Location effect on near bed flow structure around a straight spur dike

Mojtaba Mehraein*, Seyyed Amin Najibi** and Masoud Ghodsian***
*Kharazmi University, Karaj, Iran (Corresponding author, e-mail: mehraein@khu.ac.ir)
**Msc student, Tarbiat Modares University, Tehran, Iran
***Prof, Water Research Institute, Tarbiat Modares University, Tehran, Iran

The scour hole around the hydraulic structures is a challenging subject in hydraulic engineering. Studying of the flowfield around the hydraulic structures may increase the knowledge of the researchers about the effect of the different parameters on scour process. Spur dikes are one of the river training structures. The scour hole around this type of structure correlated to the flowfield especially in the near bed levels. The turbulent parameters such as root mean square of the velocity component in each direction, Turbulent kinetic energy and Reynolds stresses in near bed level for different location of the straight spur dike located in a 90° sharp bend was studied experimentally. Results showed that the location of the straight spur dike affects the near bed turbulent parameters. The maximum value of the Reynolds stresses, root mean square of the velocity components and turbulent kinetic energy are most for Θ=45°.

Keywords: Spur dike, ADV, 90° bend, experimental studies

1 INTRODUCTION

Bank erosions and sedimentation are the major constraints in rivers. Spur dikes are common structures that may used as training structures in the outer bank of the bend rivers. This type of structure deviate the approaching flow and decrease the sediment deposition in the inner bank. The scour hole formed around the spur dikes correlates to turbulent flow around the spur dikes.

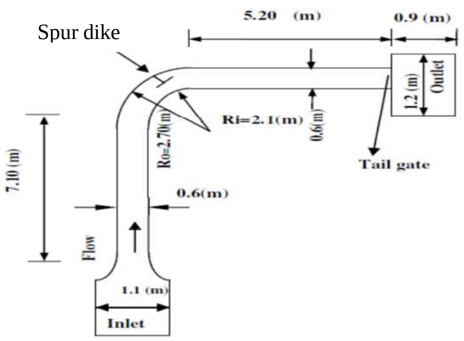
Many previous researches were conducted to study the correlations of the scour and near bed turbulence parameters such as quadrant analysis, triple correlations, shear stresses and root mean square of the velocity components. Sweep and ejection events have the main role on sediment transport as the bed load or suspended load. These processes are studied extensively [1, 2]. Different researchers used different methods to estimate the bed shear stress 3D complex flows. Some researchers used linear relation between bed shear stress and Turbulent kinetic energy [3]. Some others used linear correlation between the velocity fluctuation in vertical direction and bed shear stress [4]. Reynolds stresses are weighted average of the turbulent bursting processes (inward interaction, outward interaction, sweep and ejection) and the bed shear stress also can be estimated using Reynolds stresses in different directions [5]. Physically, the scour process has great correlation with turbulent parameters but previous studies showed different results to find that which parameter has the main role on sediment transport process.

According to the best knowledge of the authors no studies were conducted to find the effect of the straight spur dike location in the 90° sharp bend on turbulent parameters. The scope of this study is to investigate the turbulent parameters such as turbulent kinetic energy, turbulent fluctuations of the vertical velocity and near bed Reynolds stresses along the mean values of the velocity in the 90° bend for different spur dike locations.

2 EXPERIMENTAL SET UP

Experiments were carried out at the Hydraulic Laboratory of Tarbiat Modares University, Tehran-Iran. The main channel consisted of a 7.1 m long upstream and a 5.2 m long downstream straight reaches. A 90°channel bend was located between the two straight reaches. The channel was of rectangular cross section 0.6m in width and 0.7 m in height with a 2.5 m radius of bend to the centerline. The bed and sides of the channel were made of glass supported by a metal frame. Measurement of discharge was done using a calibrated orifice set in the supply pipe. Depths of flow and bed profile were measured by a digital point gage with an accuracy of ±0.01mm. A sluice gate was located at the end of the main channel to control the flow depth. Nearly uniform sediment with a median size d_{50}= 1.28mm here d_{50} is the sediment diameter that 50% of sediments is smaller than this diameter. The standard deviation of the sediment was $(d_{84}/d_{16})^{0.5}$=1.3 and covered the total length of the channel. Spur dikes were made of Plexiglas having a 1cm and 10 cm thickness and length respectively fixed to the outer side wall of the channel. Spur dike was located at sections 30°, 45° and 60°. Experiments were conducted with a discharge of 25 lit/s and a depth of flow of 0.117m.

