Numerical Sand Prediction Model Analysis for Sand Onset, Sand Volume and Sanding Rate.

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Abstract- Sand production occurs during the hydrocarbon production from a well when the reservoir sandstone is weak enough to fail under the in-situ stress conditions and the imposed stress changes due to the hydrocarbon production. A 3D Numerical Geomechanical Model of Greater Ughelli Depobelt in the Niger Delta was analysed by assessing the mechanical response to rock. This was done through the analysis and modelling of information from offset data. The developed model is capable of assessing the conditions that lead to the onset of sanding, the rate of sanding and the volume of sand that would be produced.

***Index Terms*-** Critical wellbore pressure, uniaxial Compressive strength, Rock Failure, Mogi Criteria, Young Modulus, Shear stress.

I. Introduction

Mechanisms causing sand production are related to the formation strength, flow stability, viscous drag forces and pressure drop into the wellbore (Osisanya, 2010). The critical factors leading to accurate prediction of sand production potential and sand production are: formation strength, in-situ stress, and production rate. Other factors are reservoir depth, natural permeability, formation cementation, compressibility, surface exposed to flow, produced fluid types and phases, formation characteristics, pressure drawdown and reservoir pressure. Predicting sand production involves developing empirical and analytical. Numerical analytical techniques are also sometimes used. They are models developed from finite element analysis. The techniques above use production data, well logs, laboratory testing, acoustic, intrusive sand monitoring devices, and analogy (Osisanya, 2010). Techniques. Empirical techniques relate sand production to some single parameter or group of parameters such as porosity, flow or drawdown, while analytical techniques relates to rock stresses.

II. IDENTIFY, RESEARCH AND COLLECT IDEA

In developing this numerical model, the work will incorporate a computer model which will be used to carry out these analytical predictions based on input data considering hydrib approach with the assumption that the formation is heterogeneous, discontinuous and non-linear in nature. Geomechanical model determination for shear failure was carried out by using input and output data obtained from offset data. This data were used to obtain the maximum horizontal stress, fracture break down pressure, collapse pressure, maximum drawdown pressure, critical wellbore pressure, failure stresses and porosity at different depths.
Some regressional plots for different criteria will be developed to show the effects of these stresses, porosity, drawdown, critical pressure, failure criteria and unconfined compressive strength (UCS) in predicting sand production at different well directions respectively.

III. EQUATIONS FOR NUMERICAL SAND PREDICTION MODEL DEVELOPMENT

For the purpose of this research, all equations used for the development of the software are based on 3D-Mogi Coulomb failure Criterion.

Stress Regimes: There are three stress regimes inherent in wellbore; for this research work, the stress regimes are used to determine the maximum horizontal stresses while considering the biot's constant (as 0.5) at some point.

- Normal faulting stress regime (k =0.5)

$$\sigma_H = \sigma_h + k * (\sigma_v - \sigma_h)$$
3.1

- Reverse and strike slip faulting regime

$$\sigma_H = \sigma_h + \frac{\sigma_h}{\sigma_v} * (\sigma_v - \sigma_h)$$

Cylindrical stress determinations:

$$\sigma_z = \sigma_{z'}$$

$$\sigma_{r\theta} = (\sigma_{y'} - \sigma_{x'}) sin\theta cos\theta + \sigma_{x'y'}(cos^2\theta - sin^2\theta)$$

$$\sigma_{rz} = \sigma_{x'z'}cos\theta + \sigma_{y'z'}sin\theta)$$

$$\sigma_{\theta z} = \sigma_{y'z'}cos\theta + \sigma_{x'z'}sin\theta)$$

Virgin stress determinations before excavation:

$$\sigma_{xy}^o = 0.5(\sigma_h - \sigma_H) sin2\alpha \, cos \, i$$

$$\sigma_{yz}^o = 0.5(\sigma_h - \sigma_H) sin2\alpha \, sin \, i$$

$$\sigma_{xz}^o = 0.5(\sigma_H cos^2\alpha + \sigma_h sin^2\alpha - \sigma_v) sin2i$$

