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Deriving Pseudo-Static Elastic Moduli from Dynamic Elastic Logs: A Wellbore Stability Analysis in OSA Field, Niger Delta, Nigeria

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ABSTRACT

The problematic effect of sonic logs on the prediction of wellbore stability in the Niger Delta is that accurate predictions are usually compromised by dynamic elastic properties that excessively predict the stiffness of the rock and cause inaccurate estimates of the stress and failure of the rock. This study aims to obtain trustworthy pseudo-static elastic moduli from dynamic elastic well logs using wellbore stability in the OSA Field, Niger Delta, Nigeria. Modulus of Dynamic Young and Poisson ratio values of Dynamic Young that came out of dipole sonic and density logs were reduced to pseudo-static counterparts through existing empirical rock-physics correlations. A one-dimensional Mechanical Earth Model was subsequently developed using these properties to determine in-situ stresses and rock strength parameters. The findings demonstrate that pseudo-static moduli are 25-30% lower than dynamic values and can give more realistic values of stress, fracture gradient and trend of rock strength. The obtained geomechanical model demonstrates that the regime of stress is characterised by the prevalence of horizontal tectonic loading, which regulates the risk of wellbore failure and sand production. This study revealed that pseudo-static elastic characteristics can greatly increase the accuracy of the wellbore stability and drilling design in the OSA Field.

Keywords: Pseudo-Static Moduli; Dynamic Elastic Logs; Wellbore Stability; Well Logs; Mechanical Earth Model; Poisson Ratio; Dynamic Elastic Properties; One-dimensional Geomechanical Model; Geophysical Logs; Dynamic Young modulus; OSA Field.

1. Introduction

The study of wellbore stability is one of the most important parts of petroleum engineering that helps to reduce the risks of borehole collapse, stuck pipes, and sand production, which collectively contribute to the drilling expenses worldwide (Osaki et al., 2019). Jamshidi et al. (2024) noted that one problem that persists in the construction of accurate mechanical earth models (MEMs) to analyse the problem is the upscaling of the dynamic elastic properties obtained after petrophysical logs.

Agbasi et al. (2021) added that sonic and seismic pseudo-static elastic moduli are needed to perform geomechanical simulations, under the influence of long-term and stationary loading. In the Niger Delta basin, which is highly prolific but geomechanically demanding and has its Agbada Formation reservoirs and active growth faults, defining a safe mud weight window is the most important issue of concern to prevent the occurrence of wellbore instability during drilling (Osaki et al, 2021 and Olotu et al., 2022).

In the recent study by Ogbuagu et al. (2025) in the region, geomechanical characterisation has been further achieved, and it is shown that hydrocarbon-bearing sands in the Niger Delta tend to be weak and stiff with respect to brine sands and shales, thus being highly susceptible to deformation.

There is an existence of gap in existing research establishing field-specific correlations to scale dynamic log measurements to pseudo-static moduli to use in wellbore stability applications in this area (Osaki et al., 2018). The purpose of this research is to come up with and confirm the existence of a strong correlation to use dynamic logs to determine pseudo-static elastic moduli in the OSA Field of the Niger Delta.

1.1. Aim and Objectives

This study aimed to obtain trustworthy pseudo-static elastic moduli from dynamic elastic well logs using wellbore stability in the OSA Field, Niger Delta, Nigeria. The objectives are to:

a) Derive pseudo-static elastic moduli from the computed dynamic elastic properties using established empirical rock physics correlations; and

b) Develop a one-dimensional geomechanical model for the OSA Field using the pseudo-static elastic properties to estimate in-situ stresses and rock strength parameters.

