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Estimation of the In-Situ Stresses for One Iraqi Oil Field: A Case Study

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Abstract : A crucial and important input component for constructing a geomechanical model and estimating wellbore failure is the magnitude of the in-situ stresses (vertical stress, and minimum and maximum horizontal stresses). In this study, the field case was conducted to calculate the in-situ stresses for the area of interest that extended from the Sadi to Zubair formations in order to reduce the issues that were associated during activities. To achieve the purpose of this study, the prevalent data in the area of interest was gathered and checked. Then, the mechanical rock properties, hydrostatic pressure, and formation pore pressure were computed to construct the profiles of the in-situ stresses. Finally, the magnitude of the in-situ stresses is important to decrease the problems that are associated with drilling and production operations.

Keywords: Horizontal stresses, Vertical stress, Pore pressure, Poisson's ratio.

1. Introduction

Understanding the stress state on rock and the subsequent strain (deformation) on that rock is the foundation of the geomechanics study. Stress is the strength and orientation of the exterior forces operating at a particular location. A shear failure might occur if the force acting along the surface is the so-called shear stress. In contrast, normal stress occurs when the applied force is perpendicular to the surface of the rock and may lead to tensile or compressive failure (Fjar et al., 2008).

It is very useful to study the stresses on each plane of an infinitesimal cube, each plane of the cube will have shear and normal stresses. At any point, a body undergoes a set of forces for which all shear stresses are not present, and the three normal stresses have their maximum magnitudes. These stresses are called principal stresses, and they act perpendicularly on the planes where all shear stresses are zero. Thus, it is essential to assign the stress status since the principal stresses can be provided straight information about the minimum and maximum magnitudes of the normal stress components (Jaeger et al., 2007).

In-situ stresses or far-field stresses data plays a key role in different stages of oil and gas well construction, planning, excavations, completion and production. Knowing of in-situ stresses and mechanical rock properties are very useful prior to implementing any rock stress analysis and failure assessment (Aadnoy & Looyeh, 2019). In situ stress state is the original stress situation in the rock prior drilling or other disorders. Where, the formation rocks are nearly in equiponderant with small or not motion taking place in the formation rocks system (Adil Issa et al., 2021; Issa & Hadi, 2021). Furthermore, when constructing a geomechanical models, the magnitudes and directions of the far-field stresses is crucial for carrying out numerous applications, such as wellbore stability assessment and sand production control (Peng & Zhang, 2007).

In general, there are three mutually perpendicular principal stresses in the subsurface, these called the in situ stresses, which can be expressed as the overburden (vertical) stress (σ_v), the maximum(σ_H) and minimum (σ_h) horizontal stresses. The in situ stress magnitudes and directions are very diverse in various geologic, geographic, and tectonic regions. Three principal stresses, named as the greatest stress (σ_1), the intermediate stress (σ_2), and the least stress (σ_3) are correspond to the three in situ stresses. Based on the faulting theory (Anderson, 1951), assuming that the faults were created by shear failures caused by in situ stresses .In situ stress states can be describe depending on the relation between the three principal stresses and three in situ stress regimes (Normal, Strike-slip, and Reverse faulting regimes)(J. J. Zhang, 2019; Zoback, 2007).

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In this study, the field case was conducted to compute the far-field stresses along the area of interest to reduce the issues that are linked with activities. Thus, the profiles of the Young's modulus, Poisson's ratio, and pore pressure were developed to calculate the profiles of the in-situ horizontal stresses.

2. State of Far-Field Stress (In-Situ Stress)

Three principal stresses, referred to as in-situ stresses or far-field stresses, are often applied to the earth's surface. These stresses show how the rock was before any actions, such as drilling operations, but not alone (Zoback, 2007). In oil and gas wells, the far-field stress data is crucial in different stages of constructing, designing, excavating, completing, and producing (Aadnoy & Looyeh, 2019).

Anderson (1951) divided the fault regimes into three types: normal fault regime, strike-slip fault regime, and reverse fault regime based on the magnitude of in-situ stresses. The relationship between the three far-field stress regimes and the three principal stresses, as shown in Fig.1 and Table 1, can be used to define the in-situ stress status (Scholz, 2019; J. J. Zhang, 2019).

