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Numerical Evaluation of Submerged Vanes Application in Sedimentation and Erosion Potential of Open-Channel Junctions Flow

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ABSTRACT: Open-channel junctions have been widely used in different hydraulic and agricultural networks. Formations of a low pressure zone with recirculating flow at downstream edge of the junction (with high sedimentation potential) accompanied by a high-velocity zone (with high erosion potential) located at the opposite wall of junction are the most characteristic features of flow in junctions. Literature addressed a lot of numerical studies on evaluation of flow pattern in open-channel junctions and elimination of aforementioned problems using geometrical modifications, application of lateral channel separating wall, implementation of oblique angles of lateral channel, and so on. Using submerged vane to reduce amount of erosion as well as sedimentation potential, has comprehensively been assessed in the present paper. First, the numerical model was validated by previous studies. Second, a large number of numerical models have been performed to evaluate the effects of mentioned solution in open-channel junctions. Moreover, optimal ranges of different submerged vane's parameters have been introduced. The results showed a comprehensive reduction in sedimentation and erosion potential of open-channel junctions. For example, 89% reduction in length of separation zone has been detected in one of the proposed solution. In addition, the best performance of these vanes was observed in discharge ratio of 0.25. Moreover, applications of vane with height of more than 0.5h (h represents the water depth) and/or angle of more than 40° are not suggested.

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1- Introduction

Open-channel confluences have been widely used in water and agricultural engineering. Different specific regions including separation zone, stagnation point, and contraction zone are significant characteristics of this type of flow. Recirculating flow in separation zone not only provides suitable condition for sedimentation but it also increase flow velocity in contraction zone leading to local erosion at the opposite wall of the channel. A large number of researches have been carried out to reduce sedimentation and velocity in the mentioned areas.

Best and Reid [1] has focused on the size of separation zone, and evaluated effective parameters which may control the aforementioned area. Numerous angles of junctions ranging from 15° to 90° have also been investigated in their research in order to find their effects on flow pattern of the junctions. Ramamurthy et al. [2] derived a relation between the depth of flow at the junction and the ratio of the branch discharge to the total discharge on the basis of the momentum principle. A large number of experiments have been performed by Weber et al. [3] to explore the flow pattern of open channel junctions. In their study three velocity components, turbulence stresses and water surface mappings were obtained. Huang et al. [4] developed a numerical model to study flow pattern of a 90° open-channel junction using the k-ω turbulent model in case of different junction angles. Bonakdari and Zaji [5] used a hybrid Genetic Algorithm (G.A.) and Artificial Neural Network (A.N.N.) to evaluate flow pattern of a straight open-channel junction. They obtained a more accurate model than a genetic programing method for different velocity components of the flow. Yuan et al. [6] investigated velocity fluctuations within the shear layer in an open channel confluence. They have provided different features of this type of flow including Reynolds stresses, vorticity magnitudes, and so on.

While application of submerged vanes have been extensively evaluated in the intake structures, the mentioned strategy is not utilized in junctions sufficiently. In the present study, three dimensional numerical modeling has been used in order to evaluate effects of submerged vanes on flow pattern of straight open-channel junctions. Vanes were implemented to reduce size of separation zone and subsequently flow velocity in contraction zone.

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2- Methodology

Reynolds Averaged Navier Stokes (RANS) equations have been solved here as the governing equations (Equations 1 and 2). Assuming steady state condition, ANSYS FLUENT software were utilized to solve the mentioned equations. Due to required accuracy of turbulence model especially in case of recirculation and secondary flows capture, Reynolds Stress Model (RSM) was implemented in the present study.

$$\frac{\partial U_i}{\partial x_i}=0 \tag{1}$$

$$\rho U_j\frac{\partial U_i}{\partial x_j}=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}(2\upsilon S_{ji}-\rho\overline{u_iu_j}) \tag{2}$$

where x_i= spatial coordinates, i and j=1, 2, 3; U_i=mean velocity in the x_i-direction; t=time; g=gravitational acceleration; ρ=density of fluid; P=pressure; $\overline{u_iu_j}$ ν=molecular viscosity; = terms in Reynolds stress tensor.

To validate numerical model, experimental results of Weber et al. [3] in a 90° straight confluence were used. A sketch of their experimental flume has been illustrated in Figure 1.

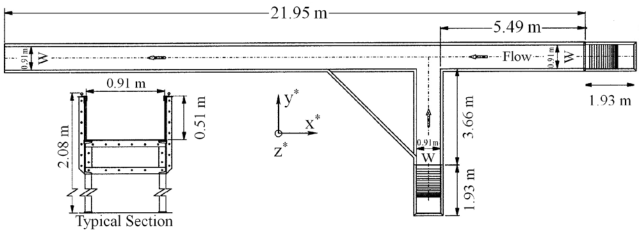

Figure 1. Experimental flume of Weber et al. [3]

In the present study, x*, y*, and z* were used to show dimensionless coordinates normalized by channel width. Subsequently, application of submerged vanes were investigated to reduce sizes of both separation zone and contraction area. The mentioned reductions may lead to reduce both potentials of sedimentation and erosion in this type of flows. A large number of numerical models have been developed to present optimized specifications of these vanes in junctions.

3- Results and Discussion

Contours of normalized velocity in a horizontal plane with z*=0.278 and a vertical plane with x*=-2 have been depicted in Figure 2 in case of numerical and experimental results.

