Numerical simulation of the transport diffusion of suspended sediment during the construction of artificial island in Taozi Bay of Yantai

Ting Xu [1], Xiaohui Tian [2]

[1]Tianjin Research Institute for Water Transport Engineering, M.O.T, Tianjin, 300456, China

[2] The Tourism Bureau of Yantai E&T Development Area, Yantai, 264006, China

Keywords: suspend sediment, transport diffusion, Taozi Bay, artificial island.

Abstract. Suspended matter in the sea increases rapidly as a result of the reclamation project during the construction period, which in turn influences the marine ecosystem. Therefore, the study on the transport diffusion of suspended matter in reclamation projects provides an important reference for regional environmental quality assessment and comprehensive ecological impact assessment. This paper takes artificial island reclamation project in Taozi Bay of Yantai as an example, based on the two-dimensional tidal current field mathematical model of engineering waters, the dispersion scope of suspended sediment caused by reclamation overflow during construction of artificial island is predicted by two-dimensional suspended load mathematical model and the accurate simulation of the dispersion of suspended sediment during construction is explored usefully. The results show that the transport and dispersion of suspended sediment produced during construction of artificial island are closely related to the tidal movement and the tide direction and hydrodynamic intensity determine the transport and dispersion direction and range of suspended sediment to a certain degree. During reclamation construction of artificial island, the sediment dispersion during reclamation construction will not affect the Golden Beach as the discharge concentration at the overflow port is low and the envelope range of sediment dispersion is small. Generally, the influence of suspended sediment on the marine environment during construction is just temporary and disappears with the completion of construction, then the suspended sediment will not impose long-term adverse influences on the marine environment.

Introduction

With the high-speed development of marine economy, the shortage of land resources in coastal regions is increasingly prominent. The reclamation project changes the original eco-environment of the ocean and then brings many eco-environment problems while bringing huge benefits. During the construction of reclamation project, the suspended matters in the waters increase rapidly, the original hydrological dynamic conditions of waters change, and the pollutant dispersion ability reduces, thus affecting the surrounding marine ecosystem [1-5]. Therefore, the research of the transport and dispersion rules of suspended sediment during construction of reclamation project is of important significance in providing references to the evaluation of the regional eco-environment quality and the comprehensive ecological influence of engineering construction. Taking Artificial Island Reclamation Project in Taozi Bay, Yantai as an example, based on the two-dimensional tidal current field mathematical model of engineering waters, the dispersion scope of suspended sediment caused by reclamation overflow during construction of artificial island is predicted by two-dimensional suspended load mathematical model and the accurate simulation of the dispersion of suspended sediment during construction is explored usefully in this paper.

Study Area

The proposed artificial island planning project is located in Taozi Bay, Yantai, with a total planned area of 6km2, offshore distance of 2.5km and distance to the Jiahekou in the east of about 6.2km. The construction of the artificial island involves in seabed soil borrowing and dispersion of reclamation sediment, which will impose certain influence on the surrounding water environment.

The influence scope of the dispersion of suspended sediment caused by reclamation overflow during construction of artificial island in Yantai is calculated and analysed in this paper.

The pollution of suspended matters from the overflow port of cofferdam to the waters mainly depends on the concentration of suspended sediment in the sluicing of the overflow port of cofferdam and the concentration of suspended sediment depends on the cofferdam's hydraulic load, hydraulic retention time and grain size distribution of dredged materials. The wastage rate during construction should be confirmed according to the specific site construction conditions and adopted pollution control measures, which is complex. According to the national sewage discharge standard, the discharge concentration increment of suspended sediment at the overflow port should not be more than 150mg/L, which generally cannot meet the standard under the actual construction conditions. According to the actual monitoring of this kind of project, the concentration at the overflow port is about 1000mg/L, so the source strength of each overflow port is about 1.53kg/s if 5 cutter suction dredgers with the standard productivity of 3500m^3/h are used for reclamation[6-8]. The overflow port in the artificial island planning scheme is planned to locate with its back to the shore (to reduce the influence on Golden Beach) and three overflow ports are planned to set. The location of overflow ports is as shown in Fig. 1.

