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# Stability analysis of a horizontal oil well in a strike-slip fault regime

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## Abstract

Fault regimes have significant effects on the stability of oil wells. Although vertical wells have different geo-mechanical behaviors, horizontal wells have more critical conditions when they encounter fault regime changes. In this study, a horizontal oil well is considered at a specific depth in the Mansouri oil field including the poroelastic state of rock mass and anisotropic horizontal stresses. The simulation of stability analysis is conducted with a Finite Element simulator (ABAQUS) and consists of two steps: (1) geostatic and (2) drilling. The geostatic step shows the initial in-situ stress conditions before drilling; in the drilling step, the well pressure has been increased continuously from the formation pore pressure (lower limit of allowable mud pressure window) to fracture pressure limit (tensile failure limit). The mud pressure optimization has been conducted based on the stress and plastic strain reduction at the borehole wall. The general results confirmed that the best direction for drilling horizontal oil wells in formations with anisotropic horizontal stresses is along the minimum horizontal stress and the optimum mud pressure in horizontal wells is higher than the minimum level of the well pressure (formation pore pressure). In addition, this analysis showed that the determination of critical well pressure which can create plastic strain on wellbore wall is very useful for stability evaluation of horizontal oil and gas wells.

## 1. Introduction

Controlling the effective parameters on well stability has become more complex with the increasing demand in hydrocarbon reservoirs production over the last decades; so have been the drilling operations. Not only technical challenges result in longer drilling operations, but also any instability in the wellbore could increase the time and cost of the operation significantly (Fjaer, 2008). Drilling data shows an estimation of at least 10 % of well cost spent on unexpected events which are related to the instability of the wellbore. Stability issues are caused by a combination of interactions between rock and fluid such as clay swelling, tectonic stress conditions (Zhang, 2013), unusual formation behaviors such as abnormal formation pressure regimes and inappropriate drilling operation such as drilling open-hole in weak formations (Zare-Reisabadi et al., 2012; Gentzis, 2009; Al-Ajmi and Zimmerman, 2009). Although recent researches in rock mechanics improved the drilling operations significantly (Zare-Reisabadi et al., 2012), the majority of the decisions in this area have been made based on previous data and experiences. Despite so many efforts over the years, operational problems related to the instability of the wells still occur. If the instability is not treated effectively, further challenges such as bit failure, wellbore break down, BHA (Bottom Hole Assembly) erosion, mud loss, bit changing and directional drilling cannot be avoided (Aadony, 2003; Haimson, 2007). Fault regimes and specifically reverse fault and strike-slip fault regimes have significant effects on the stability of vertical wells and even more on horizontal wells (Zoback, 2007). Due to tectonic and reverse fault force in the subsurface, the critical re-distributed stresses are created which can severely destroy the borehole (Zoback, 2007; Fjaer, 2008). In the present study, the influence of a strike-slip fault regime on the stability of a horizontal oil well in the Mansouri oil field will be investigated. The mud pressure optimization will be performed in the allowed (standard) mud pressure window (Shu-qing, 2011; Rutqvist et al., 2012). The subsurface tectonic processes and fault forces generally occur in the three-dimensional place, therefore, a three-dimensional finite element model is provided to analyze the well stability (Papamichos, 2010, Xu et al., 1997).

In this research, Mohr Coulomb failure criterion has been used for investigating the horizontal oil well stability. The fault regime is strike-slip and the allowable mud pressure has been assumed to be between formation pore pressure and tensile failure limit (fracture pressure) in the depth of interest. This analysis has been done using the ABAQUS finite element software. According to an FMI logs (Formation Micro Imager logs) from a well in this oil field, the maximum horizontal stress direction is along a Northeast - Southwest trend and the minimum horizontal stress direction trends Northwest - Southeast, perpendicular to the maximum horizontal stress direction. Stability analysis of a horizontal well is performed both along the maximum horizontal stress (azimuth angle = 0º) and minimum horizontal stress (azimuth angle = 90º) with anisotropic state of horizontal stresses in the formation (Lee et al., 2012; Oliver et al., 2012). Wellbore stability optimization is done based on the well pressure (bottom hole fluid pressure) and the borehole directions along minimum horizontal stress or maximum horizontal stress in the Asmari Formation and the Mansouri Formation at the depth of 2313 m. The well stability analysis in the Asmari Formation has been done on the vertical well too.

In all cases, the borehole stability was satisfied by minimum mud pressure (formation pressure) in the vertical well. Due to the sensitivity of the horizontal wells, stability analysis will be performed specifically for the horizontal well in this study.

