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Numerical Study of the Influence of Donghai Bridge on Sediment Transport in the Mouth of Hangzhou Bay

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Abstract

Donghai Bridge locates in the north mouth of Hangzhou Bay and south of Nanhui nearshore waters, where is the main channel for water and sediment exchange between Yangtze River Estuary and Hangzhou Bay. The construction of Donghai Bridge would influence the sediment transport in the mouth of Hangzhou Bay. In this paper, numerical simulations of the hydrodynamic environment and sediment transport process were carried out before and after the construction of Donghai Bridge by using ECOMSED model. Moreover, the satellite remote sensing images from MERIS and TM sensors were used to provide further proofs about the influences of the sediment transport caused by the construction of Donghai Bridge. The results show that a sediment belt, which is about 3.5 km wide, has developed in the west of the bridge axis at flooding time. However, it is only about 1 km and just located in the east of the bridge axis at ebbing time. The reason is that the velocity increases between the piers, and thus makes an intensification of sediment resuspension. Contrast to the increasing of the suspended sediment concentration (SSC) near the bridge axis, the SSC decreases about 5% in the area about 5 km away from the sediment belt. The results also show that a high SSC region with 8% increase appears between the northeast of Tanhu Island and the west of the bridge, and a low SSC region with 12% decrease appears just to the south of the high SSC region.

Key words: Donghai Bridge; Hangzhou Bay; numerical simulation; satellite image; sediment transport

1. Introduction

Donghai Bridge is the first sea-crossing bridge in China with length of 32.5 km. The construction of Donghai Bridge began on June 26, 2002 and the main structure was finished on May 25, 2005[1]. Donghai

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Bridge locates in the north mouth of Hangzhou Bay and south of Nanhui nearshore waters, where is the main channel of tide current in the north Hangzhou Bay, and also the main channel for water and sediment exchange between Yangtze River Estuary and Hangzhou Bay[2-4]. The construction of bridge would influence the hydrodynamic environment and sediment transport in the mouth of Hangzhou Bay. In this paper, numerical simulations of the hydrodynamic environment and sediment transport process were carried out before and after the construction of Donghai Bridge by using numerical model ECOMSED (Estuarine, Coastal and Ocean Modeling System with Sediments) [5]. Moreover, the satellite remote sensing images from MERIS and TM sensors were used to provide further proofs about the influences of the sediment transport caused by the construction of Donghai Bridge.

2. The numeric model and method

2.1. The model domain and grid setup

The model domain is shown in Fig 1, which covers the whole Yangtze River Estuary and Hangzhou Bay, from 120.3°E to 123.5°E and 29.5°N to 32.5°N, including realistic coastline and topography. The region is horizontally divided into 300*300 orthogonal curvilinear grids, and 10 sigma layers in the vertical direction. In order to catch the fine structure around the bridge, this paper uses local mesh densification method. The black rectangular area as shown in Fig 1 is the area of grid refinement with a resolution of 220m. To accelerate the numerical simulation speed, ECOMSED uses a mode splitting technique, and here the time step of internal mode is 10s, while time step of external mode is 2s.

2.2. Test method

Two tests were designed to study the influences of Donghai Bridge. Test 1 is before the construction of Donghai Bridge, and test 2 is after the construction of Donghai Bridge. In test 2, we lay the piers on the bridge axis, the procedure is as follows, (1) extract information of piers from SPOT5 high-resolution satellite image(panchromatic image, March 25, 2006); (2) lay piers on the bridge axis, revise the depth of grid point which locates on the pier to change it to land. As the paper focuses on the influence of Donghai Bridge on sediment transport in the mouth of Hangzhou Bay, small-scale phenomena like flow around a circular cylinder have not been taken into account. So on the premise of the same flow area, 32 equivalent bridge piers have been laid according to the length ratio of the realistic bridge van to bridge pier. The section between Dawugui Island and Kezhushan Island become seawalls after the construction of bridge, so test 2 blocks the channel between Dawugui Island and Kezhushan Island.

