Reliability Evaluation of Jacket-type Offshore Platforms Subjected to Wind, Wave, and Current Loads

Z F Song

School of Civil Engineering, North China University of Technology, Beijing 100041, China

Abstract: The aim of this study is to evaluate the reliability and sensitivity of jacket-type offshore platforms under wind, wave, and current loads. The reliability of the platforms are comprehensively determined based on the deformation and energy of the jacket platform. The Young’s Modulus; the yield strength; the strain hardening rate; the diameter and thickness of members; the water depth; the wave height and period; the wave velocities on the surface, middle, and base of the platform; the drag coefficient; the inertial coefficient; and the horizontal concentrated scaled loads are defined in the study as random variables. The sensitivity of the performance functions to the above-mentioned variables is determined, and the variables that most influence the performance of the platform are identified. Main conclusions are drawn as follows: the increasing mean and decreasing standard deviation of wall thickness in Type-1, Type-4, and Type-2 jacket members can effectively reduce the deformation and total strain energy of platform structures. For jacket structures in the plastic state, increasing the mean and decreasing the standard deviation of yield strength is a reasonable method for reducing deformation. Maximum deformation and strain energy are highly correlated whether the load level is high or low, and the correlation of these indicators with the variables considered gradually increases with the load level.

Preface

An offshore platform possesses many features of a complicated structure, a large bulk, a high construction cost, and is located in the complex and harsh marine environment. The structure of an offshore platform is constantly subject to the forces of wind, waves, current, sea ice, and tides. Adverse factors, such as environmental corrosion, adhesion of marine creatures, the washing away of subsoil, basic dynamic softening, and material aging can weaken the structural members and the overall resistance of a platform, affecting its service, safety, and durability [1]. There have been a number of offshore platform accidents both domestically and overseas (see Fig. 1) that have resulted in significant economic losses and adverse social impact. For example, in the winter of 1964, two new drilling platforms located in the United States at Cook Inlet, Alaska, were severely damaged by sea ice. After hurricanes Hilda and Betsy, 22 of
around 1000 platforms in the Gulf of Mexico collapsed or were otherwise damaged, becoming non-operational. After Hurricane Andrew in 1992, 19 of around 3850 platforms in the Gulf of Mexico were damaged and non-operational. On December 18, 2011, a Russian oil platform sank after impact with sea ice. The reliability of offshore platforms has been an important subject upon which both domestic and overseas researchers and engineers are focused.

Many domestic and overseas researchers have studied the reliability of offshore platform structures. Frieze [2] compared different regulations dictating the reliability level of offshore platform jacket structures in procedures API RP 2A-LRFD and SNAME T&R Bulletin 5-5A, and conducted an in-depth discussion of their reasoning. Zhu [3] discussed the main problems of reliability analysis of offshore platform jacket structures, and provided a general analysis procedure for the safety factor method. Deng [4] presented a reliability estimation method for offshore platform jacket structures, taking into account punching failure and buckling failure of members. This method can determine the main failure modes of the structural system of the platform. Salau [5] derived a time-dependent reliability equation for offshore platform jacket structures, and accurately ascertained the reliability of corroded jacket members. Jin [6] considered the coupling effect between offshore platform jacket members, piles, and soil, and evaluated the jacket reliability under extreme load. Hezarjaribi [7] combined the nonlinear pushover method with the wave load incremental method to evaluate the nonlinear response of the offshore platform jacket-pile-soil system under the action of waves through sensitivity analysis. Leira [8] studied the reliability of the offshore platform field-related response.

![Fig.1 Collapse of offshore platform](image)

However, previous studies have been limited to the reliability of the platform structural members and jacket systems, and do not take into account the sensitivity and correlation of jacket behavior to different loads. Therefore, the reliability and sensitivity of offshore platform jacket systems under the action of wind, wave, and current loads were selected as the object of this study, with the intent of comprehensively evaluating platform reliability from the perspective of maximum deformation and total strain energy in the platform jacket members. The sensitivity of the jacket structure deformation and strain energy to variable physical parameters, geometric parameters, and wind, wave, and current loads were studied, and the most influential variable is identified. Finally, the correlation between performance functions is discussed.