## 2. Geological background

### 2.1 Zagros fold and thrust belt and plate tectonic setting

The Zagros fold and thrust belt (Zagros FTB) is an approximately 1,800-kilometre (1,100 miles) long zone of deformed crustal rocks, formed in the foreland of the collision between the Arabian Plate and the Eurasian Plate (Fig. 1). It hosts one of the world's largest petroleum provinces, containing about 49% of the established hydrocarbon reserves in fold and thrust belts and about 7% of all reserves globally (Cooper, 2007).

The Zagros FTB is formed along a section of the plate boundary that is subject to oblique convergence with the Arabian Plate moving northwards with respect to the Eurasian Plate at about 3 cm per year. The degree of obliqueness reduces southwards along the Zagros, with the collision becoming near orthogonal within the Fars domain (Fig. 1). The relative movement between the plates is only partly taken up within the Zagros, the remainder is taken up by deformation in the Alborz mountains (Talebian and Jackson, 2004; Hatzfeld, 2011).

### 2.2 Study area

Between the two main salients of the Zagros FTB, the Dezful embayment (Figs.1 and 2) developed in an area that lacked an effective basal Hormuz salt detachment, resulting in a steeper topographic slope of 2°, compared to 1° for both the Lorestan and Fars domains (McQuarrie, 2004). During Miocene, this area became a depocentre in which locally thick Gachsaran salt was deposited. The presence of locally thick Gachsaran salt has caused disharmonic folding between the sequences above and below that layer (Sherkati, 2005).

The Mansouri oil field is located in the Dezful embayment in southern Iran far from the Zagros mountains, at a distance of sixty kilometers to the south of Ahwaz city in Khuzestan province (Figs. 1 and 2). From a geological point of view, the Dezful embayment is a part of northeastern Arabian plate (Talebian and Jackson, 2004; Hatzfeld, 2011). The Mansouri oil field was discovered on seismics in 1962 and hydrocarbons are present in the Asmari Formation (Oligocene-Miocene). The structure of Asmari Formation consists of an asymmetric anticline with a dip of zero to 10 degree with a thickness of 631 m and it is divided into three geological intervals which are presented in table 1.

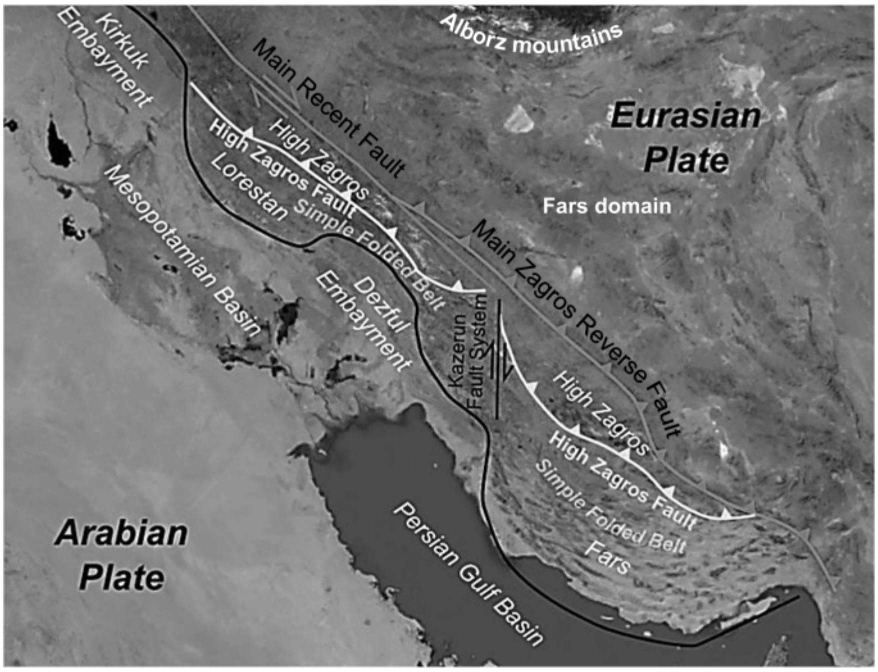


Figure 1: Schematic map of the Zagros fold and thrust belt (Iran).

| Asmari Formation | Depth (m) | Thickness (m) | Lithology |
|---|---|---|---|
| Upper section | 2185-2460 | 275 | limestone/marl/shale |
| Middle section | 2460-2643.5 | 183.5 | sandstone/ dolomite/limestone |
| Lower section | 2643.5-2816 | 172.5 | dolomite/limestone |

Table 1: Geological intervals of the Asmari Formation.

