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Damping Plate Effects on the Fatigue Life of Riser Connected to Cell Spar Platform

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Abstract

Spar platforms have been installed as a competitive alternative offshore production structure for deepwater oil field. Since the first spar platform was constructed, its configuration has evolved to the so-called the truss spar and then the cell spar. This paper describes the dynamic analysis and fatigue life assessment of steel catenary riser (SCR) connected to cell spar platform. Two different cell spar platforms are considered herein; the original cell spar and the modified one. The original cell spar was modified by introducing an additional damping plate at its bottom in order to reduce wave-frequency motions. Firstly the wave-frequency motions of cell spar platforms are calculated based on the potential theory. Then, the dynamic responses of SCR induced by platform motions are computed. Finally the fatigue life of SCR is estimated by spectral method and the performance of two spar platforms are compared in terms of the fatigue life. Through the present study, it is found that the fatigue life of the modified cell spar increases only slightly.

Keywords: cell spar platform, damping plate, steel catenary riser, spectral fatigue analysis, fatigue life

1 Introduction

The development of offshore oil and gas in shallow water is almost completed, while the exploration and production moves to deeper water. In deepwater, the dynamic behavior of the platform becomes more important for design criteria. It is particularly the case for the tension and fatigue life of risers. Because of the excellent motion characteristics, spar platforms have been installed as a competitive alternative offshore production structure for deepwater. The first spar platform, Neptune Spar, was installed in Gulf of Mexico in 1996. Since the first spar platform was constructed, its configuration has evolved to the so-called the truss spar and then the cell spar. The natural periods of classical spar platforms are relatively long, 30 sec for heave, 60 sec for pitch, due to small waterplane area. In case of truss spar and cell spar, the natural periods are also far from typical wave periods. Therefore spar platforms are an attractive solution for deepwater regions where the environmental conditions are severe.

However, the heave motion of the classical spar is highly amplified at resonance due to its small damping. Moreover, large nonlinear unstable pitch motions are induced when the pitch natural period is about double the heave natural period and the heave motion exceeds higher than a certain threshold. Similar motion characteristics are shown in case of the cell spar, too. The mechanism of this unstable pitch motion is investigated mathematically by using the Mathieu-type equation. From the previous research, it was found that an additional damping plate reduced the heave motion at resonance and stabilized the nonlinear unstable pitch motion (Rho and Choi 2003, Lim and Choi 2006).

In this paper, the effect of the additional damping plate on the fatigue life of the steel catenary riser is investigated. Two different cell spar platforms are considered; the original cell spar and the modified cell spar. The original cell spar is Red Hawk cell spar installed in Gulf of Mexico. And the modified cell spar is similar to original one but it has an additional damping plate at its bottom. The fatigue life of SCR is estimated by spectral fatigue method and the performance of two spar platforms are compared in terms of the fatigue life.

2 Motion Analysis of Cell Spar

First of all, the motion responses of two different spar platforms are calculated in order to assess the fatigue life of SCR. The original cell spar is Red Hawk cell spar installed in the Gulf of Mexico in 2004. Red Hawk cell spar consists of a bundle of seven cylinders as shown in Figure 1. The center cylinder and three outer cylinders are 85 m long, while the other three cylinders are 170 m long. The diameter of each cylinder is 6 m. The particulars of the original cell spar are listed in Table 1. The modified cell spar is similar to the original one but it has an additional damping plate at its bottom. The diameter of the additional damping plate is taken to be 24.5 m and its thickness to be 0.25 m.

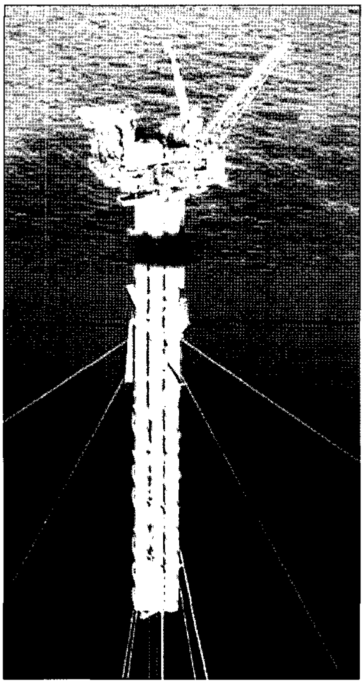

Figure 1: Red Hawk cell spar

Table 1: Particulars of Red Hawk cell spar

Red Hawk Cell Spar	
Location	Gulf of Mexico
Water Depth	1,615 m
Displacement	21,800 ton
Draft	155 m
Cell Diameter	6 m
Cell Length	170 m, 85 m
Damping Plate	4 Plates

