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# Laboratorial investigating of the scouring extension in the range of trapezoidal and rectangular Multiple vanes to direct the flow in the rivers' bends

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**ABSTRACT**

In this study the application of trapezoidal vanes in the river's bend as the substitute for the rectangular structures to control the erosion in the external bank has been implemented. To reach the research objective, some experiments with a number of 11 trapezoidal vanes with the angle of 30° (towards the upstream) of the distance of 56 cm under the different hydraulic conditions have been conducted. To compare the results some experiments were implemented using the rectangular vanes by the Froude number of 0.24 and the distance of 56cm. The obtained results show that in all of the Froude numbers in the experiments by the presence of trapezoidal vanes the scouring was kept away from the outer bank and transferred to the structures' nose which is the same flume's breadth center. Also, in the downstream of the trapezoidal vanes a sediment hill is created which plays a remarkable role in external bank's restoration. In the rectangular structure the nose scouring in most of the structures extends towards the external bank. The length and the distance of the created hill in their downstream from the external bank are respectively lower and higher in trapezoidal vanes. The calculated scouring rate by the SURFER software is 56% more in the rectangular vanes than the trapezoidal ones. The dimensions of the scouring hollow around the structures increase towards the end of the bend gradually. The maximum scouring depth in the rectangular vanes is 251.2 mm which has occurred in the structure's nose and is more about 63.17% than the maximum scouring depth in similar experiment about the trapezoidal vanes.

***Key words :*** *Froud number, Trapezoidal vane, 90 degree bent*

## Introduction

The flow pattern after entering the bend as the outcome of two opposite forces with non-uniform vertical distribution— one of these forces is the centrifugal force which is greater in the surface than its amount on the bed and is towards the outerbank, and the other force is a hydrostatic force with the opposite direction and distribution of the above force— changes and creates a spiral flow form in the bendwhich causes the river's morphology in the bend. Modifying this pattern to control the erosion and sedimentation changes is one of the watershed engineers' goals. In the past, there were created different methods to this aim. A number of these methods were aimed at displacing the erosive hole from the bank heel to more distant areas to prevent from damaging and collapsing of the bank. Among these

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methods the spur dike structures can be referred to. The spur dike structures are usually constructed perpendicular on the bank and non-submerged. These structures should be constructed with certain distances from each other to make the modification flow pattern conditions prevent from the spiral flow being closed to the bank, meanwhile determining the appropriate distance causes the sedimentation between the vane and as a result causes its fixation. Tal'at *et al* (2009) conducted their research in order to introduce the non-submerged spur dikes to decrease the river side's erosion. They found that the spur dike performance has a reverse relationship with the spur dike distance, while it has a direct relationship with spur dike's length in the stable angle and distance. Hashemi Najafi (2008) implemented the experiments about the effect of angle on the L-shape spur dike's scouring. The results of their study showed that the maximum scouring depth in the edged L-shape spur dike towards the upstream is less than the blade spur dike. Also, if the edged L-shape spur dike is used towards the upstream the 60 angle leads to the least scouring depth, which is 110 for the edged L-shape spur dike towards the upstream. Buyan *et al.*, (2010) used the triangular vanes linked to the bank to control the river's curve erosion in a laboratorial research.The results of their research showed that in case of installing the vanes with 30 degree towards the upstream and with equal distance, the scouring depth in the vane's heel is less than the rectangular vanes and usual spur dikes, whereas the flow distribution pattern is modified in way that the talwegis transferred to the middle of the river and the sediment hills will be created behind the vanes. Implementing an experiment on the single trapezoidal vane and comparing it with the single rectangular vane, Keramatzadeh*et al* (2014) showed that the hole scouring depth in the heel of trapezoidal vane is 65.3% less than the same place of the rectangular vane. Accordingly, in this study the application of trapezoidal vanes under the different hydraulic conditions has been investigated and the sediment pattern with the bed conditions has been compared in case of the rectangular vanes existence.

