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Predicting static rock mechanical parameters through log based dynamic values and its impact on analysis of in-situ stresses: A case study in Gollappalli formation, KG Basin

Abstract

Mechanical parameters of a reservoir rock play an important role in well bore stability studies and in situ stress analysis. Their applicability is now increasingly being felt in designing of hydraulic fracturing program, especially of tight and low porosity reservoirs. The fracture propagation and fracture mapping are strong functions of the values and directions of the in-situ stresses. The estimation of the in situ stresses requires the knowledge of the Static moduli such as Young's modulus and Poisson's Ratio of the rock. Static rock mechanical parameters that are measured on cores, are generally used in wellbore stability and in-situ stress applications as they are considered to give accurate and realistic values than those derived from well logs. But they have their own limitations as coring cannot be carried out in every well over large intervals, owing to its high costs and enormous amount of time taken. This paper aims to develop a technique to predict static rock mechanical parameters through wire line logs and study its impact on analysis of in-situ stresses.

Introduction

The estimation of the in situ stresses is very crucial in oil and gas industry applications as their knowledge is essential in the design of hydraulic fracturing operations in conventional and unconventional reservoirs. Static moduli are often used in wellbore stability and in-situ stress applications to evaluate the possibility of breakouts, elevated pore pressure, and tectonic stress distribution [7]. The static elastic mechanical parameters are obtained by measuring the deformation of rocks when pressure is offered to the rocks, while the dynamic elastic mechanical parameters are measured from density and acoustic velocity in the rocks. Static method is a direct way of measuring the rock mechanical parameters as they are measured on core samples and so, are considered more accurate for geo mechanical studies. Measurements through static method, however, require a large amount of core derived data to accurately describe the mechanical characteristics of the reservoir. As cores are not taken in every well and continuous data is not available, this methodology has its limitations. This paper aims to develop a technique to predict continuous static rock mechanical parameters through log based dynamic rock mechanical parameters and analyse its impact on in-situ stresses. Study has been carried out in two wells with eight core samples for Gollapalli formation from the shallow offshore field of KG basin.

Methodology

In this study firstly, the mechanical parameters like young's modulus and Poisson's ratio on core samples were determined. Subsequently, these core derived values were compared with the log derived dynamic values and then their relationship was used to generate a transform to predict the continuous static rock mechanical parameter curves in the well. The transform so generated can also be used to generate continuous static curves from the log derived dynamic data in wells, even where no core data is available.

In this study, core samples from tight sandstone reservoir of the Gollapalli formation from the shallow offshore field of KG basin have been used for the experimental measurements. Total eight numbers of core plugs of 1" diameter were used for the study. The average effective porosity of the samples, which is measured using Boyle's law method, lies in the range 6-14% and the permeability is less than 1 mD. In order to simulate the reservoir conditions, core derived mechanical parameters determination were carried out with Acoustic velocity system (AVS) equipment. The maximum confining and pore pressure of this equipment can be varied up to 10,000 psi.

Relationship between dynamic and static mechanical parameters

According to the elastic wave propagation theory, the dynamic elastic modulus (E_d) and dynamic Poisson's ratio (μ_d) are obtained as follows:

$$E_d = [\rho v_s^2 (3v_p^2 - 4v_s^2)/(v_p^2 - v_s^2)] \times 10^{-6}$$

$$\mu_d = (v_p^2 - 2v_s^2)/[2(v_p^2 - v_s^2)]$$

Where, ρ is the density of the rock, g/cm3, v_p and v_s are compressional and shear wave velocity respectively, m/s. take the average of wave velocity before and after the acquisition constant static mechanics as v_p and v_s. The static Young's modulus E_s is the ratio of axial stress σ_1 and axial strain ε_1. The static Poisson's ratio μ_s is the opposite of the ratio of radial strain ε_2 and axial strain ε_1 [5].

In the present study, the core derived static values and the estimated log based dynamic values of Young's modulus and Poisson's ratios are given in Table-1. The values have been plotted in Fig-1 to observe the relation between them.

