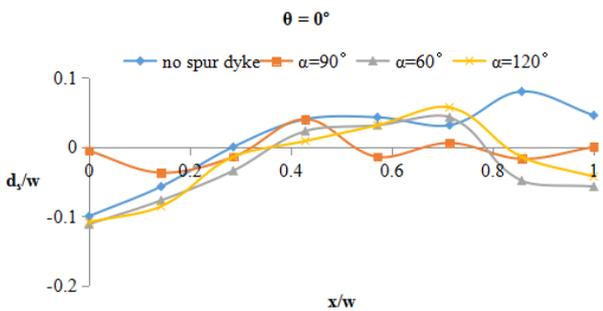
**Figure 15.** Bed variation of Bend 1 at angular displacement  $\theta = 80^\circ$  along the transverse direction when dyke installed at location 3,  $\theta = 60^\circ$



**Figure 17.** Bed variation of Bend 3 at angular displacement  $\theta = 40^\circ$  along the transverse direction when dyke installed at location 1,  $\theta = 0^\circ$

### 3.4 Bed Variation along the Transverse Direction of Bend-3

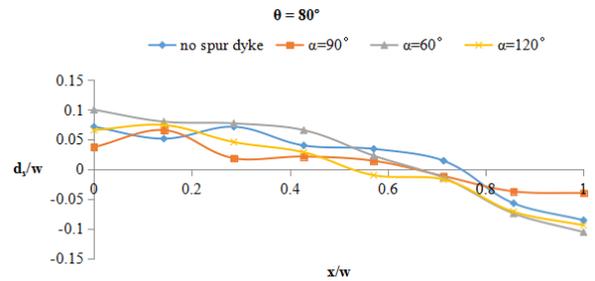
Figure 16 shows the bed variation along the transverse direction at angular displacement ( $\theta = 0^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 0^\circ$  (location 1) of Bend 3. In this figure maximum scouring occurs near the spur dyke but  $\alpha = 90^\circ$  shows less scouring near spur dyke in comparison to  $\alpha = 60^\circ$  and  $120^\circ$ .



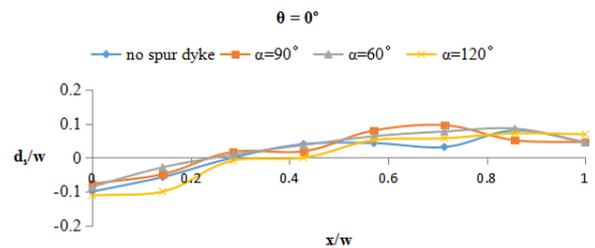
**Figure 16.** Bed variation of Bend 3 at angular displacement  $\theta = 0^\circ$  along the transverse direction when dyke installed at location 1,  $\theta = 0^\circ$

Figures 17 & 18 show the bed variation along the transverse direction at respective angular displacement ( $\theta = 40^\circ$  and  $\theta = 80^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 0^\circ$  (location 1) of Bend 3. In Figures 17 & 18, all the graphs at  $\alpha = 60^\circ, 90^\circ, 120^\circ$  and without spur dyke shows almost same bed variation.

Figure 19 shows the bed variation along the transverse direction at angular displacement ( $\theta = 0^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 40^\circ$  (location 2) of Bend 3. In this figure, all the graphs show almost same bed variation.



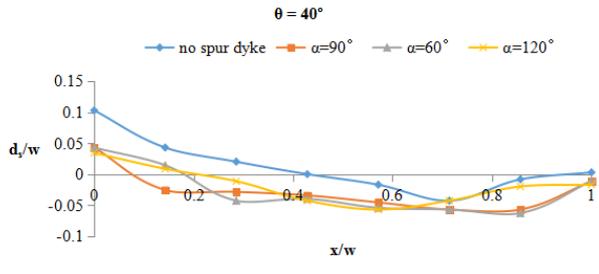
**Figure 18.** Bed variation of Bend 3 at angular displacement  $\theta = 80^\circ$  along the transverse direction when dyke installed at location 1,  $\theta = 0^\circ$



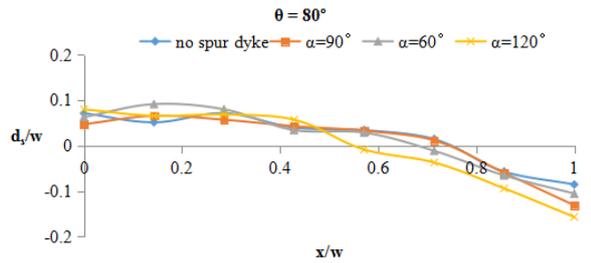
**Figure 19.** Bed variation of Bend 3 at angular displacement  $\theta = 0^\circ$  along the transverse direction when dyke installed at location 2,  $\theta = 40^\circ$

Figure 20 shows the bed variation along the transverse direction at angular displacement ( $\theta = 40^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 40^\circ$  (location 2) of Bend 3. In this figure near spur dyke maximum scouring occur but at  $\alpha = 60^\circ$  shows the more scouring in comparison to  $\alpha = 90^\circ$  and  $120^\circ$ .

Figure 21 shows the bed variation along the transverse direction at angular displacement ( $\theta = 80^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 40^\circ$  (location 2) of Bend 3. In Figure 21, all the graphs at  $\alpha = 60^\circ, 90^\circ, 120^\circ$  and without spur dyke shows almost same bed variation.

