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STRUCTURAL SAFETY ASSESSMENT OF EXISTING ICE-RESISTANT JACKET PLATFORMS IN ICE ZONE

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ABSTRACT

Until now dozens of offshore structures have been deployed in Bohai bay since the first drilling platform was erected in 1965. The oil and natural gas resources of Bohai Bay are mainly marginal oil fields. It is necessary to build both ice-resistant and economical offshore platforms. Full-scale measurement for many years shows the design of some ice-resistant platforms is not so sophisticated, the most significant is that ice induced vibration is the main which has caused harmful accidents in Liaodong bay of Bohai. In order to ensure security operation, structural safety assessment and life extension become key problems. In this paper, failure modes of ice resist jacket platforms, the related failure evaluation criteria, and risk grade are treated. Combined with monitoring data of ice loads, assessment strategy is presented. Lastly, as an application example, safety assessments of a practical platform in Bohai Bay are carried on.

1 INTRODUCTION

Different types of steel structures can be applied for the development of offshore hydrocarbon fields in ice zone. Normally, there are two types of steel offshore structures designed to resist ice forces. One is the caisson structure, which is rigid and has strong ability to withstand extreme ice force and dynamic ice force. The other is jacket structure, which is more economic as it uses less steel in the same depth of water, and is prevalent and accepted in cold engineering. Since the late 1960's, there were nearly 100 offshore platforms after the establishment of the first platform in Bohai Sea. The design life of jacket platforms is about 15-20 years. It is recognized that the repair cost is so expensive, compared with the initial cost of a new platform, the owners expect the existing platforms which exceed or approach their design life carry on with producing.

Technology for safety assessment of offshore areas with moderate ice conditions is a key concern for safe development of offshore hydrocarbon fields in the ice zone. It is of particular importance to reduce the risk through selection of appropriate technology for the existing jacket platforms. At present, safety assessment of existing offshore jacket platforms for life extension is mainly based on API-2A WSD [1], ISO19900 [2], ISO19902 [3], or ISO13822 [4], etc. During the early 1990's an API task group developed RP 2A section 17 for the assessment of existing platforms [5]. Additionally, RP 2SIM (Structural Integrity management) will, for the first time, provide the engineer with fitness-for-purpose acceptance criteria against the platform's ultimate load capacity, measured as the Reserve Strength Ratio (RSR) [6]. Nowadays, offshore platforms are traditionally designed on a component-by-component basis, such that under all combinations of design loading every component in the structure has utilization ratio derived using the strength formulations from the API RP 2A, of unity or less. However, it is recognized that fixed offshore structures are usually redundant and have a number of different load paths such that failure of one member is unlikely to lead to catastrophic structural collapse, provided that adequate redundancy is available. So for existing offshore structures, it is possible that isolated component failure(s), i.e. loads exceeding the component capacity, will be acceptable, provided that sufficient reserve against overall system failure exists. Assessment analysis in RP2-SIM provides a best estimate of the strength of the structures. It seeks to utilize the available reserve strength and redundancy not accounted for design. The assessment of an existing platform is solely intended to demonstrate fitness-for-purpose; metocean and structural criteria for an existing platform may be significantly different from a new design. To demonstrate structural fitness-for-purpose with ultimate strength methods there are two types of acceptance criteria available. The first is specific metocean loading criterion such as wave height, current, etc., and the platform should be shown to withstand without collapse. Alternatively, a minimum acceptable RSR is a measure of the platform loading relative to loads caused by the 100-year metocean conditions used for the design of the new platform. So it can be concluded that the current design codes and safety assessment criteria for offshore structures mainly deal with the extreme force, not the dynamic ice loads, because the interaction between ice and the structure is very complicated, and the dynamic force is hard to be simulated and a practical dynamic ice force model has not been well developed.

However, it is well known that ice could induce vibrations on slender jacket structures and the periodic loads are formed because of the ice failure of the structure. The phenomenon of ice-induced structure vibrations has been noticed and studied since the early 1960s [7]. In the 1970s, lighthouses in the Gulf of Bothnia encountered ice-induced vibrations and one of them collapsed [8]. Further, in the 1980’s, Molikpaq, the sand base of the caisson structure, in the Beaufort Sea, was liquefied because of ice-induced vibrations [9]. Since the late 1980’s, ice-induced vibrations have been noticed after the establishment of the first platform in Bohai Sea [10]. Based on the field monitoring data of the oil platforms in Bohai Sea, the probability of potential risk provoked by ice induced vibrations is greater than the collapse under extreme ice load. So, ice-induced vibrations are the key issues that endanger safe development of existing offshore structures, especially for the slender ice-resistant jacket platforms. So the evaluation methods or acceptance criteria available in API-2A WSD are not so sophisticated for existing structures in arctic area, dynamic assessment should be also involved.