Virgin stress determinations after excavation:

$$\sigma_{r\theta} = \left[\left(\frac{\sigma_x^o - \sigma_y^o}{2}\right)\left(1 - 3\frac{a^4}{r^2} + 2\frac{a^2}{r^2}\right) sin2\theta\right] + \sigma_{xy}^o \left(1 - 3\frac{a^4}{r^2} + 2\frac{a^2}{r^2}\right) cos2\theta$$

$$\sigma_{\theta z} = (-\sigma_{xz}^o sin2\theta + \sigma_{yz}^o cos\theta)(1 + \frac{a^2}{r^2})$$

$$\sigma_{rz} = (\sigma_{xz}^o cos2\theta + \sigma_{yz}^o sin\theta)(1 - \frac{a^2}{r^2})$$

Stresses around wellbore for a Deviated Well:

$$\sigma_\theta = \sigma_x^o + \sigma_y^o - 2(\sigma_x^o - \sigma_y^o) cos2\theta - 4\sigma_{xy}^o sin2\theta - P_w$$

$$\sigma_z = \sigma_z^o - v\left[2(\sigma_x^o - \sigma_y^o) cos2\theta + 4\sigma_{xy}^o sin2\theta\right]$$

$$\sigma_{\theta z} = 2(-\sigma_{xz}^o sin\theta + \sigma_{yz}^o cos\theta)$$

Stresses around wellbore for a Vertical Well:

$$\sigma_{\theta =}\sigma_H - \sigma_h - 2(\sigma_H - \sigma_h) cos2\theta - P_w$$

$$\sigma_z = \sigma_v - 2v(\sigma_H - \sigma_h) cos2\theta$$

Deviatoric Stresses

$$S_1 = \frac{2\sigma_1 - \sigma_2 - \sigma_3}{3}$$

$$S_2 = \frac{2\sigma_2 - \sigma_1 - \sigma_3}{3}$$

$$S_3 = \frac{2\sigma_3 - \sigma_1 - \sigma_2}{3}$$

Principal Stresses

$$\sigma_1 = \max(\sigma_{p1}, \sigma_{p2}, \sigma_r)$$

$$\sigma_3 = \min(\sigma_{p1}, \sigma_{p2}, \sigma_r)$$

$$\sigma_2 = \frac{\sigma_1 + \sigma_3}{2}$$

Rock Failure

$$F = a + b\left(\frac{\sigma_1 + \sigma_3}{2}\right) - {}^1\!/_3 \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}$$

Where;

$$a = \frac{2\sqrt{2}}{3} c \, cos\phi$$

$$b = \frac{2\sqrt{2}}{3} sin\phi$$

if

$\boldsymbol{F \geq 0}$, ***stable well with low risk of sand production***

$\boldsymbol{F <}$ 0, *Unstable well with high risk of sand production*

Critical Wellbore Pressure

$$\boldsymbol{P_{cw}} = \frac{1.5\sigma_x - 0.5\sigma_y - 0.5\alpha P_o\left(\frac{1-2v}{1-v}\right) - 1.732\tau_i}{1 - 0.5\alpha\left(\frac{1-2v}{1-v}\right)}$$

$$where; \quad \tau_i = \frac{0.025UCS}{10^6 C_B}$$

$$Tensile = \frac{2c \cos\phi}{1 + sin\phi}$$

$$P_o = \sigma_v - \left[(\sigma_v - P_H)(\frac{\Delta\tau_n}{\Delta\tau})^3\right]$$

$$v = \frac{3k_b - \tau_m}{2(3k_b + \tau_m)}$$

$\boldsymbol{P_{cw}} < 0, well\ is\ not\ affected\ by\ sand\ production$

$\boldsymbol{P_{cw}} \geq \mathbf{0}, well\ would\ be\ affected\ by\ sand\ production$