## 3. Rock material parameters and in-situ stresses estimation

In this analysis, Mohr-Coulomb failure criterion is used for simulating the fracture initiation on the wellbore wall and the input data for ABAQUS software are based on this criterion. Input data contain density, Young's modulus (E), dilation angle (ψ), friction angle (ϕ), porosity (n), Poisson's ratio (ν), cohesive strength (C) and Biot's factor (α) (Fjaer, 2008, Zoback, 2007).

### 3.1 Rock material parameters

Parameters related to the rock are in the table 2. These parameters contain physical and mechanical specifications of the rock.

### 3.2 In-Situ vertical stress estimation

In this case, in-situ vertical stress has been determined by Terzaghi equation. The density has been assessed from surface until depth 2313 m by density logs. Finally, density has been put in Terzaghi equation to calculate the in-situ vertical stress. Vertical stress at a specific depth is equal to weight of

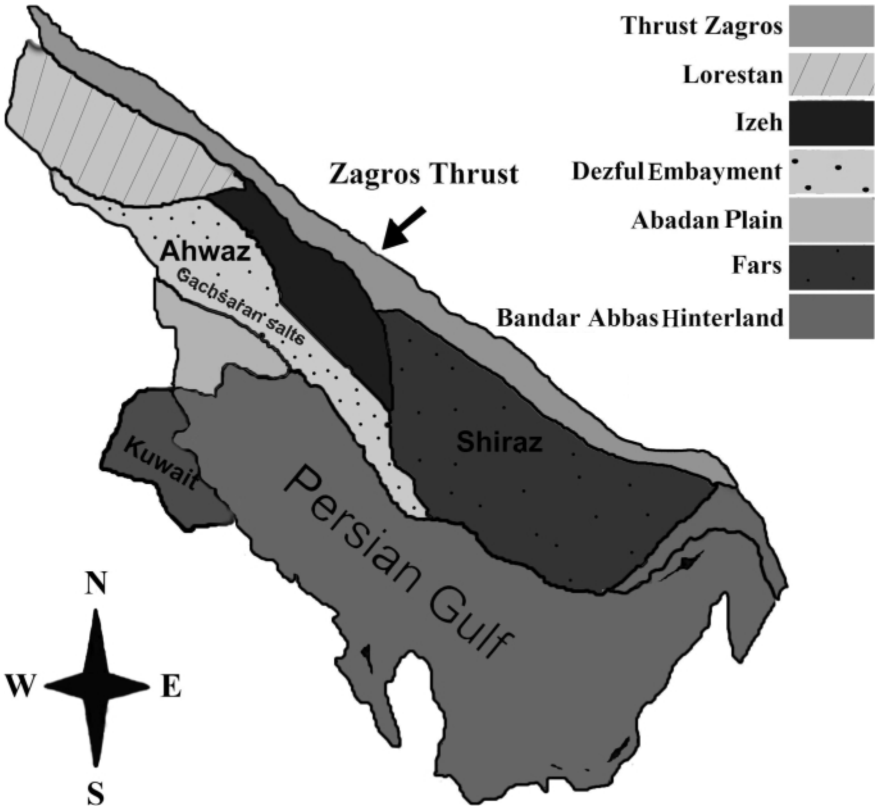


**Figure 2:** Sketch map of the geological zones of the Zagros.

overburden (Fjaer, 2008; Zoback, 2007). Thus, vertical stress can be calculated by Eq. 1.

$$S_v=\int_0^z \rho\,(z)g\,dz \approx \bar{\rho}\,gz \tag{1}$$

Where ρ(z) is density as a function of depth, g is acceleration of gravity and $S_v$ is average overburden density.

### 3.3 Minimum and maximum horizontal in-situ stresses:

Due to lack of mini fracture test, leak-off test and hydraulic fracture data for in-situ stresses, determination of minimum and maximum horizontal stresses based on the strike-slip fault regime is calculated by minimum and maximum horizontal stress of Rummel's equation (Klee et al., 1999); Eqs. 4 and 5 are applicable for the depth range between 500 m to 3000 m. K is the ratio of maximum or minimum horizontal stress to vertical stress (Eqs. 2 and 3).

$$K_{max}=\sigma_{hmax}/\sigma_v \tag{2}$$

$$K_{min}=\sigma_{hmin}/\sigma_v \tag{3}$$

$$K_{max}=0.98+250/z \tag{4}$$

$$K_{min}=0.5+150/z \tag{5}$$

Maximum and minimum values of horizontal stress in strike-slip fault regime have been calculated by Eqs. 2 and 3 which are derived from equations 4 and 5. They are presented in table 2.

