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A new method for dynamic prediction of reservoir pore pressure in development Wells

Ying Gao

Institute of Geology, No.4 Oil Production Plant, Daqing Oilfield Company, Daqing, Heilongjiang 163511, China

Abstract: The rapid development of social economy in our country, the industry in innovation and development of the growing demand for oil, promote people to constantly increase the intensity of oilfield development, and oilfield development time prolonged, and the application of water injection production in the process of development, cause of formation pore pressure is more and more complex, as the new adjustment well drilling work more difficult. Therefore, the research on dynamic prediction methods of reservoir pore pressure in development Wells is intensified, which can predict reservoir pore pressure in development Wells in a short time, and the pore pressure can be predicted more accurately through the comparative analysis of predicted and measured pressure, providing strong support and guarantee for the design and construction of drilling engineering.

Key words: Development well reservoir; Pore pressure; Dynamic prediction; The new method.

1. Introduction

Formation pore pressure prediction is generally in combination with acoustic and resistivity logging data and corresponding calculation, and only in the existing drilling, or goal well drilling can only be carried out under the condition of existing around, and in the process of actual prediction to comprehensively consider the p-wave velocity equation of stress, but there exist certain disadvantages to the these equations, The predicted structure is affected by the rate of compaction trend. Therefore, it is difficult to ensure the accuracy of the normal compaction trend velocity calculation when the shallow velocity logging data are incorrect or incomplete. To solve this problem, a new dynamic pore pressure prediction method is applied to further improve the accuracy of pore pressure prediction.

2. A new method for dynamic prediction of pore pressure

2.1 Calculation principle

Eaton Method is commonly used in the calculation of formation pore pressure curve, and the calculation formula is:

$$\sigma = (OBG - PPG_N)\left(\frac{dco}{dcn}\right)^E$$

Among them, σRepresents the effective stress equivalent density (g/cm^3);

OBG Represents the pressure equivalent density of the overlying rock (g/cm^3);

PPG_N Represents the equivalent density of formation pore pressure (g/cm^3);

Dco Represents the acoustic time difference of undercompaction;

dcn Represents the acoustic time difference of the normal compaction curve;

E It represents the power index, which is a specific parameter that is mainly taken in combination with experience, laboratory specimen tests and engineering measurement information data。

The acoustic time difference of normal formation compaction curve and related parameters of geological deposition history play an important role in the calculation of Eaton method [1]. Due to the relatively complex sedimentary history, the information of sedimentary history is lacking in many cases. Therefore, the normal formation compaction curve needs to be calibrated according to the actual situation observed in existing drilling and drilling engineering. When has the anticline structure, and at the same time orogeny caused by horizontal extrusion effect is significant, under the condition of local stress is affected by the structure is very big, causing the overlying rock pressure coefficient value and density of integral calculation data have large deviation, the information obtained from this kind of cases, the accuracy of dynamic pore pressure prediction results under the influence of a certain extent, It shows a decreasing trend. Therefore, the results of numerical calculation of overlying rock pressure based on three-dimensional geostress field are used as OBG, and the pore pressure is calculated and analyzed in detail using Eaton formula to effectively solve this problem. The pore pressure results obtained will be included in the influence of anticlinal structure on overlying rock pressure. Therefore, this dynamic pore pressure prediction method is more accurate than the conventional overlying rock pressure prediction method based on density integration with depth. When the other parameters in Eaton formula are set to, E is 3, the normal hydrostatic pressure density is PPGN=1.03 g/cm3, and the information data applied to calibrate the curve for the well already drilled or the pore pressure already drilled around the target well are measured formation pressure coefficient (PP), overflow drilling fluid density value and other measured data.

2.2 Calculation process

The calculation flow of the new pore pressure dynamic prediction method applied in this paper mainly includes the following three steps:

(1) Three-dimensional seismic wave interpretation structure to establish a geological model, this step mainly uses three-dimensional geological analysis software, combined with block seismic information data, to create the geological structure of each layer of the block [2].

(2) In the process of single well geomechanical analysis of the upper strata of adjacent Wells, the deep strata of some development Wells lack relevant logging information data. Therefore, the single well logging information data of the drilled upper strata can be analyzed in detail to obtain the magnitude and direction of the principal component of ground stress in the upper strata. In the process of this analysis, the relevant personnel can calculate pore pressure, overlying rock pressure coefficient and other parameters based on the actual drilling information, such as transverse wave, longitudinal wave, density log and other relevant logging information data of acoustic logging. The minimum horizontal principal stress among the three components of ground stress can be calculated according to Poisson north, elastic modulus and other relevant parameters, and the relevant parameter values in the work can be effectively calibrated and calculated with the help of floor drain test. This analysis process is relatively complicated. In the process of calculating pore pressure using acoustic logging information data, due to the lack of analytical function relationship between acoustic wave and pore pressure, semi-empirical and semi-analytical empirical formula method is usually used to calculate pore pressure in detail.