According to Figure 2, numerical and experimental contours of velocity are in good agreement with each other. Obviously, separation (I) and contraction (II) zones and developing flow area (III) have been captured by numerical model. Also, amounts of maximum velocity after the junction and variations of velocity along the depth have been evaluated in the present study. These variables are also verified the acceptable accuracy of the developed numerical model.

Figure 3 shows normalized vectors of velocity in case of a simple junction and a junction with a vane of 0.3h (h represents the depth of flow) height located at the angle of 20° with respect to flow direction. Based on this figure, application of submerged vanes lead to significant reduction of separation zone length by deflecting flow toward this area and generation of appropriate secondary flows at the section of the channel.

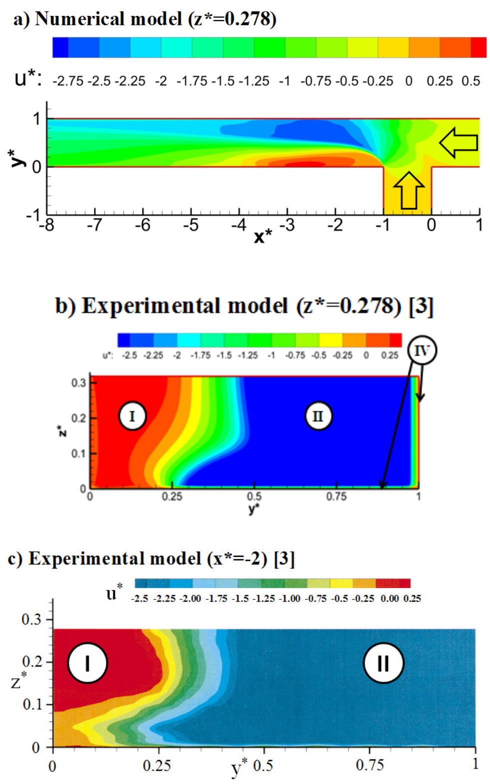

Figure 2. Contours of u* velocity at the z*=0.278 and x*=-2 in numerical and experimental models

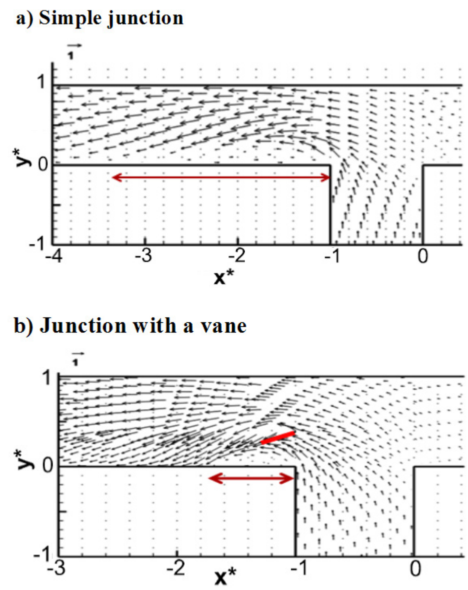

Figure 3. Velocity vectors in z*=0.014

Furthermore, normalized velocity vectors of u* in a plane located at z*=0.278 (near the surface) have been shown in Figure 4 in case of a simple junction and a junction with a vane of 0.3h height located at the angle of 20° with respect to flow direction.

Utilizing the mentioned submerged vane causes 65% and 28% reduction in separation zone length and width, respectively. As mentioned before, this reductions in length and width of separation zone lead to reduce sedimentation potential of this area. Consequently, this phenomenon reduces velocity in contraction zone which may result to reduction of erosion at the opposite wall of the junction.

Further investigation have been conducted to find optimum values of vanes' specifications including height of vanes, number of vanes, angle of implementation, appropriate layout and discharge ratios. For this purpose a large number of numerical models have been developed in the ANSYS FLUENT software to find the best amount of each parameters. Obtained values were reported in the conclusion section of the present study.

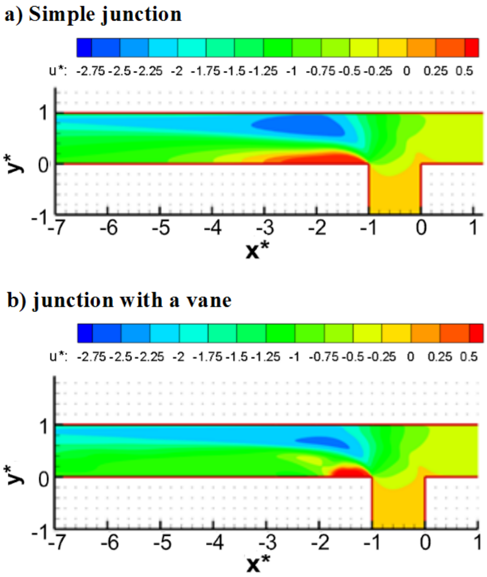

Figure 4. Comparison of flow pattern in a simple junction and a junction with vane

4- Conclusion

• Application of submerged vane causes significant improvement of flow pattern immediately after the junction and leads to reduce potential of both sedimentation and erosion. For example, one of the best configuration of submerged vane implementation (a vane with 0.3h height at the angle of 20°) resulted to 6.5% of maximum normalized velocity reduction, in addition to 53% reduction in separation zone length.

• Using a vane with height of more than 0.5h is not recommended.

• Application of a vane with the angle of more than 40° with respect to flow direction in the main channel is not suggested.

• Placement evaluation of submerged vanes shows that application of two vanes with normalized distance of 0.286 (start from x*=-1) has the best performance on flow pattern improvement.

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