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In-Situ Stress Estimation Techniques for Wellbore Stability Analysis Under Transverse Isotropic Condition

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Abstract

In situ stresses are considered as pivotal factors in rock sciences in addition to petroleum engineering issues including wellbore stability and hydraulic fracturing. In situ stresses are mainly estimated by costly and time consuming methodologies directly. Moreover, the outcomes of these approaches are limited to a certain depth of the well. Therefore, these methods cannot be generalized. In the present study, a model based on the shear moduli and poro-elastic parameters in an environment under transverse isotropic conditions has been employed whereby the results further discussed. Elastic parameters, strength, and in situ stress according to the hypotheses underlying the both models were calculated for a well in the west of Iran. Shear moduli-based method is proposed to predict the maximum horizontal stress. Here, acoustoelastic parameter was set to 0.52. Of course, $C_{66}/C_{44} < 2$ is not much acceptable. However, the stresses were calibrated using the cores. Although this method enabled to predict the revers faulting regime correctly, however, regarding the model, stress has been underscored, and the outputs are not consistent with the calliper log. Subsequently, poro-elastic based mechanical model in accordance with caliper log estimated a more reliable in situ stress under transverse isotropic conditions. Furthermore, break-out and break-down have been properly determined that they could be due to the shale layers within the formation.

Keywords: In Situ Stress, Transversely Isotropic, Wellbore Stability, Mechanical Earth Model, Poro-Elastic Equations, Mohr-Coulomb Criterion.

Introduction

In-situ stress in oil industry is a key parameter in excavation and hydrocarbon production operation and in areas such as hydraulic fracturing and the well collapse. Precise recognition of the stress of formation is very important in effective management of reservoirs against failures due to decreased pore pressure and increased effective tension [1]. In this paper, two in-situ stress methods will be compared based on poro-elastic equations and shear module in order to perform mechanical evaluation of a vertical well under transverse isotropic in oil the field of west of Iran.

Methodology

Estimation of in-situ stress through a shear module based method

In this method, three shear modules will be determined through well sonic data, i.e. Stoneley waves and the shear wave velocities [2]. The following equations are used for the estimation of horizontal stresses.

$$C_{44} - C_{66} = A_E(\sigma_v - \sigma_H) \quad (1)$$

$$C_{55} - C_{66} = A_E(\sigma_v - \sigma_h) \quad (2)$$

$$C_{55} - C_{44} = A_E(\sigma_H - \sigma_h) \quad (3)$$

where C_{44}, C_{55} and C_{66} are respectively shear modules, which will be calculated through the following equations:

$$C_{44} = \rho V^2_{S(slow)} \quad (4)$$

$$C_{55} = \rho V^2_{S(fast)} \quad (5)$$

$$C_{66} = \rho V^2_{stoneley} \quad (6)$$

where in equation (1), A_E is acoustoelastic coefficient defined in the following way:

$$A_E = 2 + (C_{456} / G) \quad (7)$$

In above equation, G is the shear module of formation and C_{456} is defined as the nonlinear stiffness parameter of formation:

$$C_{456} = (C_{155} - C_{166}) / 2 \quad (8)$$

By using Dipole Shear Sonic Imager, it is possible to calculate the acoustoelastic coefficient from equation (7) and horizontal stresses from various experimental equation; however, two out of these three equations are independent. In addition, when the magnitude of horizontal stress is the minimum value, and overburden stress is available, it is possible to calculate parameter A_E as follow:

$$A_E = (C_{55} - C_{66}) / (\sigma_V - \sigma_h) \quad (9)$$

After determination of acoustoelastic parameter, it is possible to calculate the magnitude of maximum horizontal stress in a certain depth using the following equation:

$$\sigma_H = \sigma_h + (C_{55} - C_{44} / A_E) \quad (10)$$

Thus, the magnitude of horizontal stress of formation in various depths can be calculated as a function of three shear modules C_{44}, C_{55} and C_{66}. The estimation of stress magnitude in shale with transverse isotropic is possible through shear module equations. Generally, in shale transverse isotropic, C_{66} will be greater than C_{44} and C_{55}. In order to overcome this problem, the following equation will be presented with consideration of Thomson parameter.

$$C_{66} / C_{44} = 1 + 2\delta \quad (11)$$

Estimation of in-situ stress through Poro-elastic equations

The common equation for calculation of the value of effective stress is poro-elastic experimental equation where overburden pressure, pore pressure, poisson ratio and tectonic strains where with consideration of traverse isotropic behavior of reservoir rock, the magnitude of in-situ stress will be determined through the following equations.