In this paper, failure modes of ice-resistant jacket platforms, the related failure evaluation criteria, and risk grade are treated. Combined with monitoring data of ice loads, assessment strategy is presented. Lastly, as an application example, safety assessments of a practical platform in Bohai Bay are carried on.

2 STRUCTURAL FAILURE MODES OF ICE-RESISTANT JACKET PLATFORMS INDUCED BY ICE LOADS

Full scale observations carried out in the Bohai Sea show that ice-resistant jacket platforms in marginal oil fields are slender, and their basic frequency is roughly 1-2 Hz. Although under extreme static ice loads the safety reserves of ice-resistant jacket platforms are greater, and the structures could withstand the push-over ice force. Both vertical structures and conical structures encounter significant ice-induced vibrations. The failure modes of ice-resistant platforms in marginal oil fields are quite complicated.

2.1 Structural Safety Damage under Extreme Static Ice Load

In the current code-based design of offshore platforms, the seismic load, waves, sea current, wind, and ice loads are usually converted into equivalent static actions. The strength, stiffness and stability demands of the structures or components are evaluated under all sorts of equivalent static loads combination to guarantee that the stress, deformation and buckling load are less than their threshold values, respectively. It is recognized that the assessment of existing offshore structures is different from the design code of the new platforms. In the API RP-2A or DIS 19902, an ultimate strength assessment of existing jacket platforms determines the actual system capacity of the analyzed structures. It can be expressed in terms of the Reserve Strength Ratio (RSR), which is a measurement of the structure’s ability to withstand loads in excess of those determined from the platform’s design. The RSR is quantified as the ratio of the structure’s ultimate strength to a reference level load, and is expressed as:

$$R_s = F_u / F_d \quad (1)$$

Where R_s is the RSR, F_u and F_d represent sidelong force or overthrow moment of the foundation under ultimate and design load, respectively. When the design depth of water is greater than 30 meters, RSR can be described by the overthrow moment, or else sidelong force [10]. Tab.1 shows results of the maximal deformation, the maximal stress, and RSR of typical ice-resistant structures in Bohai Sea, such as JZ20-2 MUQ, JZ20-2 NW, JZ20-2MSW, and JZ9-3GCP, under extreme ice loads. The design ice thickness is about 42cm there. The maximal ratios of the calculation to the threshold for the deformation and stress are 27.3% and 27.1%, respectively. The safety reserves are greater, so the structures could withstand the push-over ice force. Even so, structural safety damage under extreme static ice load should be considered in the assessment of existing jacket plat

Table 1. The maximal deformation, stress of ice-resistant platforms and the RSR under extreme ice forces

platform	Maximal deformation(mm)		Maximal stress(MPa)		RSR
	Calculation value	threshold value	Calculation value	threshold value	
JZ20-2MUQ	15	168	23	225	11.2
JZ20-2MSW	24	130	61	225	5.42
JZ20-2NW	12	118	32	225	9.83
JZ9-3GCP	24	88	36	225	3.67

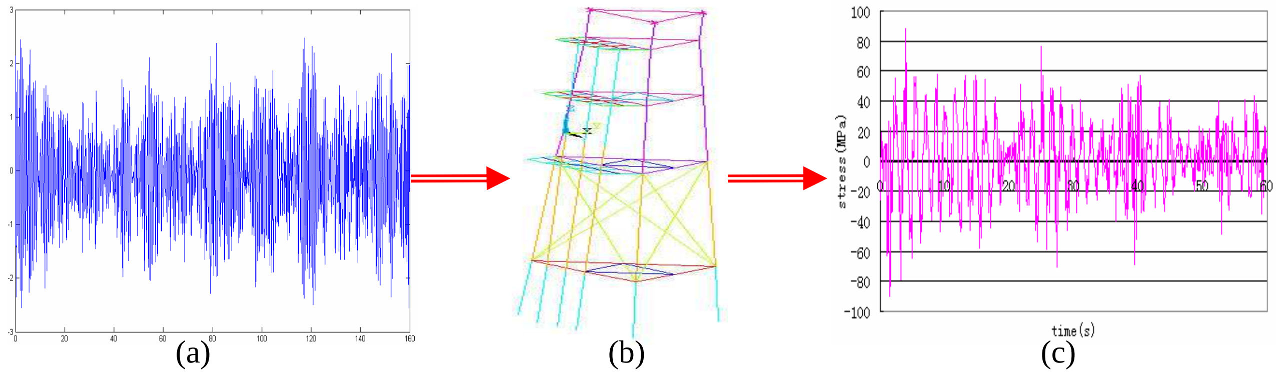
2.2 Structural Failures under Dynamic Ice Load

