Advances in Energy Research, *Vol. 3, No. 1 (2015) 1-10*
DOI: http://dx.doi.org/10.12989/eri.2015.3.1.001

The impact of sidetracking on the wellbore stability

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(Received December 16, 2014, Revised February 1, 2015, Accepted February 11, 2015)

Abstract. In the past sidetracking was the means to bypass a damaged zone or to correct the direction of a wellbore. Nowadays, this method is very common and useful in relocating the bottom of a wellbore in a more productive zone and consequently enhancing the production of a reservoir by saving a significant amount of time and money. In this paper, the stability of the bend area is assessed considering varied conditions of stress regime and sidetrack orientation. In general, the stress regime and the orientation of the principal stresses have negligible effect on the stability of the sidetrack compared to sidetrack inclination. On the other hand, the sidetrack deviation angle from the vertical main well plays the major role in the stability of the bend area.

Keywords: multi-lateral well; NYZA; optimum pressure; optimum trajectory; junction

1. Introduction

Sidetracking is the term used for drilling a directional hole to bypass an obstruction in the well that cannot be removed or damage to the well, such as collapsed casing that cannot be repaired. Other applications of sidetracking are deepening a well or relocating the bottom of the well in a more productive zone (Oil and Gas Well Drilling and servicing eTool).

To sidetrack, a hole (window) is made in the casing above the obstruction. The area below the window is then plugged with cement. In order to drill off the sidetrack at a desired angle from the main well, drill tools such as a whipstock, bent housing, or bent sub are employed (Oil and Gas Well Drilling and Servicing eTool).

In the 1920's whipstocks were firstly used as a correctional device in the fields of California. This correction was conducted to divert around a fish or to bring the well back to vertical. Another use of the whipstock was to drill relief wells in case there was a surface or underground fire. Later this tool was used to intentionally deviate the well from vertical direction. Then, the word whipstock became increasingly synonymous with sidetracking. The alternate methods like knuckle joints and deflectors, used during 1920's and 1930's, were not as predictable as sidetracking (Sagle *et al*. 2001).

Nowadays, sidetracking methods are employed to economically recover more of the original oil in place, often at accelerated rates. This method minimizes the capital requirements and time

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http://www.techno-press.org/?journal=eri&subpage=7 ISSN: 2287-6316 (Print), 2287-6324 (Online)

because it utilizes the existing infrastructures to penetrate the preferred zones (Sagle *et al*. 2001).

Sidetrack technique has been used in Statfjord and Veslefrikk fields in order to stop severe mud losses in several wells drilled near water injectors. This method is also used to access pockets of isolated oil and gas in mature fields using Through Tubing Drilling and Completion (TTD&C) technology. Moreover, sidetracking is advantageous in reservoir intervals to minimize borehole length and avoid problems in overlying formations (Bensvik 2006).

A Russian oil Company drilled sidetracks at 224 wells in 2010 and gave average daily flow of 19.7 tonnes. Sidetrack drilling is carried out mainly at wells which have been taken out of operation, in order to extract residual oil reserves. In 2010 this company drilled a total of 12 sidetracks in Urevskoye field and eight sidetracks in Unvinskoye field. In Pamyatno-Sasovskoye field, which is one of the largest in the Volga region, total additional oil production achieved by drilling of sidetracks was 67,300 tonnes (Annual report 2010, LUKOIL).

Another Russian oil company sits on 1000 wells on the Sakhalin Island which are un-active. Reserves are proven, but the wells have been drilled over a period of half a century. Implementation of new technology such as extended reach sidetracks into these mature oilfields would increase production significantly (Drnec and Przhegalinsky 2008).

A joint venture of three companies managed to drill a 650-m horizontal sidetrack with a complex 3D profile to improve productivity and to maximize reserves recovery in a mature Chinese oil field. The target was a low-quality clastic reservoir with very thin oil pockets of 1.5 m thickness (Shlumberger 2011).

Due to the apparent thin oil column in Gunung Kembang Field in the South Sumatera Extension area of Medco E&P Indonesia working areas, three horizontal wells, GK-1 HW, GK-3 HW and GK-6 HW, were executed in 2004 by side-tracking existing vertical wells, GK-1, GK-3, GK-6 (Hudya *et al*. 2007).

