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Possibility of Reducing Sedimentation at Lateral Diversion

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Abstract

Sedimentation in lateral diversions causes many problems such as reduction of system delivery efficiency and increasing of maintenance costs. There are several methods for sediment control in lateral diversions and suitable means are required to reduce these difficulties. An effective method for preventing sediment deposition at entrance of diversions is submerged vanes. When submerged vanes are used, the sediment entering into the diversion is eliminated for the range of q_r *(specific discharge ratio which is defined as ratio of diversion unit discharge to main channel unit discharge) to be less than 0.2. Beyond this value, the efficiency of the vanes diminishes. The performance of the vanes can be enhanced in several ways such as by installing skimming wall and sill. In this research, Current Deflecting Wall-Sill (CDW-Sill) was used as a new way of sediment control at lateral diversion and the performance of sediment control of CDW-Sill was investigated. The results showed that the performance of the CDW-Sill, up to the available specific discharge ratio of 0.6, was better than the submerged vanes. However up to specific discharge ratio of 0.4, the width of main CDW channel equal to 14 cm had the best performance for different widths of secondary CDW channel which eliminated the sediment uptake.*

Keywords: Lateral diversion, Sediment reduction, harbor, Current Deflecting Wall-Sill.

INTRODUCTION

Lateral diversions are structures which divert water directly from a river for irrigation networks, water supply, power stations, and other water uses. In design of rivers' lateral diversion, problems related to erosion and accumulation of sediment must be considered. Lateral diversion should be designed in a manner that minimizes the amount of sediment that is transported into the diversion channel. Flow pattern in lateral diversion is turbulent and wholly three-dimensional (3D). Figure 1 shows a schematic view of the 3D flow patterns generated by the lateral diversion [1 and 2]. As shown in Figure 1, a relatively large amount of bed sediment enters into the diversion channel for a larger portion of the near-bed flow is diverted. Sedimentation in lateral diversions causes many difficulties such as reduction of channel conveyance efficiency and increase of dredging costs. Annually, large quantities of sediment are removed from lateral diversions and high costs associated with frequent maintenance dredging leads to a strong interest to find solutions for reduction or even prevention of sediment entering and depositing in lateral diversions. Therefore, researchers have so far sought for useful ways of reducing sedimentation in lateral diversions [3, 4, 5 and 6].

Several methods have been introduced to sediment control in the lateral diversion and suitable means are required to overcome these difficulties. An effective and cheap method based on modification of the bed-shear stress distribution is the use of submerged vanes [1, 6, 7, 8, 9 and 10]. Submerged vanes change the near bed flow pattern and produce a scour trench in front of the lateral diversion. This makes submerged vanes useful to be the means of minimizing bed sediment transport into diversion [9]. Efficiency of submerged vanes is limited to a certain hydraulic condition. For the values of q_r<0.2 (ratio of unit discharge in the lateral diversion to unit discharge in the main channel), submerged vanes eliminate the sediment entering into the diversion. The effectiveness of the vanes diminishes in q_r>0.2. The performance of the vanes can be improved in several ways. One way is the use of a skimming wall in along with the vanes. The vanes and the wall are effective for values of q_r up to about 0.3. Another way is to widen the diversion entrance [6 and 9]. Barkdoll et al. [9] found that other ways such as modified vane shape and uniformity of flow distribution into the diversion are not effective.

