Dynamic Response and Fatigue Damage Analysis for Drilling Riser

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***Abstract*—Drilling riser is the key equipment that connects subsea wellhead to drilling platform. The security of drilling riser concerns whether the drilling operation can be completed successfully. Drilling riser suffers fatigue damage as a result of its vibration under environmental loads. This paper established nonlinear dynamic analysis method of drilling riser based on pipe-soil interaction in time domain. Rainflow counting method, S-N curve and Miner-Palmgren rule are used to establish fatigue damage model and corresponding computer program is developed. The effects of soil stiffness, wall thickness and welding eccentricity on fatigue damage of drilling riser are derived, which provide theory basis for the design and operation of drilling riser.**

Keywords-Drilling Riser；Dynamic Response；Fatigue Damage；Soil Stiffness；Wall Thickness; Welding Eccentricity

I. INTRODUCTION

Drilling riser is an important channel connecting subsea wellhead and drilling platform, whose main functions are to separate seawater, guide drilling tool and loop drilling fluid. As the important but fragile part of the drilling system, security of drilling riser should be emphasized. Vibration can be induced by wave and current and results in fatigue damage. So it is important to conduct dynamic response and fatigue damage analysis for drilling riser. As the drilling riser is usually perpendicular to the sea level, fourth-order linear partial differential equation is used to calculate lateral displacement of drilling riser[1][2]. Finite element method (FEM) software is used to analyze mechanical characteristics of drilling riser, which can take the geometric nonlinearity caused by overlarge lateral displacement into consideration[3][4]. There are two methods used to calculate the fatigue damage of ocean risers: one is with S-N curve and Miner linear cumulative damage criteria; the other one is fracture mechanics. Usually the first one is applied in the engineering. But in recent years method of ductile mechanics is being given more and more attention and got into application in offshore engineering[6].

Time domain nonlinear dynamic analysis for drilling riser used in Jack-up platform is conducted in this paper. Rain-flow counting method, S-N curve and Miner linear cumulative damage criteria are used to establish the fatigue damage model for drilling riser. Meanwhile parameters sensitivity analysis of influencing factors on fatigue is done which provides theoretical foundation for design and operation of drilling riser.

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II. NONLINEAR DYNAMIC ANALYSIS FOR DRILLING RISER IN TIME DOMAIN

Before the FEM model of drilling riser is established, the environmental loads and constraint conditions are need to be analyzed which is vital for the overall model of drilling riser.

A. *The overall model of drilling riser*

The top part of drilling riser used in Jack-up platform is connected to the blow out preventer (BOP) and the bottom part is penetrated into soil, which means that it is perpendicular to seabed. Besides gravity and buoyancy, there are also lateral hydro-force caused wave and current. As the length of drilling riser is far larger than its diameter, beam element can be used in this model. The overall model of drilling riser is shown in Fig.1.

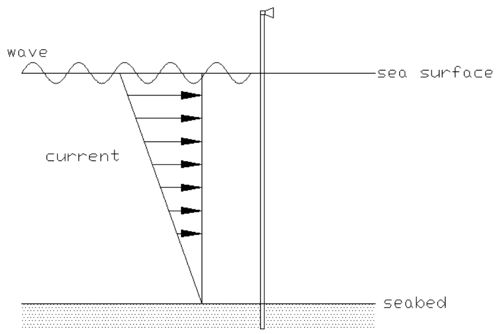

Figure 1. The overall model of drilling riser

B. *The theory of environmental loads*

Environmental loads are mainly come from wave and current. As the dimension of drilling riser is relatively small (Ratio of outer diameter and wave length is less than 0.2), Morison equation is used to calculate fluid force, which is composed of drag force and inertia force. The equations are as followed:

$$F = F_D + F_I \tag{1}$$

$$F_D = \rho C_D D_o V_{fn} \,|V_{fn}|\,/2 \tag{2}$$

$$F_I = \rho \pi D^2 C_M a_{fn} / 4 \tag{3}$$

where F_D is the drag force; F_I is the inertia force; ρ is seawater density; C_D is the drag coefficient; C_M is the inertia coefficient; D_o is the effective outside diameter; V_{fn} is the velocity of water particle; a_{fn} is the acceleration of water particle.

C. Boundary conditions

Besides the environmental loads resulted from wave and current, the two ends are constrained. How to deal with the boundary condition matters the order of accuracy. As the BOP is connected to the upper end of drilling pipe used in Jack-up platform, pin joint is used. The penetration depth of bottom end of drill riser into soil usually ranges from 30m to 100m[7]. Drilling riser can produce lateral vibration owing to environmental loads. As a result there is interaction between soil and the segment of pipe penetrated into soil. PSI element in ABAQUS can simulate the interaction between pipe and soil really good, so it is used to create the interaction model.