░2. Literature Review

The geophysical logs yield dynamic elastic moduli, whereas static moduli needed to assess the wellbore stability are a fundamental problem in the field of geomechanics (Etim et al., 2025). According to Zi et al. (2021), the dynamic moduli, which are determined based on the velocity of sonic waves, characterise the response of rocks to small strain and rapid conditions, and the static moduli, which are determined based on the core stress-strain tests, represent the response of the rock to the slow and large-strain loads occurring during drilling. The importance of this scaling issue is that wellbore stability models that can forecast safe mud weight ranges to avoid wellbore collapse or fracturing depend on precise static properties (Mahdi, 2026). Measurements of direct core are both sparse and expensive, and robust correlations are required to process the vast available dynamic log data into dependable pseudo-static inputs of Mechanical Earth Models (MEMs) (Ajibade et al., 2025).

The empirical research in the Niger Delta highlights geomechanical peculiarities of the region and the need to have field-calibrated correlations. Opara et al. (2021) discovered that the unconsolidated, friable sandstones of the paralic Agbada Formation are a prolific hydrocarbon reservoir, which is subject to unique mechanical behaviour. From their study, Ubuara et al. (2024) found that the sand in the Niger Delta that contains hydrocarbons is found to be weaker, less elastic, and has a higher Poisson ratio than the sand in the brine and shale, thus it is highly susceptible to deformation and sand production. This variability that is lithology dependent implies that standard global correlations to transform dynamic into static moduli are frequently ineffective (Ayyed & Hadi, 2025).

Therefore, an evident research gap is that of coming up with a locally tested correlation of the OSA Field, Niger Delta, Nigeria. Although such studies prove the usefulness of locally obtained correlations, they are field-specific. Thus, this study will directly fill this gap by combining the available well-log data and known rock physics concepts to come up with a calibrated pseudo-static correlation.

░3. Geology of the Location

Three main lithostratigraphic units dominate the OSA Field in the Niger Delta Basin: the upper Benin Formation of continental sands and gravels, the Agbada Formation of alternating paralic sandstones and shales that contain the majority of hydrocarbons, and the lower, over-pressured Akata Formation of mostly marine shales (Uko et al., 2017). Differential compaction of under-compacted shales of OSA Field drives extensive growth faulting and rollover structures in this Tertiary succession, which shows progradation from deep-marine muds to fluvial-deltaic sands (Bate et al., 2023). According to Kalu et al. (2020), the mechanical anisotropy and elastic properties obtained from sonic and density logs are influenced by the sandstone–shale interbeds in the Agbada interval of OSA Field. In order to integrate static stress estimates with in-situ mechanical behaviour, dynamic elastic moduli obtained from logs are essential. They correlate with lithology and porosity variations typical of these paralic deposits.

