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Prediction Relationships between Dynamic and Some Static Properties of Sedimentary Rocks in Kirkuk, Northern Iraq

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Abstract

The dynamic and static properties of rocks are essential demand for different types of engineering projects. In many situations there are difficulties in obtaining an adequate number of rock samples for laboratory tests in to determine the geotechnical properties of these samples. Therefore, to define the variety of static property parameters of certain rocks derived from the non-destructive geophysical refraction seismic technique, which is conducted in the field, could be achieved by solving problems in measuring the compression and shear wave velocities. Other procedures are the laboratory core sample, the Ultrasonic pulse test and the density measurement. Fifteen sedimentary rock samples composed of silty sandstones, Claystone, and clayey siltstone were prepared in the laboratory to measure compression and shear wave velocities then to calculate dynamic properties such as shear, Young's bulk, and Poisson's ratios.. The static properties, uniaxial compressive strength, material index, internal friction angle, and Young's modulus was determined by certain equations. The goal of this research is to derive empirical equations relating the dynamic parameters to the static parameter of the study rocks. The studied samples were classified as very strong competent and dense rocks.

Keywords: *Empirical relation, dynamic modulus, static modulus, Kirkuk, Iraq*

1. Introduction

Knowledge of geotechnical properties of rocks is necessary for conducting various engineering projects, such as tunnels, quarries, roads, underground storage dams, buildings and drilling operations for groundwater, and fossil oil explorations. There are two methods for obtaining both static and non-static properties of the rocks. The first is a destruction method where the stress-strain relation is drawn to know the deformation behavior of the rocks, under conditions where the measurements of geotechnical properties could not be achieved easily to get and prepare intact rocks especially where the subsurface bed rocks are not outcropped to the surface. The second one is a non-destructive method used to determine dynamic moduli. The Ultrasonic pulse test for the compression and shear wave elastic velocities is applied to calculate the rock elastic dynamic properties. By constructing empirical relationships between the static and dynamic properties, the amount of the static property for a certain rock could be estimated from knowing its dynamic one. Many researchers studied the correlation between the static and dynamic properties of different rocks in many locations around the world. Altindag (2012) analyzed the data on sedimentary rocks from previous studies to correlate compression velocity with some mechanical properties; he constructed some empirical equations with high correlation coefficients. Hammam and Eliwa (2013) investigated the dynamic and static properties of soil in Saudi Arabia. They used cross-hole seismic and pressure meter methods to establish a good comparison between Young's and shear moduli and the standard penetration test. Najibi et al. (2015) correlated static uniaxial compressive strength and dynamic properties of limestone rocks in Iran and suggested equations that compared their relations with previous studies. Broton et al. (2016) studied the relationship between static and dynamicmodulus of different igneous metamorphic, and sedimentary rocks and proposed new relationships for those parameters. Majstorovic et al. (2019) measured the compressive strength and compression with shear wave velocities and dynamic modulus for different rocks to find relationships between those parameters. Using the least-squares method, they developed new empirical correlation equations. Garia et al. (2020) provided an overview of the correlation between variation in mineralogy and porosity with saturation condition and sedimentary rock compression wave velocity. The yielded analysis showed an increase in quartz content in the sandstone that led to a decrease in young modulus and compression velocity. Mehammod et al. (2020) carried out a refraction seismic survey at a site in Egypt to delineate subsurface characteristics by measuring compression and shear wave velocities. They determined the material index coefficient for the subsurface rocks and soils, categorized them into three different competent materials. Al-Awsi et al. (2021) investigated the ability of the geophysical Ultrasonic method to estimation geotechnical parameters for engineering applications. They classified the studied rock samples into incompetent and fairly competent materials, and they are suitable as foundations for engineering projects. Panchal et al. (2024) studied the correlation between the static

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modulus determined by the uniaxial compression test and the dynamic elastic modulus determined by the Ultrasonic pulse velocity test for different sedimentary, metamorphic and Igneous rocks. They proposed a correlation equation using the linear regression statistical method.

