4th Specialty Conference on Coastal, Estuary and Offshore Engineering
4e Conférence spécialisée sur l'ingénierie côtière et en milieu maritime

Montréal, Québec
May 29 to June 1, 2013 / *29 mai au 1 juin 2013*

Assessment on impacts of Huanghua Port Stage II on mitigating sediment siltation during a storm surge in Bohai Bay, China

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Abstract: Huanghua Port locates on a silt-muddy coast in Cangzhou City, Hebei Province of China, about 90 km east of the Bohai Bay, which is in the northeast of China. The Stage I of Huanghua Port was implemented in December of 2001, including embayed port basin with two jetties in length of 9 km. On October 11, 2003, a storm surge in Bohai Bay caused by the combined effect of cold-air outbreaks and surface inverted trough led to a significant sediment siltation in the outer channel and port basin, reaching 9.7 million m^3. This extreme event consequently led to the extension project of two 10.5 km jetties in order to protect the outer channel and cut down the sediment siltation, which is called the Stage II of Huanghua Port. In this paper, Delft3D-FLOW and Delft3D-SED are employed to establish tidal flow and sediment transport numerical models for Huanghua Port coastal water. The validated models are used to simulate tidal flow and sediment transport under a storm surge caused by an 8-class gale. The comparison and analysis of the characters in flow and sediment transport are made between Stage I and Stage II, and the impacts of Stage II of Huanghua Port on mitigating sediment siltation during a storm surge are assessed.

1 Introduction

Bohai Bay coast is one of the regions that suffer from severe storm surge, a one in forty years storm surge occurred in Huanghua Port (see Fig.1， which shows Stage I）sea area on Oct.11, 2003, which led to heavy sediment siltation in port region and caused serious economic losses ，thus affecting the harbor operation. Thereafter, two 10.5 km jetties were extended (called Stage II, see Fig.2b) from the jetty heads of Stage I to the area where water depth is about -6m. To assess the performance of the Stage II, a tidal flow and a sediment transport numerical model for Huanghua Port coastal water are established on the basis of Delft3D-FLOW and Delft3D-SED and they have been well validated by the field data measured in 2010 and 2011 (Tongji University, 2011). The previous study pointed out that the tidal variation induced by a gale has significant influence on sediment concentration and sediment siltation in Huanghua sea area (Feng et al., 2008). In this study, the water level rise caused by a storm surge is simulated by a wind force (i.e. a gale). The wind shear stress is calculated by the equation below:

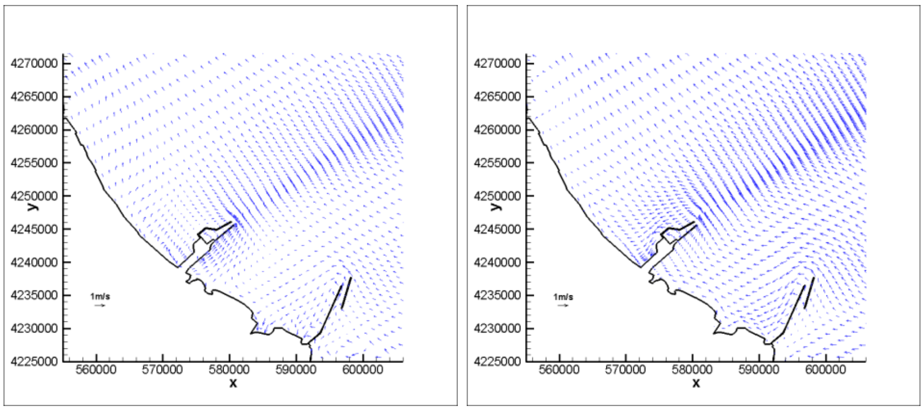
[1] $|\vec{\tau}_s| = \rho_a C_d U^2_{10}$

Where ρ_a is the air density; U_{10} is the wind speed 10m above the mean sea level; C_d is the wind drag coefficient with a constant of 0.0022 (Wang et al., 2001). An ENE gale with a speed of 19m/s, the mean wind condition during the storm surge occurred on Oct.10-13, 2003, and a summer spring tide are adopted for the prediction of sediment transport.