2.3. Initial and boundary conditions

Two tests have the same initial and boundary conditions. This paper mainly simulates the hydrodynamic field and suspended sediment in July 2010, when the Yangtze River has the largest runoff around the year. Initial flow field and water level are set to zero, and the initial temperature and salinity fields are digitized from the *Marine atlas of Bohai Sea Yellow Sea East China Sea*. The initial field of surface suspended sediment concentration is set to the climatology distribution of the monthly-averaged concentration retrieved by the satellite remote sensing, which is taken from *the Second Institute of Oceanography*, SOA, with an assumption of vertical uniform distribution. The runoff of Yangtze River is from *Changjiang Maritime Safety Administration*, and the runoff of Qiantang River is taken from *Editorial Board of China Bay Survey*[6]. Surface suspended sediment concentration of river mouth boundary is retrieved by MERIS full resolution data[7], with an assumption of vertical uniform distribution. Offshore open boundary conditions are determined based on tidal harmonic constants provided by OTPSnc(OSU Tidal Prediction Software). Otherwise, the wind field data is taken from QSCAT/NCEP.

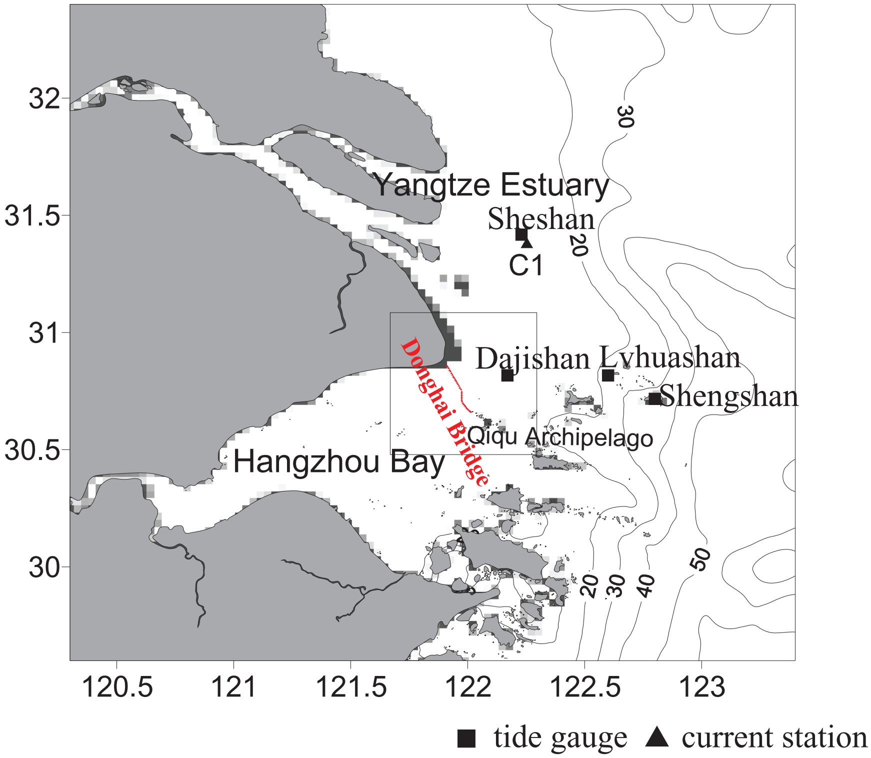


Fig. 1. Topography of the study area (unit: m)

3. Results and Discussion

3.1. Model validation

This paper uses the water-level data sets from the *Tide Table* of 4 tide gauges(Fig 1, Sheshan, Dajishan, Lvhuashan, Shengshan) to verify the simulation results of tidal level between July 1 to 30, 2010. The validation of tide current uses the in-situ measured current velocity and direction at station C1 (Fig 1, 122.25°E, 31.38°N) from 8:00, Oct. 11 to 5:00, Oct. 12, 2010. Owing to the limited space, only parts of the verification results are shown in Fig 2 and Fig 3. It can be seen that the simulated results agree well with the observation, which indicates that this model can reproduce the main dynamic processes in the model domain.

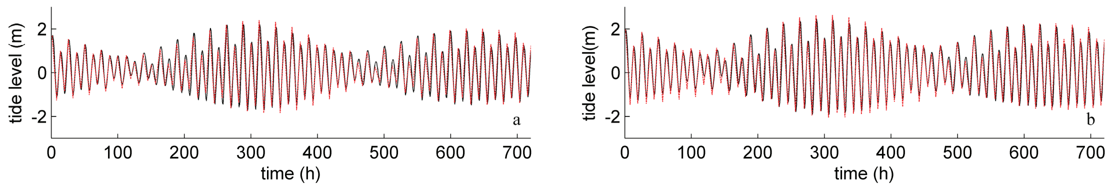


Fig. 2. Comparison of the tide level between the model simulation and tide gauges observation from July 1, 2010 to July 30, 2010(a. Sheshan b. Dajishan; black line for numeric results in test 2, red line for tide Gauge observation data)