Wellbore instability can happen in different ways such as hole pack off, excessive reaming, overpull, torque and drag. This requires additional time to drill a hole, driving up the cost of reservoir development significantly. There are some uncontrollable and controllable factors which control the stability of a wellbore. Uncontrollable factors are the earth stresses (horizontal and vertical), pore pressure, rock strength and rock chemistry. Controllable factors include mud weight, wellbore azimuth and inclination. A proper drilling program optimizes the controllable factors with the knowledge of uncontrollable factors. The controllable factors are heavily dependent on rock mechanical behavior of rock (Mohiuddin *et al*. 2006). The drilling engineers alleviate the stress concentration using mud pressure and optimization of wellbore orientation. In general, variation of wellbore inclination is restricted and thus the stability should be controlled by means of suitable mud pressure employment (Al-Ajmi 2006). Design of wells using principles of rock mechanics is well reported in the literature (Mohiuddin *et al*. 2006).

For instance, Drilling of overburden shales in offshore Nigeria resulted in several problems of stuckpipes and sidetracks. A detailed rock mechanics study was conducted to characterize the state of in-situ stress, rock strength, and formation pore pressure. These parameters were used to perform a geomechanical simulation and estimate safe mud weights. Use of these mud weights led to a marked improvement in wellbore stability (Mohiuddin *et al*. 2006).

Although the most conventional and simplest model for wellbore stability analysis is linear elastic, because of its limited number of parameters to be defined (Soliman and Boonen 2000): however, the elastoplastic model is employed in this research as it gives more realistic results for mechanical stability. Therefore, in this behavioral model the medium is capable of absorbing more stresses and accepting more deformation after its peak strength (McLellan *et al*. 2002).

Table 1 In-situ stress regimes

Stress regime	Relative magnitude of the stresses	σ_v (Psi/ft)	σ_H (Psi/ft)	σ_h (Psi/ft)
Hydrostatic	$\sigma_v=\sigma_H=\sigma_h$	1.0	1.0	1.0
NF	$\sigma_v>\sigma_H>\sigma_h$	1.0	0.86	0.76
NF with isotropic horizontal stresses	$\sigma_v>\sigma_H=\sigma_h$	1.0	0.75	0.75
SS	$\sigma_v>\sigma_H>\sigma_h$	0.89	1.0	0.85
NF-SS	$\sigma_v=\sigma_H>\sigma_h$	1.0	1.0	0.75
RF	$\sigma_v>\sigma_H>\sigma_h$	0.89	1.1	0.98
SS-RF	$\sigma_v>\sigma_H=\sigma_h$	0.9	1.1	0.9

Table 2 Rock mass geomechanical parameters

Parameter	Dimension	Quantity
Tensile strength (T)	MPa	2.9
Cohesion (C)	MPa	2.5
Internal friction angle (φ)	Degree	30
Bulk modulus (K)	GPa	8.93
Shear modulus (G)	GPa	6.15
Yong's Modulus (E)	GPa	15
Poisson's Ratio (υ)	-	0.22

In this research, the criterion for assessing the wellbore instability is based on the development of yielded (plastic) area. The criterion which is often used for indication of wellbore instability risk is the Normalized Yielded Zone Area (NYZA), which is dividing the cross-sectional area of plastic zone to original area of the wellbore. From the experience gained, the instability often occurs when the amount of NYZA is more than one (McLellan *et al*. 2002). Furthermore, the FLAC3D numerical code (using the Mohr-Coulomb failure criterion) is utilized to carry out the stability analyses. This software is a three dimensional finite difference code which is developed for implementation of mechanical calculations in the engineering problems (ITASCA 2006). The variation of plastic zone with respect to the variation of mud pressure in the bent area is determinable by the aid of this numerical code.

2. In-situ stresses and geomechanical parameters of the rock mass

In this research study, a rock mass from one of the Iranian oil fields is considered to be subjected to the stress regimes mentioned in Table 1. The geomechanical properties of this rock mass are presented in Table 2. The formation is assumed to exist at a depth of 8000ft, with a pore pressure gradient of 0.45 Psi/ft.

