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Research Article

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Research on the law of hydraulic fracture and natural fracture intersecting extension in the heterogeneous fractured reservoir

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ABSTRACT

For heterogeneous fractured reservoir, the production capacity of hydraulic fracturing well is limited by the ability of hydraulic fracture communication with natural fracture. This paper uses the numerical analysis method, according to the fluid-structure interaction theory and fracture mechanics theory, the three-dimensional fluid-structure coupling hydraulic fracture mechanics model is established based on the principle of hydraulic fracturing, using the fluid-structure coupling element C3D8RP to simulation the behavior of seepage and stress coupling on the reservoir rock, the fracture damage element with pore pressure is used to simulate the fracture propagation. The numerical analysis indicated that the main factors influencing the shear slippage damage of natural fracture is approaching angle and differential horizontal stress. While in the condition of low differential horizontal stress and approaching angle, under the action of hydraulic fracture, the shear strain is smaller when hydraulic fracture extension through the interface layer, and the energy dissipation is less, the hydraulic fracture is easily through the interface layer and penetration with the natural fracture, thus result in the open of the natural fracture and the dense hydraulic fracture network is formed.

Key word: natural fracture; fluid-structure coupling; approaching angle; differential horizontal stress

INTRODUCTION

The existence of natural fracture has a significant impact on forming geometrical morphology and extension rules of fracture. In the foreign country, LAMONT.N et al. studied the influence of Natural fracture to extend the hydraulic fracturing fracture in the rock in the early time . DANESHY. A. A. thought that Tiny natural fracture in the rock on the effects of a hydraulic fracture extension is not obvious, but Medium and large natural fracture have great influence on hydraulic fracture extension [1-2]. MURPHY. H. D found that Shear stress is a major cause of force of rock burst, Hydraulic fracturing fracture is caused by shear slip along with the formation of rock joint surface[3]. WARPINSKI. N. r. et al thought that Natural fracture prone to shear failure with the hydraulic fracture and natural fracture intersection interference occuring[4]. In the domestic, Zhou Jian and Chen Mian using large size true triaxial press machine confirmed that Natural fracture prone to shear failure[6-9] in the low ground stress difference and approaching Angle. Zhao Jinzhou et al. using numerical method studied the influence of the horizontal ground stress difference and approaching Angle to steering extension seam width of fracture[10].

In this paper, we use ABAQUS software as a platform, the nonlinearity three-dimensional fluid-structure coupling hydraulic fracture model is established based on the principle of hydraulic fracturing, it makes a numerical simulation study of open and shear failure mechanism of hydraulic fracture and natural fracture, which are interfered. The Drucker-Prager criterion is used as the yield condition of rock formation in the calculations, then the hydraulic fracture and natural fracture intersecting extension law can be obtained under the different approaching angle and differential horizontal stress, which can provide a guidance for oil field fracturing[11-13].

Fracture damage evolution mathematical model

Fracture damage criterion

The secondary stress criterion is used to judge whether the fracture interface elements are damaged, when the damage stress value of fracture damage element reaches the threshold value, hydraulic fracture begins to damage, the formula is:

$$\left\{\frac{\langle\sigma_n\rangle}{\sigma_n^o}\right\}^2+\left\{\frac{\sigma_s}{\sigma_s^o}\right\}^2+\left\{\frac{\sigma_t}{\sigma_t^o}\right\}^2=1 \qquad (1)$$

The normal stress and tangential stress are σ_n 、σ_s 、σ_t , the rock tensile strength is σ_n^o , the shear damage critical stress are σ_s^o and σ_t^o .The symbol expresses that fracture damage elements are not affected by stress.

Fracture damage evolution equations

Using mixed damage evolution mode to describe evolution process after fracture damage elements are damaged, We assume that the critical damage energy in the shear direction is equal, the damage evolution equations are:

$$\begin{aligned}&G_n^C+\left(G_s^C-G_n^C\right)\left(\frac{G_S}{G_T}\right)^{\eta}=G^C\\&G^C=G_n+G_s+G_t\end{aligned} \qquad (2)$$

The mixed mode fracture energy is G^C , The normal and tangential fracture energy are G_n、G_s、G_t , the material related parameter is η , $G_S=G_s+G_t$, $G_T=G_n+G_S$.