Formation Strength (Rock's compressive strength)

$$UCS = \left(\frac{0.0025 * shear\ strength * YoungMoudulus}{C_B * 10^6} * 0.08 * Vsh + 0.0045 * (1 - Vsh)\right)$$

$$YoungMoudulus\ (G) = \frac{9 * P_b * shearModulus}{3P_b + shearModulus}$$

$$\boldsymbol{shear\ strength} = \frac{2cos\phi}{1 - sin\phi}$$

$$\boldsymbol{shearModulus} = P_b t_s^2 B.$$

$$\boldsymbol{Friction\ angle\ (\phi)} = 26.5 - 37.4(1 - NPHI - Vsh) + 62.1(1 - NPHI - Vsh)^2$$

$$C_B = \frac{1}{K_b}$$

$$K_b = P_b(t_c^2 - {}^3/_4\, t_s^2)$$

$$\boldsymbol{Drawdown\ failure} = \frac{\Delta P}{UCS}$$

$$c = \frac{UCS(1 - sin\phi)}{2cos\phi}$$

$\boldsymbol{if\ Drawdown\ failure \geq 1.7, well\ is\ subject\ to\ sand\ production}$

$\boldsymbol{if\ Drawdown\ failure} < 1.7, well\ is\ not\ subject\ to\ sand\ production$

Analytical Model for Sand Volume Produced

$$\boldsymbol{C_{snd}} = \frac{-N + \sqrt{N^2 + 16P_w\sigma_H}}{8\sigma_H}$$

$$\boldsymbol{V_{snd}} = \frac{pi}{4}\left(\frac{1 - C_{snd}}{C_{snd}}\right){W_r}^2$$

$\boldsymbol{if\ C_{snd}\ and\ V_{snd}} > 0\ means\ well\ is\ subject\ to\ sand\ production$

$\boldsymbol{if\ C_{snd}\ and\ V_{snd} \leq 0\ means\ well\ is\ not\ subject\ to\ sand\ productio}$

IV. RESULTS ANALYSIS/DISCUSSION

The interface below shows the result of the Geomechanical sand prediction (GSP) model for each regressional plots Greater Ughelli and Costal Swamp Depobelt after it has been ran successfully.

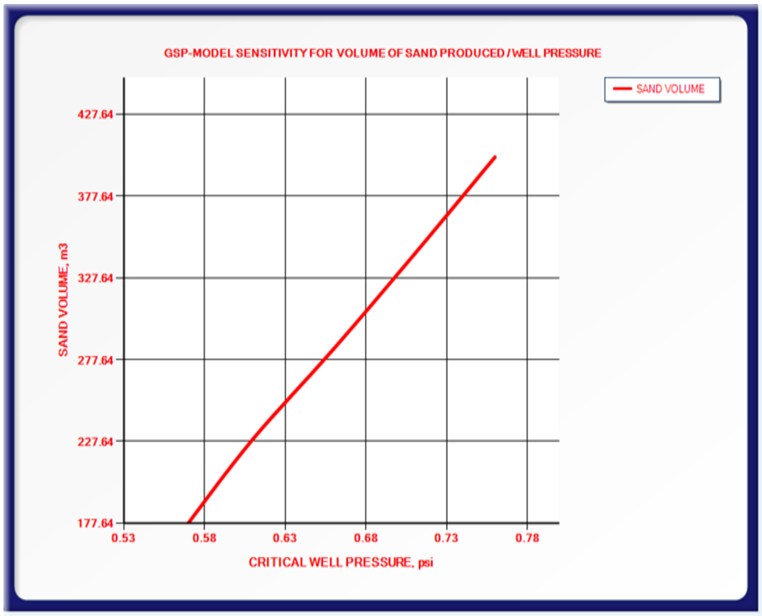

Figure 1: Volume of sand plot

Negative critical pressure indicates there will be no sand produced. The plot on figure 4.1 indicates that sand will be produced with the least critical well pressure of less than 0.58psi producing 177.64m^3 of sand volume, it also ascertains the volume of sand that will be produced pending on the rise or fall of the critical well pressure over a period of time as the well continues to produce. On a general note, an increase in the critical well pressure increases the volume of sand to be produced.

