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University of Baghdad
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Estimation of the Rock Mechanical Properties Using Conventional Log Data in North Rumaila Field

Wafa Al-Kattan and N. Jasim Al-Ameri
University of Baghdad, College of Engineering, Petroleum Engineering Department

Abstract

Hydrocarbon production might cause changes in dynamic reservoir properties. Thus the consideration of the mechanical stability of a formation under different conditions of drilling or production is a very important issue, and basic mechanical properties of the formation should be determined.

There is considerable evidence, gathered from laboratory measurements in the field of Rock Mechanics, showing a good correlation between intrinsic rock strength and the dynamic elastic constant determined from sonic-velocity and density measurements.

The values of the mechanical properties determined from log data, such as the dynamic elastic constants derived from the measurement of the elastic wave velocities in the material, should be more accurate than that determined by direct strength tests with core samples. This can be attributed to the scale effect and sampling disturbances.

The aim of this study was to present methods of determining measures of some mechanical properties, from available well log data (conventional sonic, density, and gamma ray) for a well in North Rumaila field.

The mechanical properties include formation strength and Poisson's ratio. For the formation strength, combined elastic modulus (Ec) and shear modulus (G) were determined. The Poisson's ratio was determined by using three different techniques to permit the accuracy of their values. The elastic modulus, shear modulus, and Poisson's ratio were then correlated with depth and effective stress.

The results show that combined correlations are important source of the prediction of overpressure zones which represent a major problem encountered in drilling and production process.

Kew Word: mechanical properties, North Rumaila field, elastic modulus, shear modulus, Poisson's ratio, effective stress

Introduction

Effective stress laws and their applications are not new, but are often overlooked or miss-applied.

At depth reservoir rocks are subjected to in-situ stress arising from the combined effects of overburden pressure (external stress), which is exerted by the weight of overlying rocks; tectonic stresses that are generated by the large-scale movements in the earth crust; and pore pressure that is exerted by the fluids present in the rock pores.

It is common practice to choose a net effective stress that is thought to result in identical rock properties.

According to Terzaghi[1], an effective stress law is a mean to convert two variables, external stress (σ) and pore pressure P_p, into one equivalent variable (σ_{eff}):

$$\sigma_{eff} = \sigma - \alpha P_p$$

Where α is the effective stress coefficient (Biot constant) which is assumed to be 1.0 at high pressure.

Normal pressure refers to formation pressure which is approximately equal to the hydrostatic head of a column of water of equal depth (approximately 0.465 psi/ft depth). Formation with pressure higher than hydrostatic is referred as bring abnormally pressured.

High formation pressures cause major changes in subsurface-rock parameters. In over pressured shales, the acoustic velocity and density are lowered and porosity is higher than that in normal pressures.

Because formation-fluid pressure, in an abnormal pressure zone, is increased the effective stress is expected to decrease.

The aim of this study is to draw attention to the potential impact of very high pore pressure on rock mechanical properties.

The effects of effective stress decreasing on the compressional wave velocity (Vp), combined elastic modulus (Ec), shear modulus (G), and Poisson's ratio for the studied aria, a deep well in North Rumaila, were determined.

Direct measurements of rock strength and Poisson's ratio are not easily obtained for typical hydrocarbon wells, so it is of interest to develop means of obtaining them indirectly from more easily available measurements. One such possible source is from wireline logging data, principally, the sonic, density, and gamma ray logs.

Poisson's ratio should, in principle, be derivable from the sonic compressional and shear wave velocities, Vp and Vs respectively. Because V_s is not available, alternative methods were used to estimate values of Poisson's ratio.

The studied interval, ranges from 2000 to 5200 m, passes through many complex formations. The formation materials include limestone, dolomite, anhydrite, and some sand enterbeded with beds of shale and salt.

The results of the derived mechanical properties of the studied interval were correlated with depth and effective stress; the abnormal pressure zone can be detected easily from the correlations.

Good correlation between effective stress and Poisson's ratio is observed in abnormal interval zone.

