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Study on the Effect of Non-Uniformity Load and Casing Eccentricity on the Casing Strength

Wang Guohua[a], Chen zhengmao[a], Xiong Jiyou[a] , Yang Keli[b],a*

[a]State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation; Southwest Petroleum University, Chengdu 610500, People's Republic of China
[b]CNOOCPOC,Shenzhen 518054, People's Republic of China.

Abstract

Casing strength under the complex geological conditions is one of the major problems urgently to be solved at home and abroad. Catching the main characteristics and trends of casing collapse under the complex geological conditions, and based on which, carrying out the method study of casing strength analysis under the inhomogeneous load, as well as consideration of the law about how the non-uniformity load and the casing eccentricity influence on casing strength are of great significance. Setting a suit of method and theory about casing strength under the complex geological conditions has certain reference value. This paper affords a new sight for the casing strength design and safety assessment under the complex geological conditions by research on the relevance between the casing strength and the complex geological conditions. Meanwhile, consideration gives the non-uniformity load and the law about how the casing eccentricity influences on the casing strength. The results show that the increasing off-center distance will aggravate the non-uniformity of the loads when the casing skews along the relative off-center direction of 90° and 270°, thus the casing collapse risk goes up evidently.

Key words: creeping stratum non-uniform load casing eccentricity numerical simulation casing strength

1. Introduction

The Non-Uniformity Load and Casing Eccentricity have been closely associated with the Casing Strength. Of particular relevance to casing design, the work by Cheatham and McEver, though published

* Corresponding author. Tel.:+86-13438164140.
E-mail address: iamwgh@hotmail.com.

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in 1964, is still a pioneering work. Willson indicated that Incorporating Nonuniform Loading Effects Into the Casing Design[2].Typically, well design proceeds with the goal of combating the nonuniform load. If this load occurs slowly, adjustments to the tubular design may be minimal, as the cross-sectional ovalization can only occur at the same rate as the formation movement[1]. However, the casing eccentricity is an important effect of casing strength. Manoochehr Salehabadi show that the casing eccentricity is an important issue in the casing stability analysis of the wellbores drilled in gas hydrate bearing sediments in deepwater environments[3]. Ferda Akgun indicated that the inclination angle has a major effect on the casing eccentricity[4]. However, Predecessor's research had not incorporating nonuniform loading effects into the casing eccentricity in the Vertical section under the complex geological conditions.

The objective of this study is to investigate the relationship between the effect of nonuniform loading and casing eccentricity on the casing strength under the complex geological conditions. The results of this Simulation Study are useful for evaluating the casing security and the casing design under the complex geological conditions.

2. Analysis for the impact of terrestrial stress non-uniformity on the casing collapse

The mechanics factor can be regarded as the direct cause for casing deformation, so the research on the casing pipe collapse mainly focuses on casing pipe's stress variation. Generally, casing material's yield failure judgment use the Von-mises yield criterion[6]. Therefore, the following analysis of casing yield failure is mainly studied the casing's equivalent stress on its inner wall.

After cementation, the casing, cement sheath and rock become a whole. In the plastic flowing strata such as mudstone, paste mud shale and salt rock, the casing bears the inhomogeneous external load, which belongs to the plane strain type. That is to say, only in the direction of paralleling to some plane the strain exists and it does not exist in the vertical direction because the radial dimension of the casing and cement sheath is far less than the axial size judged from the rock mechanics and elastic-plastic mechanics theory. The casing is buried in several kilometer strata, its length and diameter ratio is greatly big. According to the actual situation, this model takes out the casing as an independent object from the cement sheath. Figure 1 is the mechanical model of casing. This kind of problem may be regarded as the plane strain, and other supposition is that casing is an ideal circular and the wall thickness is uniform. " a" is the casing inner radius, " b" is the casing external radius[5].

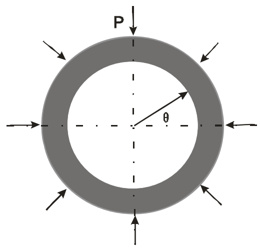

Fig. 1 The mechanical model of casing

According to the above established mechanical model of casing deformation and collapse, at first it analyzes and calculates from the point of plane type. The finite element model for plane object analysis is established.

