

Determination some of Physical and Geotechnical Properties of the Calcareous Rocks in Kufa Quarry Using Ultrasonic Velocities

Emad H. AL-Khersan
Department of Geology
College of Science
Basrah University

Salman Z. Khorshid
Department of Geology
College of Science
Baghdad University

Haider H. Faraj
Department of Geography
College of Basic Education
Misan University

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ABSTRACT

Ninety eight oriented hand samples were collected from five sites represent calcareous outcrop of Euphrates Formation. These sites were chosen as a completed recovery for a region located at Kufa Quarry-Bahar Al-Najaf area / Middle of Iraq, in order to perform a geophysical study aimed to measure some of the geotechnical and physical properties for these rocks using New Sonicviewer instrument. Moreover, isotropy and seismic impedance were also determined. Longitudinal and Transverse seismic wave velocities had been measured for all samples. The average value for longitudinal velocities is 4294 m/sec and for the transverse velocities is 1870 m/sec. High consolidated limestone, dolomitized limestone and dolomite rock samples show highest longitudinal and transverse seismic velocity values, however, marl rock samples reflect the lowest values. Seismic velocities were measured in three directions;(bed strike, true dip and vertical on bedding plane). Therefore, isotropic factors were determined. It shows the existing of anisotropy between the different types of the considerable rocks of the area.. Finally, V_p , V_s , geotechnical and physical properties were measured for 17 saturated rock samples belong to site four. The results were compared with that of dry samples tests; however, saturated samples give clear decline in their values related to velocity and most of the remaining properties.

تقدير بعض الخواص الفيزيائية و الجيوتقنية للصخور الجيرية في مقلع الكوفة باستخدام

السرعة الزلزالية

حيدر حسان فرج
قسم الجغرافية
كلية التربية الأساس
جامعة ميسان

سلمان زين العابدين خورشيد
قسم علم الأرض
كلية العلوم
جامعة بغداد

عماد حسن رضا الخرسان
قسم علم الأرض
كلية العلوم
جامعة البصرة

المخلص

تم جمع 98 نموذجاً يدوياً موجهاً من خمسة مواقع تمثل مكاشف لصخور تكوين الفرات الجيري في منطقة الدراسة الواقعة في مقلع الكوفة - منطقة بحر النجف / وسط العراق، وذلك لغرض إجراء دراسة جيوفيزيائية هدفها قياس بعض الخواص الفيزيائية لهذه الصخور باستخدام جهاز توليد الموجات فوق الصوتية، فضلاً عن حساب معامل التماثل ومعاملات المرنة المختلفة وبعض الخواص الهندسية. تم قياس سرع الموجات الزلزالية الطولية والمستعرضة للنماذج الصخرية في منطقة الدراسة، وكان المعدل العام للسرعة الطولية 4294 م/ثا والسرعة القصية 1870 م/ثا، حيث أظهرت نماذج صخور الحجر الجيري عالي الصلابة والحجر الجيري المتدلمت وصخور الدولومايت أعلى قيم للسرع الزلزالية الطولية والقصية، في حين عكست صخور الصلصال أوطاً قيم لها، كما تم حساب عاملي التماثل للصخور من خلال قياس السرع الزلزالية في ثلاثة اتجاهات (باتجاه مضرب الطبقات، باتجاه الميل، وبالاتجاه العمودي على مستوى الطبقات)، وأوضحت قيم هذين العاملين عدم تماثل صخور المنطقة قيد الدراسة، كما تم تحديد نوع شحنة التفجير الملائمة لعمليات قلع الصخور في منطقة الدراسة. وأخيراً قيست السرع الزلزالية الطولية والقصية والخواص الجيوتهكنيكية والفيزيائية لـ 17 نموذج صخري مشبع بالماء الاعتيادي تابع للموقع الرابع وقورنت هذه النتائج مع نتائج فحوصات النماذج الجافة، حيث أعطت نماذج الصخور المشبعة انخفاضاً واضحاً في قيم السرع الزلزالية ومعظم الخواص المتبقية.

