

# Extreme water level and wave estimation for nearshore of Ningde City

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**Abstract.** The high and low design water levels are calculated by observation tidal data in sea areas of Ningde offshore wind power project from September 2010 to August 2011, with the value 318 cm and -246 cm, respectively. The extreme high and low levels are also calculated using synchronous difference ratio method based on station data from 1973 to 2005 at Sansha station. The value is 431 cm and -378 cm respectively. The design wave elements are estimated using the wave data from Beishuang Station and Pingtan station. On this basis, the SWAN wave model is applied to calculating the design wave elements in the engineering sea areas. The results show that the southern sea area is mainly affected by the wave effect on ESE, and the northern is mainly affected by the E waves. This paper is helpful and useful for design and construction of offshore and coastal engineering.

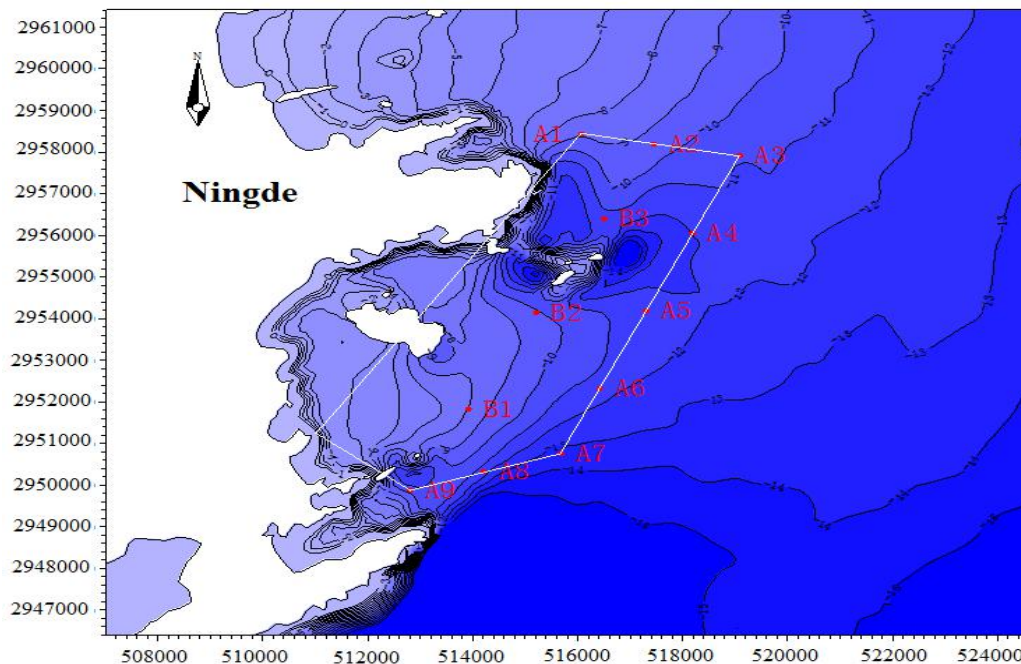
## 1. Introduction

The design of water level and wave elements is an important part of offshore engineering design. Teng and Xiu [1] used several station observations to study the extreme waves in the south of Bohai Sea. Since the advent of satellites, altimeter measurements of wave heights have been available. Wang *et al* [2] used satellite wave data to estimate extreme wave in the Bohai Sea.

In the practical engineering design, due to the lack of long-term wave observation data, the wind wave data are usually used to calculate the offshore wave elements in the engineering area. The numerical simulation method (hindcast and forecast) has become more important for wave investigation since the appearance of models. Lei *et al* [3] used a wave model to simulate the wave elements in the the Bohai Sea. Yin *et al* [4] studied interaction of waves and tide surge by a joint numerical model. Qiao *et al* [5] gave the extreme wave parameters by wave simulation under tropical cyclones wind forcing of Tonkin Gulf. Wang *et al* [6, 7] studied waves in the Bohai Sea and South China Sea respectively such as wave characteristics and extreme parameters.

