Laboratory Determination of Compressional and Shear Wave Velocities and their Inter-relationships on Core Samples of GS-15 & 23 Structures of KG Basin

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Summary

Compressional and Shear wave velocities (V_p & V_s) have been measured on dry and brine saturated core plugs of GS-15 and 23 structures of KG Basin under ambient as well as insitu confining pressure conditions. The data generated demonstrate simple linear relationships between V_p and V_s. For dry core plugs, the V_p-V_s curve passes through zero and it indicates a nearly constant Compressional to Shear wave velocity ratio. However, for brine saturated core plugs, the relationship between V_p and V_s is found to be as follows:

For GS – 15 V_p (m/sec) = 1.54 V_s + 782
For GS – 23 V_p (m/sec) = 1.20 V_s + 1251

Both the Compressional and Shear wave velocities correlate linearly with porosity. The relationships of Compressional and Shear wave velocities with porosity show that the velocities decrease with increase in porosity. Based upon these relationships, the matrix velocities V_p & V_s arrived at are 5866m/sec & 3227m/sec and 5685m/sec & 3751m/sec for GS-15 and 23 structures respectively.

Introduction

The velocity ratio V_p/V_s is becoming a very useful parameter in the determination of rock properties. Previous laboratory and well log studies have suggested correlations between lithology, porosity and V_p/V_s values (Picket, 1963; Gregory, 1977; Benzing, 1978; Tathom, 1982; Eastwood, 1983;; Rafavich et al, 1984; Costagna et al, 1985).The ratio of V_p to V_s has been used as a lithology indicator by Picket. There is a distinct difference in V_p/V_s for limestones, dolomites and clean sandstones. This separation appears to result from the difference in Poisson's ratio 'σ' of the matrix material, namely quartz and calcite.

Also, it has now been well established that the primary factor affecting acoustic velocities in porous media is porosity. Wyllie et al (1956) have reported a time average equation for the relationship between velocity and porosity which is given as:

$$\frac{1}{Vp} = \frac{(1-\phi)}{Vm} + \frac{\phi}{Vf}$$

when both V_m and V_f are fixed, only variable is ϕ. However, it is not suitable for every field as velocities are related to other parameters also besides porosity.

Picket (1963) proposed a velocity – porosity relation:

$$\frac{1}{V} = A + B\phi$$

Where, A and B are constants for a given rock type & in Wyllie's equation,

$$A = \frac{1}{V_m}$$

$$B = \frac{1}{V_f} - \frac{1}{V_m}$$

Methodology & Results

After cleaning the core plugs thoroughly and making them free from foreign materials, porosities and permeabilities were measured on dry plugs. Then the acoustic velocities were determined in the Acoustic velocity measurement system. Plugs were then fully saturated with brine to determine porosity (ϕ) and saturated bulk density (ρ_b) by saturation method. Then again the acoustic velocities were determined on saturated core plugs.

For determination of V_p and V_s, the core plug is placed in the pressure vessel between two platens which consist of piezoelectric transducers, one of which acts as an emitter and the other as a receiver. A Compressional ultrasonic (P) and two orthogonally polarized shear waves (S1 & S2) are propagated through the core sample. A short duration electrical pulse is supplied to the emitter transducer which is converted into mechanical wave on impact by the emitter. This wave is now transmitted to the core sample. After travelling through the core sample, the pulse is picked up by the receiving transducer, reconverted to an electrical signal and complete waveform is displayed on the oscilloscope. The velocities are calculated as follows:

$$V_p = L / \Delta T_p$$
$$V_s = L / \Delta T_s$$

Where V = Pulse propagation velocity in m / sec.
L = Pulse travel distance in centimeters
ΔT = Effective pulse travel time (i.e. measured time minus zero time correction)
Sonic travel time $\Delta T = 1/V$

This is done under ambient as well as insitu confining pressure conditions by applying pressures with the help of a hand pump provided for this purpose.