Due to the internal dynamic characteristics of ice load and ice-structure interaction, the ice breaking period may coincide with the natural period of the structure .It may cause the resonance vibration, which is quite harmful to the structure. Intensive ice-induced vibration has observed in some platforms in Bohai Sea in recent years. The dynamic performance requirements of ice-resistant platforms include the structural dynamic characteristics (the structural natural frequency) and ice-induced vibrations. The intensive ice-induced vibration could result in significant cyclical stress at the tubular joints of jacket structures hat may cause fatigue failure, the damage of facilities (pipeline systems) and discomfort of the crew members on platforms. Thus, multiple failure modes of structure, facilities and crew members under dynamic ice loads are treated herein.

2.2.1 Fatigue Failure Induced by Ice-vibrations

In order to verify the possibility of the structural fatigue failure under ice vibrations, estimating whether the cyclical stress of a hot-spot is greater than the fatigue limit stress is needed. Fatigue damage of the platform is induced by cyclical stress of the tube node. With the typical deck vibration response (see in figure 1 a) and the finite element model of the jacket platform (see in figure 1 b), the authors analyzed the fatigue stress using ANSYS software, as shown in Fig.1. Here are the monitored data of the structural vibrations under typical ice conditions which are chosen to validate the significance of the cyclical stress.

According to the type of the node and the structural parameters, The Stress Concentration Factors (SCF) of the node is considered based on the criterion promulgated by DNV [11]. In addition, according to the *S-N* curve of the steel provided by API 2A [12], the fatigue limit stress is about 41MPa when the limit fatigue life is $N = 10^8$. As shown in Fig.1 (c), the cyclical stress amplitudes of the structure induced by the typical ice condition are greater than the fatigue limit stress amplitude, in one minute the number of times is about 16, considering the SCF. So the cyclical stress induced by the ice forces may cause fatigue damage. It is easy to come to the conclusion that the cyclical stress is great enough to evoke fatigue damage and fatigue evaluation for the jacket ice-resistant platform in ice zone is nece.



(a) (b) (c)

Figure 1. Fatigue stress analysis by ANSYS software based on monitoring data.

2.2.2 Failures Induced by Deck Accelerations

Based on the data observed on the jacket platforms, sea ice can induce the periodic load and make the offshore jacket structures vibrate with major acceleration. Figure 2 shows the every-day max acceleration of ice-resistant platforms in winter 2004/2005. As production platforms, the vibrations have caused accidents.On January 28, 2000 one of the pipelines on the platform suddenly broke during steady-state vibrations as shown in figure 3. This caused high-pressure natural gas to rush out. Figure 4 shows the broken pipeline caused by vibrations. On February 7, 2000 a flange on the pipeline loosened during vibrations and caused leakage. The writers designed all kinds of torque spanners. During the examination and repair of offshore platforms in Spring, we found that connected bolts of 47% the flanges with graphite gaskets are loosed and the lowest remnant preload is only 50N.m. For a living platform, intensive deck vibrations could discomfort the crew members and even affect work efficiency or health

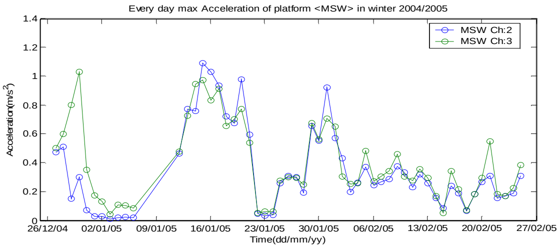


Figure 2. Every-day max acceleration of jacket platform in winter

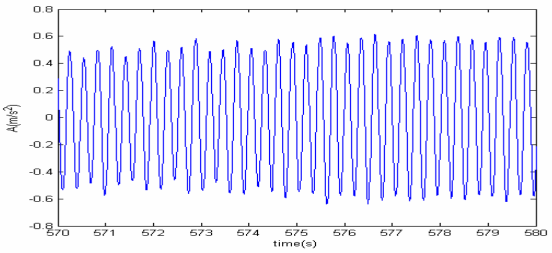


Figure 3. Steady state vibration caused by ice crushing failure

Figure 4. Broken pipeline caused by vibrations

.2.3 Evaluation Criteria and Index of Ice-resistant Jacket Platforms

The failure modes of ice-resistant platforms induced by ice loads include the following three major types:

(a) Structural safety failure mode, which includes the excess of the maximum deformation or strength of the structure to the threshold values under extreme static ice load and fatigue damage of tubular joints under ice-induced vibrations.

