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Loads of casing and cement sheath in the compressive viscoelastic salt rock

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ABSTRACT

The purpose of the research is to calculate loads applied to downhole casing and cement sheath in the viscoelastic salt rock under the action of in situ stress. Considering that materials of the viscoelastic salt rock around the wellbore and cement sheath are compressible, a geomechanical model which includes casing, cement sheath, and salt rock is developed. The Burgers creep model is adopted to describe the long-term rheological behavior of salt rock, and the three components model is used to describe that of cement sheath under in situ stress. Adopting the elastic viscoelastic corresponding principle (EVCP[1]), the solutions of loads of casing and cement sheath are obtained in the compressive viscoelastic salt (CVS) on the basis of the elastic solutions of the same problem. The limit value of loading of casing is more than that of cement sheath in the given example, which exponentially increases with time. Compared to the limit value of loading of casing in the uncompressible viscoelastic salt (UVS), it is increased by 10.0% in the compressible viscoelastic salt. The limit loading of cement sheath in CVS is about 0.5% less than that of cement sheath in UVS. Taking the surrounding salt as the uncompressible material is very dangerous to assess the damage risk of downhole casing, and likely causes the collapse of casing.

1. Introduction

Drilling and completing wells through the deep thick salt formation is technically challenging and costly. In order to isolate the abnormal formation pressure, prevent the borehole sloughing and ensure the safety of well testing and completion, the steel casing is run and cemented on the outside after drilling (Li, 2008). Casing and cement sheath are surrounded by the viscoelastic rocks such as salt, mudstone and shale. The creep load caused by the salt rock flow is applied to the outer surface of casing that may result in the collapse of casing. So the creep load must be considered in the casing design. With the extension of oil field exploitation period, the salt loading becomes bigger and bigger which may increase the risk of casing collapse in cased wellbore sections (Zhao et al., 2011). The high pressure water invades the formation near wellbore in the water flooding extraction, speeds up the creep rate of salt rock. It also results in the increase of load exerted on the external surface of casing (Lang et al., 2013). The more the limit value of load is, the more the risk of casing collapse is (Huang et al., 2008). The heavy casing or the pipe in pipe casing is used to reduce the collapsed risk of casing in the salt formation. But it will increase the cost of well and the complexity of well completion (Pattillo and Smith, 1985). In order to analyze the load of casing and ensure the safety of downhole casing in the well life, it is necessary to develop an appropriate geomechanical model which includes the salt, cement sheath, and casing. The value of loads applied to the surface of casing and cement sheath are the basis parameters of well design. The creep of salt rock should be considered when the load of casing is calculated. (Willson et al., 2003). The analytical and numerical analysis methods are often adopted to research the load applied to the external surface of casing in the viscoelastic salt rock under the action of in situ stress.

The stress and strain relations of the materials of salt rock and cement sheath, namely the constitutive equations, are necessary to determine the load of downhole casing in the viscoelastic surrounding rock (Zhang and Liu, 2000; Zeng et al., 2002). The creep tests of core samples from oil fields can determine the strength, elastic modulus and viscous parameters of rock, establish the relationship between the creep rate and time, as well as the constitutive equation of rock. According to the creep test results of rocks, the mathematical regression method is adopted to determine parameters in the rock constitutive equation (Jiang et al., 2014). The viscoelastic constitutive relations of rock can be described by the Maxwell (Deng and Huang, 1994),

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[1] EVCP is the abbreviation of elastic-viscoelastic corresponding principle. CVS is the abbreviation of compressible viscoelastic salt. UVS is the abbreviation of uncompressible viscoelastic salt.

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Burgers (Liu and Wang, 2005), Kelvin (Yin et al., 2004; Li et al., 2007), and Heard (Zhang, 2009) creep model. Some researchers took the rock as a Kelvin creep material, casing as an elastic material, to calculate the load of casing. The Burgers model which is comprised of a Maxwell and a Kelvin model can reflect the viscoelastic behavior of the material of rock. The Burgers model should be adopted to analyze the load of casing in the creep salt rock under the high in situ stress (Macini et al., 2006). After the creep constitutive relation of surrounding rock was determined, a finite element model which included the viscoelastic creep surrounding rock, cement sheath and casing was established to analyze the load of casing (Yang et al., 2006).

The existing models in literatures treated the cement sheath as the rock (Li et al., 2007). And the influence of cement sheath on the load acting on casing and the volumetric deformation of the creep rock were not considered in existing models (Yin et al., 2004). It did not coincide with the mechanical properties of downhole viscoelastic salt rock. The calculating methods of casing loading in the viscoelastic creep surrounding rock included the EVCP method (Li et al., 2007), the half-inverse method on the basis of the stress function in the theory of elasticity (Yan et al., 2006) and the hereditary integral method (Qian and Gao, 2011). The viscoelastic problem in the Laplace domain can be transformed into the elastic problem in the time domain to obtain the solution of the problem. In Laplace domain, the solution of viscoelastic problem is the same as that of the elastic problem in form. And then substituting the expression of parameters in the Laplace domain, the viscoelastic solution in the time domain is obtained by the Laplace inverse transformation of the elastic solution. Studies showed that the load of casing increases with time, and finally reaches to a limit value. The limit value of load of casing exerted by the creep rock under in situ stress was the same as that of the elastic solution of the problem. The existing geological mechanical model included the viscoelastic surrounding rock and the elastic casing. Taking the rock as the incompressible material, the genetic integral algorithm was adopted to calculate the load of casing (Dou et al., 1996). The load of casing can be determined by the displacement reverse analysis method based on least squares (Yang et al., 2006) and initial strain method (Wang et al., 2005).

