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Study on the Influence of the National Deep-sea Center Engineering on Hydrodynamics by Numerical Model

Xing Wang[1,2], Ying Liu[1,2,*], Xiren Jiang[1,2], Wenpeng Song[1,2] and Baolei Li[1]
[1] North China Sea Environmental Monitoring Center, State Oceanic Administration,
No.22, Fushun Road, Qingdao, China
[2] Shandong Provincial Key Laboratory of Marine Ecology and Environment & Disaster Prevention and Mitigation, China
*Corresponding author

***Abstract*—A high resolution numerical model of Laoshan Bay is established in order to study the Influence of the National Deep-sea Center Engineering on Hydrodynamics. The model is verified by the observation data. The results show that although the hydrodynamic characteristics of the Laoshan Bay did not change, the tide currents near the project change obviously after the construction of the project, and the hydrodynamic environment in the cove significant reduced.**

Keywords—hydrodynamic; National Deep-sea Center; Laoshan Bay; numerical model; FVCOM

I. INTRODUCTON

Qingdao is located in the east coast of China. Surrounded by the sea on three sides, Jiaozhou Bay on west side, Yellow Sea on south side and Laoshan Bay on the east side. It's famous for marine tourism, port and marine science and technology industry. Many Marine scientific research and management organizations in China are located in Qingdao, and National Deep-sea Center is the latest one.

FIGURE I. GENERAL PLANNING OF THE NATIONAL DEEP-SEA CENTER

National Deep-sea Center is located on the east coast of Qingdao, facing the Laoshan Bay, which is called the blue silicon valley of China. It's the homeport of “Jiao Long” bathyscaphe, it will gather national deep-sea scientific research personnel, and also will become the base of deep-sea equipment and industries [1].

The general planning of NDC (National Deep-sea Center) is shown in Fig. 1, and it shows the design of the wharf and breakwater of this project, which is shown in detail by Fig. 2. Surrounded by a cove in Laoshan Bay, the oceaneering will change the current in the cove, and may influence on hydrodynamics of the Laoshan bay. A high resolution 3D numerical model is established in order to represent the main dynamics and to study the influence of the project NDC on hydrodynamics [2].

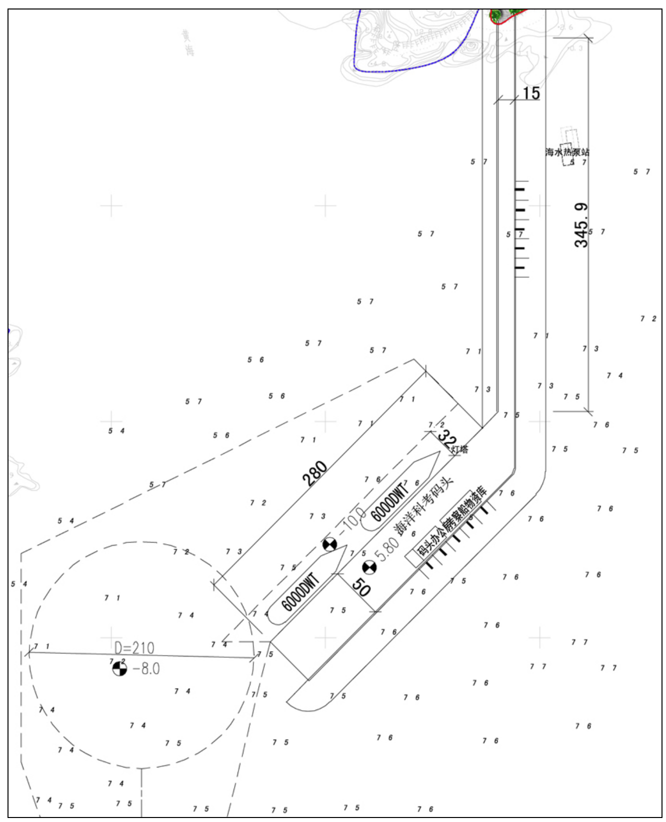

FIGURE II. 2 DESIGN OF THE WHARF AND BREAKWATER

II. NUMERICAL MODEL

The numerical model used in this study is FVCOM: a prognostic, unstructured grid, finite-volume, free-surface, three-dimensional (3D) primitive equation coastal ocean and estuarine model developed by Chen et al. [3]. FVCOM utilizes a modified Mellor and Yamada level 2.5 (MY-2.5) and Smagorinsky turbulent closure schemes for the default setup of vertical and horizontal mixing, respectively [4]. Unlike existing coastal finite-difference and finite-element models, FVCOM solves the hydrostatic primitive equations by calculating fluxes resulting from a discretization of the integral form of these equations on an unstructured triangular mesh. A state-of-the-art-transformation is used to represent the vertical coordinate. This approach not only takes advantage of finite-element methods for grid flexibility and finite-difference methods for numerical efficiency but also provides a good numerical representation of momentum, mass, salt, and heat conservation. The detailed description of FVCOM is given in user manual written by Chen et al. [5].