$$\sigma_h = \frac{E_{11}}{E_{33}} \frac{v_{31}}{(1-v_{12})}.(\sigma_v - \alpha.P_p) + \alpha.P_p + \frac{E_{11}}{(1-v_{12}^2)}.\varepsilon_h + \frac{E_{11} v_{12}}{(1-v_{12}^2)}.\varepsilon_H) \quad (12)$$

$$\sigma_H = \frac{E_{11}}{E_{33}} \frac{v_{31}}{(1-v_{12})}.(\sigma_v - \alpha.P_p) + \alpha.P_p + \frac{E_{11}}{(1-v_{12}^2)}.\varepsilon_H + \frac{E_{11} v_{12}}{(1-v_{12}^2)}.\varepsilon_h) \quad (13)$$

Geographical and geological situation of region

The investigated well in this study is located in oil field of west of Iran and in neighborhood of Iran-Iraq border. The mechanical model of earth is widely used in oil and gas industry. This model is a combination of mechanical features of earth and effective in-situ stresses. The mechanical model of earth extracted using elastic and mechanical features could calculate the stress status from data related to an oil field.

The results and discussion

Mechanical properties of formation

In order to determine the mechanical properties of formation, dynamic elastic parameters of reservoir rock have been estimated as a function of compressive wave speed, shear wave speed, and formation density. Then, the determined dynamic module will turn to static module using various equations. In following, the uniaxial compressive strength has been estimated using Bradford equations and calibrated using triaxial test data.

In the next step, pore pressure which is one of the most important parameters involved in the construction of mechanical model has been estimated through Eaton equation. The obtained results of pore pressure using acoustic log have been calibrated by MDT data. Then the other effective parameter, i.e. the main vertical stress has been calculated through integrating the rock density from the surface to the desired depth. In order to determine the elastic properties of formation under transverse isotropy conditions, five rigidity parameters were determined using compressive and shear velocity in horizontal and vertical directions. In order to achieve this objective, two hypotheses have been proposed. In the first section, it was assumed that the observed anisotropy in part of the shear waves has been due to the shale layering characteristics; therefore, the background rock has been considered as isotropic and in the second hypothesis, the anisotropy parameter of Thomson has been considered to be close to zero.

According to the results obtained from mechanical analysis under transverse isotropic conditions, there would be the possibility of comparing the efficiency coefficient of shear module and poro-elastic equations in the prediction of in-situ stress. Mohr-Columbus criterion has been used for prediction of shear fracture observed in caliper log so that the results of in-situ stress estimation could be evaluated using shear module and poro-elastic methods.

Shear module based method

First minimum and maximum horizontal stresses have been calculated. Column (b) of Figure 1 shows the stress obtained from equations based on shear module. The examination of this column and stress regime could help to understand that the fault regime of region is transverse which seems logical according to Iran fault map. As perceived from column (b) of Figure 1, minimum and maximum horizontal stresses are close to each other; however, the mean value of maximum horizontal stress is a bit higher than mean of minimum horizontal stress. Thus, with a better insight into the accuracy of the results, it is possible to compare the shear fracture data predicted by Mohr-Coulomb criterion using in-situ stress with the shear fracture observed in the caliper graph.

In Figure 1, column (a) shows gamma depth and graph. In columns (b) and (c), maximum and minimum horizontal stresses, vertical stress and safe window of drilling mud are shown respectively. Horizontal stress has been calibrated by a single data test which has not provided an acceptable result. The black and smoky areas in the window of drilling mud indicate respectively the formation impact and shear fracture in formation. On the other hand, if the drilling mud weight exceeds the gray or dark olive area, then the mud loss phenomenon will happen that ultimately leads to well rupture. Therefore, the white area in the middle of drilling mud window is considered as safe. The caliper graph of well B is shown in column (d) of Figure 1. In general, the purpose of this study is to predict shear fracture using shear modulus equations. The negative point of Mohr-Columbus criterion is that it does not take into account the impact of intermediate stress. The estimated in-situ stress seems unreliable because it is in good agreement with the calibration points; however, more effort should take for achieving better results.

Poro-elastic method

The results of estimating in-situ stress using Poro-Elastic equations are shown in Figure 2. The results of this model show that the region fault regime is of inverse type.

