Diaokou River Estuarine Sediment Movement Numerical Simulation Analysis Based on two Dimensional Numerical Model

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Abstract. The sediment movement and deposition diffusion regularity of the Diaokou River are related to the safety and stability of the northern coast and coastal ports of the Yellow River Delta, and the deposition of sediment in the estuary will lead to the extension of the river and the increase of river resistance. As a result, the water level of the Yellow River estuary and the lower reaches of the Yellow River rises, which has a negative impact on the flood control safety of the lower reaches of the Yellow River. Therefore, it is of great significance to study the sediment deposition and diffusion law of the Diaokou River into the sea. Using the verified two-dimensional numerical model of marine sediment of estuary rivers, the sediment movement of Diaokou River into the sea is calculated, and the marine dynamic characteristics such as tidal current and tide in the sea area near the Diaokou River into the sea are analyzed. The spatial and temporal distribution of sediment concentration in sediment movement and the increase of sediment deposition thickness in sediment movement are consistent with the analysis results of measured data.

1. Introduction
On November 23, 2009, the State Council approved the Development Plan of the Yellow River Delta Efficient Ecological Economic Zone, making the development of the Yellow River Delta a national strategy. The banks of Diaokou River Road and the estuary area are important components of the Yellow River Delta Efficient Ecological Area.

Diaokou River is the Yellow River into the sea route from 1964 to 1976. Since the Yellow River changed its channel to Qingshuigou in 1976, the natural morphology and ecological environment of Diaokou River have changed greatly due to changes in water and sediment, marine dynamic effect and human activities. The rapid development of industry and agriculture within the scope of river management has resulted in serious shrinkage of river channels, greatly reduced flow capacity, coastline erosion, shrinkage of freshwater wetland area, destruction of biodiversity and other phenomena[1].

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Diaokou River channel is the reserve channel of the Yellow River after the completion of Qingshuigou channel. In the Comprehensive Management Plan of the Yellow River Estuary reviewed by the Ministry of Water Resources in 2011, Diaokou River was taken as the alternate flow route, and Maxin River and Shishihu River were taken as the possible alternate flow routes in the future, and each flow route was alternated into a river. The Yellow River Basin Comprehensive Plan (2012-2030) approved by the State Council in March 2013 adopted the scheme recommended in the Yellow River Estuary Comprehensive Management Plan for the estuary flow route arrangement. During the planning period, the Qingshuigou flow road should be mainly used, and it should be kept as stable as possible and maintained for a long time to carry out ecological water diversion from the Diaokou River flow road. On the premise of ensuring the flood control safety of the lower reaches of the Yellow River and controlling the water level of Xihekou to be less than 12m at a flow rate of 10000m³/s, the rotation river route is used in turn according to certain control conditions. After the completion of the Qingshuigou river route, the spare Diaokou river route to the sea is given priority.

The diversion of Diaokou River can shorten the distance of the river to the sea, transport reliable water for the northern nature reserve, and protect the erosion of the coastline near the mouth of the Diaokou River, so the use of the Diaokou River is one of the feasible schemes. Sediment movement and sedimentation diffusion from the Diaokou River to the sea are not only related to the security and stability of the buildings in the north coast of the delta and the coastal ports, but also the sedimentation outside the estuary extends the channel and the resistance of the river increases. As a result, the water level in the mouth of the Yellow River and the lower reaches of the Yellow River will rise, which has a negative impact on the flood control safety of the lower reaches of the Yellow River. Therefore, it is of great significance to study the deposition and diffusion of sediment movement into the sea of Diaokou River. In the study of sediment transport into the sea of Diaokou River, many people use less measured data to analyze and discuss. For example, Peng Jun analyzed the vertical distribution of velocity and suspended sediment concentration at each station based on the on-site hydrological observation data of the strongly eroded coastal section of the Yellow River Delta in October 2010. Huang Bo explored the coastal erosion of the Diaokou River at the mouth of the Yellow River and its influence on the standby flow path to the sea by systematically analyzing the historical monitoring data of the entire process of the Yellow River Diaokou River, including the characteristics of seawater inflow, shoreline, sea topography and ocean dynamics.

Due to the lack of measured data, the analysis of the spatial and temporal distribution of sediment transport in Diaokou River is not comprehensive enough. The two-dimensional marine dynamic sediment mathematical model in the Yellow River Delta can make up for the lack of measured data. In this paper, two-dimensional numerical simulation is used to simulate the deposition and diffusion of sediment into the sea of Diaokou River. The movement of sediment into the sea in the delta sea area, the spatial and temporal distribution of deposition patterns, and the influence of river channel extension of sediment deposition on the water level of the Yellow River estuary and the lower reaches of the Yellow River are analyzed, so as to provide an important reference for the development of efficient ecological economic zone in the Yellow River Delta and the management of the Yellow River estuary.