## Materials and Methods

The effective variables to dimensional analysis are:

- The channel's geometry: channel breadth (B), bend's radius (R)
- Spur dike's geometry: spur dike's length (L), the angle of placing the trapezoidal vane (θ), the space between the vanes (S)
- Properties relevant to the flow hydraulic conditions: the flow velocity in the upstream (U), flow depth (do), and the gravity acceleration (g)
- Sediment properties: the average sediment diameter ($d_{50}$), sediment density ($p_s$)
- Properties of the fluid: special gravity (p), and dynamic viscosity (μ)

$$F(\mu, \rho, g, d_{50}, \rho s, do, R, L, B, s, \theta)=0 \quad .. (1)$$

If three factors of flow depth (do), flow velocity (U), and special gravity of the fluid (p)are selected as the repeated factors, regardless of $\rho/\rho_s$ and $d_{50}/y$ because the materials and the type of fluid are considered identical in all of the experiments, and since the flume flow is turbulent, the Reynolds number can be passed up. According to the dimensional analysis based on the Buckingham -π method there is the result:

$$f\left(Fr,\theta,\frac{S}{do},\frac{L}{do}\right)=\frac{ds}{do} \quad f\left(Fr,\theta,\frac{S}{do},\frac{L}{do}\right)=\frac{ds}{do} \quad .. (2)$$

Where ds is the scouring depth, do is the flow depth in bend's upstream, *Fr* is Froude's upstream number, θ is the angle of the structure with the perpendicular line on the bank, S is the space between the structures, and L is the length of the structure.

In order to implement the experiments rectangular cross-sectional bend shape flume with the breadth of 0.7 m, and height of 0.5 m was used. The proportion of flume curve radius to its breadth is 4. The used flume is the direct entrance channel with the length of 6.5m to a channel with the bend of 90^ and length of 5 m, where the bend channel is linked to the control valve of the flow depth and then the exit reservoir by another direct channel. As the amount of scouring during 180 minutes was so remarkable and almost had a stable status, the applied time for the experiments considered to be 180 minutes. Investigating the Froude's number effect on the bed scouring pattern in the angle of 90° with the presence of trapezoidal vanes linked to the bank, the experiments for the angle 30° and four Froude's numbers (0.32, 0.29, 0.26, 0.24) flow depth of 0.13 m were implemented.

The applied sediments had identical grading with

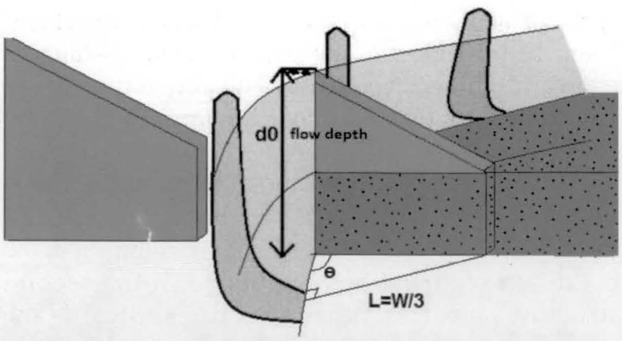


**Fig. 1.** The appearance of all of the trapezoidal vanes placing in sediment bend in 90°

average size of 1.49 mm. the topography measuring bed machine was used to collect data with accuracy of ± 1 mm in breadth, and ±0.4 mm in depth. The output data of this machine is equal to its laser distance from the sediment surface. To investigate the scouring amount around the structures more detailed, the space of the perpendicular sections on the flume's wall considered less near the structure. Also, data collection was done from the distance of 2 meters of the direct output way. After data collection and converting the limited bend data from the polar status to Cartesian, using the Excel and Surfer software the output data was analysed which has been illustrated in form of diagram and graph as well as presenting the quantitative digits. The length of the trapezoidal and rectangular vanes designed in a way to make the distance of the structure's peak from the outer bank after its installing as its one third. The height of the great and small bases of the trapezoidal vanes selected to be level with water and sediments surfaces, respectively. According to these explanations, for each experiment a number of 11 trapezoidal vanes were used in which the length of the great base was 33.5 and the small base was 21, and its length was equal to 54.4. The experiments were implemented for the angle installation of 30° and the Froude's numbers (0.24, 0.26, 0.29, and 0.32) and the flow depth of 0.13 m. For the control experiment 11 rectangular vanes with the length of 54.4 and the height of 40 cm were used. The experiments for the installation angle of 30°, the Froude's number (0.29), and the flow depth of 0.13 m were conducted.