A. Equations

Under σ coordinates:

$$\frac{\partial uD}{\partial t}+\frac{\partial u^2D}{\partial x}+\frac{\partial uvD}{\partial y}+\frac{\partial u\omega}{\partial\sigma}-fvD=-D\frac{\partial}{\partial x}(g\eta+p_{\mathrm{atm}})-D\int_\sigma^0(D\frac{\partial\rho}{\partial x}-\sigma\frac{\partial D}{\partial x}\frac{\partial\rho}{\partial\sigma})\mathrm{d}\sigma+\frac{\partial\tau_x}{\partial\sigma}$$

$$\frac{\partial vD}{\partial t}+\frac{\partial uvD}{\partial x}+\frac{\partial v^2D}{\partial y}+\frac{\partial v\omega}{\partial\sigma}+fuD=-D\frac{\partial}{\partial y}(g\eta+p_{atm})-D\int_\sigma^0(\frac{\partial\rho}{\partial y}-\sigma\frac{\partial D}{\partial y}\frac{\partial\rho}{\partial\sigma})\mathrm{d}\sigma+\frac{\partial\tau_y}{\partial\sigma}$$

$$\frac{\partial P}{\partial z}=-\rho g$$

$$\frac{\partial Du}{\partial x}+\frac{\partial Dv}{\partial y}+\frac{\partial\omega}{\partial\sigma}+\frac{\partial\eta}{\partial t}=0$$

where u, v, w are the components of the velocity vector in the x, y, σ directions respectively; D is the water depth; η is the free surface; ρ is the specific mass; P is the pressure; f is the Coriolis parameter; g is the gravity acceleration; g is the free surface; P_{atm} is the atmospheric pressure; τ_x, τ_y are the bottom friction term in x, y directions respectively.

B. Grid Resolution

The computational domain is: East Longitude from 120.64° to 120.88°, North Latitude from 36.21° to 36.47°. The horizontal grid mesh is shown in Fig. 3 and Fig. 4, the max resolution is 10m. Different colors represent different depths in the figures, and the vertical grid is divided into 6 Sigma layers.