## 4. Determination of the fracture pressure (tensile failure limit)

Based on the strike-slip fault regime ($\sigma_{hmax}>\sigma v>\sigma_{hmin}$), the general formula for calculating fracture pressure in vertical wells are as follows (Fjaer, 2008, Zoback, 2007).

### 4.1 With anisotropic horizontal stresses ($\sigma_{hmax}\neq\sigma_{hmin}$)

$$P_{frac}=3\sigma_{hmin}-\sigma_{hmax}-P_f+T_0 \tag{6}$$

### 4.2 With isotropic horizontal stresses ($\sigma_{hmax}=\sigma_{hmin}$)

$$P_{frac}=2\sigma_{hmin}-P_f+T_0 \tag{7}$$

The general formula for calculating fracture pressure in the strick-slip fault regime ($\sigma_{hmax}>\sigma_v>\sigma_{hmin}$) for horizontal wells are as follows (Fjaer, 2008, Zoback, 2007).

### 4.3 With anisotropic horizontal stresses ($\sigma_{hmax}\neq\sigma_{hmin}$)

#### 4.3.1 Along minimum horizontal stress:

$$P_{frac}=3\sigma_v-\sigma_{hmax}-(\alpha\times P_f)+T_0 \tag{8}$$

#### 4.3.2 Along maximum horizontal stress:

$$P_{frac}=3_{\sigma hmin}-\sigma_v-(\alpha\times P_f)+T_0 \tag{9}$$

$P_f$ is pore pressure and *a* is Biot's factor.

## 5. Poroelastic model

Deep underground rocks are made up of matrix and non-solid sections. Non-solid section contains pores, cracks, fractures and also fluid in the pores (Fjaer, 2008; Zoback, 2007). Pore pressure effectively affects the distribution of stress (Aadony, 2003). In the majority of the oil fields, pore pressure was one of the most important issues for instability of the

| Vertical stress (Mpa) | Formation pore pressure (Mpa) | Minimum horizontal stress (Mpa) | Maximum horizontal stress (Mpa) | Porosity (%) | Biot's factor |
|---|---|---|---|---|---|
| **58.7** | 21.23 | 32.87 | 63.98 | 27 | 0.918 |
| **Cohesion (Mpa)** | Tensile strength (Mpa) | Internal friction angel (degree) | Young's modulus (Gpa) | Density (Kg/m$^3$) | Poisson's ratio |
| **5.45** | 2.04 | 39.04 | 5.02 | 2188 | 0.18 |

**Table 2:** Physical and mechanical parameters of the rock.

wells (Papamichos, 2010; Shu-qing, 2011). Based on the stress distributing equations in elastic and porous elastic modes addressed in different references (Fjaer, 2008, Zoback, 2007), mud pressure analysis is investigated between pore pressure limit ($\alpha.P_f$) and tensile failure limit (fracture pressure).

### 5.1 Finite Element Simulation

The finite element method is one of the solution methods for differential equations for one specific object or specific structure under the physical conditions. In this method, object, area or structure is divided into one, two or three dimension parts. Each of these separated parts is named a finite element. The method works based on the continuum modeling and the elements boundary points are called node (Sadrnejad, 2009; Wang and Sterling, 2007).

The horizontal Well is modeled as a cubic block with 6×2.376×2.376 $m^3$ dimensions. The inner well diameter is 8.5 inches (0.216 m). The reservoir rock which contains the borehole is defined with porosity and permeability (Wang and Sterling, 2007; Papamichos, 2010;). Porosity, permeability and the fluid specifications are modeled in an in-situ stress condition to show the underground condition of borehole and its stability (Mackerle, 1997). The contour of fluid flow between the borehole and the reservoir is shown in Fig. 3.

The simulation consists of two fundamental steps: (1) the geo-static step and (2) the drilling step and applying the pressure into the well. Elapsed time for each of these steps is 1 second and total time of the static analysis would be 2 seconds.

#### 5.1.1 Geo-static step

In this step, the pre drilling condition is modeled, the system is balanced and the equilibrium condition is satisfied. It needs to be mentioned that stress, strain, displacement values and pore pressure changes are negligible. With applying the in-situ stress condition and the gravity force into the rock model, the simulation represents real world condition before drilling operation commences. The required time for this step is 1 second (Papamichos, 2010; Gentzis et al., 2009).

#### 5.1.2 Drilling step and applying well pressure

In second step, with the commencement of drilling, stress regime on the wellbore wall will be changed and the stress, strain and displacement values with pore pressure will be increased near the well. In this step, we try to decrease and optimize the plastic strain, displacement and stress values on the borehole wall as much as possible after drilling by applying mud pressure into the well (Xu et al., 1997). The time for this step would be also 1 second which starts from second 1 and it continues until second 2.

