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The Model of Pressure of Surrounding Rock Under Effect of Shear Stress

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Abstract

In order to describe the effect of shear stress on the sidewall rock mechanic distribution accurately, in this paper, we have established the micro unit stress equilibrium equation for failure zone and damage zone of the sidewall rock based on damage mechanical mechanism. Establishing the model for calculating radial stress, circumferential stress and shear stress of the sidewall rock considering the shear stress. We have obtained the scope of failure zone and damage zone of the sidewall rock by using central difference method. The result shows that the calculated result considering the shear stress is fit to the actual one.

Key words: Damage mechanics; Surrounding rock; Shear stress

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INTRODUCTION

The radial and circumferential stress distribution of the rock around the borehole have a key guidance on the study of borehole stability and conducting perforating and fracturing successfully[1]. Most scholars[2] ignored the role of shear stress on studying the stress of sidewall rock. H.M.Westergaard[3] have studied the stress distribution problem of the rock around borehole firstly; Hubbert and Willis[4] have studied the variation of the in-situ stress from normal fault area to thrusting fault area and calculated the stress around borehole in the dual-axis stress field using elastic solution.

At this time, there are only radial and circumferential stress in the micro unit, and in order to judge whether the micro unit exceed the strength limit the radial and circumferential stress are used as maximum and minimum principal stress. Under the effect of the shear stress, the direction of the maximum and minimum principal stress is not radial and circumferential direction, they will be deflection in some certain, and it can be shown in Figure 1.

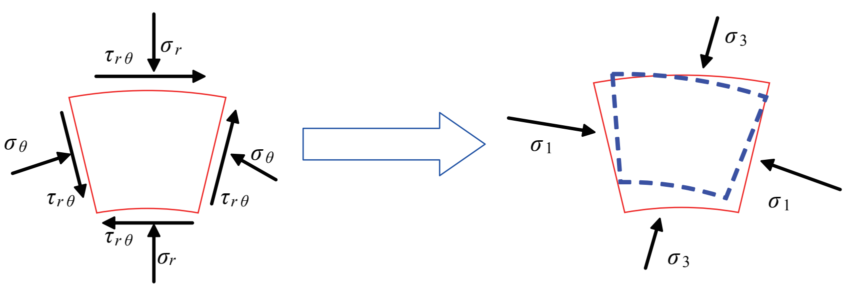

Figure 1
The Phenomenon of Stress Deflection Under the Effect of Shear Stress

1. THE ESTABLISHMENT OF SIDEWALL ROCK MODEL

We assume that the borehole is vertical. The stress distribution regulation is the matter of plane strain. Because of $\tau_{r\theta} = \tau_{\theta r}$, and under the effect of seepage the sidewall rock equilibrium differential equation is:

$$\frac{\partial \sigma_r}{\partial r}+\frac{\sigma_r-\sigma_\theta}{r}-[\phi_f\frac{\mathrm{d}p_f}{\mathrm{d}r}+\phi_p\frac{\mathrm{d}p_p}{\mathrm{d}r}]+\frac{1}{r}\frac{\partial \tau_{r\theta}}{\partial \theta}=0. \qquad (1)$$

The rock micro unit in the damage zone satisfies Mohr-Coulomb failure criterion.

$$\sigma_1 = m\sigma_3 + \sigma_c(1\text{-}D). \qquad (2)$$

Where: $m=\dfrac{1+\sin\phi}{1-\sin\phi}$.

The damage variable can satisfy the relationship as follow:

$$\begin{cases} D=0 & (\xi \le \xi_c) \\ D=\dfrac{\lambda}{E}\left(\dfrac{\xi}{\xi_c}-1\right) & (\xi \ge \xi_c) \end{cases}. \qquad (3)$$

We can get the equivalent maximum and minimum principal stress according to the related knowledge in the elasticity.

$$\begin{cases} \sigma_1=\dfrac{\sigma_r+\sigma_\theta}{2}+\sqrt{\left(\dfrac{\sigma_r-\sigma_\theta}{2}\right)^2+\tau_{r\theta}{}^2} \\ \sigma_3=\dfrac{\sigma_r+\sigma_\theta}{2}-\sqrt{\left(\dfrac{\sigma_r-\sigma_\theta}{2}\right)^2+\tau_{r\theta}{}^2} \end{cases}. \qquad (4)$$