INTRODUCTION

Geophysical seismic surveys had been used widely for different important fields in order to identify the geology of the layers beneath the suggested sites that are considered as convenient locations for such engineering establishments like dams, tunnels, nuclear and electrical power energy stations. Ground water existence, rocks nature and its bearing capacities are the main factors that must be taken into consideration during geophysical surveys (Mousa, 2003, Espinosa *et al.*, 2006). Ultrasonic technique was used in this study to determine both longitudinal and transverse seismic velocities (VP, Vs) for rock samples. Moreover, rocks evaluation depending upon this technique gives good idea about the nature of these rocks and its geotechnical and physical properties. This may led to estimate the factors affecting on VP and Vs which occurred due to stresses and water saturation (ASTM, 2008). Many researchers inside and outside Iraq had been performed their studies concerning with ultrasonic technique.

The studied area reaches about 12 km² locates at the middle of Iraq with latitude (31°40'05''-31°50'31'') N and (44°13'00''-44°19'22'') E. It represents the calcareous outcrops in Kufa quarry-Bahar Al-Najaf area (Fig. 1). Lithologically, more than (25) % of the investigated area are covered by Quaternary deposits and

flood plain deposits (Holocene). Most remaining parts of the area were mainly consisting of calcareous Tertiary.

Euphrates Formation (Lower Miocene) (Jassim and Goff, 2006). Tectonically, the area understudy was situated inside the stable shelf (Salman zone) which characterized by the existing of NE-SW lineaments parallel to the main valleys trend in the whole area (Buday and Jassim, 1987).