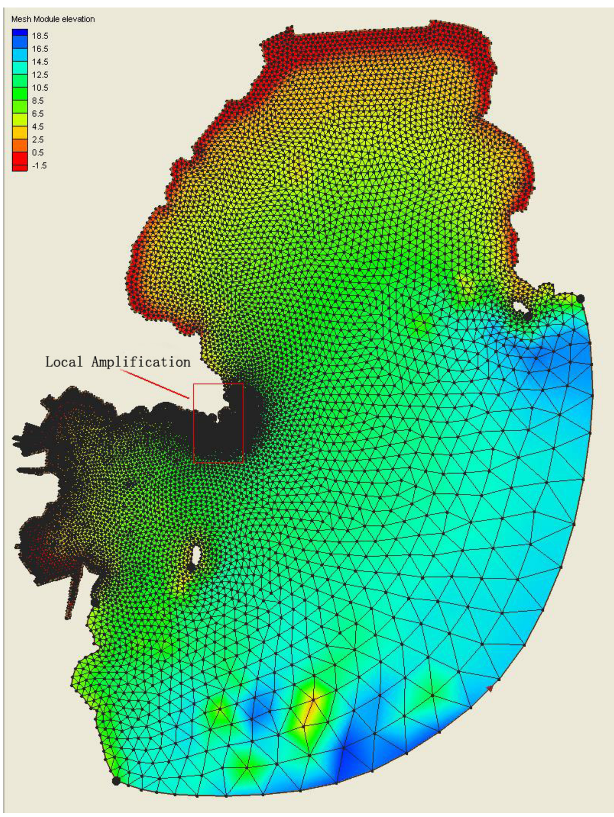

FIGURE III. CONFIGURATION OF THE COMPUTATIONAL MESH

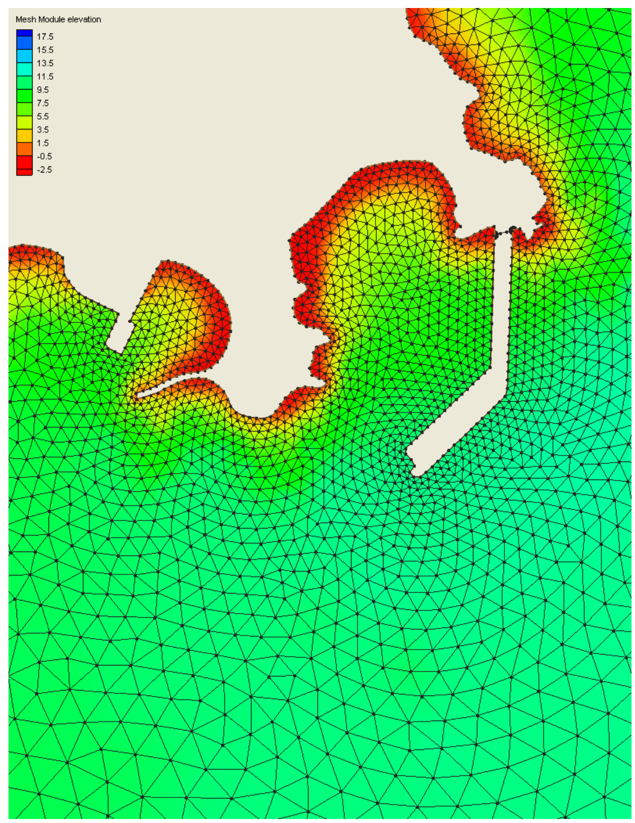

FIGURE IV. CONFIGURATION OF THE MESH GRID NEAR NDC

C. Boundary and Initial Conditions

1) Vertical boundary

$$\omega(0)=\omega(-1)=0$$

$$\frac{K_M}{D}\left(\frac{\partial U}{\partial\sigma},\frac{\partial V}{\partial\sigma}\right)=-\left(<wu(0)>,<wv(0)>\right)\qquad\sigma\to 0$$

$$\frac{K_M}{D}\left(\frac{\partial U}{\partial\sigma},\frac{\partial V}{\partial\sigma}\right)=C_Z(U^2+V^2)^{1/2}(U,V)\qquad\sigma\to -1$$

where $C_Z = MAX\left[\frac{K^2}{\left[\ln\{(1+\sigma_{kb-1})H/z_0\}\right]^2}, 0.0025\right]$

$K = 0.4$ is the Karman constant

2) *Horizontal boundary*

The normal velocity at the closed boundary is zero.

The model is forced with the four main tidal components in the area M_2, S_2, O_1, k_1, extracted from the Bohai and Yellow Sea hydrodynamic model's results. The method of water surface elevation series imposed in the open ocean boundary in order to represent the tidal waves is as follows:

$$\zeta = \sum_{i=1} \{ f_i H_i \cos[\sigma_i t + (V_{0i} + V_i) - G_I] \}$$

where f_i, σ_i are the cross factor and angular velocity of the ith tidal component（M_2, S_2, O_1, K_1）respectively, H_i, G_i are the amplitude and angle of the tidal harmonic constant respectively, $V_{0i} + V_i$ is the tidal argument [6]。

3) *Initial conditions*

The initial condition in this model is a cold start solution, the formula is as follows:

$\zeta\ (x, y, t)_{t=0} = 0$

$h\ (x, y, t)_{t=0} = h_0\ (x, y)$

$u\ (x, y, t)_{t=0} = 0$

$v\ (x, y, t)_{t=0} = 0$

$w\ (x, y, t)_{t=0} = 0$

III. ANALYSIS AND MODEL VALIDATION

A. *Model Validation*

This model is verified by the current observation data at the two stations in the study area in 2006, station A (120°44′25″E, 36°19′18″N) was located at about 1km southeast from the project, and station B(120°41′58″E, 36°17′03″N) was located at about 5km southwest from the project. Observation time was from 10a.m. in November 29th to 11:30a.m. in November 30th, observation interval was half an hour.