(b) Human factor failure mode, which may cause the physical discomfort, affect the work efficiency, and even endanger the health of the crew members due to significant vibration of platform deck.

(c) Facilities failure mode, which refers to the unserviceability or damage of the facilities on the platforms caused by ice-induced vibrations, such as fatigue fracture of pipes and looseness of flanges.

So the multiple evaluation criteria and index of ice-resistant offshore platforms under ice loads are summarized in Table 2.

Table 2. Discrimination index of ice-resistant platforms evaluation criteria

Failure type	Performance description	Failure discrimination index
Structure	Structural safety damage under extreme static ice load	Structural deformation or strength
	Structural fatigue damage under dynamic ice load	Cyclical stress of tubular joints
Human	Physical discomfort, degrading work efficiency, and even endangering health of the crew members induced by deck vibration	Equivalent deck acceleration, frequency, duration, and direction.
Facilities	Unserviceability or damageability of facilities on the platforms induced by deck intensive vibration	Equivalent deck acceleration

3 RISK ASSESSMENT STRATEGY OF ICE-RESISTANT JACKET PLATFORM

Risk assessment of ice-resistant jacket platforms is the evaluation of the risk or damage aspects of a particular system or homework, whether those risks are from human, hardware or software failures, or environmental events, or from combinations of such failures. An essential aspect of the risk assessment process is up-to-date platform information. Information on the original design, fabrication and installation, including results of numerical analyses, in-service inspections, engineering evaluations, structural assessments, modifications, strengthening, repairs, and operational incidents. Then an engineering evaluation should be performed. The evaluation establishes the requirement for structural assessment to demonstrate fitness-for-purpose. In this paper, risk assessment strategy of ice-resistance jacket platforms is presented, including dynamic ice load model, ice fatigue environmental parameters, and quantified risk assessment methods.

3.1 Dynamic Ice Loads

According to the form of platform's leg, there are two kinds of structures for ice-resistant jacket platforms, including vertical and conical structures. For vertical structures, three vibration modes, quasi-static force induced vibrations, steady-state vibrations and random vibrations, may appear during ice crushing failure with the ice speed changing from low to fast. The maximum vibrations appear in the steady-state vibrations, which have been measured on some vertical platforms in Bohai Bay. For the conical structures, the ice may fail in bending in most cases and the steady-state vibration disappeared. But the breaking period could coincide with the natural period of the structure and evoke resonance vibrations.

3.1.1 Dynamic Ice Load Model of Vertical Structures

Dynamic environmental forces can be characterized either in the time domain or in the frequency domain. A frequency domain method is often used for stochastic environmental forces. Tuomo Kärnä and Qu present a spectral model for dynamic ice forces on narrow vertical structures. The model is developed using results of spectral analyses of ice force data collected in full-scale test in the Bohai Bay, and its function can be expressed as [13]:

$$S(f) = \frac{7.2\sigma^2}{1 + 10.4 \times 7.2^{1.5} f^2} \tag{2}$$

Where σ is the mean square deviation of the ice force, can be given by:

$$\sigma = \frac{I_F}{1 + m I_F} F^p \tag{3}$$

Where I_F - the strength of ice, taking 0.4; m - constant, equal to 3.7; F^P - the static ice load of the vertical structures,

$F = \alpha \sigma_C D t$; where α =0.4~0.7, is taken as 0.4 herein;

σ_C is the uni-axis compression strength of ice, σ_C =2.1MPa;

D is the diameter of vertical leg; t is the ice thickness.

3.1.2 Dynamic Ice Load Model of Conical Structures

The dynamic ice load on the upward facing cone is similar to a pulse function. Yue and Bi [14] developed a load function of the ice acting on an upward cone. The period of ice force is related to the breaking length and the ice speed. At the high speeds, the significant ice-induced vibration will be evoked. The ice-load function expression is defined as

$$F(t) = \begin{cases} F_0\left(1 - \dfrac{t}{\tau}\right) & (0 \le t < \tau) \\ 0 & (\tau \le t < T) \end{cases} \qquad (4)$$

Where F_0 -ice force amplitude, T - ice force period, τ - the time of ice and cones interaction. Deterministic ice force function has clear physical meaning and it can be used in rough fatigue analysis.