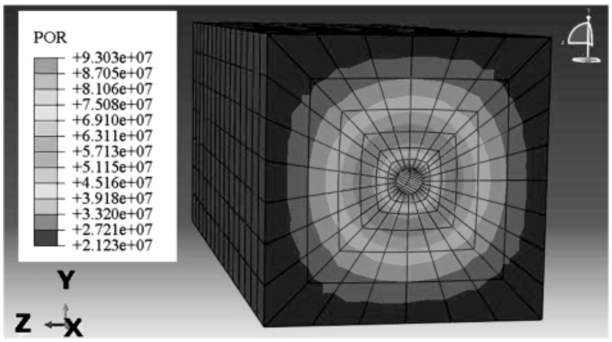


**Figure 3:** Radial fluid flow between external boundaries and borehole.

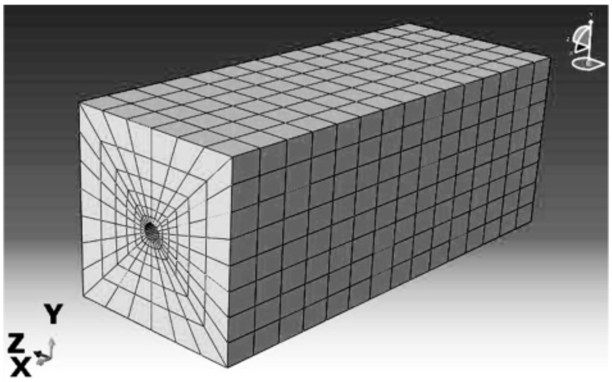


**Figure 4:** Structured hexagonal meshing.

#### 5.1.3 Meshing

Model meshing technique is based on the structural and hexagonal method; based on this method, the well was meshed into cubic elements which is shown in figure 4 (Aadony, 2003).

## 6. Results

### 6.1 Horizontal well stability analysis along the minimum horizontal stress

In this study, the horizontal well is designed to be along the minimum horizontal stress with azimuth angle of 90° and is

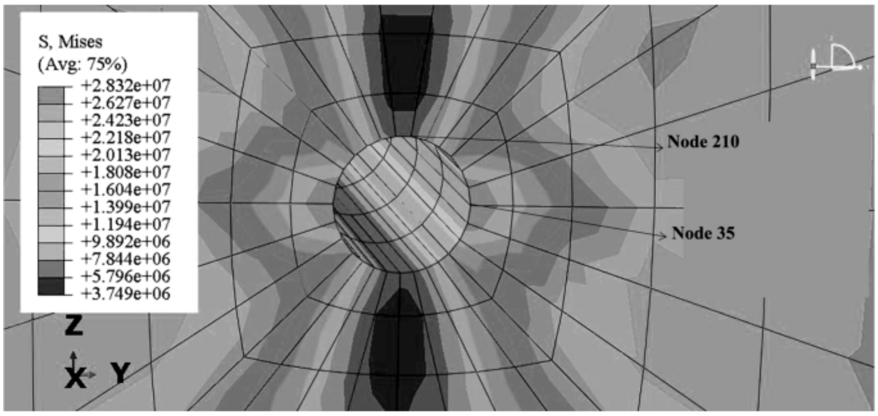


**Figure 5:** Node number 210 on the vertical edge and the node 35 on the lateral edge.

also perpendicular to the Northeast - Southwest direction of the maximum horizontal stress. The static analysis results have shown that the difference between maximum horizontal stress and vertical stress which were applied in longitudinal sides of the model is low; consequently, stresses on the borehole wall will have the same values and they will not create any instability by producing plastic strains or large stresses on the wellbore wall during applying optimized pressure into the well. In the drilling step, pressure analysis is performed within the allowable mud pressure window by constant increasing of well pressure between formation pressure and fracture pressure for determination of optimized well pressure window and the most optimized well pressure.