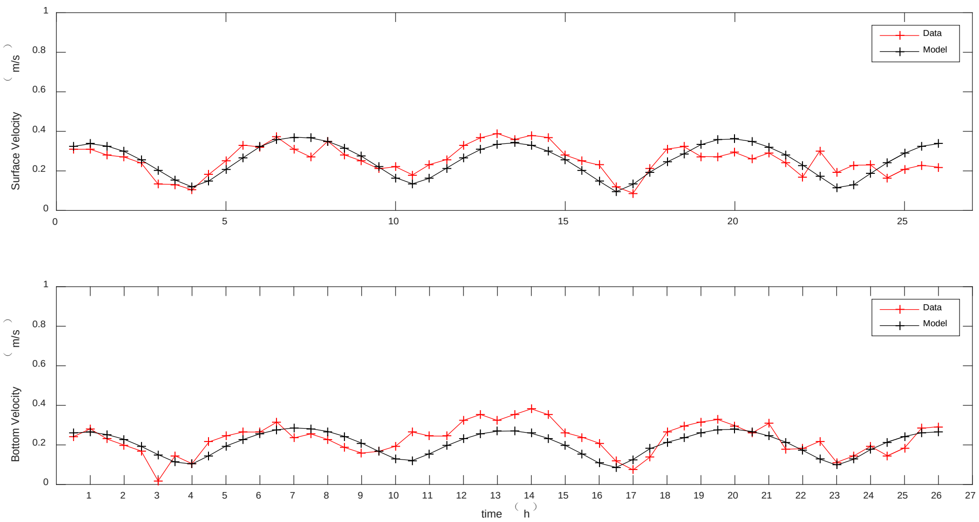

FIGURE V. VERIFICATION OF CURRENT VELOCITY AT STATION A

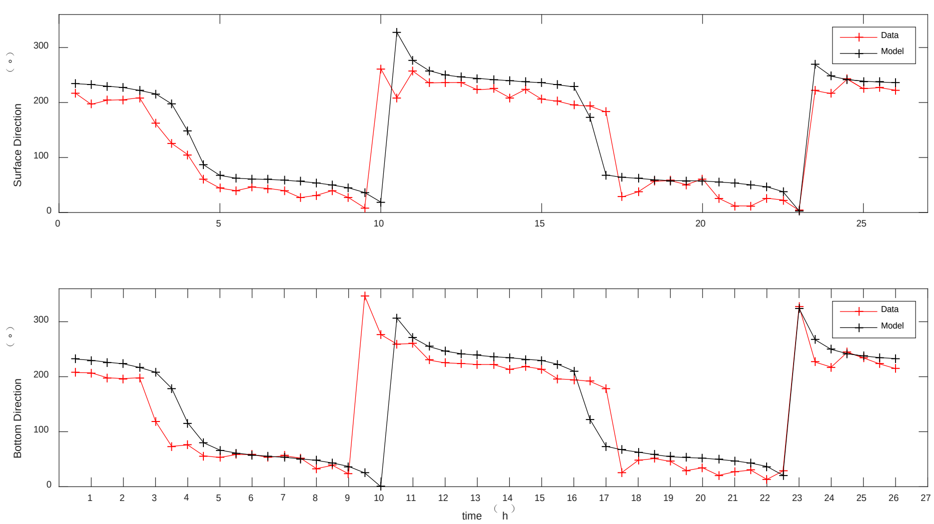

FIGURE VI. VERIFICATION OF CURRENT DIRECTION AT STATION A

Fig. 5 to Fig. 8 show the comparison between the modeled and observed current time series for all stations. There is a general agreement in current velocity and directions between the modeled and the observed. This reflects that the hydrodynamic model predicted is reliable [7].

