

Numerical Simulation of Tectonic Stress Field and Fracture Prediction of Dongying Formation in SX Fault Zone of QK Sag

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Abstract: The characteristics of stress field is the key problem to study the control of strike-slip fault zone on reservoir formation, which is of great significance to the exploration and development of structure-controlled oil and gas fields. Dongying Formation in QK Sag is a fractured reservoir, and oil and gas come from the underlying layer through fault migration and accumulation, fault has a significant control on oil and gas migration and accumulation, and oil and gas are still in the process of migration and accumulation. The distribution law of the structural stress field can better guide the direction of oil and gas exploration in QK area, which is of great significance for oil and gas exploration and development in this area. In this paper, the finite element numerical simulation method of tectonic stress field and the regional geological background are used to determine the structural development characteristics of the study area by establishing the real three-dimensional geomechanical model, fault distribution, formation morphology and rock mechanics parameters in the study area. The study shows that the fault has a controlling effect on the distribution of stress, and the difference stress value in the fracture zone is large and the fracture development degree is high. The simulation results are in good agreement with the calculation results of curvature properties, and have a good correspondence with the productivity of a single well, which has a certain guiding effect on the accuracy of the structural stress of Dongying Formation in SX fault and the exploration and development of the structural oil and gas reservoirs in this group.

Keywords: QK Sag; SX fault; Tectonic Stress Field; Fracture Prediction.

1. Introduction

The structure in the basin has an increasingly important impact on the control of oil and gas storage, especially the densely developed fracture system in the formation, which can communicate with multiple closed reservoirs in the formation, so the study of strike-slip fault zone and its derived fractures is particularly important^[1].

Previous studies have gained a great understanding of the characteristics of fracture development. The main methods used include core data observation, imaging logging data analysis, outcrop observation, numerical simulation of tectonic stress field, etc. Narr et al.^[2] used the curvature method to study the fracture and characterize the fracture from the curvature mechanism. Aghli et al.^[3] conducted research on fracture identification through logging data and imaging logging techniques. Sun Shuai et al.^[4] identified cracks in field geological outcrops and established the relationship between rock elastic modulus and fracture formation. Zeng Lianbo et al.^[5] studied the distribution state of ground stress and believed that ground stress has a major controlling factor on fracture development, and the magnitude and direction of ground stress have a great influence on fracture development and prediction. Due to the limitations of the research data, such as human measurement errors, insufficient logging data, lack of seismic data or poor deep resolution, the above studies have shortcomings and cannot identify and predict fractures accurately. Therefore, this paper takes SX fault zone in QK Sag as an example, under the condition of simultaneous tectonic stress action and preexisting fault development, based on the finite element numerical simulation technology combined with seismic

attributes to identify cracks^[6], and quantitatively predicts the spatial distribution characteristics of its stress field from the essential structural stress-strain controlling fracture development. It provides some guiding significance for oil and gas exploration and development in QK area

QK Depression, located in the west of H Depression, is an extensional basin developed on the basement of the pre-paleogene system, with various types and different orders of tectonic belts. In the upper part of the tectonic area, the depression is controlled by Hy fault, Hs fault and SX fault, and the Paleogene Kongdian Formation, Shahejie Formation and Dongying Formation developed from the bottom up, among which Member 3 of Dongying Formation (E3D3), Member 1 of Shahejie Formation (E2S1) and Member 3 of Shahejie Formation (E2S3) are the main oil and gas producing layers^[7]. SX fault, located to the east of the QK main depression, connects the Paleogene sandstone formation with the buried-hill reservoir of the Slt bulge, and is an excellent channel connecting the Shaliangtian bulge and the QK main depression. The present tectonic stress field in the study area was generated under the background of the Alpine movement, which led to a series of near east-west faults generated by right-lateral strike-slip shear in the SX fault zone, and a series of shear tectonic fractures were derived along the faults.

2. Construction of Geomechanical Model and Loading Boundary Conditions

The distribution and development of tectonic joints are controlled by the construction and regional tectonic stress field. By constructing the real three-dimensional geological

model, this paper analyzes the finite element numerical simulation, and determines the stress distribution

characteristics of the research area.

