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RESEARCH ARTICLE

THE STATIC STRESS-STRAIN RATIO MODELLING FROM WELL DATA SATISFYING THE A3-FIELD WELL BORE STABILITY IN THE NIGER DELTA BASIN

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ABSTRACT

The modulus of elasticity is one of the major parameters satisfying well bore stability and it has been modelled to account for this purpose in the A3-Field of the Niger Delta Basin. Three different suites of logs (Q, R and S) were available for this research. Microsoft Excel was used for the data processing and computation of results after due process had been taken to free the data from noise. The results obtained from the three separate data yield $\log E_s = 2.4292 \log E$ from well Q, $\log E_s = 2.4314 \log E$ from well R and $\log E_s = 2.4339 \log E$ from well S. The parameter P, chosen as the local fit constant, shows almost sameness and as such averaged as 2.4315. If the dynamic young's modulus is known, then $\log E_s = 2.4315 \log E$ is adequate for computation of static young's modulus. This result had been tested with the model from Bradford approach although very slight deviation is noted. Bradford case study excluded Niger Delta Basin which could be the reason for this. The coefficients of determination of the three relations strongly established the advantage of P value obtained from this finding. The differences in the coefficients of determination show that this research finding improves the outcome when compared to Bradford constant by 0.0169 for well Q, 0.0031 for well R, 0.0241 for well S, in the Niger Delta basin. These differences are appreciable results needed for accurate prediction of brittleness and stability parameter and development of the oil wells.

KEYWORDS

Model, Young's modulus, Well data, Local fit, Velocity, Sonic.

1. INTRODUCTION

The ratio of stress to strain defines young's modulus. The elastic and strength properties of rocks are important parameters used to evaluate rock brittleness (Li et al., 2015; Grieser and Bray, 2007; Rickman et al., 2008; Guo et al., 2012). This helps to assess the favorability of reservoirs for cracking or fracturing actions. As projected by Grieser and Bray, that the rocks with a high Young's modulus and low Poisson's ratio will be brittle (Grieser and Bray, 2007). Britt and Schoeffler resolved that shale with a static Young's modulus higher than 20.684 GPa will be brittle (Britt and Schoeffler, 2009). Most of researchers have worked on related research and reported that it is more practical to compute brittleness on the basis of mechanical properties of the rock (Ozfirat et al., 2016; Zhang et al., 2018). They made use of Young's modulus, Poisson's ratio and Lame's constant as necessary parameters for their findings. In other study, authors noted that the areas with high Young's modulus and low Poisson's ratio were more productive for hydraulic fracking because of their high brittleness (Rickman et al., 2008). A group researchers also reported that lames' coefficient and shear modulus obtained from density log are another widely-used geophysical method to predict rock brittleness; the zones with small λρ and high μρ are taken as brittle zones (λ is lames' coefficient, ρ is density and μ is shear modulus (Goodway et al., 2010; Perez and Marfurt, 2013). A group researchers have also worked on young's modulus and textural attribute to consider a better technique for static young's modulus for accurate outcome; as at then, Bradford technique was recommended (Atat et al., 2024a).

Models could help explain a system using scientific ideas and language (Saglam-Arslan and Arslan, 2010; Atat et al., 2020d). Since Physics creates an application field for mathematics, modelling is required to connect between real word and mathematics (Atat et al., 2020d; Blum, 2002). If a model (this research outcome) expresses some aspect of the real situation as challenges are being solved, then the goal of this study would be achieved. This model may be adequate to resolve well borehole stability problems (Berry and Houston, 1995). With the exploration and development of oil and gas reservoirs, the growing consequence of hydraulic fracturing leads to the need for a deeper understanding of the mechanical properties. However, well failure rises with depth (that is, wells deeper than 1.5×10^3 m) (Atat et al., 2024a).