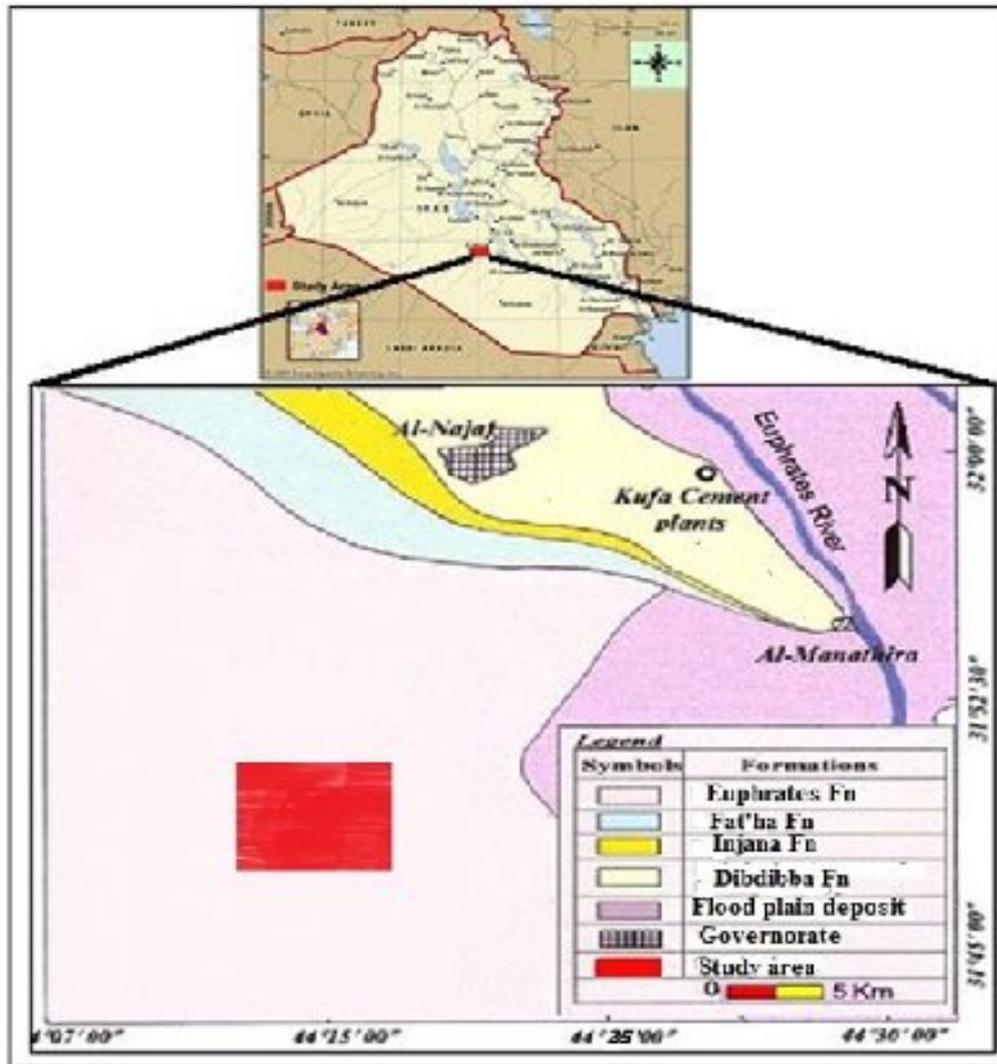


Fig. 1: Geological map and location of the studied area (After Al-Ali, 2004).

The main tasks of this paper are to:

- 1- measure VP, Vs and bulk densities for the extracted calcareous rock samples in order to study their geotechnical and physical properties and make a comparison among them.

- 2- identify the isotropy property for these samples to determine the regional trend of weak zones in the studied area. This may help workers in quarry operations.
- 3- calculate seismic impedance for the rock samples and determine the explosive type used for quarrying in the area.

FIELD WORK

Ninety eight oriented hand samples (mainly consist of hard limestone, dolomite, dolomitic limestone, marly limestone, fossiliferous limestone and marl) were collected from five sites represent Euphrates calcareous outcrop Formation during June / 2008 (Fig. 2). Altitude (strike and true dip) and coordinates for these sites were recorded more than once at each sampling site using Brunton Compass and Global Positioning System (GPS) respectively (Table- 1). After that, the extracted hand samples were brought to the workshop and trimmed into standard cubic sizes (with 10 cm length for each edge) using rock sample cutter. On the other hand, 19 hand samples were broken during cutting and transportation.

