Numerical Simulation of Suspended Sediment Diffusion in Waterway Dredging

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Abstract: Suspended sediment produced by channel dredging will affect the marine environment. In this paper, a two-dimensional mathematical model of tidal current in Sanmen Bay was established. A continuous moving point source was used to simulate the diffusion of suspended sediment in the dredging process of a channel in the Sanmen Bay. The diffusion rule was analyzed, the calculation results show that the suspended sediments diffuse with the rising and falling tides, and the transport direction of the suspended matter was basically the same as the tidal current.

1. Introduction

The construction process of channel dredging project was bound to increase suspended sediment, the high concentration of suspended sediment will turbulently diffuse outward under the hydrodynamic action of tidal currents, which may cause harm to marine life and affect the ecological environment of the sea area surrounding the project. The dynamic evrioments in a bay was variable, therefore the movement of suspended sediment was complicated. Its movement form can be either suspended load, bed load, or floating mud density flow[1].

Furthermore, the movement of suspended sediment changes the sediment concentration in local waters. From the perspective of marine ecological protection, it was necessary to study the diffusion of suspended sediment caused by channel dredging. At present, the numerical simulation of suspended sediment diffusion basically adopts convection-diffusion equation. Generally, a certain approximate method was used to generalize the construction process, and the sediment stirred up during the construction process was taken as an additional source term in the convection-diffusion equation.

Wu Xiuguang[2] established a 2D mathematical model of tidal current and suspended sediment transport and diffusion, which was discretely solved by the finite element method of unstructured grids. The model was applied to simulate the suspended sediment diffusion and transport during the dredging process of the Cangnan Power Plant's harbor basin and waterway. The simulation results were in good agreement with the monitoring results in the construction process. Chen Zuhua [3] established a new method to simulate the sediment transport in the open water area of the estuary by using the distributed point source diffusion model and a plane two-dimensional viscous sediment mathematical model, and conducted a numerical simulation of the sediment transport process in Macao waters. Ma Fuxi used large eddy simulation (LES) method to simulate the movement of pollutants in water by introducing buoyancy characteristics, compared with the experimental results. This paper used the mathematical model of convection and diffusion, taking the construction problem of the dredging of a channel in Sanmen Bay as an example, to numerically simulate the diffusion of suspended sediment, analyze its diffusion rule.

2. Numerical Model

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2.1 Hydrodynamic Model

The hydrodynamic model was established based on the two-dimensional incompressible Reynolds average Navier-Stokes shallow water equation. After integrating the horizontal momentum equation and the continuous equation in the range of h=η+d, the following two-dimensional depth average shallow water equation can be obtained.

$$\frac{\partial h}{\partial t}+\frac{\partial h\bar{u}}{\partial x}+\frac{\partial h\bar{v}}{\partial y} = hS \quad (1)$$

$$\frac{\partial h\bar{u}}{\partial t}+\frac{\partial h\bar{u}^2}{\partial x}+\frac{\partial h\bar{v}\bar{u}}{\partial y}= f\bar{v}h-gh\frac{\partial \eta}{\partial x}-\frac{h}{\rho_0}\frac{\partial p_a}{\partial x}-\frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial x}+\frac{\tau_{sx}}{\rho_0}-\frac{\tau_{bx}}{\rho_0}- +\frac{\partial}{\partial x}\left(hT_{xx}\right)+\frac{\partial}{\partial y}\left(hT_{xy}\right)+hu_s s \quad (2)$$

$$\frac{\partial h\bar{v}}{\partial t}+\frac{\partial h\bar{u}\bar{v}}{\partial x}+\frac{\partial h\bar{u}^2}{\partial y}=-f\bar{u}h-gh\frac{\partial \eta}{\partial y}-\frac{h}{\rho_0}\frac{\partial p_a}{\partial y}-\frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial y}+\frac{\tau_{sy}}{\rho_0}-\frac{\tau_{by}}{\rho_0}- +\frac{\partial}{\partial x}\left(hT_{xy}\right)+\frac{\partial}{\partial y}\left(hT_{yy}\right)+hv_s s \quad (3)$$

$$\frac{\partial S}{\partial t}+\frac{\partial(\bar{u}S)}{\partial x}+\frac{\partial(\bar{v}S)}{\partial y}=\frac{F_s}{h}+D_x\frac{\partial^2 S}{\partial x^2}+D_y\frac{\partial^2 S}{\partial y^2} \quad (4)$$