2 Influence of a gale on flow field

2.1 Gale-induced flow in Stage I

Fig.1 is the net flow field induced by the gale at the moment of the maximum flood and ebb flow respectively in Stage I. The main direction of gale-induced flow is from SE to NW due to ENE gale, near-shore topography and land boundary. The figure also shows that the ebb flow enhances the gale-induced flow. The whole flow fields during the storm surge present that the gale enlarges the currents along jetties and shore.



(a) at maximum flood moment (b) at maximum ebb moment

Fig.1 Net flow field induced by a gale at the moment of the maximum flood (a) and ebb (b) flow

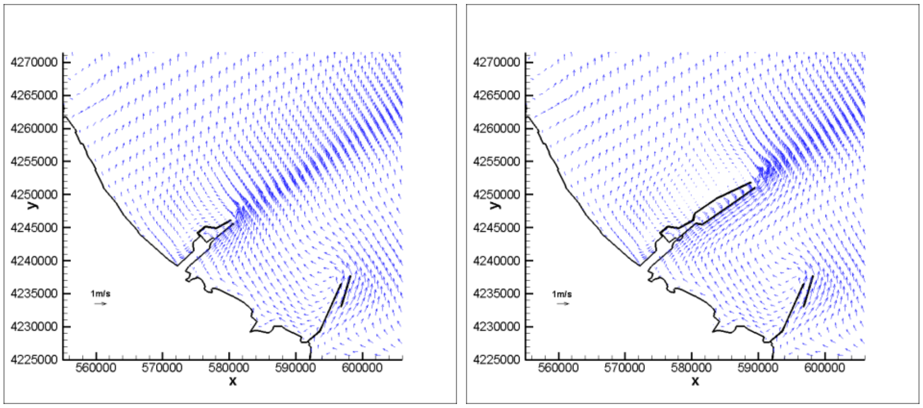
2.2 Comparison of flow fields in Stage I and II

The tidal flow in Huanghua Port sea area is controlled by an anti-clockwise tide (i.e. western branch of the Bohai tides). Before the construction of Huanghua Port, tidal flow in Huanghua Port water acted as obvious anti-clockwise flow (Wu et al. 2005), especially under the influence of gale. Fig.2 shows the maximum ebb flow fields in Huanghua Port Stage I and Stage II respectively during a combined spring tide and gale force. In Huanghua Port Stage I, the tidal flow around Huanghua Port presented such feature as reciprocating current along jetties and formed a cross-flow in the entrance of the port, which may cause the carried sediment depositing and shallow the navigation water depth here. In Huanghua Port Stage II, the jetties of both south and north sides were extended nearly 11 km and separated the port into southeast part and northwest part, leading to a significant decrease of water exchange compared with Stage I. However, the extension of jetties much strengthens the reciprocating currents along jetties. Under the effect of ENE gale, an interesting phenomenon is demonstrated that the flood flow along the north jetty is stronger than that along south jetty and the ebb flow along the north jetty is weaker than that along south jetty in the Stage I. This phenomenon has been proved to be more obvious after the Stage II. Certainly, a new cross-flow appears in the new entrance of the port.

3 Influence of a gale on sediment fields

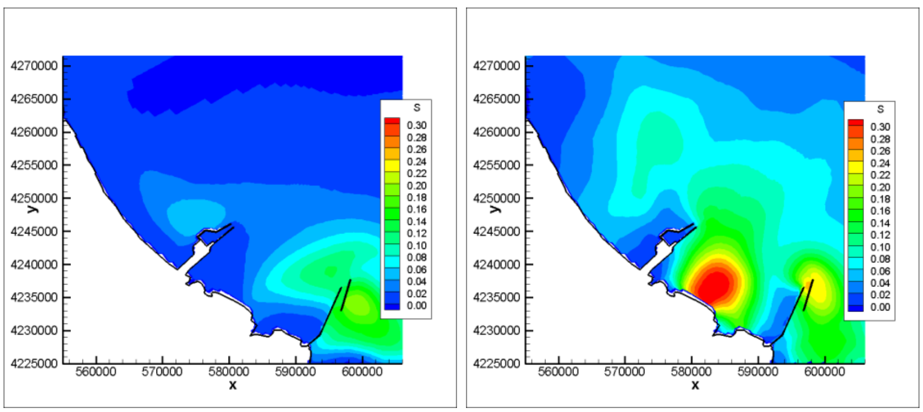
3.1 Influence of a gale on sediment distribution in Stage I