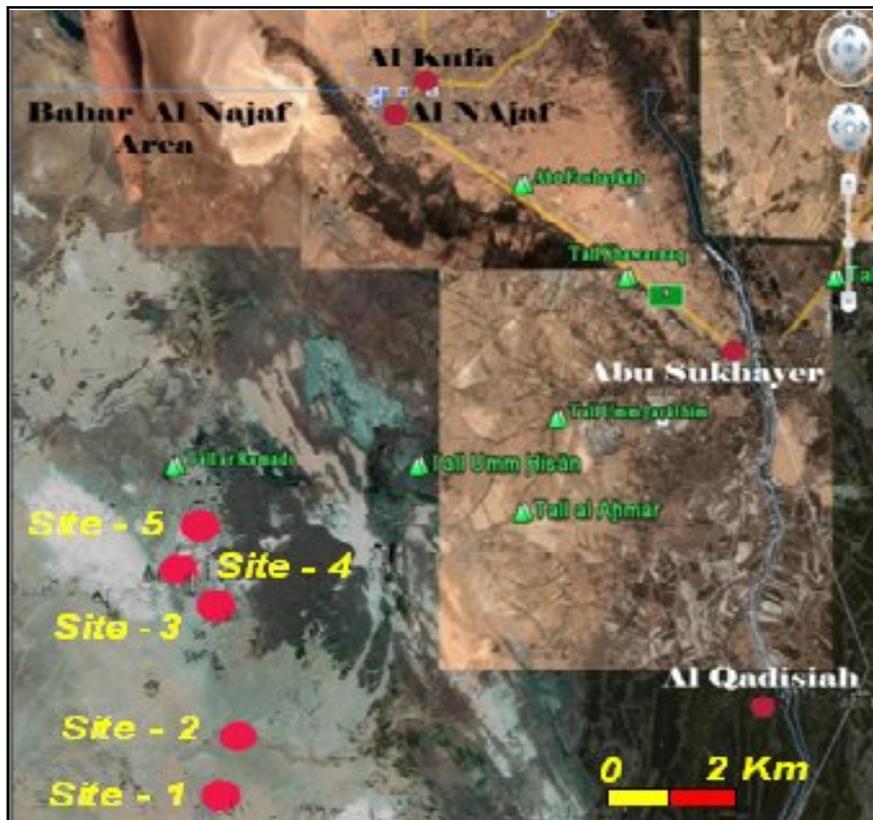


Fig. 2: Image taken for area understudy and the selected sites were illustrated.

Table 1: General Sampling Information about Rock Samples Collected from the Studied Area

Site No.	Coordinates		No. of samples	Altitude	
	Easting	Northing		Strike	True dip
1	44°19'22"	31°48'18"	13	N50°W	40°NE
2	44°14'22"	31°44'23"	20	N78°W	12°NE
3	44°14'09"	31°49'26"	15	N72°W	18°NE
4	44°13'41"	31°49'49"	20	N60°W	30°NE
5	44°13'49"	31°50'31"	30	N78°W	12°NE

MEASUREMENTS FOR DRY SAMPLES

For evaluating the mechanical properties of the calcareous rocks in the area, laboratory measurements have been done of both longitudinal and transverse wave velocities for 79 hand samples collected from the area under investigation. These measurements were conducted using New Sonic viewer (Model-5217A) available in Baghdad University. The arrival time of the propagated wave (T) was measured in three directions (strike, true dip and vertical to the bedding plane) and then after, VP and Vs were measured using the following equations:

$$V_p = L / T_p \dots\dots\dots 1$$

$$V_s = L / T_s \dots\dots\dots 2$$

Where L is sample length (cm), Tp and Ts is arrival time (mil sec). It appears that VP is ranged between (1574-7120) m/sec and the average is (4294) m/sec. However, Vs is found to be ranged between (759-3596) m/sec (average equal to 1870 m/sec). The minimum velocity values for each P and S waves represent marl hand samples and the maximum values are belong to hard limestone. Values in between referred to dolomitic limestone, marly limestone and fossiliferous limestone (Table-2). The average values of VP versus the corresponding Vs were plotted for all sites (Fig.3).

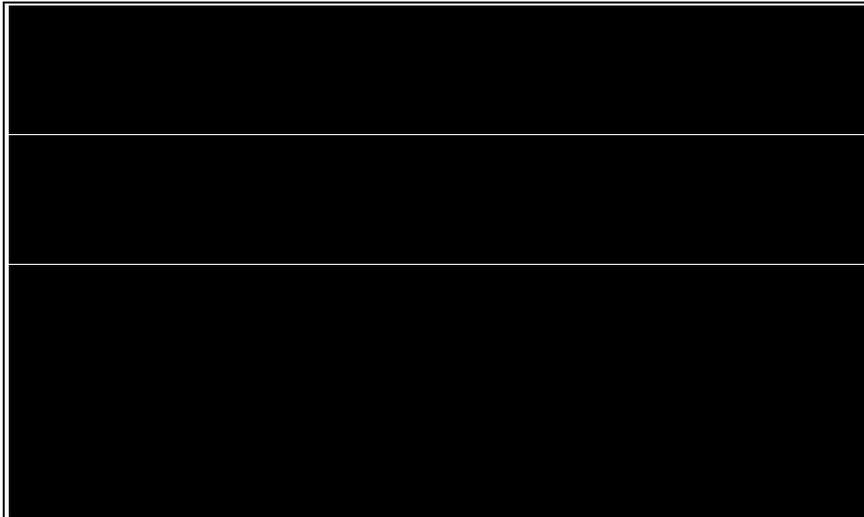


Fig. 3: V_p Versus V_s relationship.

