Sensitivity analysis of wave direction in wave numerical model

Liu zhen1,2, CHEN Han-bao2*, Xu Ya-nan2, Cheng Yong-zhou1, Zhao-xu2
1Changsha University of Technology, changsha, Hunan,China
2Tianjin Water Transport Engineering Research Institute, tian jin, China
*Corresponding author’s e-mail: chenhanbao@tiwte.ac.cn

Abstract: The sensitivity analysis of wave direction is carried out for three cases, namely, the excavation of outer channel, surge and typhoon in the shield port. The results show that for the sheltered port with excavated outer channel, the wave direction sensitivity near the entrance is strong, and the one-way wave sensitivity is stronger than the multi-directional wave, so it is suggested that the main wave direction analysis should be densified to 32 azimuth angle; for the swell sea area, when its long-period characteristics lead to the wave near shore transmission process, the greater the wave direction change, the more concentrated the wave direction perpendicular to the shoreline, so the wave direction of the swell sea area is divided. For the influence of typhoon, the wave direction should consider the possibility of the change of the strong typhoon path, and for the strong wave direction, it is suggested to be increased to the four or eight azimuth.

1. Introduction
In natural coastal construction projects, including ports, artificial islands, revetments, etc., waves are one of the important marine hydrodynamic forces and are often the most destructive. Wave height, period, wave direction, wave spectrum, etc. are many elements describing wave characteristics [1-2]. Wave direction and the protective effect of breakwaters, wave force, wave climbing and wave crossing are closely related to the effect and safety of coastal engineering [3]-[4], so it is very important to accurately grasp the incident direction of the wave.

There are many ways to express the wave direction. Generally, the wave direction of the open sea is divided into sixteen azimuth angles and 22.5° equal divisions. When calculating design waves with different return periods, if the frequency of the typhoon is not enough, the direction will be affected. It is merged into eight directions, even four directions. When extreme or sudden weather is the controlling wave element of coastal waves, the wave field should be simulated in the whole process, and the wave direction will also change with time and space. Due to the complexity of wave propagation and deformation [5-8], deep water nearshore and engineering wave simulations will use different models. At this time, the wave direction will undergo some generalization processing, and sometimes small-scale models will re-use the sixteen azimuth angle [9]. A better method is to use generalized large-scale simulation wave direction results on the boundary during small-scale simulation. At present, whether it is large-scale or near-shore engineering simulation, multi-directional random waves with clear direction distribution are rarely used.

Sensitivity analysis refers to the study of relevant factors from the perspective of quantitative analysis, which refers to an uncertain analysis technique for the degree of influence on a certain key index or a group of key indicators when a certain change in wave direction occurs. The essence is to explain the law of the impact of these factors on key indicators by changing the values of the relevant
variables one by one. When the coastal sand transport is significant, the wave direction is directly related to the direction of the sand transport, and the wave direction will directly affect the port entrance. The direction of the wave is a sensitive factor.

For the shielded port that excavated the outer channel, the MIKE21-BW\textsuperscript{[10-11]} wave mathematical model is used to select typical projects to simulate and analyze the wave direction sensitivity, and to compare the different lengths of the breakwater. The wave direction change of the offshore wave refraction under the action of the swell, using the SWAN \textsuperscript{[12-13]} wave mathematical model, takes a generalized topography, and simulates the change of the wave direction from the deep water area to the nearshore wave.

When a typhoon passes through the border, the wind speed is higher, and the typhoon waves caused by it are more likely to cause larger marine disasters. The time and location of the typhoon’s landing are difficult to predict. The typhoon movement path is very random. The wave height influence is also different. Tang S.T and Ran X.J \textsuperscript{[14]} translated the "Kanu" path eastward and constructed 8 different Typhoon path, study the wave height distribution of the Yangtze River estuary under different typhoon paths. When the typhoon center position and the typhoon movement direction are different, the maximum wind speed The location of the typhoon center and the area where the effective wave height appears will show a big difference. Regarding the influence of the typhoon path in the wave direction, the paper takes the "Mangkhut" typhoon path and four hypothetical typhoon paths as examples to obtain the extreme wave heights of the nearshore survey points, and analyze the influence of path changes on the control wave direction and wave height.