Where: t is the time; x, y were the Cartesian co-ordinates; η was the surface elevation; d was the still water depth; h=η+d, was the total water depth; $\bar{u},\bar{v}$ were the velocity components in the x, y direction; $f=2\Omega\sin\phi$ is the Coriolis parameter(Ω is the angular rate of revolution and ϕ the geographic latitude) ;g is the gravitational acceleration; ρ is the density of water; ρ_0 is the reference density of water; the lateral stresses T_{ij} include viscous friction, turbulent friction and differential advection.

2.2 Hydrodynamic Calculation Conditions

The main research object of the mathematical model was the middle part of the Sanmen Bay. The northern side of the model bank boundary was located in Changsha mountain, and the south side of the model bank boundary was located in Shitang Town. The coordinate range is N28°16′ 48″ ~N29°35′ 42″ , E121°15′ 08″ ~ E122°49′ 24″ , the entire computational domain was about 11939km^2.The grid layout makes full use of the advantages of the triangular grid and was divided according to the principle of dense grids in key water areas and sparse in other water areas. The grid layout in the calculation domain takes into account the difference of water flow and terrain gradient, the grid near the project is further refined to ensure the accuracy of flow field simulation before and after the project. There are 32566 computing nodes and 61994 elements. The maximum water depth in the domain was more than 70m, and the minimum space step was about 5m. The dynamic calculation time step was adopted. The grid layout was shown in Figure 1. The measured 15 day continuous tide was selected as the hydrodynamic condition for this calculation.

