COMPARISON OF TIDAL CURRENTS UNDER DIFFERENT NOURISHMENT SCHEMES AT WEST BEACH OF BEIDAIHE, CHINA

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This paper detailed a study on the tidal current field around a beach nourishment project including submerged breakwaters and jetties. The effect of different nearshore structure arrangements on the tidal current field is studied utilizing a numerical model established based on the solution of two-dimensional shallow water equations and an unstructured grid. In order to calibrate the numerical model, the field survey was conducted at 5 tidal current stations and a tidal level station around the project area. According to a primary analysis on stability, environment, sight of the beach, and construction quantity, four project schemes are chosen and simulated. After comparing the modeling results, the effects of submerged breakwaters and jetties are discussed. Conclusively, it is feasible to protect the filled sand on West Beach by jetties and submerged breakwaters through obvious tidal current velocity reduction in the nearshore area.

Keywords: beach nourishment; tidal current field; West Beach in Beidaihe

INTRODUCTION

Beaches are one of the most important tourism resources, which is a lovely place for people to travel and relax. However, erosion of beaches has become troublesome in the recent decades. An estimate made by Bird (1985) shows that about 70% of the world's sandy beaches are retreating at a rate of 0.5~1.0 m a year. While according to van der Salm and Unal (2003), 95% of the world beaches are eroding due to human activities and moving dynamics.

In general, tidal currents do not cause beach erosion or deposition directly, but they carry sediment along the coast in the nearshore zone, and this may eventually be delivered to beaches alongshore (Bird, 2008). For this reason, tidal currents may play a certain role in some beach erosion cases.

The attraction force of the Moon and the Sun that exerted on the Earth's hydrosphere causes ocean tides. Tidal currents are produced in coastal settings when the tidal wave becomes constricted, such as at the entrance to a bay or tidal inlet (Davis Jr and FitzGerald, 2004). Simply speaking, tidal current is a periodic horizontal motion of sea water under the effect of tidal force caused by the Sun and the Moon.

The study of numerical tidal current model can be traced back to 1960s in the world and 1970s in China. The three-dimensional numerical tidal current model based on Reynolds Averaged N-S Equations is widely known as an effective model to study general free surface flow, but it is limited by the capacity and performance of computer for the fine calculation of the model in large scale, especially in a model coupled with wind wave, sediment transport and bed deposition and erosion. In the coastal zone, the vertical scale of coastal tidal current is much smaller than the horizontal one, so the vertical acceleration term can be ignored. According to the shallow water assumption, a two-dimensional tidal current model can be given out. The two-dimensional numerical tidal current model has been widely used in some regions such as to study the rule of tide and tidal current (Cao and Fang, 1990; Zhang, et al., 2007), to compute the tidal current field around coastal engineering (Wan and Li, 2000; Shi and Li, 2003) and environmental engineering (Liu et al., 2009; Gu and Kuang, 1996).

So far, plenty of numerical models have been developed and have been able to simulate the tidal current, such as CH3D (Sheng, 1986), POM (Blumberg and Mellor, 1987), ADCIRC (Luettich et al, 1991), EFDC (Hamrick, 1992), FVCOM (Chen et al., 2003), ELCIRC (Zhang et al., 2004), MIKE3-Flow (DHI Hydraulics, 2005), Delft3D-Flow (WL | Delft Hydraulics, 2006), SELFE (Zhang and Baptista, 2008), and so on. Generally speaking, those models use the following methods: 1) curvilinear orthogonal grid or unstructured triangular grid; 2) finite difference (FD), finite volume (FV) or finite element (FE) for the space discretization method (SDM); 3) upwind scheme, Lagrange method, central difference (CD) method or Crank-Nicolson method to solve the advection term; and 4) ADI, semi-implicit theta, Crank-Nicolson, Rungga-Kutta, or Euler et al. for the time discretization method.

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In this paper, a two-dimensional numerical tidal current model is established based on the solution of two-dimensional shallow water equations. Unstructured triangular grids are utilized in the modeling. Field survey of current and tidal field is conducted to calibrate the numerical model. With the calibrated model, four different schemes with different arrangements of nearshore structures are simulated. After comparing the modeling results, the effects of submerged breakwaters and jetties are discussed.

STUDY AREA

West Beach locates in the southwest of Beidaihe District of Qinhuangdao City, which is in the west of Bohai Bay (Fig. 1), Hebei Province, China. Beidaihe District has a shoreline of totally 18.4 km long and it is famous for its wide beach, soft sand and mild wave. West Beach locates in the northeast of Dai river, with several famous and scenic bathing places lying on (Fig. 1). It is characterized by relatively short (about 3.5 km in length) embayed beach bound on either extremity by headlands; at the southwest end of the beach there is a jetty used to lead the flow of Dai river; at the northeast of the beach there is a cape, where there used to be a jetty which was dismantled in 2002.

Figure 1. Study area.

According to the economic statics, about 2/3 tourism income in Qinhuangdao City is from beach tourism, reported by Qinhuangdao Mineral Resource and Hydrogeological Brigade (2009). However the beach has been eroding since 1950s, with sand coarsening, rock outcropping and slope steepening. It is recorded that the width of West Beach had a average width of about 110 m in the 1960s; its average width is around 55 m with the maximum width of 76 m and minimum width of 26 m in the 1980s; in 2000, the maximum width of West Beach is 58 m and the minimum width is only 15 m; and in 2007, its average width is only 17 m, which is 93 m narrow compared to 1960s. If no improvement is applied, the beach might disappear soon. Recognizing the importance of Beidaihe's beaches to tourism and the economical benefit to the City of Qinhuangdao, the local government initiated a beach nourishment project to protect and enlarge the beaches in 2007.

PROJECT DESCRIPTION

This project is a planned beach nourishment project for the whole West Beach. According to a primary analysis on stability, environment, sight of the beach, and construction quantity, an initial plan of 50m-wide beach nourishment with jetties and submerged breakwaters is proposed: the jetties are designed to be built on the extremities of the beach, and a channel for tidal current is reserved in the east jetty. The submerged breakwaters are designed to be built in -4 m depth sea area, about 450 m off the seashore; the crest of the breakwater is 1.5 m below the mean sea level. Some of the borrowed sands are gotten from the dredging of nearby rivers and navigation channels, and the other from sea bed of -15 m depth area off the West Beach. The median grain size of the borrowed sands ranges between 0.42 and 0.61 mm, while the median grain size of the native beach is 0.34 mm. The designed beach slope is 1:10 below low water level and 1:8 above low water level. Designed berm height is 3 m (China's 1985 national height datum) and filled sand volume is 256.7×10^4 m^3 with an overfilling factor of 1.12, which are calculated according to Coastal Engineering Manual.