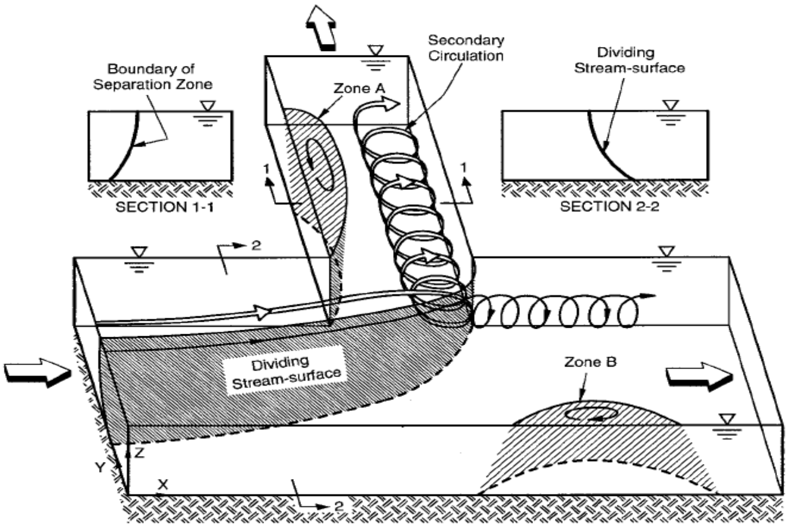


Figure 1. 3D flow pattern in lateral diversion [2].

Neary et al. [2] stated that effective strategies for reducing sediment transport into the diversion should be regarded as: reducing the strength of the secondary circulations, limiting the extent of the dividing stream surface at the bed and increasing the acceleration of longitudinal velocities in the main channel around the stagnation point. The dividing stream surface determines the rate of flow entrance into the diversion channel, therefore the use of a system that has a similar structure to the flow pattern in lateral diversion, which would decrease strength of vortexes and remove bed load from diversion entrance, can increase the performance of diversion in diverting water without sediment. Objective of this study is to explore the possibilities to apply a simple and effective structure to reduce sedimentation at the lateral diversion.

Siltation is an important problem in river harbors. A relatively new method to minimize harbor sedimentation is the use of Current Deflecting Wall-Sill (CDW-Sill). The CDW is a flow training structure that extends through the full depth of water. This passive structure is a curved (in the horizontal plane) vertical wall that is located at the sea side of a harbor entrance [11, 12, 13, 14 and 15]. During 1991, the CDW was used at the entrance of the Kohlfleet harbor in Hamburg and studies showed that sedimentation could be reduced by about 40%. Further researches have shown that when a sill is added to the CDW, the performance of structure is potentially increased by 10–25% [14, 16 and 17]. In Figure 2, design of the CDW-Sill for Parkhafen harbor is shown.

The CDW alter the flow pattern in such a way that a vortex with a horizontal axis over the width of the entrance is created and therefore sediment transport into the harbor is reduced (Figure 3). In fact, these vortexes act as an artificial sill that causes the water near the bed of the river to hardly enter into the harbor. A low sill at the sea side of the harbor deflects the bed load sediment away from the harbor entrance. The function of the CDW-Sill is that it captures the water required at the harbor from the upper section of the water column that contains little sediment [12, 13 and 18].

Winterwerp [17] stated that the efficiency of CDW-Sill strongly depends on its detailed shape and structural details such as the length and curvature of the CDW, the distance between the CDW and the streambank (defined as the CDW channel) and the shape and height of the sill.

The aim of this study is to investigate and evaluate the performance of CDW-Sill as a new method of reducing sedimentation at lateral diversion. Also, the performance of CDW-Sill in conjunction with submerged vanes will be examined.

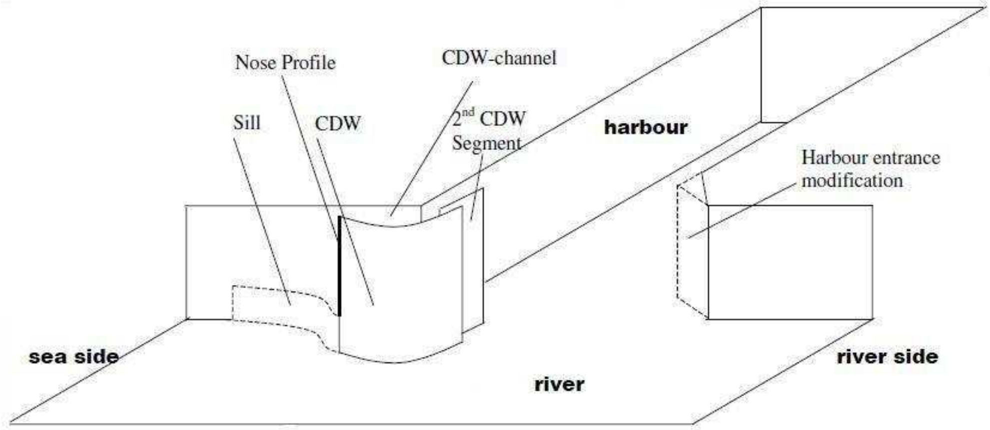


Figure 2. Design of the CDW-Sill for Parkhafen harbor and its components [14].