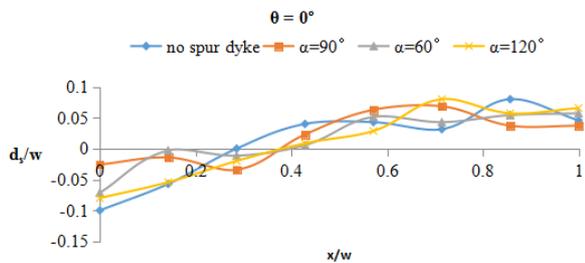


**Figure 20.** Bed variation of Bend 3, at angular displacement  $\theta = 40^\circ$  along the transverse direction when dyke installed at location 2,  $\theta = 40^\circ$



**Figure 21.** Bed variation of Bend 3 at angular displacement  $\theta = 80^\circ$  along the transverse direction when dyke installed at location 2,  $\theta = 40^\circ$

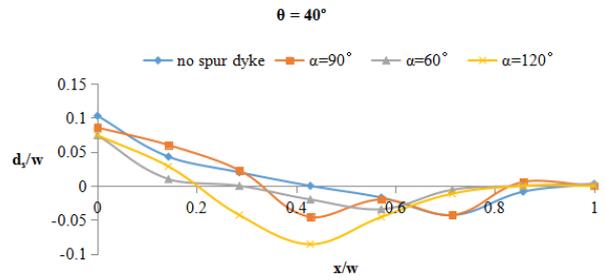
Figures 22 and 23 show the bed variation along the transverse direction at respective angular displacement ( $\theta = 0^\circ$  and  $\theta = 40^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 60^\circ$  (location 3) of Bend 3. In these figures, all the graphs at  $\alpha = 60^\circ, 90^\circ, 120^\circ$  and without spur dyke shows almost same bed variation.



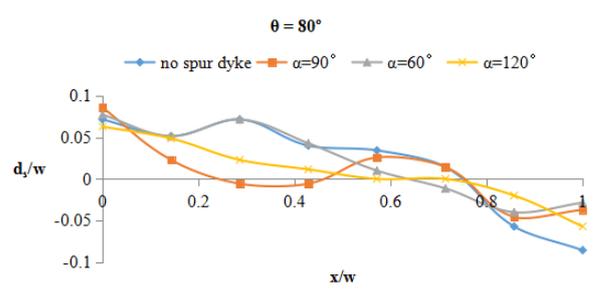
**Figure 22.** Bed variation of Bend 3 at angular displacement  $\theta = 0^\circ$  along the transverse direction when dyke installed at location 3,  $\theta = 60^\circ$

Figure 24 shows the bed variation along the transverse direction at angular displacement ( $\theta = 80^\circ$ ) of various orientation of spur dyke ( $\alpha = 60^\circ, 90^\circ$  and  $120^\circ$ ) and without spur dyke which is installed at  $\theta = 60^\circ$  (location 3) of Bend 3. In this figure, graph of without spur dyke shows maximum scouring near concave (outer) side of bank. This scouring is minimized by installing spur dyke at  $\alpha = 60^\circ$  and  $90^\circ$  but  $\alpha = 120^\circ$  dose not minimize much scouring. Maximum scouring is minimized by  $\alpha = 60^\circ$  in

comparison to  $\alpha = 90^\circ$ .



**Figure 23.** Bed variation of Bend 3 at angular displacement  $\theta = 40^\circ$  along the transverse direction when dyke installed at location 3,  $\theta = 60^\circ$



**Figure 24.** Bed variation of Bend 3 at angular displacement  $\theta = 80^\circ$  along the transverse direction when dyke installed at location 3,  $\theta = 60^\circ$

#### 4. Conclusions

Following conclusions have been drawn from the present study:

It was observed that in meandering portion there was scouring on the bed but on the same flow condition there was no scouring in straight channel.

The maximum scouring occurs in between  $\theta = 60^\circ$  to  $80^\circ$  of the outer side of bend and it is having a peak at  $\theta = 80^\circ$ . This was found without installing spur dyke.

When spur dyke is installed at location 1 ( $\theta = 0^\circ$ ), this affects the bed till  $\theta = 40^\circ$ . After that spur dyke's effect reduces on bed. So it does not reduce the scouring at  $\theta = 60^\circ$  to  $80^\circ$ .

When spur dyke is installed at location 2 ( $\theta = 40^\circ$ ), scouring near angular displacement ( $\theta = 60^\circ$ ) reduces.

When spur dyke is installed at location 3 ( $\theta = 60^\circ$ ) scouring near angular displacement ( $\theta = 80^\circ$ ) reduces. So it does not minimize the scouring at  $60^\circ$  to  $80^\circ$ .

Spur dyke oriented at ( $\alpha = 60^\circ$  or  $90^\circ$ ) reduces the scouring and maximum scouring is minimized by  $\alpha = 60^\circ$ . But spur dyke oriented at  $\alpha = 120^\circ$ , it reduces the scouring very less.

Scouring around spur dyke is more for the spur dyke's angle  $\alpha = 90^\circ$  but the extent of this scouring is more for  $\alpha$

= 120°.

The extent of scouring around spur dyke occurs in that direction where the spur dyke is oriented.

When spur dyke installed at location 2 ( $\theta = 40^\circ$ ) than scouring around spur dyke is negligible in comparison to other location because near  $\theta = 40^\circ$  zone prevails no flow condition.

As we know maximum scouring occurs at concave (outer) side of bend but the location of this maximum scouring depends on bend geometry. If bend is sharp ( $R_c/w < 3$ ), scouring will be more near the end of bend at outer side.

If bend is sharp, spacing of spur dyke should be less for protection of bank.

Bed pattern (scouring & deposition) of bend 1 & bend 3 are different because bend 1 continues with straight portion while bend 3 continues with other bend hence we can say transition zone affects bed pattern (scouring & deposition).

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