Comparison of RSM and LES Turbulence Models on Sharp Bend

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1-Introduction

In nature, many rivers follow a sinuous course and are classified as meandering rivers. They have a strong secondary flow, which causes bed scour at the outer banks and deposition takes place along the inner banks. In addition, the water intake should be sited where there is the maximum strength of the secondary flow which causes sediment movement from the inner bank towards the outer bank and the lowest levels of sediment enter into the intake. Moreover, changes in the meanders and their bed and bank erosion, cause the river bend to move and result in the destruction of the surrounding structures, agricultural farms and adjacent pumping stations indicating that there is a need to understand the flow patterns, maximum secondary flow position and shear stress in river bend using mathematical models.

2- Materials and Methods

The experiments were performed in a 1.3 m wide laboratory plexiglass flume consisting of a 193° bend with a constant centerline radius of curvature of R = 1.7 m, preceded and followed by straight reaches 9 m and 5 m long, respectively. The flume has been located in the hydraulic laboratory of EPFL in Lausanne, Switzerland. The bed was covered by a quasi-uniform sand with a diameter d = 0.002m. Although the curvature ratio R/B = 1.3 is representative of sharp natural meander bends the bed has been frozen for future examinations after sediment injection for three weeks and forms a developed topography.

In this paper, the Fluent software is used for three-dimensional simulation of flow pattern. The Reynolds Stress Model (RSM) of the Reynolds-Averaged Navier-Stokes (RANS) equations has been applied in the current study. The Large-Eddy Simulation (LES) technique of large vortices modeling also determines the flow pattern and hence has lower operating expenses than DNS and a higher operating cost than RANS models. The LES model assumes a filtering model to represent the behavior of submeanders and then calculates the three-dimensional time-dependent structure of turbulent flow in large meanders.

Before performing a calculation using Fluent, a computational domain must be generated to define the geometry of the problem. The Gambit software was used for mesh generation. This study comprised of 910,000 computing nodes in Gambit. This computational grid was obtained finally after size reduction was done as much as possible and testing several networks in Gambit and then the Fluent software. Figure 1 shows the laboratory channel with the computational grid.

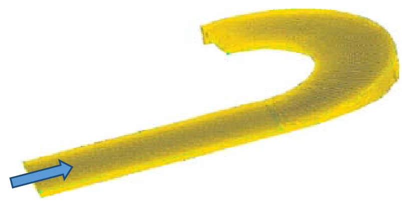

Fig 1. The computational domain developed in Gambit

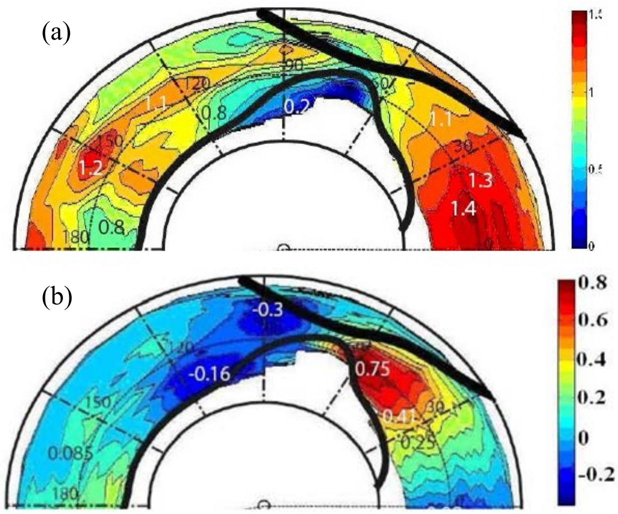

Fig 2. Experimental results: (a) Longitudinal depth-averaged velocity (Us/U), (b) Transversal depth-averaged velocity (Un/U)

3- Results and Discussion

Depth-averaged quantities are usually used to describe the general features of the flow field and velocity distribution in complex three-dimensional flows. Figure 2(a) shows the longitudinal depth-averaged velocity (Us) normalized by the average velocity (Us/S). The flow shows no separation at the inner bank of the cross section at about 30 degrees in the bend. Flow separation zone is between 30 and 120 degrees and has the maximum width of 75 degrees which is about 60 percent of the total width.

Figure 2(b) shows the transversal depth-averaged velocity (Un) normalized by the average velocity (Un/S). The normalized transversal depth-averaged velocity was positive between 15 and 75 degrees and toward the outer bank. Conversely, it was mainly negative and toward the inner bank between 75 and 135 degrees. Finally it was positive again after 135

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degrees till the end of the bend.

Figure 3 shows the normalized longitudinal depth-averaged velocity (Us/U) predicted by (a) the RSM model and (b) the LES model.

