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Application Effect of Fault Slip Evaluation Technology: A Case Study of Y101 Well in Luzhou Area

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Abstract: *According to previous studies, fault slip in shale gas fracturing is the main factor leading to the shear deformation of casing in horizontal Wells of shale gas. How to evaluate fault slip is crucial to the fracturing effect of horizontal Wells. At present, fault slip analysis mainly focuses on the study of models without a relatively complete evaluation process. Researchers have carried out a lot of exploration work and formed a fault slip evaluation technology based on three-dimensional seismic data. The main method is to apply fault and ground stress modeling methods and calculate the maximum critical injection pressure of faults according to the Coulomb fracture criterion to evaluate the fault slip, so as to reduce the risk of fault slip caused by the fracturing process. The results show that the slippage is determined by the magnitude, direction and occurrence of faults.*

Keywords: *Coulomb Rupture Criterion, Horizontal Well, Fault Slip, Modeling, Maximum Critical Injection Pressure*

1. Introduction

In shale gas exploitation, horizontal Wells need to be fractured in order to increase the production of shale gas Wells. If there are faults around the Wells, this process may cause the fault to slip and cause casing shear deformation, which will hinder the transportation of downhole tools, lead to the production reduction or suspension of shale gas Wells, increase production costs, and seriously affect the construction of shale gas production capacity.

Domestic and foreign scholars have carried out a large number of studies on the problem of fault slip. Currently, it is generally believed that the stress balance of the fault is changed during fracturing to induce slip, and different faults slide differently in the same stress field. Li Jun et al [1] pointed out that during the fracturing process, a large amount of fracturing fluid entered the formation, changing the original ground stress state and causing the fault to slip. Sun Keming et al. [2] studied the influence of factors such as ground stress, fault dip Angle, cohesion and internal friction Angle on fault slip.

Generally speaking, the current fault slip analysis focuses on the qualitative research of parameters, and there is no complete quantitative evaluation process [3-8]. Based on the interpretation of 3D seismic data, this paper applies fault and ground stress modeling methods, quantifies the actual stress state of the fault and the relative position relationship between the fracture criterion and Mohr circle according to the Coulomb fracture criterion, and clearly puts forward the calculation method and process of the maximum critical injection pressure required for fault reactivity, so that the evaluation of fault slippage can be quantified.

2. Overview of the Study Area

The research area is located in the Xiangxianyang 101 well area of Desheng in southeast Sichuan Basin, the main target layer is Wufeng Formation-Longmaxi Formation, with great resource potential.

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It is a concentrated upper production area during the 14th Five-Year Plan period, and is the main body of future production capacity construction, with complex stresses and fractures.

According to previous studies in Luzhou area, the total casing variability was 50.4% and the fracturing casing variability was 46.5%, which seriously affected the production progress. Statistical analysis of 166 casing variation points showed that 122 (73%) casing variation points were characterized by fracture slip and bedding plane slip, among which fault slip was one of the important factors affecting casing variation (Figure 1).

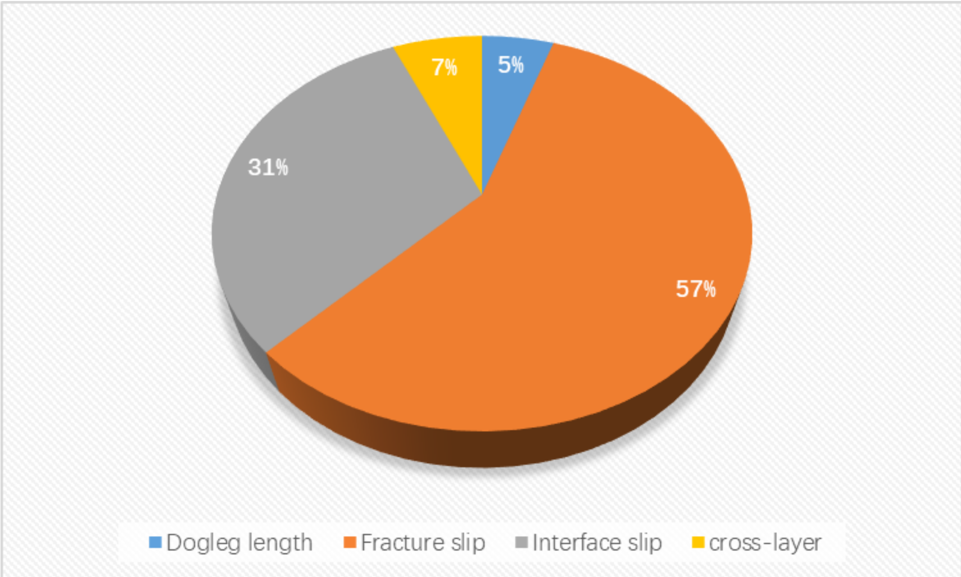

Figure 1: Single factor nested variable proportion analysis

In this study, the test analysis of platform A well in Y101 well area of Luzhou area is carried out, and the evaluation method of fault slip is defined.