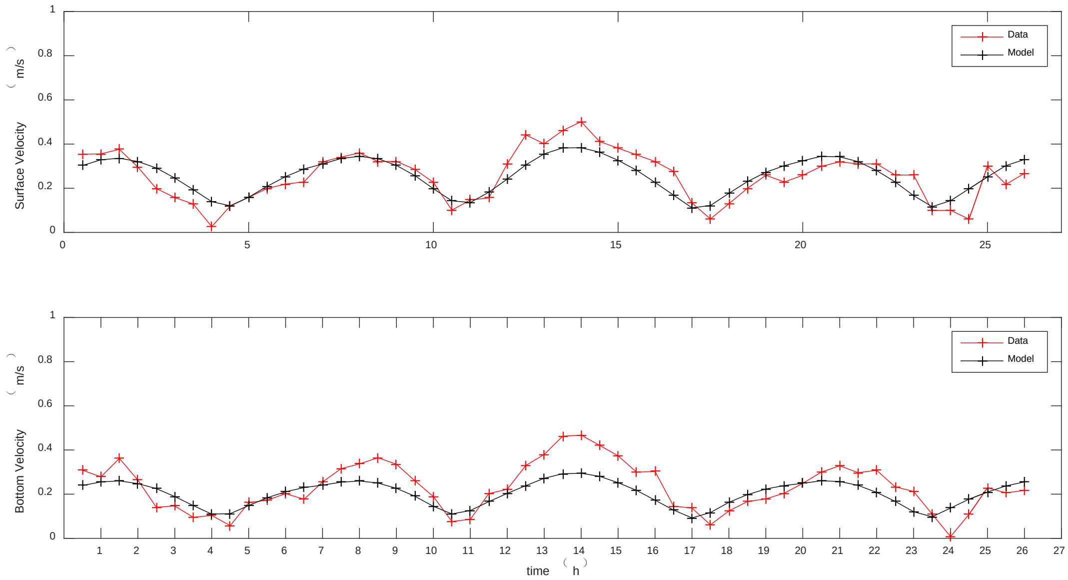

FIGURE VII. VERIFICATION OF CURRENT VELOCITY AT STATION B

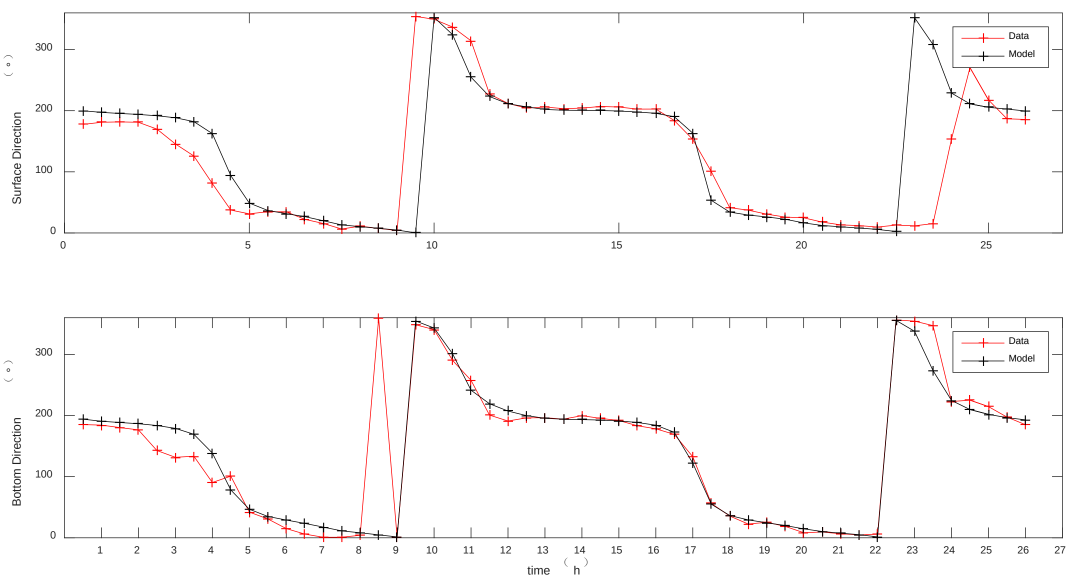

FIGURE VIII. VERIFICATION OF CURRENT DIRECTION AT STATION B

B. *Current Analysis*

The validated model helped to study the hydrodynamic characteristic in Laoshan Bay. The local surface flood currents and ebb currents near the engineering are presented in Fig. 9 and Fig. 10 respectively, while the surface flood currents and ebb currents in study area are presented in Fig. 11 and Fig. 12 respectively.

The model results show: the surface velocity is generally 10%~30% larger than the bottom current in Laoshan Bay, the difference between surface current directions and bottom current directions are small. The velocity of flood is slightly larger than the ebb's, whereas the duration between the twoare on the opposite trends. The current velocity is larger in the southeast of Laoshan Bay at flood tide, the maximum velocity can reach 0.8m/s; and the currents near the project from west turn to the southwest, the maximum velocity can reach 0.6 m/s. The maximum current velocity is 0.7m/s at ebb tide, and the currents near the project from northeast turn to the east, the maximum velocity can reach 0.5 m/s. The currents direction in the study area is almost the opposite while the flood tide and the ebb tide.

