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Fatigue analysis of Vortex-induced Vibration of risers based on Shear 7

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Abstract

Riser as connection the only channel of drilling platforms and the seabed wellhead is important for deep water drilling, and the marine environment is extremely complex, on the riser VIV will speed up the riser fatigue damage, so in order to ensure the reliability of the riser, reducing the loss of ocean drilling, to the deep ocean environment of riser VIV fatigue damage.This paper studies the VIV fatigue damage mechanism, and the Shear 7 software about VIV fatigue damage calculation method, to 2000m depth of riser system VIV fatigue damage analysis, it is concluded that natural frequency of the riser system, RMS stress as well as the annual rate of fatigue damage, the shortest root stress of the riser system is obtained and the fatigue damage rate occurs at the top of the riser;By analyzing the influence of roof tension coefficient and outer diameter parameters of risers on the VIV fatigue damage of risers, it is concluded that the higher top tension coefficient is, the lower fatigue damage rate of risers is, the longer service life is, the smaller outer diameter of risers is, and the lower RMS stress and fatigue damage rate of risers are.

Keywords

Vortex-induced vibration;RMS stress;Fatigue damage rate;Top tension rate.

1. Introduction

The vortex-induced vibration(VIV) of riser will cause high-frequency alternating stress, and the continuous vorticity induced vibration will easily lead to riser fatigue, which will reduce its mechanical properties and accelerate the riser fracture [1,2]. The stability of riser system will directly affect the smooth progress of deep water drilling. C. Ridge [3] et al. experimentally tested the response results of single vorticity induced vibration of risers at the full-size interface, and converted the experimental results into the Shear 7 life curve and damping coefficient of risers. Liangbin Xu [4] et al. used Shear 7 to analyze the vortex-induced vibration performance of bare risers, staggered distribution risers with buoyancy blocks and full buoyancy blocks, and quantitatively analyzed the natural frequency, root mean square displacement, root mean square stress and fatigue damage of risers under different buoyancy block distribution schemes. It is concluded that the staggered distribution of buoyancy blocks is the best solution.

2. VIV fatigue mechanism

2.1. Fatigue damage computing method

Fatigue damage calculation method: the amplitude of stress in one cycle was counted, and the occurrence times of stress amplitude were counted by rain-flow counting method. Finally, the fatigue damage of one cycle was calculated according to Miner criterion [5].

Fatigue analysis, generally according to the material S-N curve, according to the heat treatment on the surface of the component, roughness and temperature, the influence factors such as

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structure size effect correction curves, and calculation of stress amplitude under different condition combination, the rain flow count method is adopted to stress amplitude cyclic number, and the size of the average stress, W and stress amplitude values stored in the matrix, the damage accumulation by linear damage rule of Miner, corresponding fatigue calculation results. The linear equation of cumulative fatigue damage[6,7] is:

$$\sum \frac{n}{N} = 1$$

Where: n -- the number of load cycles of each stress amplitude; N -- Fatigue life for each stress amplitude.

2.2. Shear 7 computing method

Shear 7 software can be directly calculated modal vibration mode and natural frequency of curvature and inherent characteristic parameters, such as, can also be based on the finite element method to get high precision of structure modal parameters, and the modal parameters in Shear 7, according to the modal superposition theory to calculate the structure of each node RMS displacement and RMS stress and fatigue damage rate, etc. Shear 7 could simulate a variety of models and boundary conditions according to the principle of energy balance. Here, the mechanical model and boundary conditions as shown in Figure 1 were selected as the calculation model, so as to obtain the results of modal responses of each order and calculate the overall response of the riser by using the theory of modal superposition[8].