3. Fault Slip Evaluation Method and Process

With geophysical data as the core data source, the formation pressure, ground stress and 3D discrete fault model data were obtained. According to the classical geomechanical theory (Coulomb-Moore criterion), the static fault slip evaluation was completed in the pre-pressure stage.

3.1. 3D Depth Domain Fracture Modeling

Taking platform well circumference as modeling range, 3D discrete fracture modeling technology is used to obtain 3D discrete fracture analysis results and calculate the dip Angle, inclination and strike of the section (Figure 2).

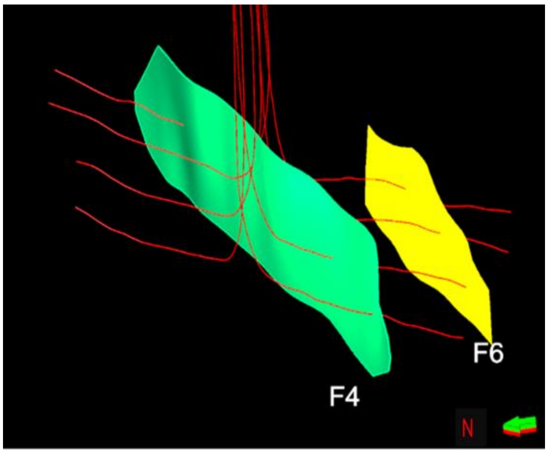

Figure 2: Modeling of periwell fracture

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3.2. Ground Stress Modeling

The in-situ stress data is derived from the measured velocity and density of drilling and logging. The three-way principal stress can be calculated by the equations related to the stress, velocity and density, and the direction of the principal stress can be obtained from the logging collapse curve. The obtained anisotropic stress data are fitted to the ground stress field around the shaft, and the distribution characteristics of the stress field are defined (Table 1).

Table 1: Geostress data

Depth(m)	Horizontal maximum principal stress(MPa)	Horizontal minimum principal stress(MPa)	Vertical stress(MPa)
3653	94	81.7	87.3
3679	94.3	81.8	87.9
3714	94.2	81.9	88.1
3750	95	82.6	88.1
4018	93.9	81.8	88
4033	94.5	82.1	88
4143	96.2	83.8	87.8
4158	95	82.6	87.6
4195	93.9	81.7	87.5
4244	93.9	81.6	87.3
4284	94.3	82	87.1
4327	93.6	81.4	87
4600	92.7	80.6	86.7
4727	92.6	80.5	86.5
4980	92.7	80.6	86
5041	91.7	79.7	85.9
5405	91.6	79.9	85.4

According to Anderson theory, the earth stress field around well is analyzed, and the property of stress field is judged by the relationship of three stresses (maximum horizontal principal stress, minimum horizontal principal stress and vertical stress), which provides the basis for geomechanical analysis (Figure 3).