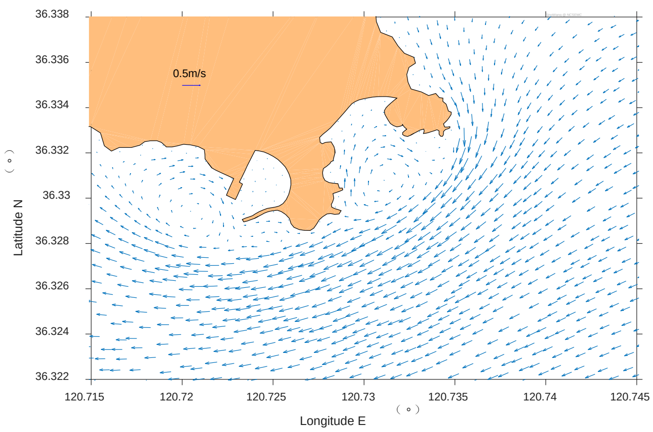

FIGURE IX. SURFACE FLOOD CURRENTS NEAR NDC

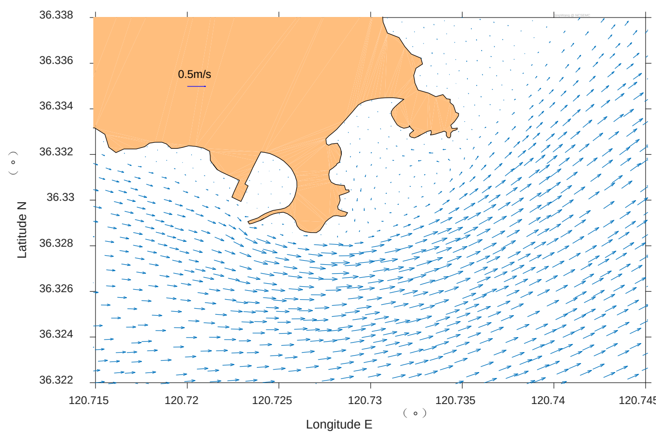

FIGURE X. SURFACE EBB CURRENTS NEAR NDC

IV. INFLUENCE OF ENGINEERING ON HYDRODYNAMIC

A. *Current Field*

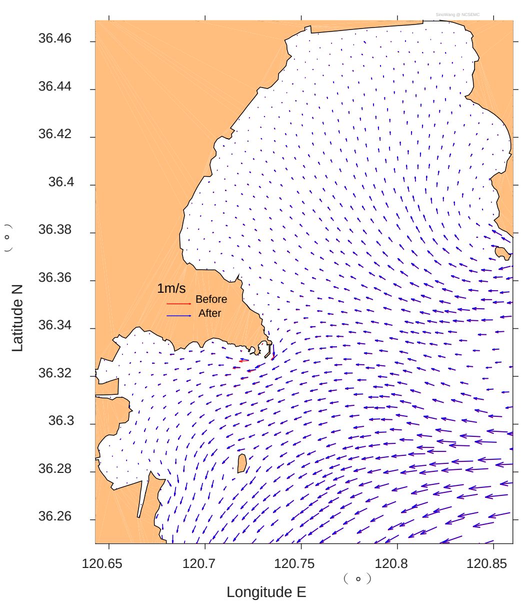

FIGURE XI. COMPARISON OF SURFACE FLOOD CURRENTS IN LAOSHAN BAY

Through the analysis of model results, the hydrodynamic characteristics of the Laoshan Bay did not change mainly. The surface flood current field and ebb current field of study area are presented in Fig. 11 and Fig. 12 respectively. The red arrows indicate the currents before the construction of project NDC, and the blues indicate the currents after the construction of project NDC. The marine engineering shows little influence on the current field of the large study area.