The equation of motion of a floating structure in regular waves can be written as follows:

$$\sum_{j=1}^{6} \xi_j[-\omega^2(M_{ij}+a_{ij})+i\omega b_{ij}+c_{ij}]=F_i \tag{1}$$

where

M_{ij} : Mass Matrix or Moment of Inertia Matrix
a_{ij} : Added Mass or Added Moment of Inertia
b_{ij} : Damping Coefficients
c_{ij} : Hydrostatics Coefficients
ξ_i : Complex Amplitudes of Motion
F_i : Complex Amplitudes of Exciting Force and Moment

In this paper, the hydrodynamic coefficients and the wave-frequency motions are calculated using the 3-D diffraction program package. Panel models are shown in Figure 2 Figure 2(a) represents the original cell spar, and Figure 2(b) shows the panel model for the modified cell spar. Figure 2(c) shows the enlarged figure of the additional damping plate.

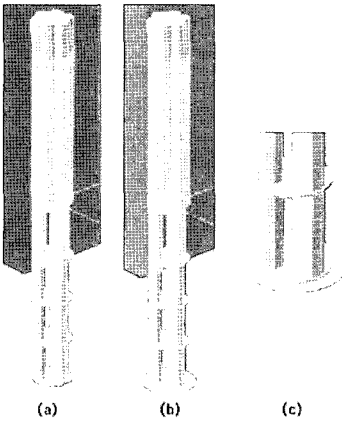

Figure 2: Panel model of cell spar platforms

The heave and pitch transfer functions of the original cell spar are illustrated in Figure 3, while those of the modified cell spar in Figure 4. In each figure, the solid line indicates the calculated results, and the symbols mean the model test result (Lim and Choi 2006). The heave response of original cell spar is highly amplified at resonance, but the model test yields to slightly less than the half value. The difference may be caused by viscous effect. This viscous effect also affects the difference of natural frequency between the calculation and the experiment. The experimental data of the original cell spar shows nonlinear unstable pitch motions at the heave natural frequency (Lim and Choi 2006). The heave response of the modified cell spar is similar to that of original cell spar except for resonance. According to the model test, heave motion is remarkably reduced due to the additional damping plate. Moreover the nonlinear unstable pitch motions are also reduced.