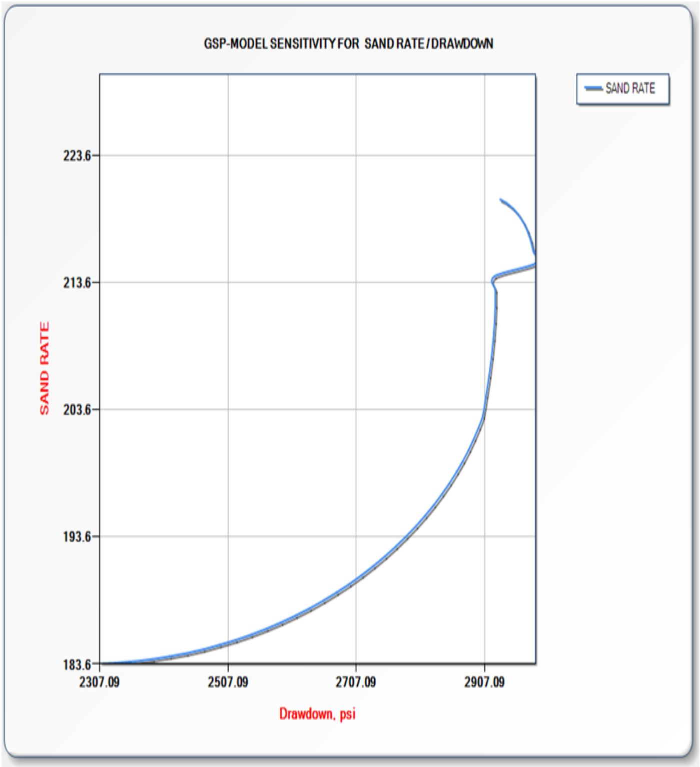

Figure 2: Sand Rate Plot

As expected higher drawdown results in production of higher percentage of sand, this is due to higher drag force separating the fluidized sand from the sand mass leading to sand production. The result on the pressure drawdown shows that for an excavated rock, the rate at which sand would be produced remains relatively constant over a period of time within a certain pressure range and then a considerable higher rate will be experienced when a higher drawdown pressure is applied. From figure 4.2 at a drawdown pressure of 2507psi, the sand production rate was 184.6.

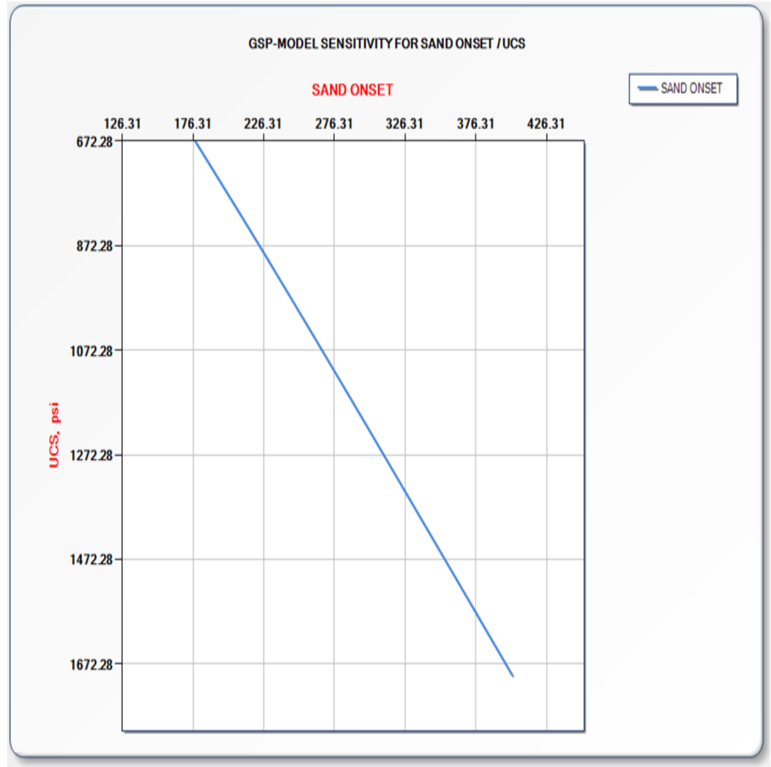

Figure 3: Sand Onset Plot

Uniaxial Compressive Strength (UCS) helps to determine the strength of the core sample by ascertaining the point at which the rock will fail. Once this happen, the integrity of the rock is questioned. From the plot, the reservoir rock was able to withstand the USC pressure until a little above 176.31psi when the rock gave way. This point of failure can be used to predict when the reservoir is likely to start producing sand.

