Study of Passing Ship Effects along a Bank by Delft3D-FLOW and XBeach[1]

Minggui Zhou[1], Dano Roelvink[2,4], Henk Verheij[3,4]and Han Ligteringen[2,3]

[1] School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai, China, mgzhou@sjtu.edu.cn

[2] Coastal Systems & Engineering and Port Development, Unesco-IHE Institute for Water Education, Delft, The Netherlands;

[3] Hydraulic Engineering, Delft University of Technology, Delft, The Netherlands;

[4] Deltares, Delft,The Netherlands.

***Abstract*—When a ship sails with a certain speed, there is always a return current along and under the ship. The return current induces a water level depression around the ship. When the ship travels along a bank, the flow field around the ship is asymmetrical. Additional bank effects will be induced. A reliable estimation of all these effects and the resulting behaviour of the passing ship moving along the bank is of great importance to ensure the safe passage of the ship through the restricted waters. The paper presents results of numerical predictions with the open source software Delft3D-FLOW and XBeach of the effects of a ship travelling along a bank. Both models solve the depth averaged non-linear shallow water (NLSW) equations. By applying a moving pressure field method, simulations are carried out for a ship travelling along a sloping bank with a certain speed. Water level fluctuations of the free surface and the depth averaged flow velocities are obtained. The water level fluctuations at three different wave gauges are compared with data from measurements in a physical model. Based on all computations, conclusions are presented about using the moving pressure field method to simulate the passing ship effects sailing along a bank.**

Keywords—passing ship effect; moving pressure field; water level fluctuations; depth-averaged velocity

INTRODUCTION

During the last decades, the main dimensions of ships have been increasing constantly, but the waterways such as channels, rivers and canals are seldom expanded at the same rate. As a result, the waterways become restricted and the ship behaviour will be more influenced by the restrictions. When a ship sails with a certain speed, there is always a return current along and under the ship. The return current induces a water level depression around the ship. And when a ship is moving close to a bank, the flow field around the ship is asymmetrical which is ship-bank interaction effect or bank effect. Bank effect will adversely affect the ship's manoeuvring performances.

In the past decade, many investigations on passing ship effects have been carried out both experimentally and numerically. Kazi(1998) applied Delft3D to model the ship-induced water motion in a river. The water level depression and depth averaged flow velocities are obtained. Pinkster(2004) focused on the low frequency hydrodynamic forces on the moored ship induced by the passing ship. He addressed two methods: double-body method and free-surface method, to predict the low frequency wave due to a passing ship.

[1] Supported by National Natural Science Foundation of China (51061130548, 51179019)

Both methods are subsequently applied to cases involving a complex harbour geometry. Velegrakis(2006) presented the field study results of the near shore characteristics of waves generated by both conventional and high speed passenger ferries and analyses were carried out. Dam et al.(2008) showed the characteristics of ship waves in a narrow channel restricted by vertical walls, based on the observed data and the results computed by a 2D model, where the propagation of waves generated by a moving ship is simulated by solving 2D depth-integrated Bounssinesq equations. Schipper(2009) proposed a new wave pool concept using ship hull as a wave generator. Based on the towing tank experiment an optimum hull size and velocity are derived to maximize the potential use for surfing. Lataire(2009) summarized the results of forces due to bank effects as well as wave elevation at three wave gauges from physical models with irregular bank geometries. Ma(2012) applied two numerical model, Delft3D-FLOW and XBeach, to study the passing ship effect, and selected XBeach model to investigate the effect of side basin and current on passing ship effect after comparisons.

In this study, Simulations are carried out for a ship travelling along a sloping bank with a certain speed in two open source software Delft3D-FLOW and XBeach. The numerical results of water level fluctuations and depth averaged flow velocities are obtained by solving the depth averaged non-linear shallow water (NLSW) equations. The measured water level fluctuations due to the primary long wave at three different wave gauges are well reproduced, which proves the moving pressure field method. Based on all computations, conclusions are presented about using the moving pressure field method to simulate the passing ship along a bank.

METHODS AND MODELLING

Selected models for passing ship effects

This template Two 2DH shallow-water flow models are selected to study the free surface waves generated by the passing ship: Delft3D-FLOW and XBeach.