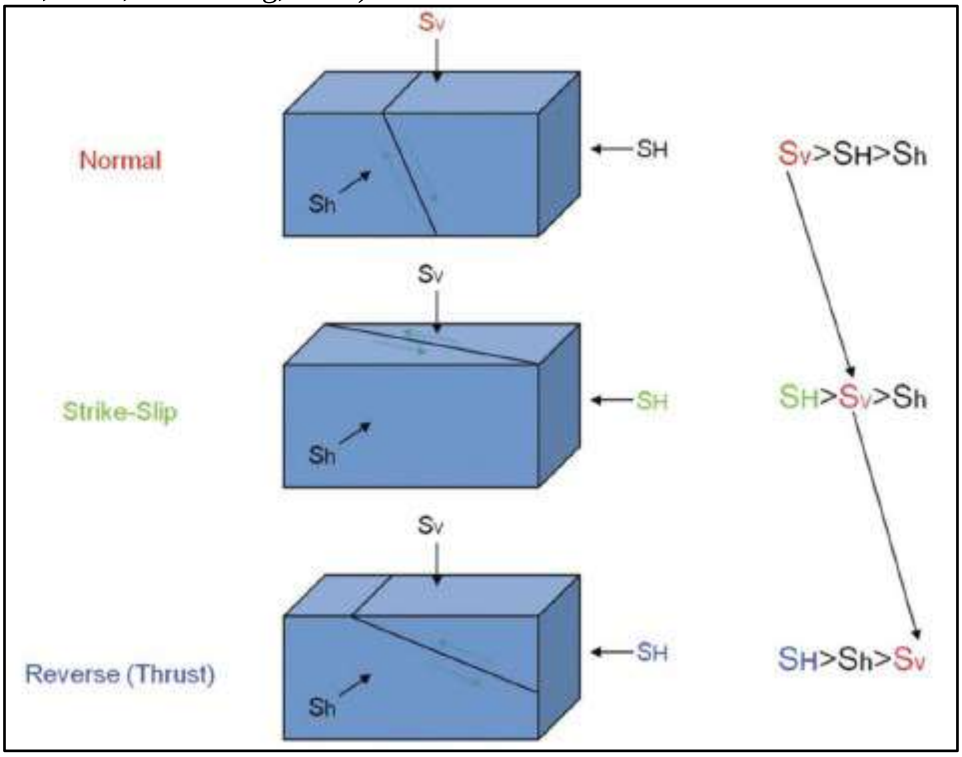

Fig.1. Diverse faulting stress regimes (Wikel, 2011).

Table 1. Faulting regimes and relative stress magnitudes (Zoback, 2007).

Regime	Stress		
	σ_1	σ_2	σ_3
Normal	σ_v	σ_H	σ_h
Strike-slip	σ_H	σ_v	σ_h
Reverse	σ_H	σ_h	σ_v

2.1. Overburden Stress (σ_v)

The pressure placed on a point by the weight of subsurface formations that contain fluid, often referred as vertical stress or overburden stress (σ_v). One of the main principal stresses is vertical stress, which points toward the earth's center. At certain depth, overburden stress can be estimated using Eq.1 (Alam et al., 2019), where ρ_b is the bulk density of formation rocks as a function of depth (z); g is the gravity acceleration (m/sec^2).

$$\sigma_v = \int_0^z \rho_b (z) g dz \quad (1)$$

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It is crucial to remember that the density log does not capture data at the top intervals of the well; in this instance, the unlogged interval can be extrapolated linearly to assess shallow formation bulk density (Bell, 2003).

2.2. Minimum Horizontal Stress(σ_h).

A vital component in any application related to geomechanics, including but not limited to wellbore instability analysis and sand production prediction, is the minimum horizontal stress, which is linked to far-field stresses. However, both the direct and indirect approaches are used in the petroleum industry to calculate the minimal horizontal stress. Leak-off tests (LOT), extended leak-off tests (X-LOT), and mini-frac tests are examples of well tests that use the direct technique. While, the indirect technique uses measurements of petrophysical data (Raaen et al., 2006).