On the other side, in order to analyse the responses in frequency domain, it need to build ice force spectrum. Yue et al. studied the type of ice force spectrum with field data, and built the ice force spectrum for conical structures based on the ice force history of years' field tests, and its function can be expressed as [5]:

$$S(f) = \frac{10 F_0^{\,2} T^{-2.5}}{f^{3.5}} \exp(-5.47 T^{-0.64} \frac{1}{f^{0.64}}) \qquad (5)$$

Where F_0 -ice force amplitude, T - ice force period of conical structures.

3.2 Ice Fatigue Environmental Parameters

Ice fatigue environment is the important factor to risk assessment for ice-resistant jacket platforms. Long-time ice condition data is the base of building the model of fatigue ice environment. Ice fatigue environmental parameters should include these five factors, ice thickness, ice velocity, ice flexural strength, ice period and ice flow direction. Yue et al. [16] accumulated integrated several years' ice condition data in Bohai Sea, which compose the foundation of building the ice fatigue environmental model. The statistical distributions of ice period and ice thickness are chiefly discussed as follow.

(1) **Ice thickness**

Based on ice thickness data of 8 years, 1996-2004, in JZ20-2 sea region of Bohai Sea, the statistical result indicates ice thickness preferably obey logarithmic normal distribution and passes the *K-S* check of conspicuous level *a=0.05*. The probability density function can be expressed as:

$$f(h) = \frac{1}{0.5503 h \sqrt{2\pi}} \exp[-\frac{1}{2}(\frac{\ln h - 1.8671}{0.5503})^2] \qquad (6)$$

Where h is the ice thickness.

(2) **Ice velocity**

Based on the data of 4 years' field test, 1996-2000, the probability analysis of ice velocity is carried on. The statistical results indicate ice velocity follows Rayleigh distribution and passes the *K-S* check of conspicuous level *a=0.05*. The probability density function can be expressed as

$$f(V) = \frac{V}{826.5512} \exp(-\frac{V^2}{1653.1024}) \qquad (7)$$

(3) **Ice flexural strength**

For the vertical structures, the yield compression strength of ice follows normal distribution, and the ratio of mean to standard value is 0.961, coefficient of variation is 0.115. And for the conical structures, the yield bending strength of ice belongs to normal distribution, the ratio of mean to standard value is 0.757, and the coefficient of variation is 0.159. In Bohai Sea, the compression strength is 2.1MPa, and the bending strength is 0.7MPa.

(4) **Ice drifting direction**

Field observation indicates that the ice drifting direction in JZ20-2 sea region of Bohai Sea is mainly controlled by tide and affected by wind. Because the tide in Bohai Sea belongs to regular tide, short-term data is enough to characterize the distribution of ice drifting direction. The statistical results of ice drifting direction are shown in Fig.5, and the benchmark is true north direction and the clockwise rotation is positive. It can be found from Fig.5 that the directions of NE and SW are the main ice drifting directions in JZ20-2 sea region of Bohai Sea

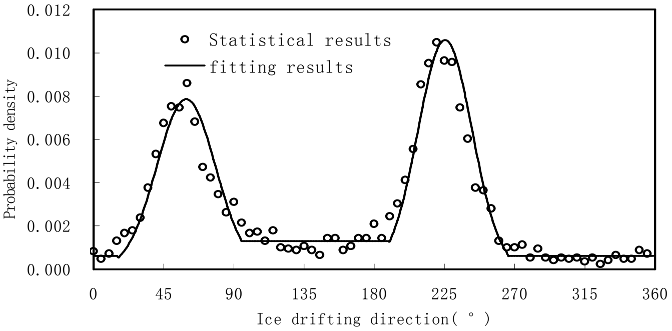


Figure 5. Probability distribution of ice drifting direction

(5) **Effectual ice period**

The grade of ice condition is the dominating factor to weigh the degree of ice condition and it varies from 1 to 5 along with light ice condition to heavy ice condition. It is obvious that the effectual ice period also changes with different grade of ice period. Calculating occurrence probability of the grade of ice condition in 1960-2004, we will get the probability distribution of the grade of ice condition. In Bohai Sea, the average effectual ice period of 44-year is 42 days

3.3 Risk Assessment of Fatigue Failure Induced by Ice-vibrations

Firstly, risk assessment of fatigue failure for ice-resistant jacket platforms needs to determine whether the cyclic stress of hot-spot induced by ice-vibrations under normal ice condition is so significant, i.e. it also need to determine whether the cyclic stress amplitudes are greater than the fatigue limit stress, based on the ice environmental parameters and structural dynamic characteristic. Then the evaluation of fatigue life by ice vibrations should be performed if the cyclic stress of tube node is great enough to evoke fatigue damage. The process contained in risk assessment of fatigue failure is illustrated in Figure 6, and it is continuous and sequential and provides a logical framework.