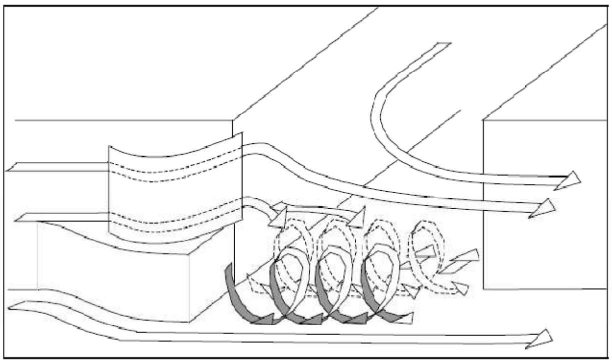


Figure 3. Flow pattern in harbor entrance with CDW installed [13].

Experimental Set up and Procedure

The experiments were conducted in a sediment channel with a lateral channel perpendicular to the main channel. The main channel is 0.6 m wide and 6 m long. It was filled with a 15 cm deep layer of uniform sediment and the grain diameter was 1.145 mm. The lateral diversion was located 3.2 m downstream of the channel entrance. Lateral channel was 4 m long and 0.24 m wide. The diversion floor level was the same as the bed level in the channel. Experimental discharges tested in the main channel were 13.75, 19.44 and 24.72 $L.s^{-1}$.The relative discharges of the flow into the diversion which is defined as ratio of diversion unit discharge to main channel unit discharge (q_r) were equal to 0.2, 0.4 and 0.6. These relative discharges were regulated by an inlet valve and downstream tailgates. In all of the experiments, the mean velocity of flow in the main channel was adjusted to a value 1.05 times the velocity of incipient motion of the bed sediment, as determined from the shields diagram. Each experiment ran for five hours during which rate of sediment transport into the diversion had no sensible variation and depth of scour hole in downstream of diversion reached the relative equilibrium. At the end of each experiment, amount of sediment entering into lateral diversion was collected, dried and weighed.

The performance of Current Deflecting Wall-Sill in sediment control was investigated and compared with performance of submerged vanes under the same hydraulic condition. Also, the performance of combination of CDW-Sill and submerged vanes was examined. A schematic layout of Current Deflecting Wall-Sill in front of diversion and its variables tested is shown in Figure 3. In table 1, CDW-Sill parameters which were tested in experiments are shown. In this research, effect of width of main CDW channel (W_m) and width of secondary CDW channel (W_s), in other words, location of ending point (z) of the main CDW were investigated. The radius and length of secondary CDW were set with an 18 cm and 11 cm respectively. Dimensions and array of submerged vanes were selected based on researchers' recommendations [3, 4, 5, 8 and 10].

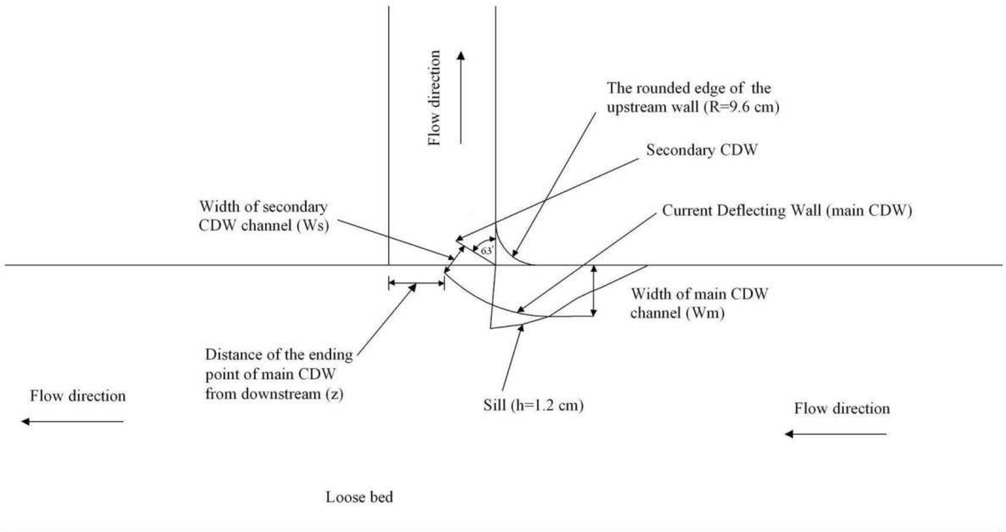


Figure 4. Current Deflecting Wall in front of diversion and its parameters.