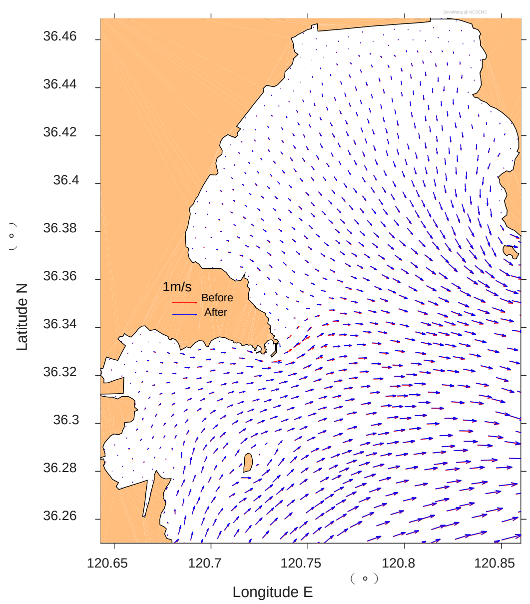

FIGURE XII. COMPARISON OF SURFACE EBB CURRENTS IN LAOSHAN BAY

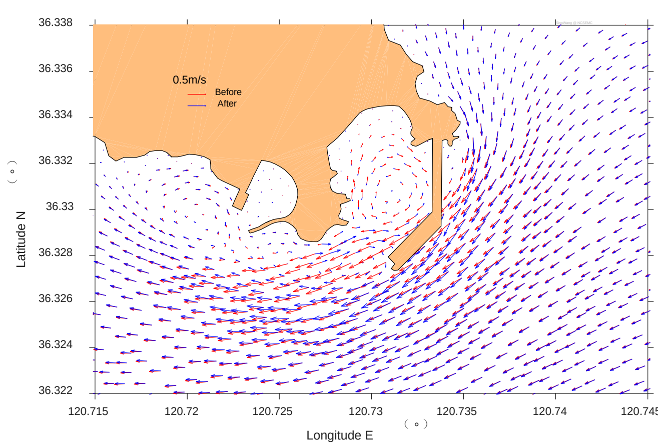

FIGURE XIII. COMPARISON OF SURFACE FLOOD CURRENTS NEAR NDC

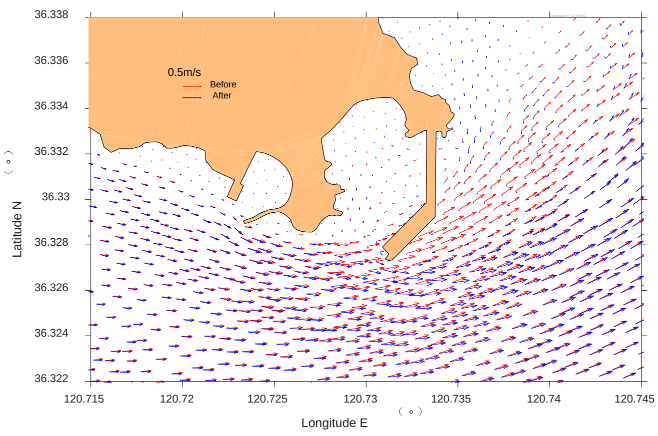

FIGURE XIV. COMPARISON OF SURFACE EBB CURRENTS NEAR NDC

The local surface flood current field and ebb current field near the project are presented in Fig. 13 and Fig. 14 respectively. Those show the current field near project changes significantly, but only within a range of 2km around the project. Due to the influence of marine engineering, the current changes more obviously in the west area of the project at flood tide while it changes more obviously in the east area of the project at ebb tide. The vortex intensity is much reduced and its direction is reversed in the cove at flood tide.

B. *Current of Representative Points*

In order to study the characteristics of the current field near NDC and the hydrodynamic changes before and after the construction of the project, 10 representative points were chose in the sea area near the breakwater and wharf [8]. The locations of 10 points are show in Fig. 15.

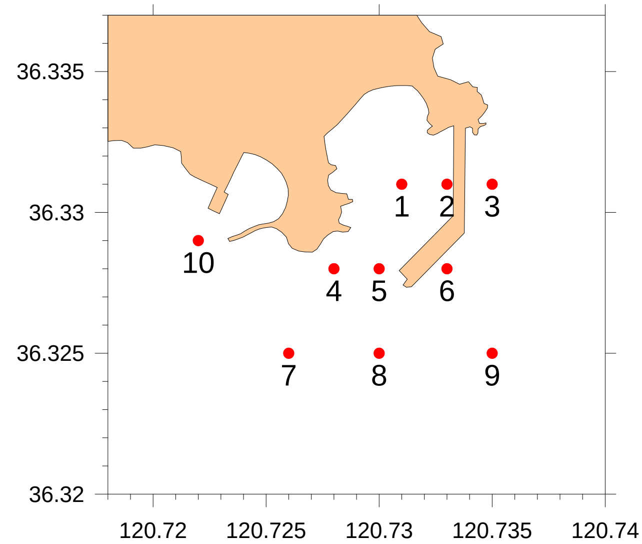

FIGURE XV. LOCATIONS OF REPRESENTATIVE POINTS

The hydrodynamic environment in the cove (1#,2#,4#,5#) is much reduced, while outside of the cove, most points currents are enhanced at flood tide and reduced at ebb tide. See table 1 and table 2 for more details.

The abbreviations in the table are as follows, FD: flood tide, EB: ebb tide, LY: layer, PN: point, BN: before the construction of NDC, AN: after the construction of NDC, SF: surface, BM: bottom, CV: current velocity, CD: current direction, CC: current change, SV: surface velocity, BV: bottom velocity, SD: surface current direction, BD: bottom current direction, AB: absolute, RP: relative percentage.