The values of Compressional and Shear wave velocities (V_p & V_s) on individual dry and saturated core plugs of GS-15 and 23 structures under ambient as well as reservoir confining pressures along with the values of the ratio Vp/Vs are given in the Table. The data indicates that the velocities at reservoir confining pressure are more as compared to those at ambient conditions for both the structures.

Also, for dry core plugs, the relationships between V_p and V_s show linear trends passing through zero giving constant values for the ratio V_p/V_s.

However, when the core plugs are saturated with brine, it is found that the wave velocities increase significantly as compared to those of dry core plugs both under ambient as well as under reservoir confining pressure conditions. The relationships established between V_p and V_s for brine saturated core plugs under reservoir pressure conditions are given by the following equations (Figure Nos. 1a & 1b):

For GS-15 $V_p(km/s) = 1.54\ Vs + 0.78$
For GS-23 $V_p(km/s) = 1.20\ Vs + 1.25$

Similar relationships have also been established by Costagna et al (1985) and Han et al (1986) with different values of coefficients for water saturated clastic silicate rocks and sandstones respectively.

The velocity data on saturated core plugs shows a considerable degree of dependence of velocity upon porosity. Both V_p and V_s correlate linearly with porosity (Figure Nos. 2a & 2b and 3a & 3b). The V_p-ϕ and V_s-ϕ cross-plots on a linear scale give the following relationships:

For GS-15 structures:

$$V_p(m/s) = 5866 - 132\ \phi$$
$$V_s(m/s) = 3227 - 80\ \phi$$

For GS- 23 structures:

$$V_p(m/s) = 5685 - 133\ \phi$$
$$V_s(m/s) = 3751 - 114\ \phi$$

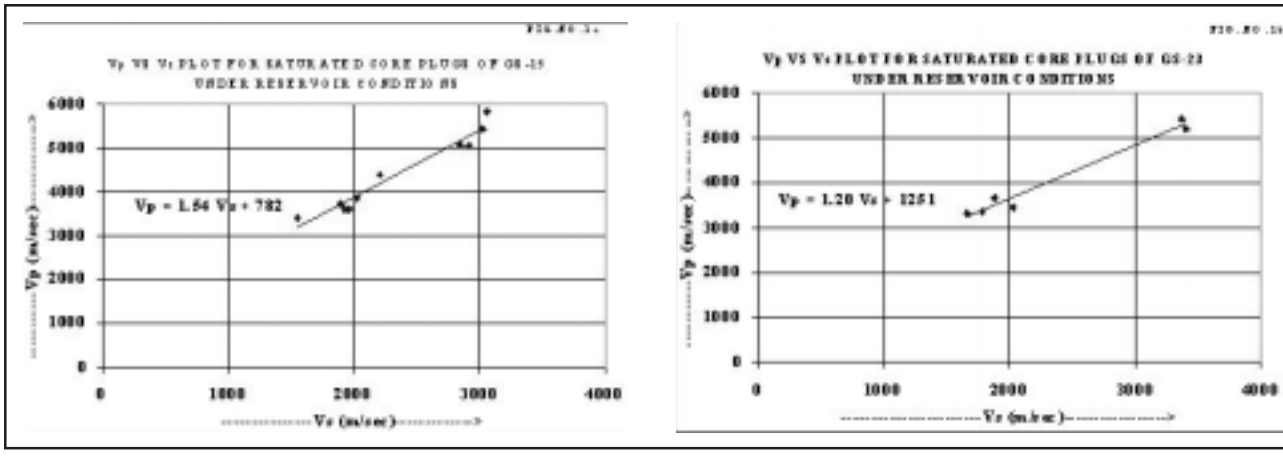

Fig 1 : Vp vs Vs Plots of saturated Plugs for (a) GS-15 and (b) GS-23 Structures Under Reservoir Confining Pressure