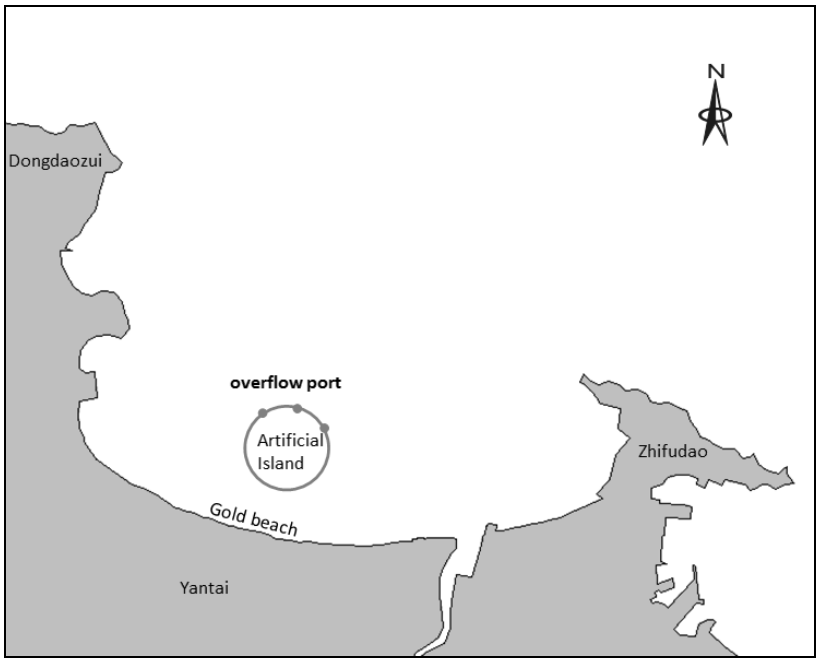


Fig.1: Location of overflow port during construction of artificial island planning scheme

Mathematical Model

2D flow governing equation

Continuity equation:

$$\frac{\partial \zeta}{\partial t}+\frac{\partial[(h+\zeta)u]}{\partial x}+\frac{\partial[(h+\zeta)v]}{\partial y}=0 \tag{1}$$

Equation of motion:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-fv=-g\frac{\partial \zeta}{\partial x}-\frac{\tau_{bx}}{\rho(h+\zeta)}+E_x\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\frac{1}{\rho h}\left(\frac{\partial S_{xx}}{\partial x}+\frac{\partial S_{xy}}{\partial y}\right) \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}-fu=-g\frac{\partial \zeta}{\partial y}-\frac{\tau_{by}}{\rho(h+\zeta)}+E_y\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-\frac{1}{\rho h}\left(\frac{\partial S_{yx}}{\partial x}+\frac{\partial S_{yy}}{\partial y}\right) \tag{3}$$

In these formulas, x y is the coordinate of rectangular coordinate system; t is time, h is the water depth (the distance from base level to bed surface), ζ is tidal level (the distance from base level to free surface), u、v is the vertical average flow components from x、y ,respectively, f is the

coriolis coefficient, g is the gravity acceleration, E_x E_y is the horizontal turbulent viscosity coefficient from x、y , respectively, τ_{bx} τ_{by} is the bed shear stress components in directions x、y with the wave-current interaction, respectively, S_{xx} S_{xy} S_{yy} is the wave radiation stress in different directions, respectively.

Equation of sediment transport

The sediment dispersion and transport adopt two-dimensional substance transport equation that considers the source item and its expression is as follows:

$$\frac{\partial(hS)}{\partial t}+\frac{\partial(huS)}{\partial x}+\frac{\partial(hvS)}{\partial y}=\frac{F_S}{H}+D_x\frac{\partial^2 S}{\partial x^2}+D_y\frac{\partial^2 S}{\partial x^2} \tag{4}$$

Where, h is the water depth (m); t is the time coordinate (s); x and y are horizontal coordinates (m); S is the average sediment content along the depth (kg/m^3); u and v are flow velocity along x and y respectively (m/s); D_x and D_y are the turbulent diffusion coefficient of sediment along x and y respectively (m^2/s), generally about 5.0m^2/s; F_s is the source sink item (kg/m^2·s), $F_s=F_s'+F_s''$, where $\mathrm{F_s^{'}}=\alpha\omega\mathrm{S}$ is the settling item, F'' is the sediment source item caused by dredging or blasting; $\alpha=0.20$ is the sediment settling probability; ω is the sediment settling velocity (m/s). Considering the flocculating settling of fine-particle sediment in waters, ω is 0.0005m/s.