A few tests on passing ships had already been performed both in Delft3D-FLOW and XBeach. One conclusion is that Delft3D-FLOW model cannot handle high frequency secondary waves with low eddy viscosity value. To obtain a realistic primary long wave, secondary waves have to be damped out by increasing eddy viscosity to a very high value (Ma, 2012). The non-hydrostatic flow model in XBeach could reproduce primary waves as well as secondary (short) waves with the wave length larger than a certain value. It is worthwhile to further validate the two models with physical model test data and compare the two models.

Hydrodynamic modelling of ship-induced water motions

The template In Kazi(1998), the ship is replaced by a pressure field and the movement of the ship is simulated by moving this pressure field at each time step corresponding to the ship's sailing speed. This method is called "moving pressure field" or “updating pressure head field”(Ma, 2012). This method is used in Delft3D-FLOW model and XBeach to represent a sailing ship.

The ship is represented by an imposed pressure field on the water surface. The pressure of the ship is dependent on the draft of the ship. If the position of this pressure field is updated each time step, depending on the speed of the vessel, a moving ship is reproduced in the numerical model.

MEASUREMENT CASE STUDY

A comprehensive research project has been carried out at Flanders Hydraulics Research (Lataire 2009). The layout of the test system is shown in Fig.1. The length scale for the test is 81, and all the values in this section are presented in the model scale value used in the physical tests. However, in the numerical models, these values are changed into prototype values. An 8000TEU container ship model is used in the physical model test. The main dimensions are shown in TABLEI.

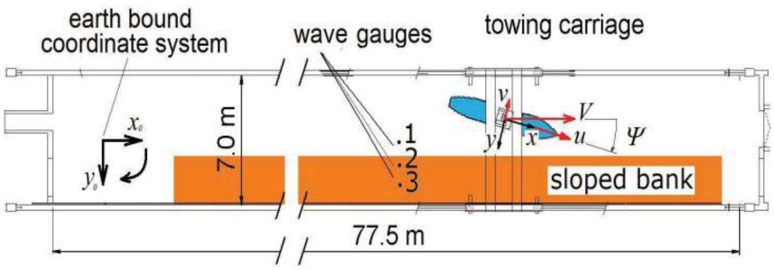


Fig. 1 Layout of the test system (source: Lataire 2009)

TABEL 1 MAIN DIMENSIONS OF THE CONTAINER SHIP

Items	model (scale:1/81)	prototype
L_{OA} [m]	4.332	350.89
B [m]	0.53	42.93
T_F [m]	0.18	14.58
T_A [m]	0.18	14.58
C_B [-]	0.66	0.66

In this paper, test F(Lataire 2009) is chosen as the study object: The ship draft is 0.180m; the water depth is 0.360m; the forward component of speed vector is 0.8012m/s, while the transversal component of speed vector is zero. The bank geometry is shown in Fig.2. The surface piercing bank with a slope of 1/3 is selected, with $y_{0max} = 3.500m$, $y_{o\alpha} = 2.230m$. The ship is moving along the sloping bank without a drift angle at the lateral position of $y_{oO=}1.435m$ from the center line of the tank. For test F, a registration of the water surface elevation is made by three wave gauges at a fixed position in the towing tank. The three wave gauges are all installed at 19.95m from the starting position of the towing tank.

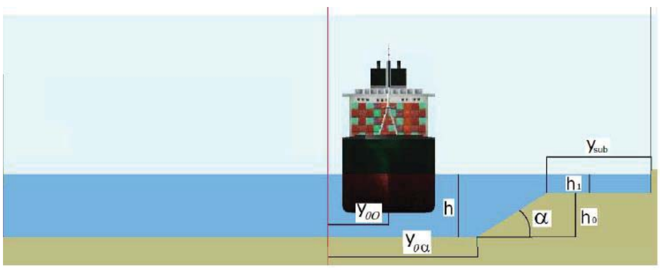


Fig. 1. Surface piercing bank(source: Lataire 2009)

RESULTS AND ANALYSIS

Model set up

Define Considering the length of the moving vessel, the distance to accelerate the vessel and the time needed for the water level at the observation position to be still again. So in total, the domain size for Delft3D-FLOW and XBeach is: 3840m×550m(prototype value). In order to make a fair comparison between the two numerical models, the same grid size should be applied in the simulations. Considering the simulation time and the size of the output file, a 5m×5m grid is chosen.

For a good reproduction the acceleration scheme of the towed ship in the experiments is applied. The start-up procedures both in Delft3D-FLOW and XBeach are read from the measurement data and implemented into the positions at each time step (Fig.3).