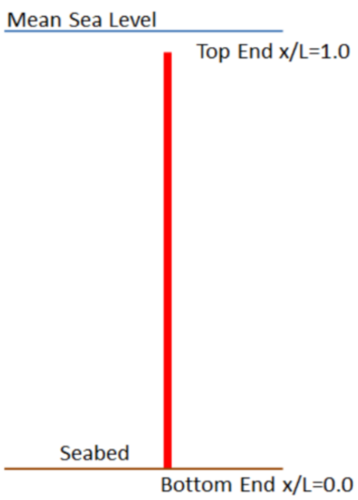

Fig. 1 Mechanical model of riser

2.3. Establishment and calculation of simulation model

In the Shear 7 , the critical damping ratio of the structure was 0.003, the Stokes number St code was 0.18, the lift coefficient model was 1, the additional mass coefficient and lift coefficient were 1, the stress concentration coefficient SCF was 1.2, and the reduced velocity double broadband was 0.4[9].VIV fatigue analysis of risers was carried out with a water depth of 2000m. The outer diameter and wall thickness of risers were 21in and 1.25in respectively. The parameters and configuration are shown in Table 1.

Table 1 2000m drilling riser system configuration and related parameters

Name	Number	Outer diameter(m)	Joint length(m)	Distance from the seabed(m)
Terminal single	1	0.5334	42.7	2021.2
Nipple	1	0.5334	17.3	1978.5
Naked single	6	0.5334	22.86	1961.2

Buoyancy single 3000ft	28	1.2827	22.86	1824.04
Buoyancy single 4000ft	12	1.308	22.86	1183.96
Buoyancy single 5000ft	11	1.333	22.86	909.64
Buoyancy single 6000ft	10	1.359	22.86	658.18
Buoyancy single 7000ft	9	1.414	22.86	429.58
Naked single	9	0.5334	22.86	223.84
Submarine BOP assembly	1	-	9.1	18.10
LMRP	1	-	7.5	9.00
The seabed wellhead	1	-	1.5	1.50

Based on the calculation of the above parameters, it is obtained that the riser system has a total of 16 excitation modes, the main excitation mode is the third order, and the corresponding frequency is 0.0973Hz.Table 2 lists the frequencies corresponding to the first ten modes.The changes of root mean square stress and fatigue damage rate of vortex-induced vibration of the riser obtained by Shear 7 calculation with the relative position of the riser were shown in Fig.2 and 3, respectively[10].

Table 2 Frequency of the first ten modes

Modal order time	1	2	3	4	5
Frequency(Hz)	0.0209	0.0418	0.0627	0.0837	0.1046
Modal order time	6	7	8	9	10
Frequency(Hz)	0.1256	0.1466	0.1676	0.1887	0.2098