Table 1. Tested parameters of CDW-Sill in experiments

Width of main CDW channel (cm)	Width of secondary CDW channel (cm)	Position (z) of the ending point of main CDW (cm)
11-15.5	5.5-10.5	10-15

RESULTS AND DISCUSSION

CDW-Sill as a flow training structure turns the flow pattern at the diversion entrance and diverts the flow of main channel into diversion. The installed sill keeps the bed load away from the diversion entrance efficiently without reducing the flow rate through the CDW channel. In initial stage of experiment, a scour hole formed under the main CDW (track line) and developed and then it joined the scour hole in front of diversion entrance. Because of circulation flows in downstream of main CDW, an artificial wall with moderate height formed in downstream of main CDW. This wall stretched from the end of Sill and continued to the downstream edge of diversion entrance. It was found that the artificial wall in the entrance had a beneficial effect on flow and approximately no sediment entered into the lateral channel from this section of the entrance. Furthermore, in higher specific discharge ratio, (q_r=0.6), scour hole depth in front of the entrance was very low. The reason was due to reduction of unsteady vortex interference in front of the diversion entrance. The downstream scour hole formed in a location further downstream of the entrance edge and because of main channel flow influence, it had extended more longitudinally. It seems that existence of CDW-Sill causes the strength of the secondary vortex entering into diversion to decrease, thus sediment entering into diversion decrease.

Secondary CDW installed was very effective in increasing the performance of CDW-Sill, such that in the case without secondary CDW, sediment entered into lateral channel from location of secondary CDW substantially. So, a secondary CDW was demanded to compliment the main CDW. In higher specific discharge ratio (0.6), some sediment entered into the diversion as being transported next to the secondary CDW. After the scour hole extended in front of entrance and became deeper, no sediment entered into the diversion from this zone, yet sediment kept entering the channel only from downstream corner of entrance (almost 30 minutes after beginning of experiment). In lower specific discharge ratio (q_r=0.2), there was flow returning from entrance of lateral channel to main channel. This returning flow pattern was observed in side of downstream lateral channel wall. Sediment rarely settled in diversion entrance and in the separation zone (zone A, Figure 1). This can be due to the increasing velocity of the near bed flow in upstream wall of diversion entrance and weakening the strength of the secondary circulation. Sediment entering into lateral diversion settled far away from diversion entrance (approximately three times width of lateral channel) with low height pile. Sedimentation pattern resembled to an almost asymmetric body, a narrow hill-like shape which stretched from upstream wall of lateral channel and extended to central axis of lateral channel with large distance.

Figures 5-a and 5-b show the performance of CDW-Sill in reduction of entering sediment versus various widths of main and secondary CDW channel respectively (W_m and W_s) in q_r=0.6. As shown in Figure 5-a, by increasing width of main CDW channel, entrance of sediment into the lateral diversion decreases at various widths of secondary CDW channel. The function of main CDW channel is to supply water needed for diversion, therefore by increasing its width, strength of incoming flow into lateral diversion reduces at the downstream edge of entrance. As shown in Figure 5-b, initially by increasing width of secondary CDW channel up to W_s=7.5cm, the performance of CDW-Sill increased. For other values of W_s, larger than W_s=7.5cm, the performance CDW reversed in various widths of main CDW channel. By contrast, at W_m=15.5, it is observed that the performance of CDW-Sill almost doesn't rely on W_s. It seems that with increasing width of secondary CDW in various widths of main CDW channel, and thus placing the ending point of main CDW at entrance suction spot, strength of the unsteady vortex extremely decreased. As mentioned before, in higher specific discharge ratio (0.6), scour hole in front of the entrance was very low. Also, in this experimental range of study, the best model case of CDW-Sill, rate of entering sediment into the water diversion reduced by 61.7 percent.