III. FATIGUE DAMAGE MODEL

Alternate stress is produced on drilling riser owing to wave load, which cause fatigue damage. Creation of reasonable and precise drilling riser fatigue damage model is critical to guarantee the safety of drilling operation. Rain-flow counting method, S-N curve and Miner-Palmgren rule are used to create this model and corresponding computer software is compiled.

A. Rain-flow counting method

The curve of Von Mises stress versus time is got after time-domain nonlinear response analysis is conducted on drilling riser. Calculation of fatigue damage needs to count the stress amplitude and number of cycles. The rain-flow method is a counting method which takes stress-strain nonlinear relation into consideration and combines hysteresis loop in the stress statistical analysis and fatigue damage theory. Every part participated into counting is counted one time. Meanwhile it is assumed that the small hysteresis loop does not influence the fatigue damage caused by big circle. It is publicly accepted as the most precise method.

B. S-N curve

S-N curve is got by tests on samples with different stress levels and statistical analysis of every group of test data. DNV's criteria presents S-N curves of different structures as shown in Fig.2 [8].

Drilling riser is tubular structure, so the effect of pipe thickness is needed to be considered. For hot region (such as welding point) , stress concentration factor (SCF) should be determined. The corresponding S-N curve is as follows[5]:

$$N = \bar{a}[S_0 \cdot SCF \cdot \left(t / t_{ref}\right)^k]^{-m} \tag{4}$$

where S_0 is the nominal stress amplitude; t is wall thickness; t_{ref} is reference wall thickness; tubular point is 0.025m, $\bar{a}$, k and m are constants. The welding part of drilling riser is circular weld. Specific values of $\bar{a}$, k and m are based on curve D of Fig. 3.

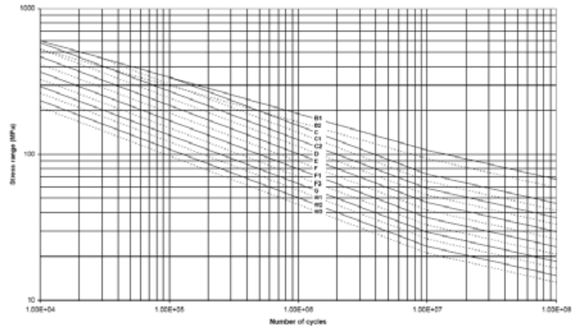

Figure 2. S-N curve

SCF takes manufacture tolerance installation and geometrical defect in connection part owing to welding techniques. As shown in Fig.3, the expression is as follows:

$$SCF = 1 + \exp(-(d/t)^{-0.5}) \cdot 3e/t \tag{5}$$

where, e is welding eccentricity. d is the pipe outside diameter.

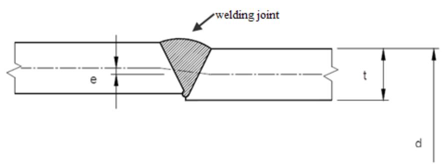

Figure 3. Geometric imperfection of welding point

C. Miner-Palmgren rule

The fatigue damage caused by alternating stress on offshore structures submitted to wave loads is a cumulative progress. For drilling riser affected by alternating stress with different amplitudes, the total fatigue damage can be got through accumulating the damage caused by stress with different amplitudes. When the total fatigue damage reached a certain value, fatigue failure occurs. Miner linear cumulative damage rule which is most widely used in engineering is as follows:

$$D = \sum_i n(S_i) / N(S_i) \tag{6}$$

where $n(S_i)$ is the number of circle time with the stress amplitude S_i , $N(S_i)$ is the number of circle time structure failure with the stress amplitude S_i , D is the cumulative fatigue damage.

IV. CASE STUDY

The dynamic response analysis method for drilling riser is established in this paper and fatigue damage model is used to conduct fatigue damage analysis for drilling riser. Effects of soil stiffness, wall thickness and welding eccentric on drilling fatigue damage are investigated. The basic parameters are presented on Table 1.

TABLE I. THE PARAMETERS OF DRILLING RISER

Parameter	*Value*
Water Depth(m)	100
Wave Height(m)	3.4
Wave Period(s)	8.1
Surface Current Velocity(m/s)	0.5
Seawater Density(Kg/m^3)	1025
Drag Coefficient	0.65
Inertia Coefficient	1.6
Soil stiffness(KN/m)	20
Length of Drilling Riser above the Seabed(m)	130
Penetration depth of Drilling Riser(m)	30
Outside Diameter(m)	0.762
Wall Thickness(m)	0.026
Material Density(m)	7850
Young's Modules(Pa)	2.1e11
Poisson's Ratio	0.3

A. The effect of soil stiffness on fatigue damage of drilling riser

Besides the effects of environmental loads, there is interaction between riser and soil. The soil stiffness affects the stress state and fatigue damage of drilling riser. A set of soil stiffness 2KN/m, 20KN/m, 200KN/m and 2000KN/m is used to conduct fatigue damage analysis for drilling riser. The results are shown in Fig. 4.