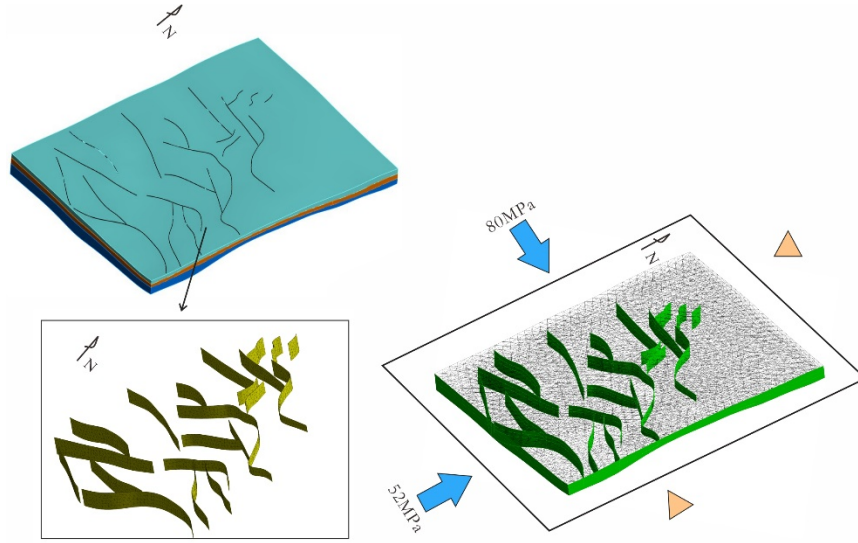


Figure 1. Mechanical model and loading boundary conditions

Reasonable geological models and boundary conditions are the basis for numerical simulation of tectonic stress field [8]. Using Rhino8 software, based on the regional tectonic background and seismic interpretation results, the structural development characteristics of the study area were determined, and the three-dimensional geological model of the Dongying Formation of SX fault zone in QK Depression was established.

In view of the different rock physical properties of different layers, the formations in the first, second and third sections of the East were vertically constructed, the formations were set as elastic medium materials, and different rock mechanical parameters were assigned respectively. The mechanical parameters were derived from petrophysical experiments and calculation of logging data, and the dynamic rock mechanical parameters of each part of the study area were calculated by using the logging data through formulas:

$$E_d = 10^{-3} \rho V_s^2 \frac{3V_p^2 - 4V_s^2}{V_p^2 - V_s^2}$$

$$\mu_d = \frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)}$$

$$S_t = 3.75 \times 10^{-4} - E_d(1 - 0.78V_{sh})$$

$$\varphi = 180/\pi \cdot \pi/12 \left[2 \left(1 - \frac{\mu_d}{1 - \mu_d} \right) + 1 \right]$$

Where, ρ is rock density, g/cm³; V_p is the p-wave velocity, m/s; V_s is shear wave velocity; μ_d is the dynamic Poisson ratio; S_t is tensile strength, MPa; V_{sh} is the muddy content, %; φ is the internal friction Angle.

According to the obtained dynamic mechanical parameters, they are further converted into static mechanical parameters that are more consistent with the actual mechanical properties, and the obtained parameters are processed on average to

obtain the rock mechanical parameters required for simulation in the study area. Considering the influence of earth gravity on the model, the gravity generated by the formation (9.8N/kg) is loaded into the model according to the actual situation in the software. In order to obtain more accurate numerical simulation results, it is necessary to define the rock mechanics parameters of the fault zone. The SX fault zone in the study area is a NW trending fault zone, and 21 of the most significant faults in the fault zone (FIG. 1) are selected to establish the fault model. The fault zone is set as a transition zone with a certain width, and since the fractures near the fault zone are mainly affected by strike-slip faults, the contact relationship between faults and strata in the study area is set as frictional contact, and the friction coefficient is set at 0.25^[9]. Because the rock mechanics parameters of fracture zone are often difficult to be measured directly, the fracture zone and surrounding rock are treated as faults together.

According to previous studies, Poisson's ratio of the fault zone usually set is slightly larger than that of the surrounding strata, and parameters such as density and elastic modulus are usually defined as 60% of the surrounding strata^[10]. If the stress is directly applied to the model, the boundary effect of mechanical loading will occur. Therefore, when the model is built, the model border will be set, and the overlying strata, the underlying strata and the surrounding rock of the model will be set to ensure the accuracy of the model.

After the geological model is established, the model of the finite element is transformed into the finite element numerical simulation of the current tectonic stress field. In order to highlight the simulation accuracy of the fault zone, the grid division of the fracture zone is more detailed than the surrounding strata, and the precision of the formation is greater than the surrounding surrounding rock. The overall model was divided into: 660335 nodes and 378710 units. The key to the research stress field is to determine the size and direction of the stress field in the research area of the research area, which is the maximum main stress direction of the north east 80c, the load stress 80mpax, the minimum main stress direction is perpendicular to the maximum main stress direction, and load the stress 55mpay.