Ningde City is located in the northeast of Fujian Province, with a coastline of 1046 km and sea area of 600 km<sup>2</sup>. There are 344 islands and the coastline accounts for about 1/3 in the province of Fujian. However, there is lack of studies in this sea area. The object of this paper is to calculate the design water level and design wave element in the engineering sea area as shown in figure 1 according to simulation and observation data analysis. There 4 parts in this paper. The second part is to estimate the engineering water level. The design waves in the open sea and nearshore are calculated in the third part. Finally the conclusion is given in the fourth part.

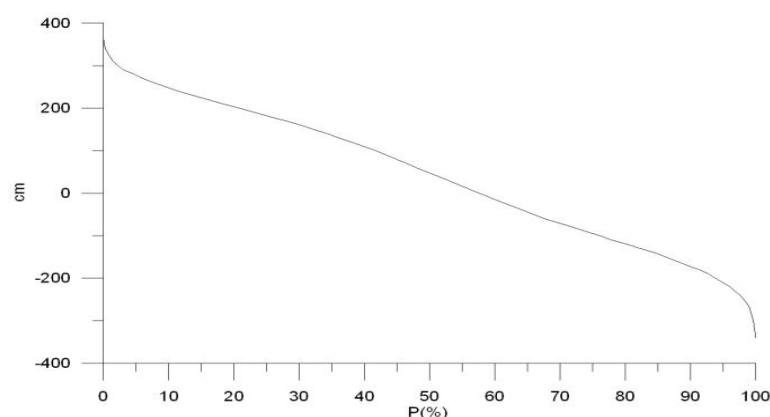




**Figure 1.** The depth and points for wave calculation.

## 2. Engineering water level

In the aspect of engineering water level, Dong *et al* [8] calculated the return values of typhoon significant wave height by a Poisson-maximum entropy distribution. Wu *et al* [9] studied storm surge during typhoon progress in the sea area around Shandong Peninsula and got the extreme parameters of sea level by numerical simulation and statistical analysis. Based on 20-year numerical hindcast data, Wang *et al* [10] studied currents and sea levels in the Bohai Sea such as long-term characteristics and extreme parameters.



**Figure 2.** The cumulative frequency curve of design water level.

There should be one or more years of measured tidal data used to determine the design of high and low water level by the method of the high tide and low tide cumulative frequency statistics. The cumulative frequency analysis was performed by using the annual hourly tide data from September 2010 to August 2011. The design high water level is taken as the cumulative frequency of 1% tide and the design low water level is taken as the cumulative frequency of 98% tide. The results are shown in

figure 2. The cumulative design high water level is 318 cm and the low water level is -246 cm respectively.

The highest and lowest tidal level data in the Sansha station from 1973 to 2005 year by year are used to obtain the extreme high and low water level, according to the Gumbel distribution method. The results are shown in table 1. The water surface depended on the 1985 national height datum.

**Table 1.** Extreme water level at Sansha station.

Return period	Sansha station		Engineering sea area	
	High level	Low level	High level	Low level
50a	441	-381	431	-378
20a	422	-374	413	-371
5a	392	-363	383	-360
1a	328	-340	320	-337

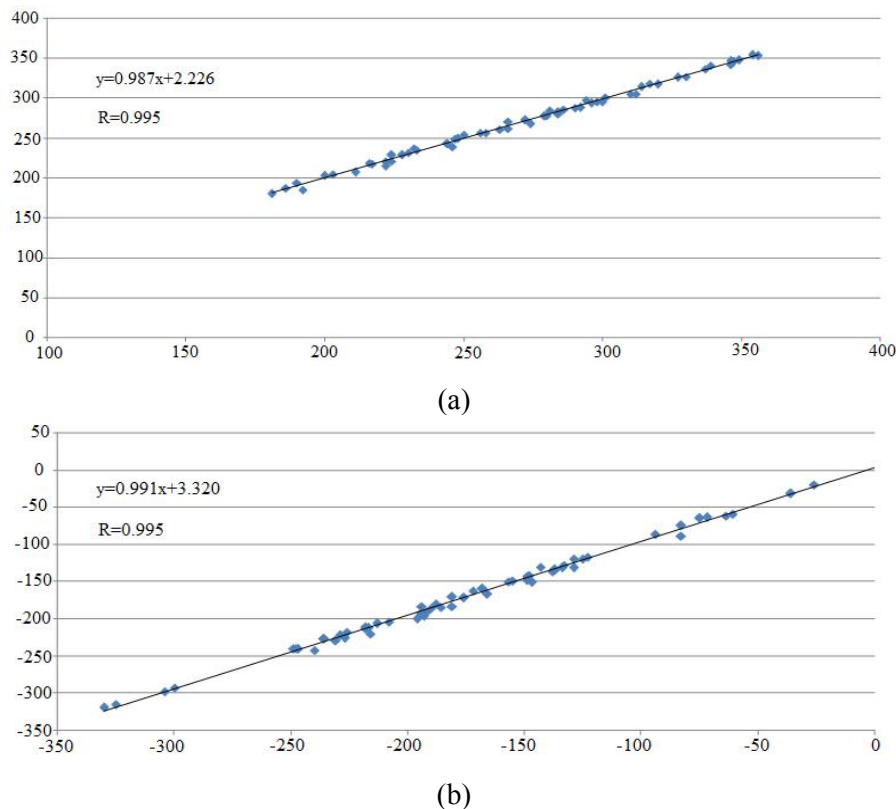
The relationship of high tide and low tide between engineering sea area and Sansha station is established by statistical analysis of 1 month synchronous tide observation. The high tide regression equation is