3. Stability analysis using numerical modeling

3.1 Numerical models

The model generated to conduct this research study consists of a vertical well (main well) and a sidetracked wellbore which is initially considered to have the same direction as the main well. Both the main and sidetracked wellbores have a 16 cm radius. The angle between the vertical direction and the sidetrack direction varies from 0° to 90° with a 15° interval. The stability of the bend area is evaluated in 8 different mud overbalance pressure conditions (0, 1.5, 3, 4.5, 6, 7.5, 9, 10.5 MPa). The mud pressure level, in which the NYZA is equal to 1, is considered to be the minimum (optimum) mud pressure needed to stabilize the bend. This optimum mud pressure calculation is performed for various circumstances of sidetrack orientations and in-situ stress regimes. Hence, a total number of 1400 models are generated. The calculations have been carried out using the Mohr-Coulomb criterion.

3.2 Stability analysis of the bend area

The most critical part of the sidetrack wellbore is the bend area. The instability in this area is the consequence of instability in both main well and the sidetrack. In order to calculate the NYZA values in this region it is necessary to determine the volume of the plastic zones in the bend area. As shown in Fig. 1, the regions with blue color are in elastic state and the other regions are in plastic state. Also as it is shown in this figure, an equivalent area consisting both main well and the sidetrack plastic zones, is considered for the calculation of NYZA. This calculation is carried out using a FISH code in FLAC3D numerical code. The NYZA can be calculated using the formula (1)

$$NYZA = 2\left[\left(\frac{V_{ABCF}}{L_1 \pi r^2}\right) + \left(\frac{V_{CDEF}}{L_2 \pi r^2}\right)\right] \tag{1}$$

The mesh generated for the main well and the sidetrack areas are the same, therefore, $L_1=L_2=L$ and hence the formula (2) is resulted

$$NYZA = 2\left(\frac{V_{ABCDEF}}{L \pi r^2}\right) \tag{2}$$

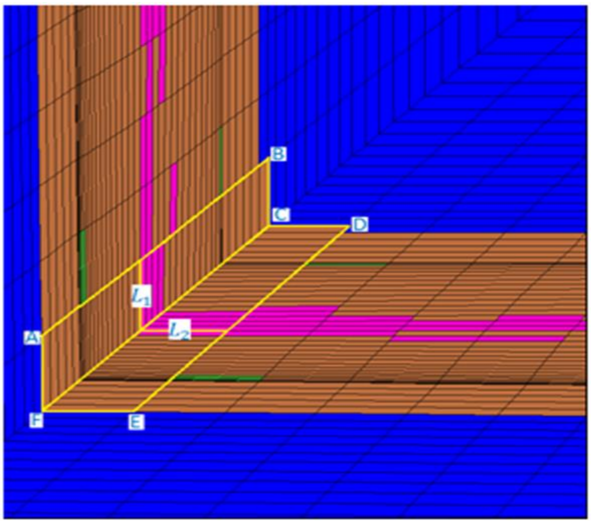

Fig. 1 Schematic view of the bend area and the surrounding plastic zone

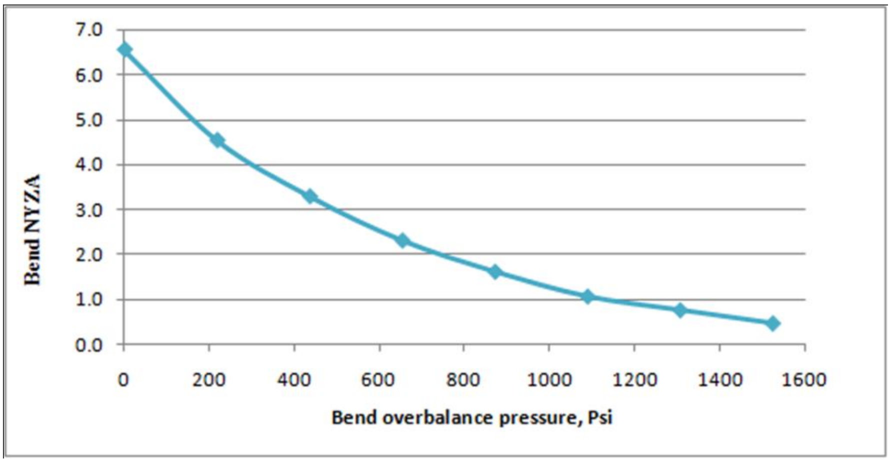

Fig. 2 Variation of NYZA vs. overbalance pressure in bend area for a sidetrack with 45^o inclination from the vertical direction and the direction along σh in NF-SS stress regime