In order to simplify the mechanical model, it makes the following supposition:

(1) The casing is absolutely circular before deformation (i.e. it does not have elliptic);

(2) The thickness of casing wall is uniform;

(3) After deformation the casing is symmetrical to the casing center;

(4) Under inhomogeneous load the casing satisfies the ellipse laylout, the load on any spot of the casing external wall is:

$$P(\theta)=[(P_1 \sin \theta)^2+(P_2 \cos \theta)^2]^{1/2} \tag{1}$$

The load acts on the node of the casing outside wall, and aims at the casing center. When $P_1=P_2$, that is elliptic mode of uniform load; when $P_1 \neq P_2$, that is inhomogeneous load mode.

Take a typical well where the total depth is 4825 meters as an example to calculate and analyze. The maximum horizontal terrestrial stress is 140 MPa, and the minimum is 134 MPa; Selecting P110 casing whose outside diameter is 177.8 mm, wall thickness is 11.51 mm, yield strength 758 ~ 965 MPa. The calculation result is as follows:

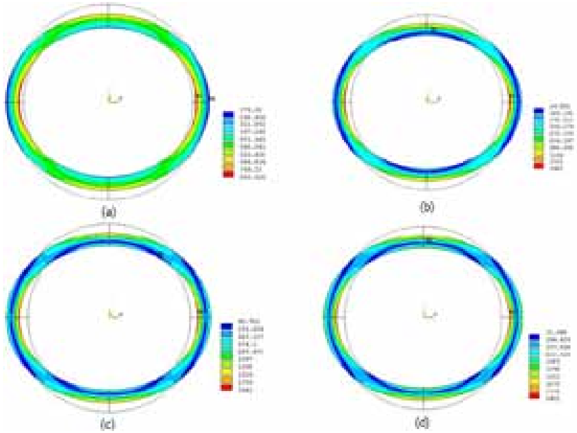

Fig.2 The Seqv of the casing inner wall under inhomogeneous load, (a)P_1=140MPa,P_2=134MPa;(b)P_1=140MPa,P_2=120MPa;(c)P_1=140MPa,P_2=110MPa;(d)P_1=140MPa,P_2=100MPa

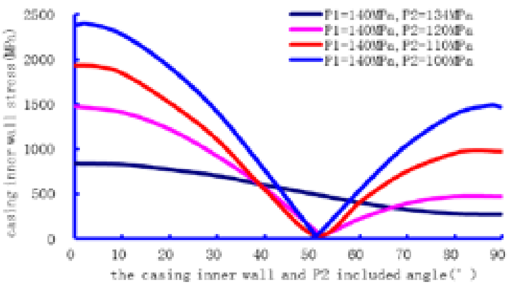

Fig. 3 The stress variation trend of the casing inner wall under inhomogeneous load

It can be seen from Figure 3, when the difference between P1 and P2 increases, the stress value will go up sharply in the two points which have 90 and 270 degrees with the maximum terrestrial stress along the casing circumferential direction. Before up to the biggest compressive strength of P110, it surpasses the casing's yield limit and the casing starts yielding. It explains that the casing collapse risk increases along with the inhomogeneity increasing

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3. Analysis for the impact of casing eccentricity on its collapse strength

With mechanical analysis of casing under non-uniform load, there is a hypothesis in modeling and deduction. That is casing centralization. Thus, it is very important to take casing off-center into consideration for casing safety evaluation in the evaporated beds. According to the casing mechanical analysis under non-uniform load, the most risk area is the points that have 90 or 270 degree between casing radial and the maximum in-situ stress. The state of stress in the most risk area plays an important role in judgment of the casing anti-collapse ability. So the equivalent stress will be used in the following analysis of casing's yield failure. For the casing in deep ground, longitudinal deformation is limited. If we do not think about the longitudinal deformation, the problem can be transformed into a plane strain one. In figure4, we can set layer-cement sheath-casing as research object. The casing radius is a_0, the cement sheath's radius is a, the layer's is a_1.

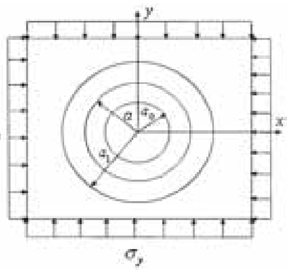


Figure 4 the mechanic model of the stratum-cement sheath-casing system

In the finite element analysis of stress, we make a 3D model of casing. For the casing length is much longer than its diameter, the end effect is neglected, and this problem has become a planar strain one. We can select the cross section of casing and cement sheath to set their geometry model, and then mesh and solve the problem.