The determination of static uniaxial compression strength and static Young modulus are two necessary parameters for any engineering project in design and construction. Therefore, this paper aims to establish empirical relationships between elastic compression, shear wave velocities and dynamic modulus with the material index, internal friction angle, Young's static modulus and uniaxial compressive strength of sedimentary rock samples taken from outcrops of the lower Bakhtiari Formation in the northeastern area of Kirkuk city.

2- Materials and methods

The uniaxial Compression Strength (UCS), static Young modulus (Es), material index coefficient (MI) and internal friction angle(Φ) amount for the rock samples in this study were determined using the empirical equations derived from many studies had been applied on the rock samples are situated in the countries nearby Iraq, as a result it might yield convinced finding.

Fifteen samples were taken from outcrop of sedimentary bedrocks of lower Bakhtiari Formation in northeastern of Kirkuk anticline near Shawan town locate about 20 km northeastern of Kirkuk city (35o 44' 51.04" N) (44o 35' 17.62"E) (Figure1), as (Compton,1962) the samples were classified into brown silty sand stones, brown claystone and brown clayey siltstone rock types.

Figure 1. Location of the study site from a satellite image (red square).

The rock samples were prepared in the to cut as cylinder shapes to determined its density(P), by Ultrasonic pulse test to determine compression(Vp) and shear(Vs) wave velocities using (Matest Ultrasonic Tester C372 N) by applying the two probes terminate form the tool upon the two end faces of the rock sample, then the dynamic shear(μ) modulus, Young(Ed) modulus, bulk (K) modulus and Possion s' ratio(σ) were calculated according to (Goodman,1989) using the following equations;

$\mu = P (Vs)2$ $E = 2\mu (1+\sigma)$

$K = E/ 3(1-2\sigma)$

$\sigma = (Vp)2 - 2 (Vs)2) /2 [(Vp)2 - (Vs)2]$

The uniaxial compressive strength(UCS), Young static modulus(Es), material index

(MI) and internal friction angle (Φ) are determined as follows:

$UCS = 7.1912Vp + 26.258$ (Tercan et al ,2005)

UCS (Uniaxial Compression Strength) Vp (compression wave velocity)

$Es = 0.74Ed - 0.82$ (Essa & Kazi ,1988)

Es (static Young modulus) Ed (dynamic Young modulus)

$MI= 3-(Vp - Vs)2 / (Vp - Vs)2-1$ (Abd-El Rahman ,1989)

(MI material index) (VP & Vs compression and shear velocity)

$\sin\Phi = 1- [(Vp - Vs)2 -2 / (Vp - Vs)2]$ (Abd-El Rahman ,1989)

The results data include dynamic parameters and some static coefficients which are subjected to statistical processes and rely on simple regression analysis to derive empirical relationships and related equations.

3- Results and discussion

Table1 shows the calculated physico-mechanical measured properties of the studied rocks, including density, compression and shear wave velocities, dynamic shear, dynamic Young, and dynamic bulk moduli, in addition to Poisson's ratio . The Vp/Vs ratio range (1.48- 1.59), the compression velocity range (1558-2109) m/s, and the shear velocity range (847-1345) m/s.The rock's density range (2.1-2.48) g/cc and the Poisson's ratio range (0.21-0.44).The shear modulus range (1578- 5140) MPa, dynamic Young modulus range (6471-12458) MPa, and dynamic baulk modulus range (5475-29661) MPa.

Table 1. physical and dynamic properties of the study rocks.

Sample no	Vp (m/s)	Vs (m/s)	P (g/cc)	μ MPa	σ	Ed MPa	K MPa	Vp/Vs	description
1	1849	1223	2.4	3589	0.28	9187	6959	1.51	Br claystone
2	1934	1239	2.3	3530	0.38	9744	13533	1.57	Br claystone
3	2109	1345	2.35	4251	0.41	11987	22198	1.56	Br. Claystone
4	1948	1236	2.48	3788	0.42	10757	22410	1.57	Br. Claystone
5	1759	1169	2.29	3129	0.26	7885	5475	1.5	Br. silty Claystone
6	1321	847	2.2	1578	0.36	4292	5109	1.55	Br. silty Claystone
7	1734	1094	2.1	2513	0.44	7238	20105	1.58	Br. silty Claystone
8	2321	1495	2.3	5140	0.37	14083	18055	1.55	Br. silty Claystone
9	1663	1069	2.35	2685	0.38	7411	10293	1.55	Br. silty sandstone
10	1762	1172	2.3	3217	0.26	8106	5629	1.5	Br. silty sandstone
11	1898	1231	2.4	3636	0.35	9819	10910	1.54	Br. silty sandstone
12	2083	1320	2.5	4356	0.43	12458	29661	1.57	Br. silty sandstone
13	1568	985	2.3	2231	0.45	6471	21570	1.59	Br. clayey siltstone
14	1932	1302	2.3	3898	0.21	9435	5421	1.48	Br. clayey siltstone
15	1753	1104	2.25	2742	0.44	7896	21933	1.58	Br. clayey siltstone