## Results

This assessment has been done to investigate the effect of Froude number as the input to the bed's scouring pattern in presence of trapezoidal and rectangular vanes in series form in bend of 90°. The experiments for Froude's numbers of 0.24, 0.26, 0.29,

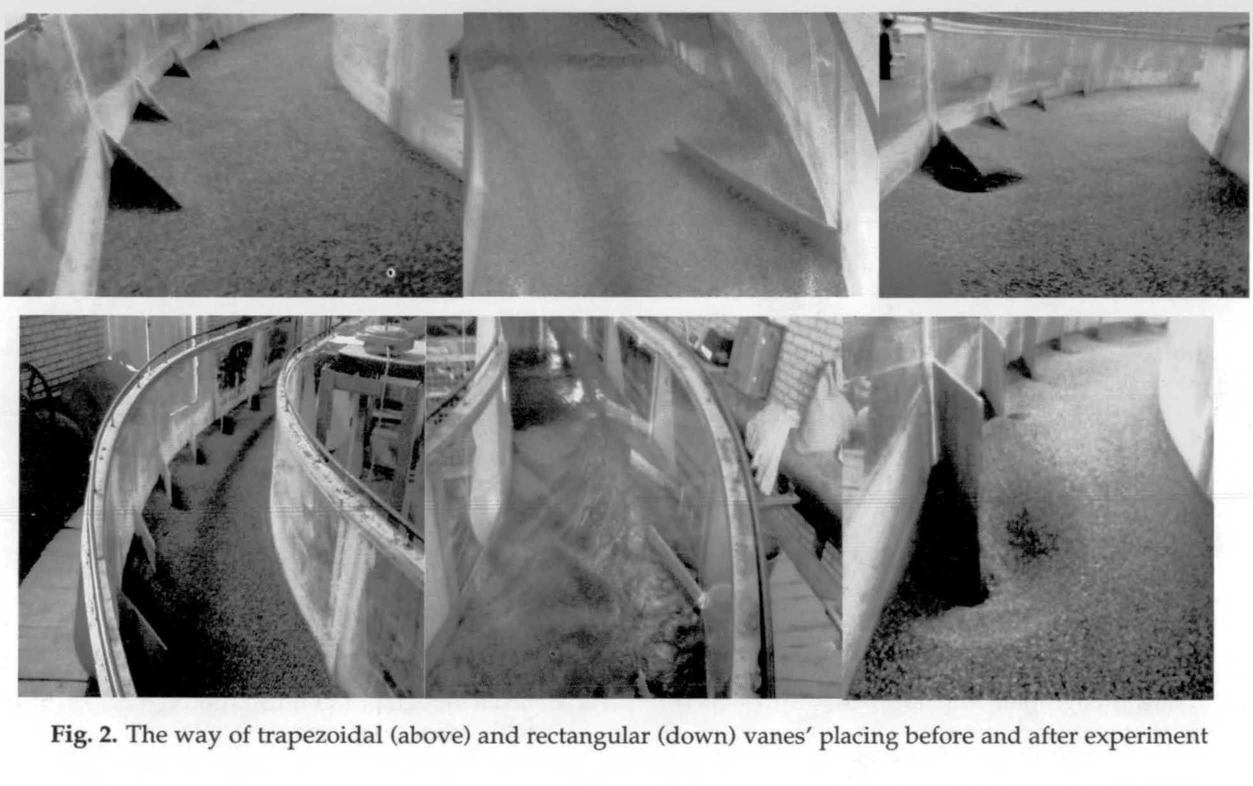

**Fig. 2.** The way of trapezoidal (above) and rectangular (down) vanes' placing before and after experiment

and 0.32, the installation angle of 30°, and the flow depth of 0.13 was planned and implemented. The scouring pattern and bed's sedimentation as well as the talwegare illustrated in form of colourful spectrum using the trapezoidal and rectangular vanes in series form after 180 minutes of testing.