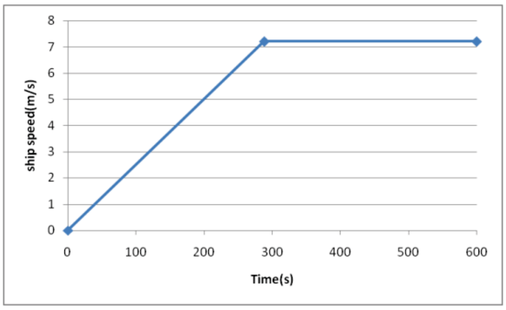


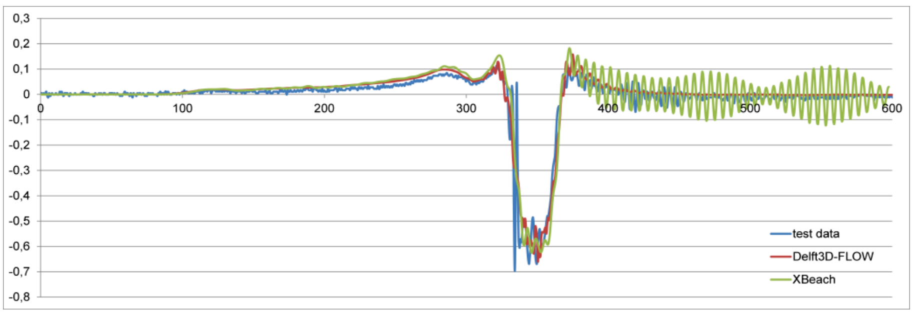
Fig. 2. A typical acceleration curve used in Bank-Interaction Effects test

One of the most effective physical factors that have influence on the output is 'Horizontal Eddy Viscosity'. In Delft3D-FLOW model, different values (1,10,50) for eddy viscosity v_h are selected to investigate the influence of viscosity on the water level fluctuations of the free surface. In XBeach, the Smagorinsky-type sub grid model is applied to calculate the eddy viscosity v_h(Roelvink et al. 2010), and the viscosity coefficient('par%nuh') is given by the user. Three values for viscosity coefficient 'par%nuh' (0.1, 0.5 and 0.9) are selected, which means three different horizontal viscosities are used to investigate their influence.

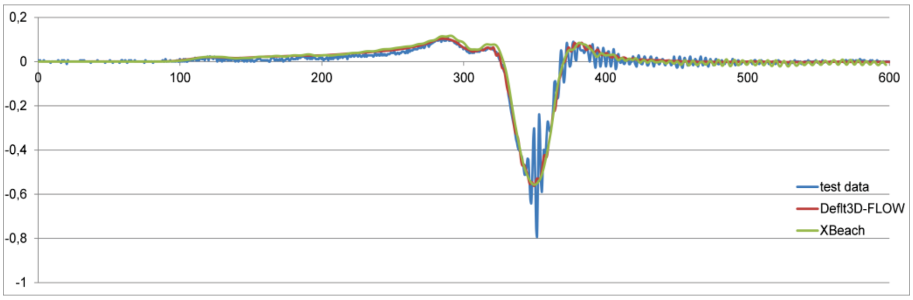
Comparisons of Results

- Results from the container ship model

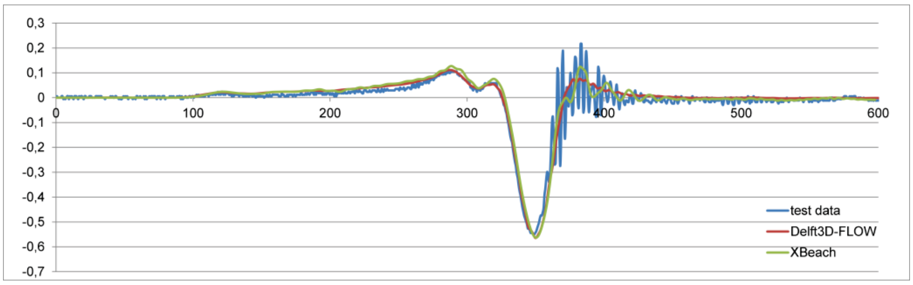
After 10 minutes simulation, the passing effect of the container ship is predicted numerically both in Delft3D-FLOW and XBeach. The fluctuations of the free surface elevation are obtained. Fig.4 shows the comparisons of the simulated water level variation at the three wave gauges with the data from measurement in the physical model. Here, the viscosity used in Delft3D-FLOW is 50 m^2/s, while in XBeach it is 0.1 m^2/s.