Along with the continuous degradation of crack damage element stiffness, the damage factor D is used to describe the degradation process of crack damage element stiffness, the calculating formula of D is:

$$D=\frac{d_m^f(d_m^{\max}-d_m^0)}{d_m^{\max}(d_m^f-d_m^0)} \qquad (3)$$

In the formula, $d_m^{\max}$ is the maximal displacement amplitude that elements can be reached in loading procedure, d_m^f is displacement amplitude when the elements are completely destroyed.

Hydraulic fracture and natural fracture intersecting extension model

Considering stratum as the infinite elastic medium, we assume that hydraulic fracture and natural fracture's height and the reservoir's height are equal, taking no account of the effect of fracture fluid loss, build force model as fig.1, rock unit uses the unit with the pore pressure of the three-dimensional C3D8RP, Hydraulic fracture and natural fracture use facture damage elements COH3D8P. The model is divided into 4080 units, 5489 nodes. The finite element model can be shown in fig.2.

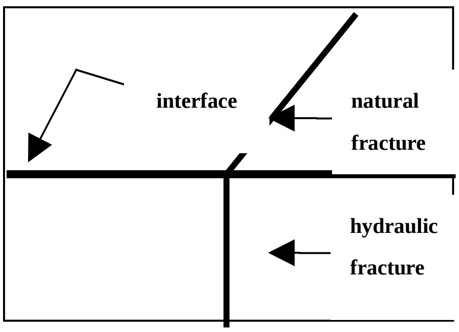

Fig.1 fracture extension mechanical model

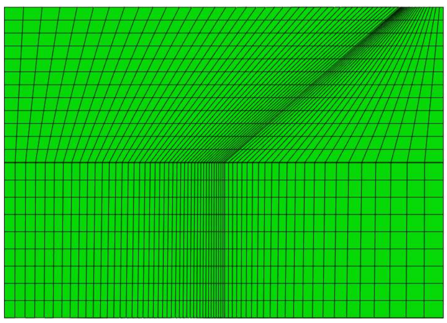

Fig.2 fracture extension finite element model

Fortran language is used to Compile SIGINI subroutine to simulate three different direction of in-situ stress for embedding in the main program. The external surface models are applied to the normal displacement constraint. The lateral surfaces are applied to the fixed pore pressure boundary. The initial pore pressure is 24.5 MPa, The initial minimum horizontal principal stress is 25 MPa, The maximum horizontal principal stress is 25.2 MPa, The vertical of overburden stress is 26 MPa, The initial porosity ratio is 0.17. Model loading includes gravity load and injection pressure load, the rate of injection flow is 0.0025m^3/s. The parameters of formation and fracture damage units can be shown in table 1.

Table1 Stratum parameters

elasticity modulus	Poisson ratio	permeability	density	void ratio
23/Gpa	0.2	2/mD	2100.kg/m^3	0.0001

The finite element simulation results and analysis

The influence of approaching angle

We assume approaching angle is respectively : 0°, 15°, 30°, 45°, under the same formation parameters. The interface shearing strength nephogram of different approaching angles can be shown in fig.4 and fig.5.