Experiments were done near threshold condition in straight channel, i.e. U/U_c= 0.98 (U is approach flow velocity and U_c is critical velocity for sediment movement). Initially, the bed surface was smoothed by a plate attached to the carriage mounted on the channel, then the inlet valve was opened slowly and the discharge increased to a predetermined value so that no scour occurs at the straight reaches of the channel. The sediment bed in the bend was fixed using special resin and no scour occurred in this region during the experiments.



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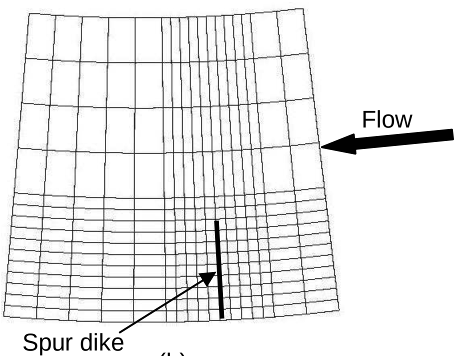

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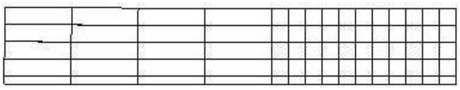

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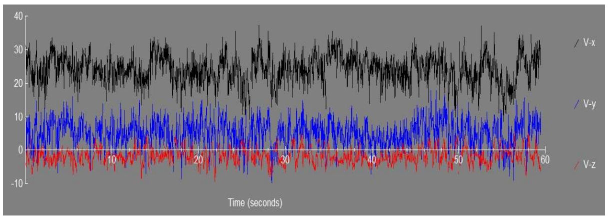
Figure 1: Plan and section view of experimental flume with measurement locations a) plan view and b) section view

The velocity data was collected using a commercially available Acoustic Doppler Velocimeter (ADV). The measurement head has four sensors mounted at a spacing of 90^o around a circle. The sampling volume of the ADV (170 mm) is a cylinder 6 mm in height and 6 mm in diameter, located 5 cm away from the head of the ADV. Flow velocity data at each point was collected at 50 Hz for 1- 5 minutes as the mean velocities and turbulent quantities did not changed with time increasing. Flow velocities were measured at 1700 locations as shown in Figures 1a and b for ϴ=45º where ϴ is the location of the spur dike with respect to the beginning of the bend. At each location, the flow was measured at 6 vertical positions: 0.05, 0.01, 0.02, 0.03, 0.04 and 0.05 above the bed. In this research only the results of the near bed (0.05 cm above bed) were analyzed and the results of other measuring points will be presented in the future manuscripts.

3 RESULTS AND DISCUSSION

The velocity components has three components in radial (u), tangential (v) and vertical (w) directions. A typical example of the time series of the measured velocity is presented in figure (2). For good description of the turbulent flow parameters, the correlation coefficient and SNR (signal noise ratio) should be greater than 70% and 14 respectively [6]. The low quality data was removed according to above criteria and the phase space threshold method was used to remove the spikes from time series of the measured data [7].



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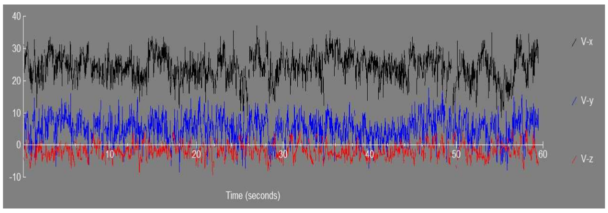

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Figure 2: A typical velocity time series at one point a) raw data and b) filtered data

3.1 Spatial Structures

3.1.1 Mean Average Velocity

ADV measure the velocity with high accuracy even at positions close to the boundary (z=0.75 cm) [8].