Table : Acoustic Velocities

Sl No.	Plug No.	Dry Plugs						Saturated Plugs					
		Ambient conditions			Insitu conditions			Ambient conditions			Insitu conditions		
		Vp (m/sec)	Vs (m/sec)	Vp/Vs	Vp (m/sec)	Vs (m/sec)	Vp/Vs	Vp (m/sec)	Vs (m/sec)	Vp/Vs	Vp (m/sec)	Vs (m/sec)	Vp/Vs
1.	GS-1	2859	1726	1.76	3470	2018	1.72	--	--	--	--	--	--
2.	GS-2	2602	1333	1.95	3248	1793	1.81	3021	1516	1.99	3857	2019	1.91
3.	GS-3	2069	992	2.09	2957	1447	2.04	2114	982	2.15	3394	1550	2.19
4.	GS-4	3838	1781	2.16	4982	2219	2.25	4455	2417	1.84	5037	2914	1.73
5.	GS-5	2367	1193	1.98	3463	1778	1.95	3135	1820	1.72	3712	1894	1.96
6.	GS-6	1728	1152	1.50	2852	1797	1.59	2778	1720	1.61	3593	1960	1.83
7.	GS-7	3767	2196	1.72	5395	2401	2.25	5141	2362	2.18	5827	3056	1.91
8.	GS-8	1961	1118	1.75	3500	2030	1.72	2093	1020	2.05	3593	1924	1.87
9.	GS-9	3335	1899	1.76	4128	2232	1.85	3599	1759	2.05	4376	2206	1.98
10.	GS-10	2542	1523	1.67	3307	1898	1.74	--	--	--	--	--	--
11.	GS-11	3273	1765	1.85	4653	2289	2.03	4265	2062	2.07	5072	2843	1.78
12.	GS-12	2129	1270	1.68	3851	1866	2.06	2742	1521	1.80	3175	2080	1.53
13.	GS-13	3635	1712	2.12	5055	2588	1.95	4977	2619	1.90	5437	3023	1.80
14.	GS-16	2260	1344	1.68	3524	1938	1.82	2965	1560	1.90	3652	1881	1.94
15.	GS-17	2484	1209	2.06	3116	1453	2.14	--	--	--	--	--	--
16.	GS-19	1702	1118	1.52	2530	1508	1.68	--	--	--	--	--	--
17.	GS-21	1883	935	2.01	2932	1692	1.73	2633	1287	2.05	3351	1785	1.88
18.	GS-22	2643	1482	1.78	3199	1788	1.79	2989	1848	1.62	3440	2026	1.70
19.	GS-23	2417	1437	1.68	3063	1925	1.59	2655	1404	1.89	3307	1664	1.99
20.	GS-24	3339	1893	1.76	4630	2460	1.88	4480	2915	1.54	5198	3401	1.53
21.	GS-25	4038	2206	1.83	4861	2763	1.76	4605	2500	1.84	5412	3365	1.61

