Turbulent Flow Measurement around a Sidewall-Mounted Rectangular Block in an Open Channel

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Abstract

We investigated the three dimensional turbulent flow characteristics around a sidewall-mounted rectangular block using a laboratory flume experiment. The experiment was conducted in the flume which is 18m long and 0.9m wide, and a rectangular block that is 0.3m wide and a height of 0.4m and 0.004m thick is mounted on a sidewall of the flume. Velocity data were collected using Acoustic Doppler Velocimeter(ADV) for the flow rate conditions : $0.0528 m^3/s$. The time-averaged velocity and water depth data were analyzed to examine the three-dimensional flow patterns downstream of the rectangular block.

Key words : spur dike, turbulent flow

1. Introduction

A spur dike can be defined as an elongated obstruction having one end on the bank of a stream and the other end projecting into the current (Ronald R. Copeland, 1983). Restorations of impaired natural channels often involve construction of spur dikes because the dike can redirect flows, protect the riverbank from erosion, create stable pools for aquatic habitat, and trap suspended sediment in backwater zones (Duan, J. G et al. 2009). Measured and simulated flow studies near a spur dike have been conducted for years to understand the effect of the dike in the flow in an open channel. Subhasish Dey et al. (2005) conducted an experiment to measure the three-dimensional turbulent flow field using the acoustic Doppler velocimeter, at a short vertical-wall abutment before and after the development of a scour hole under a clear water scour condition. J. Yazdi et al. (2010) solved the fully three-dimensional Reynolds-Averaged Navier-Stokes(RANS) equation to predict flow near the spur dike. The flow patterns around a single spur dike with free-surface flow were described employing a numerical model named Fluent in the simulation. Up to now various simulations of flow fields around spur dikes have been reported in two and three dimensions. The researchers have discovered distinct flow patterns regarding turbulence near the spur dikes. However the previous experimental studies have limitation due to the lack of measurement points. In the present experimental study, the sufficient velocity data were collected across the flume and

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the three dimensional time averaged velocity data were analysed to investigate the flow patterns near the spur dike in an open channel in detail.

2. Experimental Flume and Measuring Techniques

The experiment was conducted in the flume which is 18m long and 0.9m wide, and a rectangular block that is 0.3m wide and a height of 0.4m and 0.004m thick is mounted on a sidewall of the flume. The spur dike was attached to the channel sidewall 9m from the inlet section. Velocity data were collected using Acoustic Doppler Velocimeter (ADV) for flow rate conditions : 0.0528m^3/s. The sampling frequency for the ADV was 35.7Hz. The Dike was located at x=0 and Negative sign(x<0) and positive sign(x>0) means upstream and downstream from dike, respectively.(Fig. 2) The velocity data were measured from x=-1m to x=6m. The 7 vertical velocity profiles where z=0.005, 0.01, 0.02, 0.05, 0.08, 0.11, 0.14m and 12 transverse velocity profiles from y=0.05m to 0.85m were taken at each cross section. The cross sectional mean velocity was calculated as U=Q/(Wh)=0.279m/s where h is average flow depth and W is wide of flume and approaching flow depth at x=-5 was D=0.2204m. Also the friction velocity at x=-1 was estimated as logarithmic law and used as u_*=0.0119m/s. Hydraulic parameters for the present experiment are summarized in Table 1. Relatively larger number of data were collected in this experiment so that the secondary flow and effect range of dike are observed in detail compared to the previous experimental researches. The three dimensional velocity data at 21 cross sections including 6 upstream, 1 at the dike tip, and 14 downstream, were measured. The measured data including velocities and flow depth were used to determine the mean velocities in longitudinal, transverse, and vertical directions. Furthermore Reynolds stresses were calculated from the velocity data in time series.

Table 1. Experimental parameters Summary

Mean velocity(U) (m/s)	Average flow depth(h) (m)	Approaching flow Depth(D) (m)	Discharge(Q) (m^3/s)	u_* (m/s)
0.279	0.2098	0.2204	0.0528	0.0119

3. Experimental Data and Result

3.1 Time-Averaged Velocities

The distribution of the dimensionless velocity, u/U, at each cross sections is shown in Fig 1. The flow separation and recirculation zone can be seen in both upstream and downstream at x=-0.17m～0, at x=0～3.5m respectively. The flow recovery starts after the recirculation zone in the downstream. In Fig 1, the flow separation appears behind the dike, and the flow recirculation occurs until x=3.5m. Reattachment length and flow recovery length can be normalized by 15.9D and 11.36D respectively where D is the inflow water depth. When the flow passes around the dike, the reversed flow is observed near the free surface.