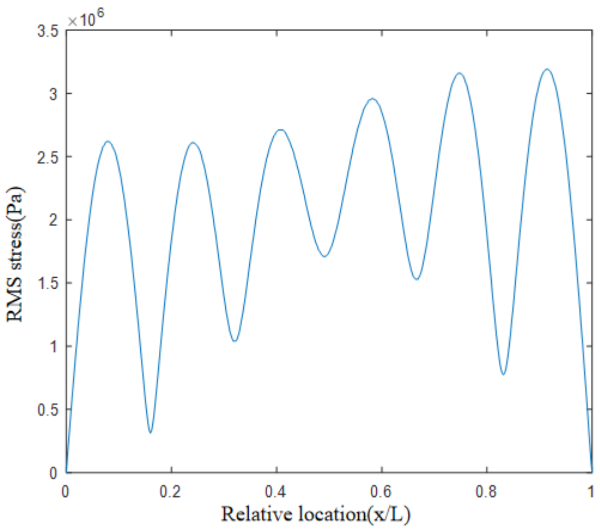

Fig. 2 RMS stress response of risers

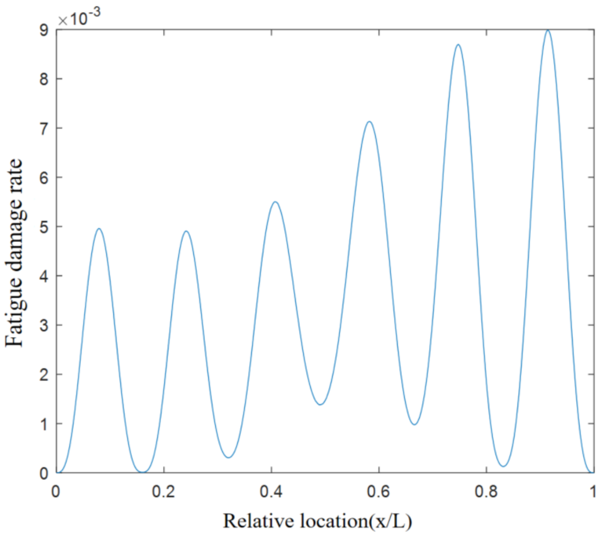

Fig. 3 Fatigue damage rate

According to Figure 3, it can be seen that the maximum RMS stress of the riser appears at the upper end of the riser x/L=0.896, and the value is 3.16MPa. The overall change shows an oscillating wave pattern. The maximum fatigue damage of the riser also occurred at the upper end of the riser x/L=0.896, with a value of 0.00899.Care should be taken to protect the riser upper end from fatigue damage when configuring the riser system.

3. Analysis of influencing factors

3.1. Top tension coefficient

For the influence analysis of the riser's top tension coefficient, the top tension coefficient R was 1, 1.2, 1.4 and 1.6 respectively [11],the coverage rate of buoyancy block was 80%,the outer diameter of the riser was 0.5334m and the inner diameter was 0.47m.The changes of RMS displacement, RMS stress and fatigue damage rate of riser system under different roof tension coefficients can be obtained through calculation, as shown in FIG. 4 and 5.

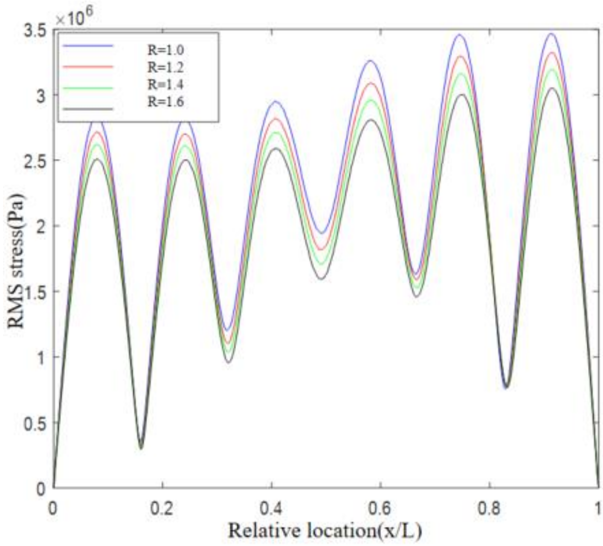

Fig. 4 RMS stress response of risers

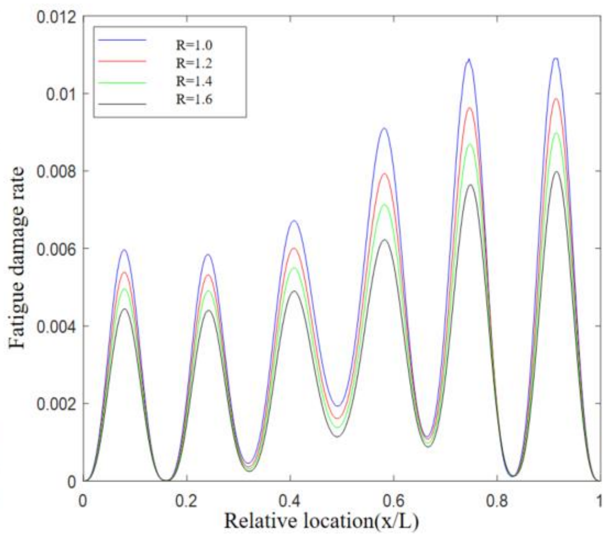

Fig. 5 Fatigue damage rate

Can see from the picture, with the increase of riser top tension coefficient, the root mean square of riser system stress and fatigue damage rate have obvious drop, top tension coefficient is 1.6 when the maximum RMS stress is 3.049 MPa, the biggest fatigue damage rate is 7.9×10^{-3}, the RMS of top tension coefficient is one of the biggest stress 3.466 MPa, the biggest fatigue damage rate is 1.09×10^{-2}, thus it can be seen that the top tension increased riser can obviously reduce the riser fatigue damage.