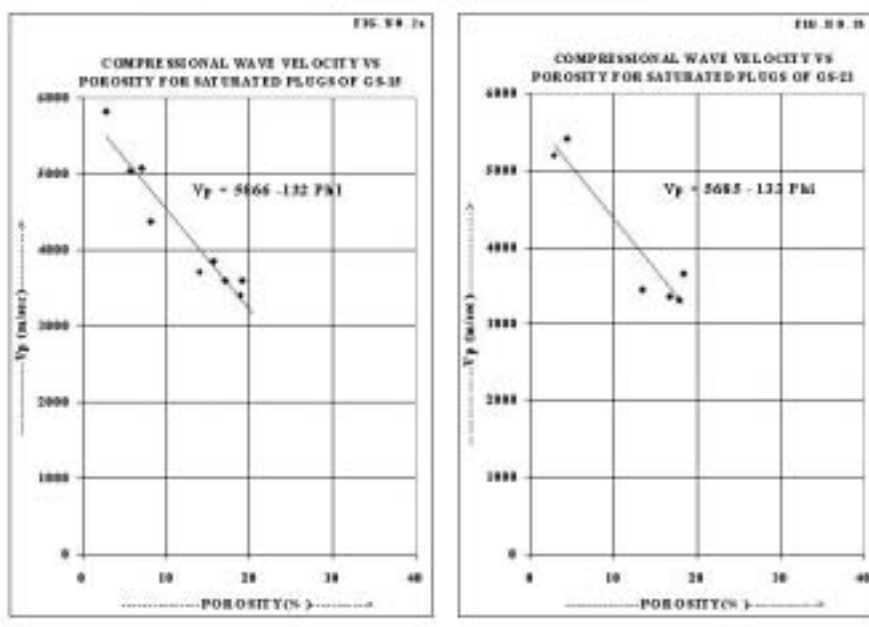

Fig 2 : Compressional Velocity Vs porosity plots of saturated plugs for (a) GS-15 And (b) GS-23 structures

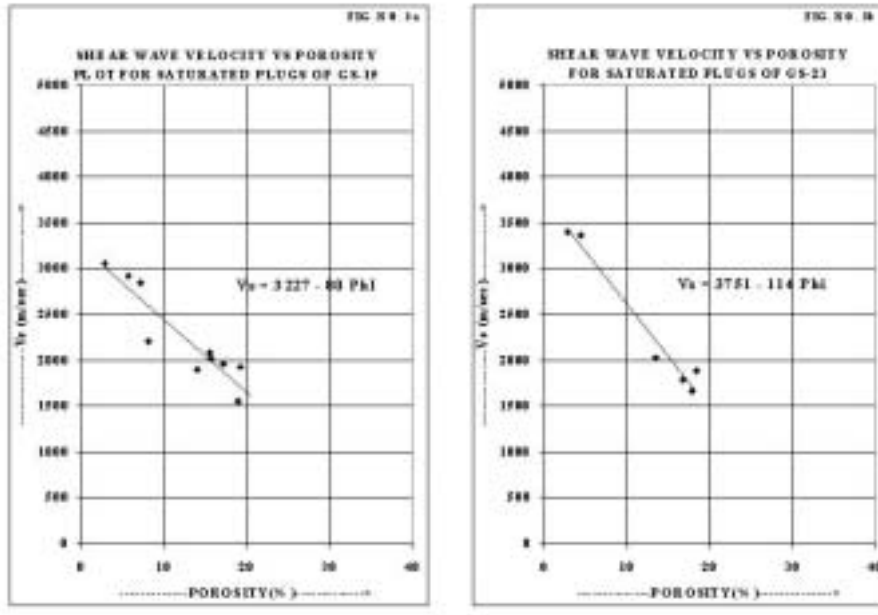

Fig 3 : Shear wave velocity vs porosity plots of saturated plugs for (a) GS-15 and (b) GS-23 Structures

Giving matrix velocities V_p & V_s of 5866 m/sec and 3227 m/sec for GS-15 and 5685 m/sec and 3751 m/sec for GS-23 structures respectively.

The relationships between transit time and porosity have also been established for both the formations.

$$\phi = 0.3226\ \Delta T - 15.806 \text{ for GS-15 structure}$$
$$\text{and } \phi = 0.2926\ \Delta T - 13.855 \text{ for GS- 23 structure}$$

The matrix times obtained from these relationships are 49 and 47 μsec for GS-15 and 23 structures respectively. Porosities determined by using these relationship match with the directly measured porosities on cores.

Conclusions

The experiments show to the first order that the velocities under reservoir confining pressure are more than