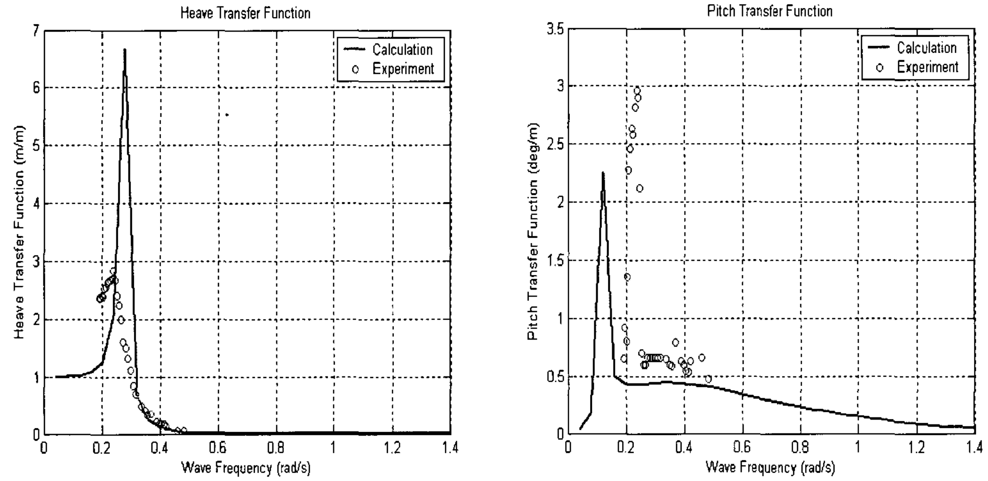

Figure 3: Motion transfer functions of the original cell spar

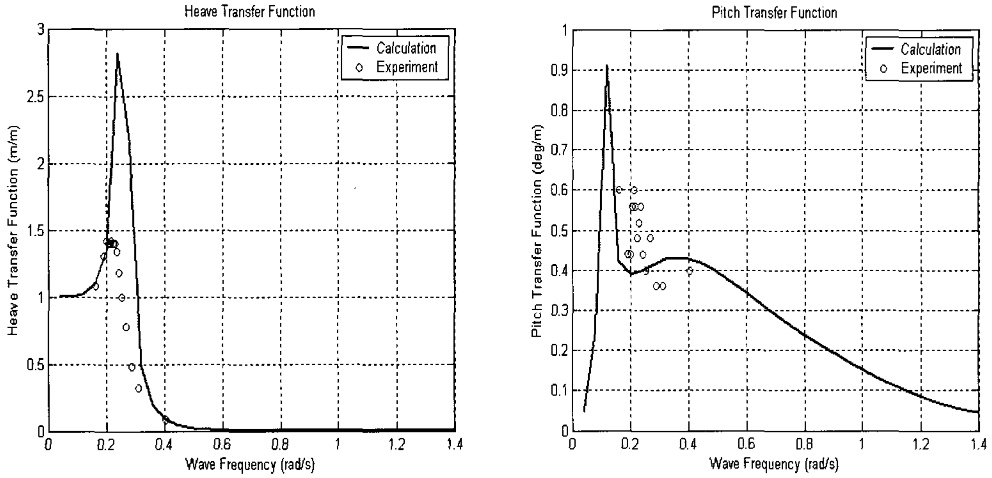

Figure 4: Motion transfer function of the modified cell spar

3 Fatigue Life Estimation of SCR

In deepwater, the fatigue life of riser must be analyzed carefully because of the increased tension and bending moment caused by severe environmental condition. In order to investigate the effect of damping plate on fatigue of riser, the fatigue life of SCR connected to cell spar platform is estimated using spectral method.

The fatigue life is estimated under the assumption that responses are linear. Firstly, the wave spectrum like JONSWAP is need for representing each sea state. JONSWAP is expressed by Eq. 2.

$$S(\omega)=\frac{\alpha g^2}{\omega^5}\exp[-\frac{5}{4}(\frac{\omega_P}{\omega})^4]\gamma^r \tag{2}$$

For each sea state, the stress transfer function is obtained as the result of the dynamic analysis of SCR. In this work, SCR is supposed to be oscillated in phase with the wave frequency motions of the floater. Then the stress response spectrum can be derived by

$$S_\sigma(\omega)=S(\omega)\times H_\sigma(\omega)^2 \tag{3}$$

If the response is narrow banded then the equivalent stress and mean zero crossing period can be defined by

$$\sigma_{eq}=(8m_0)^{\frac{1}{2}}[\Gamma(\frac{2+m}{2})]^{\frac{1}{m}} \tag{4}$$

where m is the exponential coefficient,

$$T_{z\sigma}=2\pi\sqrt{\frac{m_0}{m_2}} \tag{5}$$

The annual fatigue damage is defined by the so-called Miner's Rule.

$$D_Y=\sum_j\left(\frac{n_{\sigma_j}}{N_{\sigma_j}}\right) \tag{6}$$

In the above equation, n_{σ_j} is the number of stress cycles per year for each zero crossing period. n_{σ_j} is evaluated by Eq. 7.

$$n_{\sigma_j}=\frac{365\times24\times60\times60}{T_{Z\sigma_j}}\frac{N(T_{Zj})}{\sum_j N(T_{Zj})} \tag{7}$$

N_{σ_j} is defined by Eq. 8 as the number of cycles to the fatigue failure.

$$N_{\sigma_j} = \frac{A}{{\sigma_{eq_j}}^{m}} \tag{8}$$

Finally the fatigue life is estimated by Eq. 9.

$$L = \frac{1}{D_Y \times \gamma} \tag{9}$$

where γ is the safety factor (Barltrop 1996).

The gas export riser of Red Hawk cell spar as shown in Figure 5 is taken for numerical example. The particulars of SCR are given in Table 2. Table 3 shows the wave data of the Gulf of Mexico used for fatigue life estimation (Chang and Isherwood 2003).