METHODOLOGY

Field survey

A total of 5 current stations were set in the nearshore area around West Beach, as shown in Fig. 2. The water depth at the current stations ranges from 5 m to 15 m. Current directions and velocities were taken once an hour at the stations. A tide level station was set on the coast of Qinhuangdao near Qinhuangdao Harbor. Tidal level data were also recorded each hour. All the data collections were conducted by Qinhuangdao Mineral Resource and Hydrogeological Brigade, Hebei Geological Prospecting Bureau, China.

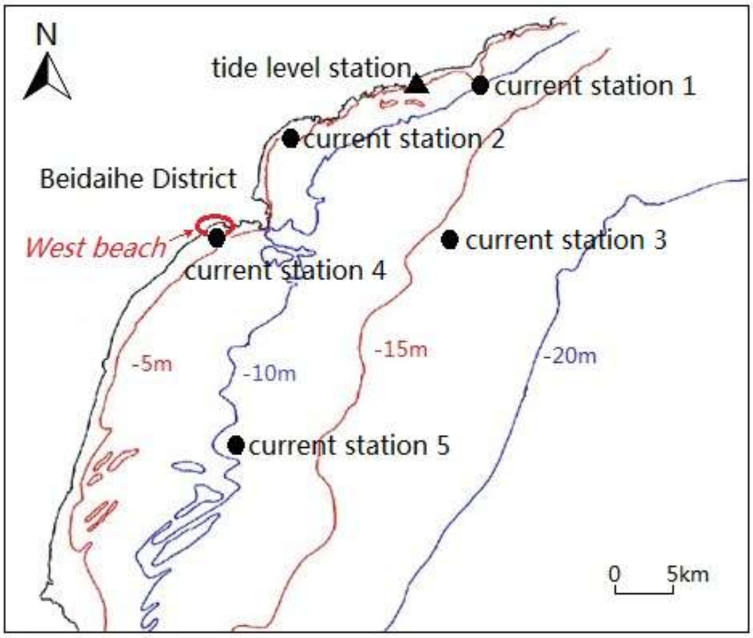


Figure 2. Survey station and water depth contour around West Beach in Beidaihe.

Current and tidal level measurements in a typical day (from 2007-7-27 7:00 to 2007-7-28 7:00) are shown in Fig. 3 and Fig. 4. As seen, the current direction changes four times a day, therefore the tidal flow type is dominated as semi-diurnal tidal current; since there is only one maximum value and one minimum value in 24 hours for the tidal level, the tidal type is diurnal tide.

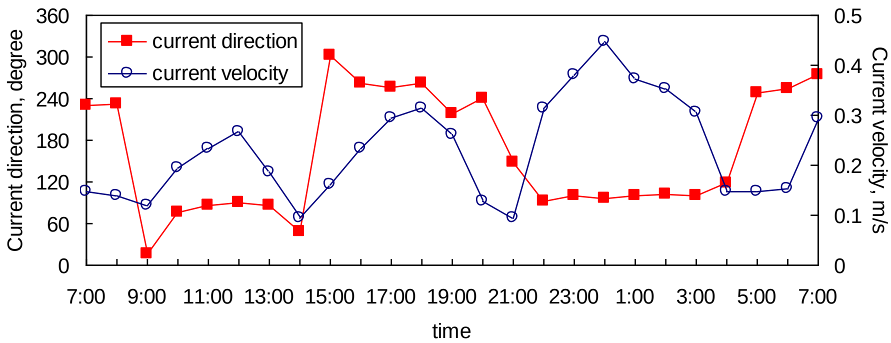


Figure 3. Current direction and velocity measurements at current station 1 in 24 hours (from 2007-7-27 7:00 to 2007-7-28 7:00).

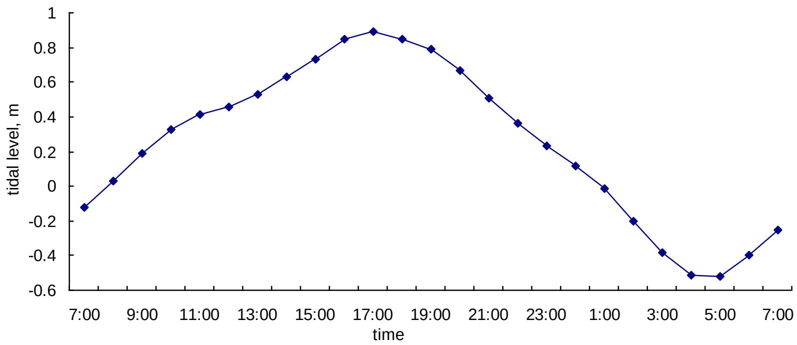


Figure 4. Tidal level measurements in 24 hours (from 2007-7-27 7:00 to 2007-7-28 7:00).

Model description

The simulation of current near the project area was conducted by using a numerical model based on the solution of two-dimensional shallow water equations which means the two-dimensional impressible shallow water equations are obtained under hydrostatic pressure and Boussinesq assumption through integrating 3D horizontal momentum equations and the continuity equation over depth $h=\eta+d$:

$$\frac{\partial h}{\partial t}+\frac{\partial h\bar{u}}{\partial x}+\frac{\partial h\bar{v}}{\partial y}=0 \tag{1}$$

$$\begin{aligned}&\frac{\partial h\bar{u}}{\partial t}+\frac{\partial h\bar{u}^2}{\partial x}+\frac{\partial h\bar{v}\bar{u}}{\partial y}=f\bar{v}h-gh\frac{\partial \eta}{\partial x}\\&+\frac{\tau_{sx}}{\rho_0}-\frac{\tau_{bx}}{\rho_0}+\frac{\partial}{\partial x}\left(hT_{xx}\right)+\frac{\partial}{\partial y}\left(hT_{xy}\right)\end{aligned} \tag{2}$$

$$\begin{aligned}&\frac{\partial h\bar{v}}{\partial t}+\frac{\partial h\bar{v}^2}{\partial y}+\frac{\partial h\bar{v}\bar{u}}{\partial x}=-f\bar{u}h-gh\frac{\partial \eta}{\partial y}\\&+\frac{\tau_{sy}}{\rho_0}-\frac{\tau_{by}}{\rho_0}+\frac{\partial}{\partial x}\left(hT_{xy}\right)+\frac{\partial}{\partial y}\left(hT_{yy}\right)\end{aligned} \tag{3}$$

where η is the surface elevation; d is the still water depth; $h=\eta+d$ is the total water depth; $f=2\Omega sin\varphi$ is the Coriolis parameter; T_{ij} is the lateral stresses.