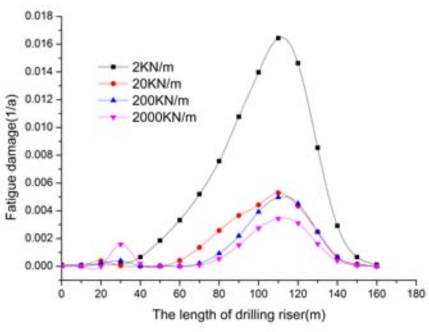

Figure 4. Effect of soil stiffness on fatigue damage of drilling riser

As shown in Fig.4, fatigue damage on drilling riser near the seabed is the most severe. The maximums of fatigue damage for drilling riser with this set of soil stiffness are 0.01644, 0.00529, 0.00497 and 0.00343. The fatigue damage of drilling riser near the seabed decreases with the increase of soil stiffness. When the soil stiffness reaches a certain value, the changes of soil stiffness have little effect on fatigue damage of drilling riser.

B. The effect of wall thickness on fatigue damage of drilling riser

Wall thickness is one of the important design parameters for drilling riser. Value of wall thickness affects the cost of drilling riser and performance of the connection device. Design of drilling riser's wall thickness should consider the structural requirement and fulfill the requirements of fatigue strength. A set of wall thickness: 0.026m, 0.036m, 0.046m and 0.056m are used in this paper. The results are shown in Fig. 6.

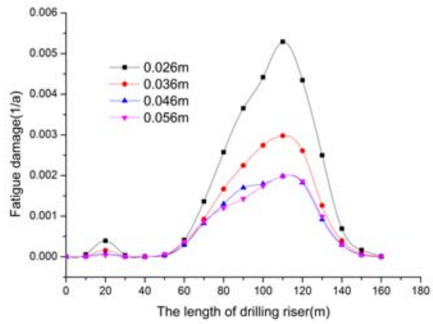

Figure 5. Effect of wall thickness on fatigue damage of drilling riser

As shown in Fig.5, maximum of fatigue damage for drilling riser corresponding to this set of wall thickness are 0.00529, 0.00298, 0.00198 and 0.00198. It is clear that increasing the wall thickness can decrease the fatigue damage effectively. When the wall thickness reaches a certain level, effects of inhibiting fatigue damage by increasing wall thickness gradually decrease. So to increase the wall thickness approximately can restrain fatigue damage effectively.

C. The effect of welding eccentricity on fatigue damage of drilling riser

The fatigue performance of welding point for drilling riser requires good welding quality. But welding eccentricity is unavoidable. Fatigue damage analysis is done for a set of welding eccentricity (0m, 0.0013m, 0.0026m and 0.0039m). The results are shown in Fig. 6.

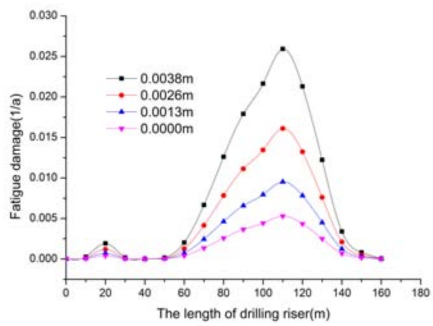

Figure 6. Effect of eccentricity on fatigue damage of drilling riser

As in Fig. 6 the fatigue damages corresponding to this set of welding eccentricity are 0.00529, 0.00953, 0.01611 and 0.02593. Increase of welding eccentricity can enlarge the fatigue damage significantly. So it is of importance to control the welding eccentricity.

V. CONCULSION

Time-domain nonlinear dynamic analysis method based on pipe-soil interaction is established. Rain-flow counting method, S-N curve and Miner-Palmgren rule are used to create the fatigue damage model for drilling riser. These are of application value for design and check of drilling riser. The model created in this paper is used to analyze the parameters affecting drilling riser whose results can provided theoretical foundation for operation and design of drilling riser. The analysis results demonstrate: The fatigue damage of drilling riser near the seabed decreases with the increase of soil stiffness; Increase of the wall thickness approximately can restraint fatigue damage effectively. Increase of welding eccentricity can enlarge the fatigue damage significantly.

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