Prediction of Dynamic Elastic Properties for Mishrif formation in West Qurna-1 oil field: an experimental work

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Article

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Posted Date: December 29th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-1148988/v1>

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Abstract

Shear and compressional wave velocities are useful for drilling operations, the exploration of reservoirs, stimulation processes, and hydraulic fracturing.

An ultrasonic device will be used in this investigation to anticipate and analyze the elastic characteristics of carbonate rocks. At the summit of the field, the well WQ1-20 obtained samples of the Mishrif formation from a variety of various depths.

The number of samples taken from the well is nine from different units whereas the number of samples taken from the main unit (MB2) was five.

The relations between the elastic properties for the carbonate rocks with P-and S-waves were defined.

The relations between V_p and V_s with elastic properties were defined by applied Regression analysis.

The results showed that a linear relationship between P-and S-wave velocities with the elastic properties of the carbonate rocks.

It is found that the relationship between V_p and Young's modulus (E) is R^2 equal to 0.979 while the relationship between V_s and Young's modulus (E) is R^2 equal to 0.925.

The relationship between shear modulus and V_s is good in comparison with V_p where the values of R^2 were 0.985 and 0.94 respectively. R^2 values for the Bulk modulus and Lamé's constant of V_p are 0.925 and 0.6, respectively, while the values for V_s are 0.925 and 0.6 for the latter. The relation between V_p/V_s ratio with Poisson's ratio showed a good R^2 with a value of 0.97.

When it comes to predicting the dynamic elastic characteristics of a material, the ultrasonic approach may be regarded as a cost-effective, easy, and non-destructive method.

Keywords: compressional wave velocity, shear wave velocity, sonic

Introduction

The shear and compressional wave velocities (V_s and V_p , respectively) are an insignificant role in the seismic inversion and the evaluation of petrophysical properties, especially for analysis of reservoir geomechanical properties. To find the geomechanical parameters such as shear modulus, Young's modulus, Poisson's ratio, bulk modulus, and Lamé parameters, both V_s and V_p with density are needed. Therefore, knowing V_s , V_p , and density, other

elastic parameters of a rock formation can be calculated in terms of the acoustic wave velocities (Liu et al. 2012). [1]

Ultrasonic wave velocity tests are sought after in rock mechanics because they are considered non-destructive to core plugs, simple to apply, and inexpensive. [2]

The methods to find the sonic velocity are frequency resonant techniques the ultrasonic and low-frequency sonic waves [3, 4].

The ultrasonic approach, which is considered the most convenient, may be used to figure out the mechanics of rocks using one of these ways.

The method of ultrasonic wave velocity is useful to find the S-and P-wave velocities and the constants of ultrasonic that are useful in defining the dynamic properties for the core plugs such as shear modulus, Young's modulus, Poisson's ratio, and bulk modulus. This method can be used in both laboratory and field because it is easy to use the device ultrasonic and fast. [5, 6]

Numerous researches employed ultrasonic techniques to separate the various geomaterials and found that this was the best approach to analyze the elastic characteristics of these materials. [7, 8-11]

P- and S-wave velocities were shown to be closely related to a wide variety of rock parameters. [2, 3, 12- 17]

Seismic velocity is strongly correlated with rock characteristics, according to the findings.

Seismic velocity and rock characteristics seem to be tightly linked, according to the findings. Analyzing dynamic elastic characteristics of carbonate rocks in Mishrif reservoir by employing an ultrasonic technique and a low-cost way to establish the association between P and S wave velocities and rock properties is what the research is all about

Location of the Study Area

West Qurna is a supergiant oil field in the southeast of Iraq; it is around 70 kilometers north-west of Basra. The field is located between (3425.000°-3400.000°) north longitudes and (716000° - 732000°) east latitudes. As shown in Figure 1.

Figure 1: Location Map of West Qurna-1 Oilfield Southern of Iraq

Geology of the Study Area

A heterogeneous carbonate reservoir has formed in the West Qurna-1 oil field, known as Mishrif.

An important reservoir not just in the West Qurna-1 area but across southern Iraq is the Mishrif formation. Above and below, as seen in Figure 2, the Khasib Formation and Rumaila Formation separate this formation.

Mishrif formation consists of the anticlinal fold with gentle dips. The length of the structure is about 42 km and width 16.5 km from the center of the area, and the depth of Mishrif

formation at top of the structure is (2207 m) at well (WQ-110), and thickness about (202 m).