Table-1: Core and log derived values for Young's modulus and Poisson's ratio

Plug No.	PR_Static	PR_Dynamic	Ym_Static *10^{10} (Pa)	Ym_Dynamic *10^{10} (Pa)
S-1	0.32	0.23	2.49	5.1
S-2	0.28	0.2	2.47	5.7
S-3	0.32	0.198	2.71	5.6
S-4	0.32	0.25	1.73	5.1
S-5	0.31	0.21	3.01	7.07
S-6	0.28	0.24	2.35	5.9
S-7	0.27	0.13	2.48	5.5
S-8	0.29	0.21	2.26	6

Fig. 1 represents the relationship between dynamic and static elastic parameters. The observations from Fig. 1(a) show that the static and dynamic Young's modulus follow the same pattern and static value of

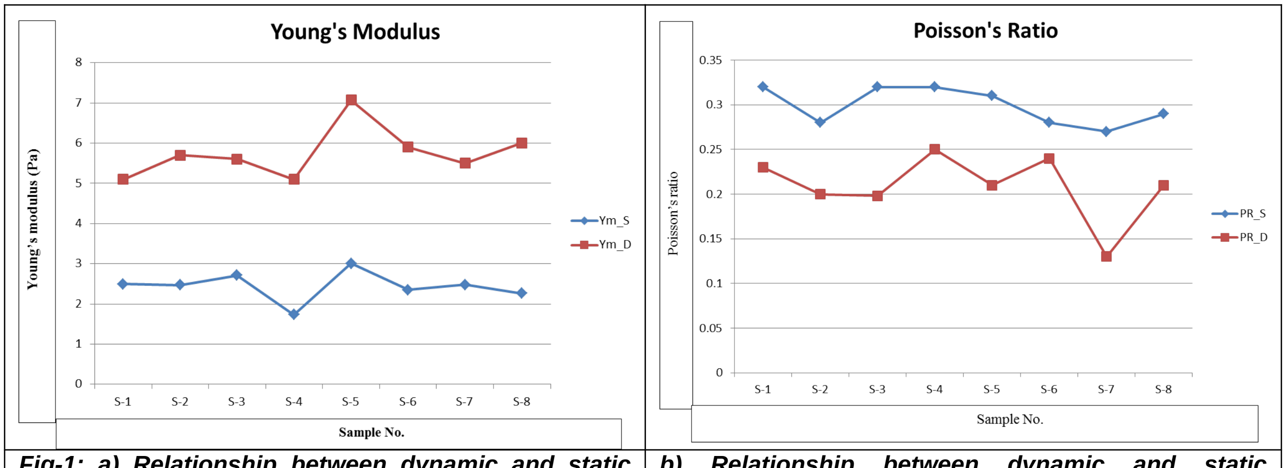


Fig-1: a) Relationship between dynamic and static Young's modulus. *b) Relationship between dynamic and static Poisson's Ratio.*

Young's modulus is less than the Dynamic value.

Fig. 1(b) shows that the static and dynamic Poisson's ratio are not falling in a particular pattern and also the static values of Poisson's ratio are more than the dynamic values.

Relationship between mechanical parameters and pressure

The effect of pressure on elastic moduli is of great importance as it gives an idea of how the elastic parameters vary with depth with increase in pressure; the Static young’s modulus and Poisson’s ratio are plotted with pressure in Fig-2.