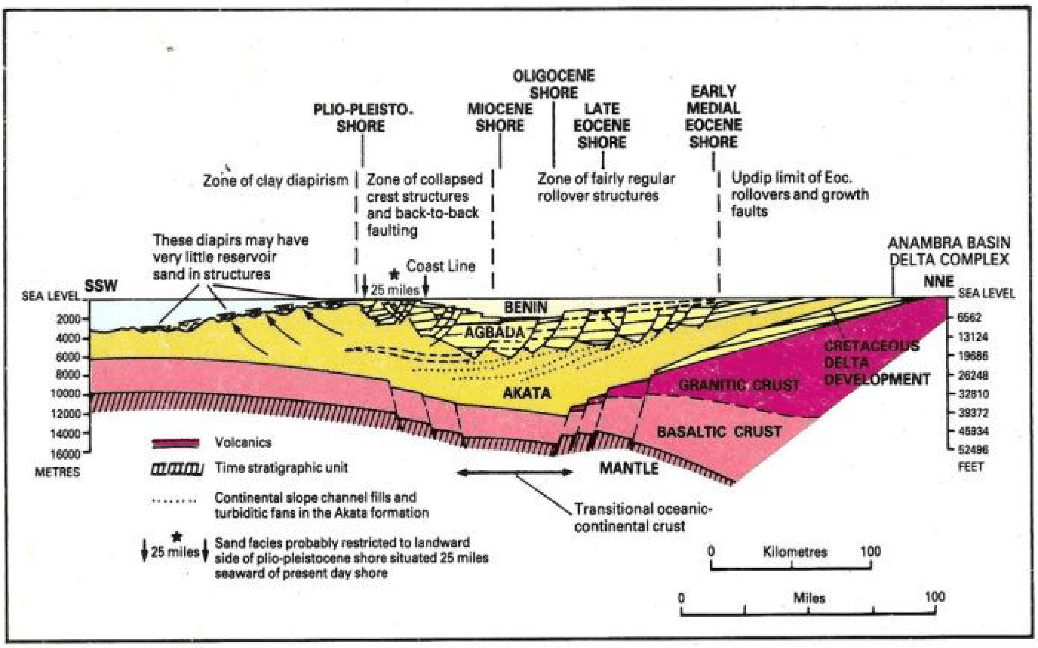

Figure 1. The Map of the Study Area Showing the Sea Level Location of Agbada and Akata Formations in the OSA Oilfield (Source: Uko et al., 2017).

4. Methodology

4.1. Dynamic Elastic Properties

Dynamic elastic properties were computed from sonic and density logs. Compressional wave velocity (Vp) and shear wave velocity (Vs) were obtained from DTp and DTs logs using these parameters:

Young’s Modulus: Young's modulus (E), which is the ratio of stress to strain within the linear elastic region, measures how stiff a material is under dynamic axial loading. It is essential for forecasting vibrational response and structural integrity in engineering applications because it is a fundamental dynamic elastic property that controls how a material deforms under quickly applied forces (Shi et al., 2022).

$$E_d = 2G_d(1-V_d) \qquad (1)$$

Poisson’s Ratio: When a material is dynamically loaded, the ratio of lateral strain to axial strain is described by Poisson's ratio (v), a dynamic elastic property. Acoustic wave velocities in materials are frequently used to calculate the dynamic value. It describes how, during dynamic deformation, a material expands or contracts perpendicular to the direction of the applied force (Siddig et al., 2021).

$$V_d = \frac{V2p-2V2s}{2(V2p-V2s)} \qquad (2)$$

Shear Stress: The internal force per unit area parallel to a material's cross-section under rapid shear or cyclic loading is known as shear stress (τ) in dynamic contexts (Li et al., 2025). It is essential for examining material behaviour under seismic events, vibrations, or other transient torsional forces and is directly related to the dynamic shear modulus (Yu et al., 2026).

$$G_d = \rho V_s^2 \qquad (3)$$

4.2. Conversion of Dynamic Elastic Properties to Pseudo-Static Elastic Moduli

Empirical rock physics correlations are used to compute dynamic properties that yield pseudo-static elastic moduli, which are crucial for applications such as wellbore stability (Jamshidi et al., 2024). This procedure entails building a Mechanical Earth Model (MEM) that combines continuous dynamic data from petrophysical logs with laboratory static measurements from core samples. According to Kruiver et al. (2021) establishing lithology-specific empirical correlations between static moduli from triaxial tests and dynamic moduli computed from acoustic wave velocities is a crucial step in calibrating the well-log data. To account for anisotropy, Hillbrick et al. (2019) gave an example of distinct linear regressions that are created for moduli measured parallel and perpendicular to bedding in anisotropic shale reservoirs. The dynamic logs are then scaled over the whole reservoir interval using these calibrated correlations, creating a continuous profile of pseudo-static elastic moduli for geomechanical analysis (Alrubaye et al., 2026).

