

# Experimental evaluation of spur dikes placement position effect on the hydraulic and erosion conditions of intakes

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## ABSTRACT

The use of spur dikes have been recently considered by researchers in order to change the direction or flow regime in the lateral intake. In this study, the effect of spur dikes on increasing the intake discharge has been examined to minimize turbulence, erosion and sedimentation. Five experimental models in two different discharges were used. The model without the spur dike is the control model, and spur dikes in the other models were placed upstream and in the direction of the intake; upstream and in front of the intake; downstream and in front of intake; and also upstream and in front of intake as a form of spur dike series. The results showed that the spur dikes downstream and in front of the intake had the highest input discharge to the intake in both discharge states. A lower rate of erosion and sedimentation was achieved when the spur dike was located upstream of the channel.

**Key words** | diversion ratio, erosion, intake, scour, sedimentation, spur dike

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## INTRODUCTION

Intakes are structures used to divert flow from the river or channel to another channel. Dewatering system can be done by the bed intake, the pump, or lateral intake, according to the characteristics of region and the way of use. The lateral intakes are one of the most important hydraulic structures. The design of these structures is one of the major engineering issues with the maximum intake efficiency and the minimum sediment entry to the intake, especially when the purpose of dewatering is the purification of water. The simplest form of intake is the creation of a 90° diversion of its direct range, resulting in the formation of a complex three-dimensional flow pattern. This complex pattern has been evaluated and analyzed by various researchers and in different dimensions.

Neary & Odgaard (1993) have shown that the sediment mode of transmission is very complicated in the place of vertical intake, and three-dimensional advanced equations are needed for further investigation. Studies were carried out by Răzvan (1989) regarding the effect of sill height in the lateral intakes, and recommendations on the intake angle have been proposed by Novak *et al.* (2014). Barkdoll *et al.* (1999)

in their studies on lateral intake, which were performed in direct path with a 90° dewatering angle, showed that the discharge diversion ratio has the greatest impact on the sediment diversion ratio. Azimi *et al.* (2019) extracted a relationship between the main channel and the intakes energy for rectangular channels. Rao *et al.* (1968) observed variations in diversion lines of flow toward the intake or the flow duct with depth. They also concluded that the width of the flow duct at the water surface to the main channel width is in the range of 0.5–1 m. Ramamurthy & Satish (1988) followed the separation momentum equations for flow in the branch channels and sub-channels. The critical flow in the downstream branch was investigated to show that the contribution of the sub-channel momentum increased with increasing the subsidiary diversion ratio. Ingle & Mahankal (1990) pointed out that the prediction of Ramamurthy & Satish (1988) cannot be used in all diversion flows for small Froude numbers and maximum shrinkage coefficient in width. A study conducted by Nazari & Shafai Bejestan (2010) also showed that the spiral flow pattern occurs in the downstream wall corner

of the intake channel near the bed, which causes the heavy transfer of bed charged particles into the intake.

Spur dikes are one of the most used hydraulic structures for flood prevention, river diversion, and channel regulation on rivers (Duan *et al.* 2009). After installing these structures, the flow characteristics change and, due to the flow constriction, the direction and velocity of the water movement also changes (Yang *et al.* 2019). These changes increase the substrate shear stress and, as a result, erosion of the bed of the channel. The use of the spur dikes increases the maximum scour, and this depth has been investigated by, including Rajaratnam & Nwachukwu 1983; Shields *et al.* 1995; Kuhnle *et al.* 1999; Kothiyari & Ranga Raju 2001; Kang *et al.* 2011; Karami *et al.* 2014; Choufu *et al.* 2019; and Nayyer *et al.* 2019. Choufu *et al.* (2019) investigated the erosion and hydraulic condition in a channel with three parallel spur dikes. The results showed that arranging spur dikes in an ascending order could reduce the maximum scour depth by 72%, and in a descending order by up to 55%. Nayyer *et al.* (2019) investigated the effects of a series of spur dike shapes on a flow field. The results showed that a protective spur dike can decrease flow intensity scour depth and characteristics. This research shows that flow diversion increases flow velocity downstream and upstream.