As it is seen in Figs 3 and 4, the maximum scouring depth has occurred in the first structure nose (5cm before the bend). Except for the structure 1 which has the maximum scouring depth in the nose, from structure 2 through 9 the nose scouring increases. The length of the created sediment hill in the structures' downstream towards the downstream of the structure 2 through 11 increases respectively. In the structure 1, the dimensions of sediment hill is equal to structure 11. The depth of the created canal in the center of the flume's breadth which has been continued during the bend is so low and has a horizontal bed. This canal starts from structure 2 and continues to the internal bank towards the structure 8. Also, this canal is far from the outer bank. So, this Froude's number has a great effect in distancing the scouring from the outer bank. There is scouring in upstream and between the space of structures and the outer bank in structures 1 and 10, but in rest of the structures this distance is even and without scouring. The above results are consistent with the results of Bhuiyan *et al* (2010) experiments.

As it is seen in figures 5 and 6, the scouring maximum depth has taken place in the first structure's nose which has been installed in the beginning of the bend. No scouring has happened in the second structure's nose. In other structures towards the downstream, the scouring maximum depth increases in the structure's nose. Except for the structure 1 which its nose's scouring is the same as the structure 11, the length of the created sediment hill in the structures' downstream increases towards downstream. There is scouring in the upstream and in the space between the structures and the outer bank in structure 1, 8, and 9, but in other structures this space is even and without scouring. The depth of the created canal in the center of the flume's breadth which has been continued during the bend is so low and has a horizontal bed. This canal starts from structure 3 and continues to the internal bank towards the structure 9. The results above are con-

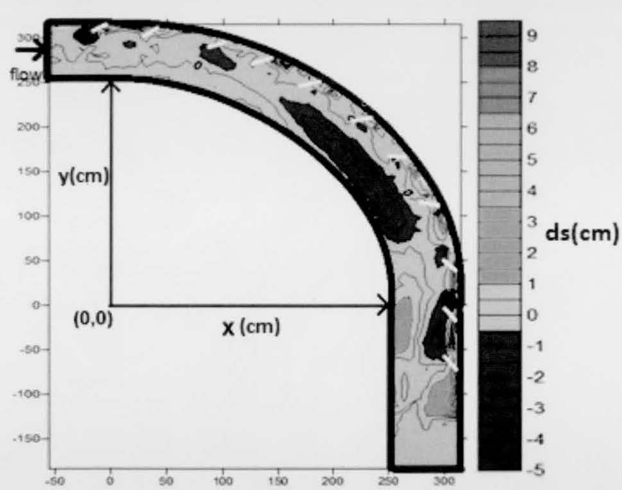


**Fig. 3.** Bed's topography (S=4L, Q=25L/s) trapezoidal vanes

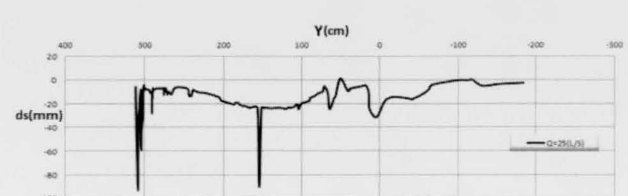


**Fig. 4.** Bed's topographic illustration (Q=25L/s, S=4L) with trapezoidal vanes

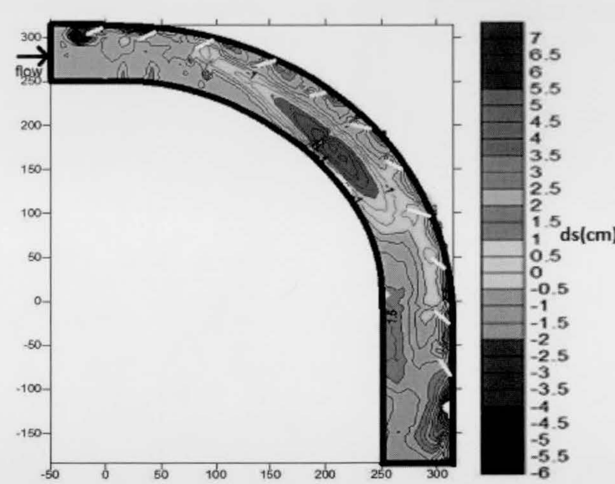


**Fig. 5.** Bed's topography (S=4L, Q=27L/s) with trapezoidal vanes

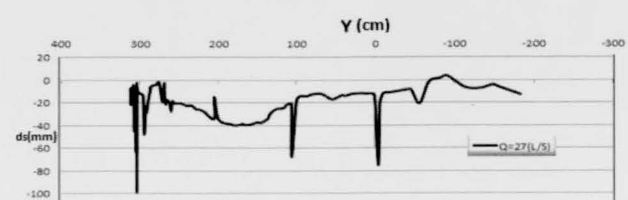


**Fig. 6.** Bed's topographical illustration (Q=27L/s, S=4L) with trapezoidal vane

sistent with the results of Bhuiyan *et al* (2010).