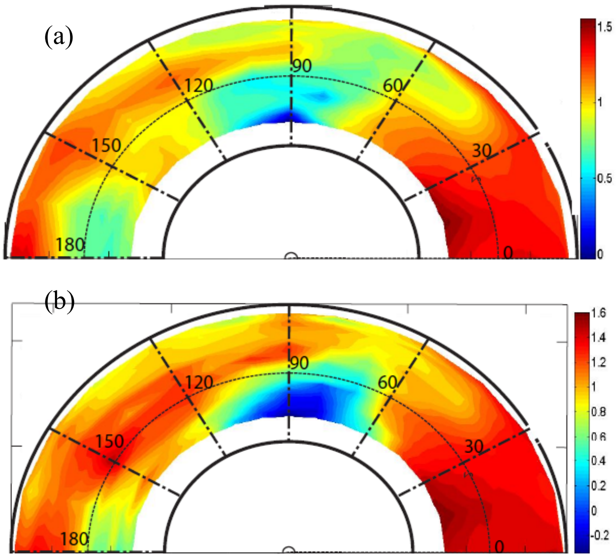

Fig 3. Predicted results of longitudinal depth-averaged velocity (Us/U): (a) RSM model, (b) LES model

Figure 4 shows the normalized transversal depth-averaged velocity (Un/U) predicted by (a) the RSM model and (b) the LES model. Table 1 shows the average error values for selected cross sections. In this Table, the amount of error of four longitudinal velocity profiles selected for each cross-section is determined, and then the average error is identified.

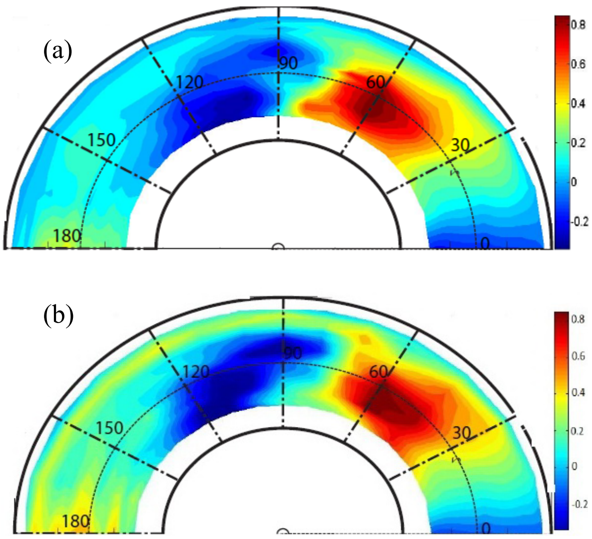

Fig 4. Predicted results of transversal depth-averaged velocity (Un/U): (a) RSM model, (b) LES model

For example, error of the LES model was about 2.1 percent for zero degree cross section and position n1.35 (n is indicative of the radial direction). Besides, the average error of longitudinal velocity at the input cross section was 4.5 percent by the LES model, which is less than that of the RSM model.

Table 1. Difference between predicted and measured values of longitudinal velocity profile (%)

Central angle (deg)	Model	n1.35	n1.7	n2.05	n2.2	Mean
0	LES	2.1	8.2	7.3	0.4	4.5
	RSM	0.4	11.2	11.4	6.2	7.3
30	LES	12.6	5.6	5.1	4.1	6.9
	RSM	12.2	12	9.8	5.8	10
60	LES	–	13	0.4	9.6	7.7
	RSM	–	13	11	17	13.7
90	LES	–	9.7	8.7	19	12.5
	RSM	–	10	2.9	9.6	7.5
120	LES	8.4	19	1.7	1.8	7.7
	RSM	20	6	10	4.7	10.2
150	LES	12	8	13	4.8	9.5
	RSM	16	19	12	8.2	13.8
180	LES	4.4	11.5	5	6.5	6.9
	RSM	25	7.5	5.7	3.7	10.5

4- Conclusions

For investigation of the numerical models of flow turbulence and comparing their results with real data, the data obtained from a laboratory flume with sharp bend and developed topography were used. The experiments were performed in a 1.3 m wide laboratory flume consisting of a 193 degrees bend with a constant centerline radius of curvature of R = 1.7 m.

To determine the flow pattern using turbulence models, the Fluent and Gambit software programs were used, and the RSM and LES turbulence models were examined. Our results showed that both models had somewhat predicted the overall pattern, but some important parts of the flow had not been predicted well predicted by the RSM model.

Although the RSM model had not been able to properly predict the flow separation zone and the angle of 85 degrees was predicted as the separation region instead of the 75 degrees angle position, the LES model predicted it properly. Besides, the LES model has been the best model in predicting the core position of the maximum longitudinal velocity. It also better predicted the cross-flow direction and its position in transversal depth-averaged transverse velocity. Finally, the average error of the difference between predicted and measured velocity profiles for the LES model was less than 8 percent, hence it has been the lowest prediction error.