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T. K. Sruthi, K. B. Ranjith, and Venu Chandra

Control of Sediment Entry into an Intake Canal by Using Submerged Vanes

T. K. Sruthi[1, a)], K. B. Ranjith[2, b)] and Venu Chandra[3, c)]

[1]*Research Scholar, Department of Civil Engineering, Indian Institute of Technology Madras, India.*
[2]*Graduate Student, Department of Civil Engineering, Indian Institute of Technology Madras, India.*
[3]*Assistant Professor, Department of Civil Engineering, Indian Institute of Technology Madras, India.*

[a)]tk.sruthi@gmail.com
[b)]ranjeethkkb@gmail.com
[c)]vc@iitm.ac.in

Abstract. River flow which is entering into an intake canal carries lot of sediment due to centrifugal action at river-intake junction and results in various problems. The present work aims to control sediment entry into an intake canal by modifying flow pattern using submerged vanes. Experiments are conducted in a 57.5 cm wide rectangular laboratory model filled with sediment, d_{50}=0.28mm, for a constant discharge of 0.025m^3/s and flow depth (H) of 8cm. A rigid bed trapezoidal channel (side slopes, 1H: 1V) of bed width 15 cm, diverting at an angle of 45^0 from river model is used as an intake channel. Submerged vanes of width 0.18H and 1mm thick are arranged in single and double rows at a spacing (V_s) of 8cm and 12cm. The angle of attack (θ) of vane with respect to flow direction in river model varies as 15^0, 30^0 and 45^0. A total of seven vanes are arranged as a crest of wave with a central vane height of 0.625 H and decreasing gradually to 0.438H on either side. In single row vane arrangement, for 'V_s'=8 cm and 'θ'=15^0, 30^0 and 45^0, the sediment entry (S) reduces to 43%, 47% and 57% of sediment entry without vanes (S_o) and it is 40%, 44% and 48% of 'S_o' for 'V_s'= 12cm. Further 'S' reduces to 38%, 39% and 47% of 'S_o', by adding a second row of vanes at a lateral spacing and 'V_s' of 8cm. It is observed that 'S' decreases with an increase of 'V_s' as well as with addition of a second row of vanes and increases with an increase of 'θ'.

INTRODUCTION

Sediment transport into intake canals from alluvial rivers has been conceived as a menace for more than three decades. The water diverted to the canals is used for thermal power plants, irrigation fields, drinking water supply as well as for the purpose of navigation (Nakato*et al*., 1990; Barkdoll*et al*., 1990; Keshavarzi and Habibi, 2005). The deposition of sediments in the canal reduces the water carrying capacity of the canal by decreasing the effective area of transport (Wang *et al*., 1996). Sediment concentration in the water delivered to power plants cause wear in machinery and the maintenance cost to benefit ratio increases (Bishwakarma, 2008). The delivery of sediment laden water into irrigation fields elevate the paddy fields and also reduce the soil fertility (Moerwanto, 1990). The frequent dredging operations undergone to alleviate the situation are neither a permanent nor economical solution. The increased sedimentation in canal also promotes vegetal growth which provides resistance to the flow (Moghadam*et al*., 2010). Adequate understanding of sediment load behavior in the intake canal is required as it has both scouring and deposition characteristics (Sajedipoor*et al*., 2010).

Sedimentation occurs due to formation of a helical vortex at the canal-river junction because of the interaction between vertical velocity gradient and secondary currents which are developed by centrifugal action (Nakato*et al*., 1990). This phenomenon is similar to that occurring at river bends. The centrifugal force developed at junctions which increase from bottom to top, induces surface fluid to move outward and near bed fluid to move inward, resulting in a spiral circulation or secondary current (Odgaard, 1984). The bed load in the river lifted up by secondary circulation gets transported and deposited in separation zones within the canal (Odgaard and Wang

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1991a, b). In regions outside the influence of transverse velocity gradient, deposition is wide spread leading to shoaling problems in canals (Barkdoll*et al*., 1999).

