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Wellbore Design and Optimization through Rock Properties Analysis and Evaluation

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Abstract- There are numerous problems encountered during drilling such as wellbore instability, drilling mud weight estimation, as well as selecting good casing and bit for the drilling operations. It is therefore important to understand and accurately determine the strength of the rock in order to avoid these common drilling problems which are mostly encountered during well operations. It is of paramount importance to determine uniaxial compressive strength (UCS) from core and log data so as to accurately predict rock strength for better well planning. In this work, we were able to obtain a correlation to determine UCS from data obtained from 30 wells in different locations in the Niger Delta region. The correlation of UCS versus Poisson's ratio gave R^2 value of 91.0%. The R^2- value tending towards 1 indicates that the regresson equation from this model can reliably predict ND-UCS and the $p<0.05$ shows that there is significant relationship between ND-UCS and Poisson's ratio. These correlations will help well engineers to make informed decisions on the prediction of the rock strength during well planning and operations as well as manage wellbore stability optimally.

Index Terms— Poisson's ratio, Uniaxial compressive strength, Wellbore stability management, Core data.

1.0 INTRODUCTION

A lot of work have been carried out in order to establish relationship between dynamic and static elastic parameters (including Young's modulus and Poisson's ratio), and it was demonstrated that dynamic Young's modulus is one to ten times larger than static Young's modulus, and there is a good correlation between static and dynamic Young's modulus (Zisman, 1933) The conversion factor of dynamic and static Young's modulus varies from one region of the world to another. In order to establish suitable transformation model between dynamic and static elastic parameters for a reservoir, it is important to carry out laboratory experiment on core samples so as to obtain the relationship between dynamic and static elastic parameters under reservoir conditions. The objective of this work is to optimize wellbore design through rock properties analysis and evaluation which will help in better well planning to ensure efficient wellbore stability management.

In solving wellbore instability problems, it is essential to study the various activities of the drilling operations and make good assessment of elastic properties of the rock formation. These properties are mostly determined under laboratory conditions on core samples and are used directly or modified to solve well problems. In carrying out proper drilling design, production program and well completion, it is crucial to consider the quantitative characterization of the reservoir rock mechanical properties such as compressive strength, Young's modulus, and Poisson's ratio, which are essential in studying wellbore instability, fracture prediction, and other drilling problems that may be faced during operations.

Static methods are generally conducted in the laboratory with specific test equipment which contains core specimens that undergo continuous compression until failure occurs. Stress-strain curves are simultaneously recorded from a computer and mechanical parameters obtained from the generated curves. Dynamic method entails calculations of mechanical parameters from compressional wave velocities (V_P) and shear wave velocities (V_S) that are obtained from logs or in the laboratory studies. Static methods are more direct and realistic, while dynamic methods are easier and more continuous therefore; comprehensive data on rock mechanical properties can be obtained from both laboratory experiments and well logs.

2.0 LITERATURE REVIEW

Lora et al (2016) carried out an experimental work to obtain geomechanical properties of Marcellus Shale through isotropic rock compression and tri-axial test. In their work, they studied rock responses to deformation and failure under different temperature and stress conditions from tri-axial tests. They also examined reservoir conditions and material properties that govern the geomechanical behavior of shale formations under in situ conditions which is of vital importance for geomechanical applications. The laboratory results from their work showed significant non-linear and pressure-dependent mechanical response as a consequence of the rock properties and occurrence of micro cracks in the shale formation. Moreover, the triaxial tests done was useful in obtaining failure envelopes and the anisotropic nature of Marcellus Shale was successfully characterized using a three-parameter coupled model.

Xu et al (2016) carried out an 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. From the test they carried out, it was discovered 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 work carried out by work Sukplum et al., 2014 established a relationship between the dynamic and static behaviors of Phu Kradung Formation Sandstone at different applied axial stress levels. The experiment was done at confining pressures of 0, 6, 12, 20, 30 MPa to obtain the compressive strength and deformation modulus. Also, in the experimental work done for the unconfined compression strength (UCS), electrical gauges were used to measure the axial and lateral deformations, while mechanical gauge and oil volume change were used for confined compression measurements. The ultrasonic waves were step measured on the rock at hydrostatic stress fields and applied compression stress level at 50 and 75 percentages of their strength under that confining stress series. The core samples were oriented at perpendicular cross lamination (0^0) and parallel (90^0) to the direction axial load was applied, so as to ensure anisotropic observation. At each state stress level, the ratio of ultrasonic wave velocities was obtained. The empirical relationship between ultrasonic wave velocities and the rock strength, and their dynamic and static elastic modulus were established. This enabled the use of ultrasonic measurement on prediction of the rock strength and deformation characteristic. The results that was obtained showed that the ultrasonic wave velocities, static elastic modulus (E_s) and dynamic elastic modulus(E_d) tend to increase with increasing applied stresses. A mathematical correlation of elastic modulus to confining stresses of each stress level was established and the effect of cross lamination on the results was also discussed. Though the wave velocities gave good correlation to deformation modulus, only dry condition of the samples was evaluated.