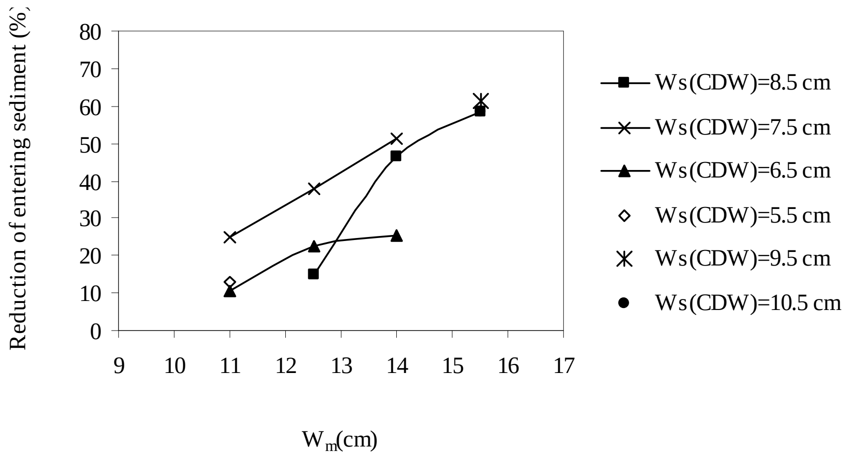


Figure 5-a. Trend variation of reduction of entering sediment into the diversion versus W_m(CDW) in q_r=0.6.

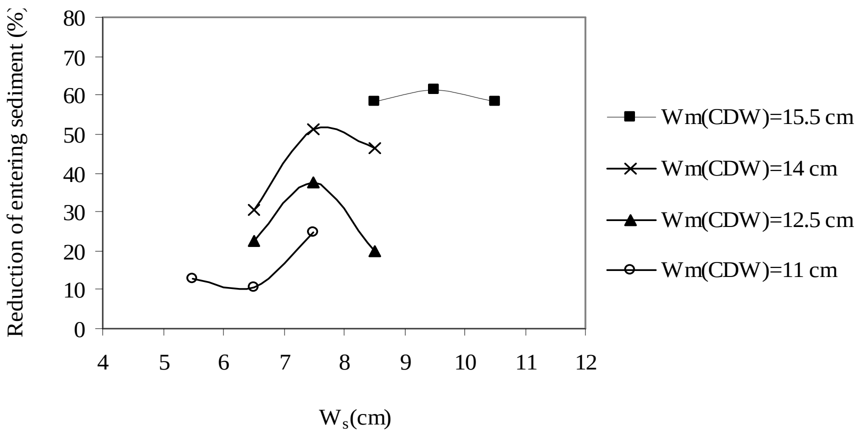


Figure 5-b. Trend variation of reduction of entering sediment into the diversion versus W_s(CDW) in q_r=0.6.

The performance of CDW-Sill in reduction of entering sediment versus various widths of main and secondary CDW channel (W_m and W_s) in q_r=0.4, is shown in Figures 6-a and 6-b respectively. In specific discharge ratio of 0.4 (Figure 6-a), by increasing width of main CDW channel up to W_m=14 cm, the performance of CDW-Sill increased. For main CDW channel widths of larger than the mentioned value, the performance CDW decreased in various widths of secondary CDW channel. It can be due to long distance of ending point of main CDW from diversion entrance. This means that the increasing width of secondary CDW channel and therefore velocity reduction in flow passing through the channel, interaction between the main and secondary CDW channel width manipulate the performance of CDW-Sill. As shown in Figure 6-b, the performance of CDW-Sill has approximately the same descending trend in various width of secondary CDW channel. In W_m(CDW)=14 cm, the CDW-Sill has the most successful performance for different widths of secondary CDW channel which eliminates the sediment uptake.
Figures 7-a and 7-b show the performance of CDW-Sill in reduction of entering sediment versus various widths of main and secondary CDW channel respectively (W_m and W_s) in q_r=0.2. In this condition, no sediment entered into diversion in all experiments except for three cases (as shown in Figures 7-a and 7-b). It shows that CDW-Sill can prevent the sediment entering into lateral diversion efficiently .Also, the CDW-Sill increases the rate of diversion discharge by 19-38 percent up to the specific discharge ratio of 0.4.