2 Analysis of the influence of shielding port excavation on wave direction sensitivity

In order to obtain relatively calm waters, some coasts with strong wave dynamics often build sheltered ports with double embankments, which are connected to the open sea through the entrance channel. In order to protect the navigation water depth of ships, sheltered ports often pass through Dredging to get the harbor basin and channel.

The diffraction of waves and the refraction of waves by the channel slope are closely related to the direction of wave incidence. When the two factors are superimposed together, the higher the sensitivity and the more complicated it is. First take a representative project for simulation, and the layout is shown in Figure 1.

![Figure1. Typical project layout](image)

In the picture, the channel bottom elevation is -14m, and the short embankment is 206m long. The two lengths of the east embankment are calculated respectively. The lengths are 650m and 500m. The outer channel direction is 60 channel direction. The length and channel width are 45m. The entrance width is 166m. The wave height is uniformly HS=2m, and the period is also uniformly TS=10s. The unidirectional irregular wave JONSWAMP, the spectral crest factor $\gamma = 3.3$, simulates a wave train of 200 waves. The frequency spectrum of the multi-directional irregular wave is the same as that of the unidirectional irregular wave. The direction distribution takes the light-transmissive distribution $\cos \theta$ with $n=5$. The simulation adopts the BW wave mathematical model. The wave direction is encrypted on the basis of the hexadecimal azimuth angle, which is 4 times Density, that is, the direction division $\Delta \theta = 5.625^\circ$, and the outer channel is the reference, respectively taking $-5\Delta \theta$, $-4\Delta \theta$, $-3\Delta \theta$, $-2\Delta \theta$, $-1\Delta \theta$, $0$, $\Delta \theta$, $2\Delta \theta$, $3\Delta \theta$, $4\Delta \theta$, $5\Delta \theta$, a total of 11 incident angles, a total of 22
groups. Calculation points are shown in figure1.

Table 1 shows the calculated point wave height change value in the port from 28.125° to -28.125°. The unidirectional wave height change value is greater than the multidirectional wave action, and the directional sensitivity of the unidirectional wave is greater than the multidirectional wave action. When the length of breakwater is 500m, the wave height change value is greater than the length of 650m, and the sensitivity of the wave height in the harbor varies with the length of the breakwater. Table 2 shows the calculated point wave height changes in the harbor when the difference of 22.5° (28.125° to 5.625°) degrees is divided according to the conventional wave direction. When the direction division differs by 22.5°, the wave changes in the harbor vary greatly with angle, and the maximum change in wave height exceeds 30%, so the current 22.5° direction division is still insufficient.

### 3 Analysis of wave direction changes near shore under swell action

On the coast, the waves propagate toward the shore from the vertical coast, which is caused by wave refraction. Propagating from the open sea to the shore, the analysis of wave direction change is the inverse process of wave direction sensitivity, that is, a small change in the wave direction near the shore corresponds to a large change in the wave direction of the open sea.

Take a generalized topography, from -100m to -10m, the uniform bottom slope of the seabed is 1:1000, and the uniform bottom slope of the seabed from -10m to the shore is 1:500, and the trend of the depth contour is 113 degrees. See the calculation range and water depth topography Figure 4, the wave direction is from 5° to 85°, with an interval of 5°. Three effective periods of 10s, 12s, and 16s are simulated and calculated, and the number of groups is 51 groups. the change of wave direction is shown in Figure3.
From the calculation results of the wave direction changes near shore under the action of swells, due to wave refraction, the wave directions are concentrated in the direction perpendicular to the shoreline when the waves propagate toward the shore. When the period is 10s, 12s, and 16s, the wave direction in deep water is 85 degrees and the wave direction is 101.7 degrees, 102.5 degrees and 103.7 degrees at the -2m isobath, and the wave direction in deep water is 5 degrees to the -2m isobath. The wave directions are 87.8 degrees, 89.6 degrees and 92.4 degrees respectively. At periods of 10s, 12s, and 16s, when the outer sea wave direction differs by 80 degrees, the wave direction difference at the -2m isobath is 13.9 degrees, 12.9 degrees and 11.3 degrees. It can be seen that when the wave directions differ greatly in the outer sea, the waves propagate to The wave direction difference decreases when near shore. The change of wave direction with long period is greater than that with short period.