$$Y=0.987X+2.226 \quad (1)$$

The correlation coefficient is 0.997 (figure 3(a)). The low tide regression equation is

$$Y=0.992X+3.496 \quad (2)$$

The correlation coefficient is also 0.997 (figure 3(b)).



**Figure 3.** (a) Regression analysis of high tide of engineering sea area and Sansha station and (b) Regression analysis of low tide of engineering sea area and Sansha station.

According to the regression equation of high and low tide of two stations, the extreme water level of different return periods is calculated. The results are shown in table 1. The extreme high level is 431 cm and the extreme low level is -378 cm in the engineering sea area.

### 3. Extreme wave parameter

#### 3.1. Extreme wave in the open sea

There are many islands in the engineering sea area with East peninsula to the west and open sea to the east. East is the dominant wave direction. The huge waves are mainly from NE to SE direction. There are two wave stations which are Beishuang and Pingtan located to the east of the engineering. The observation data from 1981 to 2000 at Beishuang station and from 1960 to 1982 at Pingtan station is used to extreme wave estimation. The results show the wave in the ESE direction is not hazardous at Beishuang station as it is under cover of Dongshuang Island to the SE. On the other hand, the strong wave directions at Pingtan station are from E to SE. Considering the engineering safety, waves for extreme estimation in the direction of NE and E are taken from Beishuang station while those in the direction of ESE are taken from Pingtan station. The P-III distribution is applied to estimate wave height  $H_{1/10}$  of different return period. The results are shown in table 2. The max value is in the E direction with the wave height  $H_{1/10}$  11.45 m of 50 year return period.

**Table 2.** Design wave height  $H_{1/10}$  of different return period (m).

Return period	NE	E	ESE
50a	8.54	11.45	10.11
20a	7.10	10.25	8.17
10a	6.07	9.23	6.75
1a	3.88	1.28	2.95

#### 3.2. Extreme wave in the shallow water

The wave model Simulating Waves Nearshore (SWAN) model is used in this study. The action density  $N(\sigma, \theta)$  is applied to calculating in SWAN model, which is equal to variance density divided by relative frequency,

$$N(\sigma, \theta) = E(\sigma, \theta) / \sigma \quad (3)$$

where  $\sigma$  is the relative frequency and  $\theta$  is the wave direction.

The evolution of the wave spectrum is described by the spectral action balance equation which for Cartesian coordinates is