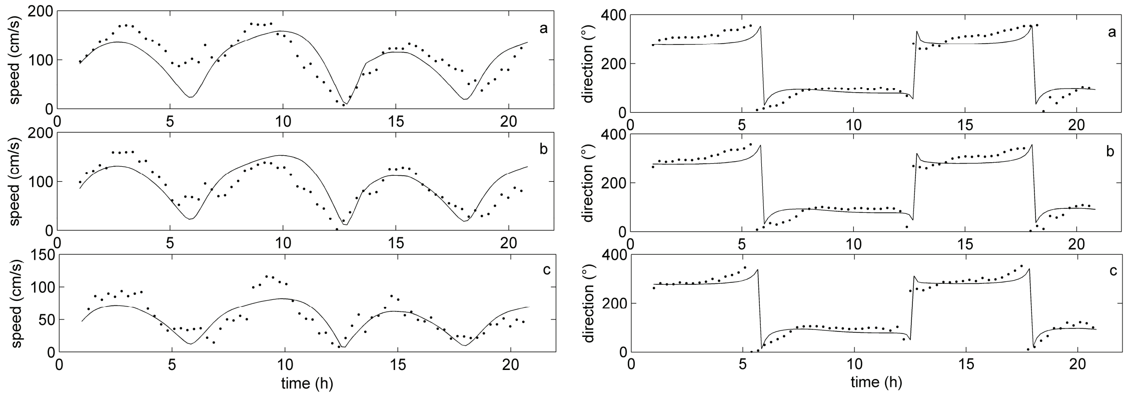


Fig. 3. Comparison of the current velocity and direction between numeric simulation of test 2 (solid line) and in-situ measured values at station C1 (◆) from 8:00, October 11, 2010 to 5:00, October 12, 2010. (a. surface ; b. 3m below surface; c. bottom)

3.2. Hydrodynamic environment changes

To determine the influences of Donghai Bridge on hydrodynamic environment in Hangzhou Bay, results of the two tests were compared. As the numeric results show, the flow field in Yangtze River Estuary and Hangzhou Bay has little change, indicating that the construction of Donghai Bridge has little influence on the flow field of the whole region, which consists with the conclusion of Sun ZG(2003)[8]. Near the bridge location, after the construction of bridge, the water flow converges, and the velocity increases more than 20% between piers, but decreases in hidden area of the piers. The influence range (the distance between the bridge axis and the location where the flow velocity reduces more than 10%) is about 1.8 km west of the bridge axis for flood tide, and about 1.4 km east of the bridge axis for ebb tide.

3.3. The influence of Donghai Bridge on sediment transport in the mouth of Hangzhou Bay

Changes of vertical averaged suspended sediment concentration (SSC) before and after the construction of Donghai Bridge are shown in Fig 4. After the construction of Donghai Bridge, velocity near the bridge decreases, thus there is a decrease of SSC in the west of bridge axis when flooding, and in the east of bridge axis when ebbing. The decreasing amplitude is about 5% ,less than 8%, which indicates that the bridge piers has an obstruction on sediment transport. The results also show that a high SSC region with 8% increase appears between the northeast of Tanhu Island and the west of the bridge, and a low SSC region with 12% decrease appears just to the south of the high SSC region**.**

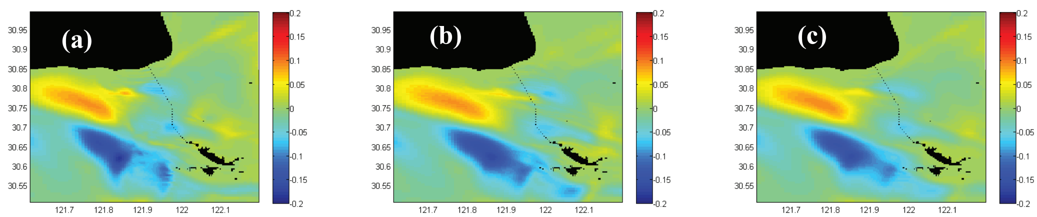
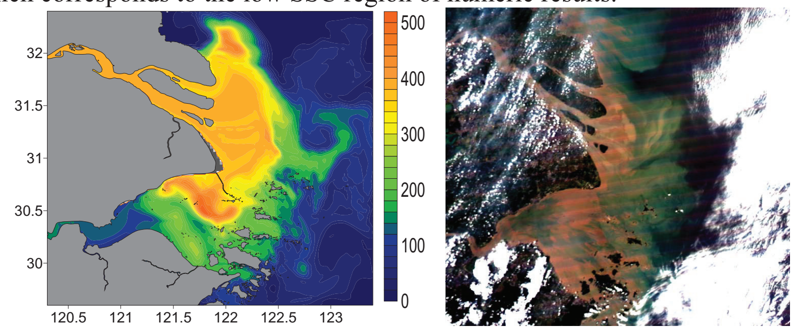