The use of spur dikes in channels such as lateral intakes that require flow diversion appears to be useful. Thus, Gohari *et al.* (2011) examined the flow characteristics at the intake aperture by simultaneously using spur dikes and submerged vanes in the intake channel. They evaluated the results in diversion ratios of 13, 18, and 24%. The results showed that the length of the flow separation zone in the intake decreases with the increase of the diversion ratio to the intake. By installing a spur dike in front of the intake, the width of the flow separation line decreases in the bed and increases in the surface, and thus the area affected by the intake in the bed was reduced and the amount of sediment entering the intake also reduced. Sajedi & Habibi (2005) examined the effect of simultaneously using submerged vanes and a series of spur dikes on increasing the efficiency of dewatering and showed that the entry of sediments into the intake decreases through simultaneous use of submerged vanes and a series spur dikes. In some studies, the use of a skimming wall on spur dikes for controlling of

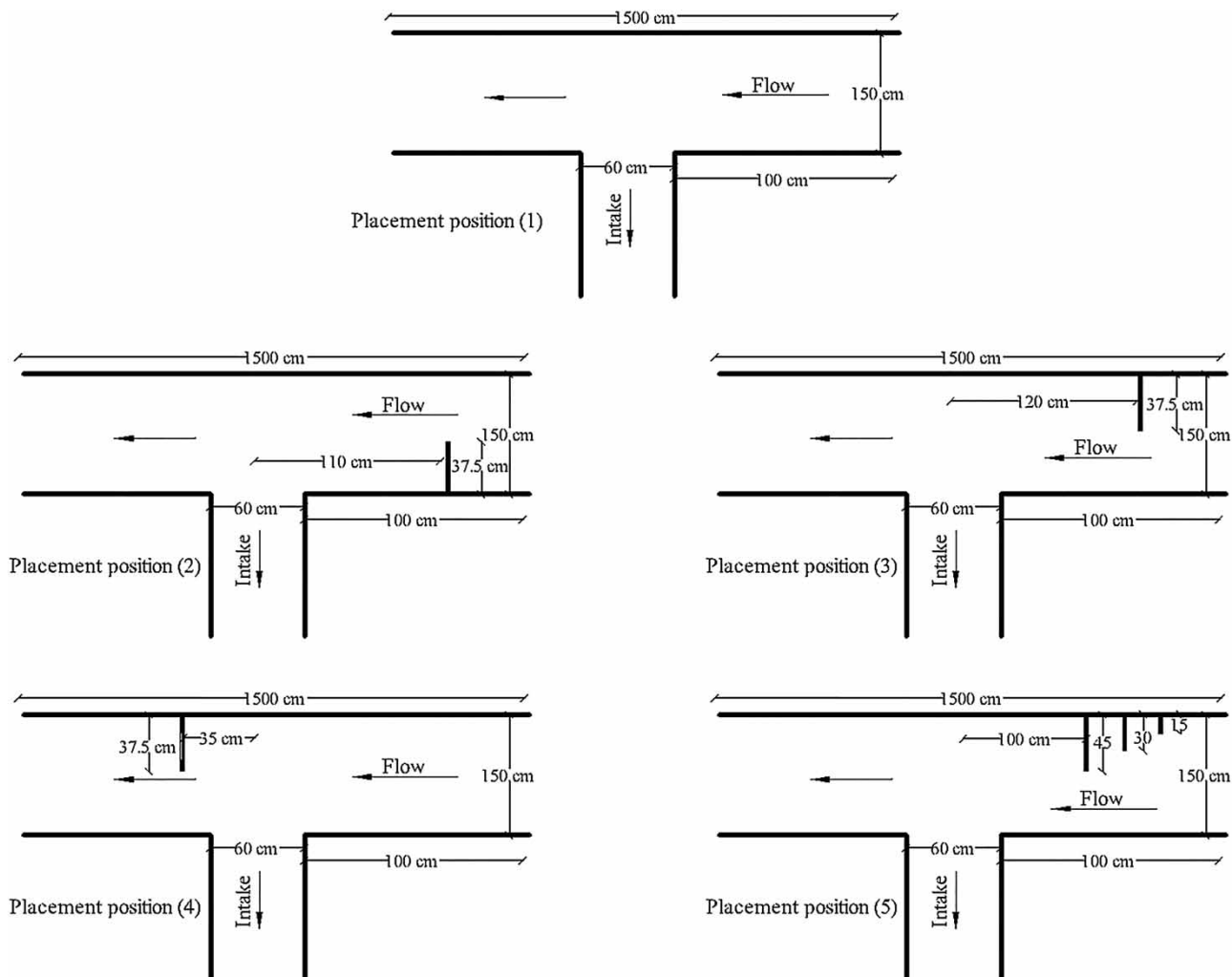
sediment entrance at lateral intakes was investigated (Moradinejad *et al.* 2017).

