Global Analysis of Ultra-Deepwater Drilling Risers

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Abstact

In recent years, the exploration activity of oil and gas industry in ultra deepwater is numerous. Global offshore industry is building systems today for drilling in even deeper water, progressively using new technologies, and significantly extending existing technologies. This is the general trend in the offshore oil and gas industry. So the technology of Ultra-Deepwater Risers, which is the main tool in drilling of oil, is more and more standard. This paper manly focuses on the global analysis of the drilling risers. And it is divided into two parts, operability analysis and hang-off analysis that are used to check the design of the Riser.

In the paper, the following is discussed:

1. Calculation of the rotation angle and stress of the Riser in the drilling mode, as well as the stroke of the telescopic joint;
2. Determination of the operability envelop;
3. Calculation of the rotation angle and stress of the Riser on the hang-off condition, and the telescopic joint’s stroke;
4. Determination of the number of the buoyancy model;
5. Check all the worked out values according to the API standard.

From all the above, it is obtained that the operability envelop is relatively small on the harsh condition and the number of the buoyancy model is a little large. And above all, the design of this Riser is successful.

Keywords: Drilling Riser、Design、Operability Analysis、Hang-off Analysis

Nomenclature

T e = effective tension
EI =bending rigidity
Ao，Ai=external section area，internal section atrea
Po,Pi =external pressure，internal pressure

Introduction

The analysis of riser mechenics can be divided into static analysis and dynamic analysis. The effect of current and the offset of the floater is taken into account in the static analysis stage, which is the first step of riser globle analysis, and also the starting point of the following eigenvalue and dynamic analysis. while the dynamic analysis can study the non-liner dynamic responses of the riser, and all the responses are usually be actived by the motion of the floater and various dynamic environmental conditions, such as wind, wave and current.

The static and dynamic analysis of the drilling riser in service are conducted by using the FEA software ABAQUS in this paper, as well as the safety of the riser on various environmental conditions.

On harsh environmental condition, the riser should be suspended at the LMRP or BOP to avoiding that the ocean surface and subsea equipments be destroyed, which is defined as hang-off condition. The hang-off condition canbe divided into two kinds, hard hang-off and soft hang-off. And the difference between is that whether the telescopic joint be wiped off. When it is hard hang-off condition, there is no telescopic joint, the heave motion of the floater is directly passed on to the riser. While when it is soft hang-off condition, the telescopic joint can offset the motion the floater passed to the riser, but the stroke of the TJ is very important now, since it falls in a allowable range. On extreme sea condition, it is difficult to meet the need of stroke, so the hard hang-off system is selected here.

The FEA process of the hang-off riser is similar to the operation riser, which is commenly be divided as static and dynamic analysis. But it needs to modify the riser model on thses two condition, and the standards of calibration are different.

Brifly Introduction of the Drilling Riser

Drilling riser is a special kind of riser, and its design process is a very important one during deepwater drilling. And in recent years,there are many accidents caused by the riser damage. It is the urgent problem that to design and analyse the drilling riser.

Risers are from the seabed BOP group to the drilling platform and connected with the control exports of cement, when the drilling platform moves horizontally relative to the seabed wellhead, in order to eliminate bending of the riser, generally install the upper ball joints or flexible joints in the bottom of the riser and BOP Group. And as the water depth increases, in order to reduce the drilling platform motion against the tube bending, a hinge or flexible joints are installated between the top of the riser and drilling platform, which can bend arbitrarily as much as 10 degrees in the vertical direction, it can effectively reduce the deflection of the riser. In order to eliminate the impact of the vertical movement of the drilling platform against the riser, elescopic joint is installated in the upper riser. Telescopic joint is composed of inner barrel and out barrel, inner barrel is connected with ball joint or flexible joint, out barrel is connected with the riser joint below, out barrel is connected to the platform by a number of tensioners.

Drilling riser bears a wide range of loads, including: wind forces, wave forces, tides, weights of the mud and pipes, buoyancy, the tension of the tensioner, as well as the force induced by pressure difference between internal mud and external water. The external force acts on the riser in various forms with the deepening of water depth so that the forces are very complex.