1. **Reliability theory**

1.1 **Latin Hypercube sampling method**

In order to accurately measure the reliability of offshore platform jacket structures under the action of wind, wave, and current, the Monte Carlo method is used for reliability computation in this study. The Latin Hypercube sampling method can efficiently generate multivariate samples and greatly reduce the number of simulations without compromising accuracy.

The mean is estimated as
\[ Y = \bar{Y} = \frac{1}{N} \sum_{i=1}^{N} y_i \]  

(1)

The \( m \)th value is estimated as

\[ Y = \frac{1}{N} \sum_{i=1}^{N} (y_i)_m \]  

(2)

The cumulative distribution function (CDF) is estimated as

\[ F_y(y) = \frac{y_{\text{le}}}{N} \]  

(3)

1.2 Sensitivity

A sensitivity coefficient represents the relative importance of a random variable to the failure probability, which satisfies the following relation:

\[ \alpha_i^2 + \alpha_j^2 + \alpha_k^2 + \alpha_l^2 = 1 \]  

(4)

where \( \alpha_i, \alpha_j, \alpha_k, \alpha_l \) (\( i = 1, 2, 3, \cdots, n \)) represents the sensitivity coefficient of the \( i \)th random variable to the failure probability, which indicates the relative contribution of each random variable to the failure probability.

The sensitivity coefficient to the reliability index is expressed as

\[ \frac{\partial \beta}{\partial u_i} = \frac{\partial \beta}{\partial u_j} \phi(-\beta) = \phi(-\beta) \frac{\partial \beta}{\partial u_i} \]  

(5)

where \( u_i \) represents the random variable in standard normal space.

The sensitivity coefficient to the failure probability \( P_f \) is expressed as

\[ \frac{\partial P_f}{\partial u_i} = \phi(-\beta) \frac{\partial \beta}{\partial u_i} \]  

(6)

where \( \phi(-\beta) \) represents a standard normal distribution function, and \( \phi(-\beta) \) represents a standard normal density function.

1.3 Correlation between performance functions in structural system

Performance functions \( Z_i \) and \( Z_j \) correspond to failure modes \( i \) and \( j \), respectively, expressed here as \( Z_i, Z_j \). The performance functions contain only two statistically independent variables, \( R \) and \( S \). The standard errors of the mean for \( R \) and \( S \) are \( \sigma_R \) and \( \sigma_S \), respectively. The performance functions \( Z_i, Z_j \) can be respectively expressed as:

\[ Z_i = a_i R - b_i S \]  

(7)

\[ Z_j = a_j R - b_j S \]  

(8)

The correlation coefficient of \( Z_i, Z_j \) can be expressed as:

\[ \rho_{Z_i, Z_j} = \frac{\text{COV}(Z_i, Z_j)}{\sigma_{Z_i} \sigma_{Z_j}} = \frac{a_i a_j \sigma_R^2 + b_i b_j \sigma_S^2}{\sigma_{Z_i} \sigma_{Z_j}} \]  

(9)

If the performance function is nonlinear, it can be expanded by a Taylor series at the check point \( X^* \), the approximate value of the correlation coefficient is calculated by a simple equation (assuming the basic variables are not related), and the correlation coefficient of \( Z_i, Z_j \) is expressed as:

\[ \rho_{Z_i, Z_j} = \frac{\text{COV}(Z_i, Z_j)}{\sigma_{Z_i} \sigma_{Z_j}} = \frac{\sum_i \left( \frac{\partial Z}{\partial X_i} \right)_i \left( \frac{\partial Z}{\partial X_j} \right)_i}{\sqrt{\sum_i \left( \frac{\partial Z}{\partial X_i} \right)_i^2} \sqrt{\sum_j \left( \frac{\partial Z}{\partial X_j} \right)_j^2}} \]  

(10)

2. Computation of wave force

The computation of wave force is generally divided into the computation of small scale wave force and the computation of large scale wave force, based on the ratio of the structural scale to the wavelength \((D/L)\) where \( D \) is the characteristic length of the object (such as diameter for a cylinder), and \( L \) indicates...
the wavelength. When $D/L \leq 0.2$, the object under consideration is considered to be small scale. When $D/L > 0.2$, the object under consideration is considered to be large scale, for which the free surface effect and the relative scale effect, namely the diffraction effect, should be considered.