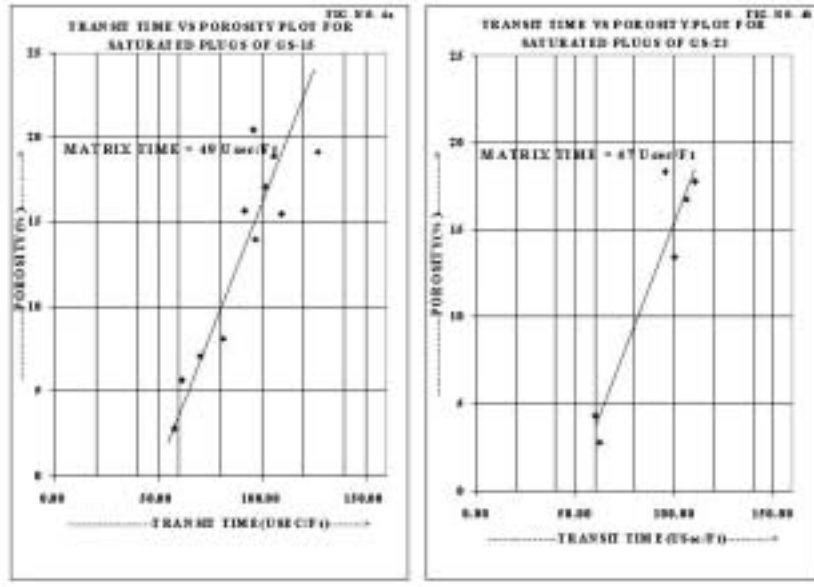

Fig 4 : Transit Time Vs Porosity Plots of Saturated Core Plugs for (a) GS-15 and (b) GS-23 Structures.

those at ambient conditions. When the core plugs are saturated with brine, the velocities increase as compared to those of dry plugs under ambient conditions.

There is a linear relationship between V_p and V_s. For dry core plugs, the V_p-V_s plot passes through zero giving a constant value of the ratio V_p/V_s. However, the brine saturated linear trend begins at V_p slightly less than the brine velocity and $V_s = 0$. The V_p-V_s plot intercepts on the V_p axis giving a velocity value of about 782 and 1251 m/sec for brine. The ratio V_p/V_s increases as we approach $V_s = 0$.

The velocities also have a considerable degree of dependence on porosity. Our data shows that both V_p and V_s correlate linearly with porosity and the velocities decrease with an increase in porosity. The matrix velocities V_p & V_s obtained are 5866 m/sec and 3227 m/sec for GS-15 and 5685 m/sec and 3751 m/sec for GS- 23 structures respectively. The Transit time-Porosity relationships can be used for determination of porosity from transit times recorded in the wells of GS-15 and 23 structures.

Views expressed in this paper are that of author(s) only and may not necessarily be of ONGC.

Acknowledgements

The authors are thankful to Dr. D.M.Kale , ED-Head, KDMIPE for the encouragement and facilities provided during the study. They are also thankful to Sh. D. Sar, GM & Head, GSSG for critically reviewing the paper.

References

Benzing,W.M., 1978, Vp/Vs relationships in carbonates & sandstones, laboratory data: Presented at the 48th Annual International SEG Meeting, San Francisco

Costagna J P, Batzle M L, & Eastwood R L, 1985 Relationships between Compressional-wave and Shear-wave velocities in clastic silicate rocks. Geophysics, 50, 4, 571-581

Eastwood, I.R., 1983, Basis for interpretation of Vp/Vs ratios in complex lithologies: SPWLA, 24th Annual Logging Symposium, G1-G17

Gregory,A.R., 1976, Fluid saturation effects on dynamic elastic properties of sedimentary rocks: Geophysics, 41, 895-921

Han, D. Nur, A & Morgan D, 1986 Effects of porosity and clay on wave velocities in sandstones. Geophysics 51, 11, 2093-2107

Lal Mohan, Pabla S S, 2004 Measurements of Compressional and Shear wave velocities on core samples of GS-15 and GS-23 structures of KG Basin. Unpublished Report, KDMIPE, ONGC, Dehradun.

Pickett, G.R. 1963, Acoustic character logs and their applications information evaluation. JPT 15, 650-667

Tathan, R.H., 1982, Vp/Vs & lithology: Geophysics 47, 336-344

Refavich, F.Kendall, C.H.St.C. & Todd, T.P., 1984, The relationship between acoustic properties & the petrographic character of carbonate rocks, Geophysics 49, 1622-1636

Wyllie M R J, Gregory A R & Gardener L W, 1956 Elastic wave velocities in hetrogenous & porous media. Geophysics 21, 41-70