Analysis of Submarine Trench Siltation in Offshore Open Sea

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Abstract. Based on the offshore submarine pipe project in Zhangpu, the siltation characteristics of submarine trench in the nearshore open sea were studied using computational fluid dynamics(CFD) methods. The results of the study show that the characteristics of water flow above the submarine trench will change significantly after the excavation of the submarine trench, which will have a significant impact on the siltation of the submarine trench. The excavation of the submarine trench will lead to an increase in the cross sectional area of the water flow over the submarine trench, causing the current velocity to be smaller than that of the neighboring waters, which leads to the siltation of the submarine trench. Under the same hydrodynamic condition, the smaller the water depth, the greater the intensity of submarine trench siltation. The results of this study can provide guidance for the process optimization of submarine trench excavation in offshore open sea.

Keywords: submarine trench; current; siltation; computational fluid dynamics.

1 Introduction

In recent years, with the development of the marine industry, marine projects such as submarine pipelines and submarine cables have become hotspots for China's near-shore coasts. In the offshore open sea, due to the lack of cover of islands and other obstacles, the ocean hydrodynamic has a significant impact on submarine siltation. In the process of submarine trench construction, due to the impact of submarine trench siltation, it will lead to submarine trench excavation quality control is difficult to ensure. Therefore, for the offshore open sea submarine trench to carry out the analysis of siltation for the submarine trench excavation process optimization and enhancement of the engineering efficiency are of great significance.

Sediment deposition and transport in the ocean is closely related to flow field properties[1-5]. At present, the study of submarine trench siltation is mainly carried out by means of field observation, physical model experiment and numerical simulation.

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Huang et al carried out siltation monitoring for the inlet channel of Lvshi port area and analyzed the siltation characteristics of the excavated channel within one year[6]. Xin et al analyzed the siltation rate and distribution characteristics of submarine trench based on the underwater topographic data measured on site[7]. He and Xin used numerical simulation to analyze the abnormal siltation phenomenon of the base channel of Hong Kong-Zhuhai-Macao Bridge immersed tube tunnel[8]. Based on the seabed topographic data, Xu et al analyzed the siltation characteristics of the trial trench and explored its siltation mechanism[9]. Liu and Zeng analyzed the silttation of Tongzhou Bay port and proposed the strategies to reduce siltation[10]. Yao et al focused on the analysis of characteristics of siltation in foundation trench for Shenzhen-Zhongshan Link project based on the measured terrain data[11].

This study takes the Zhangpu submarine pipeline project in the offshore open sea as the site, combining with the site current characteristics, uses numerical simulation methods to establish the numerical model of submarine pipe trench siltation at different depths (10m, 15m, 20m), and analyzes the siltation characteristics of submarine pipe trench at different water depths, so as to provide guidance for the optimization of submarine pipe trench excavation process in the open sea.

2 Numerical model

2.1 Governing Equations

The fluid in the numerical model is considered incompressible and viscous. The continuity equation, momentum equation and sediment motion equation are mainly utilized.

(1) Continuity equation

$$V_F \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}\left(\rho u A_x\right) + \frac{\partial}{\partial y}\left(\rho v A_y\right) + \frac{\partial}{\partial z}\left(\rho w A_z\right) = 0 \tag{1}$$

Where V_F indicates the fraction of open volume to flow; ρ indicates fluid density; velocity components of (u, v, w) are in (x,y,z) direction, (A_x, A_y, A_z) indicates the fraction of open surface at x direction, y direction and z direction, respectively.

(2) Momentum equation

$$\frac{\partial u}{\partial t} + \frac{1}{V_F}\left(uA_x \frac{\partial u}{\partial x} + vA_y \frac{\partial u}{\partial y} + wA_z \frac{\partial u}{\partial z}\right) = -\frac{1}{\rho}\frac{\partial p}{\partial x} + f_x$$

$$\frac{\partial v}{\partial t} + \frac{1}{V_F}\left(uA_x \frac{\partial v}{\partial x} + vA_y \frac{\partial v}{\partial y} + wA_z \frac{\partial v}{\partial z}\right) = -\frac{1}{\rho}\frac{\partial p}{\partial y} + f_y$$

$$\frac{\partial w}{\partial t} + \frac{1}{V_F}\left(uA_x \frac{\partial w}{\partial x} + vA_y \frac{\partial w}{\partial y} + wA_z \frac{\partial w}{\partial z}\right) = -\frac{1}{\rho}\frac{\partial p}{\partial z} + G + f_z \tag{2}$$

Where G indicates mass acceleration, and (fx,fy,fz) indicates viscosity accelerations.