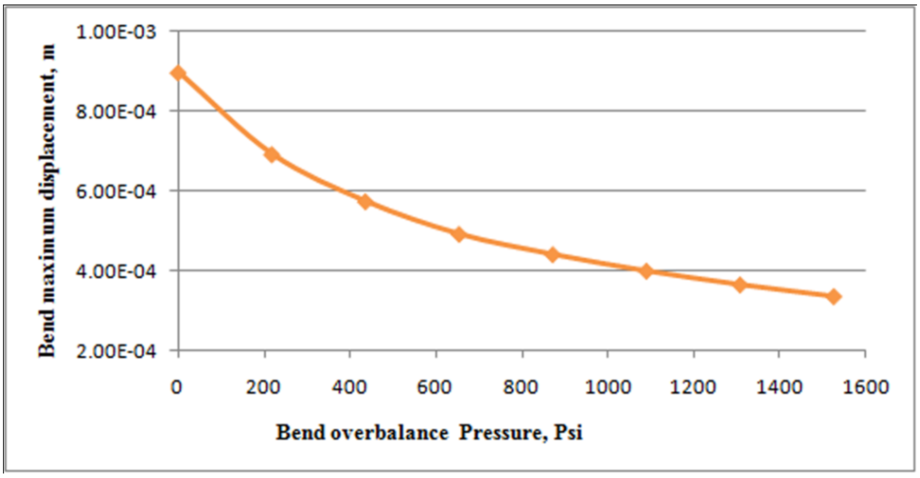

Fig. 3 Variation of displacement vs. overbalance pressure in bend area for a sidetrack with 45^{o}inclination from the vertical direction and the direction along σh in NF-SS stress regime

In this formula, "*r*" is the radius of the wellbores which is 16 cm. Moreover, V_{ABCF}, V_{CDEF} and V_{ABCDEF} are the volumes of the plastic zones related to the indicated regions in Fig. 1. In addition, the L_1 and L_2 are defined in Fig. 1. Because of the symmetry only half of the wellbores are modeled and so the resulted value is multiplied by 2 in formula (1) and (2).

As mentioned, the bend optimum mud pressure (the minimum mud pressure needed for bend stability) is the pressure in which the NYZA is equal to one. Therefore, in each model the variation of NYZA in different bend mud pressures (8 varied levels) are calculated and then the best curve is fitted to the resulted points, Fig. 2. As a result, the optimum mud pressure is accurately determined using the curve formula. It is also possible to draw the displacement vs. bend overbalance mud pressure (bend mud pressure minus pore pressure) graph (Fig. 3). In these two graphs, with the increase in mud pressure, both NYZA and displacement reduce and thus the bend area gets more stable. It can also be observed that the rate of this reduction is less in higher mud pressures. Fig. 2