In this study, the effect of the spur dike position on the intake was investigated experimentally. For this purpose, five different modes of spur dikes near the intake were investigated and evaluated in two different discharges: (i) intake without spur dike; (ii) spur dike upstream and in front of intake; (iii) spur dike upstream and in direction of intake; (iv) spur dike downstream and in front of intake; and (v) a group of spur dikes upstream and in front of intake. The input discharge to intake, the rate of erosion and sedimentation, and the rate of maximum scour were compared in these experiments.

## MATERIALS AND METHODS

In the experiments, a rectangular channel with a length of 15 m, a width of 1.5 m, with a longitudinal slope of 0.002 m was used as the main channel. The intake is a rectangular channel with a width of 0.6 m and a length of 5 m, placed 10 m away from the beginning of the main channel at an angle of 90° to the main channel. The dimensions of the channel were determined using Gohari *et al.* (2011). Both channels and spur dikes were fabricated with 5 mm thick plexiglas. The maximum adjustable flow in the main channel was 80 L/s. The length and placement position of these spur dikes are shown in Figure 1. These spur dikes were placed perpendicularly to the flow path in the main channel. The spacing between the spur dikes was decided by Choufu *et al.* (2019). To investigate the bottom of the channel scour in all experiments, well-graded sand (SW) sediments, with an average diameter of 0.9 mm and density of 2,650 kilograms per cubic meters, were placed in a 15-cm thick layer on the bed of the channel. The characteristics of these sediments were selected according to Gohari *et al.* (2011). The surface of the sediments were smoothed by the leveler and saturated at the beginning of all assembly experiments.

To determine the velocities at 10-cm intervals of length and width, two-dimensional velocimetry of Portable Emissions Measurement System (0.001 m/s uncertainty) was used at a depth of 0.6 times the height from the flow surface. Depending on the model, the velocity measurements



**Figure 1** | Spur dike placement position in five different scenarios.

continued from before the spur dike to after the intake. The Automatic Bed Profiler was used to calculate the length and width changes in the bed with 0.1 mm accuracy. Stability of flow was investigated based on velocity magnitude and changes in water level and bed of the channel. According to the Froude number, flow type is subcritical. An adjustable pump was used to set the discharge entering the main channel. A triangular weir was used for calculating discharge and setting the water surface at the end of the main and lateral channels. To compare the effect of spur dike placement positions, five different positions in two different input discharges (ten experiments) were used as shown in Figure 1. The first and second discharges were 40 and 60 L/s, respectively. Due to the constant bed slope (0.002 m), the discharge

increases with an increase in the water depth. The flow depth in the first and second series of experiments were 11.5 and 16 cm, respectively. The mean of diversion ratio is the discharge ratio entering the intake to the total input discharge at the beginning of the main channel. Due to the lack of changing the overflow valves of main channels and intake, the diversion ratio in a particular discharge will be the same. By comparing the diversion ratio for the five different modes of spur dike placement positions, the impact of spur dike placement position on the diversion ratio was determined. Velocity changes in different scenarios was also evaluated by comparing the velocities at the input of the intake and downstream of the intake in the main channel. Erosion and sedimentation were then

analyzed and discussed by calculating the maximum scour depth and bed morphology.

