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The In-Situ Stress Analysis of Casing Damage Wells in the Sixth Middle District Based on Kriging Interpolation Method

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Abstract

Casing damage is a common engineering problem, the causes of which mainly include two aspects: geological factors and engineering factors. In this paper, the application of the data of logging and hydraulic fracturing gives the calculation model of stress in three directions in the sixth middle district, and have an interpolation calculation on the in-situ stress data in the casing damage wells based on the Kriging interpolation method, and then have a study on the casing damage problems of the sixth middle district in Karamay oil field from the perspective of the in-situ stress. The results show that: the triangular nose anticlinal structure of the sixth middle district which is influenced by tectonic stress obviously is typical non-uniform loading zone; the horizontal stress is the biggest, the ratio of the two horizontal stress is 1.58, which is the major cause of the casing diameter shrinkage. According to the characteristics of the horizontal stress which is too big and the non-uniform load, it is proposed to abandon the conventional design methods of casing string in uniform load, using the non-uniform loading conditions to design, which lays the foundation for secure and stable development of the sixth middle district reservoir.

Key words: Oil field development; Casing damage; In-situ stress; Kriging method; Geometric modeling

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INTRODUCTION

Casing is a certain kind of steel pipe which protects borehole and downhole equipment and insolates formation fluid. Casing damage leads to loss of pressure, impairment, pinching of production tubing, an inability to lower workover tools, or even well abandonment. The direct and indirect economic losses caused by casing damage are considerable necessitating the research on casing damage mechanisms[1].

Large quantities of research have been carried on aiming at the solution of casing damage. The causes casing damage mainly include two aspects: geological factors and engineering factors. In-situ stress has an obvious influence on stress state of casing[2]. At present, the common method is to establish the mechanical model and mathematical model by the finite element method and computer simulation, and analyze the influence that the stress have on the casing damage by the Mohr - Coulomb yield criterion[3-8]. In this article, we use the Kriging method to study the casing damage by studying the impact that the tectonic stress and formation stress have on in-situ stress, revealing the impact that the in-situ stress have on the casing damage of the sixth middle district, so we can take more effective and preventive measures to reduce annual huge investment in repairing the casing damage wells and extend the working life of production and injection wells, producing greater economic benefit of oil field.

1. THE BASIC SITUATION OF CASING DAMAGE IN THE SIXTH MIDDLE DISTRICT

The structural shape of the bottom of the reservoir in the sixth middle district is a triangle nasal anticline located between Karamay-Wuerhe fracture and Baijiantan North fracture (Figure 1). The reservoir is conglomerate reservoir with middle porosity, high permeability and heterogeneity, whose sedimentary thickness is 45-77 m with the average value is 52 m. The reservoir has stable distribution with shallow buried depth while the mid-point of reservoir is 480 m[9].

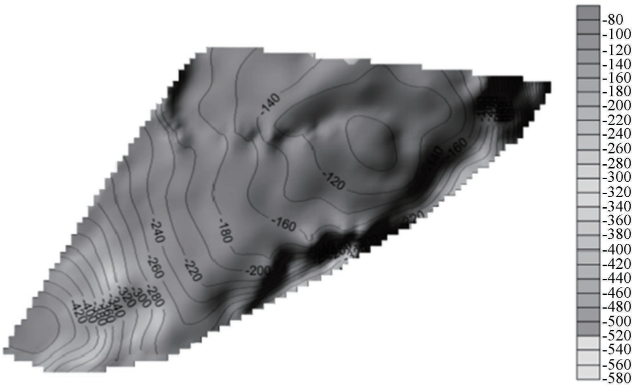

Figure 1
Distribution Contour Map of the Top of Oil Reservoir in the Sixth Middle District

Fully operational since 1973, a total of 544 wells in the sixth middle district, where 361 production wells, and 183 injection wells, among all of which there are 85 casing damaged wells reaching 15.6 percent, and the casing damaged wells severely affect the normal development of the oil yield.

Especially after 2000, casing damage problem occurs even more frequently while the number of casing damaged wells reaches 28. There are 22 wells suffering from hole shrinkage taking up 78.6% of all the casing damaged wells. Other damage types have 6 wells. The production time and depth distribution of the casing damaged wells in sixth middle district are shown in Figures 2 and 3.