(3) Sediment motion equation

In the equation of sediment motion, the critical shear stress is used as a condition for judging sediment starting, and the Soulsby-Whitehouse formula is used to calculate the critical shield number θ_{cr}.

$$\theta_{cr} = \frac{0.3}{1+1.2d_*} + 0.055[1-\exp(-0.02d_*)] \tag{3}$$

$$d_* = d_s\left[\frac{\rho(\rho_s-\rho)g}{\mu^2}\right]^{1/3} \tag{4}$$

Where d* indicates the quantized sediment grain size, ds indicates the sediment grain size, ρs indicates the sediment density; g indicates the gravitational acceleration, and μ indicates the hydrodynamic viscosity of the fluid.

The sediment-holding uplift velocity ulift was used to calculate the amount of bed sand converted to suspended sediment using the theoretical equations of Mastbergen and Berg.

$$u_{lift} = \alpha n_{\mathrm{s}} d_*^{0.3}\left(\theta-\theta_{cr}\right)^{1.5}\sqrt{\frac{gd_s\left(\rho_s-\rho\right)}{\rho}} \tag{5}$$

$$\theta = \frac{\tau}{gd_s\left(\rho_s-\rho\right)} \tag{6}$$

Where α indicates the sediment-holding coefficient, n_s indicates the bed normal vector, θ indicates the Shields number, and τ indicates the bed shear stress.

The diffusion equation for suspended mass sediment is given blow as:

$$\frac{\partial C_{\mathrm{s}}}{\partial t} + \nabla\cdot\left\{\left[\bar{u} + \frac{v}{d_s}\left(\left(107.3296+1.049d_*^3\right)^{1/2}-10.36\right)\frac{C_s}{\rho_s}\right]C_s\right\} = \nabla\cdot\nabla\left(DC_s\right) \tag{7}$$

Where Cs indicates the mass concentration of suspended sediment, $\bar{u}$ is the water-sand mixture velocity, calculated by multiplying the flux of u_{lift} and water velocity, v indicates the fluid kinematic viscosity, and D indicates the diffusion coefficient.

2.2 Simulation Setup

2.2.1. Computational domain and boundary conditions. The submarine trench siltation numerical model is shown in Figure 1. According to the project site settings, the depth of the submarine trench is set to 5 m, and the trench slope is set to 1:6. Based on the geological survey data of the project sea area, the type of surface soil around the submarine trench is medium-fine sand, with the median grain size of this soil is

0.18mm. Therefor, the grain size of the seabed soil is simplified to 0.18mm. The left boundary of the model is set to be the velocity. The numerical calculation duration is 15 days, covering a complete spring tide and neap tide period.

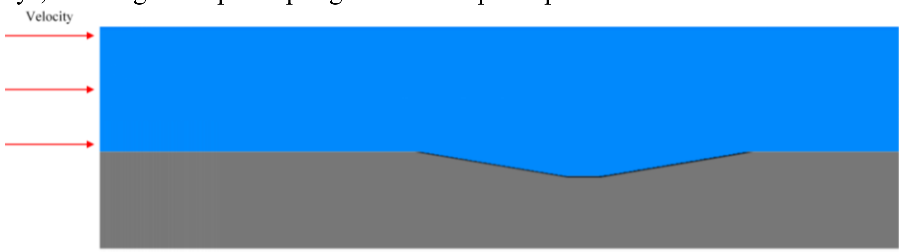


Fig. 1. Computational domain and boundaries.

2.2.2. Computational conditions. According to the depth of project site submarine pipeline road routing area, three calculation conditions are shown in Table 1, analyzing the characteristics of submarine trench under different depths(10m, 15m, 20m).

Table 1. Calculation conditions.