Direct measurements of the minimum horizontal stress (σ_h) includes implementing XLOT, the strategy of this method involves sealing the annulus of the wellbore and then the drilling fluid is pumped into the wellbore at constant flow rate (Edwards et al., 2002). Thus, pressure increase in the borehole is typically linear until the pressure reaches at some point, the fracture occurs in the wall of the borehole while the pressure buildup deviates from its linearity as shown in Fig.2, this point is defined as the fracture initiation pressure (Pi). After diverges from linearity, the pressure increases at a low rate until is reached to maximum value i.e., formation breakdown pressure (P_b).Then, the formation is broken, fracture is propagating at the same flow rate (J. Zhang & Roegiers, 2010). Later, the pressure starts to decline when the pump is shut-in and the pressure falls to the instantaneous shut-in pressure (P_{isip}). As depicted in Fig.2, the deviation point in the pressure decline curve, i.e., closure pressure (P_c) is equal to the minimum horizontal stress (J. Zhang & Yin, 2017).

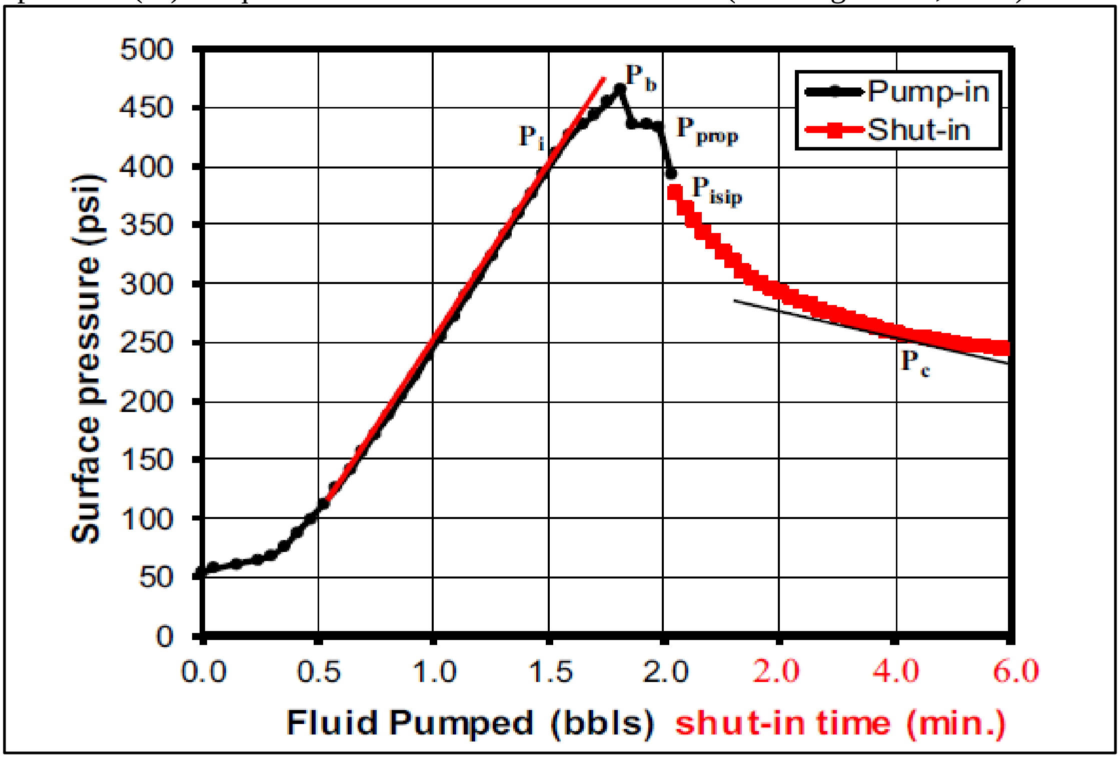

Fig.2. XLOT or Mini-frac scheme (J. Zhang & Yin, 2017).

2.3. Maximum Horizontal Stress (σ_H)

The maximum horizontal stress (σ_H)is the complex and difficult variable to be measured. In other words, it is impossible to estimate the σ_H magnitude directly. The values of σ_H were calculated using a number of different approaches, however none of these attempts produced acceptable results. The σ_H may be estimated by using multi-cycle extended leak off test (XLOT) or diagnostic fracture injection test (DFIT),(J. J. Zhang, 2019).