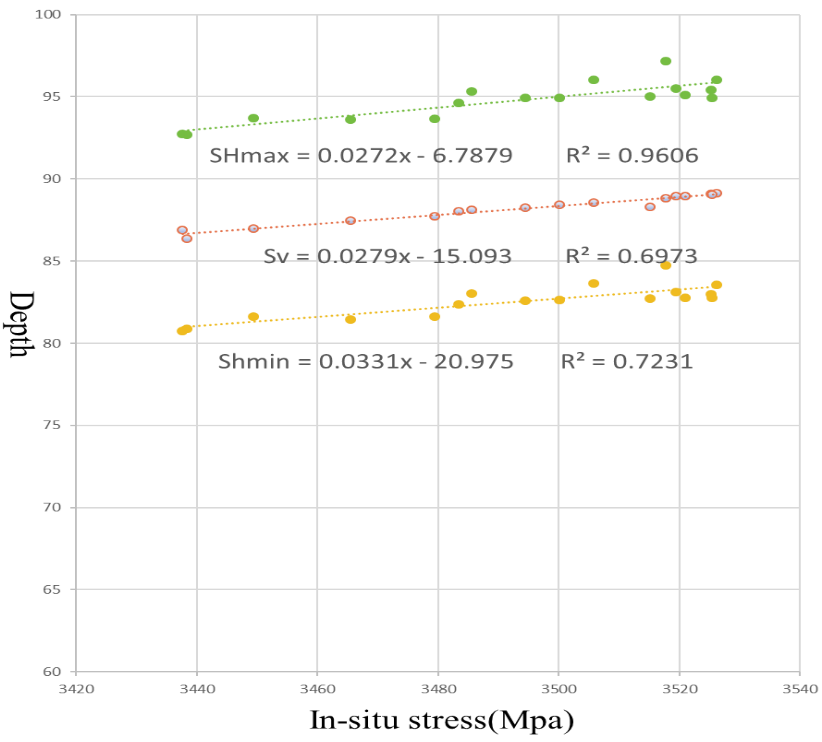

Figure 3: Graph of the variation of in-situ stress with depth around borehole

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3.3. Quantitative Calculation of the Maximum Critical pressure at Fracture

The quantitative calculation method of the maximum critical fracture pressure is studied by using the Coulomb-Moore criterion based on the characteristics of three dimensional discrete fracture, ground stress and formation pressure in the region and around the well.

Before fracturing: the fracture is in a stable state, and the sum of the friction force f generated by the normal stress σ_n of the section and the cohesion force C of the rock is much greater than the shear stress τ_n, and the fracture is stationary. In the fracturing process: the underground fluid pressure Δp is increased, which will "offset" part of the normal stress σn of the section, resulting in reduced friction force. When the sum of friction force f and rock cohesion force C is less than the shear stress τ_n, fracture slip occurs(Figure 4).

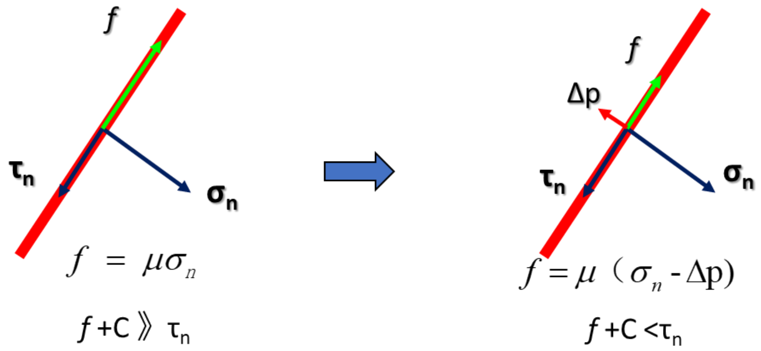

Figure 4: Variation trend of friction force f before and after fracturing

In the process of fault formation, normal stress and shear stress are two kinds of effects. According to the Coulomb criterion:

$$\tau = C+\sigma \tan\varphi \tag{1}$$

Where: τ is shear stress, MPa; C is rock cohesion, MPa; φ is the rock internal friction Angle, °; σ is the normal stress, MPa.

If f (x) = τ- (C+σ tanφ), the fault is stable when f (x) <0. When the effective stress (S_n-P_0) (Sn is the normal stress, p_0 is the critical point

When the layer pressure is equal to the net shear stress (τ-c), the rock will fail, forming a fault, which is the so-called Coulomb-Mohr failure criterion.

The normal stress σn and shear stress τ on the rock are calculated as follows:

$$\sigma n= (\sigma_1+\sigma_3) + (\sigma_1-\sigma_3) \cos 2\alpha^2 \tag{2}$$

$$\tau= (\sigma_1-\sigma_3) \sin 2\alpha^2 \tag{3}$$

When the formation fluid pressure increases, the effective normal stress decreases and the differential stress remains unchanged, which shows that the stress molar circle is close to the direction of the fracture envelope in the form of constant size. When the point in the stress mole circle intersects the fracture envelope, the slip fracture occurs at the intersection. The calculated normal stress σn and shear stress τ on the section are projected into the fault slip rupture evaluation chart. When the projection point falls on or above the rupture envelope, it indicates that the fault is in a state of instability and failure; when it lies below the rupture envelope, it indicates that the fault is in a state of stability. The increased subsurface fluid pressure Δp is the maximum critical injection pressure, and the value is the transverse displacement between the two Mohr circles before and after fracturing (Figure 5).