The flow field significantly changed by the gale force should largely affect the sediment transport. Fig.3 is the comparison of sediment distribution at the moment of maximum ebb flow in Stage I under the scenarios of an astronomical spring tide without and with a gale force. The ENE gale force increases the flood flow and decreases the ebb flow, and also enhances the currents along jetties and shore (see Fig.3), which causes two facts: i) sediments eroded from nearshore bed into the waterbody form high-concentration region; ii) sediments carried by the flood flow into nearshore cannot be carried out by the ebb flow completely. It can be seen that the high sediment concentration appears in the nearshore area, around the Stage I and the entrance of the port, which is the main cause of heavy sudden sediment siltation in the port after the October storm surge of year 2003. The large circulation between Huanghua Port and Binzhou Port (in the southeast of Huanghua Port) causes the highest sediment concentration and siltation, which also provides the sediment source to be easily eroded from the strong wind and tidal condition.



(a) in Stage I (b) in Stage II

Fig.2 Maximum ebb flow fields in Stage I (a) and II (b) during a combined spring tide and gale force

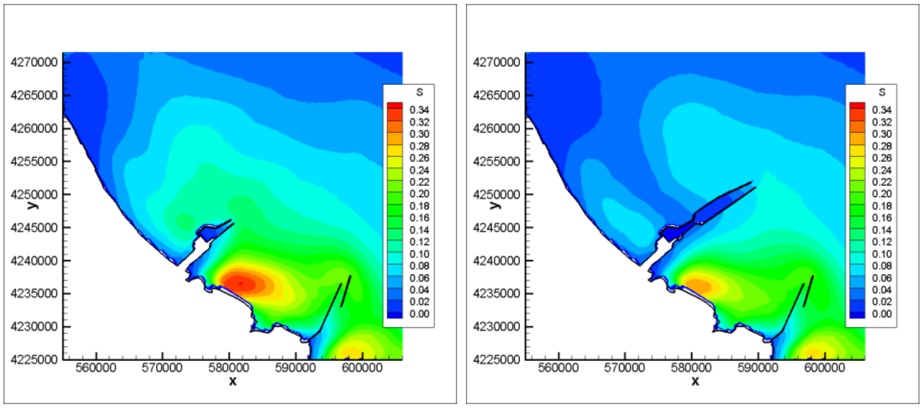


(a) without a gale (b) with a gale

Fig.3 Comparison of sediment distribution at the moment of maximum ebb flow in Stage I under: (a) without and (b) with a gale force.

3.2 Comparison of sediment fields in Stage I and II

The comparison of tidal-averaged sediment concentration fields in Stage I (a) and II (b) during a combined spring tide and gale force is shown in Fig.4. In Stage I, the high sediment concentration occurs in the regions between the southern jetty of Huanghua Port and the northern jetty of Binzhou Port, entrance of outer channel, and the place near northwest beach of Huanghua Port. In Stage II, although the relatively high sediment concentration still appears in these regions, the maximum sediment concentration is much reduced compared with that in Stage I. On one hand, the weaker circulation between the southern jetty of Huanghua Port and the northern jetty of Binzhou Port causes less sediment resuspension from the sea bed. On the other hand, stronger current along the jetties of Huanghua Port carries suspended sediment far from the nearshore area and reaches the entrance of the port with relatively lower concentration. These two factors will lead the less sediment deposition around the port entrance and outer navigation channel in Stage II.



(a) in Stage I (b) in Stage II

Fig.4 Comparison of tidal-averaged sediment concentration fields in Stage I (a) and II (b) during a combined spring tide and gale force

4 Conclusions

The tidal flow and sediment transport have been numerically studied in Huanghua Port sea area, and the influences of a gale force on tidal flow and sediment transport around Huanghua Port have been analyzed detailedly. This study presents that: i) an ENE gale induces a net SE to NW current, and also enlarges the currents along jetties and shore; ii) Stage II leads a significant decrease of water exchange in the nearshore region and an increase reciprocating currents along jetties and imbalance in the both side regions of the jetties; iii) a high sediment concentration appears in the nearshore area around the Stage I caused by the gale; iv) Stage II mitigates nearshore sediment concentration, and carries the sediment far away to the region with deeper water depth, which significantly decreases the sediment deposition in the port under the storm surge.

Acknowledgements

This study was supported by a grant from China Geological Survey Bureau (Project No.: 1212011120087) and partially supported by National Key Basic Research Program of China (Project No.: 2012CB957704).

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