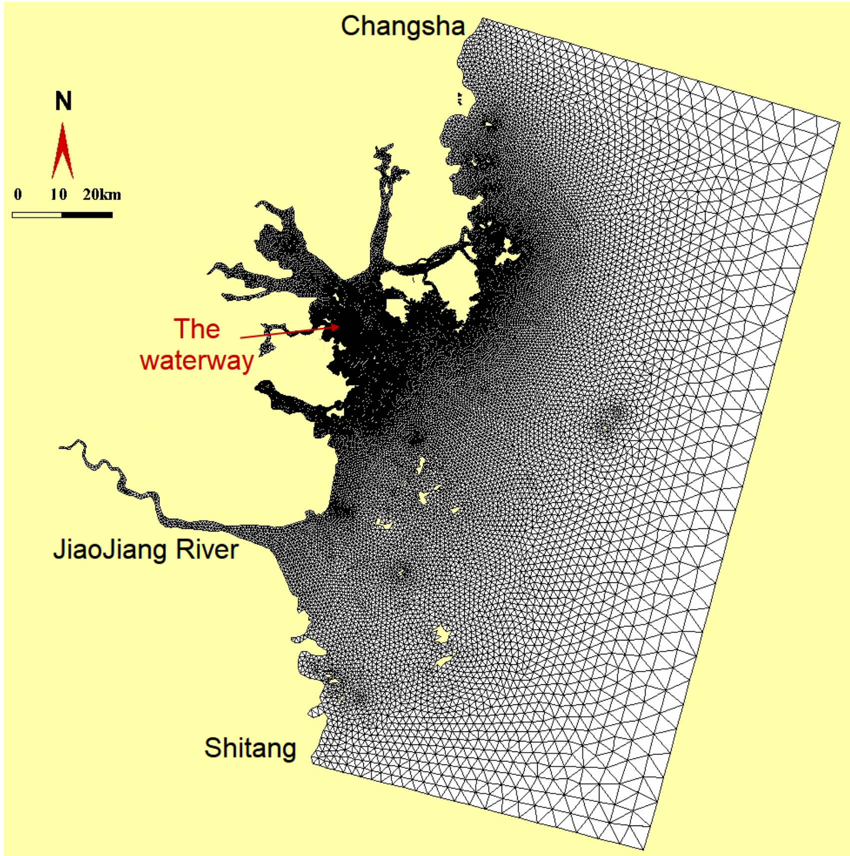

Fig.1 Calculated Area and Grid Layout Drawing

3. Source Generalization of Suspended Sediment

Consider the impact of suspended sediment caused by different construction tide types and different construction times, The measured tidal range of Jiantiao station near the project area in recent five years was used as the cumulative frequency curve. According to statistics, the 10% cumulative frequency tidal range of Jiantiao station was 5.72 m and the 90% cumulative frequency tidal range was 2.47 m, representing typical spring tide and typical neap tide respectively.

The amount of suspended sediment produced during the construction of cutter suction dredgers was calculated according to the empirical formula in 'Specifications for Environmental Impact Assessment of Port Engineering'(JTS105-1-2011),The specific formula was as follows:

$$Q = \frac{R}{R_0} \cdot T \cdot W_0 \quad (5)$$

Where, Q was amount of suspended sediment in dredging operation(t/h);

R was the cumulative percentage of suspended sediment particles at occurrence factor W_0, Take 89.2% according to the recommended value of the specification

R_0 was the cumulative percentage of critical particles of suspended sediment at site flow rate (%), Take 80.2% according to the recommended value of the specification

W_0 was the occurrence coefficient of suspended sediment (t/m3), take 0.038t/m^3 according to the recommended value of the specification

T was the maximum dredging efficiency of dredging ship (m3/h), which is 1000m^3/h.

Through calculation, the suspended solids production Q of cutter suction dredger construction operation was 42.264t/h (11.74kg/s). Therefore, the maximum source strength of suspended sediment caused by the construction of cutter suction dredger was 11.74kg/s.

The area source intensity was generalized into point source intensity, and a total of 92 point sources were arranged. The source intensity point layout was shown in Figure 2. The suspended mud was released after the hydrodynamic force of the model reaches dynamic equilibrium.