DENSITY MEASUREMENTS

Routine method was used for dry density calculation as the equation below:

$$\text{Dry density-}D \text{ (gm/cm}^3\text{)} = \text{Weight-}W \text{ (gm)} / \text{Volume-}V \text{ (cm}^3\text{)} \dots\dots\dots 3$$

This equation was applied for all 79 rock samples and it reveals that the maximum value is found to be 2720 kg/m³ (represents hard limestone samples), however, marl samples has the minimum one (1055 kg/m³). The average value reaches about 2053 kg/m³. VP and Vs values for the whole samples were drawn versus calculated dry densities and a proportional linear relationship was noticed (Figs. 4 and 5).

Porosity Measurement

In laboratory, 17 out of 20 hand samples belong to site-4 were experienced to measure porosities using saturation method with water. This method is more important in deducing pore volume (Vv) and therefore the effective porosity (n) as follows:

$$\text{Weight of fluid in space} = \text{Weight of saturated sample} - \text{Weight of dry sample} \dots\dots\dots 4$$

From the equation 4, pore volume can be determined by the equation below:

$$n \text{ (\%)} = (V_v/V) \times 100 \dots\dots\dots 5$$

Table 2: Vp, Vs and Density Values for all Dry Samples

The average calculated porosity determined by this method is found to be equal to (6.383). A relationship between the VP and Vs (for saturated samples) values versus laboratory calculated porosities plotted (Fig.6). This may help in calculating A and B constants mentioned in equation as follows:

$$1/V = A + B n \dots\dots\dots 6$$

A and B are constants and can be determined using statistical expressions as follows:

$$B = [\sum X_i Y_i - \{ \sum (X_i) \sum (Y_i) / n \}] / \sum X_i^2 - (\sum X_i)^2 / n \dots\dots\dots 7$$

$$\text{Mean X} = \sum X_i / n \quad \text{and} \quad \text{Mean Y} = \sum Y_i / n \dots\dots\dots 8$$

$$A = \text{Mean Y} - B \times \text{Mean X} \dots\dots\dots 9$$

Where X_i is the porosity values measured in laboratory, Y_i is the $1/V_p$ or $1/V_s$ values and n is sample numbers.

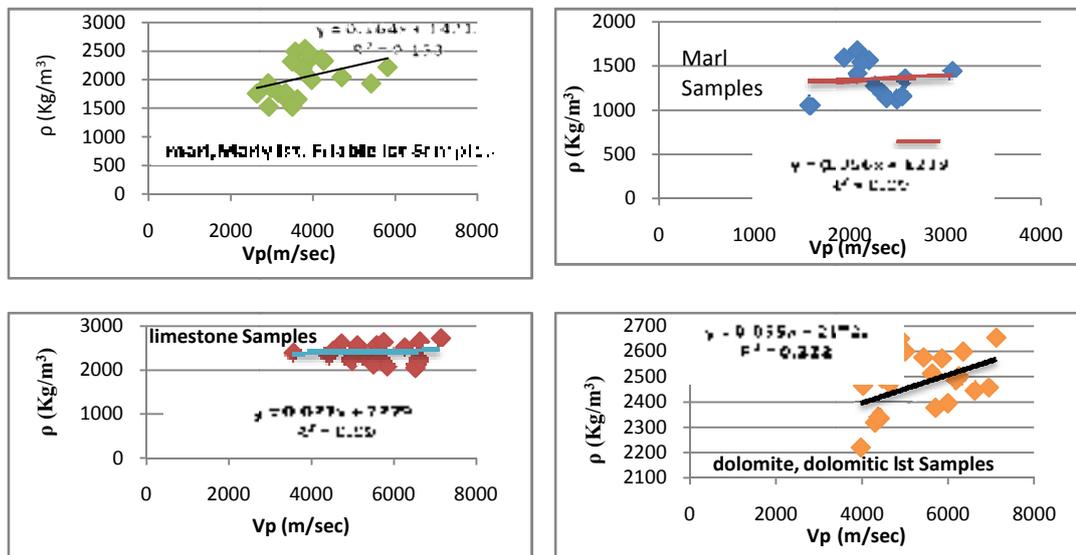


Fig. 4: V_p Versus Dry Density Relationships for Saturated Samples.