For the calculation of wave force on small-scale slender columns, the famous Morison Equation is widely used in engineering design [9]:

$$
\begin{align*}
    f_{wy} &= \frac{1}{2} C_d \rho \left( u \frac{\partial \psi}{\partial t} \right) \left( u - \omega \frac{\partial \psi}{\partial \psi} \right) + \\
    &+ C_M \rho \frac{\pi D^2}{4} \left( \frac{\partial u}{\partial x} + \frac{\partial \psi}{\partial y} \right)
\end{align*}
$$

where: $f_{wy}$ is the wave force per unit length vertically acting on the pipe column in $kN/m$; $\rho$ is the seawater density in $kg/m^3$; $D$ is the pipe column diameter in $m$; $u$ is the horizontal velocity of water particle on axis of pipe column in $m/s$; $C_d$ is the resistance coefficient; $C_M$ is the inertia force coefficient [10].

As Stokes wave theory can accurately describe the actual wave motion, standards for classification of marine platforms like ABS and DNV also suggest using three-order or five-order Stokes wave theory to conduct strength checks and structural design for marine structures. The Stokes wave theory can also be used for small-sized jacket parts [11].

This study used the ANSYS software, which can accommodate four different wave theories: the micro-amplitude wave theory with deep fading and empirical correction, the Airy wave theory, the five-order Stokes wave theory, and the stream function wave theory. If the five-order Stokes wave theory is selected, only wave height, period, and phase angle are required as inputs. If structural static analysis is performed, before inputting the phase angle, the phase angle of the maximum wave current coupling force must be determined, and this should be taken as the parameter for static analysis.

3. Reliability and sensitivity analysis of offshore platform jackets

3.1 Model parameters

The parameters of an offshore platform jacket structure were taken from Reference [10]. The platform consisted of an upper platform and a lower jacket structure (see Fig. 2), with the jacket bottom fixed by a pile foundation. The upper platform supports the frame and the deck, with external dimensions of $30 \times 20 \, m$, and the height from the water surface to the top deck was $15 \, m$. The majority of the lower jacket structure consisted of 4 main ducts using slim tubes for support, forming a spatial tower frame structure. The pile foundation was driven into the seabed soil through the main ducts. The size of main duct in the jacket structure above the mud line was $\Phi 1.2 \times 0.05 \, m$; the size of main duct in the jacket structure below the mud line was $\Phi 1.2 \times 0.05 \, m$; the size of main pipe used in the deck was $\Phi 0.78 \times 0.0381 \, m$; the size of inter-story horizontal bracing in the jacket system was $\Phi 0.78 \times 0.0381 \, m$; the size of diagonal braces in the jacket system was $\Phi 0.508 \times 0.0254 \, m$; the section area of the deck beams was $0.16 \, m^2$, with a height of $0.4 \, m$ and a width of $0.4 \, m$; the deck was $0.025 \, m$ thick, $30 \, m$ long, and $20 \, m$ wide; the water depth was $45 \, m$, with a wind velocity of $43.6 \, m/s$, an effective wave height of $14.8 \, m$, an effective wave period of $10.8 \, s$, a surface flow rate of $2.35 \, m/s$, a central flow rate of $1.96 \, m/s$, and a bottom flow rate of $1.60 \, m/s$. In order to simplify the computation, the influence of pile and soil on the behavior of the jacket structure was not considered, and the lower part of the jacket was assigned a fixed constraint.