The uniaxial compressive strength (UCS) and elastic properties of rocks such as Poisson's ratio and Young's modulus are widely used to estimate in-situ stresses, wellbore stability analysis, reservoir compaction survey and prediction of optimum drilling mud pressure (Chang et al., 2006; Abdulraheem et al., 2009). 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).

2.1 Rock Strength

Rock strength is the ability of rock to withstand stress without yielding. It is affected by the mineral content of the rock fragments and by the behaviour of the particle contacts. Deposition, diagenesis, and catagenesis are the factors that give the rock its properties, later they are modified by folding, faulting, fracturing, jointing, and weathering. As a result, the strength of rocks reflects their geological background. Rock strength is evaluated by two widely used laboratory methods which include: unconfined compressive strength (UCS) tests, and tri-axial tests.

Unconfined compressive strength (UCS) refers to the strength of a reservoir rock when a compressive force is applied in one direction without lateral constraint. Unconfined compressive strength tests are used to determine the ultimate strength of a rock, which is the highest value of stress reached before the formation fails.

2.2 Unconfined Compressive Strength (UCS)

The Unconfined Compressive Strength (UCS) test is used to determine the strength of a sample. The test is carried out by placing the sample between two platens and a small axial load of approximately 100N is applied to the sample to properly seat it in the apparatus. Axial load is applied steadily and continuously without shock until the load becomes constant, reduces or a predetermined amount of strain is achieved. This axial load is applied so as to produce a constant strain rate. The strain rate should produce failure in a time between 2 to 15 minutes.

The Unconfined Compressive Strength test has a less accurate means of strain measurement when compared with the tri axial test. It is widely used, simple, quick and easy to correlate and it is convenient and suitable for calculating sensitivities. Finally, the cost of carrying out this test is less than that required for a tri-axial test.

In the work done by Lora et al (2016) in Massachusetts Institute of Technology (MIT), they carried out an experimental work to obtain geomechanical properties of Marcellus Shale through isotropic rock compression and tri-axial test. In their work, they studied rock responses to deformation and failure under different temperature and stress conditions from tri-axial tests. They also examined reservoir conditions and material properties that govern the geomechanical behavior of shale formations under in situ conditions which is of vital importance for geomechanical applications.

The laboratory results from their work showed significant non-linear and pressure-dependent mechanical response as a consequence of the rock properties and occurrence of micro cracks in the shale formation. Moreover, the triaxial tests done was useful in obtaining failure envelopes and the anisotropic nature of Marcellus Shale was successfully characterized using a three-parameter coupled model. However, this work did not consider the effect of the drilling fluid on the rock mechanical properties and the bedding planes of the rock which is important when considering the well path during drilling operations.

3.0 Methodology

The experimental procedure adopted in this work involves; the acquisition of log data to obtain rock parameters such as the Poisson's ratio to carryout laboratory experiment on obtained core samples to determine the strength. This work will carry out graphical analysis of uniaxial compressive strength (UCS) data with the corresponding Poisson's ratio data to build a correlation for the Niger Delta.

3.1 Geomechanical Rock Properties Measurement

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

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.

i. Acquisition of Poisson's ratio data from different wells in the Niger Delta field.

ii. Validate data used for the study and ensure profile corresponds to that developed in other regions of the world.

iii. Statistical evaluation of data for the study.

iv. Graphical analysis of rock geomechanical data plotted and evaluating the correlations.

4.0 Results and Discussion

The result of unconfined compressive strength (UCS) for core 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 Poisson's ratio showed that as the Poisson's ratio increases, there is a corresponding decrease in the strength of the rock for Niger Delta region. The R^2 of 91.0% obtained from the core data shows that we can actually use this correlation to predict the value of rock strength from Poisson's ratio value for well planning purposes for the Niger Delta field.