In the earlier work, people had used finite-element methods to draw the conclusion that the load exerted to the external surface of the down hole casing is 1.1 times larger than the maximum in situ stress (Zhang, 2009). The geomechanical model included the casing and the salt formations. The volume creep of the formation rock did not considered in the calculation of casing loadings (Zhang, 2009). Regarding the salt formation as Maxwell model, a viscous elastic mechanical model for plane strain was established. But the model did not include the cement sheath. The numerical solution of casing loadings had been obtained on the basis of the simplified model (Wang et al., 2005). The developed finite element models (Yan et al., 2006; Gao et al., 2007) which included the rock, cement sheath and casing were used to analyze the loadings of casing in salt formations. In their studies, the creep formation was supposed to be viscoelastic materials. Both Maxwell viscoelasticity model and linear hardening elastic-plasticity model were used (Gao et al., 2007). The viscoelastic salt around the down hole was assumed to be a rigid body that was not agrees with practice situation. Actually, the salt formations will deform under the action of the in situ stresses. The deformation of the salt formations had significant effects on the loads of casing.

The existing geomechanical models in references usually did not include the cement sheath, and in order to more conveniently calculate the casing creep load, the salt rock and cement sheath were taken as uncompressible materials that did not accord with the practical situations of downhole salt rock and cement sheath. Adopting the above mentioned simplified models, we will underestimate the loads of casing and cement sheath exerted by the in-situ stress in salt formations. It will lead to the failure of the downhole casing. Aimed at the above mentioned disadvantages in existing researches, the paper adopts the EVCP, considers the effect of cement sheath, determines the creep model of cement sheath and salt rock to obtained the viscoelastic solutions of loads of casing and cement sheath in the CVS under the action of in situ stress on the basis of the elastic solutions of the corresponding problem. The paper also compares loads of the downhole casing and cement sheath in the CVS with ones in the UVS.

2. Loads of casing and cement sheath in elastic bounding rocks

Lame's elastic solutions of a thick cylinder are often adopted to calculate the distribution of stress and deformation of casing and cement sheath in the elastic salt rock under in situ stress. The elastic solutions are the basis of the loading analysis of casing and cement sheath in the viscoelastic salt.

2.1. Geomechanical model of casing, cement sheath and salt

A geomechanical model of casing, cement sheath, and salt around the wellbore is developed to evaluate loads of casing and cement sheath in the viscoelastic salt rock under the action of in situ stress, as shown in Fig.1. Let a donate the inner radius of casing, b the outer radius of casing, c the outer radius of cement sheath, p_o the in situ stress acting on the external surface of the geomechanical model and $_{pi}$ the hydrostatic pressure acting on the inner surface of casing which comes from the weight of the completion fluids. In order to obtain the elastic solutions of loads of casing and cement sheath, some assumptions are made as follows. (1) The salt around the wellbore, cement sheath and casing are taken for continuous, homogeneous, isotropic, elastic materials. (2) The interfaces of casing and cement sheath, cement sheath and salt are closely bonded, and the deformations and radical stresses on interfaces between two kinds of different materials are equal. (3) Compared to the depth of well, the dimension of the cross section of the geomechanical model is very small, and a long cylindrical model is loaded by forces that are perpendicular to the axial line and do not vary in length. The state of stress is called plane strain. (4) The external surfaces of the model loaded by in situ stress, p_o, are far away from the center of the borehole.

2.2. Radical displacement of casing, cement sheath and salt

The internal surface of downhole casing is loaded by the hydrostatic pressure, $_{pi}$, and external surface of casing subjected to the load, p, which comes from the in situ stress. On the basis of

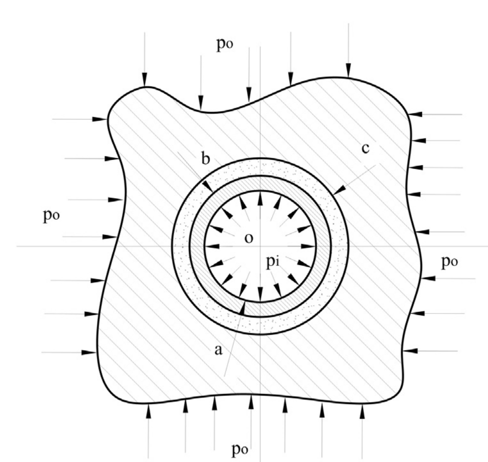

Fig. 1. Geomechanical model of casing, cement sheath, and salt around the wellbore.