3. Numerical Simulation Result

According to the applied stress boundary conditions, the structural stress field of the study area is analyzed by finite element numerical simulation, and the simulation results of

the maximum horizontal principal stress, minimum horizontal principal stress and shear stress in the study area are obtained. In the simulation results, the positive value is expressed as the state of tension stress, and the negative value is expressed as the state of extrusion stress.

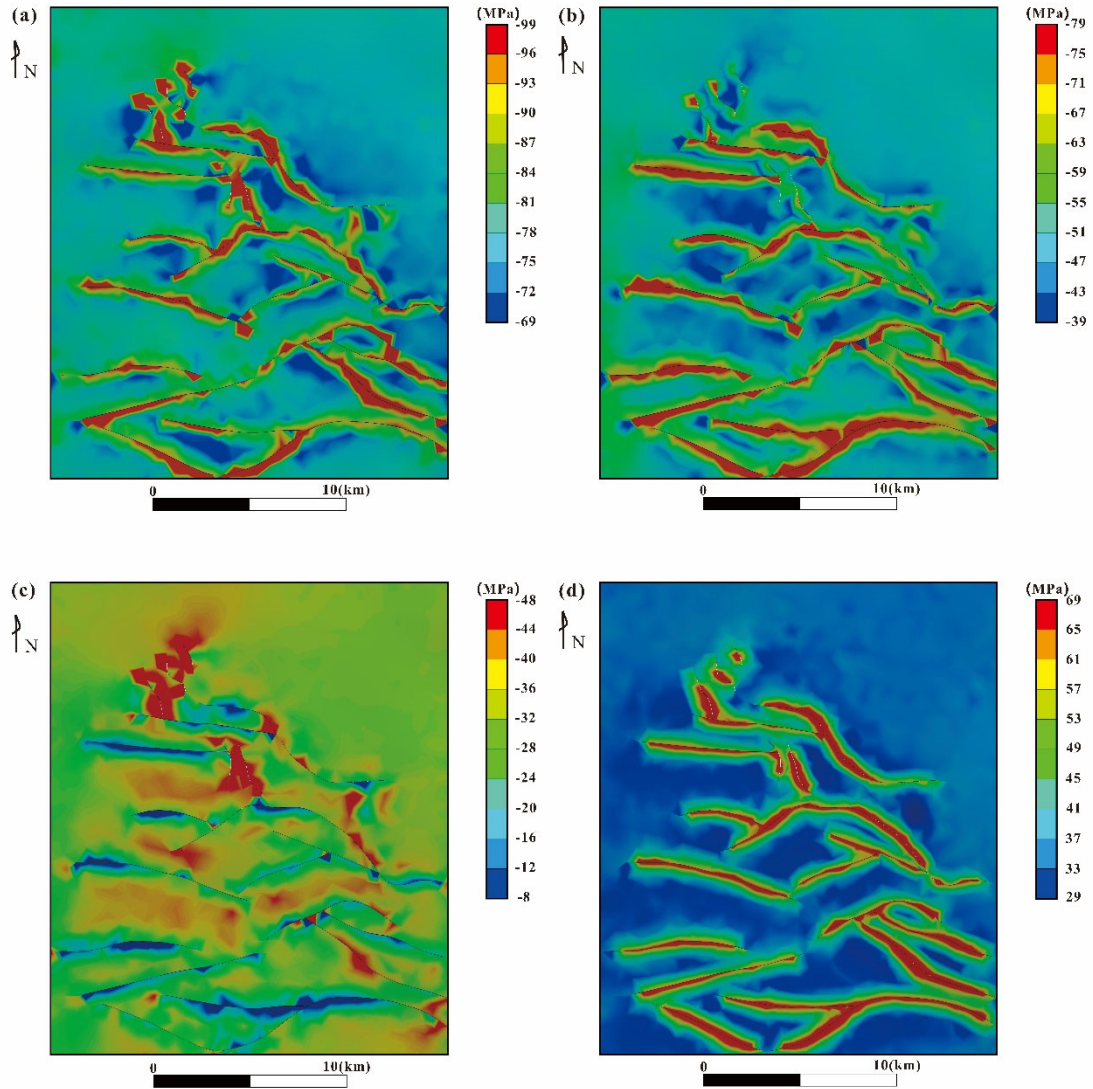


Figure 2. Stress characteristics of SX fault zone

The simulation results show that the maximum horizontal principal stress in the study area is symmetrically distributed along the strike of the fault zone, with a large stress value on the west side of the fault zone and a relatively small stress value on the east side of the fault zone, and the low stress value is basically distributed along the NW-trending strike-slip zone, and the minimum value appears inside the fault zone, which is mainly because the strike-slip tension occurs inside the fault zone under the action of left-lateral strike-slip. The stress value decreases along the direction of the maximum principal stress. The distribution value of the maximum principal stress along the fault is generally large, and the maximum value of the stress is 98MPa. Within the fault zone, the area surrounded by multiple faults presents a state of weak compression under the influence of fault strike-slip, and low values will appear, with a minimum value of about 70MPa (FIG. 2a). The stress values of the fault and the surrounding strata show a state of sudden change, which can