In addition, while deep-sea drilling operations, with the water depth increases, the gravity of the riser is gradually increasing. In order to ensure the riser be vertical, the tension of the tensioner also increases, but the tension is also limited. Therefore, in order to reduce the tension, external buoyancy modules are installed on the risers. However, the existence of buoyancy modules would increase the tide and wave forces act on the risers, and easily damage the foam, it also use air can to adjust the buoyancy of the riser. In addition, the layout of buoyancy modules is not arbitrary, the numbers of buoyancy modules is not only to ensure that the tensioner will not be pulled off, but also to ensure that there will be no buckling of the riser.

Besides, for deep-sea drilling riser, a problem that can not be ignored is what should be done when the drilling platform encounteres the storm. If the water is very deep, it's impossible that all the risers can be retrieved, it is often disconnected from the bottom of the riser, so that the riser can hang –off to the drilling platform. Since the governing of the riser is more difficult due to bad sea conditions, and in the light of the research when water depth is more than 2000 feet the cycle of vibration of the riser is similar with wave cycle, so how to hang off the riser to the platform safely under the bad sea conditions is the important aspect to be considered in the design and analysis process.

Riser motion equation

The basic assumptions of riser analysis are as follows:

(1) In the riser mechanical analysis process, assuming that the material of pipeline is homogeneous and isotropic, and it remains in the linear elastic range in the process of movement and deformation

(2) The movement speed and the speed of rotation of mud in the riser are a small amount. As a result, the centrifugal force acted on the viscous mud, the reaction force acted on the riser and the Coriolis force acted on riser can be ignored;

(3) The impact of bending rigidity of drill pipe against the riser is not considered.

(4) As a result that the ratio of length to diameter is very small, risers can be used as flexible beams for the mechanical analysis;

(5) Assume that the deformation of the beam is a small amount, and assume that deformation angle is also a small amount;

(6) provision that the direction of current and deformation of the riser are in the same vertical plane xoz, and ox-axis and the direction of flow in the same direction.

In this assumption, the equation of the horizontal movement is:

$$\frac{d^2}{dz^2}\left(EI\frac{d^2x}{dz^2}\right)-\frac{d}{dz}\left[\left(T+A_0P_0-A_iP_i\right)\frac{dx}{dz}\right]+m_x\ddot{x}=f_{xs} \tag{1}$$

where：

$$T_e(z)=T(z)+A_0(z)P_0(z)-A_iP_i(z) \tag{2}$$

Numerical Solution

There are many numerical solution methods to the static and dynmic equations of risers,such as lumped mass method,finite diiference method and finite element method. Finite element method is used commonly.

Some assumption regarding the distribution of the displacement inside the elements has to be made to express the displacements ,strain and stress of elements using the displacements of nodes. This is displacement mode or function.

This function is expressed as follow:

$$\{\delta\}=\sum_{i=1}^{n}N_i\{\delta_i\} \tag{3}$$

The strain matrix is obtained by calculating the shape functions in the cartesian coordinate system and putting them in the proper position in the matrix.Elasticity martrix $[D]$ shows the relation of stress and strain inside elements:

$$\{\sigma\}=[D]\{\varepsilon\} \tag{4}$$

Because the riser is a large deformation problem,the tangential stiffness matrix of three-dimentional elements has to be determined before the analysis. Gomertry stiffness martrix is:

$$[k_\sigma]=\int[G]^T[M][G]dv \tag{5}$$

Equivalent node forces are obtained by moving the distributed forces to the nodes with the principle of the equal virtual power:

$$\{F_e\} = \int [N]^T \{q\} dv \tag{6}$$

Where:

$[N]$ is shape function matrix;

$\{q\}$ is distrbuted force matrix。

Node forces,node displacements and elements stiffness matrixs in the globle coordinates can be obtainded by the transition matrix.Then the globle stiffness matrix can be determined by the priciple of superposion.Finally the structural equivalence equation is:

$$[K]\{\delta\} = \{F\} \tag{7}$$

Where $\{\delta\}$ is the displacement matrix of the whole structure; $\{F\}$ is the force matrix of the nodes; $[K]$ is the globle stiffness matrix .With the given constrains conditions of nodes' forces and displacements, the nodes' displacements and theelements' stresses can be obtained from the equation and also other results.