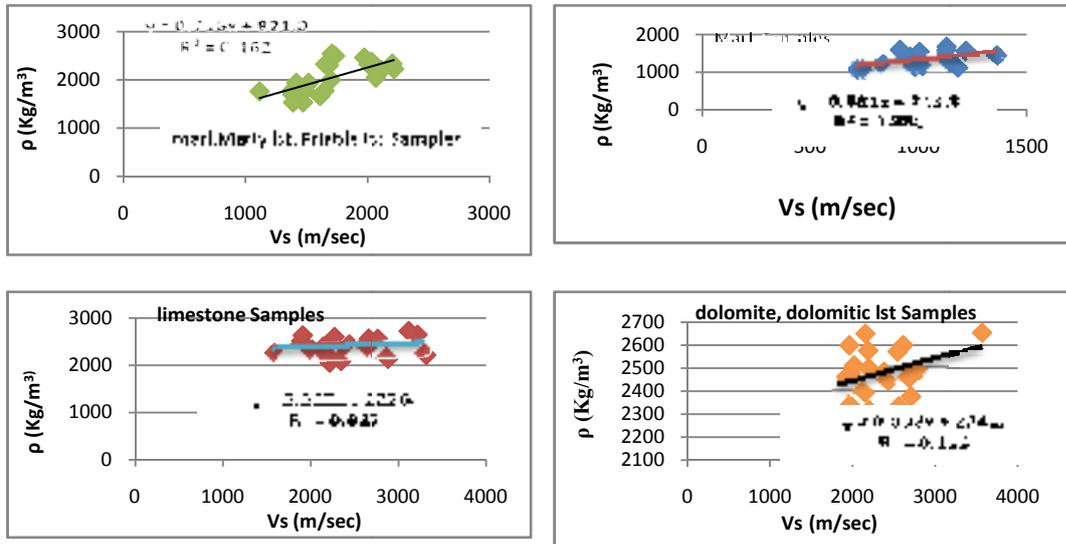


Fig. 5: V_s Versus Dry Density Relationships for Saturated Samples.

A and B constants with $1/V_p$ and $1/V_s$ are used for calculating porosities for all dry samples. The average porosities calculated depending on both V_p and V_s (for dry samples) are 1.86 % and 9.96 % respectively. It illustrates that there is significant difference between these two values. The calculated porosity value depending upon $1/V_p$ considered un virtual because this value was regarded not sensitive for porosity variations occurred in carbonate rocks in comparison with V_s value (Fig.7) (Domenico, 1984).

Finally, a reverse relationship was noticed between porosity (calculated from equation 6) versus dry density values plot (Fig.8).

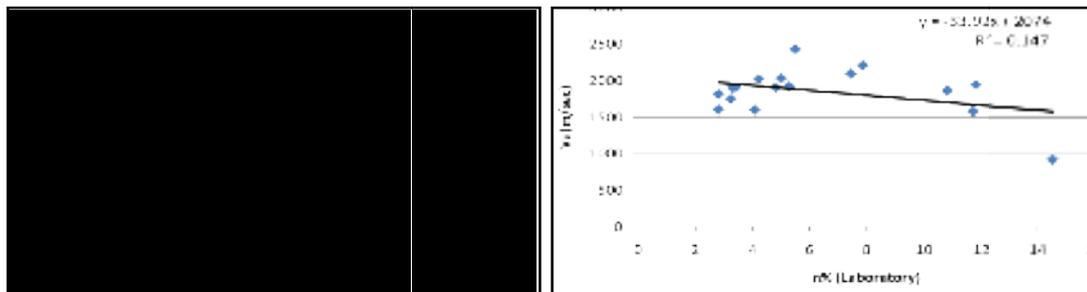


Fig. 6: V_p and V_s Versus Porosity Relationships for all Saturated Samples in Site 4.