We can get the Equation (5) by substituting the Equation (4) into Equation (5).

$$(1-m)\frac{\sigma^{r}_{r\theta}-\sigma^{r}_{\theta\theta}}{2}+(1+m)\sqrt{\left(\frac{\sigma^{r}_{r\theta}-\sigma^{r}_{\theta\theta}}{2}\right)^2+\left(\tau^{r}_{r\theta\theta}\right)^2}=\sigma_c. \qquad (5)$$

We can get the discrete model by substituting Equation (5) into Equation (1) and using central difference method.

$$\begin{cases} \tau^{r}_{r\theta\theta}=-\left(\dfrac{\tau^{r+1}_{r\theta\theta}-\tau^{r-1}_{r\theta\theta}}{4\Delta r}r+\dfrac{\sigma^{r}_{\theta\theta+1}-\sigma^{r}_{\theta\theta-1}}{4\Delta\theta}\right) \\ \sigma^{r}_{\theta\theta}=\dfrac{\sigma_c(1-D)-(1+m)\sqrt{\dfrac{K_0{}^2}{4}+\left(\tau^{r}_{r\theta\theta}\right)^2}}{1-m}-\dfrac{K_0}{2} \\ \sigma^{r}_{r\theta}=K_0+\sigma^{r}_{\theta\theta} \end{cases}. \qquad (6)$$

Where:

$$K_0=-\left[r\frac{\sigma^{r+1}_{r\theta}-\sigma^{r-1}_{r\theta}}{2\Delta r}+\frac{(p_w-p_0)}{\ln r_w-\ln R_0}+\frac{\tau^{r}_{r\theta\theta+1}-\tau^{r}_{r\theta\theta-1}}{2\Delta\theta}\right].$$

2. THE SOLUTION OF THE MODEL

2.1 The spatial discretization of the sidewall rock

We conduct the spatial discretization of sidewall rock transverse profile using point centralized method, every node can be discreted to sector, the radial step size of the node micro unit is $\triangle r$, and the circumferential step size is $\triangle\theta$. Every node has its circumferential stress (σ_θ), radial (σ_r) stress and shear stress ($\tau_{r\theta}$) data. For a certain node, it is the rth at radial direction and the θ th at the circumferential direction, and its numbering is (r,θ). The stress at circumferential direction is $\sigma^{r}_{\theta\theta}$, radial direction is $\sigma^{r}_{r\theta}$, and the shear stress is $\tau^{r}_{r\theta\theta}$. The next adjacent node at the same circumferential direction is (r + 1, θ), and the previous is (r - 1, θ); the next adjacent node at the same radial direction is (r, θ +1), and the previous is (r, θ - 1); the relationship can be shown in Figures 2 and 3.