3.2. Outer diameter

This section analyzes the influence of the riser's outer diameter *d* on the vortex-induced vibration response of the riser system, and selects 19in, 21in, 23in and 25in of the riser's outer diameter to study the vortex-induced vibration fatigue of the riser system with the top tension coefficient of 1.4[12]. The changes of root mean square stress and fatigue damage rate of the riser system are shown in FIG. 6 and 7.

The RMS stress and fatigue damage rate of riser system increase with the increase of riser diameter. The maximum root mean square stress and fatigue damage rate occurred in the same location of the riser. When the riser diameter was 25in, the maximum fatigue damage rate of the riser system was 1.6×10^{-2}, 3.88MPa, 6.6×10^{-3} and 2.83MPa, respectively. Therefore, the smaller the outside diameter was, the minimum fatigue damage rate of the riser system was.

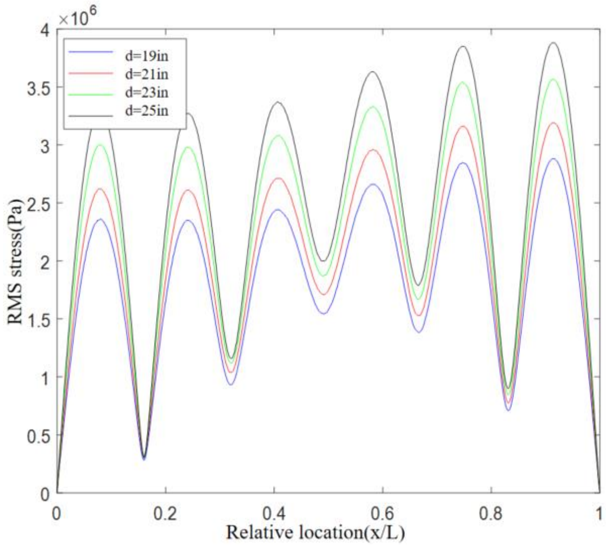

Fig. 6 RMS stress response of risers

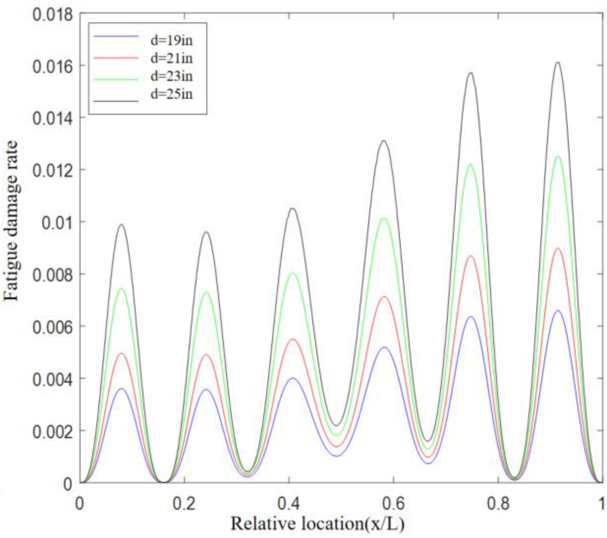

Fig. 7 Fatigue damage rate

4. Summary

(1) The Shear 7 software was used to calculate the VIV response at each node of the riser according to the theory of modal superposition, including RMS stress and fatigue damage rate. The maximum RMS stress and fatigue damage rate of the riser system generally occur at the middle and upper end of the riser[13,14].

(2) Increasing the top tension of the riser system can effectively reduce the vortex-induced vibration response of the riser. The larger the top tension is, the smaller the RMS stress and fatigue damage rate of the riser system are.

(3) The diameter of riser size also has a large influence on VIV fatigue damage, you can see the riser diameter is smaller, the smaller the RMS stress and fatigue damage, so using small riser diameter can effectively reduce the fatigue damage, but also according to the actual working condition and the rigidity of the riser is chosen and analyzed [15].

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