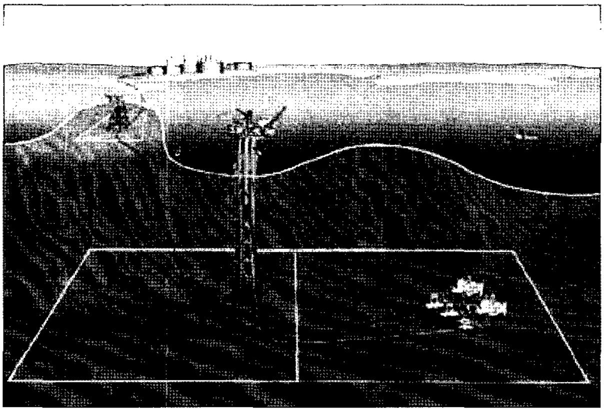

Figure 5: Riser system of Red Hawk cell spar

Table 2: Particulars of SCR

Riser	16 Inch Gas Export SCR
Water Depth	1,615 m
Riser Length	2,100 m
Horizontal Length	1,000 m
Mass	256.5 kg/m (in Air)
Outer Diameter	0.406 m
Wall Thickness	0.0254. m
Top Angle	9.5°

Table 3: Wave data for the Gulf of Mexico

Wave Case	Peak Wave Period (sec)	Significant Wave Height (m)	Exposure Hours per Year
1	4.2	1.4	2006
2	5.2	2.1	2934
3	6.2	3.3	2258
4	7.2	4.3	973
5	8.3	5.9	411
6	8.9	7.2	133
7	9.3	8.7	33
8	10.9	11.5	8.3
9	11	12.0	0.7
10	11.6	14.0	3.0

The dynamic tension and bending moment of SCR are calculated using a code ‘RIFLEX’. SCR is supposed to be oscillated in along with motions of the platform. Static line configuration is shown in Figure 6. In this figure, the result obtained from the catenary equation is also shown for comparison. It is observed that two results coincide quite well each other. Figure 7 and Figure 8 show dynamic tension and bending moment of SCR connected to original spar platform respectively when wave frequency is 0.24 rad/s and amplitude is 1 m. Static tension has maximum value at the upper end of SCR and variation of tension is almost same along SCR. Variation of bending moment at touch down point (TDP) is much larger than other parts of SCR. Although the graphs do not be shown in this paper, trends of the modified cell spar are similar to that of the original one. It means that the upper end of SCR and TDP are the critical point for both cases.