According to these experiments, under live bed condition, it was concluded that the CDW-Sill decreased the entering sediment into the diversion by 28–100 % in various diversion discharges. The comparison of Figures 5-a, 5-b and 6-a, 6-b demonstrate that the performance of CDW-Sill is sensitive to the location of ending point of main CDW. In other words, performance of the CDW could be affected by small changes in position of the ending point of CDW by means of changing the width of the main CDW channel or length of main CDW. This condition was especially observed in high values of specific discharge ratio.

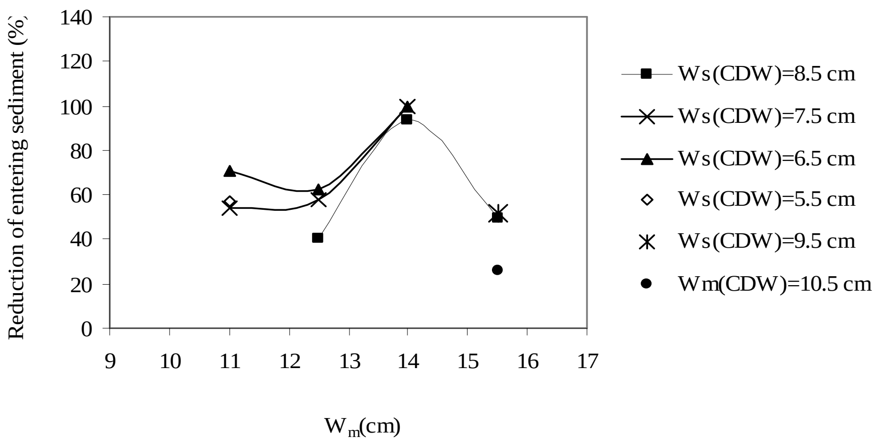


Figure 7. Trend variation of reduction of entering sediment into the diversion versus W_m(CDW) in q_r=0.4.

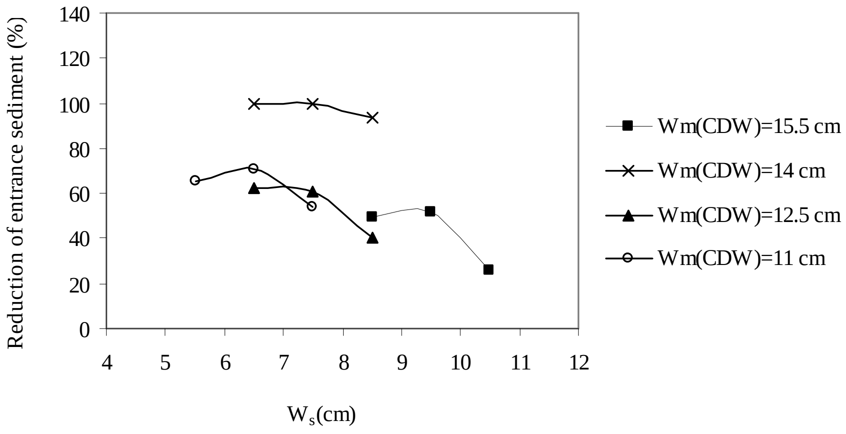


Figure 8. Trend variation of reduction of entering sediment into the diversion versus W_s(CDW) in q_r=0.4.