also indicate that the geological structure is sensitive to the change of stress, and the stress values show an obvious sudden state due to the influence of the geological structure, which also proves the feasibility of predicting the fracture development by stress field simulation. The horizontal minimum principal stress is mainly symmetrical along the fault, and the high value is mainly distributed around the fault, and the maximum value is 76MPa at the fault. Affected by the direction of stress, the high value is generally distributed on the southern side of the fault, and the stress value becomes smaller and smaller as the fault progresses to the north. Under the influence of tension, the minimum value is about 40MPa in the north-central part of the fault zone (FIG. 2b).

The development of shear cracks is related to horizontal shear stress, and it is generally believed that the higher the shear stress is, the more shear cracks will develop. The simulation results show that there is a large amount of shear stress in the middle of the fault zone. Within the fault zone,

high shear values appear in the strata surrounded by faults that strike near NW to SE in the northern section, which proves that under the influence of left-lateral strike-slip, the strata have large shear scale and fracture. Strong stress mutation occurs around the fault, and structural shear cracks are generally developed, and the stress value can reach about 47MPa. On the south side of the fault zone, especially near the east-west fault, the stress value is small, and the tension fracture may develop, and the stress value is only 10MPa. The shear stress of the strata on both sides of the NW-trending fault zone also presents a state of high stress value, which proves that the strata on the east and west sides have experienced relatively strong strike-slip faults, and have also been subjected to the effect of stress along the faults, and the strata have broken. The difference between the strata and the surrounding strata is relatively large, and local high stress values appear, which may be accompanied by the development of a large number of structural shear cracks (Figure 2c). The difference stress results show that the high value mainly exists around the fault and the surrounding strata, which proves that the stress intensity around the fault is large and the stress value is relatively concentrated. Generally speaking, the more easily the stratum is broken in the place of high stress intensity, the more likely it is to crack. The difference stress between the fault and the surrounding strata presents a sudden state, which proves that certain fault structures are generated along the fault, and a series of structural cracks are generated to share the stress, while the strata between the faults are broken and the stress intensity is released (Figure 2d)^[11].

4. Stress Result Verification

In order to verify the accuracy of stress field simulation, curvature properties were extracted from 3D seismic data in the study area to verify the simulation results. The calculated results of curvature properties were in good agreement with the results of stress values.

In addition, compared with the production data of a single well, the average daily production of C7-3-1, C7-2-1d and C7-3-2d Wells located in the fault zone is high, and the well locations are basically distributed in the strike-slip pull-apart active segment in the study area. Combined with the simulation results, a large number of fractures develop in this area, indicating that the well locations in this area are obviously controlled by the tectonic system in this area. Combined with the calculation results of single well production and curvature attributes, the accuracy of the simulation is verified. The common fracture development in the study area greatly improves the productivity of single well, and provides certain reference help for the exploration of oil and gas reservoirs in this area.

5. Conclusion

(1) The maximum horizontal principal stress in the SX fault zone is distributed symmetrically along the strike of the fault zone and is obviously controlled by strike-slip action, and the distribution of high values mainly revolves around the fault; The distribution of minimum horizontal principal stress is obviously controlled by fault. The horizontal shear stress is larger on the north side, especially the fault affected by the NW fault strike-slip and the formation surrounded by multiple

faults, all show a high shear stress value.

(2) According to the calculation results, the difference stress value near the fault zone is large, which proves that the fractures are generally developed around the fault zone, and the fracture value near the C7-3-1, C7-3-2d and C7-2-1d Wells is high, which proves that the fractures near the fault zone are densely developed, and the fractures have obvious effectiveness on the productivity of a single well. Combined with the consistency of the results of curvature attributes, the accuracy of the construction simulation is also verified.

(3) The SX fault zone has a high value of differential stress near the fault, and the strike-slip effect affects the development of a large number of strike-slip shear tectonic fractures in this region. The numerical simulation of tectonic stress field is used to predict the development characteristics of fractures, and it is of guiding significance to the exploration and development of oil and gas fields with similar geological characteristics.

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