In 1947, Russian Engineers Potapov and Pyshkin introduced the idea of using submerged vanes for river-channel stabilization. The concept remained untouched until the early 80s and in 1983 Odgaard and Kennedy studied the design aspects of employing a set of vertical submerged vanes to counteract the so developed helical vortex by generating an opposing vortex. Submerged vanes are structures placed along the river channel to alter the flow characteristics, with an initial height of 0.2-0.4 times the flow depth (Odgaard and Wang, 1991a).Extensive studies were conducted in the 1980s to understand the redistribution of flow using submerged vanes at river bends and the related design aspects. The vanes act as a flow training structure to alter magnitude and direction of bed shear stresses which modify the velocity, depth of flow and sediment transport behavior in the area of influence by vanes. The vane installed at an angle of inclination to the direction of flow produces a secondary current downstream of the vane. The optimum angle of inclination that produces minimum scour around the vanes was reported as 15^0 based on experiments conducted in a straight channel, although the angles of attack were limited to 10^0, 15^0 and 20^0 (Odgaard and Spoljaric, 1986). Increase in the angle will lead to increased flow separation at the vane edge resulting in greater scour. Depending on selective orientation of the vanes and differences in pressure distribution on both the faces, the vane aggrades one portion and degrades another portion of the stream cross-section.

Once the efficacy of submerged vanes in sediment control was established, researchers underwent several attempts on modifying the shape of vanes to improve its performance. The different shapes attempted were curved vanes (Odgaard and Wang, 1991; Gupta *et al*., 2006), sheet piles (Marelius and Sinha, 1998; Boniforti*et al*., 2015), a set of upper and bottom vanes (Barkdoll*et al*., 1999), tapered vane (Gupta *et al*., 2007; Azizi*et al*., 2012), trapezoidal, forward-swept and backward-swept vanes (Ouyang, 2009). The rectangular shapes are mainly preferred for field applications due to the ease in construction (Ouyang, 2009). However, nobody had considered the vertical turbulence that may arise because of differential height of vanes.

Submerged vanes found wide application in navigational requirements, river bank protection at bends, and protection of abutments and intakes. The degrading property of the vanes was put to use along water intakes to reduce sediment deposition inside the bay. In 1990, Nakato et al. conducted a case study for sediment control using submerged vanes at Iowa Power’s Council Bluff Power Station and obtained positive results. The lowered level of river bed, due to the formation of a scour trench, reduced the flow of suspended sediment load into the intake (Nakato*et al*., 1990; Nakato and Ogden, 1998). Barkdoll*et al.* (1999) was the first to report that formation of a scour trench is not the only criterion required for effective sediment control. The authors pointed out that the considerations for effective sediment control as minimum diversion sediment transport rate, minimum volume of sediment accumulation in the bay, acceptable volume of local scour near the intake and acceptable local scour downstream of the intake. The sediment control properties of the vanes vary with angle of attack to the mainstream flow, pattern of arrangement, number of rows and lateral and longitudinal spacing between the vanes (Wang *et al*., 1996; Yonesi*et al*., 2008; Moghadam and Keshavarzi, 2010). The sedimentation in the intake structure is also dependent on the angle of intake. An intake angle of 55^0 produces the lowest degree of secondary currents at junction, leading to lesser deposition inside the intake bay (Keshavarzi and Habibi, 2005). Except for the work by Ho *et al*. (2010), all previous studies on intake canal were conducted with an intake canal angle greater than or equal to 55^0. Ho et al., (2010) recommended the use of submerged vanes with a 45^0 intake canal.

The potential use of submerged vanes as a sediment excluder at intake canal is not fully explored in terms of varying the vane height and vane to intake spacing. The previous works in this regard were limited to vane height to flow depth (H) ratio of 0.25-0.45, vane height to vane length ratio of 0.25 to 0.5 and angle of inclination 10^0 to 40^0. Even though various arrangements of equal height of vanes in single row, multiple rows and with different spacing have been studied by researchers, there has been no mention about the effect in altering the spacing of the vanes from the intake. While the percentage reduction in sediment deposition in the intakes have been reported in a few researches, the quantity of sediment entry into the intake in comparison to the total erosion from the main channel had not been studied yet. The earlier studies were performed with an intake canal of rectangular cross-section. But, most common canal cross-section prevalent in the nature is trapezoidal. The three-dimensional flow at a canal junction and vortex formation is bound to change in the presence of a trapezoidal canal. The current work incorporates varied vane heights, different vane to intake spacing and quantification of sediment entry to the intake canal. Hence, the objective of the present study is to analyze the performance of a set of seven vanes (vane heights varying between 0.438 H and 0.625 H to form a crest of wave) arranged in single and double rows both with 8 cm and 12 cm vane spacing for angles of attack 15^0, 30^0, and 45^0. The distance between intake and vanes is kept equal to the vane spacing. Also, the canal cross-section considered is trapezoidal for better correspondence with field situations.