(a)Water level fluctuations at wave gauge1



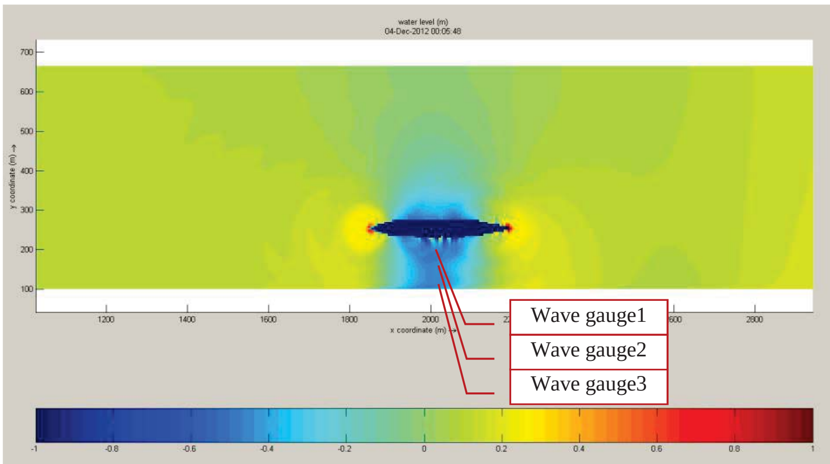
(b)Water level fluctuations at wave gauge2



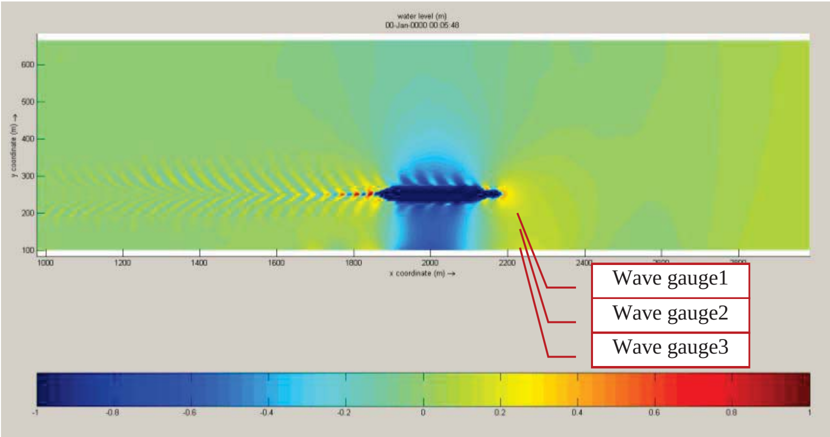
(c)Water level fluctuations at wave gauge3

Fig. 3. Comparisons of water level fluctuations among measurement data, Delft3D-FLOW and XBeach

From the above figure it can be seen that, the water level fluctuations at the wave gauges related with the primary ship wave in Delft3D-FLOW and XBeach compare well with the measurement data from the physical model. By applying “moving pressure field” method, both Delft3D-FLOW (by increasing the horizontal eddy viscosity) and XBeach could simulate the passing ship effect properly.



(a)in Delft3D-FLOW(viscosity=50m^2/s)



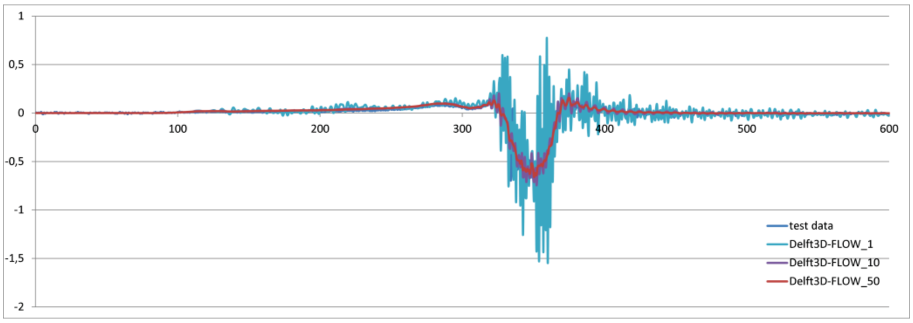
(b) in XBeach(nuh=0.1)

Fig. 4. Water level fluctuations of the free surface when the ship passes wave gauges