MODELING

Model establishment

For evaluating the arrangement of submerged breakwaters and jetties, a two-dimensional tidal current model is established to simulate the tidal current field around the beach nourishment project.

Fig. 5 shows the computational grid, which is build using unstructured triangular grid technique, covering an area of 3,000 km^2 and including all the 5 tidal current stations and one tidal level station. As shown in Fig. 5, a nested grid is used, i.e. a coarse grid is built covering all the current stations, and a fine grid is built around the West Beach. The coarse grid is built in two levels: around the fine grid is the finer and near the open boundaries is coarser. Three open boundaries are set on east, south, and west of the coarse grid, as seen in Fig. 5.

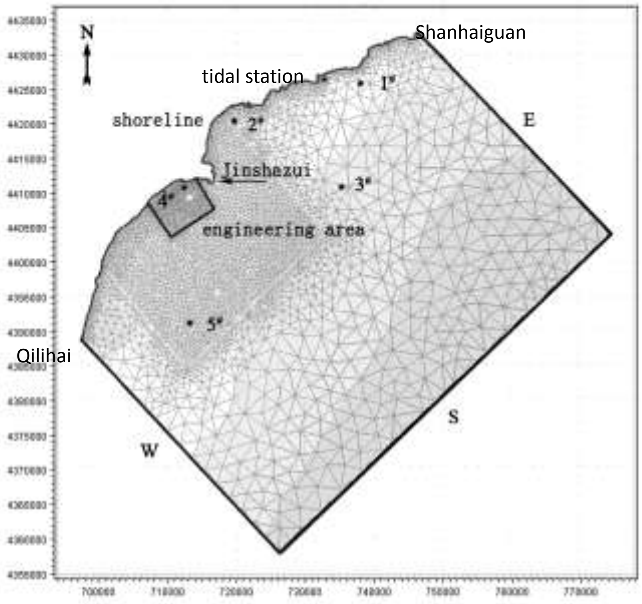


Figure 5. Nested computational grid.

An explicit method is used to solve governing equations. The use of explicit method introduces a restriction on the time step for a given spatial discretiztion due to the CFL stability condition. This can be simply described as the following equation:

$$Cr = \sqrt{gh}\,\frac{\Delta t}{\Delta L} \leq 0.5 \qquad (4)$$

Hence the time step of the model is set to 5 s. A horizontal eddy viscosity value 20 m^2/s is applied. And a Manning Coefficient of 0.0015 is used for the roughness coefficient to match the average roughness of the bed sediment.

In order to save computational time and get more accurate results, nested grid is used. A large-scale model is built to employ all the field survey data to get a verified large-scale current field and provides boundary conditions for small-scale model. A small-scale model is employed to get detailed current field around West Beach under different project schemes.

Model calibration and verification

Current field is simulated in the large-scale model for model calibration and providing boundary conditions for the small-scale model. Current stations 1 to 5 are marked up in Fig. 5 as 1# to 5#. The measured data of water level from 2007-7-27 5:00 to 2007-7-28 11:00 and the measured data of tidal current at station 3 and 5 are used to calibrate the model while the measured data of water level from 2007-7-28 0:00 to 2007-7-29 11:00 and the measured data of tidal current at station 1, 2 and 4 are used to validate the model.

Fig. 6 shows the comparison between simulated and observed water level in the tidal level station. The simulation results represent a well-matched tendency in water level. Fig. 7 shows the comparison between simulated and observed tidal current velocity magnitude and direction at two selected stations for model calibration. The results show that the tide in model is diurnal while the tidal current is semi-diurnal, which indicates the tidal current is complex. Using the same model and parameters, the model is validated. Fig. 8 shows the verification results which indicate the simulated data fit well with the observed data.

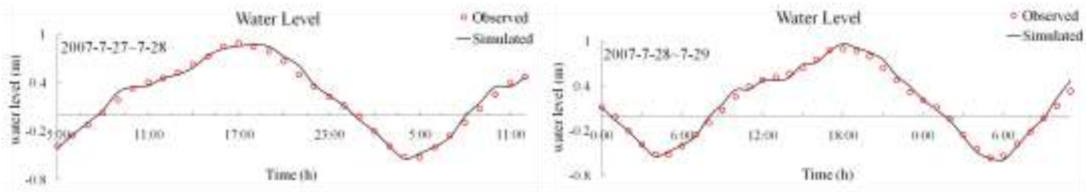


Figure 6. Comparison between simulated and observed time history of water level from 2007-7-27 5:00 to 2007-7-28 11:00 and from 2007-7-28 0:00 to 2007-7-29 11:00 respectively.

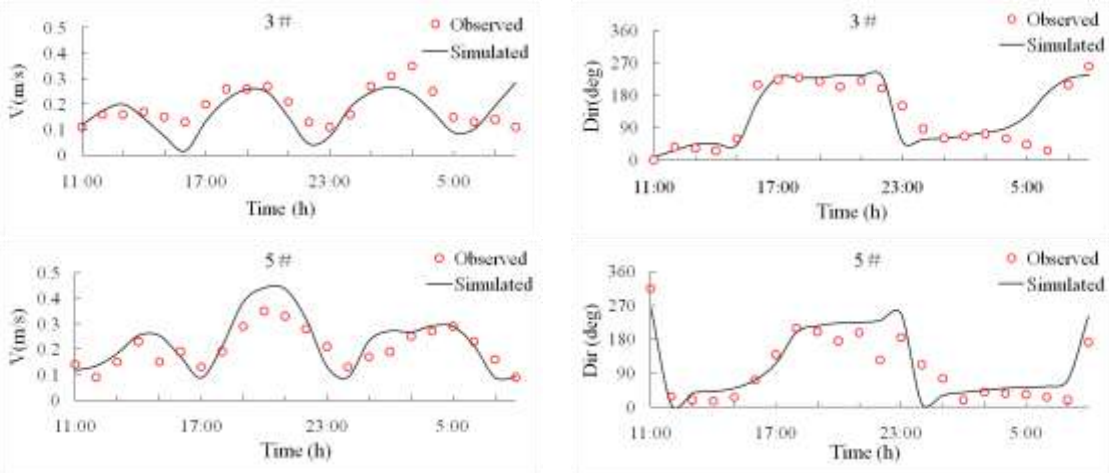


Figure 7. Comparison between simulated and observed time history of tidal current velocity magnitude and direction at station 3 and 5 from 2007-7-28 11:00 to 2007-7-29 5:00 (for model calibration).