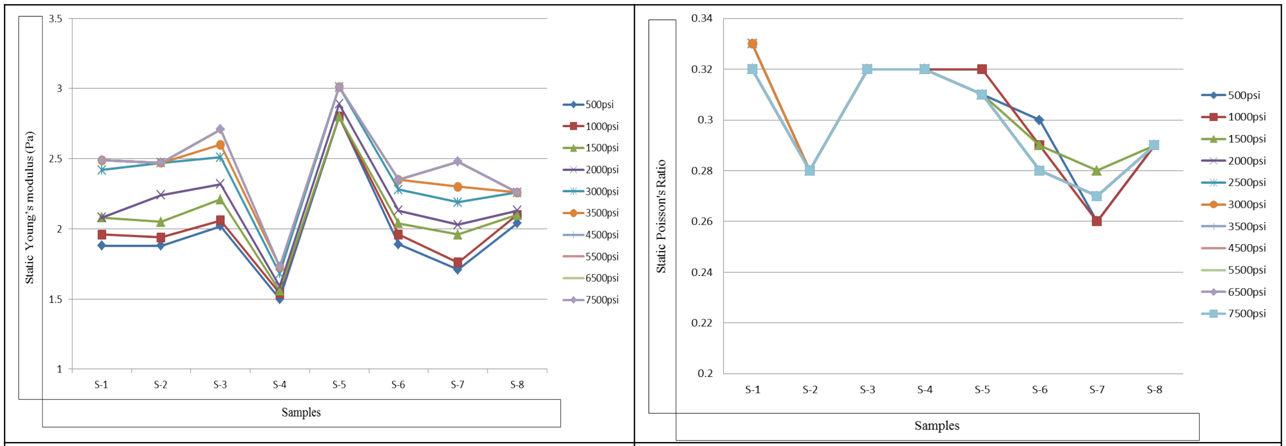


Fig-2: a) Relationship between Static Ym and Pressure ***b) Relationship between Static PR and Pressure***

In the present study, analysis of the relation between Static young’s modulus and Pressure (Fig-2a) shows that up to a pressure of 4500psi, there is an increase in young’s modulus with pressure, but beyond 4500psi pressure values, Young’s modulus remains unchanged. However, no direct relationship between Static Poisson’s ratio and Pressure is observed (Fig-2b).

Prediction of static mechanical parameters

The Plumb Bradford correlation method has been used for the prediction of static Young’s modulus using the core data. To get the maximum matching with the core data, PR multiplier 0.9 has been found to be best match and has been used to predict the static Poisson’s ratio from the log derived values. The comparison of predicted log based static parameter values at core depth with the core derived static parameters is given in Fig-3.

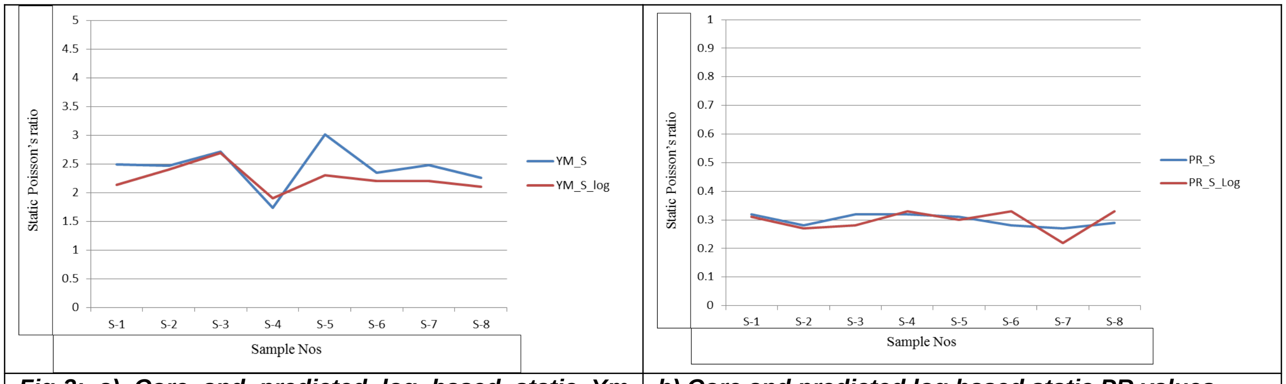


Fig-3: a) Core and predicted log based static Ym values ***b) Core and predicted log based static PR values***

The analysis shows that the values of core derived static Young’s modulus and the predicted log based static Young’s modulus values have good correlation and both have very narrow band of variation ranging from 1.8 to 3 Pa. The correlation between core and log derived static Poisson’s ratio is quite good and both have very narrow band of variation ranging from 0.22-0.33.

The continuous static curves have been predicted for the complete synrift sequence i.e Gollapalli formation for Well-X (Fig-4) and have been validated with the core data. The relation between the dynamic and static Ym (E) and PR (μ) within the formation has been defined using regression equations with the help of cross plots (Fig-5).