## RESULTS AND DISCUSSION

Flow properties in the main channel, the intake channel, and in the proximity of the spur dike were investigated for two input discharges of 40 and 60 L/s. Output discharges from the main channel and intake in any of the experiments can be seen in Table 1. The diversion ratio in a discharge of 60 L/s is significantly greater than the diversion ratio in a discharge of 40 L/s, which is mainly due to the difference between flow depths in two series of tests. As a result, it is useful to compare each series of Tests 1–5 and 6–10 for the effect of spur dike placement positions on the diversion ratio. Comparing the diversion ratio in Test 1 to Test 5 shows that the diversion discharge does not change much when changing spur dike placement position in Test 2 to Test 5. Test 3 created the greatest diversion discharge. The diversion discharge also increased in the 60 L/s discharge due to greater heights of flow. In Tests 6 and 7, the diversion ratio has not changed much; however, it reached its highest level in Tests 8 and 10. Based on the results in Test 3 to Test 5, the use of a spur dike had a greater effect on the diversion ratio than other experiments. The one-way analysis of variance (ANOVA) test at a significant level of 5% was used to investigate the difference between the placement position groups. The results showed that there is no significant

difference between the groups of placement position (all of  $P$  values were greater than 0.05 and around 1); and therefore, the differences in the diversion ratio were not significant.

Using velocimetry at different points, velocities were calculated at 0.6 times the height in different tests. The results of these experiments for discharges of 40 and 60 L/s are shown in Figures 2 and 3, respectively. Comparison of Figures 1 and 2 shows that there is a large change in velocity, while the flow direction only slightly changes. As can be seen in Figure 2, in Test 1, where no spur dike has been used, a flow formed so that maximum velocity at the beginning of the intake inlet at width of 50 cm reached about 0.31 m/s. The flow separated line in this case is poor and negligible. In Test 2, a vortex is formed after the spur dike and at the entrance of the intake channel, with a maximum velocity of up to 0.40 m/s. The length of the flow separation line was calculated to be about 130 cm. It can be concluded that reducing the distance between the spur dike and the entrance of the channel leads to a larger input discharge. In Test 3, the flow moved more rapidly toward the intake in a way that the velocity reached 0.42 m/s at the entry of intake. Mild vortexes were also formed in downstream of the spur dike and in front of the intake. In this case, the flow separated line formed more than 250 cm from the spur dike, which continued downstream of the intake. Considering the distance of the spur dike from the intake, the width of the separation was not so great that it would have a significant effect on the

**Table 1** | Diversion ratio in different tests

Number of test	Placement position	Input discharge (L/s)	Flow depth (cm)	Main channel discharge (L/s)	Intake discharge (L/s)	Diversion ratio (%)
1	1	40	11.5	35.3	4.7	11.7
2	2			32.5	7.5	18.7
3	3			31.2	8.6	21.5
4	4			32.2	7.8	19.5
5	5			33.2	6.8	17
6	1	60	16	40.4	19.6	32.6
7	2			38.6	21.4	35.6
8	3			31.9	28.1	46.8
9	4			32.2	27.8	46.3
10	5			30.8	29.2	48.7