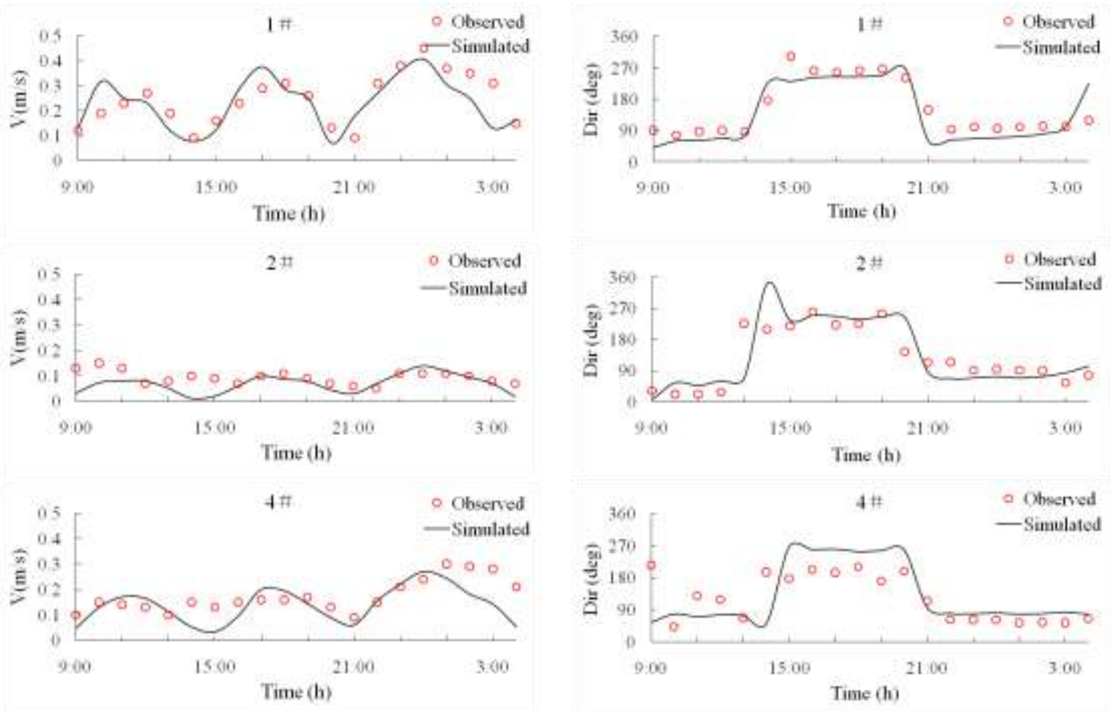


Figure 8. Comparison between simulated and observed time history of tidal current velocity magnitude and direction at station 1, 2 and 4 from 2007-7-27 9:00 to 2007-7-28 3:00 (for model verification).

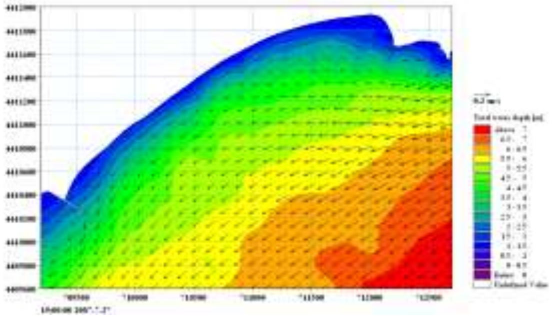
Model result and discussion

According to a primary analysis on stability, environment, sight of the beach, and construction quantity, four project schemes are simulated as shown in Fig. 9. As reference, the current field without project is also simulated, mentioned as scheme 0. Detailed current fields of scheme 0 to 4 are simulated in the small-scale model.

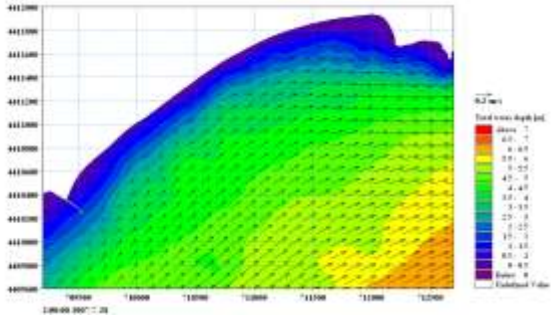
Figure 9. Project schemes for whole-beach-scale project: (a) scheme 1: 50m wide beach nourishment with jetties and 3 submerged breakwaters, (b) scheme 2: 50m wide beach nourishment with jetties and 2 submerged breakwaters, (c) scheme 3: 50m wide beach nourishment with 3 submerged breakwaters, (d) scheme 4: 50m wide beach nourishment with east jetty

Fig. 10 shows the tidal current field at the time of peak flood current and peak ebb current under scheme 0 to 4. The dominated flood current direction is from NE to SW, and the ebb current direction is from SW to NE. The tidal current velocity behind west jetty in scheme 1 and scheme 2 is slower than that in the schemes without the west jetty, which indicates the west jetty plays a key role in protecting the sheltered area of the cape near Dai River. And the east jetty plays an important role in protecting its sheltered area, for the tidal current velocity behind east jetty in scheme 1, scheme 2 and scheme 4 is slower than that in the schemes without the east jetty. But the east jetty doesn't have as much protective effect as the west jetty, for it has very little influence on the current field outside of its sheltered area.

