Application of In-situ Stress Calculation in Engineering

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Abstract. In-situ stress is an important factor affecting the stability of underground structure and the main driving force of oil and gas migration in underground. It is of great significance to the implementation of engineering, the exploitation of oil and gas and the guarantee of safety. Therefore, through the analysis of logging curves, the relevant rock mechanical parameters are extracted, then a layered model is established to calculate the ground stress and evaluate the stability of the surrounding rock. The in-situ stress obtained by parameter extraction also plays a guiding role in oil and gas exploitation and drilling target implementation.

1. Introduction

Tectonic stress, also known as ground stress, produced in the earth's crust under the influence of the motion forces of various crustal tectonics. In space, it is divided into the principal vertical stress, the horizontal maximum principal stress, and the horizontal minimum principal stress. The principal vertical stress is caused by the static rock stress, and the two horizontal principal stress is caused by the tectonic movement. There are many factors that affect ground stress, such as terrain, geomorphology, rock, structure, etc. This will complicate the initial state of ground stress. The tectonic stress of the interest of oil workers needs to eliminate the interference of various factors and study it from the regional scope. The ground stress studied by the engineering designers is the stress in the rock body related to the construction of the project, which contains the above factors, so it is necessary to synthesize various factors and carry out concrete analysis and research.

The ground stress is caused by forces acting on the unit area of the medium, and the ground stress field is composed of the different depth of the ground stress and the magnitude and direction of the ground stress, which varies with time and space. Squeezing pressure, tension, and twisting forces between rock bodies in the earth's crust and adjacent rock bodies are produced by the different movements of the earth's crust. This interaction force is called tectonic forces. In the earth's crust, because of the constraints of the surrounding strata, this tectonic force creates a resistance when acting in the surrounding formation, and the tectonic force and resistance are two forces in opposite directions of equal magnitude, a pair of forces called tectonic stresses. In general, the maximum and the minimum horizontal principal stress is based on vertical stress, Poisson ratio, shear modulus, porosity, and other rock mechanical parameters developed, the initial state of the ground stress is not only directly related to the stability of the surrounding rock and the arrangement of the project but also has a significant effect on the ground engineering. The ground stress state is closely related to the stability of the surrounding rock in underground engineering. In most cases, the ground stress has obvious directionality, and this horizontal or near horizontal ground stress controls the deformation and failure characteristics of surrounding rock in underground engineering. Therefore, in recent years, both domestic and foreign
hydropower projects and the oil industry attach great importance to the measurement and research of geo-stress.

2. Methods

2.1. Extraction of rock dynamic mechanical parameters based on sonic logging curves

The elastic mechanical parameters of rock are closely related to the ground stress occurring in the rock mass, so the rock mechanical parameters must be obtained first, and their influence should be considered when the geo-stress calculation is carried out. At present, the elastic mechanical parameters of rock are mainly obtained by dynamic methods and static methods. The static method is obtained by loading rock samples in the laboratory and measuring their deformation, and its parameters are called static elastic mechanical parameters. The dynamic method is calculated by the speed of transmission of sound waves in rock samples and the conversion of density logging values, and its parameters are called dynamic elastic mechanical parameters. Because of the high cost of measuring the static elastic parameters, and the inherent properties of rock determine the strong volatility of elastic parameters of rock formation. Therefore, the dynamic elastic parameters (mainly acoustic log data) can be used to overcome the disadvantages of the discontinuous and high cost of static elastic mechanical parameters.

Using the vertical wave time difference obtained by the sonic logging $\Delta t_p$, the horizontal wave time difference $\Delta t_s$, coupled with the formation density value obtained by the density logging $\rho$, the dynamic mechanical parameters of the rock can be obtained: dynamic Poisson ratio $\mu_d$, dynamic elastic modulus $E_d$, shear modulus $G$, volume modulus $K$, ramen coefficient $\lambda$, rock volume compression coefficient $C_b$, skeleton compression coefficient $C_{ma}$, Biot elastic coefficient $\alpha$, etc.

![Parameter Extraction Flow Chart](image)

**Figure 1.** Parameter Extraction Flow Chart
2.2. A hierarchical model calculation that considers the dip angle
The deformation of surrounding rock directly affects the stability of the underground engineering body. If the deformation of the surrounding rock is a destructive deformation, it means that the chamber is a loss of stability, if non-destructive deformation is applied, the chamber can still be stable after appropriate engineering measures are taken. Too large initial stress often causes the surrounding rock to be too large deformation or crushing. If the initial stress is high in hard rock, the strain energy stored in the rock layer can sometimes be released violently, causing rock explosion. All rock explosions produce seismic waves, the largest rock explosion magnitude of up to 5.5 on the Richter scale, not only threatening personal safety but also causing huge losses to production.

Using the method of geomechanics to analyze the geological structure of the region can only qualitatively analyze the direction of the tectonic stress in the region, but cannot get the accurate value. The best way to determine the values of local stresses in an area is to make in-situ measurements. By measuring the tectonic stress and inferring the stress state in the surrounding rock, the effect of controlling and eliminating the rock explosion is achieved. The results show that the formations of different depths of different tectonic regions, the size of the three main ground stresses are different, the differences are great and change with the change of the dip angle, and the difference of the main ground stress in different formations is related to the mechanical parameters of the rock such as elastic modulus and the size of the Poisson ratio. Therefore, the influence of stratification and inclination should be fully considered in the calculation of ground stress.