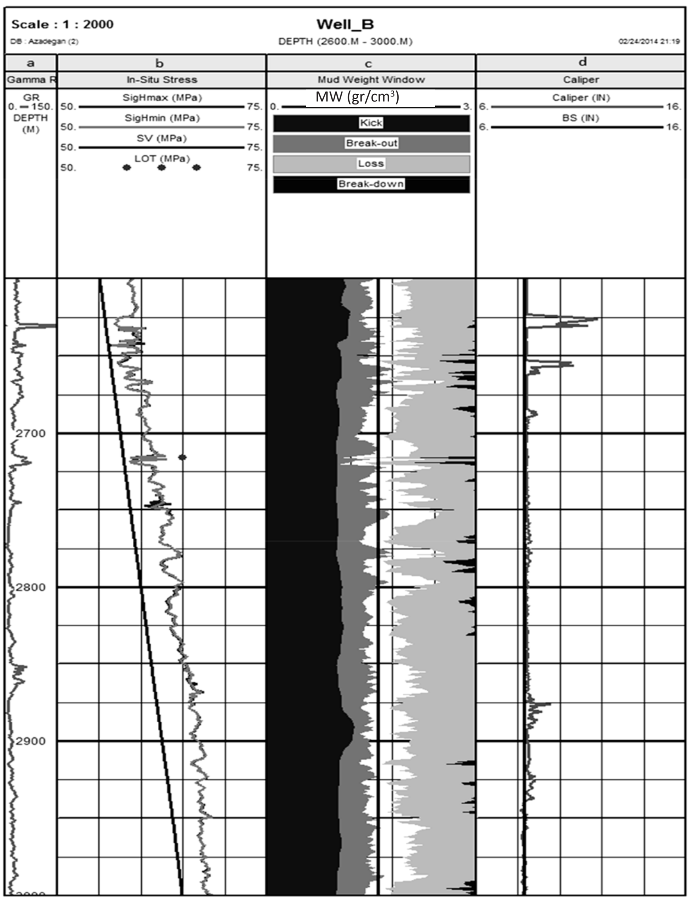

Figure 1: In-situ stress regime and a safe mud weight window analysis obtained using shear based moduli equations.

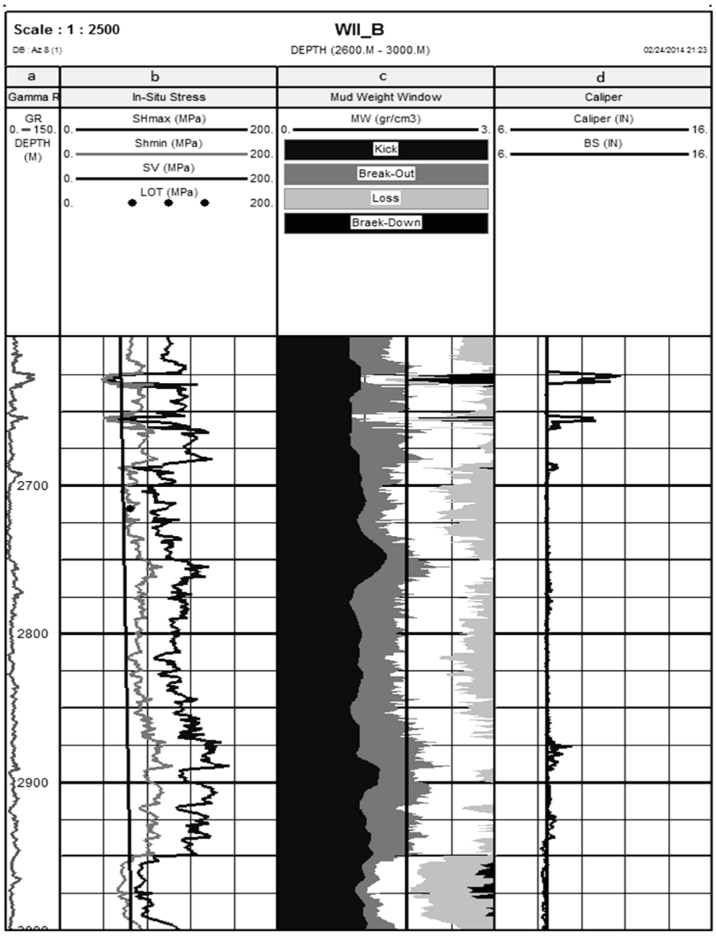

Figure 2: In-situ stress regimeand a safe mud weight window analysis obtained using poro-elastic based method.

Since the inverse fault regime is the dominant regime in west of Iran, the results presented in this section are reliable. Moreover, the results are validated with field reports and Caliper graph. Figure 2 shows the analysis of the drilling window using the Mohr-Columbus criterion. As seen in the figure, it seems that the Poro-elastic equations estimate the in-situ stress better than other methods. Moreover, the results of analysis of drilling mud window also indicate the suitability of these relationships.

Conclusions

The results of shear and poro-elastic module methods have showed that the zone fault regime is of inverse type ($\sigma_v<\sigma_{hmin}<\sigma_{Hmax}$), which according to the fault map of Iran seems logical. Different mechanical models have been constructed under transverse isotropic and isotropic conditions respectively for shear wave modules and poro-elastic equations. The results obtained from shear module method are not reliable because the designed model does not fit with the caliper graph and does not show the intervals with shear fracture. However, the results obtained from poro-elastic equations have been more accurate in calculation of in-situ stress. The mechanical model designed using poro-elastic and Mohr- Columbus criterion showed that at some intervals, (2750 and 2850 to 2950 m) the wells will suffer from a shear fracture and need maintenance.

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