CapRock I, Upper Mishrif (MA), Cap Rock II, and Lower Mishrif (LM) are all Mishrif Formation units in the West Qurna oil field (MB1 and MB2 respectively).

1-Cap Rock I

CapRock I is the upper part of the Mishrif formation. It consists of compact limestone, mudstone, and wackestone. It is locally clayey, particularly in the higher section. This unit is characterized by relatively low porosity and permeability.

2-MA unit (Upper Mishrif)

MA or upper Mishrif unit starts with the porous limestone below the tight Cap Rock I and the bottom of this unit is the top of the compact limestone of Cap Rock II. The highest section of this unit is limestone, followed lower by limestone with some packstone and lastly limestone. Fine-grained chalky textured limestone dominates the majority of this unit.

3-Cap Rock II

This unit comprises limestone developed in a sub-tidal environment, hard, thick, non-fossiliferous, and sometimes shaly. Because of its compactness and lack of porosity, this unit serves as a cap rock for unit MB1.

4-MB1 unit (Lower Mishrif)

This unit starts with the porous limestone below the tight Cap Rock II. This unit is an important portion of the Mishrif Formation since it holds a significant amount of Mishrif oil. This is because it includes the porous and permeable Rudists biostromes.

5-MB2 unit (Lower Mishrif)

Because of its high porosity and permeability, this unit is highly regarded. The Rumaila formation's sub-basinal facies lies at the base of this unit, which descends from MB1's lowest biostrome.

Figure 2: Stratigraphic column for the southern region of Iraq.

Collection and processing of samples

Eleven rock samples were taken from the well WQ1-20 for Mishrif formation. The vertical intervals between the core plugs were not equal. The length of cores was a range between 6.8 cm in core number two and 7.22 cm for core number 7. the plugs one and eight were damaged. The depth of Mishrif formation for each core is illustrated in table 1.

Table 1: The collected samples from WQ1-20

WQ	20			
diameter	3.745 cm			
Plug no	depth	unit	Length (cm)	Core description
1	2246.86	MA-1	7	Ls, bu, hd, styl, p p vug
2	2256.39	MA-2	6.8	Ls, bu, hd, f p p vug
3	2273.33	MB-1	7.14	Ls, bu, hd, styl, grad-cont
4	2279.73	MB-1	7.7	Ls, bu, hd, chky, p p vug
5	2310.78	MB-2	7	Ls, bu, hd, chky, p p vug, vug i p
6	2315.64	MB-2-1	7.05	Ls, bu, hd, chky, p p vug
7	2320.44	MB-2-1	7.22	Ls, bu, hd, chky, p p vug
8	2325.5	MB-2-2	7	Ls, bu, hd, chky, p p vug
9	2330.5	MB-2-2	7.1	Ls, bu, hd, chky, micro-frac
10	2320.62	MB-2-1	7.07	Ls, bu, hd, chky, p p vug
11	2321.86	MB-2-1	7.2	Ls, bu, hd, dead oil, chky

Density measurements

$$\rho \text{ (kg/m}^3\text{)} = \frac{\text{mass of sample}}{\text{volume of sample}} \quad (1)$$

Because of the compaction and microfractures, the density for the dry core plugs ranged from 1918 kg/m³ to 2253 kg/m³.

The calculations of velocity

The New Sonic Viewer (model 5217A) at the petroleum engineering lab at the University of Baghdad was used to determine the shear and compressional wave velocities for the core samples. Transmitted ultrasonic impulses are captured in the transit time (t). The transducers were pushed to the ends of the core samples using the core plugs, which were

then put between the transmitter and receiver until a steady transit time could be recorded. To get good contact between the transducers and the surface of samples we put special grease between them.

To calculate the shear and compressional wave velocities (V_s and V_p) values the following equations will be used :

$$V_p = \frac{L}{T_p} \dots \dots \dots 2$$

$$V_s = \frac{L}{T_s} \dots \dots \dots 3$$

Where:

L = the sample length in cm

T_p and T_s =the transit time (P and S wave)

The compressional velocity (V_p) values of samples at the study area varied from 2073.17 m/s to 4353.65 m/s with an average value of 2796.74 m/s, while the shear velocity (V_s) values varied from 1546.05 m/s to 2789.06 m/s with an average value of 1840.59 m/s.