However, the dynamic analysis of the riser not only needs the conditions as the static analysis,but also the initial conditions.

The finite element method of dynamic analysis is similar to that of static analysis.After discretenss, the standard format of equation (1)is:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \{F\} \tag{8}$$

where，[M] is mass matrix of the system (including additional mass)；[C] is damping matrix(including structural damping and the hydrodynamics damping);[K] is globle stiffness matrix; $\{x\}$ 、 $\{\dot{x}\}$ 、 $\{\ddot{x}\}$ is the displacment, velocity and accelaration vector of the nodes, repectively; $\{F\}$ is the load vector. When the displacements of the riser's nodes have been obtained, the bending moments and shearing forces can be found by using interpolating function method or difference method.

FINITE ELEMENT MODEL

The top of the riser connects to the floater by several tentioners at the operability conditions (drilling conditions), on the other hand the bottom of the riser interact with soil, and the furthest bottom is considered fixed.

The model excludes the drilling pipe. This can be considered conservative because the drill pipe contribute to the bending and axial stiffness.

Proper element type should be used to describe the mechanical charateristics for the nonlinear riser .There is a type of Hybrid beam elements in the library of ABAQUS's elements which can be used to modelling very slender structures. These structures' axial stiffness is more greater than their bending stiffness. This

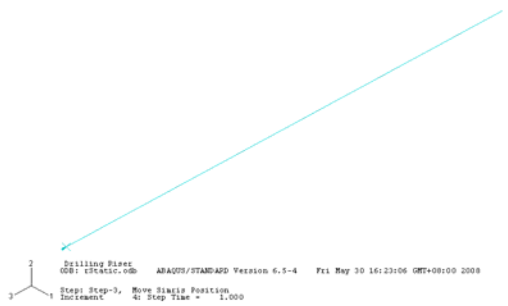

Fig.1: riser finite element model of operability

paper had considered the effects of the three-dimentional loads,so element B31H is chosen. The riser is 3073.6m(10084 ft), divided into 510 nodes and 509 elements .Six additional nonlinear springs are used to modelling the tensioners and 59 springs are also used to modelling the interaction between the casing and soil.

The finite element model of the riser is shown in Figure 1.

Once the hard-hang off mode is used, telescopic jiont is removed and the bottom of the riser is disconnected at the LMRP. B31H is also chosen to model riser. The whole model is divided into 435 nodes and 434 elements. A spring whose stiffness is very large is used to connect the riser to the floater. The riser-soil interactions do not need to model because the riser is disconnected at LMRP.

Static analysis is devided into three steps: first, initialize the model and pre-tension.The tensioners haven't added into the model. Gravity is loaded;

Second, initialize tensioners and remove the pre-tension, and apply current using the AQUA module. The displacement of the floater is zero (Neutral Position);

Third, the displacment of the floater is used as the boundary conditions. This is called Offset Position.

Dynamic analysis which is a restart analysis is conducted at the basis of static analysis. So the forth step is moving the floater to a position suitable for the floater's motion.The motion of the floater is apply at the fifth step. The motion is applied using ABAQUS's subroutine:DISP.

Hang off analysis is similar to operability analysis, which will not be further discussed here.