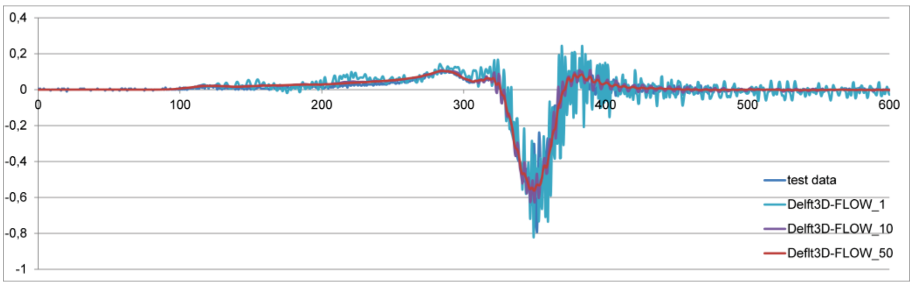
According to Fig.5, the water level depression can be observed around the ship in the two models, which is the primary long wave. In Delft3D-FLOW, the short waves around the ship cannot be seen because they are filtered out by increasing the viscosity; In XBeach, the secondary short waves around and behind the ship are observed. However, the propagation of short waves generated by the ship towards the left and right boundary is not seen. The reason may be that the term *kh* (*k* is wave number and *h* is water depth) is 8.2 (ship speed is 7.2m/s, ship wave length is 22m, and water depth is 29m) in this situation, while XBeach can only reproduce ship waves well with *kh* less than 2.

• The influence of horizontal viscosity

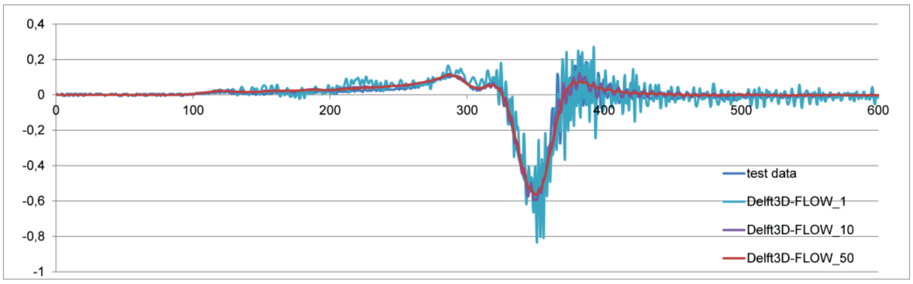
Fig.6 and Fig.7 show the comparisons of water level fluctuations at three wave gauges with different viscosities in Delft3D-FLOW and XBeach, respectively.