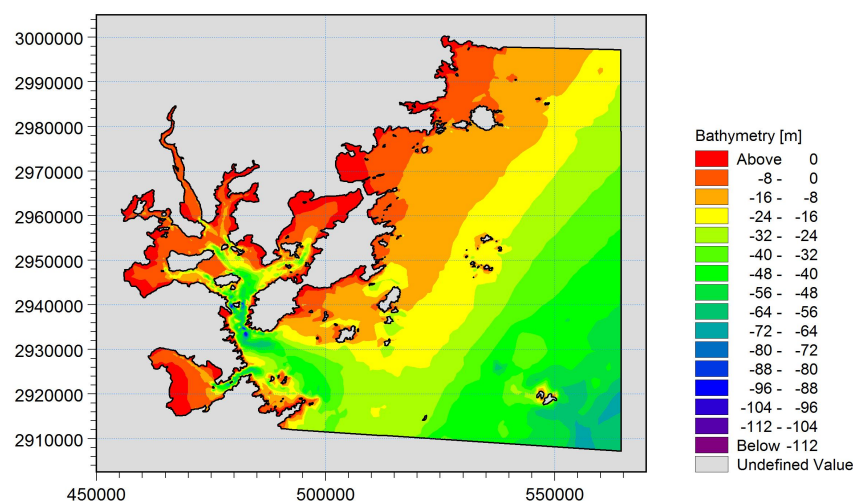
$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x} c_x N + \frac{\partial}{\partial y} c_y N + \frac{\partial}{\partial \sigma} c_\sigma N + \frac{\partial}{\partial \theta} c_\theta N = \frac{S}{\sigma} \quad (4)$$

The first term represents the local rate of change of action density in time. The propagations of action in geographical space with propagation velocities  $c_x$  and  $c_y$  in the  $x$  and  $y$  direction are the second term and the third term, respectively. The fourth term represents shifting of the relative frequency due to variations in depths and currents. The fifth term represents depth-induced and current-induced refraction.  $S$  is the source term which represents the effects of nonlinear wave-wave interactions, wind generation and dissipation. The dissipation mainly includes bottom friction, white capping and depth-induced wave breaking.

There were 30 frequencies logarithmically spaced from 0.05 Hz to 1.0 Hz. The number of iterations was set from 1, which is the default value, to 4 in order to enhance the numerical accuracy as the model integrated to the next time step. The linear wind input and growth method is used by Cavaleri and Malanotte-Rizzoli [11]. The exponential wind input and growth method is applied from Komen *et*

*al* [12]. The whitecapping dissipation method is from Komen *et al* [12]. The non-linear interaction method is used by Hasselmann *et al* [13].

The extreme wave parameters are taken as the boundary conditions. The triple triangular mesh is set to the model. The range is from 119°32' E to 120°40' E at longitude and 26°13' N to 27°10' N at latitude with the resolution 140 near the engineering. The bathymetric details for the SWAN are shown in figure 4.



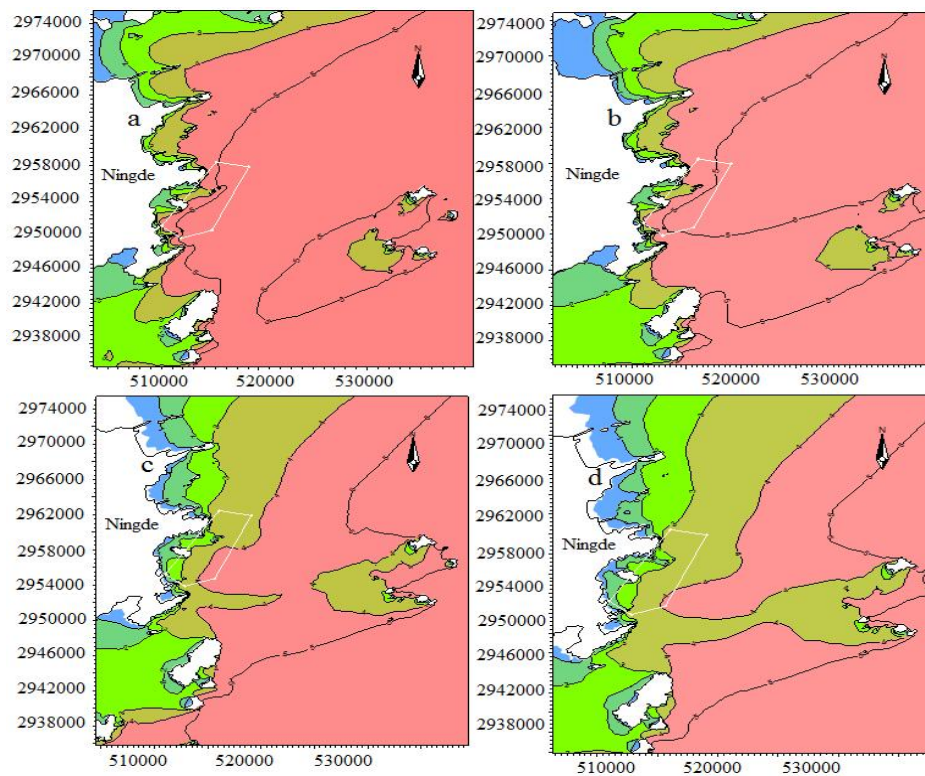
**Figure 4.** The bathymetric details for wave simulation.