The basic steps of how dynamic elastic properties are converted to pseudo-static elastic moduli are presented in Figure 2 below:

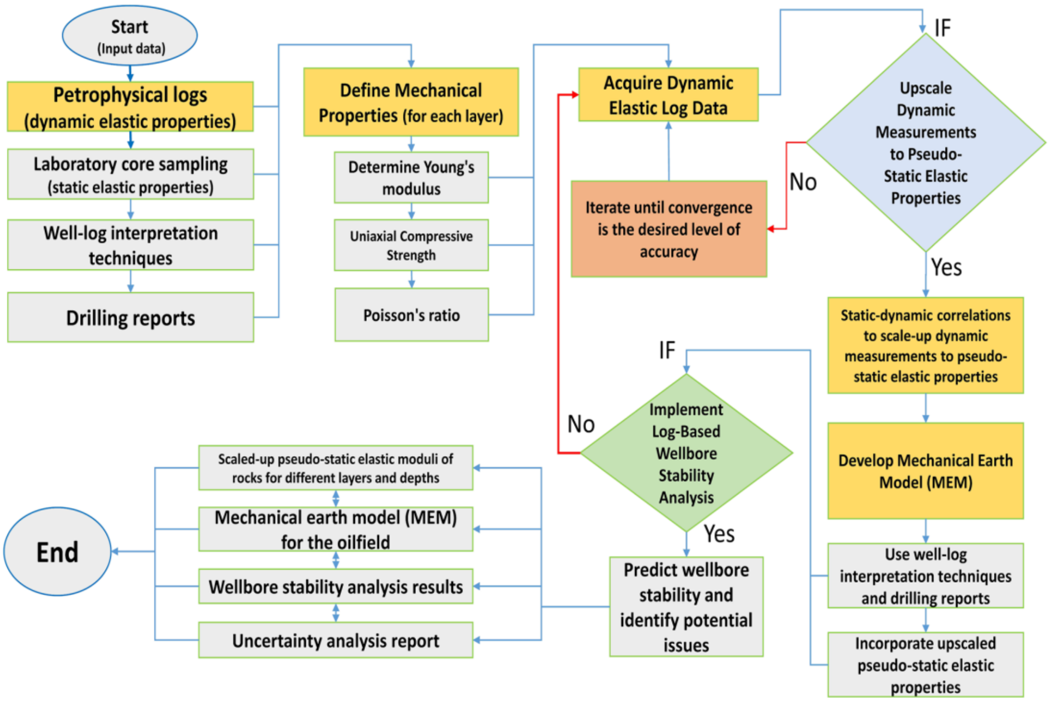

Figure 2. Conversion Steps of Dynamic Elastic Properties to Pseudo-Static Elastic Moduli in Wellbore Stability (Source: Jamshidi et al., 2024).

4.3. One-Dimensional Geomechanical Model for The OSA Field Using the Pseudo-Static Elastic Properties

To estimate the in-situ stress state and rock strength along the borehole, a one-dimensional geomechanical model is created by combining stress and pore pressure profiles with pseudo-static elastic properties derived from well logs

(Verma et al., 2021). To better represent static rock behaviour in MEM construction, dynamic elastic moduli from sonic and density logs are transformed to pseudo-static values using field-specific empirical correlations, e.g. dynamic-to-static moduli scaling (Ghasemi & Bayuk, 2020). Yin et al. (20202) noted that the 1D model framework uses density integration to calculate vertical stress, sonic/slowness methods to calculate pore pressure, and poroelastic relationships to calculate horizontal stresses. Then, stress versus failure thresholds for drilling design are constrained by integrating rock strength parameters like UCS and friction angle.