(b) Wave gauge1



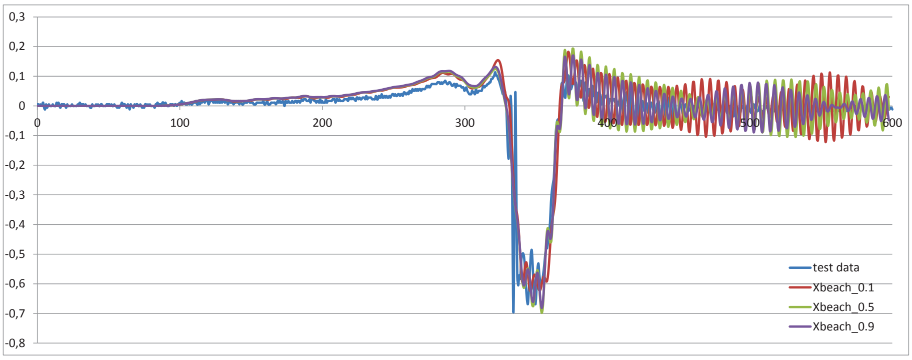
(b) Wave gauge2



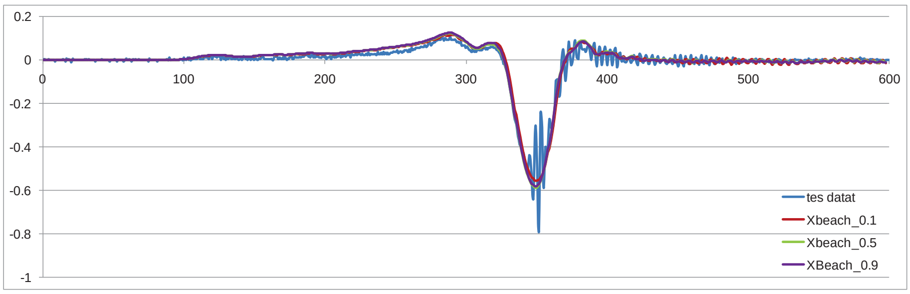
(c) Wave gauge3

Fig. 5. Water level fluctuations with different viscosity values in Delft3D-FLOW

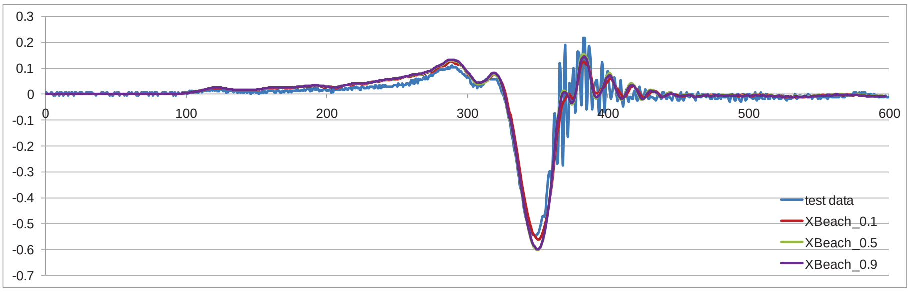
According to Fig.6, the computations do not provided good results with default viscosity value of 1 m^2/s. Many oscillations occurred at the bow and stern as the vessel moves within the domain. These oscillations are short waves that propagated rapidly. The short oscillations dominated the computed solution and hence the water level does not look realistic, especially at wave gauge1 since it is closer to the ship hull compared to the other two gauges. By increasing the viscosity, the oscillations become smaller and most of them could be filtered out when the viscosity value is 50 m^2/s.



(a) wave gauge1



(b) wave gauge2



(c) wave gauge3

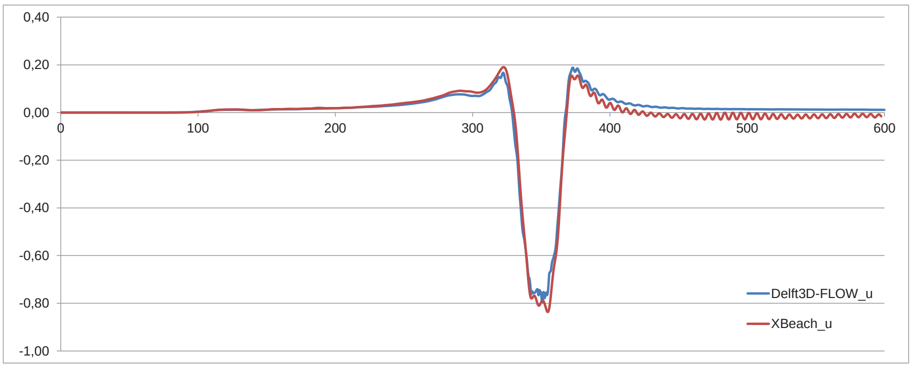
Fig. 6. Water level fluctuations with different viscosity values in XBeach

It can be seen from Fig.7 that the water level depression with par%nuh=0.1 is closer to the measurements compared with the other viscosity values. The results with par%nuh=0.5 and 0.9 are nearly the same, and the water level depressions are a little higher than the measurements. Near the ship such as at wave gauge1, the stern waves can be observed after the ship passes by. And by increasing the viscosity value, the stern waves become a little smaller. Meanwhile, the viscosity almost has no influence on the water level changes far from the stern. Therefore, the conclusion can be drawn that in XBeach, the influence of viscosity calculated by the Smagorinsky-type sub grid model on the water level fluctuations of the free surface is weak.

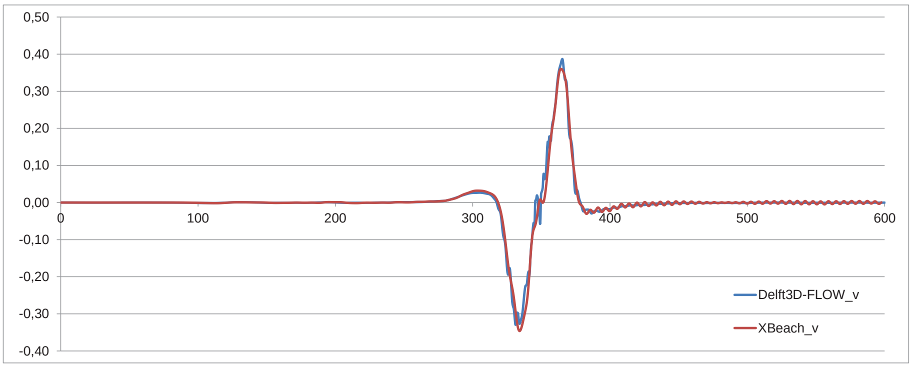
The water level fluctuations of the free surface with default value of viscosity in Delft3D-FLOW are unrealistic with a lot of oscillations in the domain compared with Fig.5 (a) with viscosity=50 m^2/s. Meanwhile, the water level fluctuations with par%nuh=0.9(or 0.5) in XBeach are nearly the same compared with Fig.5(b) and the secondary waves are also not seen travelling towards the left and right boundary, which again proves that the viscosity has little influence on the water level fluctuations with the Smagorinsky viscosity formulation.