Modulus Properties

Modulus values have been used as a measure of the strength properties and stability of rocks under different conditions of drilling and production.

The combined elastic modulus ,Ec[2], take in to consideration the effect of both shear modulus G and bulk modulus Kb,is given by:

$$Ec = \frac{4}{3} G + Kb \qquad \ldots(1)$$

Where, G is the shear modulus in psi of a material, subjected to a given total load, defined as the ratio of shear load to lateral deformation. Alone, G is serving as a direct measure of the strength of the formation solids.

The bulk modulus Kb is the reciprocal of bulk compressibility, its value depends on the compressibility of both formation solids and fluids.

The log data were used to calculate the combined elastic modulus from the equation:

$$\text{Ec} = \frac{1.34*10^{\wedge}10\rho}{t_c^2} \quad \ldots(2)$$

Where: t_c is transit time from sonic log, $\mu s/ft$

$$t_c = \frac{10^{\wedge}6}{Vp}$$

Vp is the compressional wave velocity ft / µs
ρ is bulk density from density log gm/ cc
Effective stress provided by the overburden weight may be determined from the equation:

$$\sigma_o = D\,(G_{ov} - G_p) \quad \ldots(3)$$

Where:
σ = effective stress provided by overburden weight, psi
D = depth, ft
G_{ov} = overburden weight gradient, psi
G_p = fluid pressure gradient, psi

From the correlation, given in Fig-a [2], between Ec and Kb the value of Kb was estimated, then the value of G is calculated using equation (1).

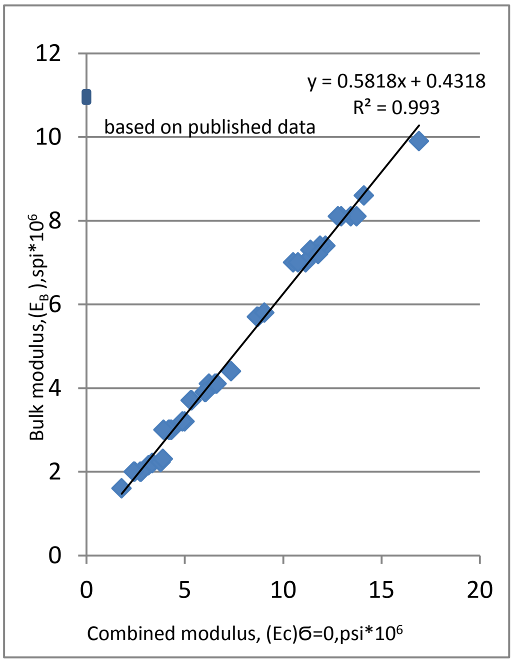

Fig. a, Estimating the bulk modulus

The estimated shear modulus, G, is a measure of the formation strength by itself.
Poisson's ratio, υ, then may be expressed in terms of the following modulus [2]:

$$\upsilon = \frac{3Kb-2G}{6Kb+2G} \quad \ldots(4)$$

Anderson et al [3] have presented an empirical relationship relating Poisson s ratio to shaliness given by:

$$\upsilon = 0.125q + 0.27 \quad \ldots(5)$$

Where q is the shaliness index and has been defined as:

$$q = \frac{\phi s-\phi D}{\phi s} \quad \ldots(6)$$

Where ϕs is porosity from sonic log
ϕ_D is porosity from density log
Poisson's ratio calculated by equation (5) was used to calculate, again, the shear modulus G by the relation [4]:

$$G = \frac{A\rho_b}{t_c^2} \quad \ldots(7)$$

Where

$$A = \frac{1-2\upsilon}{2(1-\upsilon)}$$

Using the concept of a variable overburden pressure Eaton [5] calculate the Poisson's ratio by the equation:

$$Pf = Pp + \frac{\upsilon}{1-\upsilon}(Po - Pp) \quad \ldots(8)$$

Where Pf =fracture pressure, psi
Pp = pore pressure, psi
Po = overburden pressure, psi
υ =Poisson's ratio