As it is seen in figures 7 and 8, the maximum scouring depth has occurred in the first structure nose (5 cm before the bend). Mean while, this scouring has reached to the outer bank. In structure 2 no scouring has occurred. In other structures the nose's scouring is seen less. The length of the created sediment hill in the structures' downstream towards the downstream of the structure 2 through 11 is increasing. There is scouring in the upstream and in the space between the structures and the outer bank in structure 1, 5, and 6, but in other structures this space is even and without scouring. The created canal in the center of the flume's breadth which has been continued during the bend's length starts from structure 3 towards the internal bank through the structure 8. The above results are consistent with the research results of Bhuiyan *et al* (2010).

As it is seen in figures 7 and 8, the maximum scouring depth has occurred in the first structure nose and this scouring has been continued towards the outer bank. In other structures the scouring increases according to the structure number towards the downstream. The length of the created sediment hill in the structures' downstream in structure 2 is more than the other structures, and structure 1 has the maximum scouring depth. Scouring has been occurred in upstream and in the space between the structures and the outer bank in most of the structures, so this Froude's number has had less effect on distancing the scouring from the outer bank compared with other less experimented Froude's numbers. The created canal in the center of the flume's breadth which has been continued during the bend's length starts from structure 1 towards the internal bank through the structure 11, and has covered more length of the flume than the experimented Froude's numbers. The above results are consistent with research results of Bhuiyan*et al* (2010).

The place of occurring the maximum scouring in any individual Froude number is near the nose of structure 1, and for all of the input Froude's numbers (0.24, 0.26, 0.29, and 0.32) is respectively equal to 92.5, 98.9, 84.4, and 135.6 mm. The maximum scouring depth reaches to 13.5 cm or 24.8% of the effective length of the vane, and this phenomenon is the results of the horizontal vortex in the structure's nose because of the separation flow linesin the structure's nose.

As it is seen in figure 11, with increasing the

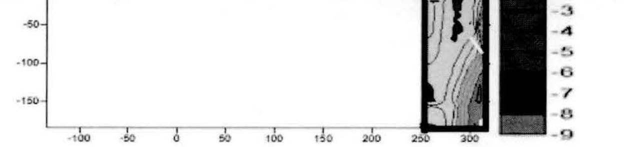


**Fig. 7.** Bed's topography (S=4L, Q=30L/s) with trapezoidal vanes

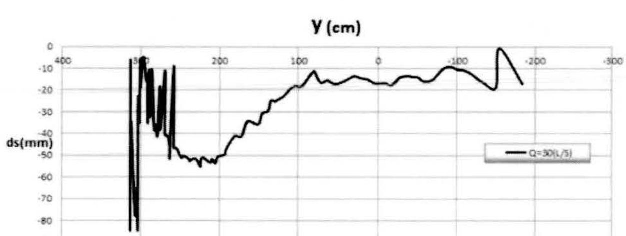


**Fig. 8.** Bed's topographical illustration (Q=30L/s, S=4L) with trapezoidal vane

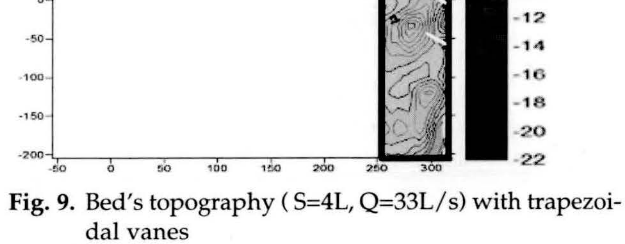


**Fig. 9.** Bed's topography ( S=4L, Q=33L/s) with trapezoidal vanes

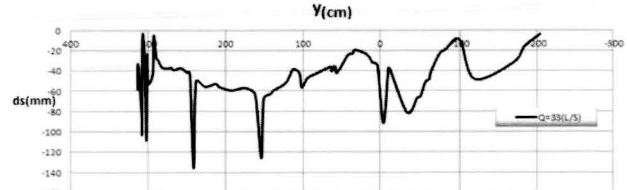


**Fig. 10.** Bed's topographical illustration (Q=33L/s, S=4L) with trapezoidal vane

Froude number the talweg's depth increases, too. In figure 12, the comparison between the talweg of the rectangular and trapezoidal vanes has been illustrated.