For areas where the tectonic stress is more gentle, such as the continuous sedimentation area of the Gulf region, the tectonic motion does not play a leading role in the formation of ground stress, and the law of geo-stress is generally: $\sigma_v > \sigma_h > \sigma_h$

$$\sigma_H = \left(\frac{\mu}{1-\mu} + \omega_1\right)(\sigma_v - \alpha\rho_p) + \alpha\rho_p$$

$$\sigma_h = \left(\frac{\mu}{1-\mu} + \omega_2\right)(\sigma_v - \alpha\rho_p) + \alpha\rho_p$$ (1)

$\omega_1$ and $\omega_2$ reflect the magnitude of the tectonic ground stress in the two horizontal directions, different regions correspond to different values. The model considers the effect of tectonic stress but does not fully consider the effect of lithology on stratigraphic stress.

For areas with strong tectonic deformation and complex geological conditions, the high-rise stress problem is very prominent, for example, the construction of the Qinghai-Tibet Railway is mostly built along the suture belt of the Yarlung-zangbo River, the area through which the tunnel passes is high and deep, the rock construction and geological structure are complex, and the surrounding rock instability such as rockburst and large deformation often appear in the construction of the tunnel, which greatly affects the safety of the tunnel construction.

In this regard, the ground stress measurement of the area is carried out by stress relief method, and compared with the ground stress of typical projects such as Chenglan, Lanyu, and Jinping. It is found that the buried depth of the tunnel along the Lalin railway line is large and the construction stress is prominent, as the overall performance is the maximum horizontal main stress bigger than the vertical main stress bigger than the minimum horizontal main stress; Average lateral pressure coefficient (1.0~1.5) is concentrated and at a higher level. Most of the maximum principal stress values range from 20 to 50 Mpa, and the gradient of maximum principal stress and buried depth is 0.0037 Mpa/m. The direction based on NNW-NNE, the horizontal maximum principal stress is perpendicular to the extension direction of the tunnel, which will cause extrusion to the surrounding rock, so it is easy to occur rock burst to endanger the safety of the project.

2.3. Oil and gas engineering evaluation based on SGR
The most important problem in oil and gas engineering is oil and gas reservoir formation, and whether oil and gas can be deposited not only depends on the oil production capacity of hydrocarbon source rock in the reservoir, but also depends on the isolation of the reservoir, the more closed the more can avoid
the loss of oil and gas in the process of transportation, this kind of closure is mainly divided into vertical closure and lateral closure. The study of vertical closure of faults is mainly aimed at the cover segment, for the reservoir of oil and gas reservoirs we mainly study from the side-by-side closure of the fault, which mainly refers to the role of the fault to prevent the oil and gas from passing through the fault side to the other plate of the fault. Since Smith first systematically expounded the problem of the lateral closure of faults in 1966, this problem has been a hot spot in the field of petroleum geology and even geosciences, especially in recent years, a large number of scholars have carried out a series of research on it, and achieved many excellent results.

![Flow chart of lateral closure assessment of fault](image)

\[ H = \frac{10 \left( \frac{\rho_{w}}{\rho_{G}} - 1 \right)}{(\rho_{w} - \rho_{G})} \]

**Figure 2. Flow chart of lateral closure assessment of fault**

The essential reason why the fault can form the lateral close is that there are different permeability between the reservoir and the fault zone or the opposite disk, that is, this kind of pressure difference, which causes the oil and gas to transfer back and forth in the reservoir and surrounding rock. When the displacement pressure of the fault zone or opposite side is less than the reservoir’s displacement pressure, the reservoir opens the oil and gas move laterally, and conversely, when the displacement pressure of the fault zone or the opposite side is greater than the displacement pressure of the reservoir, the reservoir is laterally closed. This closure can be qualitatively evaluated (e.g., the Allan plot method of rock butt closure and the Knipe diagram method) or quantitative calculation evaluation (e.g., evaluation of the mud-cover potential CSP of the closed fault of fault rock, shale smudge factor SSF, etc.).

Whether it is the shale smear factor SSF, or the mud rock smudge potential CSP only takes into account the fault displacement and the thickness of the mud rock layer, did not consider the different amount of mudstone smear at different locations. In addition, the current mud rock smudge research has neglected the plasticity of mudstone. So after G. Yielding put forward the method of evaluating the muddy content of fault rock (SGR), it was gradually accepted by the researchers and became the popular method to evaluate the sealing of fault.

The so-called SGR, usually translated into the shale gouge ratio, can also be understood from the established calculation formula as the muddy content of fault rock, that is, the ratio of the accumulated thickness to the fault distance of the mudstone layer sliding through a certain point during the fault movement:

\[ SGR = \frac{\sum T_i}{D} \times 100\%, \quad SGR - \text{tomography content}, \%; \quad T_i - \text{layer thickness}, \text{m}, \quad D - \text{vertical break of the fault, m.} \]
Using the seismic interpretation results of faults and formations, select the appropriate measuring lines, take the oil group as the unit to calculate the critical value, read the break time value covering the break level, calculate the SGR through the time-depth conversion and lithologic interpolation, and the maximum hydrocarbon column height of the point can be closed by using the SGR value of a certain point in the section, and the drilling data are used to accurately evaluate the oil and gas capacity of the closed fault, so as to reduce the drilling risk of fault trap and provide guidance for engineering production.

3. Conclusions and application examples
Gravity action and geological tectonic motion are the two most basic factors in the formation of ground stress. Geological structure, topography, lithology, and so on are the important factors affecting geostress, and fault structure are one of the main factors causing the complex change of stress in a crustal rock mass.

By establishing the corresponding study of log facies and seismic facies in Fushuang large area of Jilin Oilfield, the regional sedimentary characteristics and evolution process are clarified, and the structural characteristics and fracture characteristics are determined for the main target layer. The geophysical response characteristics of hydrocarbon source rocks and reservoirs in the study area are established. By studying the relationship between log data and lithologic parameters, the results of ground stress calculations are used to analyze the sealing and transportation of oil and gas.

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