Table 2 shows the material index (MI), internal friction angle (Φ), static Young modulus (Es), and uniaxial compressive strength (UCS). The material index values range (0.33 – 0.68), the internal friction angle range (52-65) degree, the static young modulus range (2037-6805) MPa, and the uniaxial compressive strength range (11302-16717) MPa.

Table 2. Static properties of the study rocks.

Sample no	MI	Es MPa	Φ degree	UCS MPa	description
1	0.56	4372	60	13322	Br. Claystone
2	0.36	4451	54	13934	Br. Claystone
3	0 .39	6805	55	15192	Br. Claystone
4	0.36	4816	54	14034	Br claystone
5	0.6	3291	62	12675	Br. silty Claystone
6	0.42	2037	56	9525	Br. silty Claystone
7	0.33	3089	53	12495	Br. silty Claystone
8	0.42	6697	56	16717	Br. silty Claystone
9	0.42	3390	56	11985	Br. silty sandstone
10	0.6	3828	62	12697	Br. silty sandstone
11	0.45	4354	57	13675	Br. silty sandstone
12	0.36	4878	57	15005	Br. silty sandstone
13	0.30	2077	52	11302	Br. clayey siltstone
14	0.68	4595	65	13919	Br. clayey siltstone
15	0.33	3624	53	12632	Br. clayey siltstone

The Figures (2–7), which were constructed to determine the relationships between the physico-mechanical and dynamic properties of the studied rock samples, are expressed by linear regression equations; most of them have strong correlation coefficients. Figure 2a ies the relationship between the compression and shear elastic wave velocities of the silty sandstones claystone, and clayey siltstone rocks; it shows a strong correlation coefficient and a clear linear regression curve, indicating that they have confidence values to derive dynamic moduli. Figure 2 b is a dynamic Young modulus versus static Young modulus relationship with a high correlation coefficient; the static Young modulus can be estimated accordingly, which is the most needed property for rock deformation.

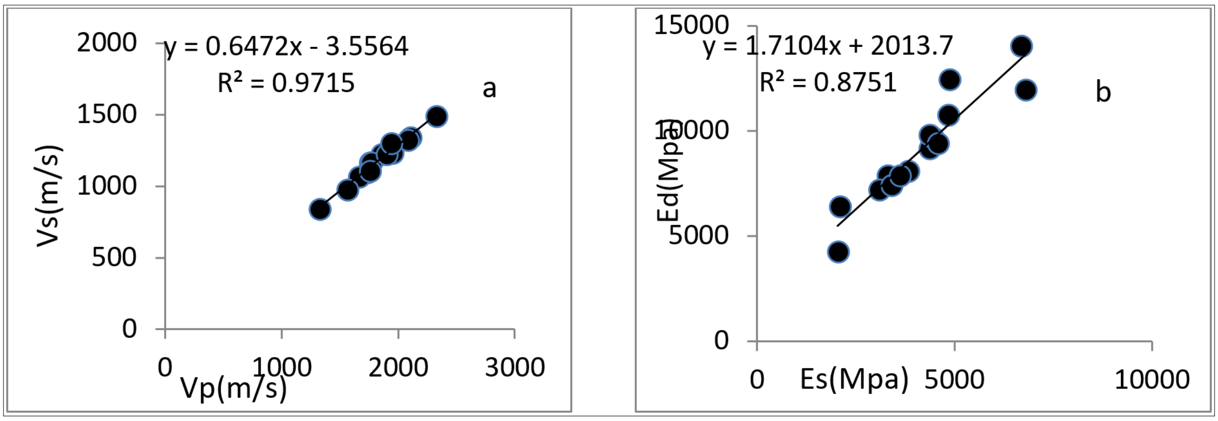

Figure 2. Relationship between: **a.** compression and shear wave velocities, **b.** dynamic and static young modulus.