Fig.7: Comparison between Laboratory Calculated Porosity and Reversal VP and Vs Values.

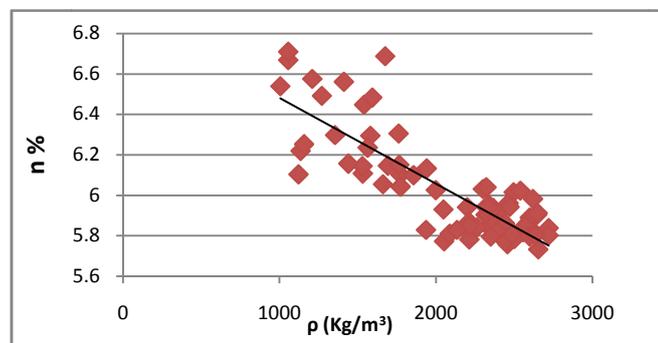


Fig. 8: Porosity Versus Density Values Relationship.

Anisotropy and Isotropy Factors

Isotropy for any rock media can be determined by calculating VP and Vs in three directions (bed strike, true dip and perpendicular to bedding plane). Difference between velocity values reflects anisotropic media and vice versa (Leslie and Lawton, 1999). Equations 10 and 11 were used for calculating isotropy factors δ and ϵ for all rock samples in the area. The maximum value for δ factor is found to be equal to (-0.009) and the minimum is equal to (-1.393). If δ and ϵ are equals or close to zero that means the media is isotropy. This indicates that anisotropy between rock types is existed between sites in the whole studied area, Furthermore; the fracturing were more effective on the rocks as causing by the blasting operations for quarrying the rocks for using it as raw materials for cement industry.

$$\delta = 4[(V_{10} / V_0) - 1] - [(V_{90} / V_0) - 1] \dots\dots\dots 10$$

- V₉₀: Seismic velocity towards bed strike.
- V₁₀: Seismic velocity perpendicular to bedding plane.
- V₀: Seismic velocity parallel to true dip of beds.

DYNAMIC ELASTIC MODULUS

All types of dynamic elastic modulus were determined for different rock samples in the selected sites of the considered area depending on VP and Vs (Table-3). In this table, type of rock samples for compressibility modulus and Poisson's ratio is against of the remaining mentioned modulus. The maximum value for these two moduli is referred to marl samples, while the minimum one is related to hard limestone and dolomite.

Young's modulus (E):

Equation 12 was used to determine this modulus depending upon VP, Vs and Poisson's ratio. The maximum and minimum values of young's modulus in the area are equal to 23.5271×10¹⁰ N/m² (referred to hard limestone, dolomitic limestone and dolomite hand samples) and 0.34777×10¹⁰ N/m² (marl samples) respectively. Marly limestone and fossiliferous limestone are characterized by its moderate values. The difference noticed between both maximum and minimum values of this modulus is related to lithology and the existence of faults, vugges and fossils within some of the extracted rock samples.

$$E = \rho V_p^2(1+\sigma)(1-2\sigma)/(1-\sigma)\dots\dots\dots 11$$

Shear or rigidity modulus (μ):

This important modulus is useful for engineering site investigation. It equals zero in liquid media. Equation 12 was used to obtain this modulus for the selected five sites depending upon Vs and density values. The maximum and minimum values of this modulus are 27.41913×10¹⁰ N/m² and 0.628246×10¹⁰ N/m². The average for these two values is 9.023441×10¹⁰ N/m².

$$\mu = \rho V_s^2 \dots\dots\dots 12$$

Table 3: Range values of the calculated elastic modulus in the study area.