The method of safety life is based on Miner's linear cumulative fatigue hypothesis and *S-N* curve data, and it usually is suitable to apply to the offshore structures. Accordingly, the method of safety life is chosen to estimate ice-induced fatigue life in this paper. In fatigue analysis, the methods of assessing cyclic stress mainly include deterministic method, spectral method and time-domain method. Compared with other methods, spectral method has such advantages such as high computing velocity and enough computing precision and so on. The flowchart of spectral method for ice-induced fatigue analysis was presented by Liu [17]. Also for the existing platforms, the cyclic stress can depend on the monitoring data during the ice vibrations [18].

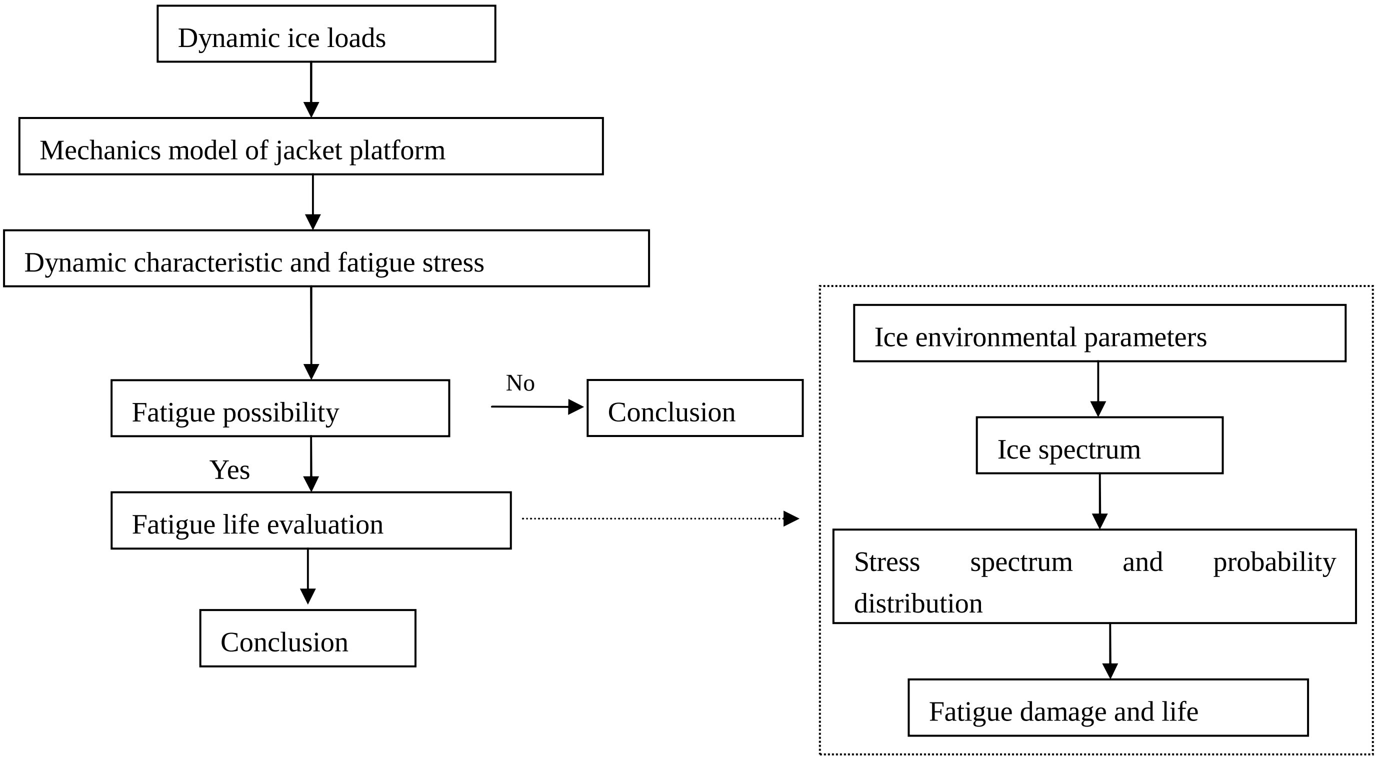


Figure 6. The risk assessment of fatigue failure proces

3.4 Risk Assessment of Acceleration Failure

Acceleration failure induced by ice vibration is specified, which as previously discussed, includes crew member and facility on the platform. Ice vibrations could influence the crew physiologically and psychologically who work and live in the vibration environment for long terms, and even endanger their health. Big amount of research indicated that the effect on bodies by vibrations lie on four main factors, i.e. acceleration amplitude, frequency, duration, and direction.