EXPERIMENTAL SETUP

Experiments were conducted in a re-circulating sediment channel with a width of 57.5 cm and a depth of 33 cm. A trapezoidal intake channel diverts from the main channel at an angle of 45^0. The intake channel has an average bottom width of 15 cm, a height of 33 cm and side slopes of 1H:1V. All experiments were conducted at a constant discharge (0.030 m^3/s) with 8 cm flow depth (H). The sediment used in the study has d_{50} equal to 0.28 mm which falls within the range of existing sediment size (Lupker*et al.*, 2011). The vanes used were of 1 mm thick and 16 mm wide. The width of vane is selected as 0.2 H as per the design guidelines given by Odgaard and Spoljaric (1986). The number of vanes inserted in a single row is seven. Experiments were conducted for a single row and a double row of seven vanes each. The spacing of vanes considered in the single row arrangement is H and 1.5H (8 cm and 12 cm). The double row arrangement has a vane spacing of H (8 cm). To simulate field conditions, 0.002 m^3 sand of d_{50}= 0.28 mm was distributed into the setup at upstream for every 15 minutes. The schematic diagram of the experimental setup is shown in Fig.1.

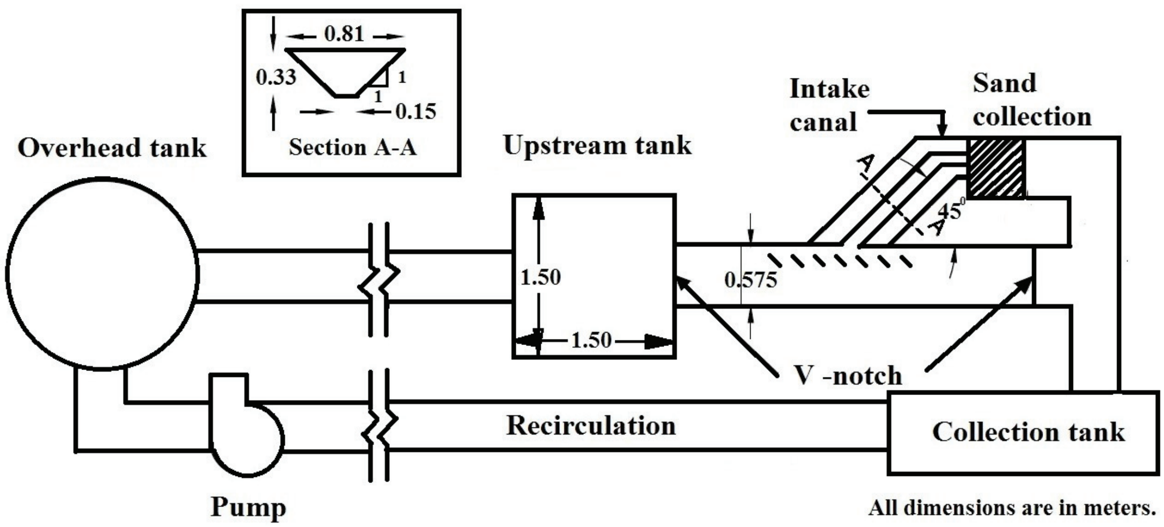

FIGURE 1. Schematic diagram of the experimental setup

The vanes were arranged in a crest of wave pattern with the vane height gradually increasing and then decreasing. The vane heights considered are 3.5 cm, 4 cm, 4.5 cm, 5 cm, 4.5 cm, 4 cm and 3.5 cm. The height varies from 0.438 H to 0.625 H. There are three variables in the experiment program, i.e., no of rows (single or double), spacing between vanes (V_s = 8 cm or 12 cm) and angle of attack ($\theta = 15^0$, 30^0 or 45^0). The vane to intake spacing is also kept equal to 'V_s'. Hereafter, a particular arrangement is presented in the manner of spacing-number of row-angle of attack and a total of nine experiments are present in this study (8-1-15^0, 8-1-30^0, 8-1-45^0, 12-1-15^0, 12-1-30^0, 12-1-45^0, 8-2-15^0, 8-2-30^0 and 8-2-45^0).