In terms of pressure gradient, the above equation may be expressed as:

$$\frac{\upsilon}{1-\upsilon} = \frac{G_f-G_p}{G_{ov}-G_p} \quad \ldots(9)$$

Where:
G_f = pressure fracture gradient, psi/ft
G_p= pore pressure gradient, psi/ft
G_{ov}= overburden pressure gradient, psi/ft

The value of the fracture pressure gradient, G_f, was measured from the DST. The pore pressure gradient G_p calculated by the equation of pore pressure prediction [6], as:

$$G_p = G_{ov} - (G_{ov} - G_{pn})(\frac{t_n}{t_o})^3$$

Where:
G_{pn}= normal pore pressure gradient (0.465), psi/ft
t_n= the normal travel time, μs/ft
t_o = the shale travel time, μs/ft

The overburden pressure gradient calculated by the equation:

$$G_{ov} = \frac{\sum \rho \Delta h}{\sum \Delta h} * 0.433$$

The determined Poisson's ratio, depending on pressure gradients, was used to calculate the shear modulus G again.
The calculated variables, Vp,Ec,and G (G was calculated by three methods),and Poisson's ratio (calculated by three methods) were plotted against the depth and the effective stress.

Results and Discussions

A reservoir rocks is subjected to external (overburden) and internal (pore fluid) pressures. Laboratory measurements [7] have shown that the acoustic velocity, Vp, is affected by the effective stress, which is the difference between external internal pressures (ΔP), rather than the absolute value of external pressure or the internal pressure. Compressional wave velocity, Vp, increase as the ΔP increases. Because ΔP determines the degree of rock compactions and its bulk modulus, it follows that Vp depends on compaction. The more compacted the rock the higher its acoustic velocity. Also the acoustic velocity depends on the elastic properties of rocks, so the combined elastic modulus, Ec, compressional wave velocity, Vp, are correlated with depth (as shown in Fig. 1).

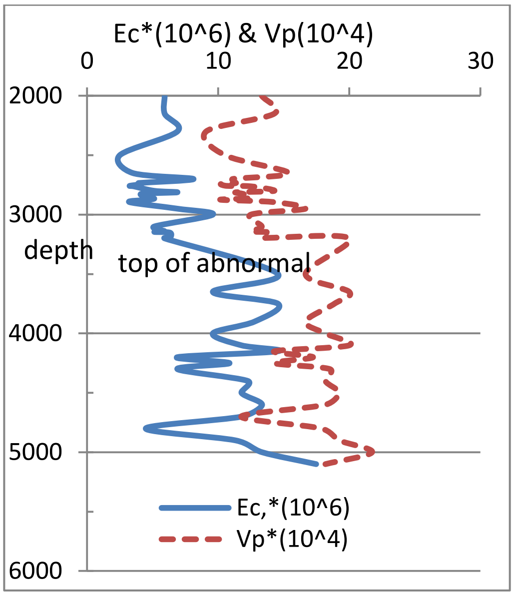

Fig. 1, correlation between compressional wave velocity & elastic Modula with depth

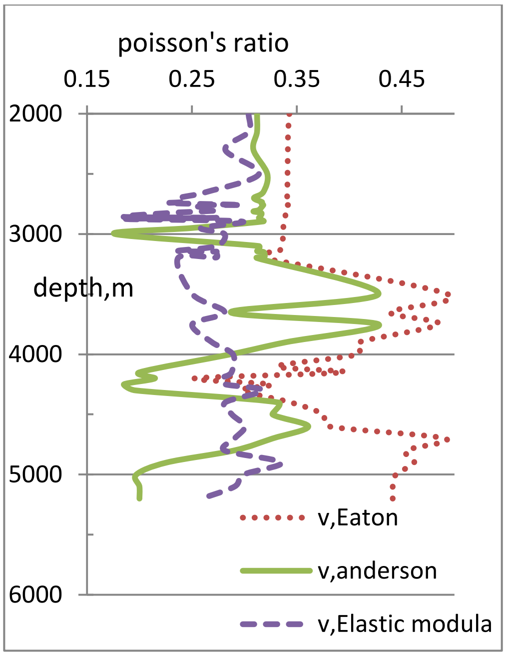

Fig. 2, Poisson's ratio correlation comparison for the studied well

In Fig.2 Poisson's ratio,calculated by three different methods, was correlated with depth.
The shear modulus, also calculated by three methods, was correlated with depth in Fig.3.