The entire jacket platform model used four element types: PIPE20, PIPE59, BEAM4 and SHELL43 (see Fig. 2). The PIPE20 element was used for the main vertical supporting members of the deck framework above the water surface, as well as for members below the mud line. Because the
hydrodynamic effect and the wave-current interaction can be considered in the PIPE59 element, it was used for jacket members below water surface but above mud line. The BEAM4 element was used for deck level frame beams, and the SHELL43 element used to model the horizontal deck. The steel material used was D36, with an elastic modulus of 2.0×10$^5$ Pa, a Poisson's ratio of 0.3, a density of 7850 kg/m$^3$, a yield strength of 360 MPa, and a strain hardening rate of 0.02. The bi-linear elastic-plastic hardening model was adopted for the steel.

When the five-order Stokes wave theory is used, the value of the phase angle $\phi$ has a significant impact on the wave load acting on the structure. Before starting the static analysis, it was necessary to determine the phase angle $\phi$ from 0° to 360° at which the wave current coupling force is at its maximum. The authors determined that the phase angle corresponding to the maximum wave current coupling force was 46° [10]. Based on the characteristics of the jacket-type offshore platform, Jinping Ou proposed the whole advancement method [1], an approximate method for limit analysis that is essentially a pushover analysis method, which treats the platform structure as resisting the horizontal force as a whole to calculate the bearing capacity of entire structure. Based on this, for the convenience of computation, the wind loads were equally concentrated at the eight nodes where platform and jacket structure intersect, and were amplified by different multiples to study the elastic-plastic mechanical properties of the jacket structure under the action of the three different applied horizontal loads.

From the point of view of deformation and energy, the reliability and sensitivity of the jacket platform under wind, wave, and current loads were studied. The jacket physical parameters (elastic modulus, yield strength, and strain hardening rate), geometric parameters (pipe diameter and wall thickness) for four classes of sections (A–D), the water depth, the wave height and period, the surface, central, and bottom flow rate, the drag coefficient, the inertia force coefficient, and the amplified wind load were defined as random variables. The statistical characteristics of each random variable are shown in Table 1. See references [12] and [13] for parameter selection rules.

![Whole model and unit types](image)

**Table 1 Statistical parameters of random variables**

| Random variable | Description | Probability distribution | Mean value | Standard error | Random variable | Description | Probability distribution | Mean value | Standard error |
|-----------------|-------------|--------------------------|------------|----------------|-----------------|-------------|--------------------------|------------|----------------|
| DW/m            | Water depth | Normal                   | 45         | 4.5            | D1              | Class A diameter/m | Truncated Gauss       | 1.2        | 0.06           |
| HW/m            | Wave height | Normal                   | 14.8       | 0.74           | T1              | Class A wall thickness/m | Truncated Gauss       | 0.05       | 0.0025         |
| TW/s            | Wave period | Normal                   | 10.8       | 0.54           | D2              | Class B diameter/m | Truncated Gauss       | 1.2        | 0.06           |
| VS/(m/s)        | Surface flow rate | Normal             | 2.35       | 0.047          | T2              | Class B wall thickness/m | Truncated Gauss       | 0.05       | 0.0025         |
| VM/(m/s)        | Central flow rate | Normal             | 1.96       | 0.0392         | D3              | Class C diameter/m | Truncated Gauss       | 0.78       | 0.039          |
| VB/(m/s)        | Bottom flow rate | Normal             | 1.60       | 0.032          | T3              | Class C wall diameter/m | Truncated Gauss       | 0.0381     | 0.00191        |
| CD              | Resistance  | Normal                   | 0.70       | 0.014          | D4              | Class D             | Truncated            | 0.508      | 0.0254         |
3.2. Reliability analysis

First, the reliability of offshore platform jacket structures under the action of the three different horizontal loads considered was studied. Defining the maximum deformation and the total strain energy as performance functions, the CDF curves of probability for the maximum deformation and the total strain energy under three load levels are shown in Fig. 3 and Fig. 4, respectively. As can be seen from Fig. 3a, for Load Level 1, the average maximum deformation was 0.125 m, with a standard error of 0.0142 m; the probability for deformation beyond a threshold of 0.12 m was 63.23 %, and the probability for deformation beyond a threshold of 0.15 m was 4.34 %. With the increase in load level, the mean and the standard error of the maximum deformation also increased. According to Fig. 3b, for Load Level 2, the mean of maximum deformation reached 0.223 m with a standard error of 0.026 m, and according to Fig. 3c for Load Level 3, the mean of maximum deformation was 0.377 m with a standard error of 0.054 m.