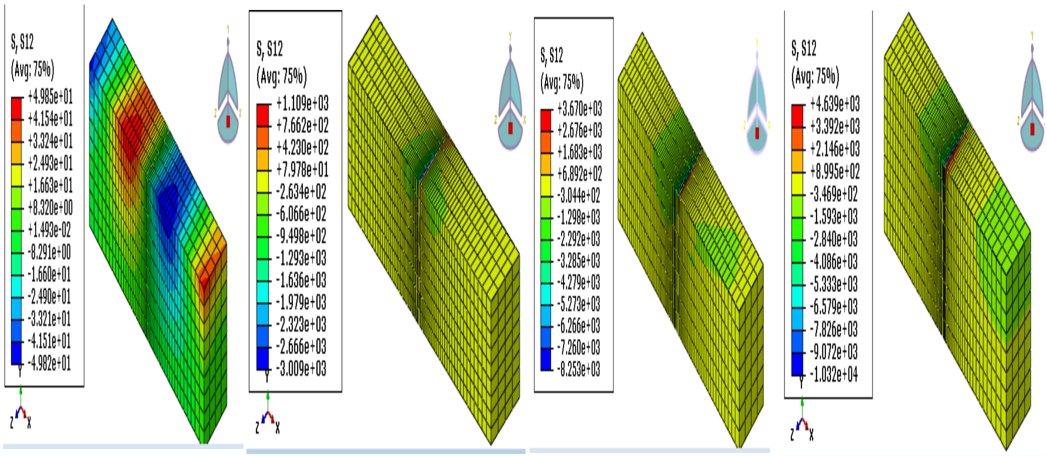

Fig.3 The shearing strength nephogram approaching angle is 0°,15°,30°,45°

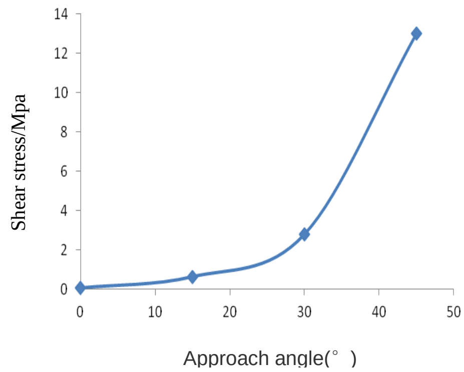

Fig.4 Fracture intersecting interface shearing strength curve under different approaching angles

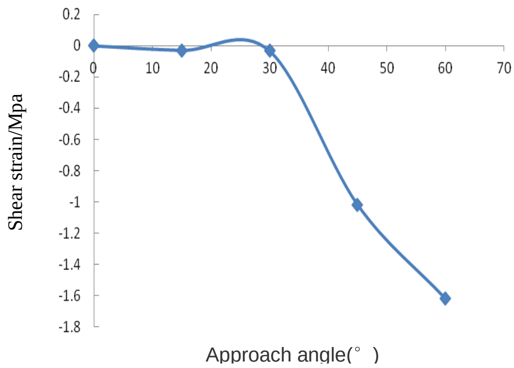

Fig.5 Fracture intersecting interface shearing strain curve under different approaching angles

It can be shown in fig.3, the interfacial shear stress and shear strain will increase along with the approaching angle increases. As the interfacial shear stress value is greater, the interface shear deformation amount is bigger, the generating plastic yielding deformation amount is larger, energy dissipation is very serious, then the hydraulic fracture through the interface intersects natural fractures will be more difficult, natural fracture is more difficult to open. The conclusion is identical with Zhou Jian et al. 's Application of indoor test results. From fig.4 and fig.5, as the shear stress generated by interfacial dislocation are greatly influenced by the angle, when approaching angle is less than 300 , the interfacial shear stress and shear strain have a little extent increase, when approaching angle is more than 300 , the interfacial shear stress and strain increase sharply. Therefore, hydraulic fracture trend can be designed according to the distribution regularities of natural fracture.

The influence of horizontal crustal stress difference

We assume the approaching angle between hydraulic fracture and natural fracture is 30 °, when the other conditions unchanged, the maximum and minimum horizontal crustal stress difference is respectively 4MPa, 6MPa, 8MPa, 10MPa. Fig.7 is the shearing strength distribution nephogram of fracture swerve extension fracture surface under different horizontal crustal stress difference.