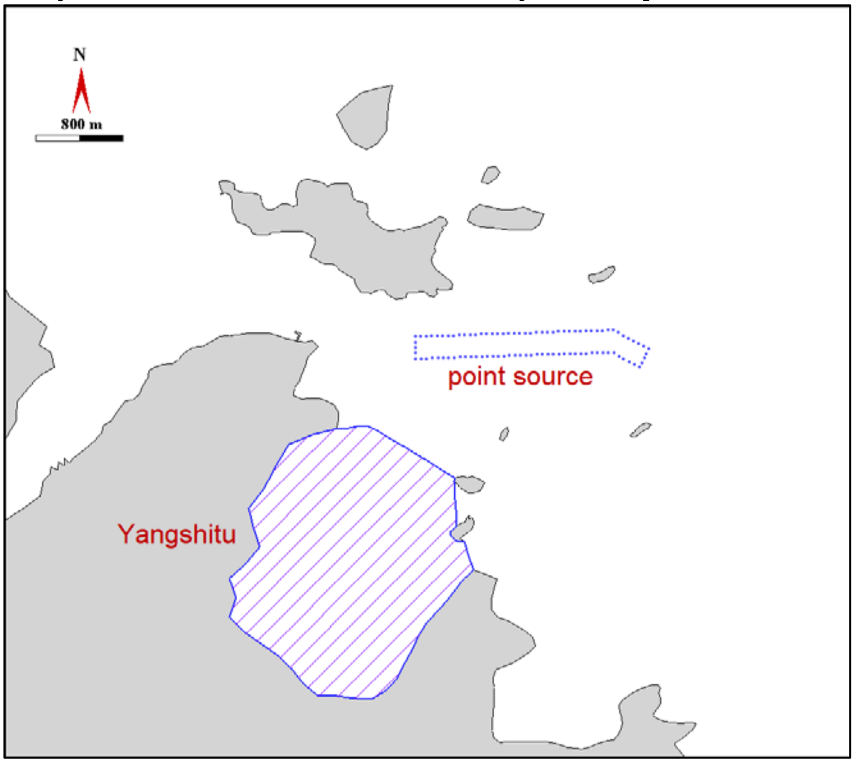

Fig.2 Schematic Diagram of Point Sources Layout of Suspended Sediment

4. Calculation Results

The envelope of suspended sediment concentration during construction at spring tide and neap tide was shown in Figure 3 ~ Figure 4, and the total envelope of spring and neap tide concentration is shown in Figure 5.The statistics of suspended sediment envelopment were shown in Table 1.

During the construction period, the increasement of suspended sediment concentration was below 100 mg/L, the envelope area with a concentration greater than 10 mg/L was 22.49 km^2 and 32.13 km^2 at spring and neap tides respectively. The envelope area with a concentration greater than 50 mg/L at spring and neap tides were 3.22 km^2 and 6.42 km^2 respectively. The total envelope area of the large and small tide concentration greater than 10mg/L was 34.44 km^2, the envelope area greater than 50mg/L was 6.42 km^2.The total envelope area of spring tide and neap tides concentration greater than 10mg / L was 34.44 km^2, the envelope area of concentration greater than 50mg / L was 6.42 km^2.

Table 1. Suspended Sediment Envelope Statistics Table (Unit:Km2)

Tide types	Concentration(mg/L)				
	10	20	50	100	150
spring	22.49	8.40	3.22	1.68	1.04
neap	32.13	21.51	6.42	2.99	1.94
spring and neap	34.44	21.60	6.42	2.99	1.94