First, the well pressure has been increased constantly between second 1 to second 2 during the drilling step from formation pore pressure of 21.23 Mega Pascal (with Biot's factor) to the tensile failure limit or fracture pressure of 93 Mega Pascal (Fig. 7). The results show that there is no plastic strain initially in the drilling step; it first appears when the pressure increased to the time 1.575 seconds and it continued to increase until the end of drilling step (Fig. 8). Figure 8 shows that, applying mud pressure more than 62.51 Mega Pascal which is equivalent to the 1.575s of the drilling step time causes plastic strain and yield stress around the bore from 1.575s (equal to 62.51 Mega Pascal pressure of the well) to the end of simulation and it will make borehole instability and it probably makes fractures and the well collapse. The stress analysis on the point number 210 on the cross section of the horizontal oil well (Fig. 5) showed that the amount of stress on the vertical edge of the bore cross section initially was high (Fig. 9, principal stress on Z direction); but then decreased since two nodes curves (Fig. 6, average stress curve) cross each other by applying pressure on the well from formation pore pressure to the fracture pressure in the time limitation of second 1 to second 2 among the drilling step (cross point in second 1.46, Fig. 6). After that, node number 35 diagram (on the lateral edge) has been increased from the time 1.46s to the end of step because of borehole instability. The cross point of the vertical edge diagram (node number 210) and lateral edge (node number 35) in the horizontal well is the most optimum well pressure in this analysis (second 1.46=53 MPa, Fig. 6, Fig. 7) and it showed in the stress and well pressure versus time curves. The time limitation from pore pressure (second 1) to optimized pressure (second 1.46) is selected as the most optimized mud pressure window (second 1 to 1.46, Fig. 7). Nodes number 210 and 35 are shown in Fig. 5 and all the curves were plotted between se-

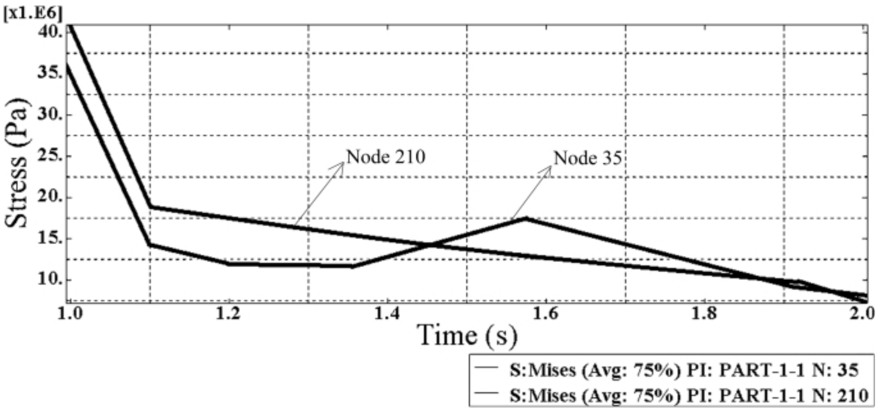


**Figure 6:** Borehole wall average stress (Pascal) versus time (s) for the node 210 (on vertical edge) and the node 35 (on lateral edge).

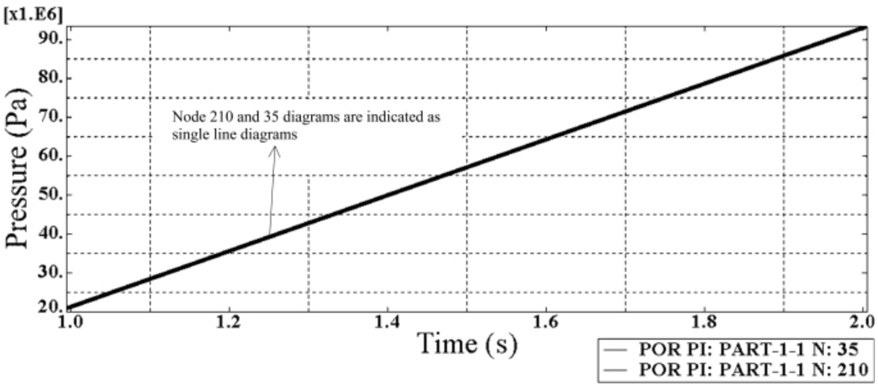


**Figure 7:** Well pressure (Pascal) versus time (s) graph.

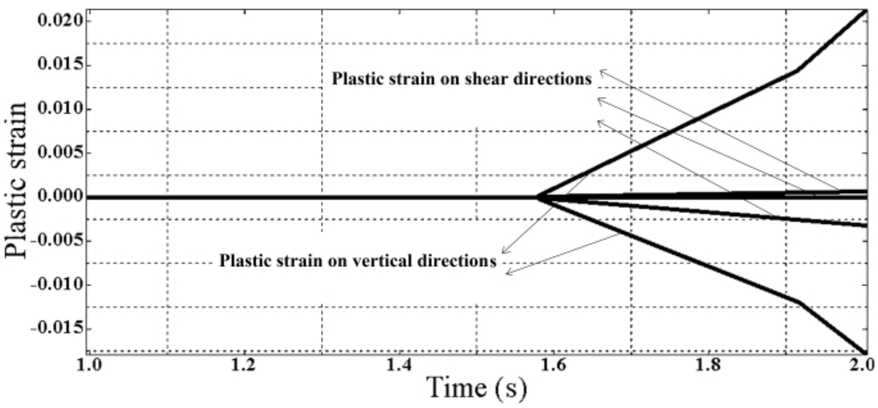


**Figure 8:** Plastic strain on various directions (vertical and shear directions) versus time (s).

cond 1 to second 2 of the drilling step and the geostatic step was not mentioned in this analysis due to the lack of any instability in the geostatic step (the time period of the geostatic step is also 1 second).