Fig. 4 shows the CDF curve of probability for the total strain energy. As shown in Fig. 4a, for Load Level 1, which is relatively light, the mean of total strain energy was only $6.72 \times 10^5$ J, with a standard error of $1.29 \times 10^5$ J. As the load level increased, a number of members in the jacket entered into the plastic state, and the total strain energy increased as well. From Fig. 4b, it can be seen that when Load Level 2 was applied, the total strain reached $2.04 \times 10^6$ J, a two-fold increase compared to Load Level 1. As can be seen from Fig. 4c, for Load Level 3, the jacket has been significantly deformed and a large number of members have entered into the plastic state, with the mean of total strain energy reaching $5.78 \times 10^6$ J,
which is a two-fold increase over Load Level 2.

3.3 Sensitivity and correlation analysis

In this section, the sensitivity of the maximum deformation and total strain energy to each random variable was analyzed by applying different load levels to the jacket platform. All calculation results are shown in Table 2 to Table 4, while Fig. 5 and Fig. 6 show the pie diagrams illustrating the sensitivity of the maximum deformation and total strain energy to each random variable under the three load levels applied. From Table 2 and Fig. 5a, it can be seen that for Load Level 1, the maximum deformation is mostly sensitive to changes in horizontal concentrated loads, which exhibit a sensitivity coefficient of 0.855—a positive value, indicating that the maximum deformation increases as the value of the horizontal concentrated load increases. The sensitivity coefficient for the elastic modulus was -0.424—a negative value, indicating that the maximum deformation decreases as the elastic modulus increases. The sensitivity coefficients for the wall thickness of Class A, D, and B members were -0.168, -0.144, and -0.027, respectively, indicating that an increase in mean wall thickness and reduction of their standard error can effectively reduce jacket deformation.

The sensitivity coefficients for the diameter of Class D, A, and C members were -0.019, -0.012, and -0.009, respectively, indicating that an increase in mean external diameter and reduction in their standard error can also reduce the jacket deformation to some extent. The sensitivity coefficients for water depth, wave height, wave period, central flow velocity, bottom flow velocity, resistance coefficient, inertia force coefficient, and yield strength were all so low that they can be neglected. With increasing load levels, there were some members entering the plastic state, and thus the sensitivity of structure to changes in yield strength increased from -0.001 to -0.010, while the sensitivity of other random variables remained unchanged. It can be seen from Table 4 and Fig. 5c that for Load Level 3, there are more members entering the plastic state, and the sensitivity of the maximum deformation to changes in yield strength was increased to -0.098. Therefore, it can be seen that for jackets in the plastic state, increasing the mean yield strength and decreasing its standard error can effectively reduce jacket deformation.

According to the information in Table 2 to Table 4 and Fig. 6, for the three load levels, the total strain energy indicates the highest sensitivity to changes in the horizontal concentrated load, followed by changes in the elastic modulus. The data suggests similar high sensitivity to the wall thickness of the Class D, A, and B members, which is similar to the sensitivities of maximum deformation. In case of a low load level, the sensitivity of total strain energy to the yield strength can be ignored. As the load level increases, the sensitivity coefficient of the yield strength increases from -0.002, first to -0.012, then to -0.092, which is caused by the gradual entering of the members into the plastic state.