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3. Results and Discussions

In order to specify the stress regime, difficulties with wellbore instability, and well planning (trajectory, suitable mud weight (MW), casing set points, etc.), it is important to understand the direction and magnitude of the minimal and maximum horizontal stresses.

Thiercelin & Plumb (1994) developed the poro-elastic horizontal strain model for fluid saturated porous materials, and it was used in this study. This model may be explained by employing static Young's modulus (E), static Poisson's (v) ratio, vertical stress(σ_v) , and formation pore pressure (p_p), and Biot's constant (α =1). This model is more accurate and takes into account anisotropic tectonic strains as well as isotropic with linear elastic properties to continuously predict the magnitude of the minimum and maximum horizontal stresses (SHMIN_PHS and SHMAX_PHS) along the area of interest using Eqs. 2 and 3, respectively (track 5 of Fig.3).

The overburden stress profile (SVERTICAL_EXT) was constructed using Eq.1 (tack 5 of Fig.3). The profile of the formation pore pressure (PPRS_EATON_S) was developed (tack 5 of Fig.3) using Eaton slowness (Eq. 4). The static Young's modulus profile (YME_STA_JFC) was established using John Fuller correlation as shown in track 3 of Fig.3. The static Poisson's ratio profile (PR_STA) was built (track 4 of Fig.3) using Eq.5.

$$\sigma_H = \frac{v}{1-v}\left(\sigma_v - \alpha\, p_p\right) + \alpha\, p_p + \frac{E}{1-v^2}\left(\varepsilon_H + v\,\varepsilon_h\right) \qquad (2)$$

$$\sigma_h = \frac{v}{1-v}\left(\sigma_v - \alpha\, p_p\right) + \alpha\, p_p + \frac{E}{1-v^2}\left(\varepsilon_h + v\,\varepsilon_H\right) \qquad (3)$$

Where:

σ_h &σ_h: minimum and maximum horizontal stresses (psi).

σ_v: Vertical stress (psi).

E: Static Young's modulus (Mpsi).

α: Biot's constant.

v: Poisson’s ratio (unitless).

α: Biot's coefficient.

p_p: Formation pore pressure (psi).

ε_h &ε_H: Strains constant in orientation of the minimum and maximum horizontal stress, respectively.

$$P_{pg} = OBG - (OBG - P_{ng})\left(\frac{NCT}{\Delta T}\right)^3 \qquad (4)$$

Where P_{pg} donates to the pore pressure gradient; OBG represents the vertical stress gradient; P_{ng} is normal pore pressure gradient; NCT refers to the normal compacted trend line that fitting compressional wave log measurements; and ΔT is the compressional transit time.

$$v = \frac{0.5-({}^{v_s}/_{v_p})^2}{1-({}^{v_s}/_{v_p})^2} \qquad (5)$$

Where v_s & v_p are the shear and compressional waves, respectively.

It is noteworthy that the minimum horizontal stress profile has been calibrated with the results of three Mini-frac tests in the field of interest (track 5 of Fig.3). Also, based on the in-situ stress values, the results showed a different faulting regime along the area of interest. These regimes dependent on the lithology of formations.