4 Sensitivity analysis of typhoon track to waves
In parts of the South China Sea and East China Sea, waves are mainly caused by typhoons. Compared with monsoons, typhoons have a low frequency, intensity and path randomness. Generally speaking, the coast of the project is close to the typhoon path and landing point, and the typhoon waves are large. Therefore, there is often a situation in which the wave design elements near the landing point of a large typhoon in history are large, and the wave design element at a distance is small. This prediction for the future is obviously inaccurate. Some normative methods simulate the maximum possible concept and make a hypothetical combination of strength and path. Although there is still a lack of theoretical basis for the combination, its rationality has become more reasonable. Discuss the sensitivity analysis of the typhoon path to the wave direction, that is, under the combined situation, not only the size of the typhoon wave changes, but the wave direction can also change.

Typhoon Mangkhut originated in the Northwest Pacific on September 8, 2018. The study uses the typhoon model and the wave model SWAN to perform the typhoon. Use the collected wave process near Dongsha Island to verify the Mangkhut Typhoon process, as shown in Figure 4 below, the calculated maximum $H_{13\%}$ is 12.3m, the measured maximum $H_{13\%}$ is 12.2m, the correlation coefficient of the two curves is 0.95, and the trend fit is good.

Figure 5 shows the path of the typhoon Mangkhut and the four possible paths assumed: the assumed path 1 is 100 km westward translation of Mangkhut, and the assumed path 2 is 100 km west of the landing point along the original path west of Mangkhut. Assume path 3 is the Mangkhut process along the original path eastward to 100 km east of the landing point; assume path 4 is the Mangkhut eastward translation 100 km. P1 to P4 are shown in Figure 5.
Figure 6. Maximum value of wave height of P4 point in different typhoon paths

The statistics of the maximum waves in each direction during the period of typhoon influence on P1~P4 are shown in Figure 6. From the calculation results, it can be seen that when the typhoon path changes at a certain point near the project, there is a big difference between the influence wave direction and the corresponding maximum wave height at that point. For points P2 and P3, the influence range of wave direction is 0°~360°. The influence range of the wave direction for point P1 is 125° to 360° and 0 to 15°, and the influence range of the wave direction for point P4 is 0 to 160 degrees.

For sea areas where strong waves are mainly typhoon waves, the wave direction should consider the possibility of changes in the path of the strong typhoon. It is recommended that the direction of strong waves be encrypted to four or eight azimuths.

5 wave direction sensitivity analysis

It can be seen from the wave simulation of the excavating outer channel to shield the port that when the wave approaches the outer channel direction, especially when it crosses the channel, the wave distribution in the port changes greatly. Take the incident wave 2 as the initial value and calculate the wave height. It can be seen that the angle difference is 5.265 degrees, and the difference of some calculated points is more than 10% than the wave height. It can be seen that from the wave direction sensitivity analysis, the excavation of the outer channel is protected It is not sufficient to use sixteen azimuth to simulate the direction of a port in the outer channel. Sixty-four azimuth can be used. The results show that the sensitivity of multi-directional irregular wave simulation is less than that of unidirectional irregular wave.

From the calculation results of wave direction changes near shore under the action of swells, for the long-period wave propagation process near shore, the line of wave direction change is larger, and the more concentrated it is in the direction perpendicular to the shoreline. Generally, for a water depth of about -10m, it is the position where the levee or entrance of a shielded port is located. At this time, the direction of the swell wave to the outer sea has doubled. Therefore, for the construction of a port in the swell sea area, when analyzing the impact of waves on the port The wave direction classification at the entrance is recommended to be doubled to 32 direction angles. When calculating the coastal sediment transport, the representative water depth of the wave is about -2m. From the simulation results of the
wave direction, it can be seen that the concentration is 1/4 of the open sea. Since the wave direction has a greater impact on the coastal sediment transport, it is recommended to be near shore. In the simulation calculation of coastal sediment transport, the results of measured sub-directions and sub-periods are used.