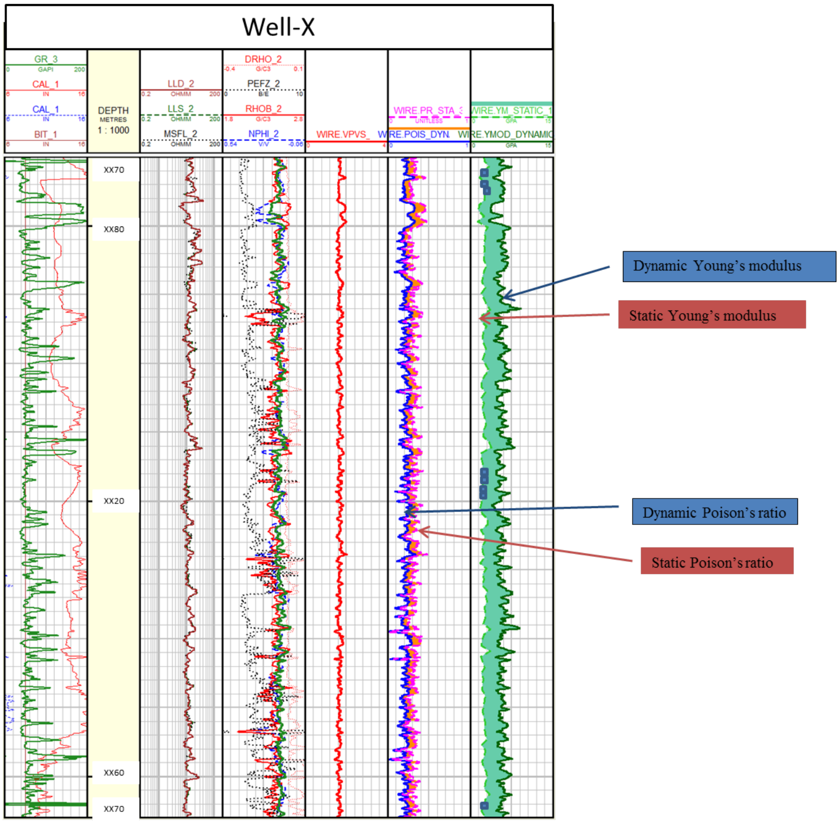


Fig-4: Continuous curves for PR and Ym within the Gollapalli formation.

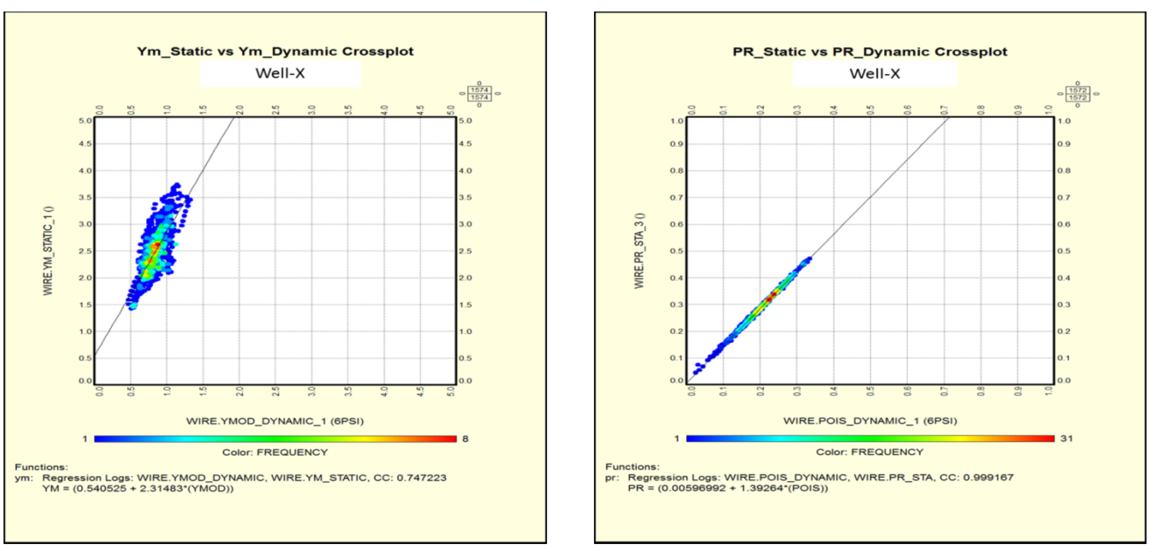


Fig-5: Regression equations showing the relationship between Dynamic and Static Ym and PR.

Ym_Static= (0.540525+2.31483*(Ym_Dyn)) & R^2=74%………. *Eq-1*

PR_Static= (0.00596992+1.39264*(PR_Dyn)) & R^2=99.9%……….*Eq-2*

Based on the validation of the technique with the available core data, the equations (1 & 2) have been used in other wells of the area to predict the continuous static moduli curves from log based dynamic elastic moduli values. Fig-6 indicates these results in the well Y.