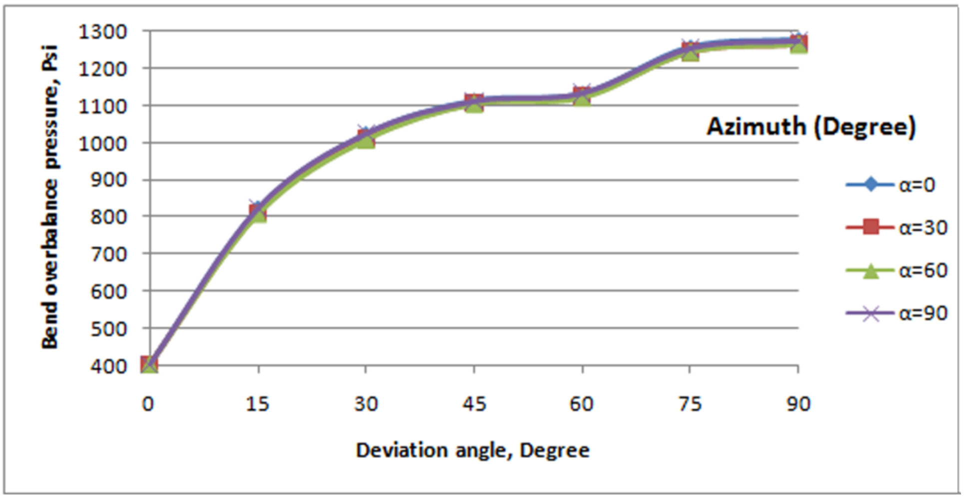

Fig. 4 Minimum overbalance pressure vs. sidetrack orientation in hydrostatic stress regime

and 3 show typical graphs for a bend with a sidetrack drilled in a 45^{o} inclination from the vertical direction and the direction along σ_h under the NF-SS stress regime.

To determine the sidetracks optimum trajectories under a particular stress regime, it is needed to accumulate the optimum bend mud pressures for several directions and inclinations of sidetracks, using the method mentioned above. As a result, graphs like those shown in Figs. 2 and 3 can be drawn. By the aid of these charts the favorable orientations of the sidetracks are predictable.

3.3 Sidetrack stability analysis in varied stress regimes

In this research study, the stability of bend area is assessed in varied stress regimes, as mentioned in section 3.2. Several different orientations of sidetrack, as elaborated on in section 3.1, are also considered in each stress condition. The minimum bend overbalance pressures resulted for different sidetrack inclinations (i) and directions/azimuths (α) are shown in Figs. 4-10. The following points are deduced from the carried-out analyses:

Generally, in all graphs similar trend is observed. The bend area, not surprisingly, gets more unstable by deviation of the sidetrack direction from the vertical main well.

The interesting point is that the direction of the sidetrack relative to the horizontal stresses has no or insignificant impact on the stability of the bend area compared to sidetrack inclination. However, considering this minor variation, the favorability of the sidetrack direction mainly decreases by its change from σ_H to σ_h direction.

Under all circumstances there is a sudden increase in the minimum bend overbalance pressure when the deviation angle from the main well direction is between 0°-15°. Then the rate of increasing reduces and in some cases, especially in Figs. 4 and 6, there is almost no changes in the overbalance mud pressure when the deviation angle varies between 45°-60°. This situation, less generally, can also be seen in case the deviation angle changes between 75°-90°.

It can be added that in general under NF stress regime, with or without isotropic horizontal stresses, the bend area is more stable and less mud pressure is needed.

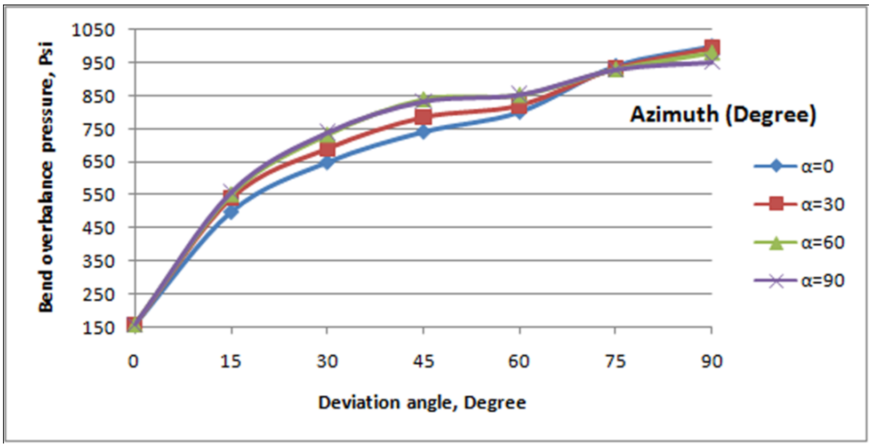

Fig. 5 Minimum overbalance pressure vs. sidetrack orientation in NF stress regime