According to the above factors, three limitations were made to estimate the effects: comfort degradation, work efficiency degradation and exposure limitation. Based on the national code Reduced Comfort Boundary and Evaluation Criteria for Human Exposure to Whole-body Vibration [19], under high frequency less than 2Hz, every stage critical value of human feeling about the relationship between vibration acceleration and duration in level librations are shown in Table 3.

Table 3. Every stage critical value of human feeling about the relationships between vibration acceleration (m/s2) and duration in level librations

	24h	16h	8h	4h	2.5h	1h	25min	16min	1min
I	0.03	0.05	0.07	0.11	0.16	0.27	0.40	0.48	0.63
II	0.095	0.158	0.221	0.347	0.504	0.851	1.260	1.512	1.985
III	0.19	0.316	0.442	0.694	1.008	1.702	2.52	3.024	3.97

(Where I is the comfort degradation boundary, II is the work efficiency degradation boundary, III is exposure limitation. II is 3.15 times as great as I, and III is twice greater than II.)

Based on the data monitored, the direction of deck vibration is mainly level, and the energy of ice-induced vibration distributes mainly on first frequency of the response. So only considering basic frequency can guarantee enough precision in evaluation of operation crew feeling by ice vibration. Vibration magnitude is denoted by acceleration root-mean-square, it is average vibration amount in certain time T. The equivalent continuous acceleration root-mean-square was expressed as:

$$a_{eq} = [\frac{1}{T}\int_0^T a_e^2(t)dt]^{1/2} \tag{8}$$

Where $a_e(t)$ is acceleration root-mean-square of certain time t, m/s^2, T is integration time, s.

Also, the acceleration response can depend on numerical simulation, such as spectrum method, which is similar to fatigue stress analysis based on ice spectrum and fatigue environment.

Effective total exposure time T′ was written by:

$$t_i' = t_i \times \frac{\tau'}{\tau_i}$$

$$T' = \sum_i t_i' = \tau' \sum_i \frac{t_i}{\tau_i} \tag{9}$$

Where t_i' - equivalent to the actual time t_i of different acceleration, τ'-allowable exposure period, the ratio of τ′ / T′ should be larger than 1.

4. AN EXAMPLE OF RISK ASSESSMENT FOR AN EXISTING JACKET PLATFORM IN ICE ZONE

In this paper, JZ20-2MSW platform is chosen as an example of risk assessment by ice-induced vibration, shown in fig.7. The platform is a jacket structure with three piles and ice-breaking cones, and the maximal dimension of the cone is 4m. The total upper mass is 200t. The elevation of work point is EL. (+) 7.5 m and the design depth of water is 16.5 m.

Mode analysis is the base of dynamic analysis of the structure, and its results can also verify the rationality of the finite element model. The first order frequency calculated is 1.36Hz，which is very close to the field result, 1.37Hz. So it is evident that the built model is authentic.

Figure 7. JZ20-2MSW platform

(1) **Extreme static ice load**

From table 1, under the extreme ice load, the maximal deformation and stress are 24mm and 61MPa, respectively. And the ratios of the calculation to the threshold are 27.3% and 27.1%, respectively. The reserve strength ratio is 5.42. So the structure could withstand the push-over ice force.

(2) **Fatigue failure**

A medium ice condition with ice thickness 20cm and ice velocity 30cm/s are chosen to validate the significance of the cyclic stress. As shown in figure 1, the cyclic stress of tube node is great enough to evoke fatigue damage and fatigue life analysis for the jacket ice-resistant platform should be conducted.

According to the above-mentioned, ice fatigue work condition chiefly depends on ice thickness, ice velocity and ice drifting direction. Because the two chief ice drifting directions are almost in a beeline, in order to reduce computing time only one ice direction is considered.

The maximal ice thickness is regarded as the maximal design ice thickness, 45cm, and the maximal ice velocity is considered to be the maximal field tested value, 100cm/s. Furthermore, taking one kind of ice thickness at intervals of 3cm and one kind of ice velocity at intervals of 5cm/s. Every kind of ice thickness and ice velocity combine to make a kind of fatigue work condition, so there are 300 kinds of fatigue work conditions in all.