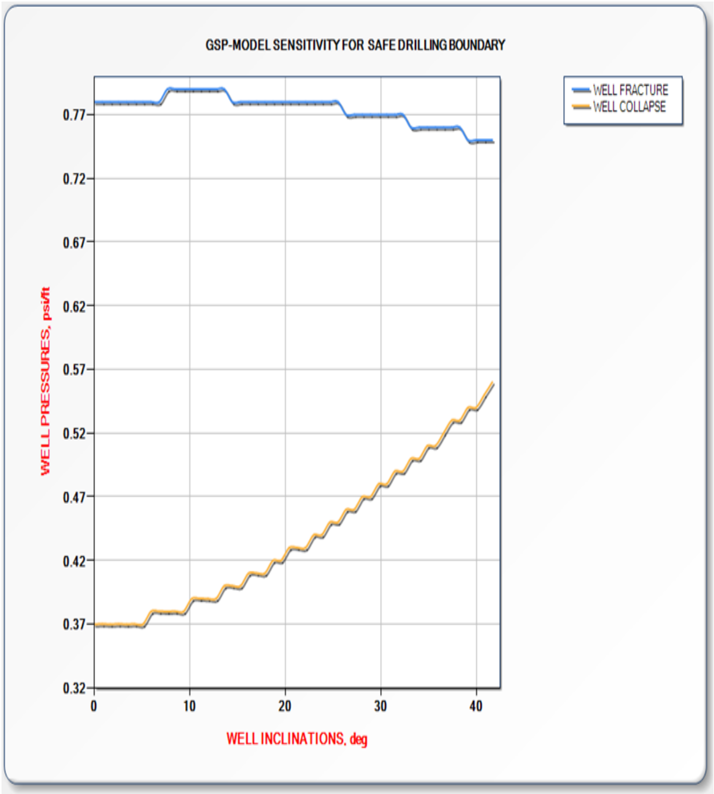

Figure 4: Safe Drilling Boundary plot

This shows that the required mud weight should be between the collapse pressure (lower bound) and the fracture pressure (upper bound). This is important to ensure a good wellbore stability and a safe drilling process. From figure 4.4 it is seen that at a well inclination of 20 degree, a mud window between 0.42 to 0.77psi/ft. Much work has be done in this area, for further knowledge, refer to Prof Adewale Dosunmu publications on Petroleum Geomechanics and Wellbore Stability.