1.1 Location and Geology Information

The Niger Delta is one of the regions in Nigeria. It is located between latitudes 3º N and 6º N and longitudes 5º E and 8º E as seen in (Atat et al., 2023a; Umoren et al., 2019; Akpabio et al., 2023b). Rainy (or wet) season and dry seasons are really common every year (George et al., 2017; Atat et al., 2020b; Ejoh et al., 2023; Atat and Umoren, 2016). The region is a major source of hydrocarbon; more than 90% of oil and gas produced in Nigeria comes from the region (Usen, 2003, Atat et al., 2024c). The thickness of sediment is about 500000km^3 (Atat et al., 2020c; Umoren et al., 2023; Umoren et al., 2020). A group researcher noted that the Akata, the Agbada and the Benin Formations are the three lithostratigraphic units observed (Atat et al., 2023b; Akpabio et al., 2023b; Atat et al., 2024b) with the Agbada lying below the Benin formation. The Agbada formation is the

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main oil reservoir in the Niger Delta (Atat et al., 2020d).

2. Theoretical Background

As earlier stated, models which may be seen as tool could help explain a system using scientific ideas and language (Saglam-Arslan and Arslan, 2010). To achieve some models, some other parameters are required like velocity, poisson ratio, shear modulus and young's modulus among others. Some researchers have recommended Equation 1 for young's modulus (dynamic) findings (Atat et al., 2022; Atat et al., 2024b). Moreso, Equations 2 has also been used for determination of poission's ratio (Atat et al., 2020a; Atat et al., 2020b; Atat and Umoren, 2016; Atat et al., 2023a). Equation 3 is adequate for shear modulus evaluation (Atat and Umoren 2016; Akpabio et al., 2023a).

$$E = 2\mu(1 + \sigma) \tag{1}$$

Where E is young's modulus in Nm^{-2}, μ is the shear modulus, σ is the poisson's ratio.

$$\sigma = \frac{\left(\frac{V_p}{V_s}\right)^2 - 2}{2\left(\frac{V_p}{V_s}\right)^2 - 1} \tag{2}$$

Where σ is Poisson's ratio, V_S is Compressional wave velocity, V_s is Shear wave velocity.

$$\mu = \rho V_s^2 \tag{3}$$

V_s is shear wave velocity, ρ is density and μ is the shear modulus.

$$Es = aE^p \tag{4}$$

Where a and p are Bradford's constants, Es is the static young's modulus, E is dynamic young's modulus.

2.1 Sonic log

Sonic log helps to determine the compressional wave velocity. It also measures the transit time of Formation (Atat et al., 2023b).

2.2 Density Log

A zone with higher density describes the number of electrons with greater densities. It really reduces the gamma ray and a lower count rate of GR is noted at the sensors; correspondingly for a zone with low density. A low-density formation decreases the GR less than a zone with high density; consequently, a higher GR count rate is observed (Akpabio et al., 2023b).

2.3 Gamma Ray (GR) Log

Gamma ray log is used to identify lithology. The gamma ray energy emitted from the lithologic units are signatures to the lithology. A scintillation detector in the tool used to detect gamma rays and the numbers detected are recorded in American Petroleum Institute (API). Minerals such as Zircon, Sphene, Monzanite and Allanite are more abundant in shales than sandstones; therefore, shales have higher gamma ray API responses compared to sand (Akpabio et al., 2023b).

3. Methodology

3.1 Materials

A-3 Field data were acquired from the Niger Delta Basin from wells Q, R and S. The generally accepted Microsoft Excel was used for the processing and computation of the data after spurious values had been removed. Depth, gamma ray, density and sonic were obtained, after sand/shale base line had been noted with the gamma ray log. Figure 1 outlines the stages taken to achieve the aim.

3.2 Method

The dependent parameters such as dynamic young's modulus, poisson ratio, shear modulus and static young's modulus from Bradford's recommendation were obtained using Equations 1 to 4 respectively. The study identified sandstones where gamma ray is less than 75 API and considered shale from greater than 75 API for the three wells.