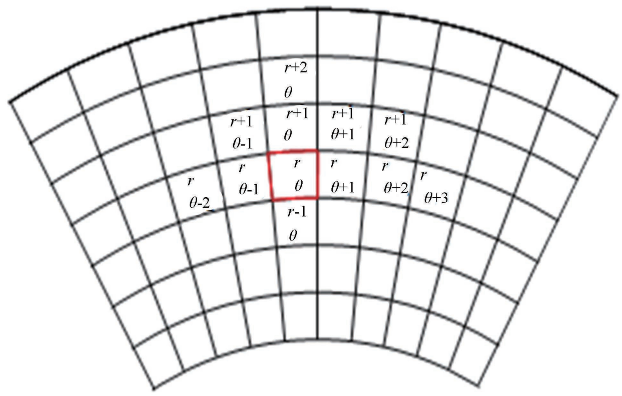

Figure 2
The Spatial Discretization Method of the Sidewall Rock

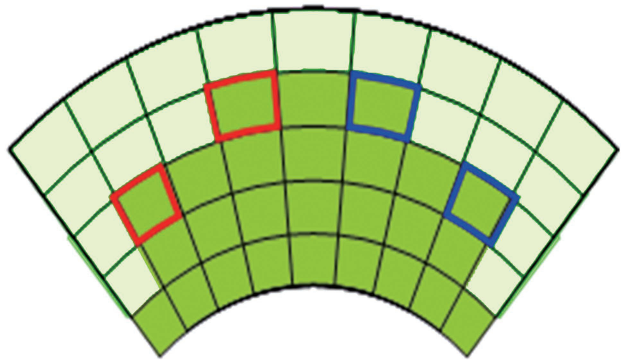

Figure 3
The Nodes at the Borderline Between Elastic and Damage Zone

2.2 The Detail Solution Process

(a) Calculating the damage variation at every node; (b) Finding the nodes at the borderline between elastic and damage zone, in other words, they are solved and unsolved stress nodes; (c) Solving the circumferential stress (σ_θ), radial (σ_r) stress and shear stress ($\tau_{r\theta}$) by using dichotomy according to forward or backward differential implicit function; (d) Searching the next node, returning to step (c) and calculating the stress at every borderline node; (e) Using step (d), returning to step (b) and calculating the stress in the damage zone; (f) Obtaining the approximate initial value, and calculating the stress at every node by iterating Equation (6); (g) Returning to step (f) until the result can satisfy the precision requirement.

3. CALCULATION EXAMPLE

Assuming that the compressional uniaxial strength limit of the rock is σ_c = 30 Mpa, E/λ = 0.5, ϕ = 30°. When the maximum principal stress σ_H is 40 MPa, the minimum principal stress σ_h is 20 MPa, We have calculated the numerical solution of the sidewall rock stress by using difference method and using computer programming, and gotten radial, circumferential and shear stress distribution regulation of the sidewall rock in the Figures 4 and 5.

It can be shown from the calculated results that: Under the effect of non-uniform in-situ stress, the damage radius of the sidewall rock is maximum at the direction of minimum principal stress. The failure zone and damage zone of the sidewall rock are not approximate ellipse, and with the difference between horizontal maximum and minimum principal stress increasing, the difference of the damage radius at the two directions is increasing.

With the difference between horizontal maximum and minimum principal stress increasing, the effect of shear stress on the stress distribution of the sidewall rock is increasing. The stress value difference will be maximum at the direction of maximum and minimum principal stress angle bisector, under the two conditions that considering and ignoring shear stress.

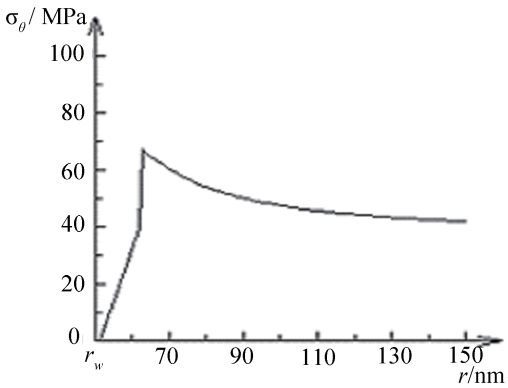

Figure 5
The Circum Ferential Stress Distribution of the Sidewall Rock

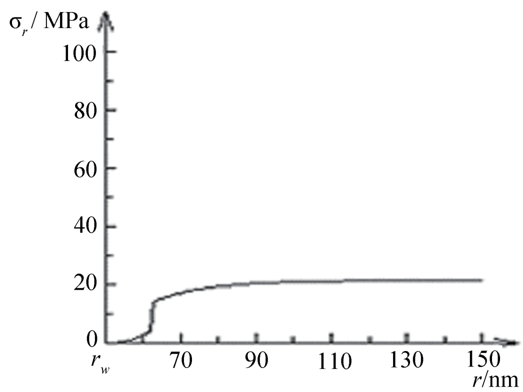

Figure 6
The Radial Stress Distribution of the Sidewall Rock

CONCLUSION

The re-orientation of the ground stress before the refracturing controls the track of new fracture extension. After initial fracturing, the stress will redirect and probably divert, because of the injection /production and the induction effect during the fracture closure. This article establishes the initial fractures and the injection / production induced stress models, which provides the necessary reference for the stress calculation before the refracturing.

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