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Effective Well operations in the Niger Delta using static and dynamic rock property correlations

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Abstract — The knowledge of the rock strength in the Niger delta field is essential in reducing problems that occur during drilling operations. The problems include; use of inaccurate drilling bit as well as casing, incorrect mud weight prediction for drilling operations which have resulted to wellbore instability problems faced in the Oil and Gas industry. It is therefore very expedient that we obtain more reliable correlation to determine uniaxial compressive strength (UCS) of the rock from log data for Niger Delta field. This will help to quickly carryout rock strength predictions for better well planning as well as on the field during drilling. In this work, we generated correlation to determine UCS from data obtained from 35 wells in various locations in the Niger Delta. The correlation of UCS versus young's modulus gave R^2 - value of 73.1% and multiple R-value of 77% showing a strong positive relationship between the data set. The correlation of UCS versus compressive velocity/transit time gave R^2 - value of 67.2% and multiple R-value of 74.3% also signifying strong positive relationship between the data set. These correlations will therefore assist well engineers in predicting rock strength during well planning and drilling operations so as to ensure optimum wellbore stability management.

Index Terms— Compressive velocity/Transit time, Uniaxial compressive strength, Wellbore stability management, Well planning, Young's modulus

1 Introduction

At every stage of the drilling operation, it is essential to consider wellbore stability in order to avoid problems which could lead to non-productive time (NPT) experienced during drilling. Wellbore instability problem during exploration and development in drilling operations cost the oil and gas industry more than $100 million per month worldwide and possibly as much as one billion dollars annually and more depending on the severity of the problem encountered. The time lost in solving these problems account for over 40 % of all drilling related NPT (York et al. 2009; Zhang et al. 2009). It is therefore important in drilling to have good knowledge of the in situ stresses in order to avoid wellbore instability problems.

The determination of in situ stresses is crucial in maintaining hole integrity and stability in order to avoid drilling problems. Rock mechanical properties analysis enhances the drilling process by integrating petro physical parameters to enhance drilling operations and avoid wellbore stability problems. The determination of reservoir rock mechanical properties is critical in reducing drilling risk and maximizing well and reservoir productivity.

Static and dynamic elastic parameters are important rock properties that are essential in determining the processes that take place in the reservoir. In most cases, dynamic and static elastic parameters are different for the same rock. Static elastic parameters are obtained in the laboratory by measuring the deformation of rocks when subjected to pressure while dynamic elastic parameters are obtained from acoustic velocity transformation in the rocks. The static elastic mechanics parameters are costly, difficult to obtain, and time-consuming, especially under reservoir conditions (including formation temperature and pressure) and are determined in the laboratory.

A large number of experimental core data is required to accurately describe the mechanical rock properties of the reservoir. It can be obtained continuously with depth by the dynamic method (including well logging method and seismic prospecting method) and it is easier to obtain the characteristics of the reservoir rock using this method.

2 LITERATURE REVIEW

The determination of geomechanical parameters such as uniaxial compressive strength (UCS), modulus of elasticity (E), tensile strength, angle of internal friction (ˆ) are very essential inorder to evaluate problems, such as wellbore instabilities, breakouts during drilling, possibility of producing sand in the well and surface subsidence (Zoback et al., 2003; Collins, 2002; Guo et al., 2007; Moos et al., 2003;). Though several works have been done in this area to measure mechanical parameters in the well during drilling, it is important to carry out laboratory experiments to obtain more reliable and accurate results. Also, laboratory tests are often used to calibrate rock properties from other information sources like petrophysical properties or well logs data. It is also essential to have high-quality core samples in order to obtain accurate and precise values. However, in drilling an oil and gas well, coring is an expensive and time consuming operation in which the core samples cannot always be extracted from incompetent, highly fractured and thin layers or block-in-matrix rocks (Gokceoglu et al., 2002). In practice, many geomechanical problems in reservoirs must be addressed when core samples are unavailable for laboratory testing.

