Petroleum 2 (2016) 108–115

Contents lists available at ScienceDirect

Petroleum

journal homepage: www.keaipublishing.com/en/journals/petlm

Original article

# Distribution laws and effects analysis of casing external pressure taking elastic parameters matching into account

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ARTICLE INFO

*Article history:*
Received 6 October 2015
Received in revised form
23 November 2015
Accepted 29 November 2015

*Keywords:*
External pressure
Casing failure
Service life
Elastic modulus
Poisson's ratio

ABSTRACT

Distribution laws of casing external pressure, which are obtained by different scholars in different conditions, are not the same. Thus, a model to calculate the external pressure of casing is established with finite element method. In the model a contact is built between the outer wall of the casing and the inner wall of the cement sheath. The casing external pressure can be got through extracting contact force of results. The numerical results and analysis show that: The largest casing external pressure exists in the direction of minimum horizontal stress of formation rather than in the direction of the maximum horizontal stress. There exists such matching between the cement sheath elastic modulus and formation elastic modulus: When the elastic modulus of the cement sheath is small, reducing its value is conducive to reduce the casing external pressure and to prolong casing service life. When the elastic modulus of the cement sheath is large, increasing its value is conducive to reduce the casing external pressure and to prolong casing service life. The casing external pressure will become large with the increase of Poisson's ratio of cement sheath. With the increase of the degree of the formation stress unevenness, the maximum casing external pressure increases and the smallest external decreases. The increasing of the non-uniformity degree of formation stress makes the non-uniformity degree of casing external pressure and the risk of casing failure increase. The study can provide certain reference for drilling workers to take measures to prolong service life of casing.



## 1. Introduction

In the area of petroleum drilling engineering, casing string serves one of the most important functions in a well. The problem of casing failure exists in almost all oil fields in a number of countries, such as the United States, Brazil, Mexico, China and so on [1–4]. This problem led to the abandonment of the wells and caused serious economic losses. Although the casing design standards, such as API, ΓOCT and SY/T, have been amended for many times, there are still a lot of casings designed obeying the standards failure. No matter what kind of standards are based on the assumption that effective external pressure is evenly distributed on the circumference of casing. This kind of design is feasible for shallow well or the wells which have no complicated down-hole problems, but it's not suitable for the well which down-hole problems are complicated. Because the working condition that the casing under uniform external pressure does not exist in most cases in the actual drilling process. Another reason is that casing external pressure is also influenced by the matching between the formation elastic modulus and cement sheath elastic modulus. These factors should also be considered in the design and calculation of casing external pressure.

Early work on the collapse strength of a casing under external pressure can be traced back to Clinedinst [5], Holmquist [6], Murchey [7] and Charles [8]. Javidi [9] investigated failure analysis of a gas tubing string and studied the corrosion impact on mechanical strength of gas tubing string. Tamano [10], Issa [11]

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Peer review under responsibility of Southwest Petroleum University.

Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.petlm.2015.11.005

and Tokimasa [12] investigated the effects of geometric imperfections on the collapse strength of casings, and presented their empirical equations using numerical analyses. They did not take into account significant geomechanical factors such as confinement mechanical stresses in design. Yin [13] established the mechanical model of casing in directional well under in-situ stresses taking the in-situ stresses and well trajectory into account. Yin [14] deduced the formula of annular volume change under the synergy of temperature and pressure according to thermoelasticity. Deng [15] analyzed the rule that the effect of cement sheath properties on the casing external pressure through the indoor simulation experiment. Due to the particularity of its experimental materials, the resulting law is different from the later scholars' research results. Yin [16], Li [17] analyzed the distribution law of oil casing external pressure according to the principle of plastoelasticity, the results were contrary to Deng found. Mirzaghorbanali [18] performed a casing collapse strength model based on the geomechanical stresses around the casing and the fluid effect. Chatterjee [19], Nabipour [20], Gao [21] used the finite element analysis (FEA) to simulate the stresses of casing-cement-formation system. The difference between the theoretical calculation and the FEA solution for von Mises stress is tiny [22,23]. Lian [24] pointed out that the problem of casing deformation failure remains fundamentally unsolvable through simply improving casing grade and wall thickness to increase flexural strength.

Based on the above analysis, casing-cement sheath-formation stress finite element model is established to study the casing external pressure considering the elastic modulus matching situation. A point-to-point contact is built between the outer wall of the casing and the inner wall of the cement sheath to simulate the external pressure of casing. Then the distribution and influence factors of casing external pressure are analyzed by numerical method.