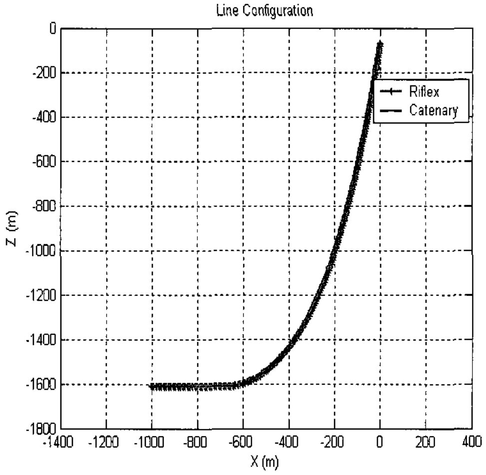

Figure 6: Line configuration of SCR

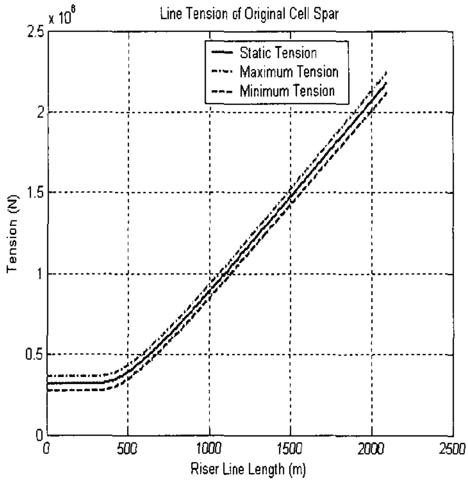

Figure 7: Dynamic tension of SCR for the original cell spar

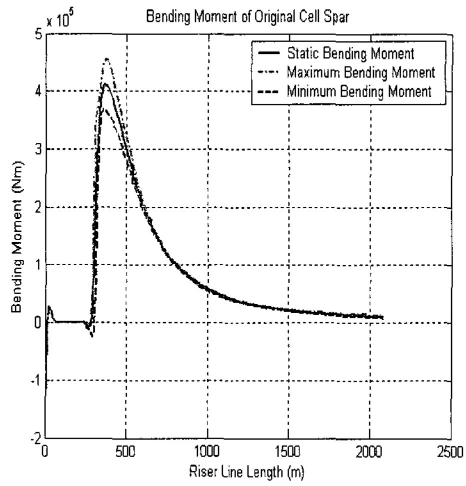

Figure 8: Dynamic bending moment of SCR for the original cell spar

The fatigue life of SCR is calculated by the statistical method as mentioned previously. For the fatigue analysis, a stress concentration factor of 1.2 was assumed, and the DNV 'E' S-N curve was used for cumulative damage calculation (Petruska and Zimmermann 2002). The safety factor used in this calculation is 10 according to the general regulation (Campbell 1999). The results are shown in Figure 9 and Figure 10. The fatigue life at critical regions is listed in Table 4. The minimum fatigue life is 50.56 years for the original cell spar and 51.68 years for the modified one. It is found that fatigue life of the modified cell spar increases slightly. However, the effect of the additional damping plate on the fatigue life is smaller than that on the motion response. It may be because the additional damping plate does not affect the high frequency motion, while the influence of high frequency motions may be dominated by wave data for fatigue analysis.

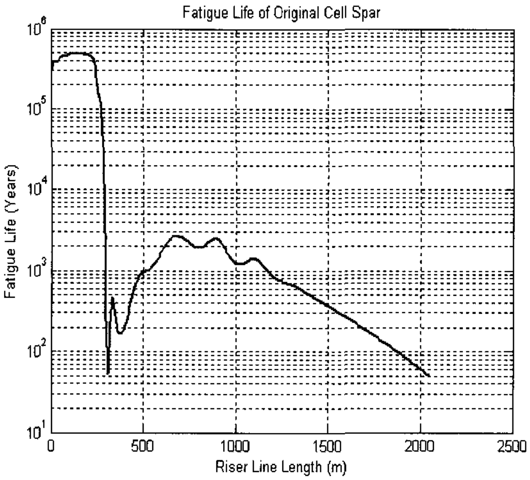

Figure 9: Fatigue life of SCR for the original cell spar

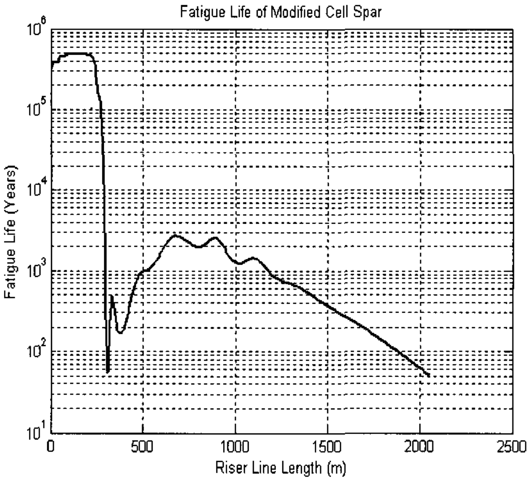

Figure 10: Fatigue life of SCR for the modified cell spar

Table 4: Fatigue life at critical regions

Fatigue life	Original Cell Spar	Modified Cell Spar
Upper End (years)	50.56	51.68
TDP (years)	53.19	54.40

4 Conclusions

In this paper, the effect of an additional damping plate on the fatigue life is investigated. Two different cell spar platforms, the original cell spar and the modified one, are considered herein. The modified cell spar was derived by an additional damping plate at its bottom. Using the motion responses, the fatigue life of SCR connected to cell spar platform is estimated by spectral method.

It is found that the damping plate reduces the motion response significantly, but fatigue life of the modified cell spar increases only slightly. It may be conjectured that the additional damping plate does not affect the high frequency motion of cell spar platform, while the high frequency motion gives a great contribution to the fatigue life.

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