The extreme wave parameters are estimated under condition of 4 water levels and 3 wave directions. The design water levels include design high and low water levels and extreme high and low water levels. The wave directions are NE, E and ESE which influence the engineering sea area most. The  $H_s$  fields of 50 year return period under 4 water levels and 3 wave directions are shown in figures 5 to 7. Furthermore, 12 points are selected as the representative points for statistical analysis. The point locations are shown in figure 1. The design wave of 50 year return period at 12 points is given in table 3. The results show that the design wave parameters are higher in the E direction than ESE direction. The south of engineering is mainly influenced by wave from ESE, while the north is mainly influenced by wave from E.

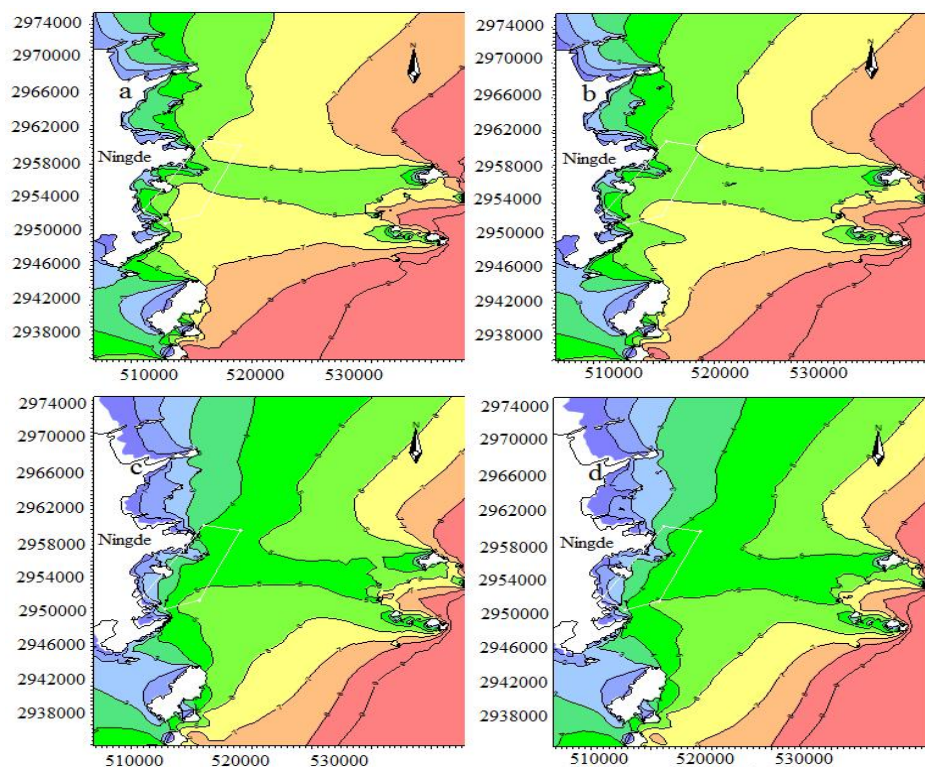
**Table 3.** Extreme parameters of 50 year return period in 12 points.

	NE		E		ESE	
	$H_s(m)$	$T_m(s)$	$H_s(m)$	$T_m(s)$	$H_s(m)$	$T_m(s)$
A1	4.98	10.5	5.98	12.1	5.72	11.4
A2	5.13	10.5	6.21	12.1	5.93	11.4
A3	5.34	10.5	6.42	12.1	6.08	11.4
A4	5.28	10.5	5.98	12.1	5.70	11.4
A5	5.47	10.5	5.61	12.1	5.83	11.4
A6	5.56	10.5	6.25	12.1	6.46	11.4
A7	5.42	10.5	6.38	12.1	6.78	11.4
A8	5.25	10.5	6.25	12.1	6.84	11.4
A9	5.07	10.5	5.61	12.1	5.84	11.4
B1	5.37	10.5	6.15	12.1	6.18	11.4
B2	4.61	10.5	5.93	12.1	5.98	11.4
B3	5.08	10.5	5.93	12.1	5.41	11.4

