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Sea Environmental Design Criteria for Coastal and Offshore Structures

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Abstract

Extreme sea statistics and combinations of environmental events or response for structures are very important problem in performance cvaluation and design of coastal and Offshore structures. A probabilistic method is developed that leads to the combination of Typhoon (hurricane) or winter storm induces winds, waves, currents and surge for a generic site. The traditional recommendation for the fixed structures is a combination of the 100 years maximum wave height with the 100 years wind and current. This approach is, however, unduly conservative, since the largest wind, wave and current values in 100 years are not experted to occur at precisely the same time.

Previous studies of combinations of extreme sea environmental conditions fall into two categories: first, the generic load model defines a surface in the multivariate space of meteorologicaloceanic variables, such as the joint probability of waves, currents, winds and storm surge; second, use the structural response to combine the environmental variables, such as overturning moment (OTM), base shear forces and etc.[1-4]. While the great majority of publications are concentrated in combinations of responses, although 100 years response is not corresponding to wave, wind and current with 100 years joint probability.

Since the combination design criteria is considered with extreme statistics of individual environmental events and their joint probability, in this paper some new concept for mentioned above problems is proposed.

1 Predition of Extreme Sea Environmental Events

In the engineering design practice three statistical models(Gumbel, Weibull and Log-normal distribution) are widely used for predition of 100 (or 50) years wave, wind, current and storm surge.

The new statistical model is proposed based on the following consideration: a discrete distribution $P_K(K = 1, 2, \cdots, n)$ —as Typhoon frequency acting on certain sea area, and a continue distribution $G(x)$ —as Typhoon wave height, wind, current or surge, and form a new distribution -- Compound Extreme value Distribution $F(x)$

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$$F(x) = \sum_{K=0}^{\infty} P_K [\, G(x)]^{K}. \tag{1}$$

Observed and hindcast Typhoon and Hurricane data show that n is fitting to Poisson distribution, and Typhoon or Hurricane characteristics are fitting to Gumbel or Weibull distribution [5,6]. So that two statistical models are derived as:

Poisson-Gumbel Compound Extreme value Distribution :

$$X_P = -\ln\left\{-\ln\left[\, 1+\frac{1}{\lambda}\ln(1-P)\right]\right\}\alpha + u. \tag{2}$$

Poisson-Weibull Compound Extreme value Distribution :

$$X_P = \left\{-\ln\left[\, -\frac{1}{\lambda}\ln(1-P)\right]\right\}^{\frac{1}{\nu}} b, \tag{3}$$

where X_P is the design extreme value with return period $T(-1/p)$, λ the mean value of Typhoon or Hurricane frequencies, α and u the parameters of Gumbel distribution, and v and b the parameters of Weibull distribution.

Formulae (2),(3) can be used for wave, wind, current and surge prediction. Some American rescarchers indicate that mentioned above new formulae also can be used for flood frequency analysis. In north Rohai Bay where some sea areas are covered by ice for different days which varies from year to year, number of observed wave data is fitting to Binomial distribution, and observed daily maximum wave heights are fitting to Log-normal distribution. Therefore, for North Rohai Bay the Binomial-Log-normal Compound Extreme Value Distribution can be derived.

2 Joint Probability of Sea Environmental Events

Joint probbility of multidimensional variables can be expressed as

$$P = \int \int_{\Omega} \cdots \int f(x_1, x_2, \cdots, x_n) dx_1 dx_2 \cdots dx_n, \tag{4}$$

where Ω is the domain of integration in the multivariate space and $f(x_1, x_2, \cdots, x_n)$ the joint probability density function of variables

Analytical solution for joint probability of non-Gaussian, correlated multidimensional variables are very complexity and it can not find practical use.

The stochastic simulation techniques are efficient for estimation of joint probability. Different methods have been developed to reduce the number of simulations, among them important Sampling procedure [7] is used in this paper.

This method is used to determine the design environmental criteria for templet platform at 145 m. depth Lufun sea area of South China Sea. 20 years hindcast Typhoon wave, wind and current data are used for simulation. Simulated results are shown in Table 1.

Table 1. Joint Probability of Wave, Wind and Current

Return period (years)	Wave (m)	Current (m/s)	Wind (m/s)
100	14.2	2.18	53.7
50	13.7	2.12	50.2
20	12.9	1.91	45.0
10	12.2	1.69	42.0

Difference between simulated joint probability and calculated results by OTM method are shown in Table 2.

Table 2. Comparison of Calculated Results

Method	Wave (m)	Current (m/s)	Wind (m/s)
Individual 100 years value	15.6	2.77	55.9
OTM method	14.3	2.31	54.7
ISP method	14.2	2.18	53.7

3 Data Sampling from Hindcast Typhoon Process

Both extreme response method and joint probability method for environmental combination criteria can not give unique solution, because different combinations of wave, current and wind can obtain 100 years response or 100 years joint probability. Proposed in this paper method consists of two steps: first, use stochastic simulation method to get different combinations of wave, current and wind with 100 years joint probability; second, calculate response to structures, and choose the extreme value from them. 100 years return period combination of wave, current and wind corresponding to extreme response is an uique solution. Therefore, for different type of structures data sampling from Typhoon hindcast process must be different. There are four cases of data sampling corresponding to different type of structures:

Maximum wave with simultaneous current and wind;

Maximum wind with simultaneous wave and current;

Maximum current with simultaneous wave and wind;

Maximum surge with simultaneous wave and current;

For instance, in the case of fixed structure, dominated load is wave load, hence the data sampling have to take case 1. For some moored structure, sometimes the wind load is dominated and the maximum wind with simultaneous wave and current can be taken as data sampling. In case of some coastal structures, data sampling have to take case 4. For some structure in shallow water the maximum current and simultaneous wave and surge cam be used as data sampling.

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