2.1 Geomechanical Rock Strength Determination

In the work done by Xu et al (2016) in which they carried out analysis on elastic characteristics of sand stone and shale based on petrophysical tests, they discovered that tight gas reservoir in the fifth member of the Xujiahe Formation contains heterogeneous interlayers of sandstone and shale which have low porosity and permeability. The test they carried out showed that the sandstone and mud stone samples have different stress-strain relationships with tendency to exhibit elastic-plastic deformation and the compressive strength correlates with confinement pressure and elastic modulus. The results obtained from the analysis based on thin-bed log interpretation match dynamic Young's modulus and Poisson's ratio predicted by theory. The compressive strength was calculated from density, elastic impedance, and clay contents while the tensile strength was calibrated using compressive strength and the shear strength was calculated with an empirical formula. Zisman (1933) in his work stated that the dynamic modulus is always greater than the static modulus which he inferred from his measurements on two limestone samples from Pennsylvania and southwest Persia. The difference was attributed to the presence of cavities and cracks between the crystals of the rock which concur to results of static and dynamic moduli in unjacketed test (the rock opened to confining fluid) he carried out. In his work, he observed that the difference is high at low pressure and decreases with increasing pressure, suggesting that most of the cracks are closed at high pressure.

2.2 Rock Geomechanical properties

Several problems encountered during oil and gas drilling operations such as stuck pipe, sloughing shale etc are attributed to poor understanding of the geomechanical properties of the rock and good knowledge of these rock properties will help in solving these problems. A rock geomechanical analysis must therefore be carried out on rock samples at depth of interest in the laboratory using triaxial set-up. It is important to preserve the reservoir rock samples taken from the well site for laboratory experiment by placing them under temperature and pressure conditions that will not alter their original properties. This must be ensured to generate reliable mechanical rock properties results as poor preservation can alter them and invalidate the test.

The uniaxial compressive strength (UCS) and elastic properties of rocks such as Poisson's ratio and Young's modulus are widely used in estimating in-situ stresses, wellbore stability analysis, reservoir compaction survey and prediction of optimum drilling mud pressure (Chang et al., 2006; Abdulraheem et al., 2009). Dynamic and static methods are used to measure elastic properties of rocks while the uniaxial compressive strength (UCS) is obtained from the static method. In dynamic method, compressional and shear velocities may be measured in the laboratory or field from logs, and the elastic properties are determined accordingly. In most cases, the values of the elastic parameters generated from static and dynamic methods are different. From literature, the value of the dynamic elastic parameter is greater than that of the static elastic parameter because static parameter values are affected by the presence of pores and cracks in the rock (Fjaer et al., 2013). The measurement of static elastic parameters is more difficult than dynamic parameters because the static parameters tests are conducted on good quality rock core specimens that may not be available in all wells. Dynamic elastic parameters are generated using ultrasonic tests on core samples or acquired from well log data. It is important to determine the empirical relationship between dynamic and static parameter for continuous and reliable prediction of mechanical properties of rocks along a wellbore.

Rock mechanical parameters such as uniaxial compressive strength (UCS), Young's modulus (E) and Poisson's ratio (v) helps to determine the rock strength and elastic properties which are needed for reservoir geomechanical modeling. In carrying out static measurements, the rock is loaded uniaxially or triaxially until the failure occurs and the stress, lateral and axial deformation are recorded continuously. The uniaxial compressive strength (UCS), static Young's modulus (E_s) and Poisson's ratio are determined using the stress and strain data. In the dynamic method, the rock specimen is affected by the dynamic load of wave propagation and compressional and shear wave velocities (V_p and V_s, respectively) are measured in the laboratory or in the field (sonic logs).

The dynamic Young's modulus (E_d) and Poisson's ratio (v) are determined using the laboratory or sonic log data from density, V_p and V_s as shown below (Asef and Najibi, 2013):

$$E_d = \rho V_s^2 \{(3V_s^2 - 4V_s^2)/(V_s^2 - V_p^2)\} \qquad 1$$

$$\upsilon = \frac{\left(V_p^2 \big/ V_s^2\right) - 2}{\left(V_p^2 \big/ V_s^2\right) - 1} \qquad 2$$

The static parameters are more realistic and lower than the corresponding dynamic data due to pore pressure, cementation, stress-strain rate and the amplitude. However, there are no general mathematical relations between the static and dynamic data. Hence, empirical relations between UCS and static Young's modulus with dynamic data in a variety of lithologies are reported in the literature (Najibi et al., 2015).

3.0 Methodology

The experimental procedure adopted in this work involves; the acquisition of log data to obtain rock parameters such as the compressive velocity/transit time and the young's modulus and to carryout laboratory experiment on obtained core samples to determine the strength. This work will carryout graphical analysis of rock data plotted and evaluating the correlations for the Niger Delta.