Oprability Results Analysis

1 Distribution of effective tension and bending moment:

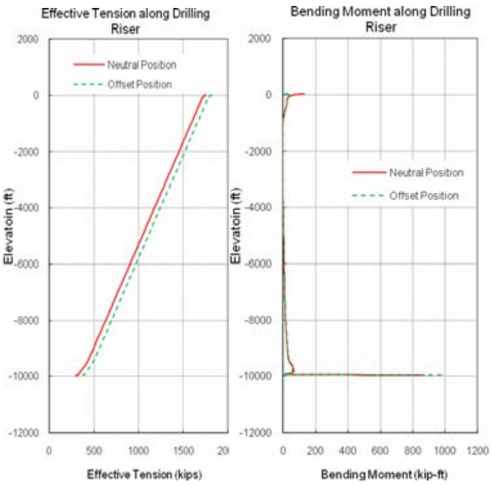

Fig.2: 100-year Eddy+1year Bottom

The effective tension and bending moment on the above condition

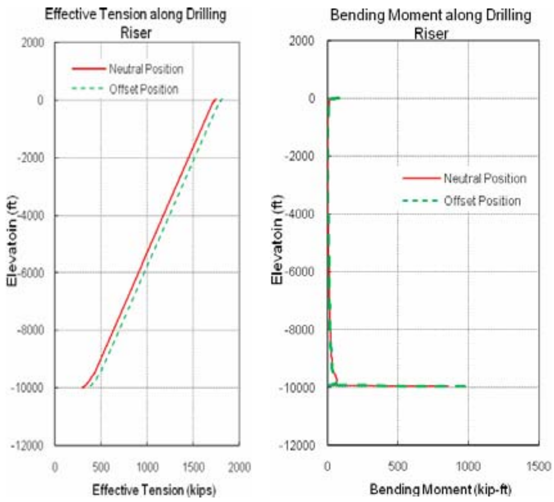

Fig.3: 10-year Eddy+1year Bottom

The effective tension and bending moment on the above current condition

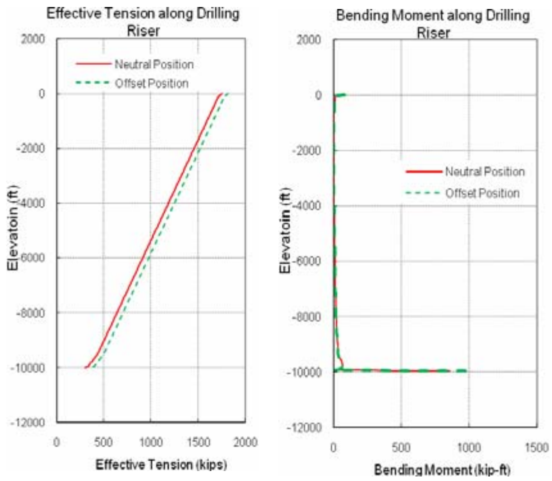

Fig. 4: 1-year Eddy+1year Bottom

The effective tension and bending moment on the above current condition

It presents that the effective tension of risers reduces from up to down through the static analysis result. The trend of the bending moment corresponds to the actual condition, there is a large value around the tensioner ring, and maximum at the bottom of riser. That's because the bending load of deepwater risers is usually larger at 20-30 m water depth, and also the failure of the existing risers appears at the position of 2-3 risers under water. It presents that these positions are dangerous and should take serious considerations of the strength of risers. Since there are flex joint、LMRP and BOP, it can withstand high bending moment for the bottom, and so in the local analysis, we can take serious considerations for the riser bottom to the capable of resisting bending moment.

It may affect the effective tension and bending moment to add an excursion at the top of risers, but not large. Since the bottom of risers and soil interaction, the three current considered in this paper have little effect to the effective tension and bending moment of static risers.

2、The rotation angles of flex joint are listed as below:

current	Top		Bottom	
	average	maximum	average	maximum
1	3.42	4.95	5.85	7.27
2	2.50	3.94	5.77	7.05
3	2.00	3.42	5.75	7.08

1：100-yearEddy +1year Bottom

2：10-year Eddy +1year Bottom

3：1-year Eddy +1year Bottom

Table 1: the rotation angle of flex joint on operational condition (deg.)

The result above shows that:

For the rotation angle of the upper flex joint, comparing the result with the criteria, it is found that the average and maximum value of the 1st current rotation angles both dissatisfy the requirement; the average angle value of the 2nd current dissatisfy the requirement, but the maximum value doesn't; and the 3rd current angles both satisfy the requirement defined by the criteria.

For the rotation angles of the bottom flex joint, the result of the three current presents that the average and maximum value are both unaccepted by criteria. Though the intensity of the three current damps in turn, only for the value of the top current, and so does the rotation angle of the top flex joint, it utilize 1-year bottom data for the bottom current, and there is a little range for the bottom flex joint. It recommends choosing lower intensity bottom current for analysis and may get satisfy result.