Fig. 4. Changes of vertical averaged SSC(mg/L) before and after the construction of Donghai Bridge(a. flood tide b. ebb tide c. mean tidal period)

3.4. Comparison of numeric simulation results and remote sensing images

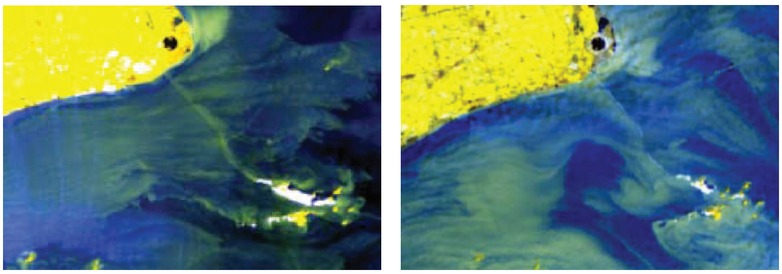
Comparison of surface SSC between numeric simulation result (12:00, July 31, 2010) and MODIS images (12:43, July 31, 2010) is shown in Fig 5, and it can be seen that the simulated results agree well with the remote sensing image. SSC decreases from costal area to open sea, both Yangtze River Estuary and Hangzhou Bay have a high concentration. In the north of Hangzhou Bay, the suspended sediment was spread westward as a tongue, which reflects that there are a large amount of sediments transported from the Yangtze River Estuary to Hangzhou Bay.

Fig 6 is the remote sensing images of Donghai Bridge and surrounding area. As the Fig 6 shows, sediment belt, which is about 3.5 km wide, has developed in the west of the bridge axis when flooding. However, it is only about 1 km and just located in the east of the bridge axis when ebbing. The reason should be that the velocity increases between the piers, and thus makes an intensification of sediment resuspension. After the construction of the bridge, there is a low SSC area in the northwest of Qiqu Archipelago, which corresponds to the low SSC region of numeric results.

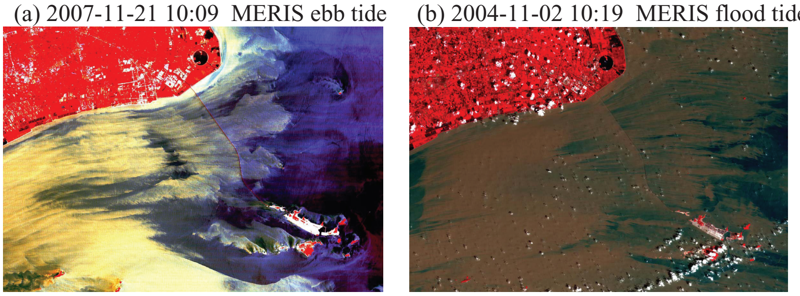


(a) (b)

Fig. 5. Surface SSC(mg/L) at 12:00 derived from model (a) and true color image of MODIS at 12:43 (b) on July 31,2010



(a) 2007-11-21 10:09 MERIS ebb tide (b) 2004-11-02 10:19 MERIS flood tide



(c) 2007-7-28 10:18 TM flood tide (d) 2009-9-19 10:14 TM flood tide

Fig. 6. Comparison of the SSC distribution between flooding and ebbing by remote sensing images

4. Conclusions

(1)After the construction of Donghai Bridge, a sediment belt, which is about 3.5 km wide, has developed in the west of the bridge axis when flooding. However, it is only about 1 km and just located in the east of the bridge axis when ebbing. The reason is that the velocity increases between the piers, and thus makes an intensification of sediment resuspension. Contrast to the increasing of the suspended sediment concentration (SSC) near the bridge axis, the SSC decreases about 5% in the area about 5 km away from the sediment belt.

(2)A high SSC region with 8% increase appears between the northeast of Tanhu Island and the west of the bridge, and a low SSC region with 10% decrease appears just to the south of the high SSC region after the construction of Donghai Bridge.

Acknowledgements

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