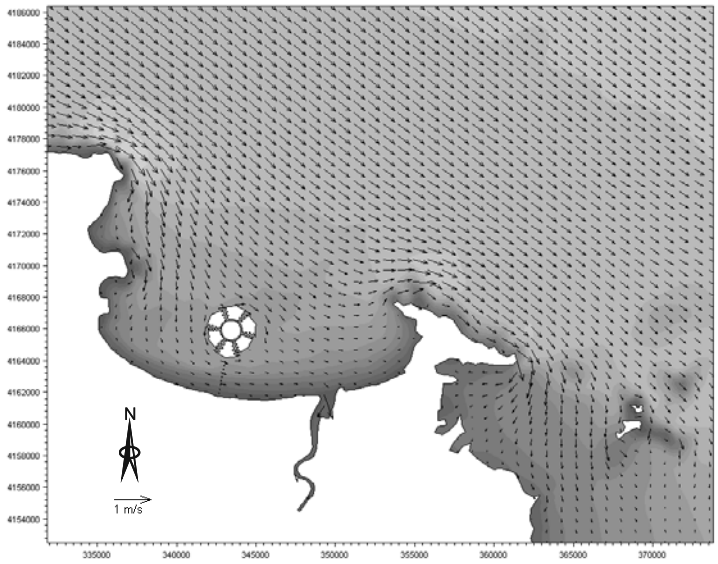
Predicting results of sediment dispersion during reclamation construction

Fig.2 is the diagram of ebb and flow rapids field after implementing the artificial island planning scheme. In the engineering waters, upon ebb rapids, the current approximately flows to the southeast and then is divided into two strands at the artificial island, which move forward around the island, converge near the southeast corner of the island and flow away along the shoreline of Taozi Bay. Upon flow rapids, the current approximately flows to the southwest and then converges after division. The overall tide flow is weak in the engineering waters, the average flow velocity is 0.03~0.08m/s and the maximum flow velocity is 0.05~0.15m/s.

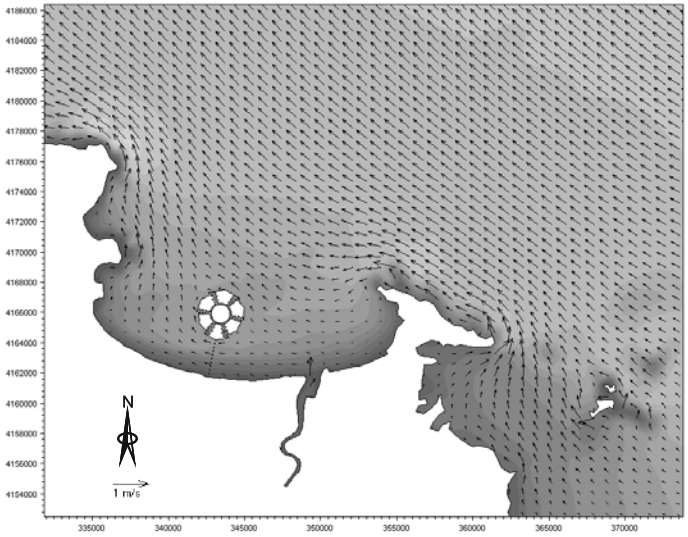
Fig.3 shows the envelope range of sediment dispersion during reclamation construction of artificial island, in which the envelope area with the suspended sediment concentration of more than 10mg/L is 3.78km^2, that with the suspended sediment concentration of more than 100mg/L is 0.82km^2, that with the suspended sediment concentration of more than 150mg/L is 0.57km^2. As the discharge concentration at the overflow port is low and the envelope range of sediment dispersion is small, the sediment dispersion during reclamation construction will not affect the Golden Beach.

Conclusion

Taking planning scheme of artificial island reclamation project in Taozi Bay, Yantai as an example, and the transport and dispersion rules of suspended sediment caused by reclamation overflow during construction is predicted by numerical simulation method in this paper. The calculation results show that the transport and dispersion of suspended sediment produced during construction of artificial island are closely related to the tidal movement and the tide direction and hydrodynamic intensity determine the transport and dispersion direction and range of suspended sediment to a certain degree [9-12]. During reclamation construction of artificial island, the sediment dispersion during reclamation construction will not affect the Golden Beach as the discharge concentration at the overflow port is low and the envelope range of sediment dispersion is small. Generally, the influence of suspended sediment on the marine environment during construction is just temporary and disappears with the completion of construction, then the suspended sediment will not impose long-term adverse influences on the marine environment.