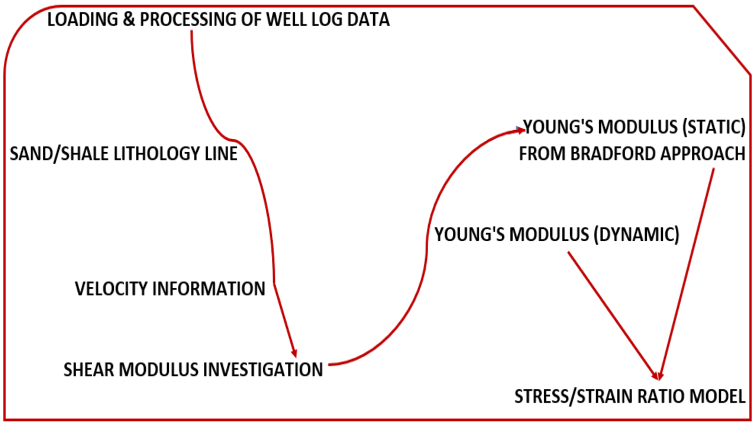

Figure 1: The research workflow

4. Results And Discussion

4.1 Results

Information on the stability of the wellbore is really necessary as failure rate is possible with increase in depth. Research on the stress-strain ratio model is appropriate and important. The outcome of this research is clearly presented in Figures 2 to 4 for well Q, Figures 5 to 7 for well R and Figures 8 to 10 for well S