Casing stress calculation involves material properties of the casing, the cement ring and the stratum. Referencing on a typical well's data，this paper selects the parameters as follows：the elastic modulus of casing:210 GPa; the poisson's ratio of casing:0.3; the elastic modulus of cement ring:7 GPa; the poisson's ratio of cement ring:0.18; the elastic modulus of salinastone:5GPa; the poisson's ratio of salinastone:0.45.

This study analyses the interaction of the casing, the cement ring and the stratum. Considering the boundary effect on the results and according to Saint Venant's principle, we define the stratum size for 3 m x 3 m, the wellbore diameter 0.2508 m, the casing outer diameter 0.2508m, the casing wall thickness 15.88mm. It adopts the method of moving working plane in this model in which we can draw geometric figure for any casing eccentric distance and its eccentric angle.

Here we define the displacement vector from the center of the wellbore to the center of the casing whose modulus is the casing's eccentric distance as the casing eccentric distance vector. The angle from borehole high edge turning clockwisely to the eccentric distance vector is defined as the casing eccentric angle. The angle between the horizontal projection of the casing eccentric distance vector and the due north direction is defined as the casing eccentric azimuth whose positive direction counted from due north direction turning clockwisely, noted as $\varphi_{\theta\sigma}$; simultaneously, the eccentric azimuth relative to the maximum principal stress direction is called as the casing relative eccentric azimuth, noted as $\varphi_{\theta\sigma}$.

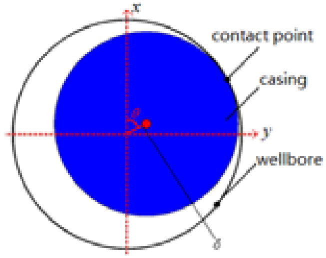


Figure 5 the contact mode of the casing and the wellbore

4. Results and discussions

According to the general relationship between tectonic features and the stratum principal stress direction, the maximum horizontal principal stress direction is approximately NW 45º(135ºand 315º).

The following stress contour is under the condition of 1.70 g/cm3 mud weight, 7GPa cement elastic modulus, 45°casing relative eccentric azimuth and 5mm casing eccentric distance. From the picture, we can conclude that the direction of the maximum stress parallels the minimum horizontal principal stress (45°and 225°). The succeeding results show that no matter what the casing relative eccentric azimuth is, the direction of the maximum stress is a constant.

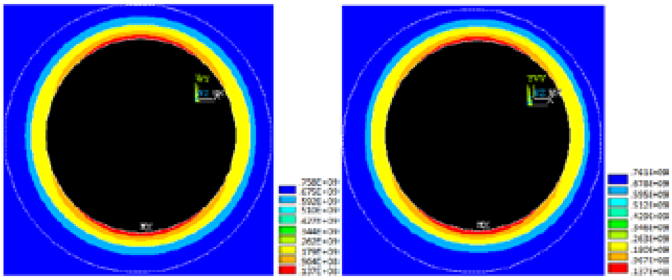


Figure6 the stress contours when the casing relative eccentric azimuth is 45 °,(a)the casing eccentric distance is 5mm,(b) the casing eccentric distance is10mm

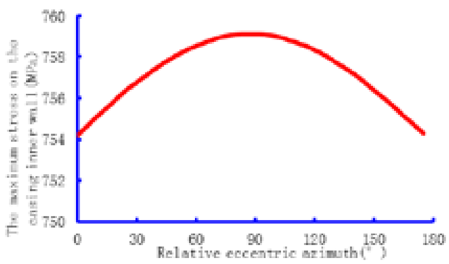


Figure 7 The changing mode of the maximum stress on the casing inner wall varying with the value of $\varphi_{\theta\sigma}$ when the value of the casing eccentric distance is 5mm