As it is observed in figure 12, the rectangular vanes' talweg is deeper than the trapezoidal vanes.

In figure 13, the Volume ofscouring has been shown in different Froude numbers. As it is seen, with increasing the Froude number the Volume of scouring increases, too.

The rectangular structure with the distance of 56 cm and the discharge of 30 L/s in a 180-minute-experiment was used for comparison. The bed's topography and the talweg flume are shown by a colourful spectrum in figures 14 and 15, respectively.

As it is seen in figures 14 and 15, the maximum scouring depth has occurred in the first structure nose (5cm before the bend). In the nose of structure 2 the scouring depth is almost zero. Except for structure 2, the nose scouring has reached to the outer bank. So, in this experiment the outer bank has not been protected. In all of the structures, except for structure 1 which its downstream sediment hill dimensions are more than the others, the sediment hill dimensions increase towards the downstream. The created canal in the flume's breadth centerwhich has continued in flume's length covers the all outer bank from the structure 3 towards downstream.

Comparing the rectangular and trapezoidal vanes in discharge of 25 L/s and the distance of 56 cm (4L) the following results are obtained:

The created scouring in the structures' nose has continued to the outer bank in rectangular vanes, while in the trapezoidal vanes the scouring in structures' nose is negligible but not about the structure 1. So, the trapezoidal structure has a better performance than the rectangular one on this matter in