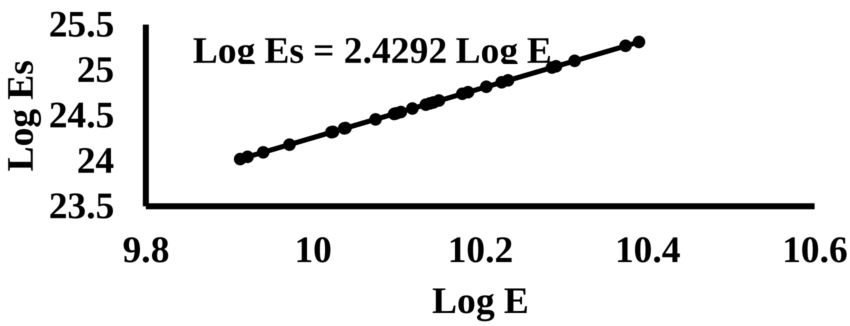

Figure 2: Logarithm relationship of static and dynamic young moduli from Well Q

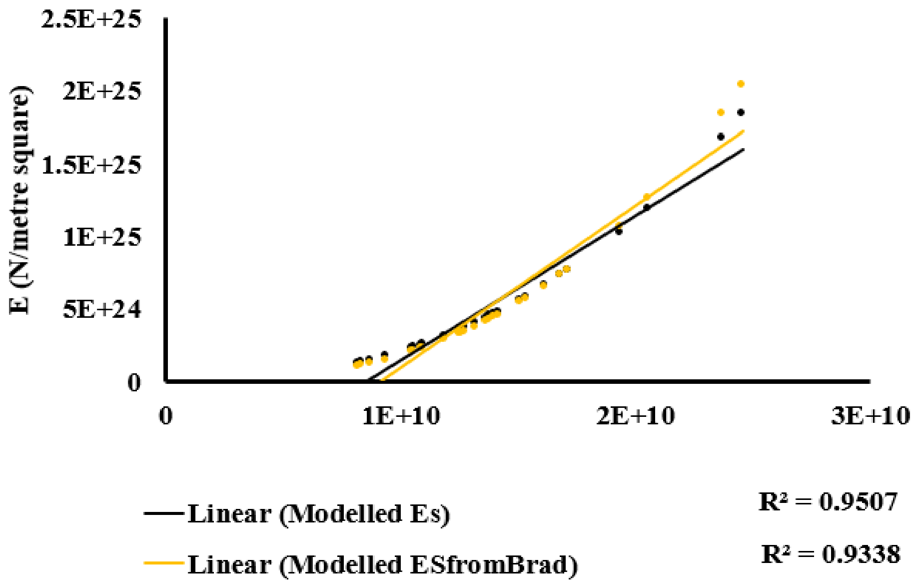

Figure 3: Well Q coefficient of determination outcomes from E-Es curves

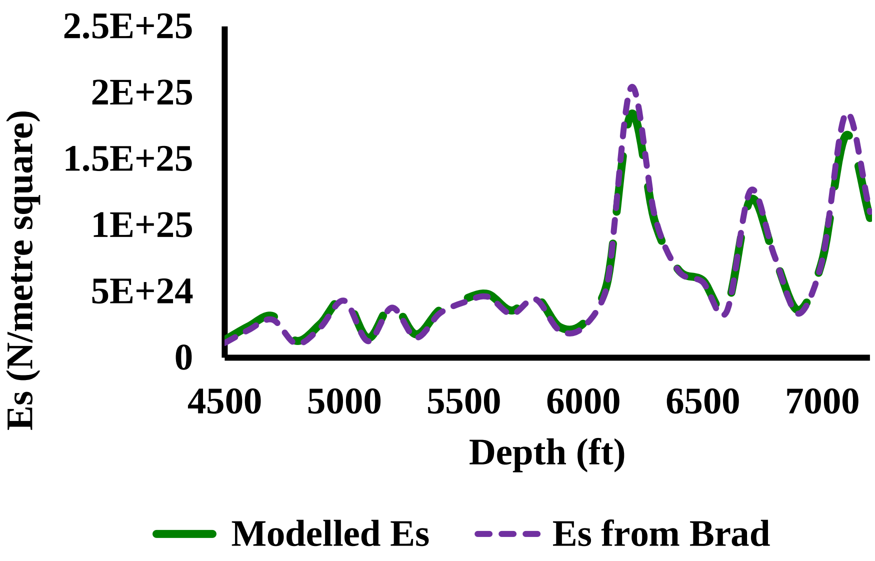

Figure 4: Appreciable variation in Modelled Es and Es from Brad with Depth from well Q