The bed was leveled prior to each run. The initial bed elevation was measured using a digital point gauge. The test section for the measurement of bed levels is 56 cm x 112 cm. Some portion (say 0.75 cm) of the main channel width on either side is neglected in considering the test section. From the intake channel center point, 56 cm on both upstream side as well as downstream side (total 112 cm) is considered for the test section. The discharge through the flume was measured both at the upstream and downstream of the main channel using V-notches. The discharge through the intake channel is obtained by subtracting downstream discharge from the upstream discharge in main channel. The volume of sediment collected in the intake channel is measured after stoppage of flow. The total amount of sediment eroded from the main channel was determined from the final bed elevation, so as to calculate the percentage of sediment entry into intake channel. The scour depth around all the vanes was measured. Initially, the readings were taken at an interval of 10 minutes up to 30 minutes, then, at 15 minutes interval up to 90 minutes and afterwards at an interval of 30 minutes up to 180 minutes (T), because afterwards not much change in the bed levels were noticed. The observations were checked for repeatability by repeating a single experiment thrice and the standard deviation between the values was ±0.006. Hence, the values were accepted henceforth.

RESULTS

The experimental results are presented in terms of sedimentation percentage (%) in the intake channel and variation of local scour with time. Local scour is the scour occurring around the vanes. The bed level contour for the best vane arrangement is also presented to visualize the erosion pattern.

Local Scour Due to Different Vane Arrangement

Local scour occurs around any object that obstructs the natural course of flow. If the vane-induced scour is high, it will turn detrimental to the structure. Therefore, along with counteracting the secondary current at the junction, the scour developed by the vanes should also be under check. In the present study, the local scour around all the vanes were measured for all the nine experiments carried out. It is observed that, maximum scour is at the downstream side of the vanes. As the object of interest is the maximum scour (D_{smax}), only the scour at the downstream is used for presenting the results. From the downstream scour values of all the vanes, the maximum value is used for presenting the maximum local scour ratio (D_{smax}/H). Table 1 presents the values of maximum local scour ratios for different vane arrangement. The time scale is also made non-dimensional by taking the ratio of time elapsed (t) to the total time of experiment run (T). The variation of local scour with time for different vane arrangements is shown in Fig. 2. The wavy nature in all the plots indicates that the erosion and deposition takes place intermittently. The local scour ratio becomes constant after an average time of 90 minutes, when the rate of erosion is equal to the rate of deposition.

The near bed flow carrying the bed load gets deflected outwards due to the inclination of the vanes away from the intake. The scour increases when greater amount of sediment is removed from the bed. The linear relation of local scour with 'θ' is observed from the local scour ratio plots. It is observed from Fig. 2 that the lowest local scour ratio is for 'θ'=15^0both for 'V_s'= 8 cm and 12 cm and the scour increases with an increase in 'θ'. From the experimental results, for any 'θ', it is observed that with vane arrangement 8 cm (2 rows), the lowest local scour ratio is noticed as compared to 8 cm (1 row) and 12 cm (1 row) arrangements. In addition, it is noticed that, for 8 cm (2 rows) the scour around each of the fourteen vanes is of lesser intensity compared to the scour at each of the seven vanes for 8 cm (1 row) as well as for 12 cm (1 row). The scour closer to the intake is least for 8 cm (2 rows) i.e. lesser amount of suspended sediment is in close proximity of the intake.

TABLE 1. Maximum local scour ratios (D_{smax} /H) for different vane arrangements with 'V_s'= 8 cm or 12 cm and 'θ' = 15^0, 30^0 or 45^0.

t/T	V_s= 8 cm (1 row)			V_s= 12 cm (1 row)			V_s= 8 cm (2 rows)		
	15^0	30^0	45^0	15^0	30^0	45^0	15^0	30^0	45^0
0.06	0.21	0.35	0.56	0.23	0.34	0.26	0.16	0.41	0.24
0.11	0.19	0.41	0.31	0.16	0.43	0.26	0.11	0.46	0.3
0.17	0.34	0.59	0.39	0.26	0.48	0.33	0.18	0.4	0.26
0.25	0.38	0.56	0.49	0.38	0.46	0.49	0.24	0.44	0.36
0.33	0.4	0.54	0.58	0.49	0.46	0.61	0.3	0.49	0.46
0.42	0.45	0.65	0.64	0.58	0.58	0.68	0.38	0.56	0.51
0.5	0.5	0.75	0.69	0.63	0.68	0.7	0.44	0.61	0.53
0.67	0.53	0.75	0.74	0.63	0.68	0.7	0.43	0.61	0.53
0.83	0.53	0.75	0.75	0.63	0.65	0.69	0.44	0.61	0.6
1	0.53	0.75	0.75	0.63	0.68	0.7	0.44	0.6	0.63