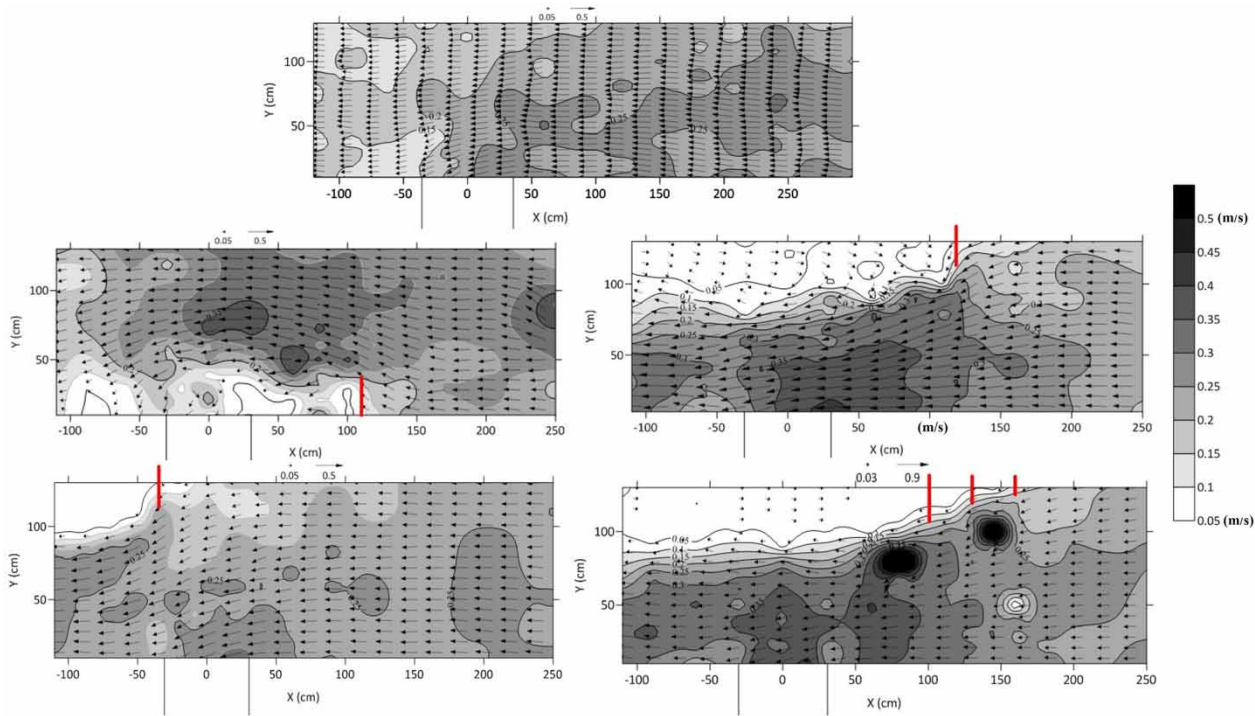


Figure 2 | Direction and velocity (m/s) plan in different parts of the main channel for 40 L/s.