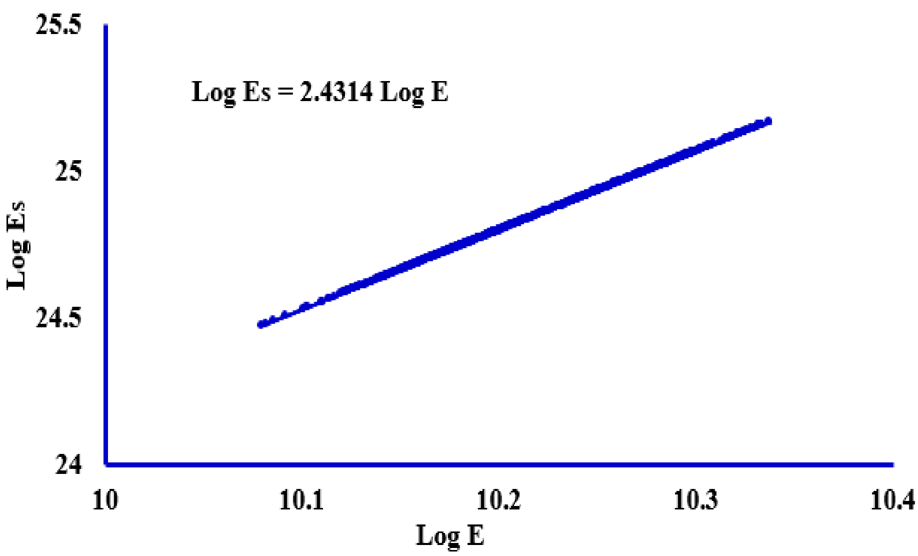

Figure 5: Logarithm relationship of static and dynamic young moduli from Well R

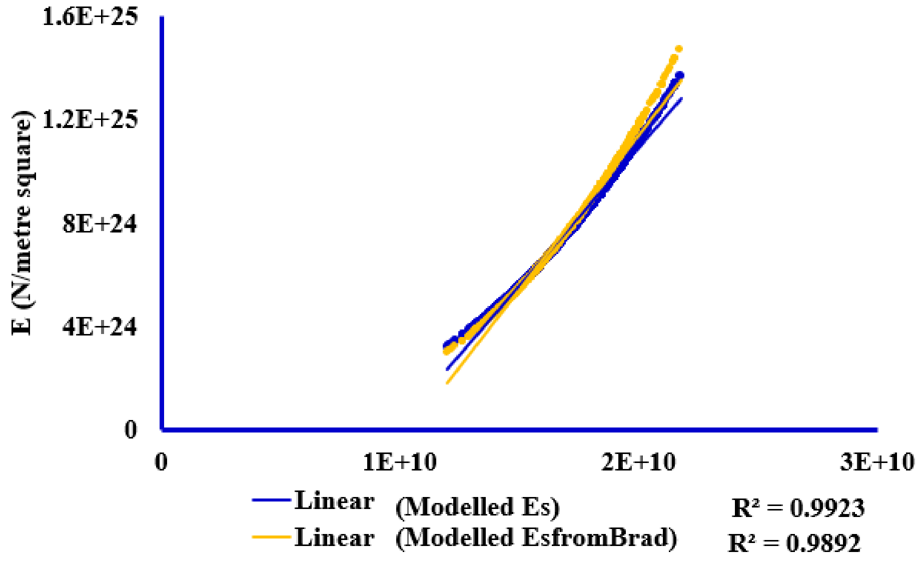

Figure 6: Well R coefficient of determination outcomes from E-Es curves

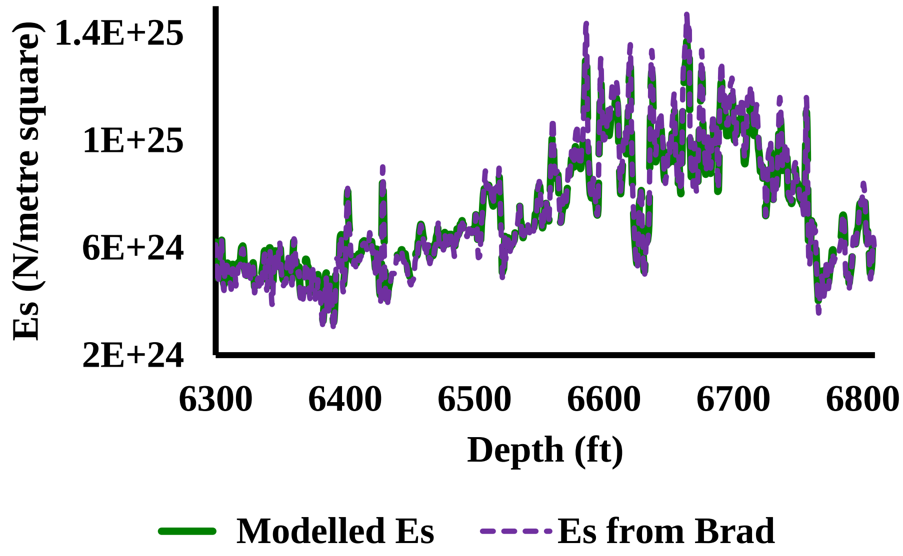

Figure 7: Appreciable variation in Modelled Es and Es from Brad with Depth from well R