| Performance function | DW | HW | TW | VS | VM | CD | CE | E | fy |
|----------------------|----|----|----|----|----|----|----|----|----|
| D                    | 0.003 | -0.001 | 0.002 | -0.008 | -0.001 | -0.001 | 0.001 | -0.001 | -0.424 | -0.001 |
| E                    | 0.002 | -0.002 | 0.002 | -0.008 | -0.002 | -0.001 | 0.000 | -0.002 | -0.247 | -0.002 |
| D                    | -0.003 | -0.012 | -0.168 | -0.006 | -0.025 | -0.009 | -0.008 | -0.019 | -0.144 | 0.855 |
| E                    | -0.004 | 0.005 | -0.082 | -0.005 | -0.016 | -0.007 | 0.001 | -0.012 | -0.094 | 0.952 |

| Performance function | DW | HW | TW | VS | VM | CD | CE | E | fy |
|----------------------|----|----|----|----|----|----|----|----|----|
| D                    | 0.003 | -0.001 | 0.002 | -0.008 | -0.001 | -0.001 | 0.001 | -0.001 | -0.416 | -0.010 |
| E                    | 0.002 | -0.002 | 0.002 | -0.008 | -0.002 | -0.001 | 0.000 | -0.002 | -0.231 | -0.012 |
| D                    | -0.003 | -0.011 | -0.165 | -0.006 | -0.027 | -0.009 | -0.006 | -0.018 | -0.143 | 0.860 |
| E                    | -0.004 | -0.005 | -0.076 | -0.005 | -0.018 | -0.007 | -0.000 | -0.012 | -0.096 | 0.957 |
### Table 4: Sensitivity of maximum deformation and total strain energy to each random variable (Load Level 3)

| Performance function | DW | HW | TW | VS | VM | VB | CD | CE | E | fy |
|----------------------|----|----|----|----|----|----|----|----|----|----|
| D                   | 0.002 | -0.001 | 0.002 | -0.008 | -0.001 | -0.001 | 0.001 | -0.002 | -0.340 | -0.098 |
| E                   | 0.001 | -0.002 | 0.002 | -0.008 | -0.001 | -0.001 | 0.000 | -0.003 | -0.189 | -0.092 |

| Performance function | B | D1 | T1 | D2 | T2 | D3 | T3 | D4 | T4 | LOAD |
|----------------------|---|----|----|----|----|----|----|----|----|------|
| D                   | -0.003 | -0.010 | -0.132 | -0.012 | -0.054 | -0.005 | -0.007 | -0.016 | -0.122 | 0.899 |
| E                   | -0.003 | -0.000 | -0.060 | -0.003 | -0.044 | -0.004 | -0.003 | -0.011 | -0.083 | 0.964 |

(a) Load level 1

(b) Load level 2

(c) Load level 3

Fig.5 Sensitivity pie diagrams of the maximum deformation to each random variable

Fig.6 Sensitivity pie diagrams of total strain energy to each random variable
Fig. 7 shows the sensitivity coefficient curve for the main random variables of the jacket assembly when subjected to the three load levels. It can be seen that as the load level increases, the maximum deformation and total strain energy gradually grow less and less sensitive to changes in the elastic modulus, and exhibit significantly increased sensitivity to changes in the yield strength and wall thickness of Class B members. The sensitivity of the deformation and strain energy to changes in the wall thickness of Class A and D members also decreases with increasing load, while their sensitivity to other random variables did not show significant change.

There is a correlation between the performance functions defined by the maximum deformation and the total strain energy of the platform. This section quantifies the extent of this correlation. The correlation coefficients under three load levels are shown in Table 5, while Fig. 8 shows the scatter plots of their correlation under Load Level 1, which is quite high. According to Table 5, the correlation coefficients are 0.971 for both Load Levels 1 and 2, and for Load Level 3, the correlation coefficient reaches 0.980. Therefore, with the increase in load level, the correlation between the maximum deformation and the total strain energy increases gradually. This is because as the load increases, more members approach the yield state, resulting in the increased impact of yield strength on the two performance functions. It can also be seen that regardless of the load level, the two performance functions considered in this study exhibit significant correlation in excess of 0.7 - 0.8.