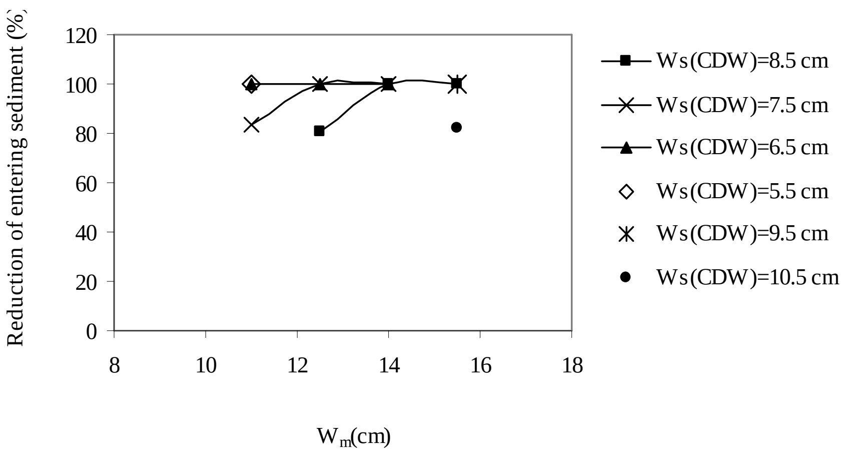


Figure 9. Trend variation of reduction of entering sediment into the diversion versus W_m(CDW) in q_r=0.2.

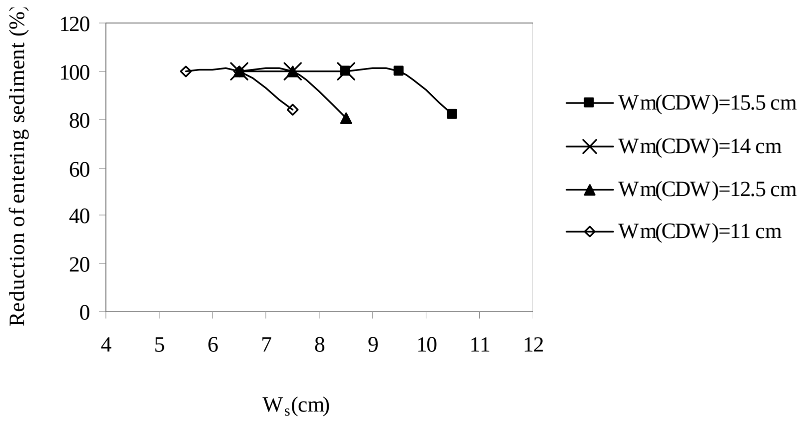
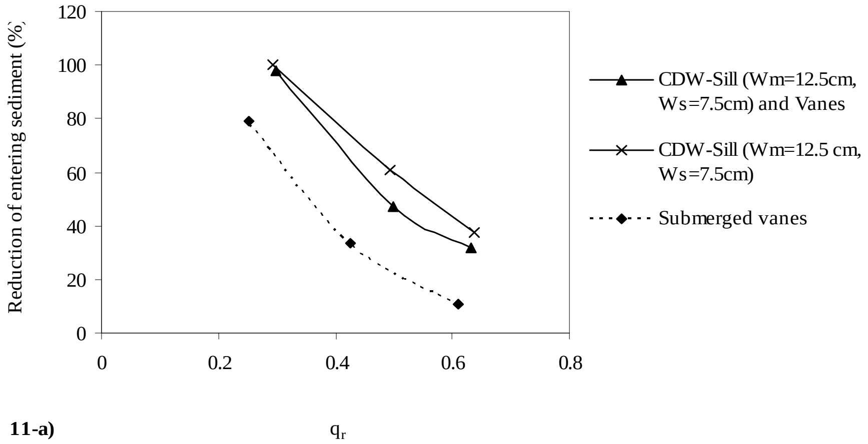
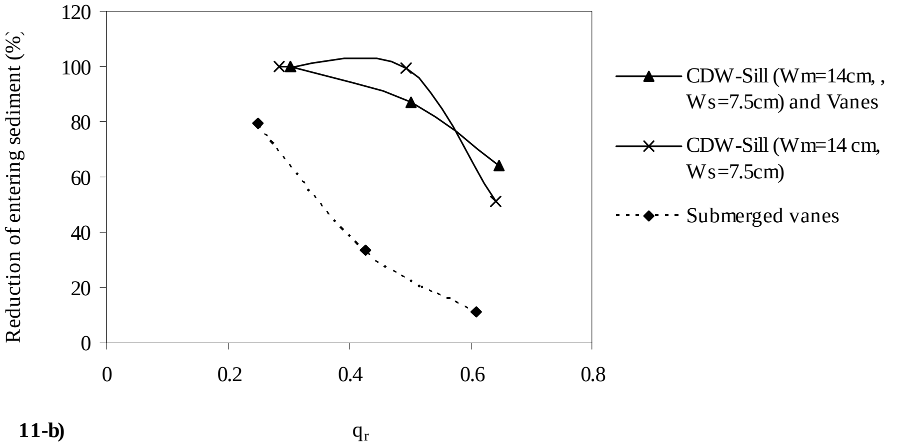