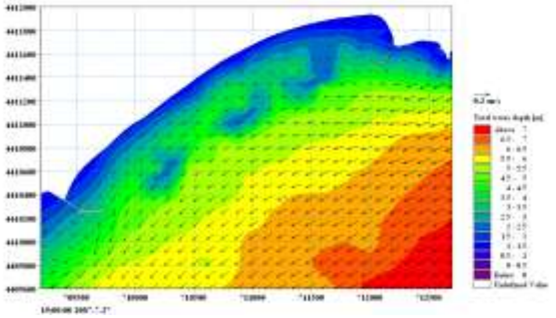
Because Fig. 10 shows the qualitative results of the simulation, and in order to show some quantitative results, some observation points arre set as seen in Fig. 11. T1~T2 are the points in the tidal channel. N1~N9 are points in nearshore area along the shoreline from west to east. J1~J3 are the points around west jetty and J4~J6 are the points around east jetty. O1~O5 are the points between or behind three submerged breakwaters, while S1~S5 are the points between or behind two submerged breakwaters.



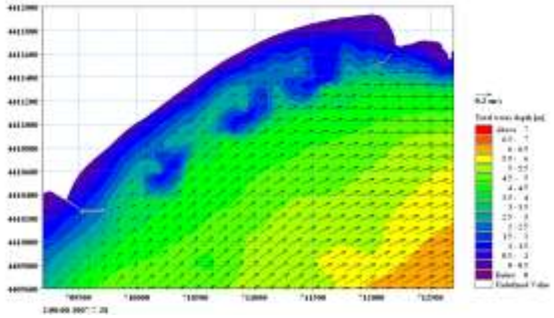
a) peak flood current of scheme 0



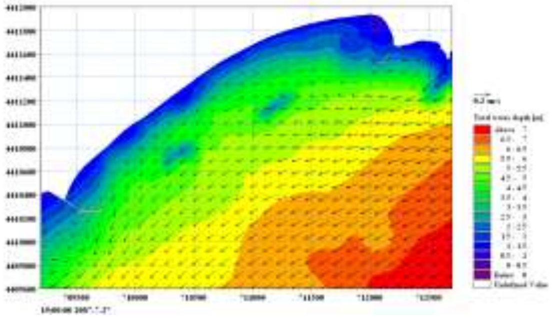
b) peak ebb current of scheme 0



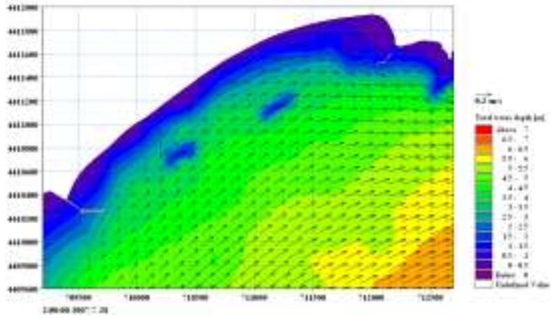
c) peak flood current of scheme 1



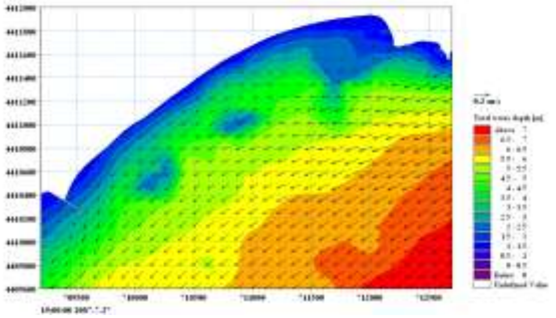
d) peak ebb current of scheme 1



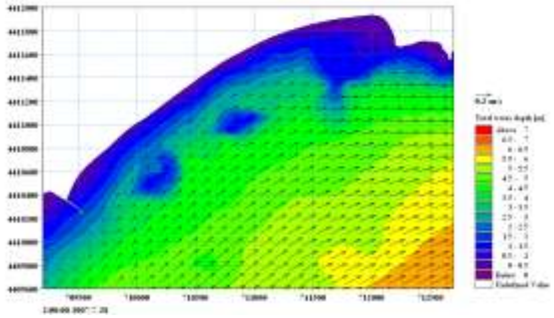
e) peak flood current of scheme 2



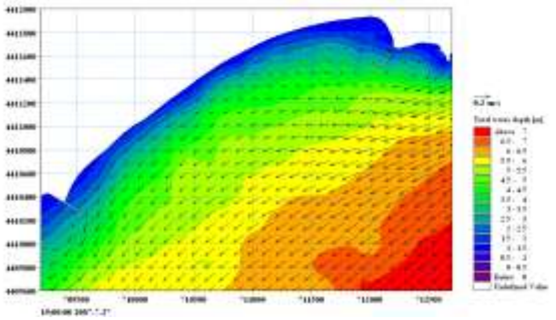
f) peak ebb current of scheme 2



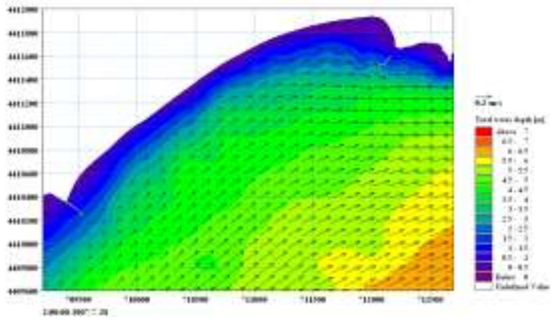
g) peak flood current of scheme 3



h) peak ebb current of scheme 3

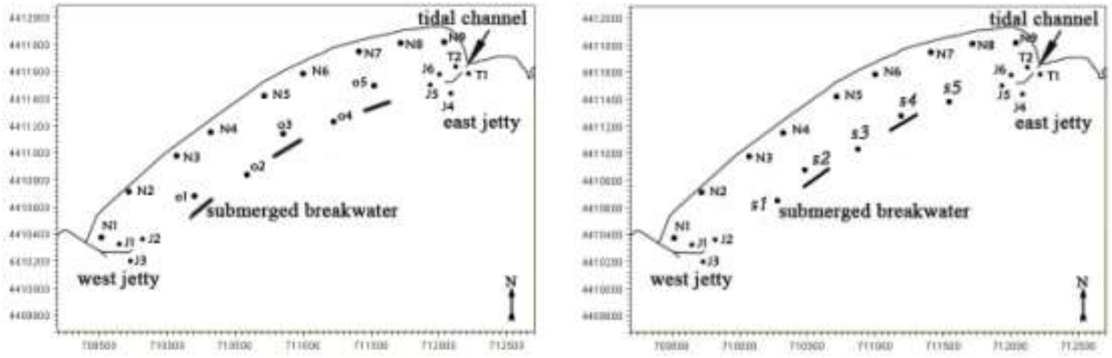


i) peak flood current of scheme 4



j) peak ebb current of scheme 4

Figure 10. Simulated peak flood and ebb tidal current fields under scheme 0 to 4.



a) observation points of scheme1 and scheme3 b) observation points of scheme2

Figure 11. Location of observation points.