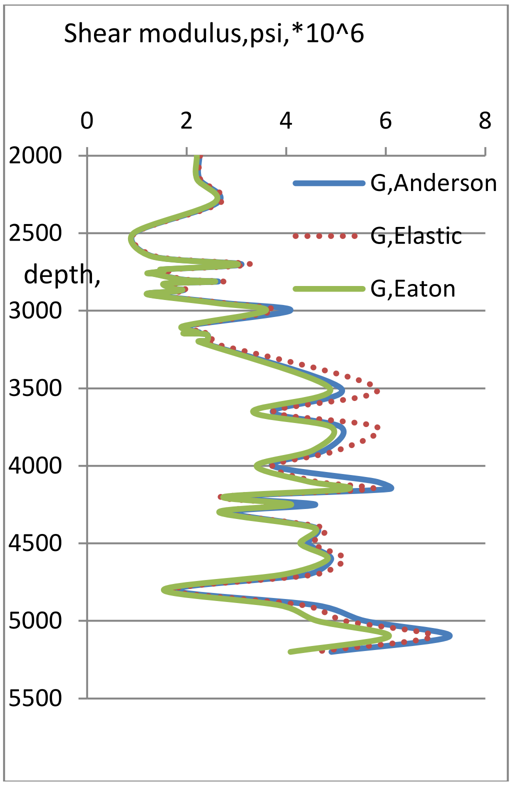

Fig. 3, the correlation between shear modulus & depth for the studied well

The trends of increasing Vp, Ec, G, and υ with depth is obvious, and the abnormal pressure zone can be detected between 3200 and 5200 m depth.
To show the effect of the effective stress, ΔP, on Vp, Ec, G, and υ, the normal interval, Fig(4-5), and abnormal pressure intervals (Fig. 6 to 9) were separated .
In Fig. 4, the normal zone, the effect of lithology on Vp, Ec, G is more than the effect of effective stress since the important factor here is the rock density. Any increase in bulk density, grain size would cause an increase in Vp, but its influence on the strength of the rock is small.

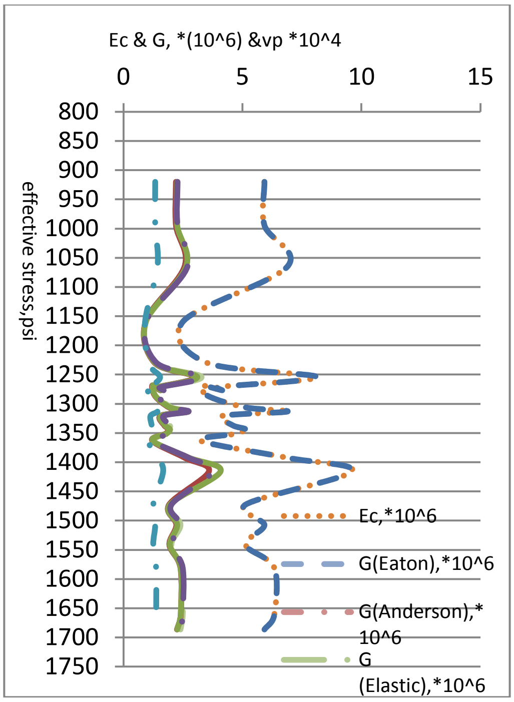

Fig. 4, the correlation between elastic Modulus Ec , shear modulus G , compressional wave velocity Vp with effective stress Ϭo in the normal zone

