Study of the Effect of Effective Length Variations of Triangular Vanes on Erosion and Deposition Patterns in a 90° Mild Bend

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1-Introduction

A lateral pressure gradient distribution is developed within the cross section in the river bends due to centrifugal forces. As the flow becomes closer to the bend apex, the upper surface layer of the flow moves towards the outer bank and the lower layer near the bed moves towards the inner bank forming a circulation flow that is called secondary flow. As results of the interference of longitudinal and secondary flows, a spiral form of flow is developed along the bend. When the down flow of the secondary flow near the outer bank reaches the bed, it will suspend the bed material at the outer bank toe. These particles are transported to the downstream or the inner bank. These flow patterns alter the topography of the river's bed by scouring the outer bank toe and depositing the eroded sediments in the inner bank. The maximum scour depth takes place when high secondary flows and spiral flows occur, making the banks unstable and resulting in significant erosion (Biedenharn et al. 1997; Julien 2002). Therefore, it has been of interest to hydraulic engineers to develop some measures to minimize the scouring process by modifying the flow pattern within the river bends. Spurs are expensive flow-altering structures used for riverbank protection. Developing scour at the toe of the spurs which may result in failure of the structure has also been a main concern for engineers. Therefore, many attempts have been made to modify the shape and geometry of the spurs. In this regard, several studies have been carried out on triangular vanes (or triangular spurs) by Johnson et al. (2001); Bhuiyan et al. (2010); Bahrami Yarahmadi and Shafai Bejestan (2014, 2015). Bhuiyan et al. (2010) studied the effect of triangular vanes on banks erosion control in a sinusoidal channel with moving bed. They used both single and multiple vanes with an effective length of one-third of the channel's width. Their results showed that when a single or a group of vanes are installed on the outer bank, the scour hole formed into the outer bank is filled and the thalweg is shifted towards the center of the river. They also found that vanes installed with a 30-degree angle would produce better results than those installed with a 20-degree angle. Bahrami Yarahmadi and Shafai Bejestan (2014, 2015) studied the effects of angle and spacing of the triangular vanes on scour and deposition patterns around the vanes at a mild 90-degree bend. Their results showed that the best performance, minimum scour around the structure and the sediment deposition in between the vanes, is observed when the vanes are installed with the space of 5 times the effective length of the structure and angle of 23 or 30 degrees to the upstream bank.

There is no comprehensive study about the effect of effective length of triangular vanes on the scour-deposition pattern around them. Therefore, the present study was conducted to study the effect of structure's effective length variations on erosion and deposition patterns.

2- Experimental setup

The tests were conducted in a single-bend flume at the Hydraulics Laboratory, Water Science Engineering Faculty, Shahid Chamran University, Ahvaz - IRAN. The flume was rectangular in cross section with a constant width (*B*) of 70 cm and a central angle of 90 degrees. The ratio of the bend radius to the flume width (*R*/*B*) was 4, and the lengths of the straight reaches at upstream and downstream of the bend were 5 and 3 meters, respectively. A slide gate was installed at the end of the flume to control the flow depth. The flow discharge was measured by an ultrasonic flowmeter - Digi Sonic E+ model (accuracy of ±0.01 l/s). The flume bed was covered with uniform sand with a mean diameter of d_{50}=1.5 mm and a geometric standard deviation ($\sigma = \sqrt{d_{84}/d_{16}}$) equal to 1.22 in all the experiments.

To investigate the effect of the effective length (*Le*) of triangular vanes on bed topography, several vanes with effective length of one third, one fourth, one fifth, and one seventh of the flume width (23.3, 17.5, 14 and 10 cm) were tested. In all the tests, the single triangular vane was installed at an angle of 30° to the upstream bank and at section 72° from the beginning of the bend on the outer bank, where the maximum scour depth usually occurs. The triangular vanes were made of Plexiglas with a thickness of 5 mm. The tests were conducted under different flow conditions (Froude numbers 0.194, 0.214, 0.233 and 0.253). The flow depth was kept constant at 13 cm in all the tests. The flow depth was chosen such that the vane crest level at the outer bank and the water surface were the same. All the tests were carried out under clear water conditions. A total of 16 tests were carried out. Each test lasted for 3 hours. Once the bed was drained at the end of each test, the bed topography was measured using a laser meter (with an accuracy of 1 mm).

3- Results and discussion

Fig1 shows the bed topography in the vicinity of the triangular vane. This Figure demonstrates the fact that by installing the triangular vane at the outer bank, the scour hole is developed around the tip of the structure.