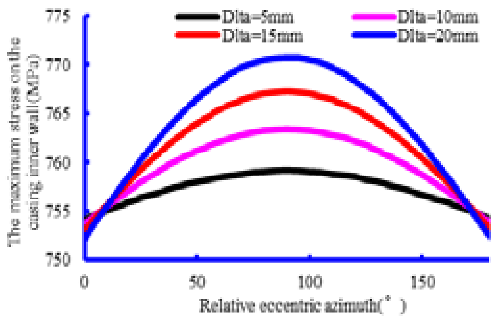
Figure 7 shows the maximum stress of the casing inner wall varies with the relative eccentric azimuth when the value of the casing eccentric distance is 5mm. From figure 8 we can see that when $\varphi_{\theta\sigma}$ is 90°, the maximum value of the maximum stress on the casing inner wall is at the minimum principal stress direction, and the value is 759.12MPa. When it is eccentric in the direction of the maximum stratum principal stress, the value of the maximum stress on the casing inner wall is minimum. The detailed results are listed in Table 1.

Table 1 different maximum stress of casing inwall with different relative eccentric azimuth of casing(the value of the eccentric distance of casing is 5mm)

$\varphi_{\theta\sigma}$ (°)	maximum stress(MPa)	$\varphi_{\theta\sigma}$ (°)	maximum stress(MPa)	$\varphi_{\theta\sigma}$ (°)	maximum stress(MPa)	$\varphi_{\theta\sigma}$ (°)	maximum stress(MPa)
0	754.23	50	757.99	100	759.05	150	756.72
5	754.67	55	758.24	105	758.96	155	756.35
10	755.1	60	758.47	110	758.83	160	755.95
15	755.52	65	758.66	115	758.68	165	755.55
20	755.93	70	758.82	120	758.48	170	755.13
25	756.32	75	758.95	125	758.26	175	754.7
30	756.7	80	759.04	130	758.01	180	754.27
35	757.06	85	759.1	135	757.72		
40	757.39	90	759.12	140	757.41		
45	757.7	95	759.1	145	757.08		

Figue 8 lists the varying mode of the maximum stress on the casing inner wall varying with the value of $\varphi_{\theta\sigma}$ when the value of the cement ring elastic modulus is 7GPa and the value of the casing eccentric distance are respectively 5mm,10mm,15mm,and 20mm.

From Figue 8 we can see that the maximum value of the maximum stress on the casing inner wall is gradually increasing with the increment of the casing eccentric distance. Nevertheless, when $\varphi_{\theta\sigma}$ = 0°±10°and $\varphi_{\theta\sigma}$ =180±10°the maximum stress on the casing inner wall is gradually reducing with the increment of the casing eccentric distance.



Figue 8 The varying mode of the maximum stress on the casing inner wall varying with the value of $\varphi_{\theta\sigma}$ when the value of the cement ring elastic modulus is 7GPa

Furthermore, when the value of the relative eccentric azimuth is 90° ,the difference of the maximum stress is more than 10MPa under the condition of the value of the eccentric distance is 5mm and 20mm, thus it can be seen that casing eccentric can produce a lot of stress increment. It is in agreement with the former assumption of casing centralization, in which it shows that the maximum stress on the casing inner wall appearing in the angle of 90° and 270° from the tangential of the casing to the maximum geo-stress direction. This states that when casing skewing along with $\varphi_{\theta\sigma}$=90° , the increasing casing eccentric degree will lead to the load's heterogeneity increment. Consequently, the casing becomes increasingly unsafe.

5. Conclusion

In the finite element model, it calculates and analyzes the stress on the casing inner wall under the condition of the casing is elliptic. Under the non-uniform terrestrial stress, the casing off-center has great influence on the maximum stress of the casing's inner wall.in the relative off-center direction of 0°, the maximum casing stress varies contrarily with the off-center distance. And in the direction of 90°, the maximum casing stress is upward with the off-center distance increasing. The greater the off-center distance is, the more the stress amplitude varies on the casing inner wall, so the greater the maximum stress on the casing inner wall is.

Combined with the conclusion that the maximum stress is in the two points which have 90° and 270°with the maximum terrestrial stress along with the tangential of the casing under the assumption is that the casing is centralized, It takes regards that the increasing off-center distance will aggravate the non-uniformity of the loads when the casing skews along the relative off-center direction of 90° and 270°, thus the casing collapse risk goes up evidently. So in the designing and correcting of casing strength, it should consider the impact of the casing eccentricity on its strength under the complex geological condition besides considering the non-uniform loads for the aim to ensuring the casing strength and its safety allowance.

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