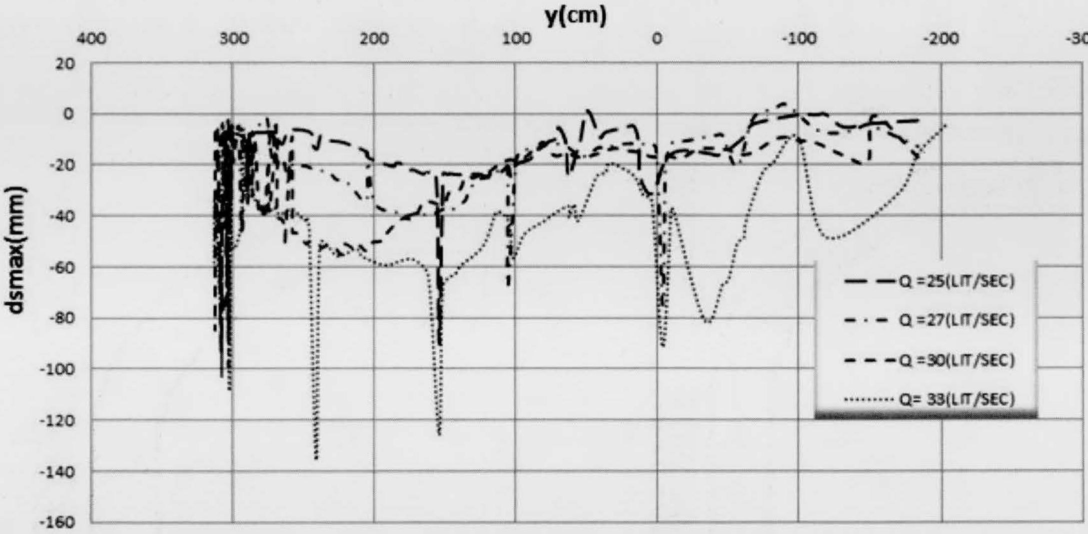


**Fig. 11.** Talweg diagram in flume of the input different Froude numbers with trapezoidal vanes

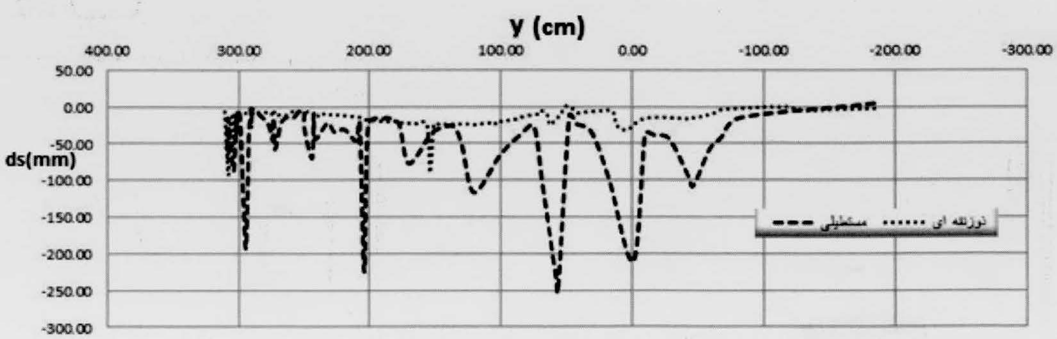


**Fig. 12.** Talweg diagram in flume of the Froude number and fixed distance using trapezoidal & rectangular vanes

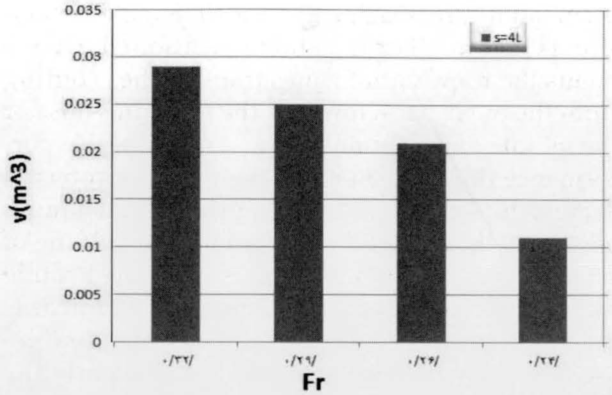

**Fig. 13.** Volume of scouring diagram for discharges of 33, 30, 27, and 25 L/s with trapezoidal vanes

protecting the outer bank.

In all of the structures the length of the created sediment hill in trapezoidal vanes' downstream is more than the rectangular ones, while the distance of the created sediment hill in trapezoidal vanes' downstream is less than the rectangular ones from the outer bank. These length and distance of the sediment hill indicate the better performance of the trapezoidal vanes in protecting the outer bank than the rectangular ones.

In rectangular vanes upstream the structures and in the distance between the structures and the outer bank in all of the structures there is scouring, whereas in the trapezoidal vanes this distance is even and without scouring. This event indicates the better performance of the trapezoidal vanes in protecting the outer bank than the rectangular ones.

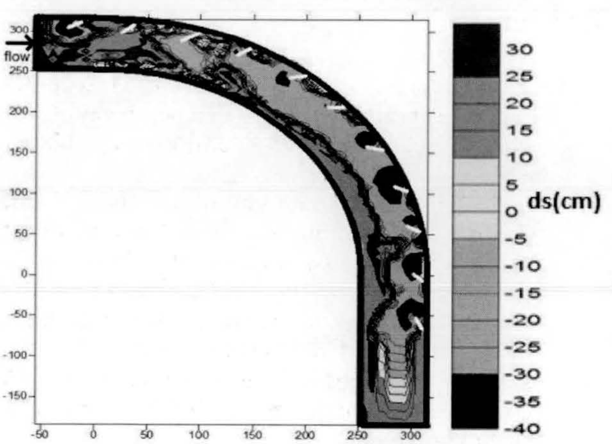

**Fig. 14.** Bed's topography (S=4L, Q=25L/s), rectangular vanes

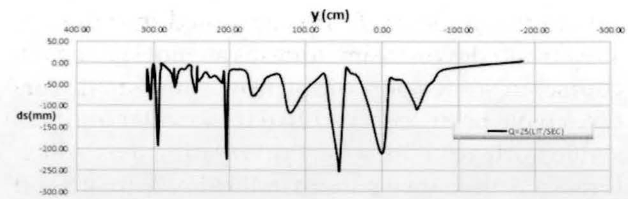

**Fig. 15.** Illustration of bed's topography (Q=25L/s, S=4L), rectangular vanes

The trapezoidal vanes have transferred the created canal in the flume bend to the center of the bend, but this canal has reached to the outer bank in the rectangular vanes. The cause of this better performance by the trapezoidal vanes is transferring the maximum flow velocity to the internal bank.