Fig. 12 shows the simulation results of tidal current velocity magnitude and direction of point T1 and T2 under scheme 0 to 4. As seen, the general tidal current velocity magnitude of T1 and T2 in scheme 1, scheme 2 and scheme 4 reduce significantly while the general tidal current magnitude in scheme3 reduce a little compared to scheme 0 (natural situation without projects). The peak ebb tidal current velocity of T1 and T2 in scheme 1, scheme 2 and scheme 4 reduced greatly and the magnitude reduce from about 0.15 m/s to less than 0.1 m/s, while the flood tidal current velocity of T1 in scheme 1 and scheme 4 increase a little but no more than 0.1 m/s. The directions of tidal current velocity of T1 and T2 in this four schemes change at slack water, especially the tidal current of point T2, which locates in the west of tidal channel, in scheme 2 flow changes from flood to ebb an hour earlier. In a word, the magnitude of tidal current velocity in the tidal channel reduces significantly after the east jetty has been set up and its direction only changes around slack water.

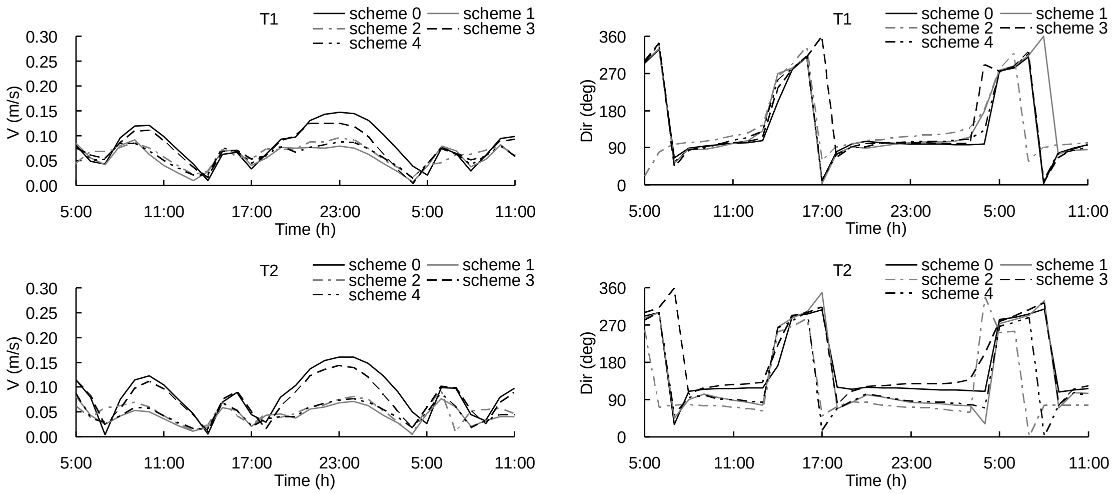


Figure 12. Comparison of tidal current velocity magnitude and direction of observation points locate in the tidal channel in scheme 0 to 4.

Fig. 13 shows the simulation results of tidal current velocity magnitude and direction of point J1 to J6 in scheme 0 to 4. J1 and J6 locate behind the west jetty and east jetty, respectively. The magnitude of tidal current velocity of J1 and J6 reduce and their directions change a lot when the jetty exists, for example, J1 in scheme 1 and scheme 2 and J6 in scheme 1, scheme 2 and scheme 4, as shown in Fig. 13. J2 and J5 locate around the head of west jetty and east jetty, respectively. The magnitude of tidal current velocity of J2 in scheme 1 and scheme 2 reduce during the modeling period, and the reduction is more significantly in the ebb period. The magnitude of tidal current velocity of J5 in scheme 1 (with east jetty) reduces, while the one in scheme 3 (without the jetty) increases. The direction of tidal current velocity of J2 and J5 changes only around slack water. J3 and J4 locate at the sea side of the west jetty and east jetty, respectively. The magnitude of tidal current velocity of J3 changes very little. The magnitude of tidal current velocity of J4 in scheme 1, scheme 2 and scheme 4 (with east jetty) increases compared with scheme 0, while it reduces in scheme 3 (without east jetty) in the ebb period. The slack water of J3 and J4 become earlier in scheme 1 and scheme 2, respectively.