The position of the maximal stress occurs at the cross point of two inclined struts, which is shown in Fig.8. According to the results of hot-spot stress and the *S-N* curve provided by API 2A, the fatigue life which is is estimated with Miner's theory and the fatigue life of JZ20-2MSW platform is 30 years. Generally speaking, the design life of offshore platform is about 15-20 years. So the result indicates that the fatigue life of JZ20-2MSW platform satisfies the design requirement.

(3) **Acceleration failure**

With numerical statistics of the data monitored on the platforms of JZ20-2 MSW in winter 2002/2003, equivalent total exposure time and acceleration in different vibration surrounding are 4.3 hours and 0.37 m/s^2, respectively.

Compared with the ISO standard about human body in vibration environment, it is found that for a living platform, intensive deck vibrations could discomfort the crew members and even affect work efficiency or health.

Similarly, to the assessing fatigue stress based on spectrum method, figure 9 shows the maximal acceleration amplitudes of JZ20-2MSW platform in 300 kinds of ice condition. The acceleration is so intensive when the ice thickness and the ice velocity are larger than 15cm and 20cm/s, respectively. So the risks of pipe fracture and flange leakage could be evoked by the serious moving ice.

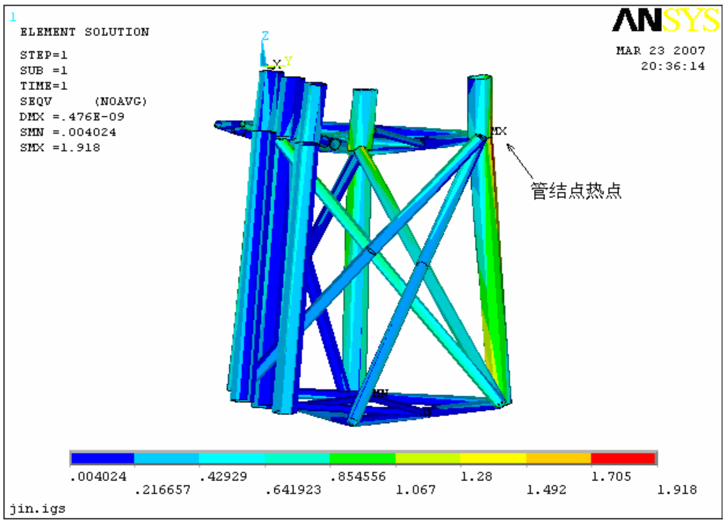


Figure 8. Typical stress nephogram of MSW platform

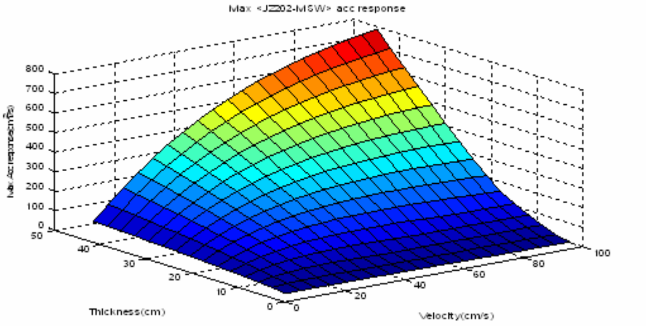


Figure 9. The maximal acceleration amplitudes of JZ20-2MSW platform

5 CONCLUSION

The design of ice-resistant jacket platform was not so sophisticated because the risk assessment only considered ultimate strength under extreme ice load, such as pushover failure mode. In this paper, based on the years' full-scale tests, the risk evaluation criteria for existing jacket platforms are treated. What's more, ice-induced vibration and failure modes of ice-resistant compliant structures are analyzed.

Although the safety reserves of ice-resistant jacket platforms are greater under extreme static ice load, the structures could withstand the push-over ice force. Both vertical structures and conical structures encounter significant ice-induced vibrations. The offshore structural vibrations induced by dynamic ice loads may evoke two kinds of risk. The intensive shaking of the deck may endanger the facilities of the platform and discomfort the crew members. Additionally, cyclical stress on tubular nodes of the jacket structures may reduce the structural fatigue life. In this paper, the assessment strategy of all kinds of failure modes is present.

Until now, ice-induced vibrations and its consequence should be considered for the risk assessment of ice-resistant platforms in ice zone. It will also bring forth studies of related problems, such as practical dynamic ice force models, fatigue analysis, a complete evaluation of crew member's health, and dynamic response analysis of pipeline systems exposed to ice-induced vibrations on offshore platforms, vibration mitigation and control.

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