Figure 10. Trend variation of reduction of entering sediment into the diversion versus W_s(CDW) in q_r=0.2.

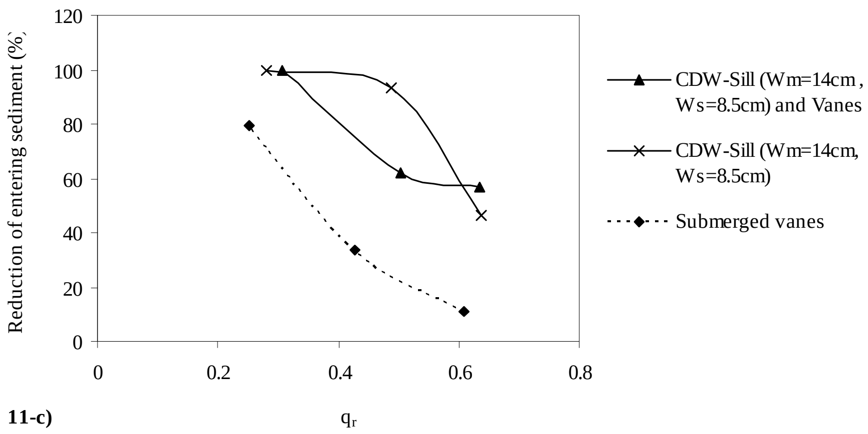
The performance of CDW-Sill, submerged vanes and CDW-Sill in conjunction with submerged vanes- in same condition experiment- are shown in Figures 11-a, 11-b and 11-c respectively. By increasing specific discharge ratio (q_r), quantity of sediment entering into the diversion (Q_{bd}) increases. In all experiments, the performance of CDW-Sill is comparable with that of submerged vanes. CDW-Sill reduces transported sediment into the lateral diversion efficiently. Performance of CDW-sill and vanes when combined, is approximately similar to CDW-Sill especially in higher specific discharge ratio (q_r=0.6). Submerged vanes do not have any effect on the performance of CDW-Sill in low specific discharge ratio (q_r=0.2). It seems that CDW-Sill can be used alone in sediment control at lateral diversion if it has an optimal design.



11-a)



11-b)



11-c)

Figure 11. Trend variation of reduction of entering sediment into the diversion versus (q_r) in three different cases.

CONCLUSION

Sedimentation is a serious problem at many river diversions. In recent decades, many studies have been conducted on the subject, aiming to reduce the sedimentation at lateral diversion. Even though, several methods have been investigated and introduced for sediment control in lateral diversions, more suitable and innovative means are required to deal with the problem.

In this research, the Current Deflecting Wall-Sill is used as a new way to reduce sedimentation in lateral diversion. It can be concluded that the CDW tested is able to decrease sediment entering into the diversion by 28–100 % in various diversion discharges. In the most successful case (the model with W_m=14cm), no sediment entered into diversion up to specific discharge ratio of 0.4. The functioning of CDW-Sill is based on its effect on the local three-dimensional flow field, in particular the reduction of the strength of secondary vortex in lateral channel and the rate of vertical vortex (unsteady vortex) in front of lateral diversion. Comparison of performance of CDW-Sill with submerged vanes showed that CDW-Sill can be used alone in sediment control at lateral diversion if it has an optimal design. It is stressed that this result stems from a series of experiments under idealized conditions only. Further and complementally researches are required to investigate the optimization of design details of CDW-Sill and thus to examine the possibility of reducing sedimentation in order to minimize its construction costs. Also, for an optimal design, a proper numerical model on the basis of measurements data will increase the confidence to design and assess the effectiveness of CDW-Sill.

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