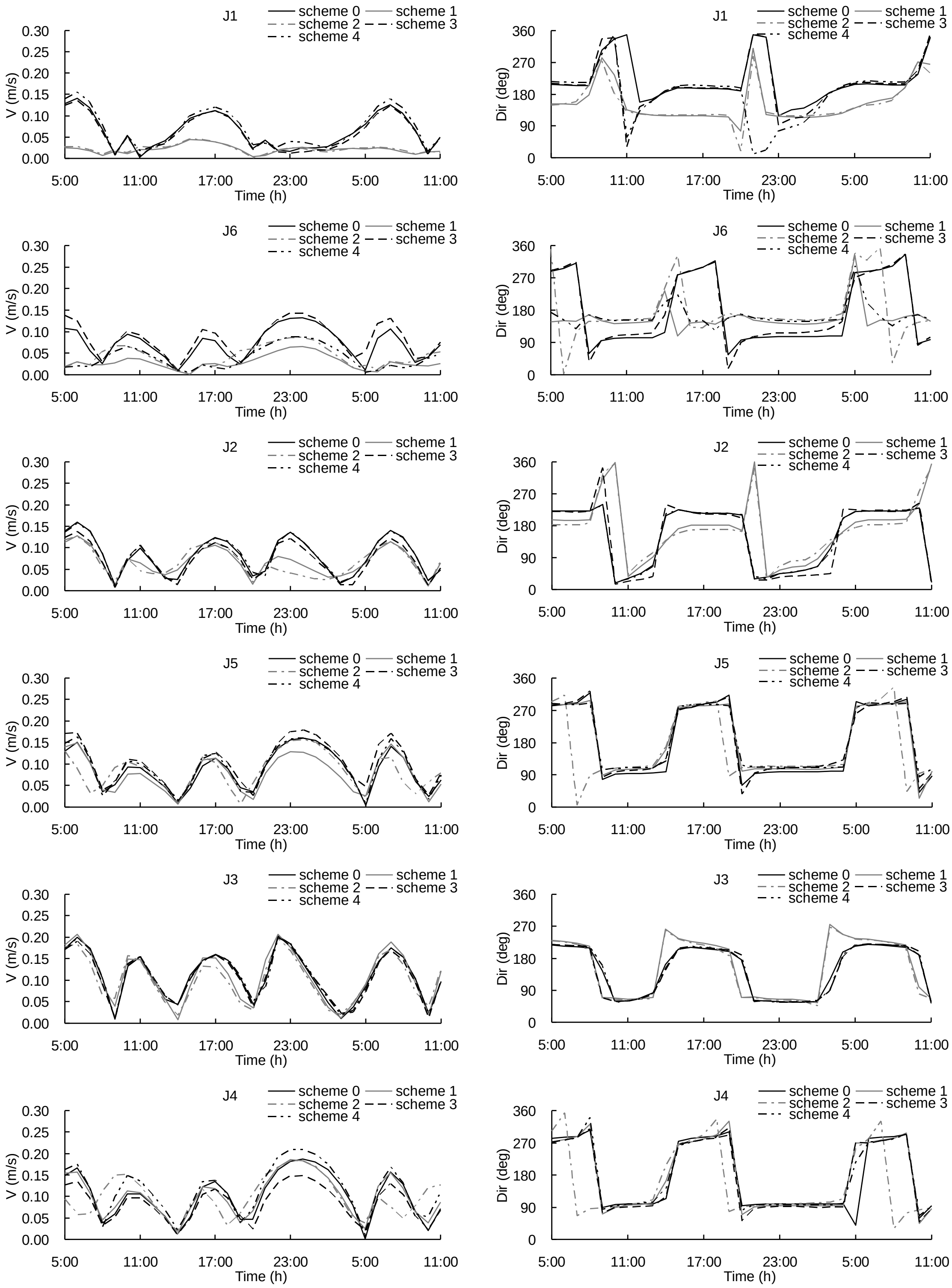


Figure 13. Comparison of tidal current velocity magnitude and direction of observation points J1 to J6 in scheme 0 to 4.

Table 1 and Table 2 show the mean flood and ebb tidal current velocities at representative points under scheme 0 to 4, respectively. Table 3 and Table 4 show the peak flood and ebb tidal current velocities of these points. The tidal current velocity between the submerged breakwaters reduces, for example, the tidal current velocity of O2 and O4 in scheme 1 and scheme 3 and the tidal current velocity of S3 in scheme 2. In scheme 4, the tidal current velocities near the east jetty namely O5 and S5 increase slightly. The direction of tidal current velocity of the points in the submerged breakwater area changes very little in scheme 1 to 4 compared to the natural situation (scheme 0). The tidal current velocity in the nearshore area under scheme 1 and scheme 2 reduces compared to scheme 0. The value of N1 and N9, which locate at the headlands, reduce most sharply. The rate of increase of the tidal current velocity of N9, which is near the east headland, reaches 28% under scheme 3. Compared to scheme 1, it’s easy to find out that the construction of the east jetty protects the West Beach efficiently. Compared to scheme 4, in which the tidal current velocity of N9 reduces most, the protect range of the east jetty is limited and it doesn’t work well without other structures (eg. submerged breakwater).

Table 1. Mean flood tidal current velocities at representative points under scheme 0 to 4

spot	scheme0	scheme1		scheme2		scheme3		scheme4	
	V(m/s)	V(m/s)	Δ(%)	V(m/s)	Δ(%)	V(m/s)	Δ(%)	V(m/s)	Δ(%)
N1	0.032	0.012	-61.49	0.011	-66.74	0.035	8.84	0.044	36.54
N2	0.051	0.042	-18.65	0.033	-34.95	0.047	-7.74	0.052	2.20
N3	0.052	0.051	-3.42	0.044	-15.96	0.064	22.88	0.057	8.12
N4	0.054	0.053	-1.41	0.044	-18.78	0.047	-13.87	0.052	-4.09
N5	0.046	0.040	-13.10	0.041	-10.93	0.045	-3.75	0.046	0.11
N6	0.057	0.053	-7.61	0.041	-27.65	0.043	-24.88	0.046	-18.66
N7	0.045	0.041	-7.91	0.035	-22.15	0.037	-17.61	0.036	-20.29
N8	0.041	0.045	8.87	0.016	-60.59	0.039	-5.45	0.031	-23.87
N9	0.025	0.019	-24.62	0.013	-49.15	0.032	28.52	0.022	-10.79
O1(S1)	0.086(0.077)	0.104	20.93	0.064	-16.88	0.109	26.74	0.086(0.077)	0.00(0.00)
O2(S2)	0.088(0.080)	0.066	-25.00	0.079	-1.25	0.071	-19.32	0.087(0.081)	-1.14(1.25)
O3(S3)	0.069(0.078)	0.063	-8.70	0.068	-12.82	0.069	0.00	0.07(0.077)	1.45(-1.28)
O4(S4)	0.073(0.072)	0.058	-20.55	0.070	-2.78	0.062	-15.07	0.071(0.072)	-2.74(0.00)
O5(S5)	0.064(0.069)	0.074	15.63	0.067	-2.90	0.059	-7.81	0.064(0.073)	0.00(5.80)