In Figure 3 the variation of the average velocity along the bend is presented for r=14 cm (r is the distance from the outer bank) in near bed layer (z=0.5 cm). In this figure α is the angle with respect to the beginning of the bend. Maximum average velocities of the flow occurred near the spur dike locations and slightly are the same for all spur dike locations. This may be due to the maximum contraction of the flow that observed near the spur dike location. As the approaching flow reached to the spur dike, the flow deviate to the inner bank and the contraction region was observed near the spur dike location. The contraction region elongates to the downstream and the maximum flow contraction was observed downstream of the spur dike where the maximum average velocity was occurred. The recirculation regions in the upstream and downstream of the spur dike were detected using the average velocity in the tangential direction. These regions formed due to the upstream down flow and the separation of the approaching flow from the spur dikes. The figures are not presented for brevity.

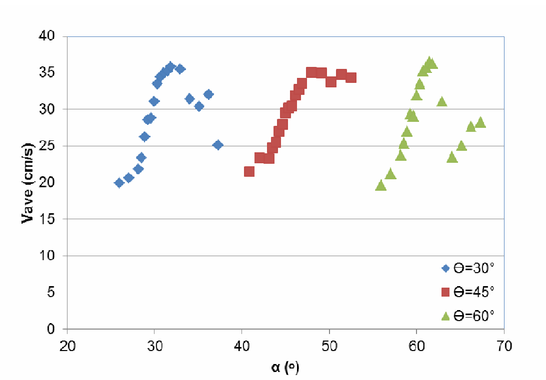


Figure 3: Average velocity along the bend for different spur dike location

3.1.2 Turbulence parameters

The root mean square of the velocity fluctuation denotes the standard deviation of the samples and the linear relation between the turbulent intensity in vertical direction and the bed shear stress can be used as a method to estimate the bed shear stress. The Reynolds stresses are the weighted average of the turbulent bursting process and can be used as a parameter to find the dominant turbulent bursting event. Turbulent Kinetic Energy in near bed layer is also used to estimate the bed shear stress and predict the scour.

3.1.2.1 Effect of the spur dike location on root mean square

Figure 4 showed the variation of the root mean square of the vertical velocity (rms w') for r=14 cm in near bed layer (z=0.5 cm) along the bend. The same trend is observed along the bend. The local maximum of the root mean square observed next to the spur dike location. The local maximum value of the root mean square of the vertical velocity for ϴ=60º is slightly greater than ϴ=30º, 60º. The velocity fluctuation along the bend decreases and reaches to the minimum value at α=32.5º, 47.5º and 62.5º for ϴ=30º, 45º and 60º respectively.

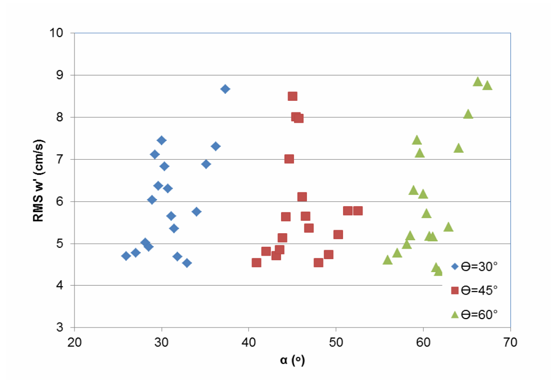


Figure 4: Variation of velocity fluctuation in vertical direction along the bend

The velocity fluctuation in vertical direction then increases again due to the shear layer formation around the spur dike.

3.1.2.2 Effect of the spur dike location on turbulent kinetic energy

Figure 5 shows the variation of the turbulent kinetic energy for r=14 cm in near bed layer (z=0.5 cm) along the bend. Similar trends can be observed for the variation of the turbulent kinetic energy along the bend for different values of ϴ. The local maximum value of this parameter occurred near the spur dike location and the local maximum value for ϴ=45º is the most.