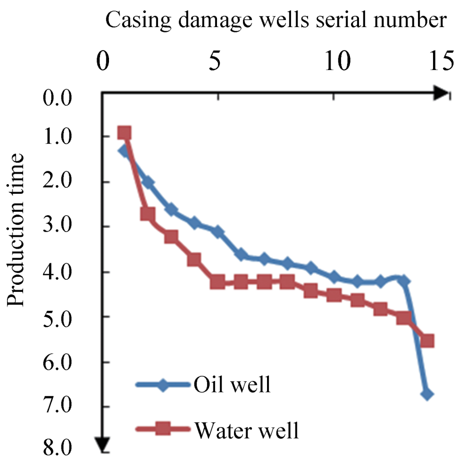

Figure 2
Production Time Distribution of Casing Damage Wells

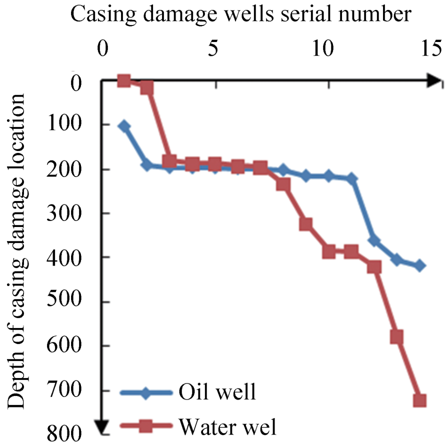

Figure 3
Depth Distribution of Casing Damage Points

From Figure 2 we can see that the production time of casing damaged wells in the sixth middle district are basically within 5 years, accounting for 88.5% of the total, and some casing damaged wells in 1-2 years. Among the casing damaged wells in the sixth middle district, there are 14 production wells, accounting for 50%, while the injection wells is 14, accounting for 50%.

From Figure 3 we can see that in the sixth middle district, the casing damaged wells mainly occur in the shallow formation with the depth range between 180 and 230 m above the reservoir. The distribution of production wells is within 40 m ranging from 180 to 230 m while injection wells are within 50 m ranging from 190 to 230 m.

The casing damaged wells in this sixth middle district has such features that buried depth is shallow, production period is short and hole shrinkage is the main damage type.

2. KRIGING MODEL

Kriging model is a mathematical method, which is based on the theoretical analysis of the variation function to have an unbiased optimal estimation on the value of the regional variable in the limited region. Kriging model is linear, because its estimation is based on the weighted linear combination of the existing data. Compared with other estimation methods, the average residual or error of the Kriging interpolation method closes to zero, and the minimum variance of the error is the significant feature of Kriging method.

Semi-mutation function of observed value can be defined as:

$$\hat{\gamma}(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[\hat{Z}(x_i)-\hat{Z}(x_i+h)\right]^2 . \qquad (1)$$

Where, $\hat{Z}(x_i)$ is the observed value of x_i; $\hat{Z}(x_i+h)$ is the observed value of x_i+h; h is lag distance; $N(h)$ is the number of intervals divided by lag distance h.

After plot of $\hat{\gamma}(h)$-h is constructed, $\hat{\gamma}(h)$ can be fitted to exponential model, Gaussian model, spherical model etc. The optimum model can be determined by least error.

Normal Kriging valuation formula can be expressed as:

$$\hat{Z}(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i). \quad (2)$$

Where, $\hat{Z}(x_0)$ is the predictive value of $\hat{Z}(x_0)$ when X takes the value of x_0; $\hat{Z}(x_i)$ is the predictive value of $\hat{Z}(x_0)$ when X takes the value of x_i; λ_i is the Interpolation coefficient.

3. THE THREE CIRCUMFERENTIALLY STRESS CALCULATION MODEL OF CASING DAMAGED WELLS

The in-situ stress is the internal force which balances each other within the rock, the concrete calculation mainly includes two aspects: vertical in-situ stress and horizontal in-situ stress. In calculation of in-situ stress, there are two main aspects to consider: vertical in-situ stress and two horizontal in-situ stress[10].

Vertical in-situ stress is caused by overlying formation gravity. Thus, it varies with formation density and depth.

Considering the formation anisotropy and tectonic stress, the two horizontal in-situ stress which are different can be calculated as:

$$\sigma_H = \left(\frac{\mu_s}{1-\mu_s} + \beta\right)\left(\sigma_v - \alpha P_p\right) + \alpha P_p , \quad (3)$$

$$\sigma_h = \left(\frac{\mu_s}{1-\mu_s} + \psi\right)\left(\sigma_v - \alpha P_p\right) + \alpha P_p . \quad (4)$$

Where, σ_H is the maximum horizontal in-situ stress, MPa; σ_h is the minimum horizontal in-situ stress, MPa; μ_s is the static Poisson's ratio of rock; P_p is the formation pore pressure, MPa; α is the pore elastic constant; β is the tectonic stress factor; ψ is the tectonic stress factor.