The numeric results in this case are summarized in table 3; the optimized stress and drilling mud pressure are presented in Mega Pascal unit.

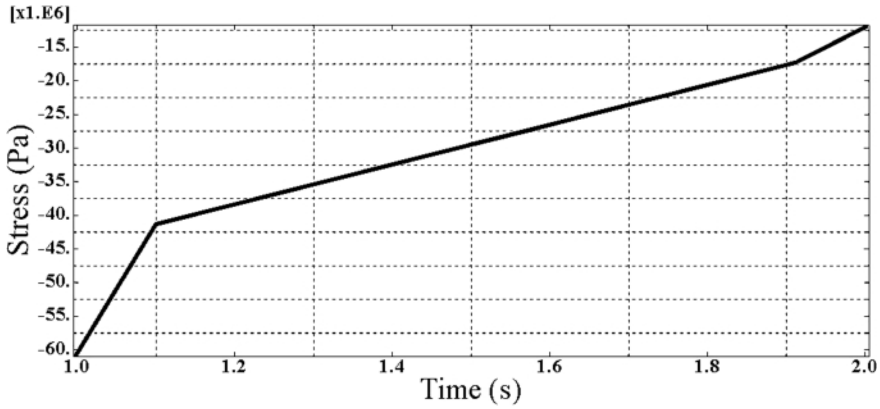


**Figure 6:** Borehole wall stress (Pascal) on Z axis for node number 210 versus time (s).

### 6.2 Horizontal well stability analysis along maximum horizontal stress

The well is along the maximum horizontal stress in Northeast - Southwest direction (azimuth angle of 0°) in this section. The analysis of well pressure shows that the tensile failure will occur at the well pressure 20.7 Mega Pascal and it will be slightly lower than the pore pressure. Thus drilling the bore in this direction may cause failure and well collapse and the probability of sand production will be high. Consequently, stability analysis is stopped in this direction and is processed just along the minimum horizontal stress direction.

| | Lower limit | Fracture pressure | Optimum value |
|---|---|---|---|
| Time (second) | 1 | 2 | 1.46 |
| Well pressure (MPa) | 21.23 | 93 | 53 |
| Stress (MPa) | 60.78 | 11.95 | 27.57 |
| Plastic strain | 0 | 2.119×10-2 | 0 |

**Table 3:** The stress on the borehole wall, well pressure and plastic strain.

### 7. Conclusions

- In the study area, the activities of the strike-slip fault regime have made large differences between minimum and maximum horizontal stresses. Drilling along the maximum horizontal stress direction causes the pore pressure to become higher than the tensile failure stress or fracture pressure and the wellbore wall has a high likelihood to get damaged.
- Applying well pressure within the mud pressure window in horizontal oil wells showed that the borehole stability will not be seen by the minimum limit of well pressure window (formation pressure) or maximum limit of well pressure; the optimum mud pressure in horizontal wells is higher than the minimum limit of the mud pressure window.
- By optimizing the horizontal oil well, the wellbore wall stresses are reduced strongly by applying a mud pressure higher than the formation pore pressure level. This pressure has balanced the wellbore wall stresses and the level of plastic strain in the well cross section has reached zero.
- The mud pressure analysis gives the optimum pressure and optimum mud pressure window at this depth. They were determined by calculating the cross point of node graphs (on the vertical edge (node 210) and lateral edge (node 35)) in the stress versus time curve.
- By assessing the plastic strain-time graph, the minimum mud pressure which can produce the plastic strain was determined. By knowing this critical pressure in drilling horizontal oil wells, no well pressure higher than this critical pressure will be applied.
- The stability analysis in the static condition has progressed with high accuracy by applying pore pressure, fluid seepage effects and mud pressure into the well.
- Based on the continuum state of the rock model in this analysis, fractures and joints effects on the wellbore stability can be analyzed in the future research.

### References

Aadony, B.S., 2003. Introduction to special issue on borehole stability. Journal of Petroleum Science and Engineering, 38, 79-82.