3、Stress results are listed as below:

current	Maximum stress
100-year Eddy+1year Bottom	51.86
10-year Eddy+1year Bottom	51.65
1-year Eddy+1year Bottom	50.42

Table 2: the maximum stress of risers on operational condition (ksi)

It presents that the maximum stress value in the analysis are all in the range recommended by API criteria (53.6ksi) according to the three current conditions, the stress are all maximum around the tensioner ring and the bottom, it corresponds to the result of the previous effective tension and bending moment and demonstrates that the strength problem should be considerate seriously at the two positions again.

4、Top tension

It should considerate avoiding the over bulking and the maximum resistant load of tensioner for the restrain of the top tension, the result shows that the top tension are in the accepted range.

current	Top tension	
	maximum	minimum

100-year Eddy +1year Bottom	1995.36	1670.64
10-year Eddy +1year Bottom	1986.02	1673.17
1-year Eddy +1year Bottom	1983.82	1674.31

Table 3: the maximum and minimum of the top tension

Analysis of the hang off condition result

1. effective tension and bending moment distribution

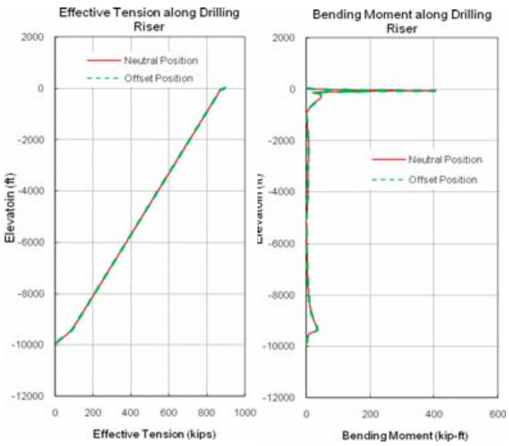

Fig.5: 100-year Eddy+1year Bottom

the effective tension and bending moment on the above current condition

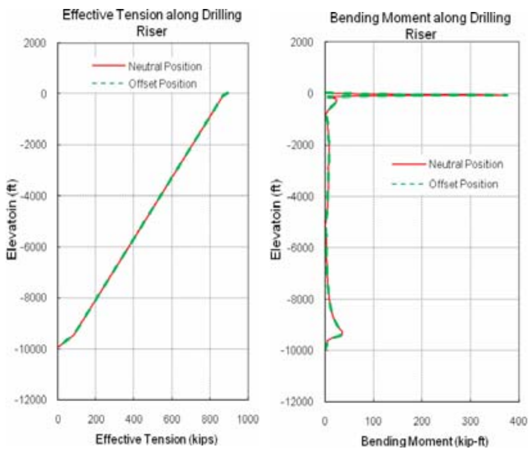

Fig.6: 10-year Eddy+1year Bottom

The effective tension and bending moment on the above current condition.

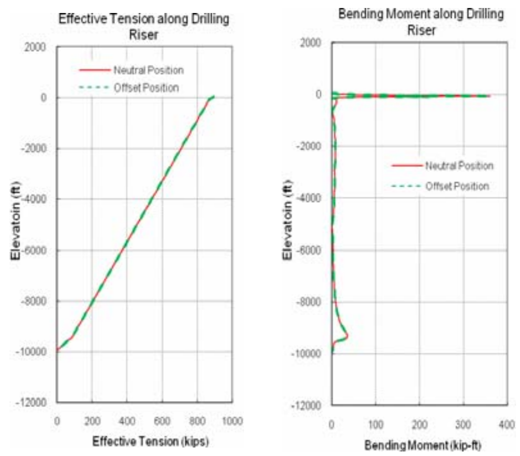

Fig. 7: 1-year Eddy+1year Bottom

The effective tension and bending moment on the above current condition

It presents that the effective tension of risers reduces from up to down according to the static analysis results. The bending moment is maximum around the top out barrel, and this position relate to a peak value of the bending moment on operational condition. And since the bottom of the riser is free, the bending moment is nearly zoro.