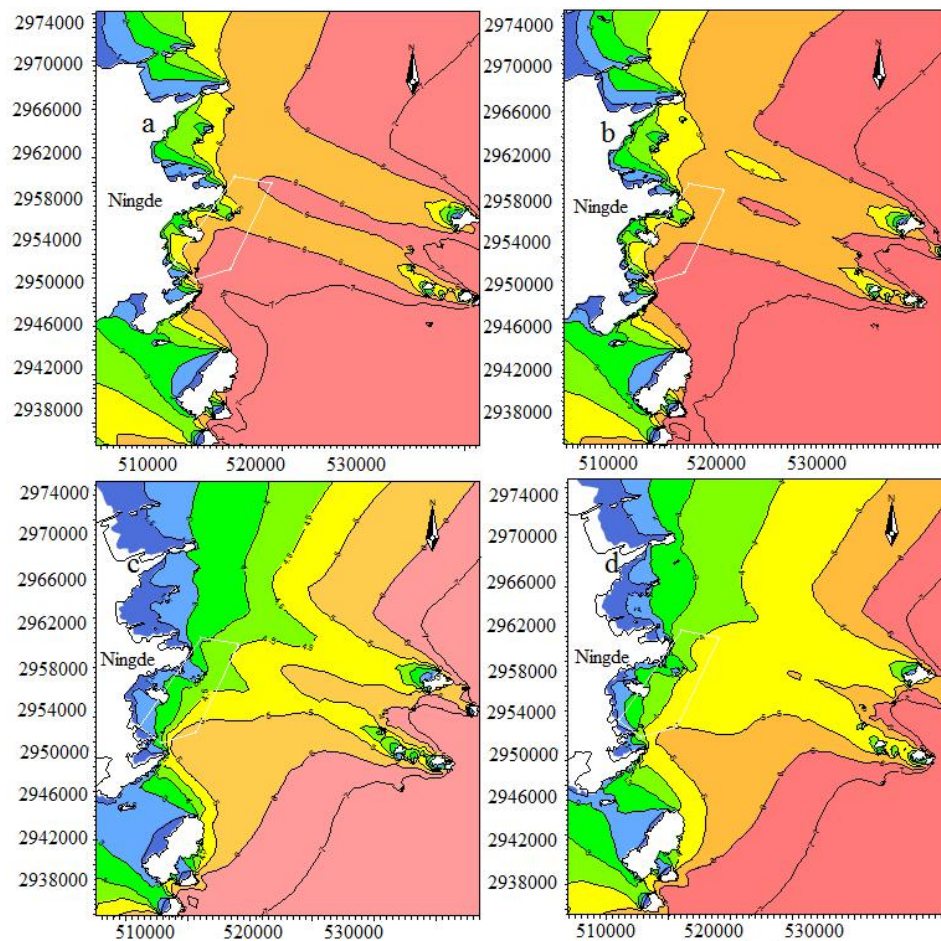




**Figure 5.**  $H_s$  of 50 year return period in NE (a: extreme high water, b: design high water c: design low water d: extreme low water).



**Figure 6.**  $H_s$  of 50 year return period in E (a: extreme high water; b: design high water; c: design low water; d: extreme low water).



**Figure 7.**  $H_s$  of 50 year return period in ESE (a: extreme high water, b: design high water c: design low water d: extreme low water).

#### 4. Conclusion

In this paper, the water level and the design elements of offshore wave are calculated using the measured data, and then the SWAN wave model is applied to simulating the wave propagation in shallow water.

The design high and low water level is 318 cm and -246 cm respectively, and the extreme high and low water level is 431 cm and -378 cm with the 1985 national height datum as the water surface. The engineering sea area is mainly influenced by wave from E direction. The wave height  $H_{1/10}$  of 50 year return period is 11.45 m.

On the whole, this paper is useful and helpful for marine disaster and coastal engineering nearshore of Ningde.

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