flood



ebb

Fig.2: Typical tidal current field in Taozi Bay

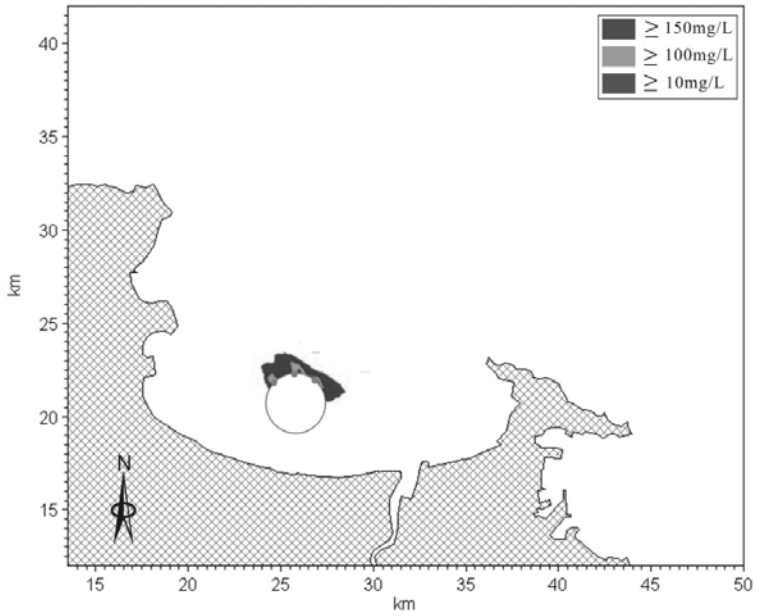


Fig.3: Distribution of sediment concentration during construction of artificial island planning scheme

Acknowledgements

The research work was supported by National Natural Science Foundation of China under Grant No. 51209111.

References

[1] Deng, M., and Y. Li, 2003. Use of SeaWiFS imagery to detect three-dimensional distribution of suspended sediment. Intl. J.Remote Sens., 24 (3): 519-534.

[2] Li, S. H., and C. X. Yun, 2006. Coastal current systems and the movement and expansion of suspended sediment from Changjiang River Estuary. Mar. Sci. Bull., 8 (1): 22-33.

[3] Zhang Y L,Baptista A M,Myers E P.A cross-scale model for 3D baroclinic circulation in estuary-plume-shelf systems: I. Formulation and skill assessment.Continental Shelf research,2004,24(18) : 2 187-2 214.

[4] Guo, Z. G., Z. S. Yang, D. Q. Zhang, D. J. Fan, and L. Kun,2002. Seasonal distribution of suspended matter in the north-ern East China Sea and barrier effect of current circulation on its transport. Acta.

[5]Deng, M., and Y. Li, 2003. Use of SeaWiFS imagery to detect three dimensional distribution of suspended sediment. Intl. J.Remote Sens., 24 (3): 519-534.

[6]Guo, Z. G., Z. S. Yang, D. Q. Zhang, D. J. Fan, and L. Kun,2002. Seasonal distribution of suspended matter in the northern East China Sea and barrier effect of current circulation on its transport. Acta Oceanol. Sin., 24 (5): 71-80.

[7]Jiang, W. S., and W. X. Sun, 2001. 3D suspended particulate matter transportation model in the Bohai Sea Ⅱ. Simulation results. Oceanol. Limnol. Sin., 32 (1): 94-100.

[8]Li, S. H., and C. X. Yun, 2006. Coastal current systems and the movement and expansion of suspended sediment from Changjiang River Estuary. Mar. Sci. Bull., 8 (1): 22-33.

[9]Liu, F., H. J. Huang, and A. Gao, 2006. Distribution of suspended matter on the Yellow Sea and the East China Sea and effect of ocean current on its distribution. Mar. Sci., 30 (1):68-72.

[10]Wu, Y. S., and Z. Y. Wang, 2002. Effect of the Bohai Sea dynamics on sediment transport discharged from the Yellow River. J. Oceanogr. Huanghai Bohai Seas, 20 (2): 22-30.

[11]Yang, Z. S., Z. G. Guo, Z. X. Wang, J. P. Xu, and W. B. Gao,1992. Basic pattern of transport of suspended matter from theYellow Sea and East China Sea to the eastern deep seas. Acta Oceanol. Sin., 14 (2): 81-90.

[12]Zheng, T. M., Y. Y. Zhao, F. Li, Y. S. Qin, and J. D. Milliman,1990. Suspended matter in summer of South Yellow Sea. Acta Oceanol. Sin., 12 (6): 749-757.