In addition, the value process of the maximum horizontal principal stress in the detailed analysis of geomechanics of a single well by relevant staff is complicated, and its value cannot be directly calibrated by ground drain test [3]. In the process of drilling engineering construction, the indirect calibration of maximum horizontal principal stress is usually carried out by matching the curve of collapse pressure and equivalent drilling fluid density of real drill. In this process, the matching mainly means that the collapse pressure should not be less than the real drilling fluid at the choke point, and the collapse pressure should not be greater than the real drilling fluid at the safe drilling depth point under complex conditions such as no jam.

There is usually a certain relationship between the characteristics of the upper and lower crustal stress distribution. When the upper reverse fault stress occurs, the transverse extrusion coefficient of the lower crustal stress will be affected to a certain extent and gradually increase. When the upper ground stress is under normal fault stress, the transverse extrusion coefficient of the lower ground stress will gradually decrease. At the same time, when the overlying rock pressure is subjected to strong transverse extrusion effect, the effect of transverse deformation is relatively large. Therefore, in the process of predicting and analyzing the geo-stress of the lower strata, the geo-stress value of the upper strata can be regarded as an effective reference data [4].

(3) The horizontal tectonic stress coefficient is defined based on the fault morphology and structural characteristics, and then the magnitude of the horizontal tectonic stress is determined. The main purpose is that when the transverse extrusion effect is relatively strong, the overlying rock pressure value is larger due to the influence of the transverse deformation effect, which leads to the corresponding increase of pore pressure. In general, the minimum horizontal principal stress coefficient corresponding to the reverse fault is not less than 1, and the overlying rock pressure in the principal stress component corresponding to the normal fault is not less than the maximum horizontal principal stress. In the process of evaluating the horizontal tectonic stress coefficient, the empirical method can be applied to determine the tectonic stress coefficient of the specific location of the target well in combination with the value of the tectonic stress coefficient obtained from the analysis of adjacent Wells with similar structures and the relevant experience. In addition. The trial-and-error method has good applicability in the value of horizontal tectonic stress coefficient, mainly by setting different values of tectonic stress system, and observing in detail whether the pore pressure obtained by it is compatible with the density curve of drilling fluid.

(4) Solve the three-dimensional fine stress field. The fineness of the calculation process is supported by the following factors: stratigraphic structure; The initial input parameters, such as pore pressure and three principal stress components, are combined with the geomechanical analysis of a single well. Due to the lack of logging information data of deep drilling strata of development Wells, the geomechanical analysis of single well is limited to the upper strata. The measured information data mainly include the minimum horizontal stress point obtained by the floor drain test and the maximum horizontal principal stress direction determined by the image logging [5]. In the calculation process, the gravity load, initial ground stress and displacement constraint boundary conditions are appropriately added to the 3D block finite element model.

(5) Predict the pore pressure. In the process of pore pressure prediction, the acoustic time difference of the formation should be calculated in detail by combining the

velocity of the formation, and the rock density of the formation should be calculated in detail by combining the acoustic time difference with the Gardner empirical formula. In the process of pore pressure prediction, the most conventional method is to calculate the overlying rock pressure accurately in combination with the compaction density. The new dynamic prediction method of pore pressure proposed in this paper is mainly to establish a three-dimensional fine ground stress field of the block, calculate the finite element values in detail, and obtain the overlying rock pressure. At the same time, the pore pressure curve is calculated in detail by Eaton formula combined with the overlying rock pressure and acoustic time difference.

3. Engineering case analysis

For example, a block contains multiple Wells such as well X7 that have been drilled with the upper reservoir as the target reservoir. This paper focuses on the formation pressure analysis of the lower source-reservoir-cap combination under 6000m in well X1. The upper X7 well has been drilled to a depth of 3,000-4,000m. The fault forms in this block mainly include reverse faults and thrust faults, indicating that the horizontal crustal stress component has a high value. Meanwhile, in the process of pore pressure prediction and calculation, the pore pressure data already drilled in the upper part should be combined, and the specific analysis and calculation are as follows.

3.1 Construct the model and boundary conditions

3D fine stress field modeling is a new technology of finite element numerical calculation, which requires the application of seismic wave information data to create an accurate geological model. On this basis, the existing rock and stratum logging information data is used to provide a perfect elastic model and other material parameters for the model construction. The finite element model of Abaqus in this block is shown in FIG. 1. The finite element model includes 370 000 nodes and about 90 000 C3D20R-20 node high-precision elements.