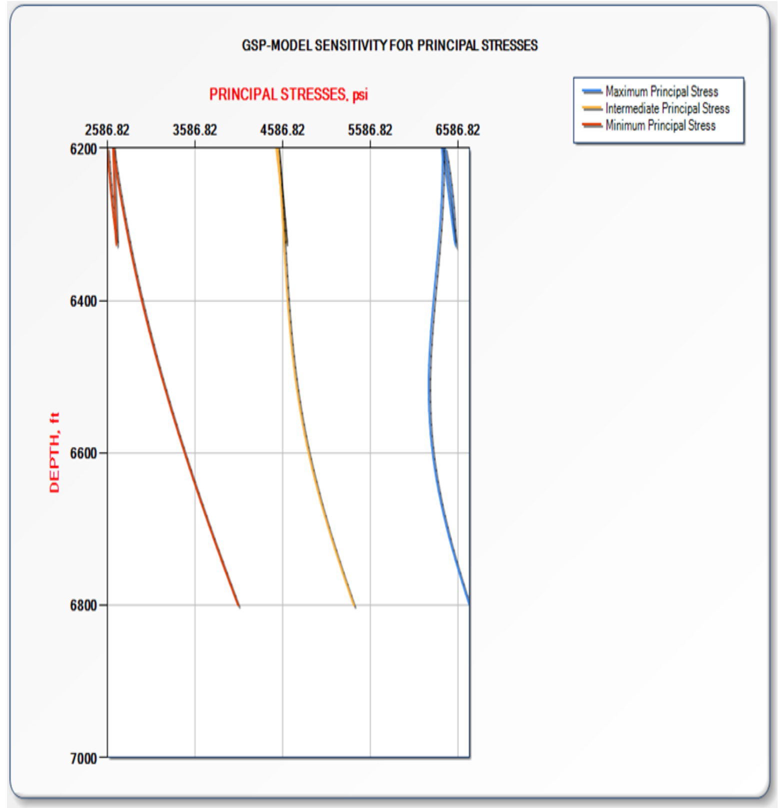

Figure 5: Principal Stresses Plot

To help prevent perforation tunnel failure, it is important that stresses around the wellbore be put into consideration. When the perforation tunnels are shot in the direction of maximum horizontal stress, the reservoir allows smaller bottomhole flowing pressure. This demonstrates that perforating in the direction of maximum horizontal stress reduces the risk of sanding. Considering the figure 4.5 if the depth of perforation is at 6600ft, the best pressure that should be used in perforating the guns should be between the ranges of 5586psi to 6586psi.

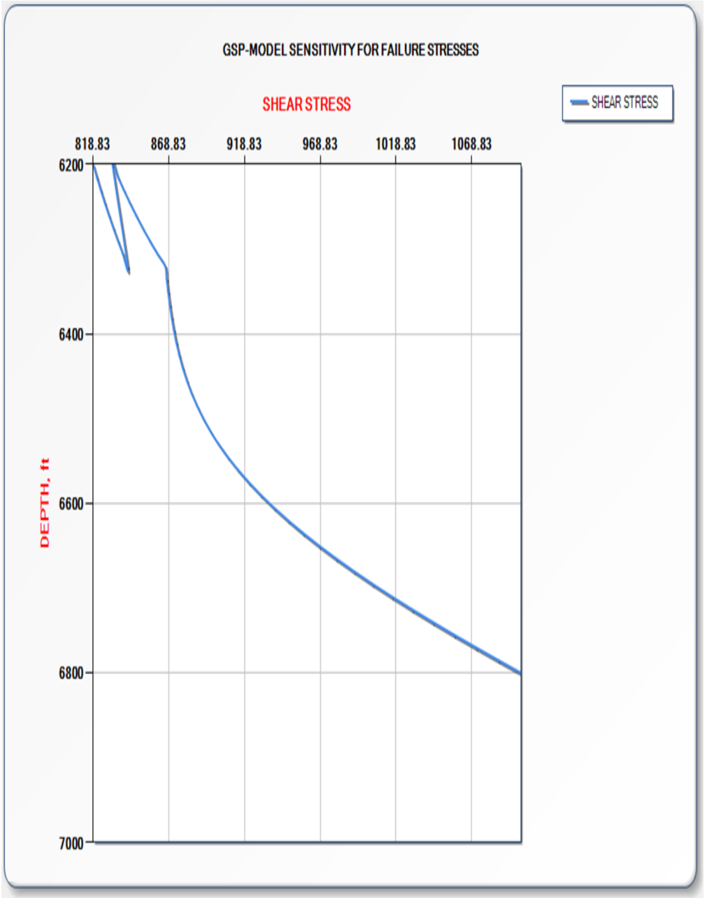

Figure 6: Stress Sensitivity Plot

As we go deeper into the formation, it becomes more compacted and consolidated, hence, requires more pressure/stress before the rock will fail as the grains are more tightly cemented together. From the plot, you will observe that at lower depth, it requires less shear stress for the rock to fail and more at higher depth. For example, at depth 6650ft, the rock gave way when a pressure of 968.83psia was applied whereas at 6800ft, it took a higher pressure of over 1060.83psia to shear the rock.

V. CONCLUSION

Every field, every well and every production plan is different and should be assessed case by case basis.

Integrating solids production assessment in the workflow of field development planning study is a rational safeguard against potential undesirable sand production interruption in the oil and gas industry which requires; ***geomechanics modeling, rock testing and production planning.***

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