Therefore, we can conclude that there is a good relationship between ND-UCS and Poisson's ratio which tends to 1, when core values are used to determine the value of the uniaxial compressive strength (UCS).

$$UCS = 26.1 - (56.05 * Poisson's\,ratio)$$

Table 1: The Niger Delta rock compressive strength and Poisson's ratio

ND-UCS (MPa) (From Core sample)	Poisson's ratio
12.0	0.261
14.6	0.231
8.50	0.308
9.00	0.318
7.40	0.325
6.80	0.325
7.00	0.330
6.80	0.330
6.00	0.350
5.40	0.340
4.20	0.390
3.30	0.410
4.50	0.374
5.80	0.390
5.50	0.394
4.20	0.394
5.50	0.394
2.50	0.400
3.00	0.400
3.00	0.412
4.00	0.400
2.20	0.430

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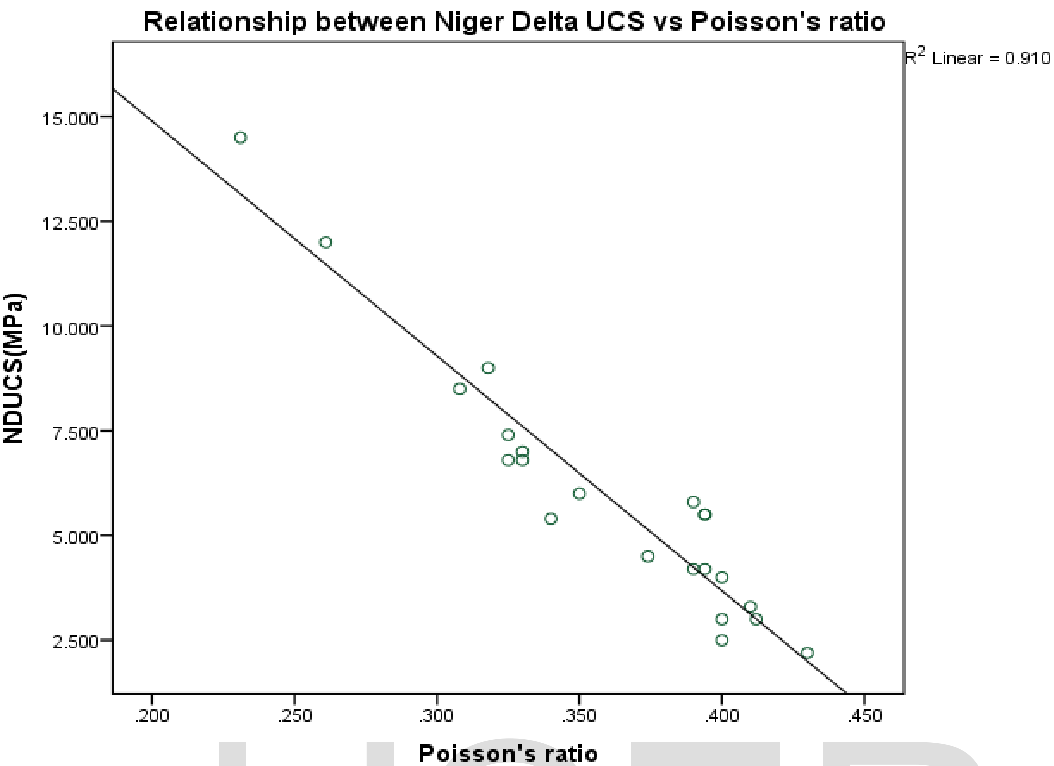

Figure 1: Plot of Niger Delta UCS vs Poisson's ratio

Model Summary[b]

					Change Statistics					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	.954a	.910	.906	.932481	.910	202.321	1	20	.000	1.586

a. Predictors: (Constant), Poisson's ratio
b. Dependent Variable: NDUCS(MPa)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	175.923	1	175.923	202.321	.000b
	Residual	17.390	20	.870		
	Total	193.313	21			

a. Dependent Variable: NDUCS(MPa)
b. Predictors: (Constant), Poisson's ratio

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	26.098	1.430		18.254	.000
	Poisson's ratio	-56.039	3.940	-.954	-14.224	.000

a. Dependent Variable: NDUCS (MPa)

The R^2 - value obtained from the model shows that the linear model explains 91.0% of the variation in Niger Delta UCS (MPa). The R^2- value tending towards 1 indicates that the regresson equation from this model can reliably predict ND-UCS and the $p<0.05$ means there is significant relationship between ND-UCS and Poisson's ratio.

The B-value on the regression coefficients table shows that any 1 unit increase in Poisson's ratio would lead to 56.04 decrease in ND-UCS (MPa) which can also be seen from the equation.

ND-UCS = 26.1 – (56.05*Poisson's ratio)

5. CONCLUSION

In this study, correlations obtained from the compressive strength and the Poisson's ratio can help to deduce the strength of the rock. The Poisson's ratio correlation gives good Uniaxial compressive strength (UCS) value determination considering the higher R^2 value of the data used but the Poisson's ratio correlation could be useful in cases where other log data are unattainable to determine the Uniaxial compressive strength (UCS). This also provides a quick way of obtaining the rock strength for the Niger Delta region during well planning stage especially for mud formulation purposes in order to prevent hole collapse.

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