The plots (Figure3a) and (Figure3b) show that the Poisson's ratio has a powerful reciprocal relationship with each material index and internal friction angle of the rocks, where the Poisson s' ratio decreases with increasing both properties. According to Sheriff and Geldart (1995), Tatham (1982), and Birch (1966), most of the studied rock material indices are classified as moderately competent to highly competent materials (Table 3). According to(Meyerhof, 1956) the studied rocks are classified as very dense materials based on their internal friction angle.

Table 3. Description of soil according to Poisson s' ratio and Material index.

Soil description parameter	Incompetent to slightly competent	Fairly to moderately competent	Competent material	Very high-quality material
Poisson's- ratio	0.41-0.49	0.35-0.27	0.25-0.16	0.12-0.03
Material index	-1 -- -0.5	-0.5 — 0.0	0.0— 0.5	0.5

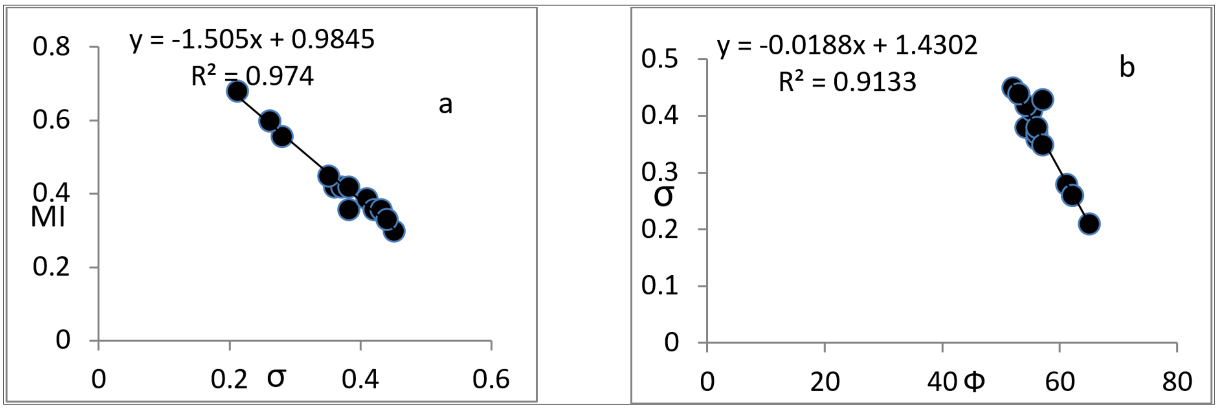

Figure 3. a. Material index versus Poisson's ratio plot, **b.** Poisson's ratio versus internal friction angle plot.

The relation between the material index and internal friction angle, as shown in(Figur4a) has a high correlation coefficient; the friction angle, which reflects the brittleness (Zhou et al,2018) of the soil and rocks, can be estimated by this relationship, which was gained by dynamic calculations. Figure 4b reveals a powerful relationship between the elastic compression wave velocity and uniaxial compressive strength. According to Bieniawsky (1989), the studied rocks are classified as very high-strength rocks.