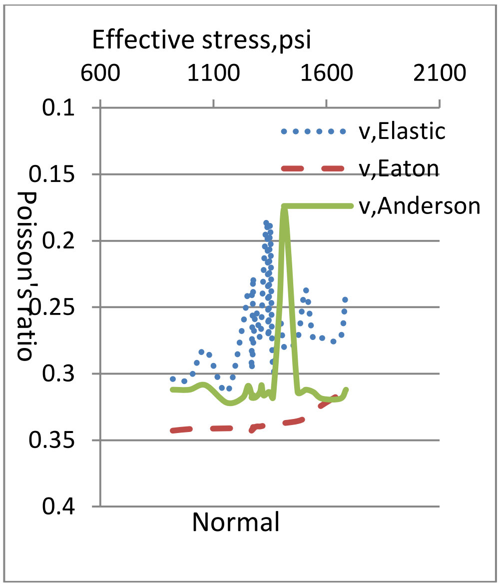

Fig. 5, the correlation between effective stress & Poisson's ratio in the normal zone

In Figs. 6,7,8, and 9,(the abnormal zone) the effective stress was correlated with Ec, G, and Vp.

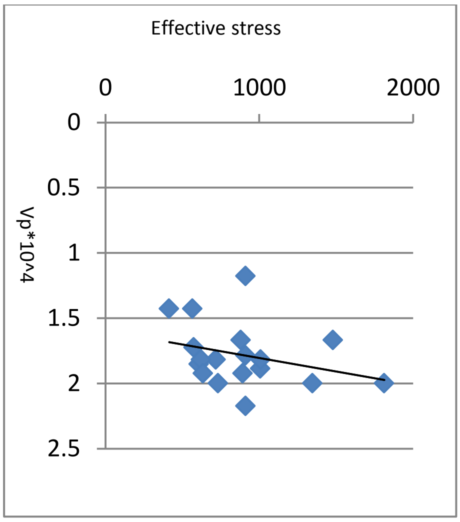

Fig. 6, correlation between compressional wave velocity Vp & effective stress Ϭo in the abnormal zone

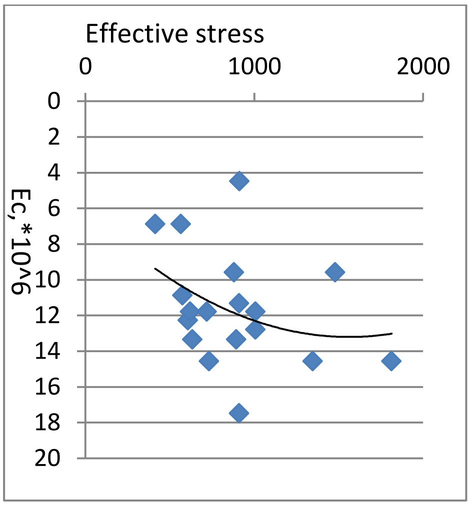

Fig. 7, the correlation between elastic Modula Ec & effective stress Ϭo in the abnormal zone

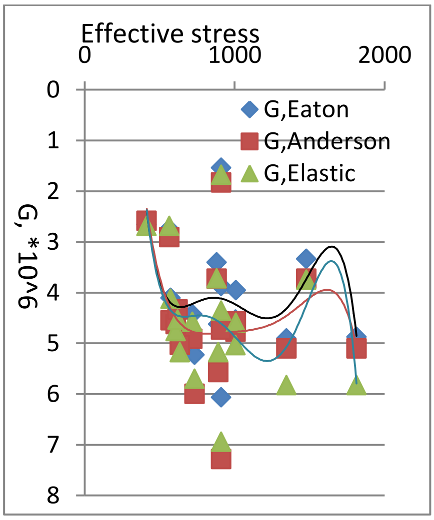

Fig. 8, the correlation between shear Modulus & effective stress Ϭo in the abnormal zone