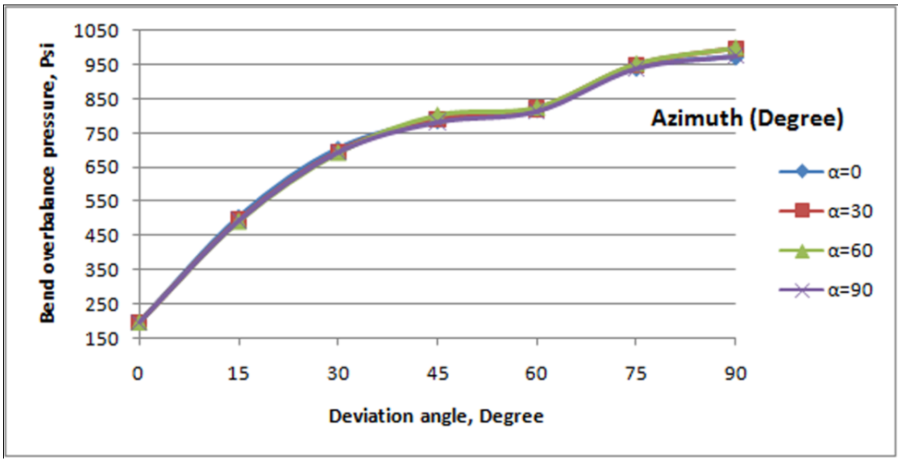

Fig. 6 Minimum overbalance pressure vs. sidetrack orientation in NF with isotropic horizontal stress regime

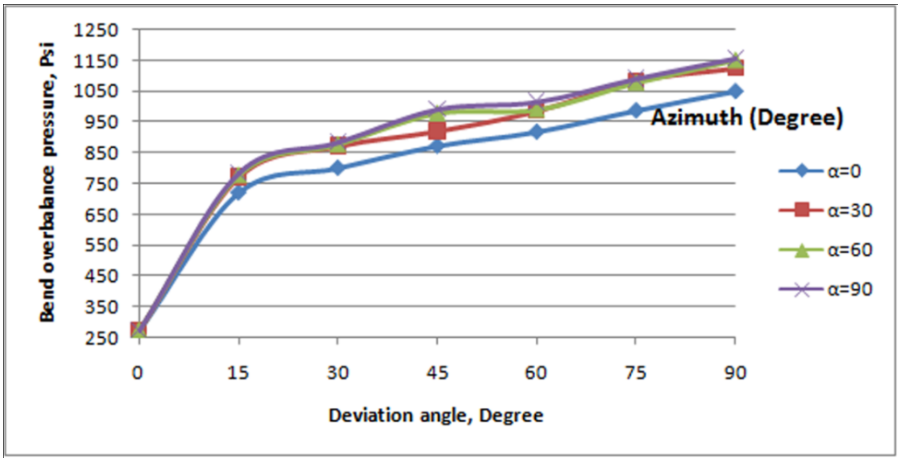

Fig. 7 Minimum overbalance pressure vs. sidetrack orientation in SS stress regime

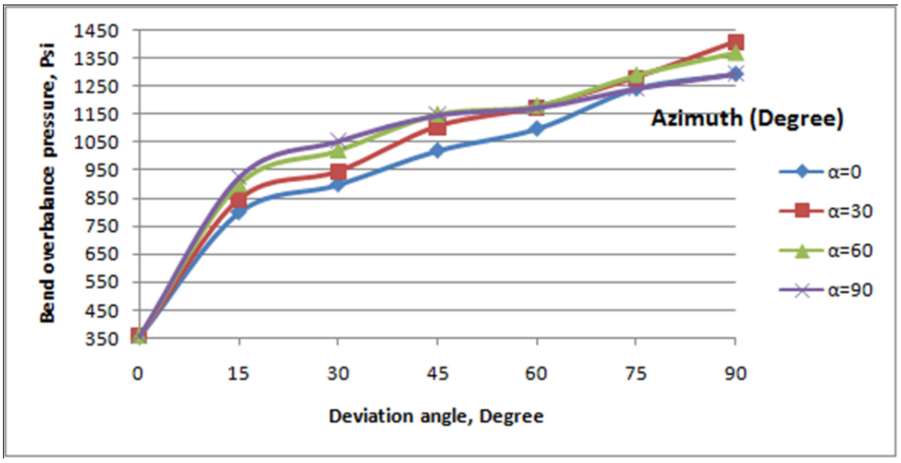

Fig. 8 Minimum overbalance pressure vs. sidetrack orientation in NF-SS stress regime