Al-Ajmi, A.M. and Zimmerman, R.W., 2009. A new well path optimization model for increased mechanical borehole stability. Journal of Petroleum Science and Engineering, 69, 53-62.

Cooper, M., 2007. Structural style and hydrocarbon prospectivity in fold and thrust belts: a global review. Journal of the Geological Society London, 272, 447–472.

Fjaer, E., 2008. Petroleum Related Rock Mechanic. Elsevier Publication Books, 491 pp.

Gentzis, T., 2009. Stability analysis of a horizontal coalbed methane well in the Rocky Mountain Front Ranges of southeast British Columbia, Canada. International Journal of Coal Geology, 77, 328-337.

Gentzis, T., Deisman, N. and Chalaturnyk, R.J., 2009. A method to predict geomechanical properties and model well stability in horizontal boreholes. International Journal of Coal Geology, 78, 149-160.

Haimson, B., 2007. Micromechanisms of borehole instability leading to breakouts in rocks. International Journal of Rock Mechanics and Mining Sciences, 44, 157-173.

Hatzfeld, D., Authemayou, C., Van der Beek, P., Bellier O., Lavé J., Oveisi B., Tatar M., Tavakoli F., Walpersdorf A. and Yamini-Fard, F., 2011. The kinematics of the Zagros Mountains (Iran). In: London Geological Society, Special Publications. Tectonic and Stratigraphic Evolution of Zagros and Makran during the Mesozoic-Cenozoic, 330, 19-42.

Klee, G., Rummel, F. and Williams, A., 1999. Hydraulic fracturing stress measurements in Hong Kong. International Journal of Rock Mechanics and Mining Sciences, 36, 731-741.

Lee, H., Ong, S., Azeemuddin, M. and Goodman, H., 2012. A wellbore stability model for formations with anisotropic rock strengths. Journal of Petroleum Science and Engineering, 96-97, 109-119.

Mackerle, A., 1997. Stability problems analyzed by finite element and boundary element techniques: A bibliography (1994-1996). Finite Elements in Analysis and Design, 26, 337-353.

McQuarrie, N., 2004. Crustal scale geometry of the Zagros fold–thrust belt, Iran. Journal of Structural Geology, 26, 519-535.

Oliver, G., Karpfinger, F., Jocker, J. and Prioul, R., 2012. Comparison between analytical and 3D finite element solutions for borehole stresses in anisotropic elastic rock. International Journal of Rock Mechanics and Mining Sciences, 51, 53-63.

Papamichos, E., 2010. Analysis of borehole failure modes and pore pressure effects. Computers and Geotechnics, 37, 141-152.

Rutqvist, J., Moridis, G. J., Grover, T., Silpngarmlert, S., Collett, T.S. and Holdich, S.A., 2012.Coupled multiphase fluid flow and wellbore stability analysis associated with gas production from oceanic hydrate-bearing sediments. Journal of Petroleum Science and Engineering, 92–93, 65-81.

Sadrnejad, S.A., 2009. Introduction to Finite Elements Method. K.N Toosi University of Technology, Tehran, 680 pp.

Sherkati, S.; Molinaro, M., Frizon de Lamotte, D. and Letouzey J., 2005. Detachment folding in the Central and Eastern Zagros fold-belt (Iran): salt mobility, multiple detachments and late basement control. Journal of Structural Geology, 27, 1680-1696.

Shu-qing, H., 2011. A study to optimize drilling fluids to improve borehole stability in natural gas hydrate frozen ground. Journal of Petroleum Science and Engineering, 76, 109-115.

Talebian, M. and Jackson J., 2004. A reappraisal of earthquake focal mechanisms and active shortening in the Zagros mountains of Iran. Geophysics Journal International, 156, 506-526.

Wang, X. and Sterling, R.L., 2007. Stability analysis of a borehole wall during horizontal directional drilling. Tunnelling and Underground Space Technology, 22, 620-632.

Xu, G., Guo, Q., Zheng, Z., McLennan, J. and Green, S., 1997. A finite element poro-inelastic analysis of borehole problems. International Journal of Rock Mechanics and Mining Sciences, 34, 424.

Zare-Reisabadi M.R., Kaffash, A., Shadizadeh, S.R., 2012. Determination of optimal well trajectory during drilling and production based on borehole stability. International Journal of Rock Mechanics and Mining Sciences, 56, 77-87.

Zhang, J., 2013. Borehole stability analysis accounting for anisotropies in drilling to weak bedding planes. International Journal of Rock Mechanics and Mining Sciences, 60, 160-170.

Zoback, M.D., 2007. Reservoir Geomechanics, Cambridge University Press, London, 464 pp.

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