Table 2. Mean ebb tidal current velocities at representative points under scheme 0 to 4

spot	scheme0	scheme1		scheme2		scheme3		scheme4	
	V(m/s)	V(m/s)	Δ(%)	V(m/s)	Δ(%)	V(m/s)	Δ(%)	V(m/s)	Δ(%)
N1	0.018	0.008	-55.56	0.008	-55.56	0.017	-5.56	0.018	0.00
N2	0.039	0.028	-28.21	0.029	-25.64	0.035	-10.26	0.039	0.00
N3	0.046	0.049	6.52	0.044	-4.35	0.052	13.04	0.048	4.35
N4	0.053	0.049	-7.55	0.053	0.00	0.049	-7.55	0.050	-5.66
N5	0.042	0.049	16.67	0.038	-9.52	0.052	23.81	0.044	4.76
N6	0.050	0.048	-4.00	0.048	-4.00	0.044	-12.00	0.049	-2.00
N7	0.049	0.050	2.04	0.050	2.04	0.043	-12.24	0.047	-4.08
N8	0.059	0.053	-10.17	0.044	-25.42	0.057	-3.39	0.050	-15.25
N9	0.041	0.029	-29.27	0.048	17.07	0.052	26.83	0.037	-9.76
O1(S1)	0.064(0.074)	0.082	28.13	0.079	6.76	0.084	31.25	0.062(0.075)	-3.13(1.35)
O2(S2)	0.070(0.057)	0.058	-17.14	0.070	22.81	0.063	-10.00	0.071(0.058)	1.43(1.75)
O3(S3)	0.061(0.067)	0.062	1.64	0.067	0.00	0.068	11.48	0.063(0.068)	3.28(1.49)
O4(S4)	0.071(0.073)	0.054	-23.94	0.071	-2.74	0.060	-15.49	0.073(0.076)	2.82(4.11)
O5(S5)	0.070(0.079)	0.073	4.29	0.074	-6.33	0.065	-7.14	0.072(0.083)	2.86(5.06)

Table 3. Peak flood tidal current velocities at representative points under scheme 0 to 4

spot	scheme0	scheme1		scheme2		scheme3		scheme4	
	V(m/s)	V(m/s)	Δ(%)	V(m/s)	Δ(%)	V(m/s)	Δ(%)	V(m/s)	Δ(%)
T1	0.077	0.079	2.60	0.073	-5.19	0.074	-3.90	0.078	1.30
T2	0.100	0.077	-23.00	0.092	-8.00	0.102	2.00	0.087	-13.00
N1	0.051	0.022	-56.86	0.021	-58.82	0.057	11.76	0.067	31.37
N2	0.089	0.069	-22.47	0.059	-33.71	0.092	3.37	0.090	1.12
N3	0.096	0.089	-7.29	0.085	-11.46	0.105	9.37	0.099	3.13
N4	0.099	0.090	-9.09	0.095	-4.04	0.087	-12.12	0.091	-8.08
N5	0.075	0.074	-1.33	0.072	-4.00	0.079	5.33	0.074	-1.33
N6	0.081	0.077	-4.94	0.071	-12.35	0.070	-13.58	0.072	-11.11
N7	0.071	0.064	-9.86	0.060	-15.49	0.064	-9.86	0.055	-22.54
N8	0.060	0.067	11.67	0.036	-40.00	0.069	15.00	0.046	-23.33
N9	0.032	0.041	28.13	0.040	25.00	0.046	43.75	0.041	28.13
O1(S1)	0.136(0.136)	0.180	32.35	0.116	-14.71	0.186	36.76	0.134(0.135)	-1.47(-0.74)
O2(S2)	0.138(0.126)	0.103	-25.36	0.132	4.76	0.109	-21.01	0.136(0.124)	-1.45(-1.59)
O3(S3)	0.114(0.123)	0.107	-6.14	0.112	-8.94	0.118	3.51	0.114(0.121)	0.00(-1.63)
O4(S4)	0.121(0.120)	0.098	-19.01	0.120	0.00	0.105	-13.22	0.117(0.119)	-3.31(-0.83)
O5(S5)	0.112(0.120)	0.130	16.07	0.115	-4.17	0.091	-18.75	0.109(0.125)	-2.68(4.17)

Table 4. Peak ebb tidal current velocities at representative points under scheme 0 to 4

spot	scheme0	scheme1		scheme2		scheme3		scheme4	
	V(m/s)	V(m/s)	Δ(%)	V(m/s)	Δ(%)	V(m/s)	Δ(%)	V(m/s)	Δ(%)
N1	0.019	0.014	-26.32	0.018	-5.26	0.018	-5.26	0.019	0.00
N2	0.057	0.044	-22.81	0.047	-17.54	0.059	3.51	0.058	1.75
N3	0.089	0.094	5.62	0.076	-14.61	0.096	7.87	0.092	3.37
N4	0.100	0.097	-3.00	0.093	-7.00	0.083	-17.00	0.092	-8.00
N5	0.073	0.078	6.85	0.067	-8.22	0.081	10.96	0.076	4.11
N6	0.095	0.092	-3.16	0.079	-16.84	0.079	-16.84	0.080	-15.79
N7	0.087	0.094	8.05	0.079	-9.20	0.073	-16.09	0.076	-12.64
N8	0.094	0.094	0.00	0.065	-30.85	0.102	8.51	0.078	-17.02
N9	0.063	0.050	-20.63	0.064	1.59	0.090	42.86	0.055	-12.70
O1(S1)	0.136(0.139)	0.175	28.68	0.143	2.88	0.176	29.41	0.131(0.142)	-3.68(2.16)
O2(S2)	0.154(0.119)	0.122	-20.78	0.142	19.33	0.127	-17.53	0.153(0.122)	-0.65(2.52)
O3(S3)	0.127(0.144)	0.125	-1.57	0.135	-6.25	0.130	2.36	0.127(0.139)	0.00 (-3.47)
O4(S4)	0.142(0.141)	0.105	-26.06	0.135	-4.26	0.112	-21.13	0.138(0.141)	-2.82(0.00)
O5(S5)	0.129(0.145)	0.139	7.75	0.131	-9.66	0.118	-8.53	0.125(0.144)	-3.10(-0.69)

CONCLUDING REMARKS

A two-dimensional numerical tidal current model is developed to simulate the tidal current in West Beach of Beidaihe at first. Then the comparison is made among four nourishment schemes. The research shows that: (1) the east jetty plays a key role in the protection of West Beach; (2) it is feasible to protect and enlarge the West Beach by beach nourishment along with jetties and submerged breakwaters; and (3) after nourishment project, the tidal current velocity reduces obviously in the near shore area, which can protect the West Beach.

This paper is part of the preliminary research achievements on beach nourishment projects in Beidaihe, China. This preliminary study contents contain the sub-main hydrodynamic force of tidal current, which is discussed in this paper, the shoreline change prediction based on one-line theory, whose partial achievement has already been published (Kuang et al., 2010) and the interaction of all these physical factors. Further study on the beach profile morphology changes by the main hydrodynamic force of wave will be issued soon.

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