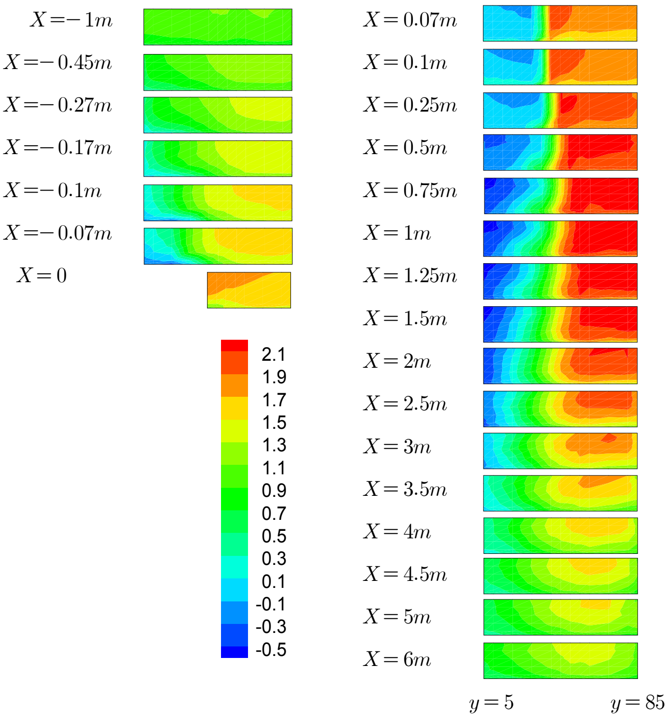

Fig. 1 Contours of dimensionless mean velocities, u/U

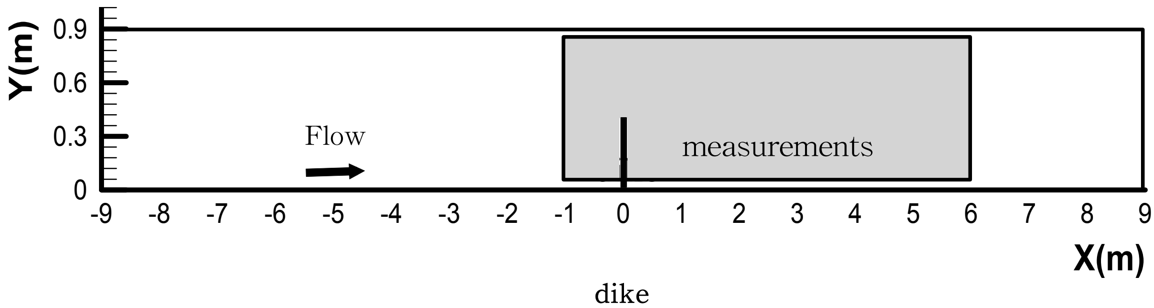

Fig. 2 Location of measured cross sections

3.2 Reynolds Stress

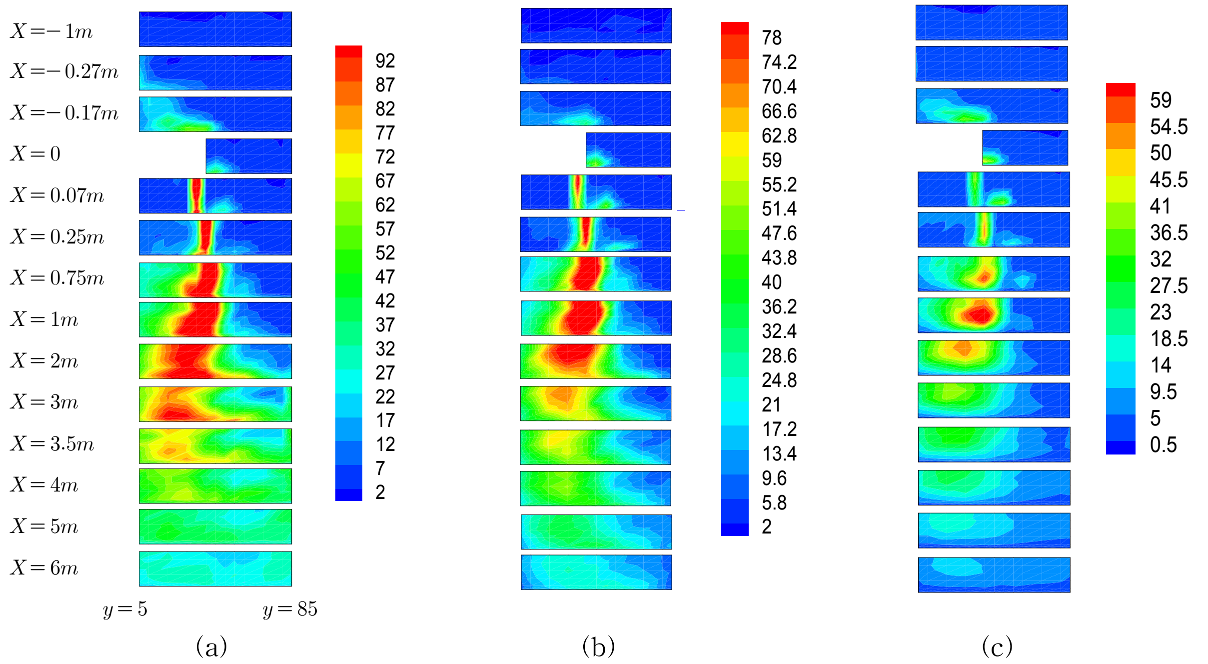

Fig. 3 Contours of dimensionless Reynolds normal stresses (a) downstream normal stresses $\overline{u'^2}/u_*^2$ (b) transverse normal stresses $\overline{v'^2}/u_*^2$ (c) vertical normal stresses $\overline{w'^2}/u_*^2$