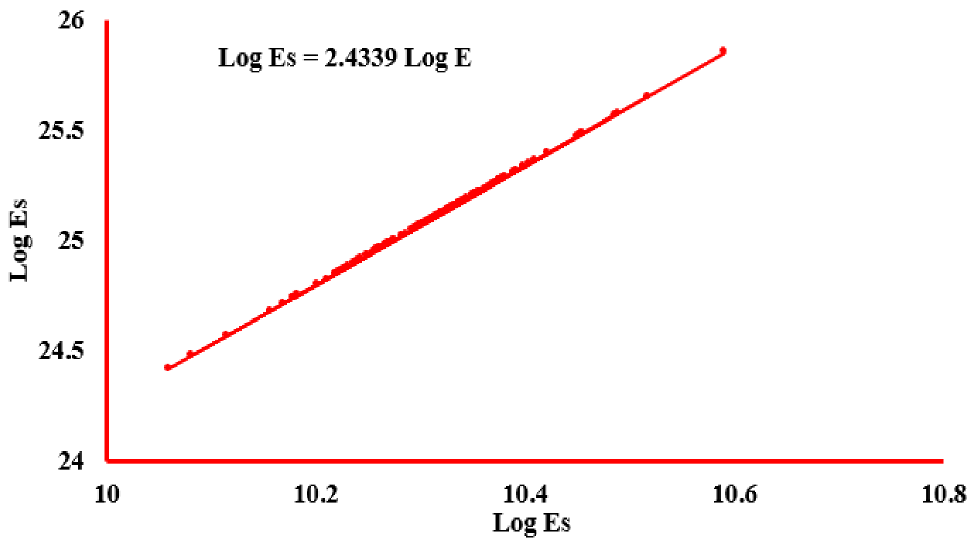

Figure 8: Logarithm relationship of static and dynamic young moduli from Well S

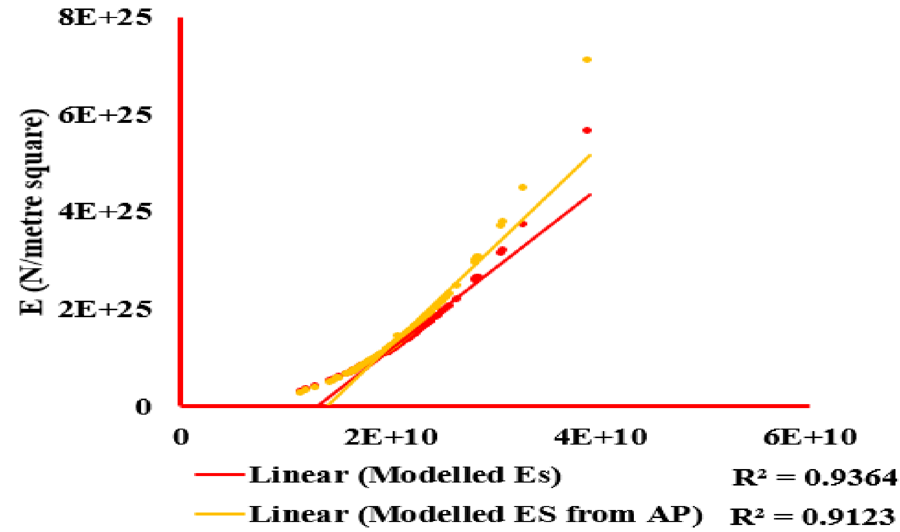

Figure 9: Well S coefficient of determination outcomes from E-Es curves

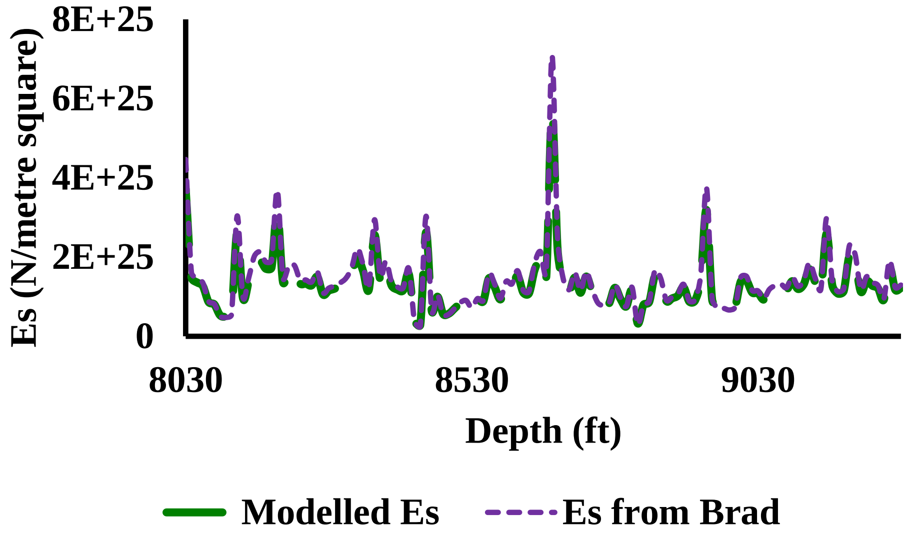

Figure 10: Appreciable variation in Modelled Es and Es from Brad with Depth from well S

4.2 Discussion

Well log data were obtained to conduct this research and the Field data available was that of A-3. Microsoft Excel is generally acceptable for processing of data and computation analyses and it was adequate for this study. Data such as sonic was used to obtain compressional wave velocity and castagna Equation but with local fit of Atat et al., 2021 was used for the determination of shear wave velocity and subsequently, shear modulus. Other parameters noted before the model outcome was established include Vp/Vs ratios, poisson ratios and dynamic young's modulus. Atat et al., 2024 have recommended Bradford approach a better technique for static young's modulus having obtained their findings from the percentile technique which have been used by researchers such as (Atat et al., 2022; Oladipo et al., 2018; Atat et al., 2018; Folk and Ward, 1957; Adedoyin et al., 2022; Atat et al., 2021; Gandhi and Raja, 2014). Having observed that Bradford investigation did not take into account the possible variation from a different basin like Niger Delta, the Authors of this research have decided to embark on this study with the outcome showing appreciable result.

Figures 2, 5 and 8 yield three outcomes which are Equations 5 to 7; the average leads to Equation 8.

$$\log E_s = 2.4292 \log E \quad (5)$$

$$\log E_s = 2.4314 \log E \quad (6)$$

$$\log E_s = 2.4339 \log E \quad (7)$$

$$\log E_s = 2.4315 \log E \quad (8)$$

If an expression is considered such that the value of the average of the coefficient of parameter from the horizontal component is P, then Equation 9 is possible. P is certainly 2.4315.

$$\log E_s = P \log E \quad (9)$$