Comparisons of depth-averaged velocity

Delft3D-FLOW and XBeach provide Generalized Lagrangian Mean(GLM) velocity in cell centre, which is depth-averaged velocity of the simulation flow domain. Fig.8, 9 and 10 show the comparisons of depth-averaged velocity between Delft3D-FLOW and XBeach at three wave gauges, respectively. The velocity is given by a vector: Component U is the depth-averaged velocity in *x* direction; component V is the depth-averaged velocity in *y* direction.

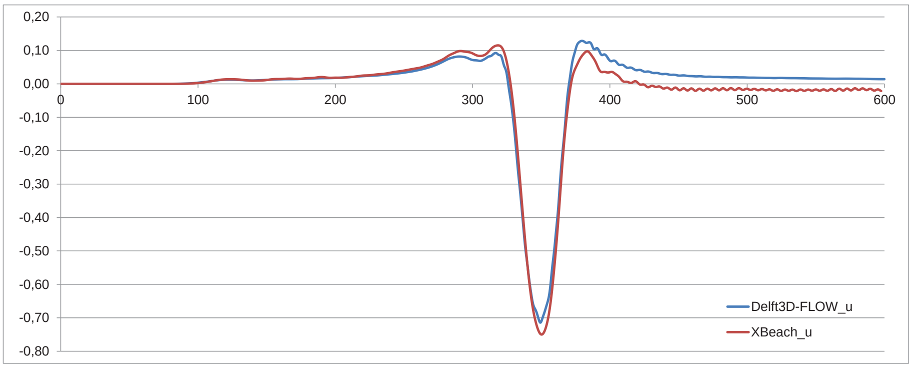


(a) component U

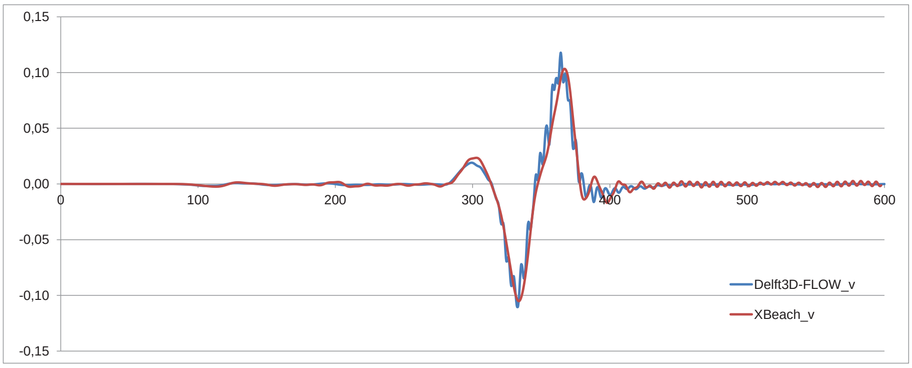


(b) component V

Fig. 7. Comparison of depth-averaged velocity at wave gauge1

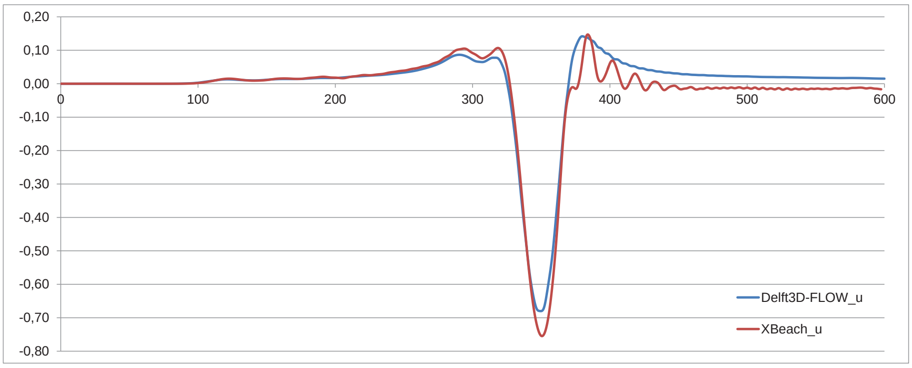


(a)component U

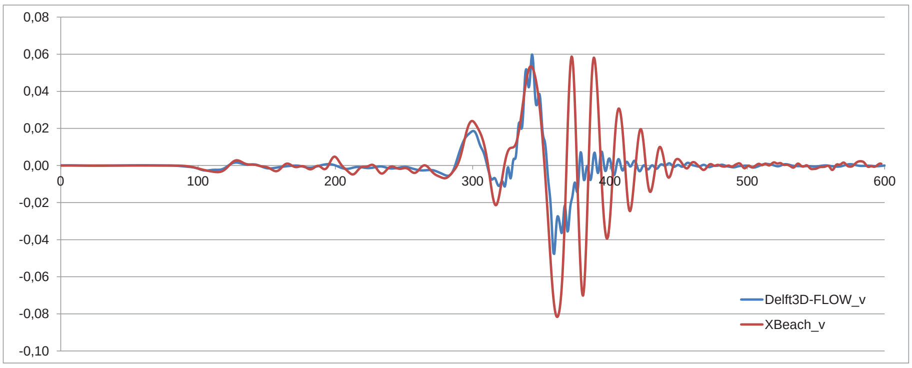


(b) component V

Fig. 8. Comparison of depth-averaged velocity at wave gauge2



(a)component U



(b) component V

Fig. 9. Comparison of depth-averaged velocity at wave gauge3

From the above figures it can be seen that, before the ship comes to the wave gauges, the depth-averaged velocity in Delft3D-FLOW and XBeach are in agreement with each other. However, after the ship passes the wave gauges, there are discrepancies between the velocities from the two models. In addition, from gauge1 to gauge3, the discrepancies become more obvious. The oscillations observed in XBeach after the ship passes are caused by the stern waves, and they may have much influence on the flow velocity near the bank. However it should be mentioned that it is not clear whether they are correct due to the large value of *kh* much larger than allowed(8.2 versus an allowed maximum 2.0).

CONCLUSIONS

In this paper, the water movement induced by the passing ship along a sloping bank is numerically simulated by applying two depth averaged (2DH) shallow-water flow models: Delft3D-FLOW and XBeach. In both models, the moving pressure field method is implemented to represent the sailing ship. The water level depression and depth-averaged flow velocity induced by the ship are obtained. The results are compared with the measurement data from a physical model. In addition, different horizontal viscosities in the two models are selected to investigate their influences on the water motions induced by the ship moving along the bank. The following conclusions can be drawn:

Both Delft3D-FLOW and XBeach could simulate the primary water movement induced by the passing ship along a sloping bank by using appropriate horizontal viscosity. The water level depressions at the three wave gauges in both models are in good agreement with the measurement data. Clear oscillations can be observed after the ship passes at wave gauge1 in XBeach, which are the short ship waves. But they do not propagate toward the left and right boundary, so XBeach could not reproduce the secondary water movement well. The reason is perhaps the value of *kh* which is out of its allowed reach.

In Delft3D-FLOW, the water level fluctuations of the free surface seem unrealistic with lower horizontal viscosity. By increasing the viscosity to $50m^2/s$, short waves around the ship are filtered out and the results are improved. In XBeach, the influence of viscosity on the water level fluctuations of the free surface is weak.

Regarding to the comparison of depth-averaged velocities from Delft3D-FLOW and XBeach, the depth-averaged velocity in both models are in agreement with each other before the ship comes to the wave gauges. After the ship passes, the discrepancies of depth-averaged velocities from both models bceome more obvious from wave gauge1 to gauge3. The causes of this difference is not yet clear, and one can not tell yet which model is the best.

Nevertheless, XBeach seems to have more advantages than Delft3D-FLOW, since in principle the non-hydrostatic model can be applied to reproduce secondary short ship waves. However, the numerical results in XBeach are not totally correct since the ship-induced secondary short waves do not propagate to the boundaries. Future work will be focused on the modification of the non-hydrostatic model in XBeach and using it to calculate the forces on the ship due to ship-bank interaction.