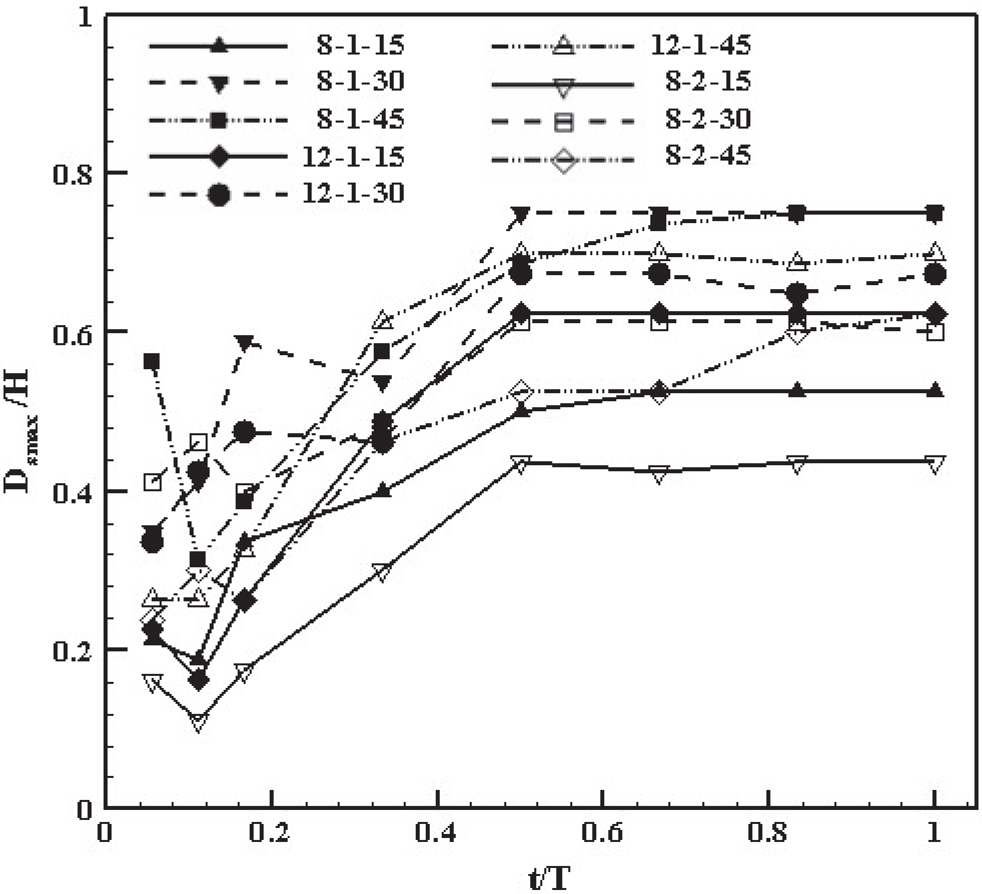

FIGURE 2. Variation of local scour ratio with time for different vane arrangements

Effect of 'θ' on Sedimentation (%) in the Intake Channel

The most intriguing factor which could be presented quantitatively is the percentage reduction of sediment entry into intake channel. Sedimentation percentage is the percentage by volume of the sediment entering into the intake channel to that of the total sediment eroded from entire test section. It is observed that the arrangement with the minimum local scour produces the lowest sedimentation in the intake channel. As the amount of sediment moving into suspension decreases, the chances for it to be transported into the intake will also decrease. The variation of sedimentation (%) with different arrangements of vane is presented in Fig. 3. From Fig. 3, without submerged vanes, almost half the quantity eroded (49.35%) from upstream is getting transported into the intake channel. For 'V_s'= 8 cm (1 row), the sedimentation (%) is 21.01 %, 23.27 %, 28.16 % for 'θ'=15^0, 30^0 and 45^0, respectively. For 'V_s'= 12 cm (1 row), the sedimentation (%) is 19.96 %, 21.78 %, 22.14 % and whereas, in the case of 'V_s'= 8 cm (2 rows), it is reduced to 18.96 %, 19.30 %, 22.95 %. The sedimentation percentage increases with an increase in 'θ'. Evaluating the two different 'V_s', the arrangement with 12 cm spacing (between the vanes and between the vane and intake) resulted in lesser sedimentation than 8 cm spacing for single row of vane arrangement. In the case of double row of vanes, a scour trench is formed along the second row of vanes. The scour trench formed due to the installation of vanes with 'V_s'= 8 cm is farther from the intake than with 'V_s'=12 cm. It was observed that the sediment coming from the upstream is directed into the scour trench and moved to the downstream. The farther the scour trench, the proximity of sediment into the intake is lesser. Hence, experiments with 12 cm (2 rows) were not performed.