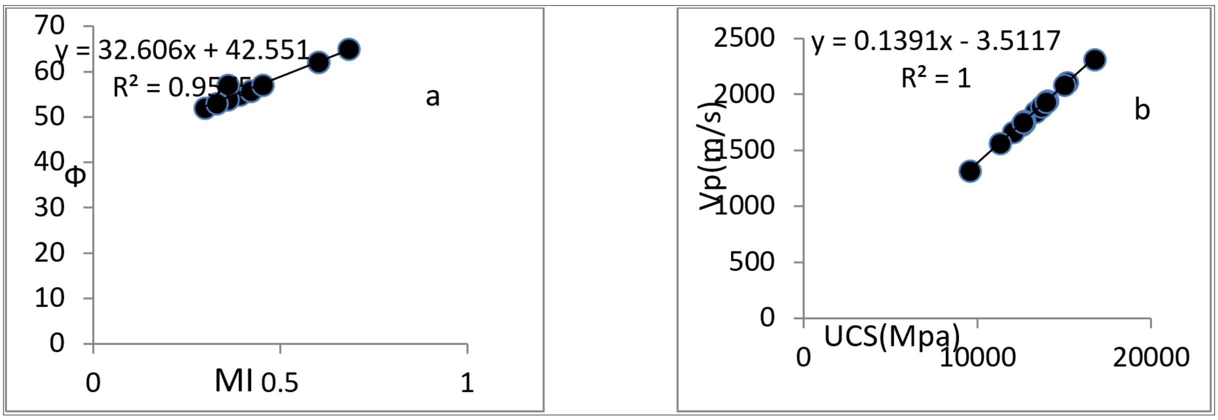

Figure 4. Relationship between **a.** internal friction angle and material index, **b.** compression wave velocity and uniaxial compressive strength.

Dynamic Young modulus in (Figure 5a) shows a strong correlation with the uniaxial compressive strength of the studied rocks; it is clear that an increase in Young dynamic modulus corresponds to an increase in the compressive strength of the rocks. This empirical relationship is confirmed by the relation between static Young modulus and uniaxial compressive strength (Figure 5 b).

Table 5. Correlation between: **a.** uniaxial compressive strength and Young's dynamic modulus, **b.** Young's static modulus and uniaxial compressive strength

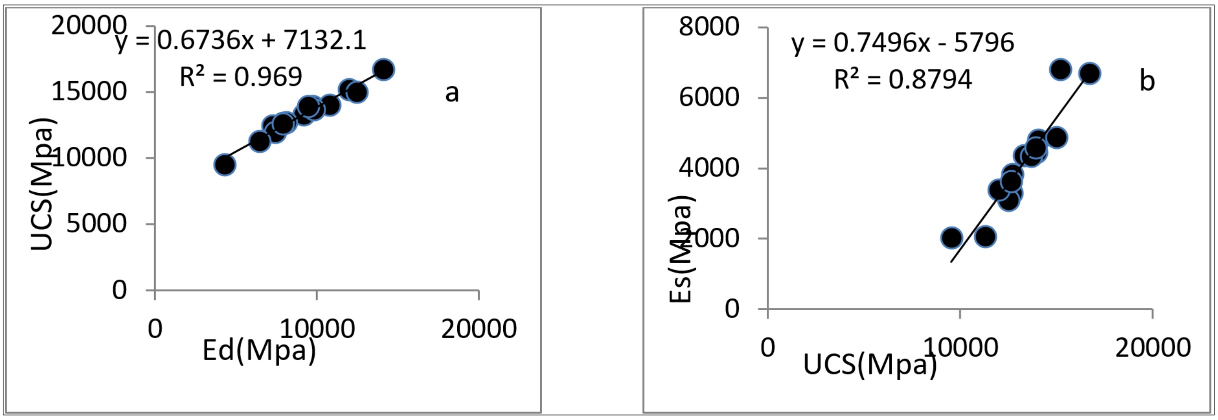

Figure 5. a. Material index versus Poisson's ratio plot, **b.** Poisson's ratio versus internal friction angle plot.

Figure 6a presents a reciprocal relationship between the dynamic bulk modulus (compressibility) and the material index with a moderate correlation coefficient. It is helpful to give information about the degree of competency in studied rocks by the dynamic property(k) indicator. Still, it has a direct relationship with the Poisson's ratio of the investigated rocks as shown in Figure 6 b.