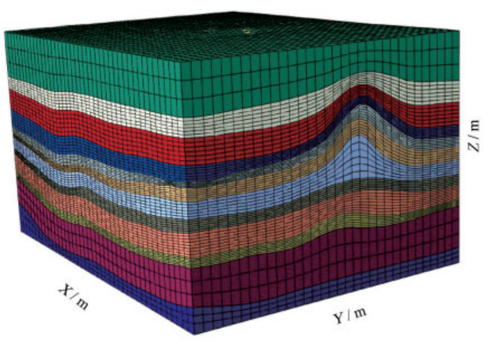

Figure 1: finite element model diagram of Abaqus

The Abaqus finite element model of this block was simplified. The changes of material properties on both sides of the fault were comprehensively considered, and the simulation of the fault plane itself was ignored. The fault plane was not considered as the fracture plane. There is gravity load in the model, and the calculation is mainly aimed at the static ground stress field. In the actual calculation and analysis process, there is no relative movement between the two ends of the fault, which proves that the simplified treatment of the model is scientific and effective. The single well ground stress field analysis result of well X7 in this block is used as the initial value of the model ground stress field. In the input process, the lateral pressure coefficient is directly converted through the single well ground stress field analysis result.

3.2 Pore pressure of X1 well based on 3D in-situ stress and zone velocity

Combined with the numerical solution of three-dimensional fine geostress field, the stress component value of the geostress field is extracted from the target well trajectory points and input into the single well geostress analysis tool. Then, based on the given layer velocity, the pore pressure of the three-dimensional geostress field is predicted for well X1, and relevant data are obtained as shown in Table 1. Through practical analysis, it is found that the rock density calculated by acoustic empirical formula is better than the density logging data, which fully shows that a layer velocity curve is reasonable and effective. Therefore, the pore pressure prediction results of the X1 well profile based on the numerical solution of the 3D in-situ stress field and the layer velocity are obtained. There is no significant difference between the pressure curves of the single well and the three-dimensional overlying rock, and thus there is little difference between the two pore pressure curves. The upper pore pressure is between 1.2g/cm3 and 2.2g/cm3, and the surrounding fault fracture zone has the phenomenon of drilling fluid leakage, and the pressure plugging operation is carried out. The predicted pore pressure value of the lower undrilled formation is between 1.9g/cm3 and 2.02g/cm3. The bottom strength obtained by acoustic wave calculation is relatively high, and the collapse pressure is not greater than the pore pressure value. The lower limit of the drilling fluid density window in this depth section is the pore pressure value, and the upper limit is the minimum stress curve. The normal fault stress and strike-slip fault stress state of the minimum principal stress curve represent the minimum horizontal principal stress. The stress state of reverse fault mainly represents the pressure coefficient of overlying rock. Combined with the prediction, the pore pressure distribution curve was obtained. During the actual drilling operation, the corresponding gas display was obtained by the gas logging in this depth section, which fully proved that the pore pressure at this position was close to the drilling fluid density, indicating that the predicted pore pressure distribution curve was very accurate.

Table 1: Formation pore pressure prediction table for well X1

Well depth formation	Interval velocity ($m.s^{-1}$)	Acoustic time ($\mu s.ft^{-1}$)	Rock density ($g.cm^{-3}$)	Equivalent density ($g.cm^{-3}$)	
1200	Tower group kosi		2000	170	
		210	0.8		
1800	Sha wan group		3400	150	
		220		1.0	
2400	Anjihaihe Formation		3500	200	
		200		1.9	

4. Conclusion

This paper mainly based on three dimensional stress field, extracted from seismic data volume of interval velocity method, in view of the development well reservoir pore pressure prediction calculation, based on the analysis of the process of 3 d geostress in single well ground stress results as an input parameter, the real drilling and drilling fluid density curve as a calculation, calibration of geostress component values of key reference data. The drilling fluid density curve is used to calibrate the value range of pore pressure indirectly to further improve the accuracy of pore pressure prediction results. In addition, this paper a block X1 well drilling practice application of the new method of pore pressure prediction, the prediction of pore pressure and drilling fluid density window, and the existing drilling section of drilling fluid density data of drilling engineering information related to material were analyzed, obtained the same between measured and predicted pore pressure and drilling fluid density, It is proved that the pore pressure prediction method proposed in this paper is reasonable and feasible. Due to the relationship between the tectonic stress system and the local anticlines, the value of the tectonic stress system changes with the change of the location in the space of the three-dimensional block, which increases the accuracy of pore pressure prediction. It needs to be studied and improved continuously in the calculation and analysis.

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