The waveform for plug no 10 as in the following figure

Figure 3: P wave velocity form for plug no 10

Dynamic elastic moduli

Shear modulus, Young's modulus, bulk modulus, Poisson's ratio, and the Lamé's constant are all examples of elastic moduli. [20].

The following formulae may be used to determine the elastic moduli of core plugs by measuring their compressional and shear wave velocities and densities:

$$E = \frac{\rho v_s^2 (3v_p^2 - 4v_s^2)}{v_p^2 - v_s^2} \quad (4)$$

$$K = \rho \left(v_p^2 - \frac{4}{3} v_s^2 \right) \quad (5) \quad (5)$$

$$\sigma = \frac{v_p^2 - 2v_s^2}{2(v_p^2 - v_s^2)} \quad (6)$$

$$G = \rho v_s^2 \quad (7)$$

$$\lambda = \rho (V_P^2 - 2V_S^2) \quad (8)$$

Where the bulk modulus K, the Poisson's ratio, the shear modulus G, the Lamé's constant, the density, the velocity of the P-wave and the velocity of the S-wave, and Young's modulus E are all included.

The Results and discussion

The properties found from compressional and shear wave velocities for the core plugs collected from the well WQ1-20 are mentioned in table 2 where the values for the elastic properties for the core samples are different.

The values of young modules (E) ranged from 1.0716 E+10 to 3.73 E+10, the bulk modulus (K) ranged from 0.4272 E+10 to 1.78 E+10, the Poisson's ratio (σ) ranged from 0.037 to 0.25.

The shear modulus (G) ranged from 0.472 E+10 to 1.62 E+10, and the Lamé's constant (λ) ranged from 0.046 E+10 to 0.84 E+10 Pascal.

To describe the relationship between the elastic modulus and the ultrasonic wave velocities for the core plugs, applying regression analysis taking the best equation that gives the best fit line and the high value of R^2 for each equation. This section aims to present and discuss the correlations found from the velocity measurements to estimate the properties of core plugs.

Table 2: For the core samples studied in this location, the velocity measurements yielded the most important attributes.

plug no	Vp(m/sec)	Vs(m/sec)	VB	E	K	VP/VS	σ	G	λ
4	2490.385	1726.667	85.6228	1.18639	0.4272	1.44231	0.0371	0.57195	0.0459
6	2381.757	1546.053	77.6886	1.0716	0.49053	1.54054	0.1359	0.4717	0.17607
7	2776.923	1961.957	79.562	1.54541	0.51684	1.41538	0.0017	0.77143	0.00256
5	2536.232	1620.37	77.1376	1.36672	0.66054	1.56522	0.1551	0.59158	0.26615
11	2571.429	1550.722	79.3416	1.12812	0.65795	1.65821	0.2142	0.46454	0.34825
10	2638.06	1822.165	77.909	1.37492	0.50231	1.44776	0.0438	0.65861	0.06323
2	2428.571	1619.048	74.9337	1.18341	0.49309	1.5	0.1	0.53791	0.13448
3	4353.659	2789.063	78.6804	3.73563	1.78892	1.56098	0.152	1.62141	0.70798
9	3349.057	1929.348	78.2396	2.07634	1.39335	1.73585	0.2516	0.82945	0.84038

The relationship between Vs and Vp

The relationship between Vp and Vs is established from the values taken from the ultrasonic device. The relationship was positive linear between Vp and Vs with the coefficient of determination R^2 equal to 0.8768 as shown in Figure-4. The equation for the relationship between (Vp and Vs) is given below:

$$V_s = 0.5368V_p + 339.22$$

Figure 4: The relationship between Vp and Vs values of Mishrif Formation

The relationship between rock density (ρ) and P-and S-wave velocities

Figures (5,6) show the connection between rock density (ρ) and (V_p - and V_s) for the rock samples. The P- and S-wave velocities rose linearly as the rock density (ρ) increased. In the following table, the empirical relationships between (ρ) and V_p and V_s are shown.

Figure 5: The relation between V_p and ρ of mishrif formation

Figure 6: The relation between V_p and ρ of mishrif formation

The relationship between Young's modulus (E) and P-and S-wave velocities

An elastic modulus is a measure of a material's ability to withstand deformation under stress. The Young's modulus of compacted cemented rocks is greater than that of porous rocks. Young's modulus is an indicator of how much stress is necessary to distort a material.