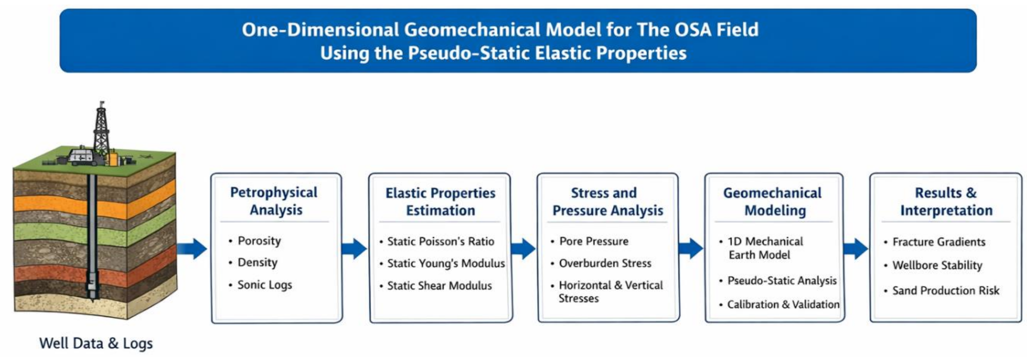

Figure 3. The Process of One-Dimensional Geomechanical Model to Estimate In-situ Stress State and Rock Strength along the Borehole Using the Pseudo-Static Elastic Properties (Verma et al., 2021).

5. Results and Discussion

5.1. Derive Pseudo-Static Elastic Moduli from The Computed Dynamic Elastic Properties

Dynamic elastic data acquired in the OSA Field through dipole sonic and density logs were effectively converted to pseudo-static elastic properties results through established rock-physics correlations. The transformation minimised the stiffness bias that existed in dynamic (high-frequency) measurements and came up with mechanically realistic values that could be used to model wellbore stability and stress.

Table 1. Dynamic Elastic Data Acquired in The OSA Field Showing the Young's Modulus, Dynamic Poisson's Ratio and Pseudo-Static Poisson's Ratio Results.

Depth (m)	Dynamic Young's Modulus (GPa)	Pseudo-Static Young's Modulus (GPa)	Dynamic Poisson's Ratio	Pseudo-Static Poisson's Ratio
1500	25	18	0.28	0.22
1800	28	20	0.29	0.23
2100	32	23	0.3	0.24
2400	35	25	0.31	0.25
2700	38	27	0.32	0.26

Dynamic Young Modulus (Ed) of 25-38 Gpa was observed in all the intervals examined (1500-2700 m), but the same pseudo-static Young modulus (Es) of 18-27 Gpa was identified, showing a steady decrease of approximately 25-30%. This decrease is attributed to micro-crack compliance and in-situ stress effects, which are not recorded by sonic measurements. In a similar manner, the dynamic Poisson (nd) 0.28-0.32 ratio was reduced to a pseudo-static (ns) 0.22-0.26 ratio, which is more appropriate in depicting the reservoir deformation when subjected to the drilling and production loads.

These results confirm that dynamic logs systematically overestimate rock stiffness, and empirical rock-physics scaling provides reliable pseudo-static moduli for geomechanical modelling. The result is presented in Table 1.

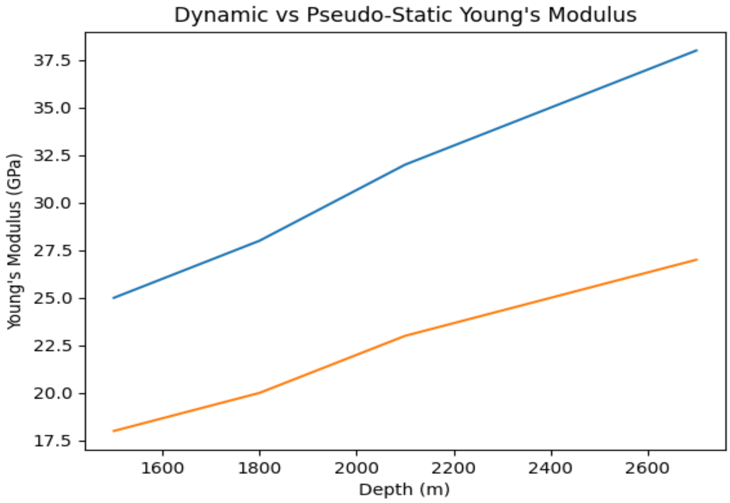

Figure 4. Graph of Dynamic Young's Modulus (Blue Line) and Pseudo-Static Young's Modulus (Orange Line) against the Depth of the Reservoirs in the OSA Oilfield.