Case	Depth (m)	Velocity
1	10	Measured tide current
2	15	
3	20	

3 Results and Discussion

3.1 Flow Field Characteristics

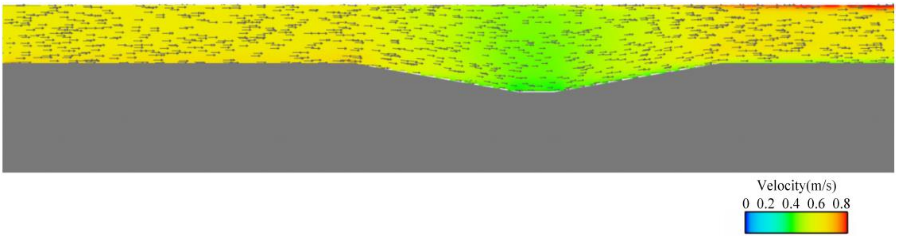
As can be seen from Figure 2, the seabed topography has a significant effect on the fluid movement characteristics. After the submarine pipe trench is excavated, the current velocity above the submarine pipe trench decreases due to the increase of the overflow section area above the submarine pipe trench compared with the neighboring unexcavated section area. By comparing Figure 2(a), Figure 2(b) and Figure 2(c), it can be seen that after the excavation of the submarine pipe trench, the smaller the depth, the more significant the change in flow velocity above the submarine trench.

The flow field at a depth of 10 m is shown in Figure 2(a). When the velocity of the current adjacent to the submarine pipe trench is 0.7m/s, the current above the submarine pipe trench is only 0.3m/s~0.5m/s, and the water velocity adjacent to the bottom of the base trench is only 0.3m/s. The flow field at a depth of 15 m is shown in Figure 2(b). When the velocity of the flow adjacent to the submarine pipe trench is 0.7m/s, the velocity of the water in the upper layer of the submarine pipe trench is about 0.5m/s, and the velocity of the water at the bottom of the base trench is about 0.3m/s. As shown in Figure 2(c), the excavation of the submarine pipe trench has the smallest impact on the change of the current flow field when the depth of construction area is about 20 m.

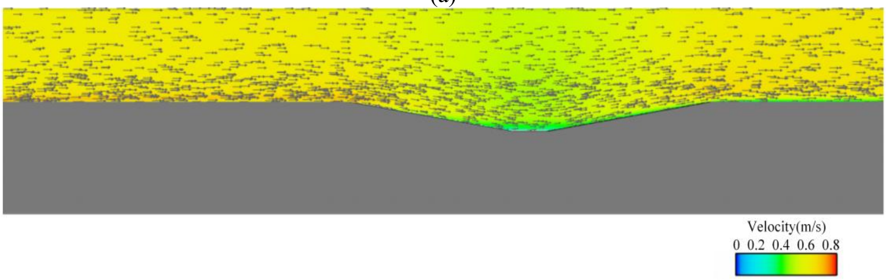
when the tidal current velocity in the vicinity of the submarine pipe trench is 0.7 m/s, the current velocity in the upper layer above the trench is about 0.6 m/s, and the current velocity of the near-bottom layer of the base trench is about 0.4 m/s. As shown in table 2.

Table 2. The flow field characteristics at different depth.

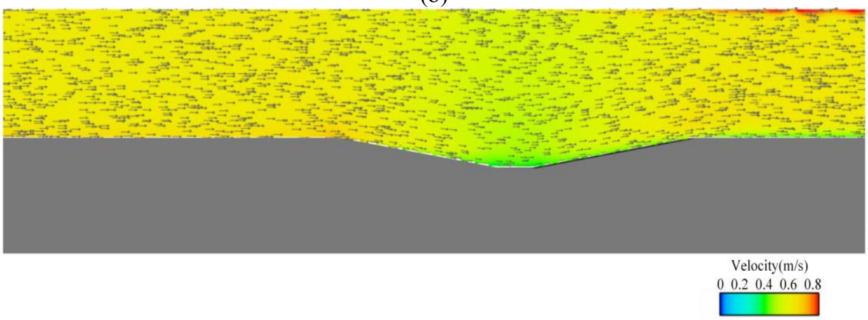
Depth (m)	Current velocity above the submarine trench (m/s)	Current velocity adjacent to the submarine trench (m/s)
10	0.3	0.7
15	0.5	0.7
20	0.6	0.7



(a)



(b)



(c)

Fig. 2. Flow field distribution near submarine pipe troughs.

3.2 Siltation Characteristics

Since the sediment transport mainly depends on the influence of flow field characteristics, there are some differences in sediment siltation of submarine trench under different flow field distributions. The siltation distribution of the submarine pipe trench 15 days after excavation is shown in Figure 3, and the siltation intensity of the submarine trench decreases with the increase of water depth.