The minimum sedimentation percentage is observed for two rows of vanes with 8 cm spacing at 'θ'=15^0. This is attributed to the formation of a secondary channel along the second row of vanes, away from the intake entrance. The intake channel bed elevation being higher than the bottom of the so-formed scour trench, the eroded sediment has a tendency to flow through this secondary channel to the downstream rather than entering into the intake structure. The lowest sedimentation corresponding to 8-2-15 arrangement is 18.96%.

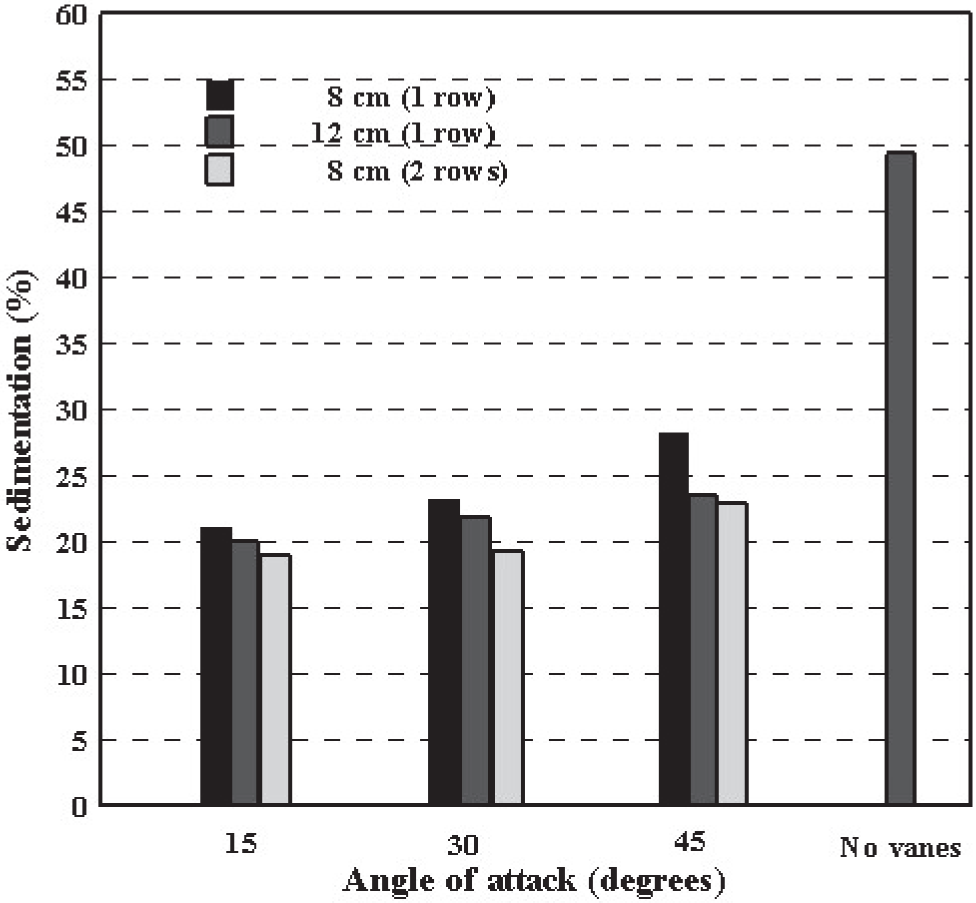

FIGURE 3. The variation of sedimentation (%) for different arrangement

Bed Topography

Figure 4 shows the contour map of the bed after experiment with 8-2-15^0 arrangement. As mentioned earlier, the area considered for taking bed readings is 56 cm X 112 cm. The contour map is made non-dimensional by considering relative distances from the origin. Width ratio (Y_r) is the ratio of y to Y and Length Ratio (X_r) is the ratio of x to X where, y= the distance of point under consideration from origin along width, Y= 56 cm, x= the distance of point under consideration from origin along length, X= 112 cm. The point (0, 0) is the reference point. The middle point of the upper horizontal limit represents the intake center point. The existence of the scour trench in front of the intake can be observed from the contour map. The trench begins at a distance of 31 cm upstream and extends to 13 cm downstream of the intake channel center point. This facilitates the movement of upstream eroded sediment directly to the downstream through this channel. The reduced bed level near to the entrance also prevents transport of sediment into the intake.