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The eroded sediments are transported downstream of the vane and are deposited near the outer bank, forming a longitudinal shape of point bar near the outer bank. Such scour and deposition patterns prove that a triangular vane can effectively modify the flow patterns.

Fig. 1 Bed topography after a test

By reducing the vane's effective length, the scour hole was formed closer to the outer bank. In effective lengths of one fifth and one seventh of the flume width for Froude numbers 0.233 and 0.253, the scour hole between the tip of the vane and the outer bank was developed to the outer bank. For an effective length of one seventh of the flume width for Froude number 0.233 and 0.253, the scour hole behind the vane's axis (towards the inner bank) was attached to the outer bank.

The most important parameter which has to be considered is the maximum scour depth. In all the tests, the maximum scour depth was located behind the vane's axis (towards the inner bank). In Fig 2 variations of maximum scour depth versus effective length of the vane for different tests are illustrated. As seen from the Figure, the maximum scour depth decreases as the effective length of the vane decreases. On the average, the maximum scour depths for the effective lengths of one third, one fourth, one fifth, and one seventh of the flume width were 0.4, 0.5, 0.55 and 0.8 times the effective length of the structure, respectively. Moreover, on the average the maximum scour depths for the effective lengths of one fourth, one fifth, and one seventh of the flume width were 87%, 74% and 82% compared to the maximum scour depth at the effective length of one third of the flume width.

Fig. 3 presents the distance of the maximum scour depth from the outer bank for all the tests. The results show that by reducing the vane's effective length, the distance of the maximum scour depth from the outer bank decreases. On the average, the distances of the maximum scour depth from the outer bank for the effective lengths of one third, one fourth, one fifth, and one seventh of the flume width were 1.3 to 1.5 times the effective length of the structure.

The eroded sediments were transported by the near-bed flow towards the outer bank and were deposited at the outer bank toe. The minimum point bar distance from the outer bank decreased by reducing the vane's effective length. On the average, the minimum point bar distances from the outer bank for the effective lengths of one third, one fourth, one fifth, and one seventh of the flume width were 8, 5, 2 and 1.4 percent of the flume width, respectively.

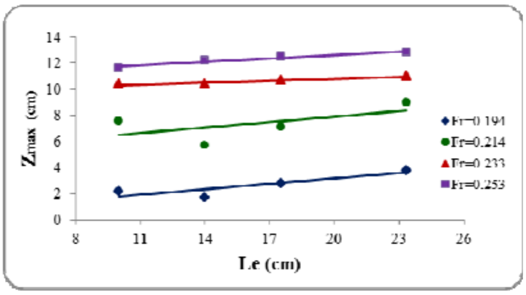

Fig 2. Variations of the maximum scour depth versus the vane's effective length for different tests

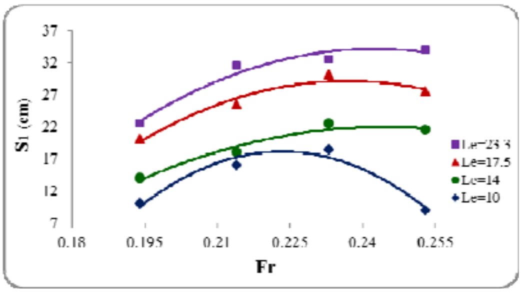

Fig 3. Distance of the maximum scour depth from the outer bank for various tests

4- Conclusions

The results showed that a triangular vane attached to the outer bank can effectively alter the flow patterns in such a way that the scour hole is shifted towards the flume midway from the outer bank and the eroded sediments are deposited near the outer bank. The maximum scour depth decreased by reducing the vane's effective length. Variations of the maximum scour depth for low Froude numbers (0.194 and 0.214) was found to be more than that of high Froude numbers (0.233 and 0.253). The eroded sediments were transported by the near-bed flow towards the outer bank and were deposited at the outer bank toe. In effective length of one seventh of the flume width for Froude number 0.233, the point bar distance from the beginning of the vane was almost 0.8 times the effective length of the vane. In effective lengths of one fifth and one seventh of the flume width for Froude number 0.253, the point bar distance from the beginning of the vane was 1 and 2 times that of the effective length of the vane, respectively. In addition, the minimum point bar distance from the outer bank decreased by reducing the vane's effective length. For effective lengths of one fifth and one seventh of the flume width, the point bar distance from the outer bank was almost 1.5-2 percent of the flume width.