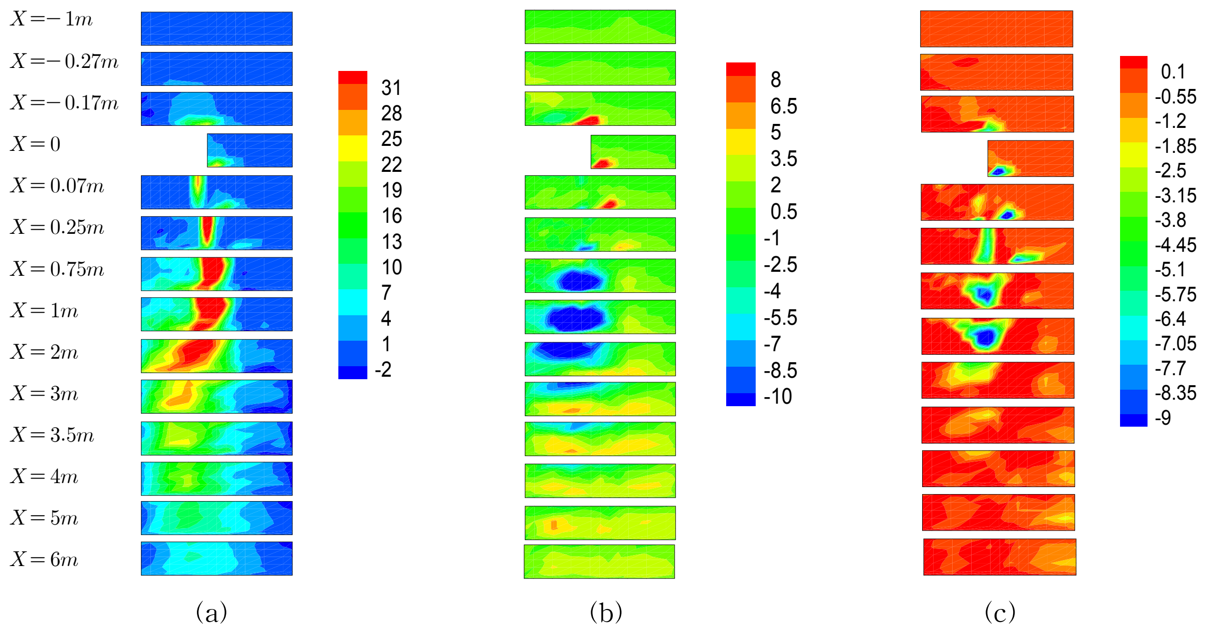

Fig. 4 Contours of dimensionless Reynolds stresses (a) $-\rho\overline{u'v'}/\rho u_*^2$ (b) $-\rho\overline{u'w'}/\rho u_*^2$ (c) $-\rho\overline{v'w'}/\rho u_*^2$

The dimensionless Reynolds normal stress and shear stress are plotted in Fig 3, 4. After the flow circumvents the dike, magnitude of Reynolds Stress increases abruptly and disperse laterally across section and the maximum value is located at the center of each cross section. As illustrated in Fig 3, nearly the same tendency is observed in normal stress distribution of $\overline{u'^2}/u_*^2$ and $\overline{v'^2}/u_*^2$. Magnitude of normal stress in $\overline{w'^2}/u_*^2$ is about 40% smaller than the other two. In Fig 4, distribution of shear stress in $-\rho\overline{u'v'}/\rho u_*^2$ is dominant because the value are obviously larger than the other two. The maximum values reach near the center at each cross section in all the stresses. Also the distribution of shear stress in $-\rho\overline{u'v'}/\rho u_*^2$ is similar with normal stress in Fig 3. The other two Reynolds shear stresses are negative in recirculation zone(x=0～x=3.5m) circulating their cells. After passing the recirculation zone, flow recovery starts as mentioned in 3.1 chapter. The sign of the Reynolds shear stress implies the behaviour of the sediment, negative value for sediment accumulation and positive value for developing the scour hole.

4. Conclusion

The laboratory experiment was conducted to study mean and turbulent flow characteristics around a spur dike. According to measured mean velocities, flow separation and recirculation zone can be seen in both upstream and downstream at x=-0.17m～0(0.77D), at x=0～3.5m(15.9D) respectively. When passing near the dike section, the flow reversed in the horizontal cross section near the water surface. Distribution of reynolds stress in $\overline{u'^2}/u_*^2$ and $\overline{v'^2}/u_*^2$ has the similar tendency across the flume and the normal stress of $\overline{w'^2}/u_*^2$ has 40% less magnitude compared to the other normal stresses. In Reynolds shear stress distribution, $-\rho\overline{u'v'}/\rho u_*^2$ is dominant and the other two shear stresses have negative value in recirculation zone(x=0～x=3.5m) that means the occurrence of the scour.

5. References

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