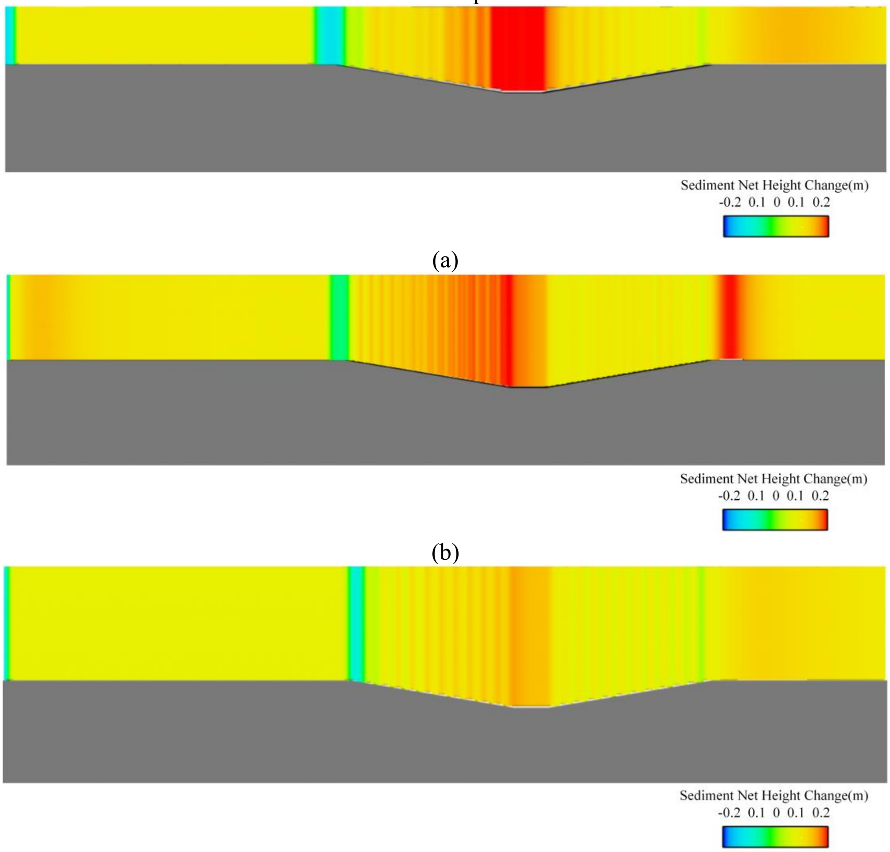


Fig. 3. submarine trench siltation distribution.

Due to the submarine trench excavation, the cross-section area of the current above the submarine trench changes significantly. As shown in Figure 3(a), the submarine trench siltation at the depth of 10m is the most significant. The bottom siltation of the trench thickness is 0.2m, and the daily siltation strength is 1.3cm/d. The siltation thickness at a depth of 15 m is shown in Figure 3(b). The siltation intensity in the submarine trench at the depth of 15m is weaker than the siltation intensity in the submarine trench at the depth of 10m. The siltation thickness is 0.165m and the daily siltation strength is about 1.1cm/d in the submarine trench at the depth of 15m. The siltation thickness at the depth of 20 m is shown in Figure 3(c). Near the outlet of the submarine pipeline at a depth of 20m, it has the minimal effect of submarine trench excavation on flow field distribution changes. Therefore, the siltation strength is the weakest at the depth of 20m, with the total siltation thickness of 15 days after the excavation is about 0.136 m and the daily siltation strength is about 0.91cm/d. As shown in table 3.

Table 3. The characteristics of submarine trench siltation at different depth.

Depth (m)	Siltation thickness (m)	Siltation strength (cm/d)
10	0.2	1.3
15	0.165	1.1
20	0.136	0.91

4 Conclusion

Based on the results and discussions presented above, the conclusions are obtained as below:

(1)The excavation of the submarine trench has a significant effect on the current flow above the submarine trench. Due to the increase in the cross sectional area of the overflow above the submarine trench, the flow velocity of the current above the submarine trench is smaller than that of the neighboring current.

(2)The greater the water depth, the smaller the siltation intensity of the submarine trench. The siltation intensity is 1.3cm/d at the depth of 10m, while the siltation intensity at the depth of 20m is about 0.91cm/d.

(3)The submarine trench excavation and subsequent process lap shall take into account the effect of submarine trench siltation on the depth of submarine trench excavation.

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