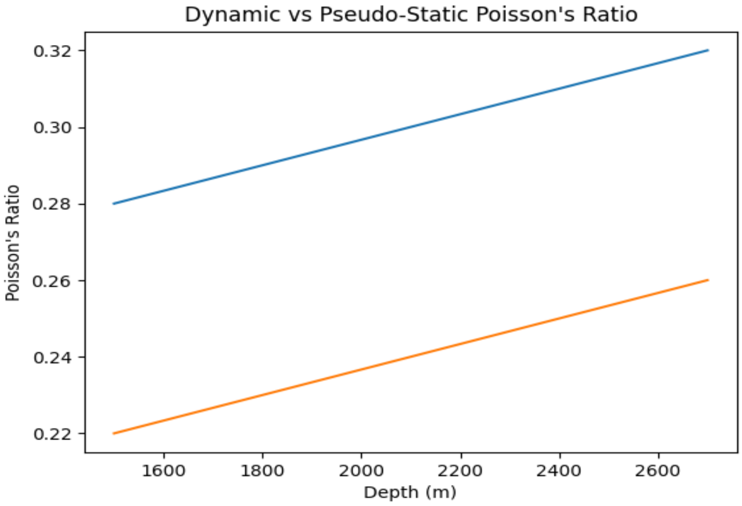

Figure 5. Graph of Dynamic Poisson's Ratio (Blue Line) and Pseudo-Static Poisson's Ratio (Orange Line) against the Depth of the Reservoirs in the OSA Oilfield.

The obtained pseudo-static elastic moduli give a real-world mechanical description of OSA Field sand-shale sequences. Davarpanah et al. (2020) noted that the process of dynamic moduli reduction to a static one enhances an approximation of horizontal stress, fracture gradient, and sand-production risk. Thus, the transformed pseudo-static characteristics are appropriate feeds to the 1-D geomechanical model and further wellbore stability analysis of the Niger Delta setting.

5.2. One-Dimensional Geomechanical Model for the OSA Field

For the OSA Field, a 1-D Mechanical Earth Model (MEM) was built to measure in-situ stresses and rock strength parameters along the wellbore using the pseudo-static elastic moduli obtained in Objective (i). The model uses poro-elastic formulations to calculate horizontal stresses by integrating overburden from density logs, pore pressure from petrophysical and drilling data, and pseudo-static Young's modulus and Poisson's ratio. The findings presented in table 2 demonstrate a mechanically consistent stress regime that is typical of the compacting deltaic sediments of the Niger Delta and is dominated by increasing vertical and horizontal stresses with depth.

Table 2. Stress Regime Dominated by Increasing Vertical and Horizontal Stresses with Depth.

Depth (m)	**Vertical Stress Sv (MPa)**	**Min Horizontal Stress Sh (MPa)**	**Max Horizontal Stress SH (MPa)**	**UCS (MPa)**	**Tensile Strength (MPa)**
1500	35	28	40	18	2.5
1800	42	34	48	22	2.8
2100	50	40	56	26	3.2
2400	58	46	64	30	3.6
2700	66	52	72	34	4

- Maximum horizontal stress (SH) is consistently greater than minimum horizontal stress (Sh), indicating a strike-slip to compressional stress regime, which controls wellbore breakout and fracture orientation.

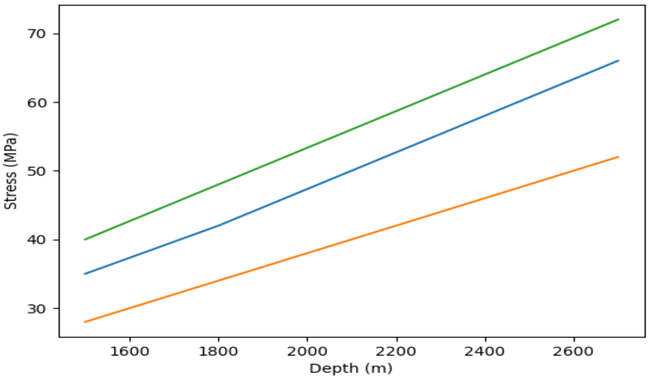

Figure 6. Graph of Stress against Depth in OSA Oilfield. Vertical stress (Blue Colour) increases from 35 to 66 MPa, reflecting progressive burial and compaction.