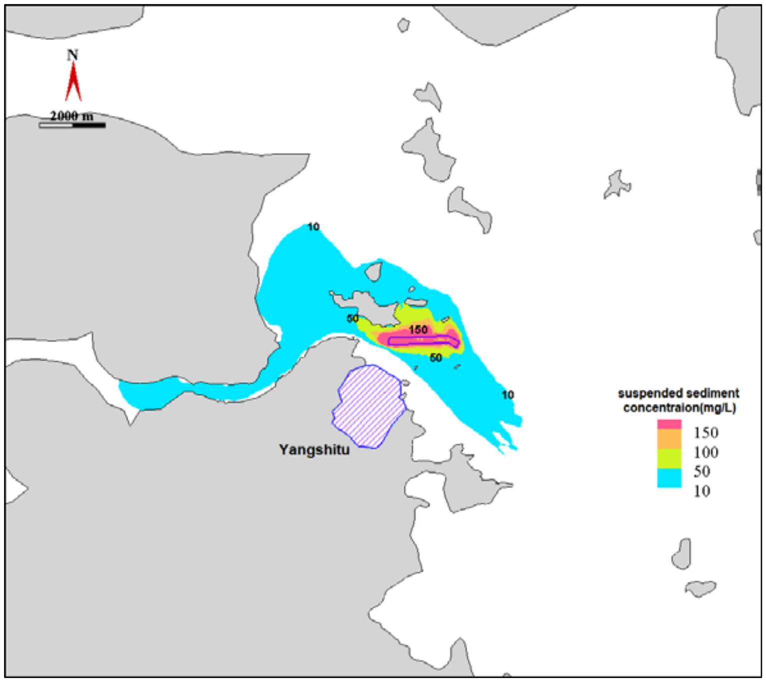

Fig.3 Envelope Diagram of Suspended Sediment Concentration At Spring Tide

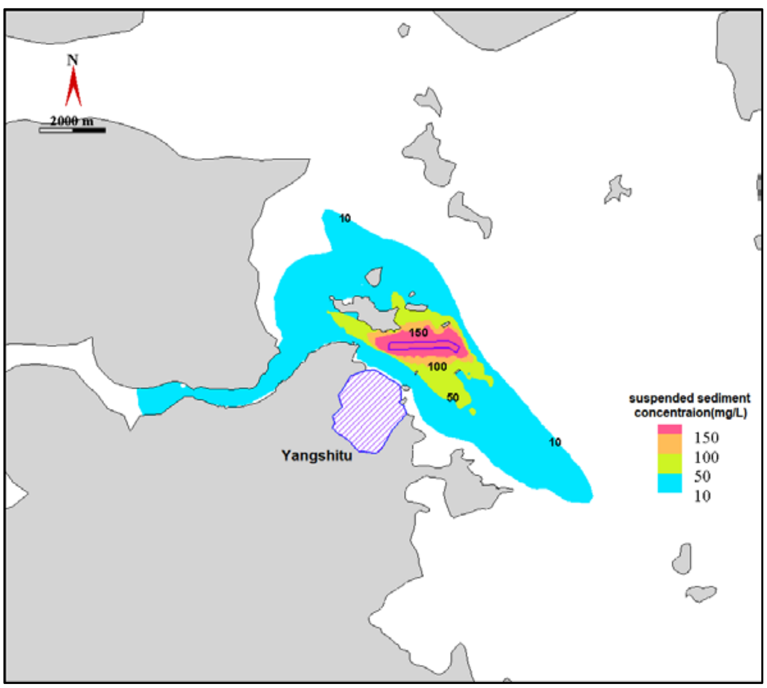

Fig.4 Envelope Diagram of Suspended Sediment Concentration At Neap Tide

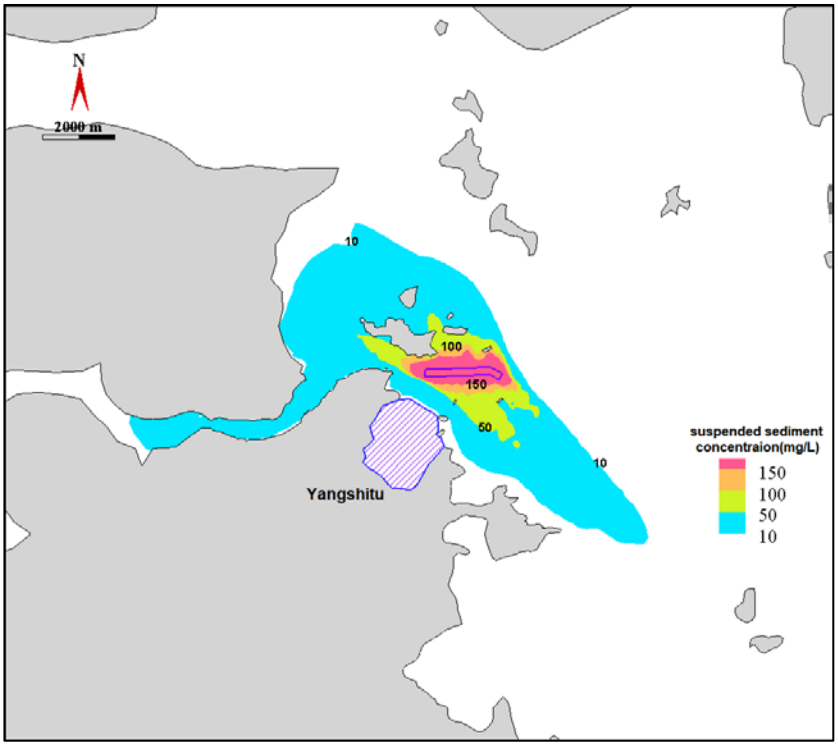

Fig.5 Envelope Diagram of Suspended Sediment Concentration At Spring and Neap Tide

5. Conclusion

After the commencement of construction, in addition to the deposition of part of the suspended sediment entering the water body, the other part was transported and diffused in the water area near the construction site under the action of tidal current. With the extension of time, the incremental concentration of suspended sediment generated by construction would gradually tend to 0, and the sediment concentration in the sea water body would gradually return to the sediment concentration in the natural state. Suspended sediment diffuses with rising and falling tide flow, and the transport direction of suspended sediment was basically the same as that of tidal current. Therefore, it can be said that the duration of suspended sediment caused by channel dredging was short, and the impact on the ecological environment is controllable.

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