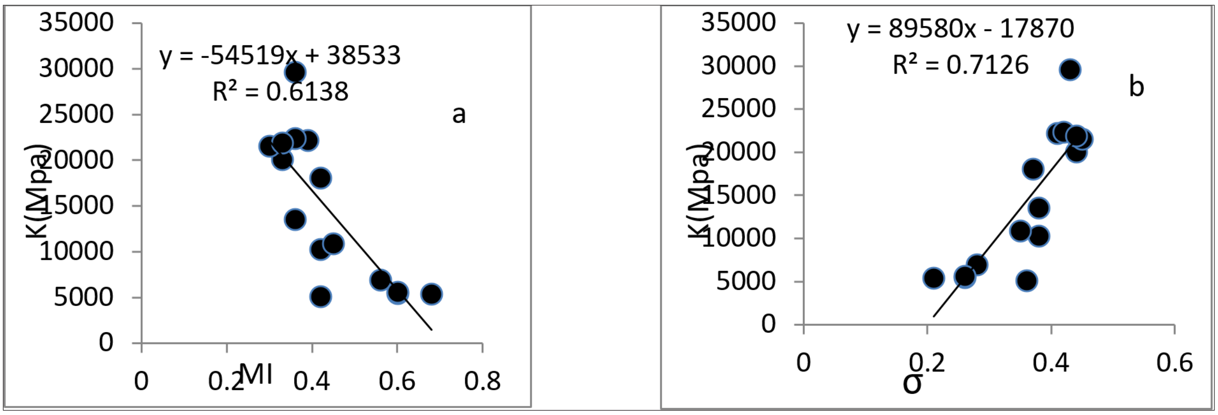

Figure 6. a. Bulk dynamic modulus versus material index plot, **b.** Bulk dynamic modulus versus Poisson's ratio plot

There is a good relationship between the compression wave velocity and the static Young modulus (Figure 7a). They have a high correlation coefficient; as a consequence, the engineer can obtain knowledge of that property from the seismic method procedure. Similarly, the relationship between the dynamic shear modulus and uniaxial compressive strength is shown in Figure 7 b.

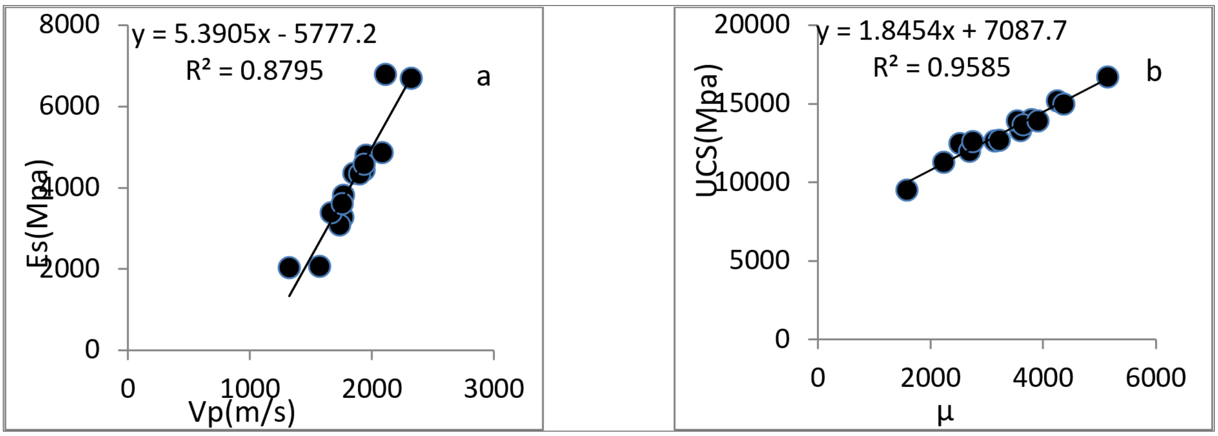

Figure 7. Relationship between: **a.**Young static modulus and compression wave velocity, **b.** uniaxial compressive strength and shear dynamic modulus.

4- Conclusions

Fifteen sedimentary rock samples have been chosen of silty sandstones, claystone and clayey siltstone compositions to determine the compression velocity, shear wave velocity, dynamic Young modulus with dynamic bulk modulus, and in static situation, material index, internal friction angle, uniaxial compressive strength and Young modulus were derived by application many available equations to construct empirical correlation equation between the dynamic and physical-mechanical properties. The highest correlation coefficient was in the high to very high range; accordingly, we could classify the studied rock into powerful rocks, moderately competent to highly competent materials, and very dense materials. Engineers might use this outcome to apply to future planned projects.