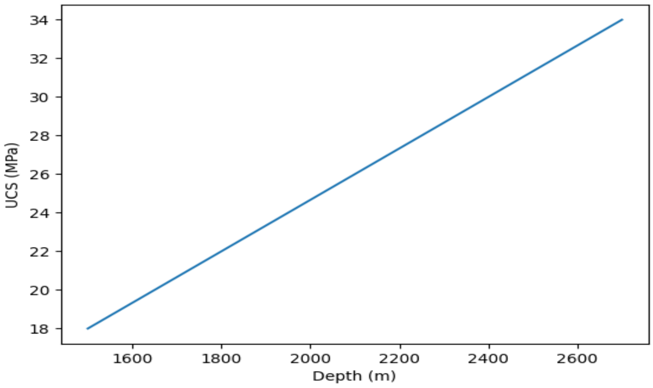

Figure 7. Unconfined compressive strength (UCS) against Depth in the OSA Oilfield. UCS increases from 18 to 34 MPa, confirming progressive mechanical strengthening with depth.

It was discovered that OSA Field sandstones change from being moderately weak to mechanically competent, according to the 1-D MEM. According to Xu et al. (2016), the over-stiff response characteristic of dynamic logs is avoided by the pseudo-static elastic moduli, which generate realistic stress magnitudes. The predominance of SH >

Sv > Sh indicates that hydraulic fractures will spread parallel to SH, while shear failure and breakouts in the Sh direction will primarily control wellbore instability. All things considered, the created 1-D geomechanical model offers a trustworthy framework for forecasting fracture gradients, wellbore stability, and the risk of sand production in the OSA Field.

6. Conclusion

This study illustrates how the wellbore stability analysis in the OSA Field can at best be reliable when dynamic sonic log elastic properties are converted into pseudo-static elastic moduli that are representative in the mechanical sense. These findings corroborated that the dynamic Young modulus and Poisson ratio constantly overestimate the stiffness of the rocks depending on the frequency, microcrack, and stress-path effects. These dynamic values were successfully transformed to pseudo-static properties using developed rock-physics correlations to give more realistic in-situ deformation behaviour of the unconsolidated to moderately consolidated sand-shale sequences of the Niger Delta.

A one-dimensional geomechanical model developed on the basis of these pseudo-static parameters produced finite vertical and horizontal stresses and depth-dependent, realistic trends in rock strengths. The model was able to identify a regime of stress that is characterised by greater maximum horizontal stress compared to minimum horizontal stress, and this means that shear-based wellbore breakouts and sand failure are the main instability processes in the OSA Field. The resulting profiles of unconfined compressive strength and tensile strength further indicated rising formation competence with burial, which has a quantitative foundation of safe mud-weight and casing design.

The 1-D Mechanical Earth Model, upon the introduction of pseudo-static elastic moduli, considerably enhanced the prediction of the gradient of fractures, collapse pressure, and the risk of production of sand. The developed workflow provides a solid and scalable model of optimising drilling and completion designs in the OSA Field and other fields in the Niger Delta that have the same geomechanical behaviour.

Declarations

Source of Funding

This study did not receive any grant from funding agencies in the public, commercial, or not–for–profit sectors.

Competing Interests Statement

The authors have not declared any conflict of interest.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

Both the authors took part in literature review, analysis, and manuscript writing equally.

Informed Consent

Not applicable for this study.

Availability of data and material

All supplementary documentation can be provided for the purpose of academic inquiry or verification.

Institutional Review Board Statement

Not applicable for this study.

Ethical Approval

Not applicable for this study.

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