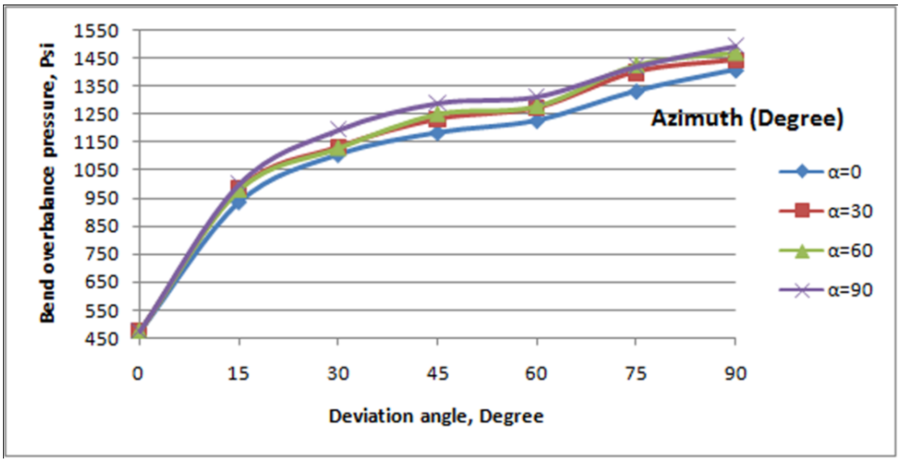

Fig. 9 Minimum overbalance pressure vs. sidetrack orientation in RF stress regime

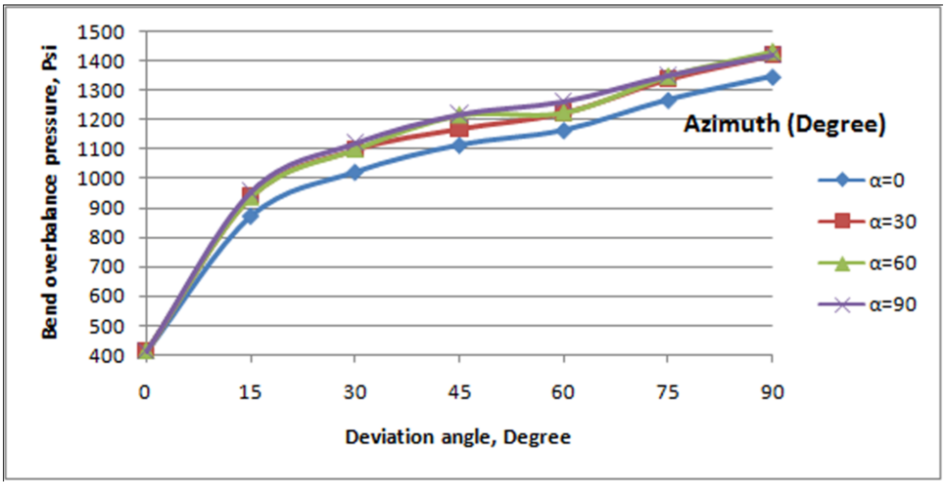

Fig. 10 Minimum overbalance pressure vs. sidetrack orientation in SS-RF stress regime

4. Conclusions

The main conclusion which can be deduced from this research study is that the type of the stress regime and the orientation of the principal stresses have no or negligible effect on the stability of the sidetrack compared to sidetrack inclination and therefore it cannot be generally considered as a factor affecting the bend stability. On the other hand, the sidetrack deviation angle from the vertical main well plays the major role in the stability of the bend area. It is predictable that by the increase of the deviation angle the bend area become more unstable. This factor have a more significant impact when the sidetrack is near the vertical position, 0°-15°. Then by the increase of the deviation angle the needed mud pressure increases with a lower rate and even in some cases no changes can be seen in the required mud pressure, especially when the deviation angle differs from 45° to 60°.

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Nomenclature

V = volume, L^3, m3

L = length, L, m
r = radius, L, m
σ_H = maximum horizontal principal stress, m/Lt^2, Psi
σ_h = minimum horizontal principal stress, m/Lt^2, Psi
i = inclination, degree
α = directions/azimuths, degree