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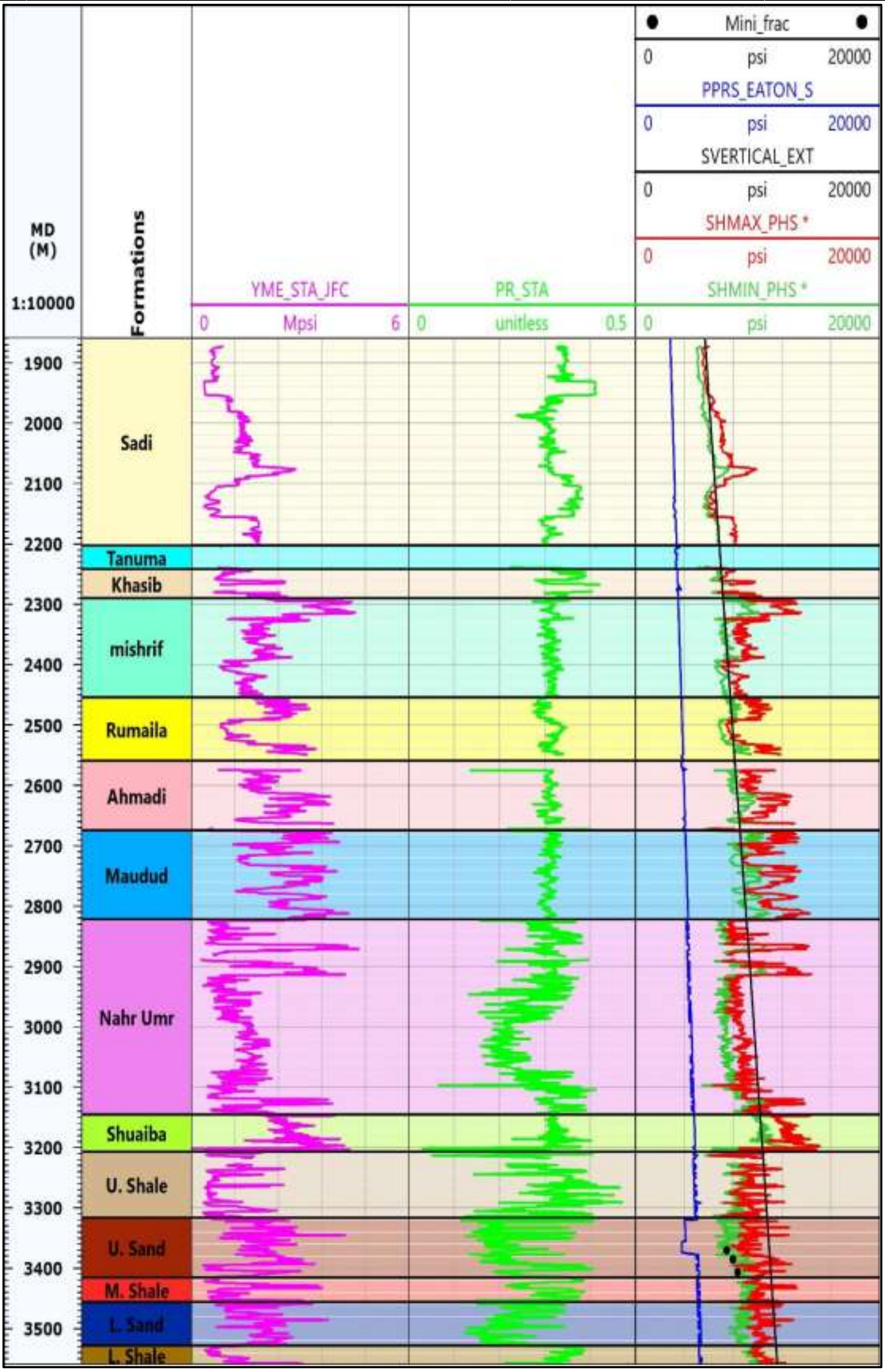

Fig.3. Estimation of the profiles of the in-situ stresses.

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4. Conclusions

For a rock mechanical and wellbore failure analysis, the in-situ stresses values are crucial inputs. According to Anderson (1951), the magnitudes of the in-situ stresses are related to the fault regimes. The faulting regimes in the area of interest (i.e., from the Sadi to the Zubair formations) are classified as follows:

- Normal regime when $\sigma_v > \sigma_H > \sigma_h$. The formations that have the type of this regime are: Tanuma not accurate, bottom Rumaila, Nuhr Umr, and Zubair.
- Strike-slip regime when $\sigma_H > \sigma_v > \sigma_h$. The formations which have this type are: Sadi, Khasib, bottom Mishrif, Ahmadi, and Shuaiba.
- Reverse regime when $\sigma_H > \sigma_h > \sigma_v$. The formations have this type are: top Mishrif and top Rumaila.
- The limitation of this study is that it requires more data points from the field tests in order to calibrate the profiles of the in-situ horizontal stresses. Consequently, more accurate results will be obtained.
- The Poro-Elastic Horizontal Strain Model is the more accurate technique that was used in this study to construct the profiles of the in-situ stresses along the area of interest.
- Usually, bulk density logs are not recorded from the surface to the Sadi formation. Thus, unlogged intervals in this case were treated using an extrapolated method.

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