## 2. Modeling

### 2.1. Mechanical model

We want to calculate the casing external pressure in certain depth in a circumference of the outer wall of the casing, as shown in Fig. 1(c) of the red line. The unevenness formation stress acting on casing can be expressed by maximum horizontal stress and minimum horizontal stress. According to Saint Venant's principle, the impact of local stress change on infinitely distant stress is very small [25–27]. So the local formation stress will not be affected by well-bore and remain unchanged where far from the axis of well-bore. In the actual situation, the local formation stress can not be affected by well-bore where the distance is 5–6 times of the hole diameter, 10 times diameter of the well will be used in the model to reduce error. And as a result of the symmetry of structure, so we study a quarter of the structure. The casing-cement sheath-formation physical model is shown in Fig. 1. In the figure, $\sigma_1$, $\sigma_2$ represent maximum horizontal stress and minimum horizontal stress.

### 2.2. Finite element model

First of all, the following assumptions about casing-cement sheath-formation system are made: (1) Isotropic material; (2) Casing is infinite in the longitudinal, only considering a cross section of casing; (3) The shape of the casing cross section is homogeneous circular, without considering the influence of ovality and the unevenness of the wall thickness [28,29].

As a result of the symmetry of structure, we analyze a quarter of the structure. PLANE42 of 2D plane element is selected. According to mesh principle, meshing is dense inside and sparse outside. So it is sparse in the position of casing and cement sheath and loose in formation. The casing is divided into 6 parts in radial direction and 20 parts in circumferential direction. So the grid number of casing is 120 in 1/4 model. The same is done to cement sheath. Formation is divided into 60 parts in radial direction and 20 parts in circumferential direction. So the grid number of formation is 1200 in 1/4 model. Meshing is shown in Fig. 2.

Symmetry constraint is applied to the bottom boundary, including casing radius, cement sheath radius and formation radius. The same constraint is applied to the left boundary. Minimum formation stress is applied to the upper boundary. Maximum formation stress is applied to the right boundary. Then the model is loaded and solved.

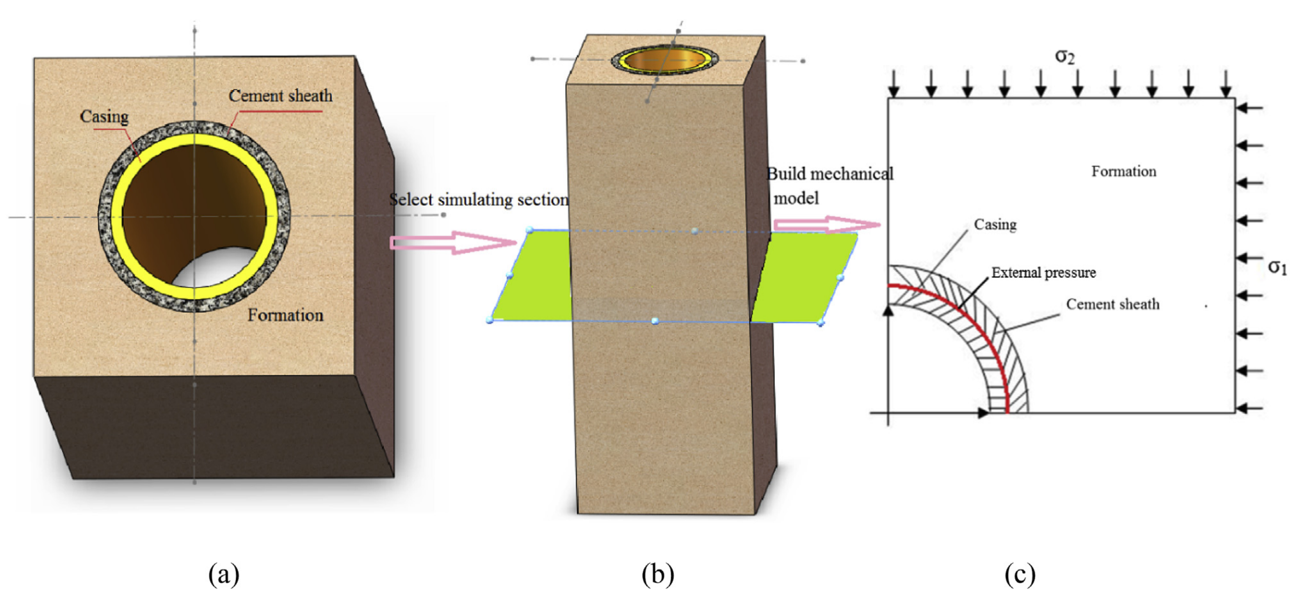


**Fig. 1.** Mechanical model diagram of casing in non-uniform force stress.