2. Numerical simulation basic theory methodology

2.1. The governing equations and deterministic conditions (Li Dongfeng, 2004, Zhang Shiqi, 1990)

It is viable to use depth-averaged planar 2-D shallow water equations as the governing equations for tidal computation. They are as follows:

The equations of continuity:

$$\frac{\partial Z}{\partial t} + \frac{\partial (HU)}{\partial x} + \frac{\partial (HV)}{\partial y} = 0$$

(1)
The equations of motion:
\[
\begin{align*}
\frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} + g \frac{\partial Z}{\partial x} + gn'f \sqrt{U^2 + V^2} \frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} &= 0 \\
\frac{\partial V}{\partial t} + U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} + g \frac{\partial Z}{\partial y} + gn'f \sqrt{U^2 + V^2} \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} &= 0
\end{align*}
\]
(2)

where \( \mu, \nu \) is \( x, y \) direction components of depth averaged velocity; \( z \), \( h \) is water level (or tidal level) and depth; \( g \) is acceleration due to gravity; \( \varepsilon \) is turbulent viscosity coefficient; \( C \) is Chezy’s coefficient, \( C \) is calculated by Chezy’s formulation:
\[
C = \frac{1}{n} \frac{1}{R^\frac{1}{2}}
\]
\( n \) is Manning roughness coefficient; \( f \) is Coriolis force coefficient; \( f = 2\sigma \sin \phi \); \( \sigma \) is rotation angular velocity of earth; \( \phi \) is the latitude of computed reach.

2.2. Boundary conditions
The deterministic conditions involve boundary conditions and initial conditions. Boundary conditions include opening boundary and closing boundary. The former is inlet and outlet water boundary, and is governed by field tidal process for model. The latter is land boundary and the normal velocity is treated as zero for model.

The outlet and open boundary condition: the tidal spring and ebb are control by the tidal level. It is calculated by the formulation:
\[
Z(x, y, z)|_i = Z'(x, y, t) = \mu_0 + \sum f H \cos(qt + G(u_0 + \mu) - g')
\]
in which \( \Gamma_1 \) expresses open boundary; subscript * expresses a given value(the measured value or analyzed value).

At the entrance, flow discharge is given, such as \( Q(x, y, t) = Q_0(x, y, t) \), \( Q_0(x, y, t) \) is the discharge process.

For the closed and rigid boundary the velocity is zero, ie: \( \mu|_n = \nu|_n = 0 \) in which, \( \Gamma_2 \) expresses closed boundary; \( \vec{n} \) expresses normal unit vector.

2.3. Model validation
The boundary conditions and validation of the model can be found in [6].

3. Calculation results and analysis
3.1. Calculation conditions
The calculation range of sediment model of Diaokou River is shown in Fig. 1. The flow and sediment process is Luokou flow 3000m3/s and flow sediment concentration 35kg/m3.

The process of sediment deposition and diffusion from Diakou River to the sea in the delta area was calculated. The river bed change and the process of sediment deposition and scour thickness were recorded once every ten days, which were equivalent to the weight of sediment to the sea of 150 million tons respectively, and about 15 million tons of sediment to the sea were recorded each time. The analysis of sediment movement and riverbed scouring and silting is as follows:

3.2. Analysis of sediment movement from Diaokou River to sea
3.2.1. Analysis of sediment movement and diffusion
Fig. 2 is the contour distribution map of sediment movement and diffusion concentration of sediment entering the sea within a day under the condition of inflow flow of 3000 m$^3$/s and sediment concentration of 35 kg/m$^3$. It can be seen from the distribution chart of sediment concentration that the sea water velocity reaches the maximum at the time of surge, which acts as a top support for the inflow water and reduces the sediment carrying capacity of river water to the greatest extent. At this time, a large amount of sediment is distributed near the mouth. The sea current takes away part of water and sediment at the time of slump, so the distribution range of sediment concentration at the time of slump is small.
Fig. 3 shows the isobathic line at 6.8m in the direction of the estuary gate. The 670th hour calculated is selected as the initial point, and the changes of sediment concentration and tide level with time in the following two periods (2 days) are selected. It can be seen from the variation of tide level with time in the figure that the tide belongs to semi-diurnal tide and the maximum tidal range is nearly 2m. It can be seen from the variation of sediment concentration over time in the figure that the sediment concentration also changes periodically with the rising and falling tide, with the maximum sediment concentration of 17.53 m$^3$/s and the minimum sediment concentration of 1.91 m$^3$/s. The above calculation results are basically in agreement with the analysis of the measured data.

3.2.2. Sediment deposition process near Diaokouhe estuary
As can be seen from Fig. 4, with the increase of sediment inflow into the sea, the maximum value of sedimentation thickness increases, the area of contour of sedimentation thickness increases, and the sedimentation range expands.
3.3. Effect of sediment deposition into sea on downstream channel

It can be seen from Fig. 5 that the influence of sediment entering the sea on the downstream rivers. The boundary point between riverbed deposition and erosion is 185.33 km away from Luokou Hydrological Station. The water level of the river above this position decreases, and the river below this position is deposited. The maximum deposition position is in the deep sea, and the deposition thickness in the sea area is significant.

![Figure 5. Influence of estuary sediment deposition to water level of the Lower Yellow River](image)

4. Conclusion

Using the verified two-dimensional numerical model of sediment of estuary rivers, the sediment movement of Diaokou River is calculated. Based on the processing and sorting of the calculation data, the marine dynamic characteristics such as tides and tides in the sea area near the entrance of Diaokou River, the spatial and temporal distribution of sediment concentration in the diffusion of sediment into the sea, and the increase process of sediment deposition thickness are analyzed. The calculated results are consistent with the measured data. The reliability of the mathematical model is further illustrated, which provides an important tool for further demonstration of Diaokou River governance scheme.

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