TABLE I. VARIATIONS OF CURRENT VELOCITY (CM/S) AND DIRECTION (°) AT FLOOD TIDE

FD	LYr	PN	1	2	3	4	5	6	7	8	9	10
BN	SF	CV	2.2	8.4	44.0	36.2	40.9	41.3	38.3	36.7	33.4	11.7
		CD	53	162	216	245	245	238	256	249	244	177
	BM	CV	2.7	6.7	37.5	32.1	31.1	33.8	28.9	28.8	27.3	12.3
		CD	45	187	225	246	252	243	260	250	241	184
AN	SF	CV	3.9	5.7	29.0	23.8	8.0	48.8	48.0	46.4	37.0	7.4
		CD	257	359	204	64	165	224	266	249	239	185
	BM	CV	4.8	5.6	28.0	21.6	8.6	43.0	34.0	37.2	31.1	4.8
		CD	272	341	212	58	160	229	276	256	237	192
CC	SV	AB	1.7	-2.7	-15	-12.4	-32.9	7.5	9.7	9.7	3.6	-4.3
		RP	77%	32%	34%	34%	80%	18%	25%	26%	11%	37%
	SD		204	197	-12	-181	-80	-14	10	0	-5	8
	BV	AB	2.1	-1.1	-9.5	-10.5	-22.5	9.2	5.1	8.4	3.8	-7.5
		RP	78%	16%	25%	33%	72%	27%	18%	29%	14%	61%
	BD		227	154	-13	-188	-92	-14	16	6	-4	8

TABLE II. VARIATIONS OF CURRENT VELOCITY (CM/S) AND DIRECTION (°) AT EBB TIDE

EB	LYr	PN	1	2	3	4	5	6	7	8	9	10
BN	SF	CV	3.2	2.3	14.1	32.3	35.0	47.1	37.1	39.9	38.5	21.6
		CD	229	162	43	96	80	71	89	79	70	121
	BM	CV	4.1	2.2	14.0	27.0	32.2	34.7	29.7	31.3	29.7	16.4
		CD	234	241	39	91	69	60	85	72	63	129
AN	SF	CV	2.8	1.0	6.8	12.3	4.5	4.3	32.9	38.0	43.2	19.3
		CD	244	343	214	111	135	230	95	92	80	122
	BM	CV	2.8	0.6	3.4	11.3	6.0	3.9	26.3	30.5	34.3	14.5
		CD	236	267	216	107	105	224	91	87	73	129
CC	SV	AB	-0.4	-1.3	-7.3	-20	-30.5	-42.8	-4.2	-1.9	4.7	-2.3
		RP	13%	57%	52%	62%	87%	91%	11%	5%	12%	11%
	SD		15	181	171	15	55	159	6	13	10	1
	BV	AB	-1.3	-1.6	-10.6	-15.7	-26.2	-30.8	-3.4	-0.8	4.6	-1.9
		RP	32%	73%	76%	58%	81%	89%	11%	3%	15%	12%
	BD		2	26	177	16	36	164	6	15	10	0

Flood , On the surface layer, currents velocity on locations of 2#, 3#, 4#, 5# and 10# is decreased, while it increased on 1#, 6#, 7#, 8# and 9#. Currents change more than 10cm/s on 3# 4# and 5#, and the maximum reduction is 32.9cm/s on 5#. On the bottom layer, similarly to the surface layer, currents on 2#, 3#, 4#, 5# and 10# are decreased, and increased on the last 5 points. The current variation ranges are more than 10cm/s on 4# and 5#, and the maximum reduction is 22.5cm/s on 5#.

Ebb , On the surface layer, current velocity increased on locations of 9#, while it decreased on other 9 points. Currents decrease more than 10cm/s on 4#, 5# and 6#, and the maximum reduction is 42.8cm/s on 6#. On the bottom layer, similar to surface, current on 9# is increased, and others 9 points are decreased, currents on 3#, 4#, 5# and 6# decreased over 10cm/s, and the maximum reduction is 30.8cm/s on 6#.

V. CONCLUSION

A high resolution 3D numerical model is established to study the influence of NDC on hydrodynamics. Based on the comparison of the hydrodynamic simulation results before and after the construction of the marine engineering, the conclusions are as follow.

The hydrodynamic characteristics of the Laoshan Bay did not change mainly after the construction of the project NDC. The marine engineering shows little influence on the current field of the large study area, but the local current field near the project changes obviously.

The construction of National Deep-sea Center shows a significant influence on the local current field. The tide currents near the project change obviously, the maximum current velocity changes more than 40cm/s, and the hydrodynamic environment in the cove reduced significantly.

The change of hydrodynamic force will lead to the change of sediment erosion and accumulation. The northeastern sand beach and the northern pebble beach in the cove may be damaged in long term influence of the project. We should pay more attention to the marine environment near this project in the future.

ACKNOWLEDGMENT

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