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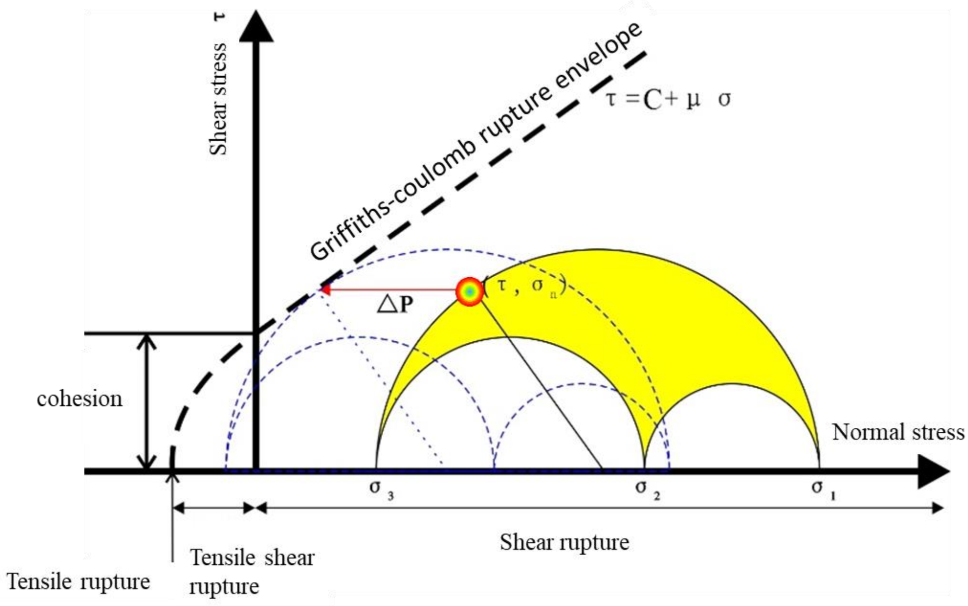

Figure 5: Coulomb criterion diagram of fault slip

4. Technical Application Effect

Based on the maximum critical injection pressure distribution, static fracture slip risk assessment was carried out to provide support for well trajectory optimization and fracturing construction parameter optimization.

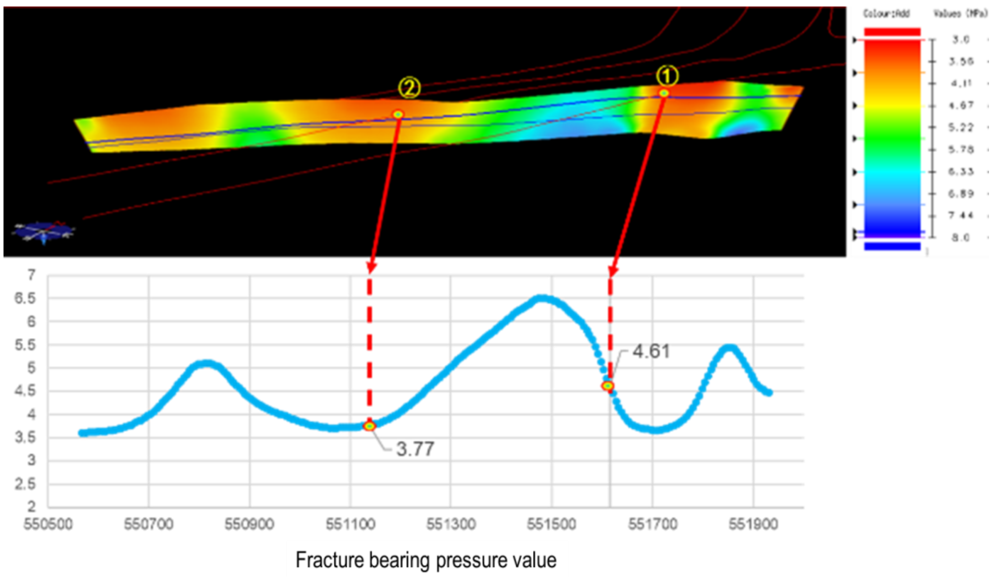

Figure 6: Fault maximum critical injection pressure distribution

Taking F4 fault as an example, it is calculated that the maximum critical injection pressure at point 1 of F4 fault at the wellbore is 4.61 MP, that is, the additional pressure should not exceed 4.61MP after fracturing the formation during fracturing (Figure 6), otherwise the fault will slip. In the fracturing design, as a risk warning, can prevent the casing change.

5. Conclusions and Suggestions

(1) Fracture stability is the content that must be analyzed before fracturing operations. Factors such as the size and direction of ground stress and fault occurrence jointly determine the fracture slip.

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(2) The stability evaluation of faults around well Y101 in Luzhou area was carried out by applying the quantitative evaluation technique of fault slip. The results showed that the maximum critical pressure level that F4 fault could withstand was 4.61 MPa, which provided data support for subsequent pressure operations.

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