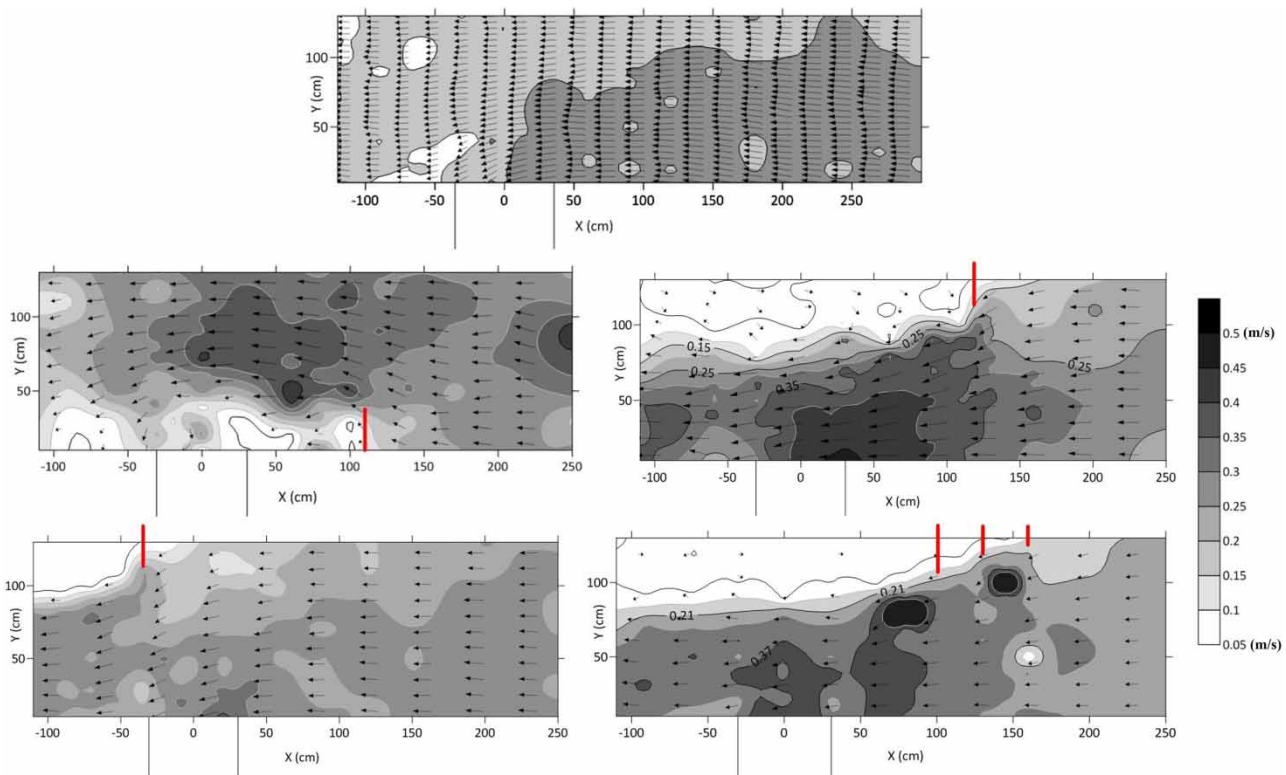


Figure 3 | Direction and velocity (m/s) plan in different parts of the main channel for 60 L/s.

diversion discharge. In Test 4, the highest velocity was at the beginning of the entrance to the intake channel and was equal to 0.34 m/s. In this case, the mild and rotational flows were formed at the entrance to the intake and also near the spur dike. The flow separated line started at the beginning of the spur dike and after the end of the intake and did not significantly affect the diversion discharge. However, due to flow constriction at the intake entrance, the diversion ratio increased considerably. In Test 5, powerful rotational flow were formed at the second and third spur dikes, which reached the maximum velocity in the second rotational flow of 0.96 m/s. Velocities at an entrance to the intake channel were evaluated at an average of 0.4 m/s. The flow separated line started at the beginning of the first spur dike and was still increasing in width after the intake. One of the most important objectives of this study is to compare velocity of flow at the channel entrance under different scenarios; hence, velocities at the nearest width to the channel entrance ( $y = 10$ ) in a discharge of 40 L/s were compared, as shown in Figure 4. As can be seen, in the Test 1, before the intake, an almost uniform flow was established and, as expected, the velocity was reduced during dewatering system, and then it becomes roughly uniform again. In Test 2, the average velocity before the spur dike was minimum, and then it was at a maximum. According to the presence of the spur dike, velocities at the intake entrance were sharply reduced and the flow slowly entered the intake. In relation to the flow path and completion of the flow separated line, and also the re-flow to the intake, the flow was diverted with greater velocity into the intake during the second half of the intake.

In Test 3 and Test 5, velocity increased after the spur dikes and, as a result, the average velocity at the intake entrance was higher than other tests. Although the rate of these velocities is approximately equal to each other, they do not have the same direction. For example, the flow in Test 5 was toward the intake and in Test 3 it was toward the main channel. However, in Test 4, due to flow constriction caused by the spur dike, which occurred after dewatering system, the flow was affected upstream and the velocity increased at the entrance of the intake and the first half of the channel. This increase in velocity is not the same as Test 5, and due to the uniformity of the flow, it created less turbulence in the intake entrance, which is expected to reduce the possible erosions.

After the flow stability, bed changes were calculated using the Automatic Bed Profiler. Morphological changes for Tests 1–5 are shown in Figure 5. As can be seen, the slight variation in the bed in Test 1, could be ignored. The maximum scour occurred in most tests at the spur dikes. The volume of sediment deposited was minimum in Test 4 and maximum in Test 2, as can be seen in Figure 6. The amount of local scour at the dikes may not be important if the dikes are designed properly. The scour rate in Test 4 was minimum and was maximum in Test 2. In Test 5, in which three parallel spur dikes were used, due to the process of changing the width of the bed, the first and second spur dikes appeared as a protective spur dike. They also reduced the maximum scour rate at the bottom of the spur dike to about half and drastically reduced scour at the mouth of the intake entrance. The maximum sedimentation occurred in Test 2. This sedimentation was located upstream of the