It may affect the effective tension and bending moment to add an excursion to the top of the riser in the static analysis step, but it is very little. Also it is because the free riser bottom, the effective tension and bending moment are mostly equivalent on static equilibrium condition. Different current have little effect for effective tension, but larger for the maximum of the bending moment, the larger the current, the larger the maximum of the bending moment.

2、The rotation angles of flex joint are listed as below:

current	The maximum of the rotation angle of the upper flex joint	The maximum of the rotation of the lower flex joint
1	11.29	0.42
2	9.42	0.42
3	8.48	0.42

1：100-yearEddy +1year Bottom

2：10-year Eddy +1year Bottom

3：1-year Eddy +1year Bottom

Table 4: the rotation angles of flex joint on operational condition (deg.)

The results of the rotation angle of the upper flex joint show that the rotation angle value under the 100-year Eddy+1year Bottom current (the maximum is 11.29 deg.) condition dissatisfies the requirement defined by criteria, the other two satisfy it. It presents that it is benefit for reducing the rotation of the top flex joint to reduce the intensity of the top current;

The rotation angle of the lower flex joint is much lower than the accepted value in criteria, and it is 0.42 degree. Because the bottom is free, and the lower flex joint can move with the riser without withstanding higher bending moment.

3. Stress results are as follows:

current	Maximum stress
100-year Eddy+1year Bottom	37.10
10-year Eddy+1year Bottom	31.92
1-year Eddy+1year Bottom	35.50

Table 5: maximum stress of the riser on operating conditions（ksi）

The stress calculation results show that, on the condition of hard hang-off, the maximum stresses are all in the API specification proposed range (53.6ksi). And the maximum stress locates at the place where the maximum bending moment occurs, which shows again that in the position where the stress is great, and vulnerable to failure, the strength should be paid more attention to.

Conclusion

The main work of this article is, by using the FEA software, the static and dynamic analysis of the preliminary design finished deep sea drilling riser on operating and hang-off condition be done, and the safety of it be checked in accordance with the code API 16Q . For the motion of the deepwater riser is non-liner, time domain method is used in the dynamic analysis process.

In addition, the 3D movement of the floater under the condition of combined wine and current, and the interaction of subsea riser and soil are taken into account. Well, during each operating condition, the response of the riser on the three kind of current combined condition is considered. From the results of the calculation, the conclusion can be educed as below:

(1) on the operating condition, the stress and the top tension under the effect of the three kind of current all fall into the codes permitted range; for the rotation angle of the upper flexible joint, only the average and the maximum of 1-year Eddy +1 year Bottom current conditions satisfy the demands, and for the rotation angle of the bottom flexible joint, neither the average value nor the maximum in the three kind of current combined state meet the requirements. Therefore, on this sea condition, the riser should not be on operating condition. And the modification of the riser design should be done: to increase the riser wall thickness, or increase the strength of the flexible joint; also the analysis can be done on mild sea conditions, so to make all the parameters meet the requirements given by the standards;

(2) hang-off conditions, all the stresses under the combined effect of the three kind of current meet the requirements. For the rotation angle of the upper flexible joint, only the angle of the 100-year Eddy +1 year Bottom condition does not satisfy the requirements, the riser on other sea conditions are safe. For the rotation angles of the bottom flexible joint, they all meet the needs of the demand, and also far less than the allowable value. Therefore, on the 10-year Eddy +1 year Bottom and 1-year Eddy +1 year Bottom Sea conditions, the hang-off condition is available;

(3) the analysis of the effective tension and moment distribution along the riser shows that the peak value of the moment and stress will occur in the vicinity of the telescopic joint, where riser strength should be paid more attention to; In addition, on the operating condition, the effective tension is small in the riser bottom, but there the moment will be extreme, which leads to great stress, the local strength there should also be paid attention to;

(4) For the drilling riser, the role of the top tension can not be ignored, in order to prevent the riser from overall buckling and the stress from exceeding the permitted value of the tensioner, the top tension must be in a certain range.

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