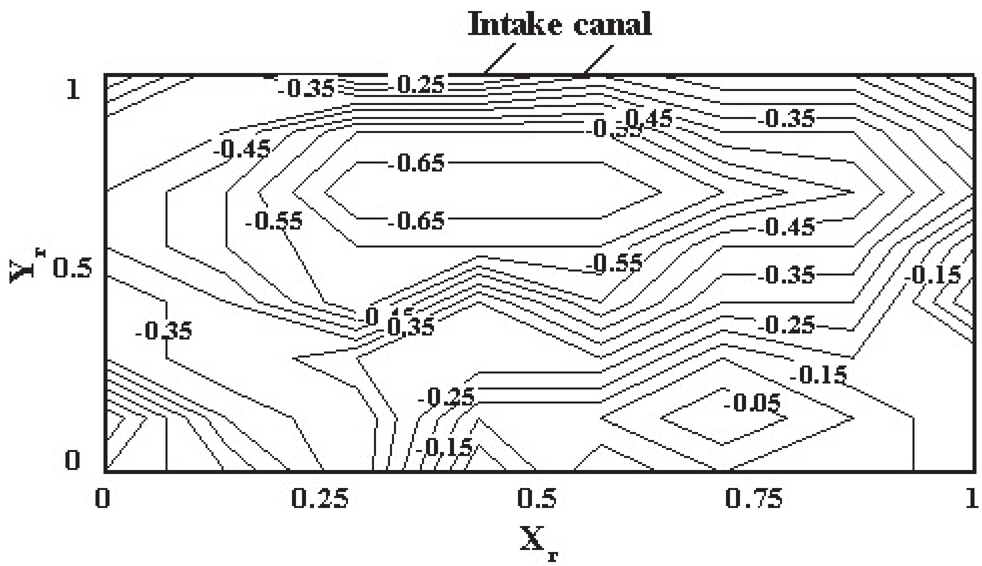

FIGURE 4. Contour map of bed after experiment with 8-2-15^0 arrangement

CONCLUSION

Intake canals are intended to transport water to power plants and irrigations fields. The increasing amount of sediment deposition in the canal leads to decrease in the water carrying capacity of the canal, operational inefficiency in power plants. Suitably designed submerged vanes can be installed to eradicate the effects to a considerable extend. The present study quantifies the variation in sediment entry into the intake canal with 15^0, 30^0 and 45^0 angle of attack in single and double rows of vane arrangement. The effect in the variation of vane spacing from the intake structure, which was neglected in the earlier researches, has also been addressed here. The previous works in this field had considered vanes of equal heights alone and only a rectangular intake canal. A non-uniform vane height arrangement in the form of a crest of wave and a trapezoidal intake channel was used for the present study. Experiments were conducted for the vanes installed at a vane spacing (V_s) = 8 cm or 12 cm for angles of attack (θ)=15^0, 30^0 and 45^0 in single and double rows. The vane to intake spacing was kept equal to the vane spacing. For arrangement with single row of vanes, for 'V_s'= 8 cm, the sedimentation (%) was 21.01 %, 23.27 %, 28.16 % and for 'V_s'= 12 cm, it was 19.96 %, 21.78 %, 22.14 % for 'θ' =15^0, 30^0 and 45^0, respectively. In the case of 'V_s'= 8 cm with double row of vanes, the sedimentation (%) reduced to 18.96 %, 19.30 %, 22.95 % for 'θ'= 15^0, 30^0 and 45^0, respectively. Sedimentation decreased with increase in distance of the vanes from intake channel due to reduced proximity of eroded sediment into the intake. The quantity of sediment entry into intake channel reduced with increase in number of rows and increased with an increase in vane spacing. Among the different arrangements, 2 rows of vanes with 8 cm spacing installed at an angle of 15^0 to the mainstream flow showed the lowest sedimentation percentage of 18.96%.The optimum angle of attack obtained is in agreement with the study of Odgaard and Spoljaric (1986).

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