Figures-7 and 8 show a linear relationship with high regression coefficient values ($R^2=0.97$ and 0.92) between E and (P- and S) wave velocities, respectively. The empirical relations between E and V_p and V_s are given below:

$$E=0.0013*V_p-2.0323$$

$$E=0.0022*V_s-2.4514$$

Figure 7-The relation between V_p and (E) of mishrif formation

Figure 8: The relation between Vs and (E) of mishrif formation

Correlation between (K) and (Vp and Vs)

Bulk modulus is another elastic constant that has been investigated in this study. These rocks are being tested for their ability to withstand compression. Compared to porous rocks, compacted cemented rocks have a higher K content. Figures-9 and 10 show the relationship between K and (P- and S-wave) velocities. There is a strong linear positive connection between the K and Vp, whereas there is a weak linear positive correlation between the K and Vs, according to the high regression coefficient ($R^2 = 0.92$). These relationships are shown in the following equation:

$$K = 0.0007 \cdot V_p - 1.321$$

$$K = 0.5789 \cdot V_p + 198.78$$

Figure 9: The relation between Vp and (K) in the study area.

Figure 10: The relation between Vs and (K) in the study area.

Correlation between (σ) and velocity Ratio (V_p/V_s)

Engineering studies rely heavily on the Velocity Ratio (V_p/V_s), which is a stronger predictor of lithology than individual velocity values, and Poisson's ratio (σ), which is a better indicator of rock quality and strength (V_p and V_s). [21,22]

The relationship between V_p/V_s and (σ) is plotted in Figure-11. It shows a linear relationship with high a regression coefficient ($R^2=0.9677$), which indicates that the Poisson's ratio increases linearly with increasing (V_p/V_s). The following equation defines this relationship:

$$\sigma = 0.78606 (V_p/V_s) - 1.0814$$

Figure 11: The relation between (V_p/V_s) and (σ) in the study area.

The relationship between shear modulus (G) and (V_p and V_s)

The shear modulus is defined as the ratio of shear stress to shear strain. It is also known as the modulus of rigidity and may be denoted by G.

Shear modulus can be used to examine the rigidity of the rock. [20]

The shear modulus of hard rocks is greater than that of soft rocks. It takes more stress to create deformation in rocks with a higher shear modulus value. The relationship between compressional wave velocity and the shear modulus with a regression coefficient that is equal to 0.94 as in figure-12.

A similar relationship between shear wave velocity and shear modulus with a higher determination coefficient R^2 that is equal to 0.98 as in figure-13.

Figure 12-The relationship between Vp and G for the core plugs

Figure 13-The relationship between Vs and G for the core plugs

The relationship between (λ) and (Vp and Vs)

Core plug seismic velocities (Vp and Vs) and the Lames constant are depicted in figures 14 and 15. The linear connection between Vs and Vp with Lame's constant and high-value regression coefficient R^2 means that the λ grows linearly with rising Vp. Here are the empirical correlations between λ and Vp and Vs:

$$\lambda = 0.0004 * V_p - 0.7303$$

$$\lambda = 0.0004 * V_s - 0.4753$$

Figure 15-The relationship between V_p and λ for the core plugs

Figure 16-The relation between V_s and Lamé's constants (λ) for the core plugs

PRESENT WORK APPLICATIONS

The estimated relationship between P-and S-wave velocities from the core plugs in the lab was used to find S-wave velocity for the log with V_p log and plotted with V_s that is found from the correlations (Pickett, 1963; Carroll, 1969; and Al-Kattan, 2015) as shown in Figure 17.

Figure 17:the Vs predicted from new correlation versus Vs from the correlations

The above figure shows a good relationship between the correlations and the new correlation.

CONCLUSIONS

This study aims to find the elastic properties for Mishrif formation in the West Qurna-1 oil field by determining the relationships between rock properties and P-and S-wave velocities from the experimental work.

The results showed a linear relationship between P and S-wave velocities with dynamic elastic properties of carbonate rock where the values of determination coefficient (R^2) are different for each value.

With R^2 greater than 0.9 between P-wave velocities and parameters such as density and lame's constant, bulk modulus, density, and lame's constant may be best linked to the P-wave velocity. Young's modulus is related with the P-wave velocity with R^2 equal to 0.97 while with an S-wave velocity equal to 0.92.

The relation between V_p/V_s ratio with Poisson's ratio showed a good R^2 with a value of 0.97.

From the current study, empirical equations were obtained that revealed the elastic properties of the carbonate rocks that can be determined by the ultrasonic wave velocities.

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