References

Al-Awsi, M.D., Khorshid, S.Z., Ahmed, M.T.(2021).Ultrasonic Method as a Tool for Geotechnical Parameters Estimation at Proposed Engineering Site/Western Iraq, Journal of Physics: Conference Series, 1818 (1), 012010

Abd El-Rahman, M.(1989). Evaluation of the kinetic elastic moduli of the surface materials and application to engineering geologic maps at Maba-Risabah area (Dhamar Province), Northern Yemen. Egyptian Journal of Geology,33: 229–250.

Altindag, R.(2012).Correlation between P-wave velocity and some mechanical properties for sedimentary rocks. Journal of The Southern Africa Institute of Mining and Metallurgy. Volume 112: 229-237.

Birch, F.(1966). Handbook of physical constants. Geol. Soc. Am. Mem. 97: 97–174.

Bieniawski, Z.T.(1989). Engineering rock mass classifications. New York: Wiley.

Brotons, V, Tomás, R., Ivorra, S, Grediaga, A., Martínez-Martínez, J., Benavente, D. and Gómez-Heras. M.(2016). Improved correlation between the static and dynamic elastic modulus of different types of rocks. Material and Structure ,49(8): 3021-3037.

Compton, R. R. (1962). Manual of field geology. Soil Science, 93(4), 295.

Eissa ,E. and kazi, A.(1988). Relation between static and dynamic Youngs moduli of Rocks. International Journal of Mock Mechanics Mining and Geomechanic Abstracts, Vol. 25, No. 6: 479-482.

Garia, S., Pal, K.A., Nair, A. M., and Ravi, K.(2020). Elastic wave velocities as indicators of lithology-based geomechanical behavior of sedimentary rocks: an overview. SN Applied Sciences (2020) 2:1521.

Goodman, R.E.(1989). Introduction to rock mechanics. (Vol. 2) : Wiley New York.

Hammam, A.H. and Eliwa, M. (2013). Comparison between results of dynamic & static moduli of soil determined by different methods. Housing and Building National Research Center journal, 9:144-149.

Majstorović, j., Gligorić, M., Lutovac, S. , Negovanović, M., and Crnogorac, L.(2019). Correlation of Uniaxial Compressive Strength with the Dynamic Elastic Modulus P – Wave Velocity and S – Wave Velocity of Different Rock Types. Underground Mining Engineering, 34 : 11-25.

Meyerhof, G. (1956). Penetration tests and bearing capacity of cohesionless soils. Journal of Soils Mechanic and Foundation Division ASCE, 82(SM1).

Mohammed ,M. A., Abudeif, A .M., and Abd el-aal, A .K. (2020). Engineering geotechnical evaluation of soil for foundation purposes using shallow seismic refraction and MASW in 15th Mayo, Egypt. Journal of African Earth Sciences 162 (2020) 103721.

Najibi, A. R., Ghafoori, M., Lashkaripour, G.R. and Asef, M. R.(2015). Empirical relations between strength and static and dynamic elastic properties of Asmari and Sarvak limestones two main oil reservoirs in Iran. Journal of Petroleum Science and Engineering 126: 78–82

Panchal, S., Ronghe, S .S. and Lokhande, R. D.(2024). Correlation between Static and Dynamic ‘ ‘Young’s Modulus of Elasticity of Different Types of Rocks. International Journal of Geology and Earth Sciences, Vol. 10, No. 1, 2024.

Sheriff, R.E., Geldart, L.P.(1995). Exploration Seismology. Cambridge university press, Cambridge.

Tatham, R.H.(1982). V p/V s and lithology. Geophysics 47 (3), 336–344.

Tercan, A. E., Unver, B., Tiryakil, B., and Ozbilgin, B.,2005. A study of relationships among mechanical, index and petrographic properties of some sandstones using canonical correlation analysis , (in Turkish). Madencilik ,vol.44,2005:3-14.

Zhou, H. , Chen, J. , Lu, J., Jiang, Y. and Meng, F.(2018).A New Rock Brittleness Evaluation Index Based on the Internal Friction Angle and Class I Stress–Strain Curve. Rock Mechanics and Rock Engineering. https://doi.org/10.1007/s00603-018-1487-0 (jun. 19, 2025)