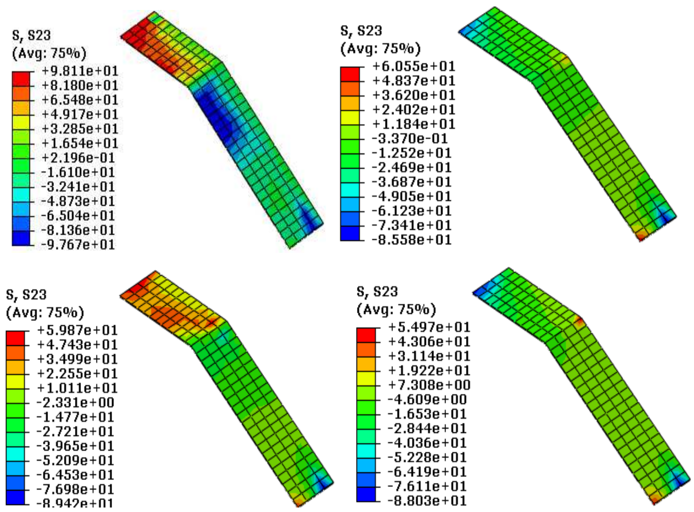

Fig.6 shearing strength distribution nephogram under different horizontal crustal stress difference

It can be seen from fig.6, the shearing strength on fracture swerve extension section can be smaller when the horizontal crustal stress difference increases, then the shear damage isn't easy to occur, so the closed natural fracture is not easy to open. The fracture intersecting interface shearing strength curve is shown in fig.7, the maximum width curve of fracture swerve extension section is shown in fig.8.

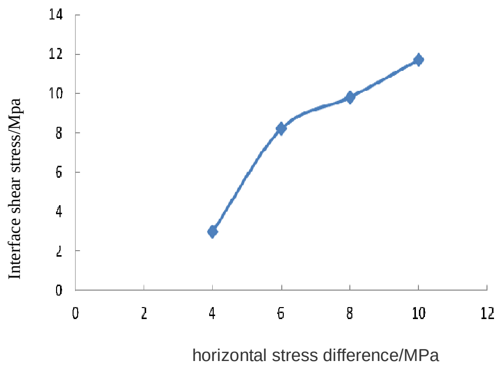

Fig.7 Fracture intersecting interface shearing strength curve

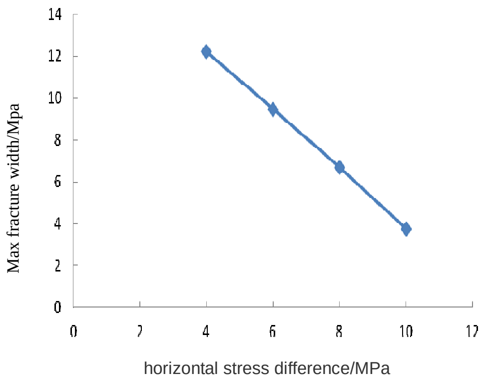

Fig.8 The maximum width curve of fracture swerve extension section

From fig.7 and fig.8, with the horizontal crustal stress difference increasing, the hydraulic fracture and natural fracture intersecting interface shearing strength is larger, then the shearing strain is larger, the energy dissipation caused by fracture propagation is very great, hydraulic fracture is easy to expand on the interface, and it is not easy to intersect extension with natural fracture. According to energy conservation law, if the loss of energy of hydraulic fracture extension in the interface is large, when the hydraulic fracture intersects with natural fracture, the extension ability along natural fracture is relatively weakened, so the crack width of fracture swerve extension section will be smaller.

CONCLUSION

(1)The mechanics model of hydraulic fracture and natural fracture intersecting is established based on the theory of solid mechanics and fracture mechanics, according to the fluid-structure interaction theory, the numerical simulation methods are used to realize extension simulation of hydraulic fracture in the heterogeneous fractured reservoir, which can provide effective methods for hydraulic fracture and natural fracture intersecting extension research.

(2)It can be indicated that from the numerical simulation results, when the approaching angles between hydraulic fracture and natural fracture get larger, the generated plastic yielding deformation amount is larger in the extension process, energy dissipation is very serious, a plenty of fracturing fluid can't flow into natural fracture, then the hydraulic fracture intersects natural fractures will be unsatisfactory, that is not conducive to form large area fracture network.

(3)When the horizontal crustal stress difference is larger, the intersecting interface shearing strength will be far larger, then the intersecting interface shearing strain can be larger, hydraulic fracture is easy to expand along the interface. Hydraulic fracture extends to the natural fracture is hindered, which can lead to hydraulic fracture is not easy to intersect extension with natural fracture to form fracture network.

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