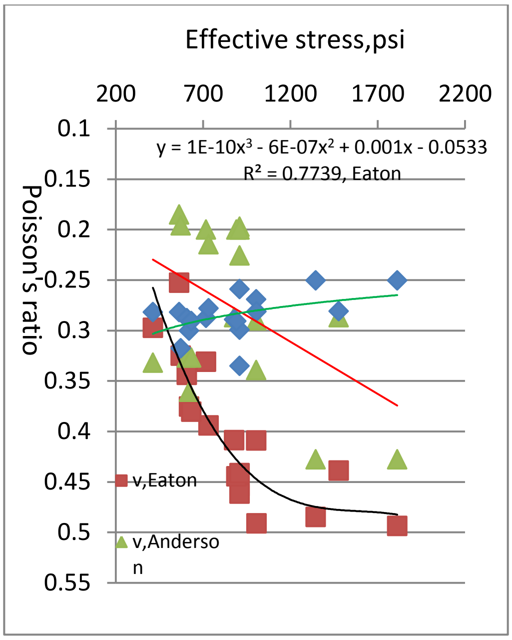

Fig. 9, the correlation between effective stress & Poisson's ratio in the abnormal zone

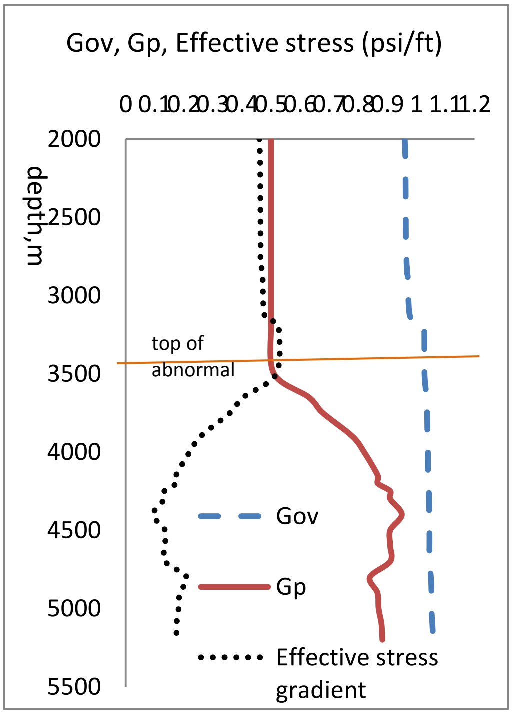

Fig. 10, Effect of different pressure gradient for normal and abnormal zone

The scattering, shown in these figures, is due to the influence of both the complicated lithology and effective stress. This is very clear in Fig. 10 which shows that the increasing in Gov (its value depends mainly on bulk density) is very small comparing to that of Gp, and the effective stress decreasing is great.

The correlation between Poisson's ratio and effective stress in Fig. 5&9 support the above illation. The estimation of Poisson's ratio, in the normal zone, depending on Eaton' s equation show that the increase in effective stress dose not affects the value of Poisson's ratio. While the value estimated from the other models, which depend on shale index, show deviations correlated with lithology changes. The higher Poisson's ratio of limestone comparing to that of anhydrite, sandstone, shale, and salt, may be the main cause of this deviations.

In the abnormal pressure zone, the effect of both the effective stress and lithology are clear. The scattering is due to the decrease of effective stress, which has influence on the dynamic elastic parameters, The higher the value of Poisson's ratio of a sediment the more vertical matrix stress is transmitted in the horizontal direction.

In overpressured shales sonic velocity and density are lower and porosity is higher than in normal pressure.

In Fig.9, good correlation between the effective stress and Poisson's ratio is observed when depending on Eaton equation. Again the scattering is great depending on the other methods.

Conclusion

In this work, we have investigated whether we can derive correlations between petrophysical and mechanical properties using wireline log data.

Neglecting the pressure effect on velocity result in over estimation of rock porosity by sonic log in over pressured formations, and under estimation of porosity in pressure depleted zones.

The effective stress coefficient (Biot constant in Terzaghi equation) assumed to be equal to 1 but it can different and more attention should be given to this constant.

The mechanical properties of rocks can be used very effectively in the planning of drilling a well.

The rock strength, determined from shear modulus (G) and poisson's ratio (V), can be used to estimate the rate of penetration (ROP) and bit wear.

More knowledge is necessary in order to get batter correlations between petrophysical and mechanical properties for Iraqi Oil Field.

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