Formation factors of two direction horizontal stress are 1.09 and 0.31 respectively obtained from hydraulic fracturing experimental data of 12 wells in the sixth middle district. Thus, the calculation formula of the horizontal in-situ stress is gained:

$$\sigma_H = \left(\frac{\mu_s}{1-\mu_s} + 1.09\right)\left(\sigma_v - \alpha P_p\right) + 0.7 P_p , \quad (5)$$

$$\sigma_h = \left(\frac{\mu_s}{1-\mu_s} + 0.31\right)\left(\sigma_v - \alpha P_p\right) + 0.7 P_p . \quad (6)$$

4. THE INTERPOLATION SIMULATION OF THE THREE-DIMENSIONAL IN-SITU STRESS OF CASING DAMAGED WELLS

We establish geometric model according to the geological structure chart of the sixth middle district. *XYZ* data file is then created. The first two columns of *X* and *Y* coordinates represent well location coordinates. The third column represents *Z* values with respect with each well location coordinate, which stand for the value of in-situ stress. Grid file of in-situ stress is created according to Kriging model. Kriging differential method can ensure that interpolation point takes the same value as the sampling point when interpolation point coincides with interpolation point[11-12].

The in-situ stress contours of the depth of the casing damage points in the sixth middle district are shown in Figures 4, 5, and 6. From Figures 4 to 6, the damage layer of casing damaged wells mainly ranging from 180 to 230 m, and the casing damage layer is shallow, where the vertical stress is relatively small, so the relatively large horizontal stress is the cause of casing damage, so the reduced diameter is the majority in casing damage. Casing damage area is between Karamay-Wuerhe fracture and Baijiantan North fracture, and Karamay-Wuerhe fracture is a large over-thrust fracture, which provides geological conditions for big horizontal stress.

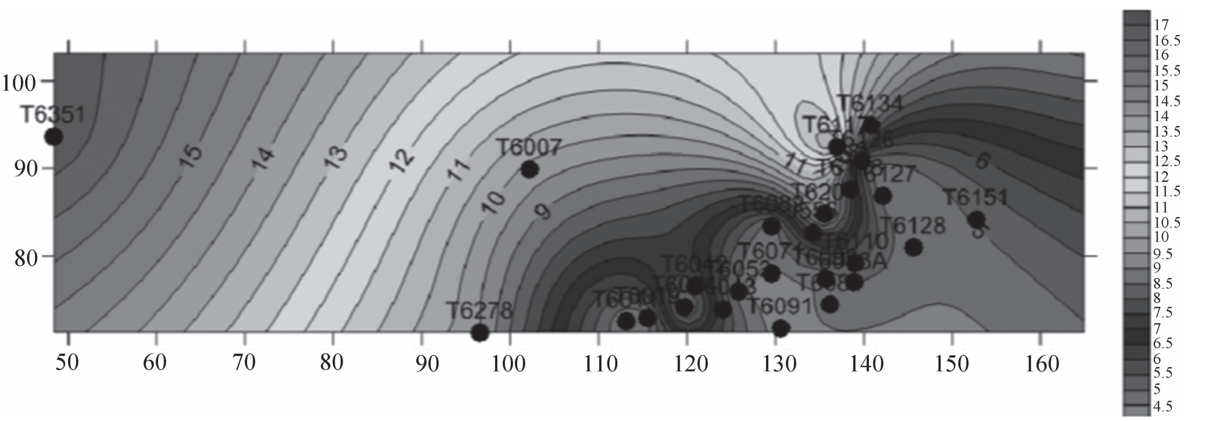

Figure 4
Depth Vertical Stress Distribution of Casing Damage Points in the Sixth Middle District