The maximum scouring depth in rectangular vanes is 251.2 mm, which has occurred in the structure's nose and is 63.17% more than the maximum scouring in similar experiment in presence of the trapezoidal vanes.

The scouring calculated rate using the SURFER software is 56% more in rectangular vanes than the trapezoidal ones.

The summary of the created flow pattern by trapezoidal vane and its comparison with other similar structures

The created flow pattern using the vane structure has been totally turbulent and is different from other scour controlling structure in the rivers' bend like submerged weir and the spur dikes (high installation angle). The scouring control process in the rivers' bend by the spur dike structure is in a way that only the input flow to the river bend will be directed towards the center of the channel, and this type of performance causes the remarkable scouring the in the nose. However, in the vane structure the sediment around and on the structure are permanently moving and the scouring hollow formation is prevented. The flow passing over the structure produces a secondary flow which is against the main secondary cell flow in the bend created as the result of two hydrostatic and centrifugal forces interaction and makes it thwarted. Once the submerged weirs are placed in the outer bend with high angle, they create three types of secondary flows in the bend; two of these flows act like the main secondary flow, they are so close to the outer bank and cause the damage to the outerbend. In front of the spur dike body structure a great semi-horseshoe vortex is usually produced, while during the use of vane structure in the angle of 60˚ it is observed that the upstream and downstream vortexes are not shaped. Of course, in some spots of the flow some small vortexes have been observed like the smaller and less stable vortexes with a vertical rotating axis which forms an alternative pattern in the downstream and beyond the structure nose. After all, they are not created in the vane structure nose. In the rectangular vanes a separated shear layer from the nose developed to the structure's downstream. This layer is produced as the result of a shear between the channel's main flow and slower flow behind the structure. During the use of trapezoidal spur dikes the moving sediments from the upstream are deposited in the structure's downstream and near the outer bank, and in this way the outer bank is protected; whereas during the use of spur dike in downstream and the structure shelter the sediments are deposited in high rate scattered in the flume's breadth, and no protection is done for the outer bank.

## Discussion

According to the results, in the bed's sedimentation and scouring in presence of the trapezoidal vanes sensible changes were created. As it is clear in the topographic figures, in discharges of 25 and 27 L/s the scouring has happened completely in the structures' nose and in this way the outer bank has been protected by the trapezoidal vanes against the scouring. In discharges of 30 and 33 L/s from the structure 7 through the end of the bend, in addition to the structure nose around the trapezoidal vanes scouring is seen in upstream and downstream bank.It is also worth mentioning that the dimensions of the scouring hole in the structure's nose are so more than the outer bank scouring. The maximum scouring depth has occurred in Froude's numbers of 0.24 and 0.26 near to the nose of trapezoidal vanes, but in Froude's numbers of 0.29 and 0.32 the scouring hallow of the structures' nose has reached the outer bank of the flume which make these Froude numbers inappropriate for the trapezoidal vanes compared with the Froude numbers of 0.24 and 0.26. In the implemented experiments— except for the structure one which has the maximum scouring depth in its nose—in other structures the scouring hallow dimensions in the structure nose increase in the structure nose towards the end of the bend because of the flow velocity increasing and the momentum's increasing as a result. So, the conclusion is that in all of the above mentioned experiments the trapezoidal vanes transfer the scouring from the outer bank towards the structure nose or the middle of the flume, and as a result of this performance the outer bend of the river is protected against the scouring. Regarding the obtained numbers form the SURFER software for the volume of scouring, it increases with increasing the Froude number. From the structure 2 through 11 towards the downstream, because of the increasing flow velocity and the momentum and consequently the moved sediments increasing from the structures' nose, the length of the created hill in downstream of the trapezoidal vanes increases. The created canal in the middle of the flume breadth which has been continued in the flume's bend has longer length with increasing the Froude number. The cause of this length increasing can be explained in this way thatwith increasing the Froude number the power of the secondary flow will be more. As a result, this secondary flow will be formed sooner and in a more distance (towards downstream) will be totally beaten by the opposite secondary flow which has been created by the trapezoidal vanes, and will left its trace in the middle of the flume.

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