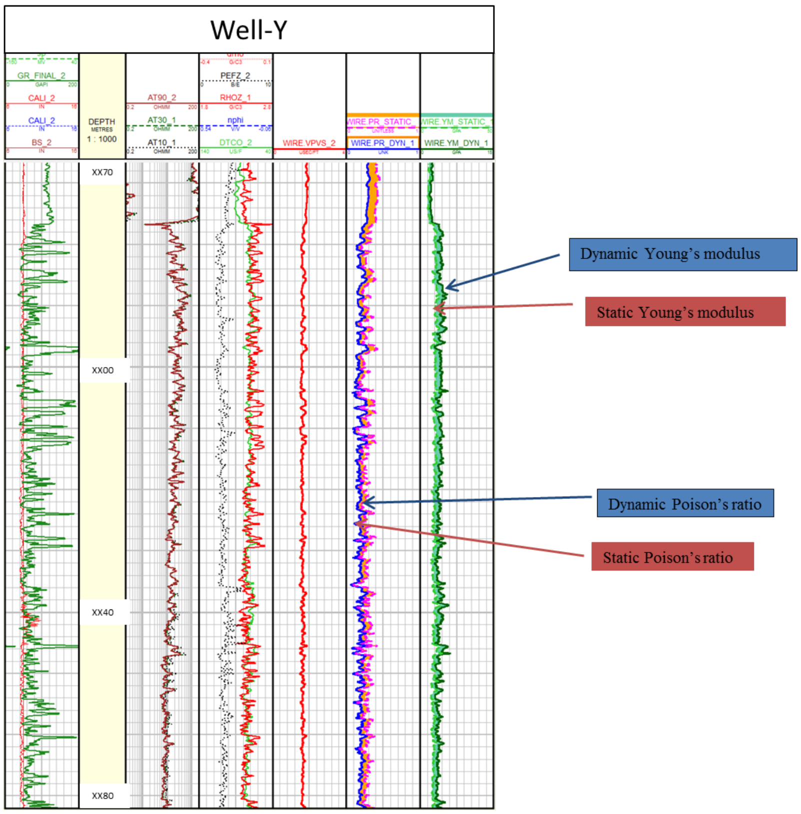


Fig-6: Determination of static PR and Ym from dynamic log values for well-Y.

Impact:

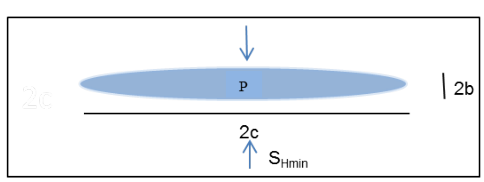
Static moduli are commonly used in wellbore stability and in-situ stress applications. Therefore, proper knowledge of the predicted static values will have a direct impact on calculation of the stress magnitudes and hydro fracturing design even for those wells where core data is not available. A common method to calculate the horizontal stress in the earth by assuming that the earth is elastic and does not deform in the horizontal direction requires the knowledge of static Poisson's ratio [7].

$$S_H = S_V \frac{\mu}{1-\mu}$$

Where: μ=Poisson's ratio, S_V *&* S_H*= vertical & horizontal stress respectively.*

A Hydrofracture can be approximated by a 2D elliptical crack whose dimensions depend on the static Young's modulus and Poisson's ratio [7].

$$b = 2c\frac{1-\mu^2}{E}(P - S_{Hmin})$$



Where: P=pore pressure, b &c = width and length of the fracture, E=young's modulus

Conclusion

The study develops a technique to predict the static rock mechanical parameters from log based dynamic values and it shows the relationship between the static and dynamic mechanical parameters. The technique has been used in Gollapalli formation and it is observed that the predicted static values match well with the core derived data. The study also shows that the dynamic Young's modulus is greater than the static Young's modulus and the dynamic Poisson's ratio is less than the static Poisson's ratio under the same reservoir conditions. The dynamic Young's modulus is almost twice of the static Young's modulus. The study also shows that the static Young's modulus increases linearly with pressure upto 4500psi, while static Poisson's ratio does not have any obvious relationship with increasing pressure. Transforms have been generated to predict static values such as Poisson's ratio and Young's modulus from log based dynamic values as they are important inputs for stress analysis in and around the well bore. This technique is helpful in geo-mechanical studies as it is able to predict continuous static rock mechanical data even for those wells where no core data is available.

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