In order to verify the accuracy of this research finding, this result had been tested with the model from Bradford approach and very slight deviation have been noted (Figures 3, 6 and 9). Bradford case study excluded Niger Delta Basin which could be the reason for this. The coefficients of determination of the three relations strongly established the advantage of P value obtained from this investigation. The differences in the coefficients of determination show that this research finding improves the outcome when compared to Bradford constant by 0.0169 for well Q, 0.0031 for well R, 0.0241 for well S, in the Niger Delta basin. These differences are appreciable results needed for accurate prediction of brittleness and stability parameter and development of the oil wells. Furthermore, Figures 4, 7 and 10 show much higher values from model used by Bradford to the local fit modelled in this study. As far as Niger Basin is concern, Equation 8 is more suitable for investigations related to stress-strain ratio information in the region.

5. Conclusion

As well failure rate rises with depth, a better stress-strain ratio expression would be appreciable if it can supply information that expresses a deeper understanding of the mechanical properties of the well. A model has been obtained which is adequate to resolve well borehole stability problems in the Niger Delta basin. This model has been compared with the technique used by Bradford; the variance seems little but appreciable since the coefficient of determination of the modelled outcome has improved the result of finding than the one of Bradford. These differences account for accurate prediction of brittleness, stability and development of the oil wells in the Field.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

The Authors consent to take part in the research project and the outcome of our study result is this article. The involvement of the Authors is voluntary and they have agreed to publish this finding in Malaysian Journal of Geosciences (MJG) as a research article.

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