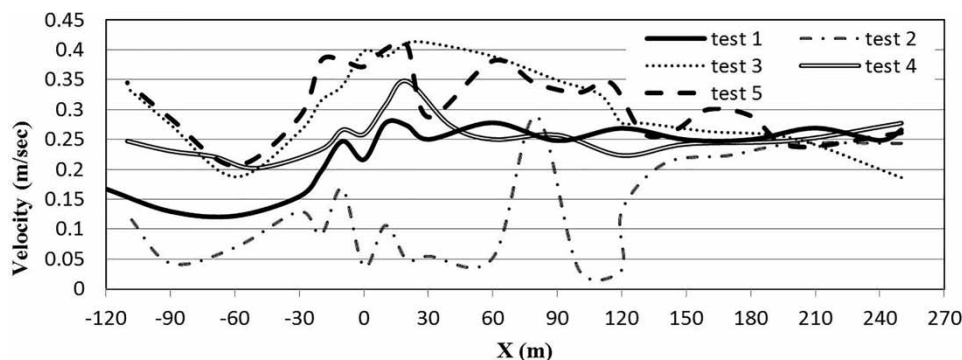


Figure 4 | Comparison of velocities at  $y = 10$  in various placement positions for discharge of 40 L/s.

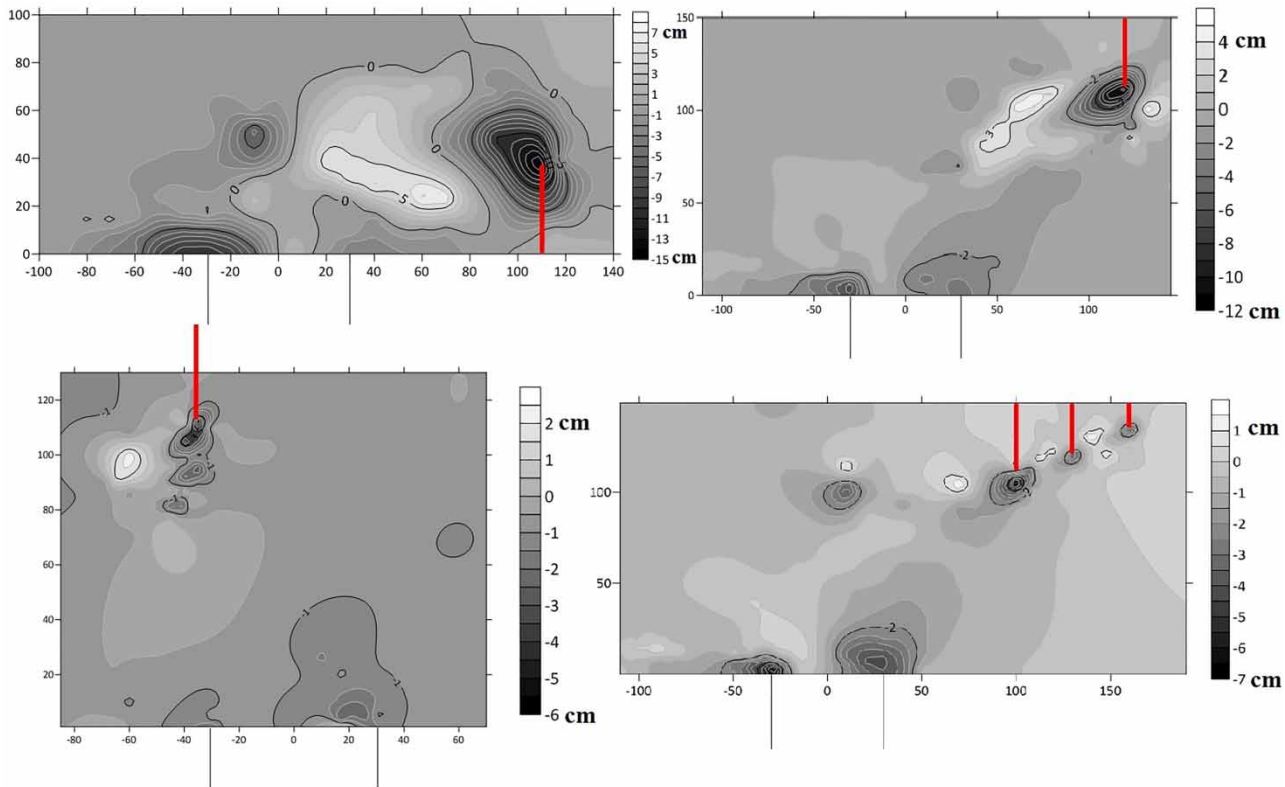


Figure 5 | Bed deformation after the stability of the flow (cm).



Figure 6 | Experimental view of flow and bed deformation in Test 2.

intake channel and, according to its direction and length, as well as the direction of flow in Test 2, diverted the flow path to the opposite side of the intake, thus affecting the rate of input discharge entering the intake. In Table 2, bed changes can be seen in different tests. The one-way ANOVA test at a significant level of 5% was used to test the significance of the difference between scour depth in the placement position groups. The results showed that, according to Table 3, the

Table 2 | Amount of bed deformation in different tests

Number of test	Sedimentation volume (cm <sup>3</sup> )	Maximum scour depth (cm)	Erosion volume (cm <sup>3</sup> )
1	22	0.6	106
2	2,907	14.5	12,445
3	566	11.41	2,015
4	155	6.44	503
5	479	6.98	3,424
6	25	1.6	387
7	3,045	14.9	35,107
8	907	13.8	9,602
9	345	7.64	1,349
10	1,076	9.5	7,166

difference in most groups is significant. Therefore, considering the lower scouring rate in placement position 4 and its significance in most cases, it can be concluded that placement position 4 has the best performance due to scouring.

**Table 3** | Result of one-way ANOVA test for scour depth

P value	Mean difference	Placement position	Placement position
0.001	-13.60 <sup>a</sup>	2.00	1.00
0.002	-11.51 <sup>a</sup>	3.00	
0.038	-5.94 <sup>a</sup>	4.00	
0.018	-7.14 <sup>a</sup>	5.00	
0.001	13.60 <sup>a</sup>	1.00	2.00
0.599	2.10	3.00	
0.013	7.66 <sup>a</sup>	4.00	
0.027	6.46 <sup>a</sup>	5.00	
0.002	11.51 <sup>a</sup>	1.00	3.00