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3.1 Geomechanical Rock Properties Measurement

The measurement of rock mechanical properties of the core sample rock will provide useful information about the formation which will assist in carrying out studies for effective wellbore stability management. In this work the rock mechanical properties obtained include elastic properties such as Young's modulus (E), and uniaxial compressive strength (UCS) of the formation. The dynamic property data are obtained for logs while the rock strength (UCS) is determined from the laboratory. This work helps to establish the relationship between the static and dynamic elastic properties for the Niger Delta field.

3.2 Procedure to evaluate rock mechanical properties

The procedure adopted for this study in order to analyze the rock mechanical properties is shown below.

- Acquisition of log data from different wells in the Niger Delta field.
- Validate data used for the study and ensure profile corresponds to that developed in other regions of the world.
- Statistical evaluation of data for the study.
- Graphical analysis of rock geomechanical data plotted and evaluating the correlations.

4.0 Results and Discussion

The result of unconfined compressive strength (UCS) for log data obtained from over 30 wells in the Niger Delta fields helps to estimate the rock strength for better well planning.

The results from the plot of the unconfined compressive strength (UCS) and compressive velocity/transit time showed that there is an increase in the wave velocity in the rock decreases as the strength of the rock increases. There R^2 of 67.2 obtained from the log shows that we can actually use this correlation to quickly predict the value of rock strength for planning in order to obtain important parameters of the rock for the Niger Delta field. The multiple R- value of 0.743 shows strong positive relationship between Compressive velocity and UCS which tends close to 1, when log values are used to determine the value of the uniaxial compressive strength (UCS).

$$UCS = 3*10^8 * \Delta t^{-3.26} \quad (2)$$

Table 1: The Niger Delta rock compressive strength and compressional velocity

Unconfined Compressive strength UCS(Log) MPa	Compressional Sonic velocity (µs/ft)
13.0	146.1
30.4	134.3
24.8	129.2
58.6	124.4
48.9	134.8
27.5	131.8
25.7	180.1
39.5	121.9
47.8	120.6
63.6	117.8
42.4	117.4
61.2	119.7
40.5	121.5
56.9	126.2
45.6	120.5
57.4	109.6
47.2	115.2
55.5	119.7
68.7	107.8
71.1	116.9
108.0	109.5
70.6	110.2
88.7	106.6
81.3	106.4
87.4	104.2
100.9	102.8
118.3	105.1
108.2	106.3
68.9	100.1
108.7	105.0
75.3	103.5
100.5	100.4
71.8	102.1
73.9	107.3
78.4	96.3
106.7	106.8
94.7	104.4

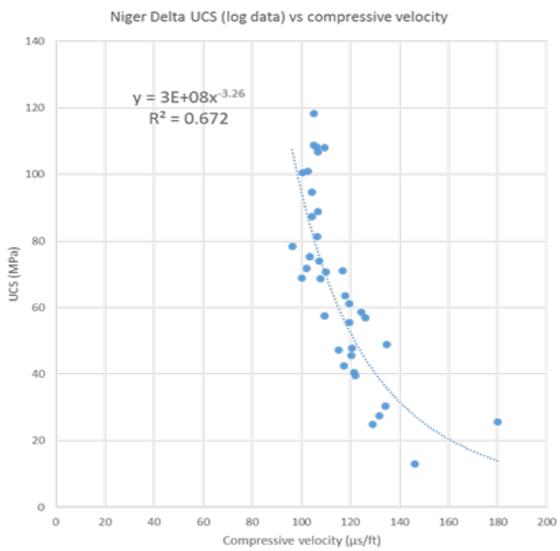


Figure 1: Plot of Niger Delta UCS vs Compressional velocity

The results from the plot of the unconfined compressive strength (UCS) and young's modulus showed that as increase the young's modulus increases, the strength of the rock increases. There R^2 of 73.1% obtained from the log shows that we can actually use this correlation to quickly predict the value of rock strength from young's modulus value for well planning purposes for the Niger Delta field. The multiple R-value of 0.771 shows strong positive relationship between Compressive velocity and UCS which tends close to 1, when log values are used to determine the value of the uniaxial compressive strength (UCS).

