Simulating extremely high ebb current velocities in the Changjing Deep-water Navigation Channel

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Introduction

Along the channel, measured tidal current velocity profiles at stations (from CS1 to CS5 (see Fig. 1) reveal an unusual maximum ebb current velocity (i.e., > 3m/s for a quite large portion of the water column at Sta. CS3 (see Fig. 2), in a survey carried out in 2002 during a wet season. This high velocity, however, has not been successfully simulated by using conventional numerical three-dimensional (3-D) hydrodynamic models. This becomes a problem when details of turbulent (e.g., shear rate, TKE, energy dissipation rate) are needed for simulating flocculation process for floc size distribution. That stimulates this study to explore the possible reasons.

The freshwater discharge in this estuary is high during the wet season (more than 53000 CMS). In general, this attributes to the large ebb current, but that is not the reason of having the observed high ebb velocity. To use an unusually small bottom friction coefficient in any 3-D model may not be the logical choice neither. There are two possible causes that may contribute to the high velocity. The first possible reason comes from the stratification effects, caused by salinity or/and suspended sediment distribution in this channel. A slight stratification in the water column can significantly reduce the eddy viscosity in the water column, and thus, contribute to the increase of current velocity near the surface. The other possible reason is the possible reduction of the constant C_μ (= 0.09 when the shear rate is not high) that used to compute the eddy viscosity in the turbulence k-ε model. Shih *et al.* (1994) indicated that this constant can be reduced to 0.05 if the shear rate is high.

Methodology

A vertical one-dimensional (1-D) model has been developed to simulate tidal flows. This 1-D model uses a semi-implicit numerical scheme to solve the vertical 1-D momentum equation with the standard k-ε model for turbulence. Stratification effect, caused by the vertical gradient of salinity and suspended sediment concentration is included. The model results were verified with data from a non-stratified tidal flow at the Menai Strait, UK (Rippeth *et al.*, 2002) and data from a slightly stratified York River site (Simpson *et al.*, 2005).

The measured time series of salinity and suspended sediment concentration (SSC) profiles for the entire simulation period are part of the input data. These profiles serve the purpose for simulating the change of eddy viscosity profile. Slightly stratified tidal flows will have a nearly linear velocity profile for most of the water column (Anwar, 1983). The possible occurrence of high gradient of SSC near the bed (when the ambient SSC is high) needs to be estimated. This 1-D model experiment found that stratification can significantly alter the eddy viscosity profile for most of the water column, but not near the bed. The salinity stratification contributes to the reduction of eddy viscosity profile, and thus, increases the velocity near the top of the water column.

Modeling results and Conclusions

This study found that the energy loss caused by the change of channel geometry, bathymetry, and bottom roughness is the main reason that causes extremely high ebb current velocity at Sta. CS3. At offshore stations, the effect of channel geometry and bathymetry is diminished, and thus, the maximum ebb current is around 2m/s. It appears that the possible occurrence of high gradient of near-bottom SSC when the ambient SSC is high is not sufficient to alter the near-bed eddy viscosity, and thus, only affects the velocity profile slightly. The reduction of C_μ from 0.09 to 0.05 (when the local shear rate is high) does not have much impact on the velocity profile neither.

This study demonstrates the importance of channel geometry and bathymetry that affect the velocity profile. It also shows the importance of having a complete measurement of salinity, suspended sediment concentration, and temperature profiles in order to have a correct understanding of the underlying processes and simulation of the current velocity in estuaries. This will be better prepared for our next-stage study on floc size distribution and the associated settling velocity.
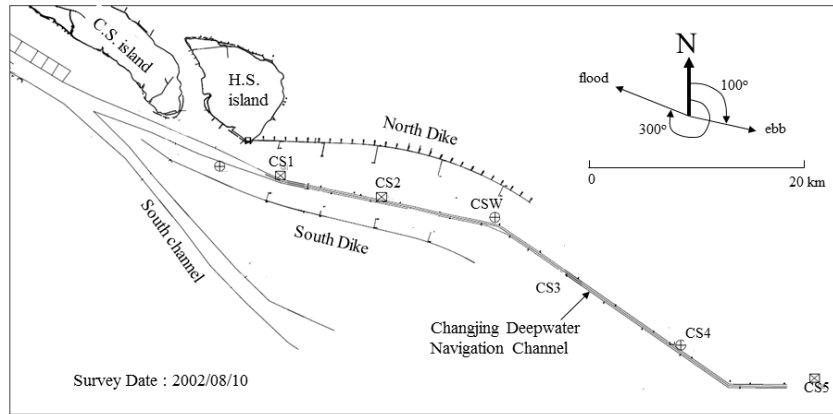
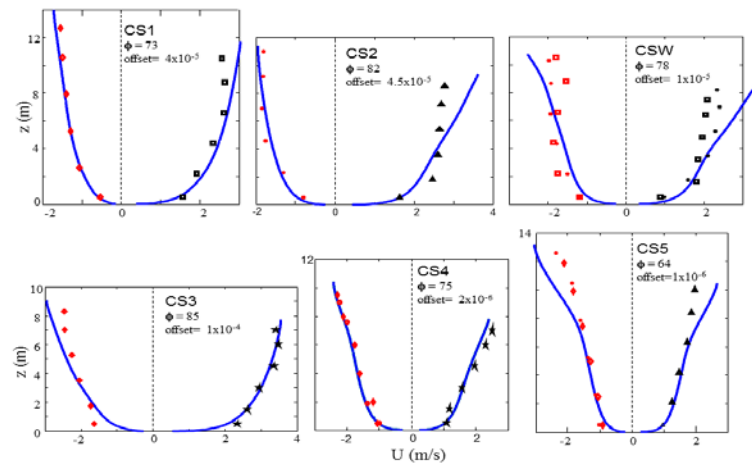Fig. 1. The six stations along the Changjing Deep-water Navigation Channel.

Fig. 2. Measured (symbols) and simulated (lines) maximum flood and maximum
ebb velocity profiles at the six stations.

References

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