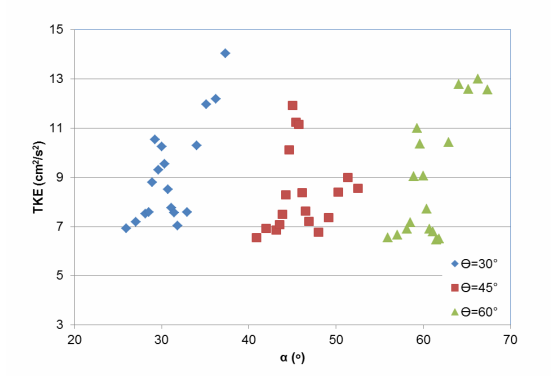
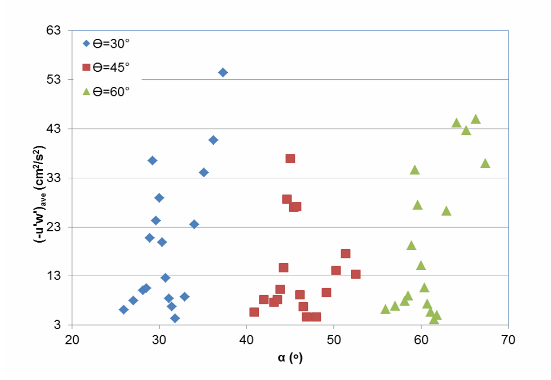


Figure 5: Turbulent kinetic energy variation along the bend for different values of ϴ

This is maybe due to the effect of the horseshoe vortex formation at the tip of the spur dike. Turbulent kinetic energy reaches to the minimum value at α=32.5º, 47.5º and 62.5º for ϴ=30º, 45º and 60º respectively and increases again in the downstream. This is also because of the shear layer formation around the spur dike.

3.1.2.3 Effect of the spur dike location on shear Reynolds stresses

Variation of the shear Reynolds stresses in x $(-u'w')_{ave}$ and y $(-v'w')_{ave}$ direction are presented in Figure 6 for near bed layer and r=14 cm. Overally, the absolute values of Reynolds shear stress in x direction is greater than the Reynolds stress in y direction.



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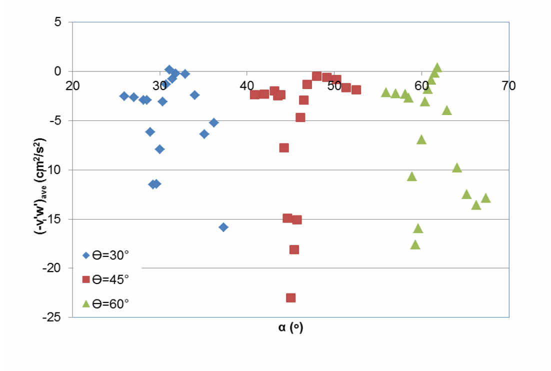

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Figure 6: Variation of Reynolds shear stresses along the bend a) $(-u'w')_{ave}$ and b) $(-v'w')_{ave}$

The absolute values of shear Reynolds stress in x direction and y direction have similar trends along the bend. The local maximum values of the shear Reynolds stress in x direction are approximately the same for different values of ϴ. However, the local maximum value of the shear Reynolds stress for ϴ=45º is the most. The negative values of the shear Reynolds stress in y direction confirmss that the flow direction is towards the inner bank. This is due to the secondary flow formation along the bend.

4 CONCLUSIONS

The effect of a standing baffle on spatial and temporal structure of flow in a rectangular open channel has been investigated experimentally using a 3D ADV. Based on the results of this experimental investigation following conclusions can be made:

1. The maximum velocity of the average velocity was observed in next to the spur dike location.

2. Similar trend for turbulent parameters such as velocity fluctuation in vertical direction, turbulent kinetic energy and Reynolds shear stress were observed along the bend.

3. Local maximum values of the Turbulent parameters were observed next to the spur dike and the local maximum values is the most for ϴ=45º.

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