$$UCS = 8.0991 * v^{0.9429}$$

Table 2: The Niger Delta rock compressive strength and young's modulus

Unconfined Compressive strength UCS (MPa)	Young Modulus E(GPa)
13.0	2.127
30.4	4.051
24.8	4.676
58.6	9.031
48.9	6.122
27.5	4.665
25.7	5.058
39.5	5.761
47.8	7.142
63.6	4.779
42.4	5.761
61.2	7.346
40.5	8.426
56.9	6.120
45.6	7.965
57.4	8.669
47.2	7.874
55.5	7.987
68.7	7.178
71.1	7.168
108.0	11.290
70.6	9.214
88.7	8.891
81.3	13.503
87.4	8.825
100.9	11.093
118.3	10.168
108.2	11.217
68.9	12.623
108.7	14.793
75.3	13.526
100.5	13.526
71.8	13.637
73.9	13.590
78.4	15.608
106.7	12.559
94.7	15.263
13.0	13.606

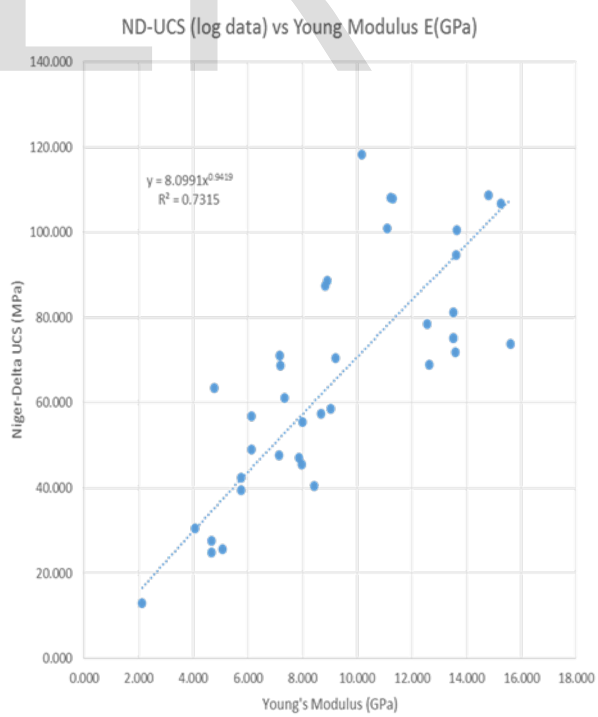
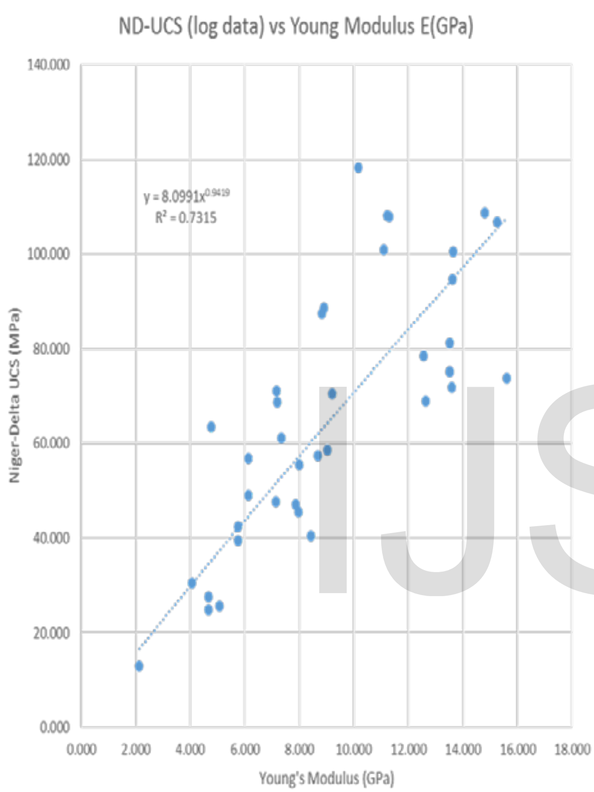


Figure 2: Plot of Niger Delta UCS vs Young's Modulus

5 CONCLUSION

In this study, correlations obtained from the compressive strength and the young's modulus will help to deduce the strength of the rock for the Niger Delta Field. The young's modulus correlation gives better Uniaxial compressive strength (UCS) value determination considering the higher R^2 value of the data used but the compressive velocity correlation could be useful in cases where the young's modulus data is not attainable. This provides a quick way of obtaining the rock strength for the Niger Delta region during well planning stage especially for mud formulation purposes for effectine wellbore management.



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