**Table 5 Correlation between performance functions**

| Item | Load level 1 | Load level 2 | Load level 3 |
|------|--------------|--------------|--------------|
| D    | 1.000        | 0.971        | 0.971        |
| E    | 0.971        | 1.000        | 0.980        |

Fig. 8 Scatter plots between maximum deformation and total strain energy (load level 1)
4 Conclusions

(1) In order to comprehensively evaluate the reliability of offshore platform jacket structures, a variety of performance functions can be considered for different research objectives. This study considers the two performance functions of maximum deformation and total strain energy for the jacket system, and quantitatively determines the structural reliability for each performance function.

(2) The extent of the sensitivity of the two performance functions to changes in each random variable was determined, and the random variables most affecting the performance functions were identified. It was observed that the reliability of the offshore platform jacket structure can be enhanced by rationally controlling the probability parameter of these random variables. Increasing the mean wall thickness of Class A, D, and B members, and reducing their standard error can effectively reduce the deformation and total strain energy of the overall jacket structure. With the increase in load level, the sensitivity of the structure to changes in the yield strength increases steadily. For jacket members in the plastic state, improving the mean yield strength and reducing the standard error can effectively control the maximum deformation of the jacket structure. With the increase in load level, the sensitivity of the maximum deformation and total strain energy to changes in the elastic modulus gradually decreases, and their sensitivity to changes in the yield strength significantly increases.

(3) Regardless of the load level, there is strong correlation between the maximum deformation and the total strain energy, which is an advanced correlation. With an increase in load level, the correlation between the maximum deformation and the total strain energy improves gradually, caused by more members entering into the yield state, increasing the influence of yield strength on the two performance functions.

REFERENCE

[1] Ou J P, Duan Z D, Xiao Y Q. Safety evaluation of offshore platform structures: theory, method, application [M]. Beijing: Science Press, 2003, 1-9.
[2] Frieze P. A., Morandi A. C., Birkinshaw M, etc. Fixed and jack-up platforms: basis for reliability assessment [J]. Marine Structures, 1997, 10(2-4): 263-284.
[3] Zhu Q X. Optimum design for offshore platform structural reliability [J]. China ocean Engineering, 1992, 6(3): 265-278.
[4] Deng H Z, Sun Q. Reliability analysis for offshore platform structural systems [J]. China Ocean Engineering, 1997, 11(1): 1-10.
[5] Salau M. A., Esz zobor D. E., Omotoso M. F. Reliability assessment of offshore jacket structures in Niger Delta [J]. Petroleum & Coal, 2011, 53(4):291-201.
[6] Jin W L. Reliability-based design for jacket platform under extreme loads [J]. China Ocean Engineering, 1996, 10(2): 145-160.
[7] Mona Hezarjaribi, Bahaari M. R., Vahid Bagheri, etc. Sensitivity analysis of jacket-type offshore platforms under extreme waves [J]. Journal of Constructional Steel Research, 2013, 83(3): 147-155.
[8] Bernt J. Leira, Daniel Karunakaran. Site-dependent reliability of a mobile jack-up platform [J]. Marine Structures, 1995, 8(2): 151-169.
[9] Morison J. R., O. Brien M. P., Johnson J.W., et al. The force exerted by surface wave on piles [J]. Petroleum Transactions, AIME, 1950, 2(5): 149-154.
[10] Yang J, Liu S J, Xie R J. Application of ANSYS in offshore oil engineering [M]. Beijing: Petroleum Industry Press, 2010, 10: 145-160.
[11] Skjelbreia, L., Hendrickson, J. A., Fifth order gravity wave theory [C]//Proceedings, Seventh Conference on Coastal Engineering, Ch. 10, 1961: 184-196.
[12] Jiang Y B. Reliability calculation and discussion of design method of cable-stayed double-layer cylindrical latticed shells[D]. Nanjing: Southeast University, 2006, 15-18.
[13] Du C. System reliability analysis of ocean jacket platforms [D]. Dalian: Dalian University of Technology, 2006, 32-37.