0.599	-2.10	2.00	
0.048	5.57 <sup>a</sup>	4.00	
0.114	4.37	5.00	
0.038	5.94 <sup>a</sup>	1.00	4.00
0.013	-7.66 <sup>a</sup>	2.00	
0.048	-5.57 <sup>a</sup>	3.00	
0.901	-1.20	5.00	
0.018	7.14 <sup>a</sup>	1.00	5.00
0.027	-6.46 <sup>a</sup>	2.00	
0.114	-4.37	3.00	
0.901	1.20	4.00	

<sup>a</sup>The mean difference is significant at the 0.05 level.

Gohari *et al.* (2011) investigated the effect of spur dike on flow characteristic in a channel. They placed a spur dike upstream of the intake and submerged vanes, and three diversion ratios of 13%, 18%, and 24% were established by adjusting the height of the flow by overflows. Their research results are comparable to the results for Test 2. The major difference between the two studies is that there was much less erosion in Gohari *et al.* (2011) at the entrance of the intake channel due to the use of submerged vanes at the intake entrance. Given the differences in the two studies, it is not possible to precisely determine the effects of submerged vanes and angles of spur dikes in the diversion ratio, and further studies are needed in this field.

## CONCLUSION

In this study, spur dike placement was investigated in four different models under two discharge conditions. The

detailed study of this work leads to the following conclusions:

- Among the scenarios examined, position 3, with the placement of spur dike upstream of the intake, had the highest divisions ratio in both discharges (40 L and 60 L)
- The differences in the diversion ratio were not significant; on the other hand, the lowest scour depth, sedimentation, and erosion occurred in position 4.
- Considering all the factors and significant levels of results, placement position 4 provides the most suitable responses.

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