For sea areas where strong waves are mainly typhoon waves, the wave direction should consider the possibility of changes in the path of the strong typhoon. It is recommended that the direction of strong waves be encrypted to four or eight azimuths.

6 Conclusions

(1) In near-shore engineering and port construction, wave direction is one of the main elements of wave dynamics. In some cases, wave direction is very sensitive, so sensitivity analysis is needed.

(2) For shielded ports with excavated outer channels, the wave direction near the entrance is very sensitive. It is recommended to encrypt to 5.625° for wave simulation.

(3) For the swell sea area, it is recommended that the main wave direction analysis of the sheltered port be encrypted to 32 azimuth; the coastal sand transport analysis of the swell sea area, and the wave direction analysis is recommended to be simulated corresponding to the wave direction period classification of the outer boundary.

(4) For the sea area where strong waves are mainly typhoon waves, the wave direction should consider the possibility of changes in the path of the strong typhoon. It is recommended that the strong wave direction be encrypted to four or eight azimuths.

References:
[1] Huang M.L, Chen H.B. (2018) Statistical characteristics of sea waves with double-peak spectrum at Indonesia's south bank of the island of Java. Journal of Waterway and Harbor. 39(6):671-675.
[2] Zhang Y.J, Xu Y.N. (2019) A study on the distribution of the wave direction near the south coast of Java island in the Indian Ocean. China Water Transport. 19(5):166-167
[3] Luan Y.-N, Liu H.Y. (2014) Experimental study on wave overtopping and stability of slope revetment section. China Water Transport. 14(6):364-366.
[4] Tan Z.H, Zhang Y.J, Chen H.B. (2019) Risk analysis on deposition of water intake in nearshore of power station under surge control. 39(4):37-42.
[5] MAA J P-Y, HSU T-W, TSAI C-H and JUANG W J. (2000) Comparison of wave refraction and diffraction models. Journal of Coastal Research, 16(4):1073-1082.
[6] Hong G.W. (1996) Mathematical models for combined refraction-diffraction of waves on non-uniform current and depth. China Ocean Engineering. 10(4):433-454.
[7] Luo Y.Y, HU W.Q. (2017) Irregular wave generation using wave spectrum method and study on the evolution of wave propagation from deep to shallow region. JOURNAL OF HYDRODYNAMICS. 32(1):40-45.
[8] Ding J, Tian C. (2015) Experimental research on wave deformation near the typical island.. JOURNAL OF HYDRODYNAMICS. 30(2):194-200.
[9] Wang H.C. (2006) Numerical analysis of wave direction on the nonlinear parabolic mild slope equation. JOURNAL OF HYDRODYNAMICS. 21(1):139-144.
[10] Yu D.Y, Li L. (2017) Study on wave diffraction of artificial island with different elements, THE OCEAN ENGINEERING. 35(1):105-120.
[11] Liu X.M, Liu H.C. (2010) Comparison study between numerical model and experiment test on wave in complex wave situation waters. Journal of Waterway and Harbor. 31(3):170-174.
[12] Shi Y, Liang S.x. (2018) Application of the SWAN model to shallow water of laboratory scale. THE OCEAN ENGINEERING. 36(6):116-123.
[13] Shao J, Hu L.X. (2015) Combined application of SWAN model and BW model in calculation of design wave factors of Zhoushan Sijiao converter station[J], Port & Waterway Engineering. 508(10):13-19.

6
[14] Tang Y.P, Ran X.J. (2018) Analysis of wave propagation characteristics of typhoon “boarding into Fujian Province after landing Taiwan Island”. Journal of Waterway and Harbor. 39(6):665-708