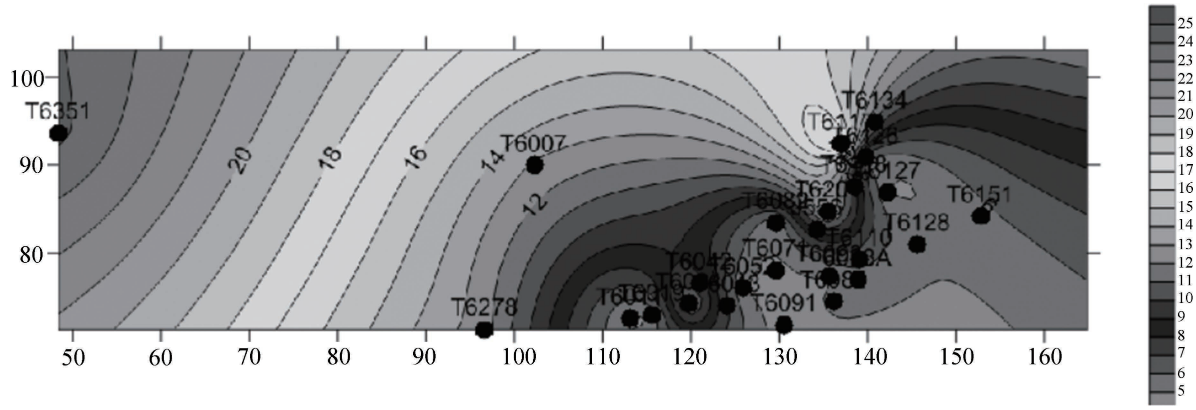

Figure 5
The Maximum Horizontal Stress Distribution of Casing Damage Points in the Sixth Middle District

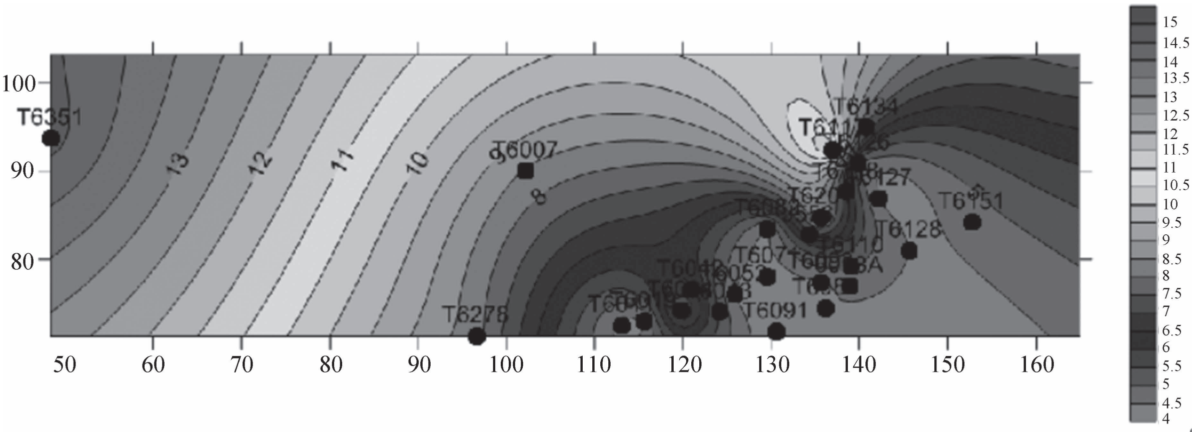

Figure 6
The Minimum Horizontal Stress Distribution of Casing Damage Points in the Sixth Middle District

Tectonic stress has a significant effect on the triangle nasal anticline in the sixth middle district, which is a typical non-uniform load zone. The calculation result of in-situ stress of casing damaged wells shows: horizontal tectonic stress is relatively obvious in this district, and the relationships among the three stresses are $\sigma_H > \sigma_v$, $\sigma_H < \sigma_h$, the ratio of the horizontal stress is 1.58.

Collapsing strength of casing is reduced due to non-uniform load. According to the further calculation, the average value of non-uniform coefficient of external load is 0.63; collapsing strength of J55 casing is 17.88 MPa; collapsing strength of N80 casing is 17.88 MPa.

Through the above analysis, we can draw the main reason of the casing damage is the non-uniform stress in the sixth middle district, the difference between the maximum stress and minimum stress is too large. Since the conventional casing is designed for uniform load, so the area is prone to have casing damage. In view of the characteristics that the horizontal stress is too large and the load is non-uniform in the sixth middle district, proposing to improve the cementing quality, and design the casing string under the non-uniform load condition instead of uniform load condition. At the same time, we should choose the reasonable casing material and increase the design strength of casing to improve its ability to resist collapse, so we replace the commonly used J55×7.72 model, N80×7.72 model by N80×10.54 or P110×9.17 model.

CONCLUSION

Characteristics of casing damaged wells in the sixth middle district is that buried depth is shallow, production period is short and hole shrinkage is the main damage type.

Kriging method is applied in establishing the three dimensional in-situ stress field contour distribution of the sixth middle district, which lays the foundation for the direct analysis of the impact that the stress have on the casing damage.

The calculation result shows: horizontal tectonic stress is relatively obvious in the sixth middle district; the relationship among the three stresses is $\sigma_H > \sigma_v$, $\sigma_H > \sigma_h$, the ratio of the horizontal stress is 1.58.

In view of the characteristics that the horizontal stress is too large and the load is non-uniform in the sixth middle district, proposing to design the casing string under the non-uniform load condition instead of uniform load condition.

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