Bulk modulus (K) and compressibility modulus (β)

Depending on young's modulus and Poisson's ratio, equation 13 was used for measuring bulk modulus. Values of this modulus were ranged between $(10.134 \times 10^{10} - 0.281 \times 10^{10}) \text{ N/m}^2$ represents both maximum and minimum values respectively. The average is equal to $3.309 \times 10^{10} \text{ N/m}^2$. High difference between these two values reflects lithological, structural and textural variations occurred in rocks existed in the interested area.

$$K = E / 3(1-2\sigma) \dots\dots\dots 13$$

(compressibility modulus is equal to 1/k).

Poisson's ratio (σ)

This ratio can be determining using equation 15 depending on VP and Vs values. Values of Poisson's ratio were ranged between (0.436–0.309) represents both maximum (marl) and minimum (hard limestone and dolomite) values respectively. Dolomitic limestone, marly limestone, fossiliferous limestone and friable rocks represent moderate values. Also the behavior of this ratio is similar for bulk modulus. It gives reverse linear relationships between VP, Vs and Poisson's ratio for all samples except marls. This is because of its highest porosity (Sharma, 1986).

$$\sigma = [1-2(Vs/Vp)^2] / [2-2(Vs/Vp)^2] \dots\dots\dots 14$$

Lame's constant (λ)

Lame's constant is considered as an important modulus. It represents scale for homogenous media strength. It can be calculated from the equation 15 below (Sjogren, 1984). The maximum value obtained for all rock types (recorded in sites 1 and 5 in the area) is $4.034695 \times 10^{10} \text{ N/m}^2$ and the minimum one is equal to $0.098677 \times 10^{10} \text{ N/m}^2$ (site-3).

$$\lambda = \sigma E / (1+\sigma) (1-2\sigma) \dots\dots\dots 15$$

VP/Vs and K/ μ relationship

This relation is very important in engineering purposes. It can be used for conduct weak zones and isolate it from the strongest one (Dutta, 1984). Table-3

illustrates the obtained values for this relation. Values for VP/Vs are ranged between (1.592-3.716) and K/μ are (0.0849-2.693). VP/Vs ratio shows close ranges in all sites under study especially site-3. A plot between these two ratios was constructed and a proportional linear relationship was observed in spite of its scattering (Fig. 9).

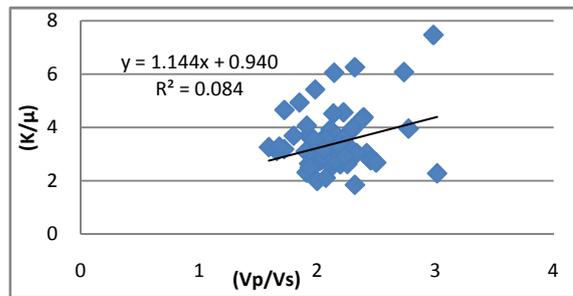


Fig. 9: Relationship between VP/Vs Versus k/μ.

Seismic Impedance

This factor is related to quarry explosive operation. Equation 16 is useful here to determine seismic impedance (I) (Stokoe and Santa marina, 2003).

$$I = \rho.Vp \dots\dots\dots 16$$

Maximum and minimum values of this property in whole studied area are ranges between (1813×10³-170×10³) gm.sec/cm³ respectively.

The average value is equal to 941×10³ gm.sec/cm³. This value is corresponding to a type-II of explosive charge used for quarrying operation named "**50% Nitro-glycerin + 2.3% Gumcotton + 40.3% Ammonium Nitrate + 5.5% Cellulose + 1.9% others**" (Duvill and Atchison, 1957 in Al-Asadi, 2004).

Static and dynamic Elastic Parameters

Static elastic parameter was measured for eight rock samples in laboratory using compression instrument and then equation 17 below (Table-4).

$$E_{Static} = (F/A) / (\Delta L/L) \dots\dots\dots 17$$

L is sample length with dimensions (1×1×2) cm³, however ΔL is the change occurred in sample length due to the applied force F. On the other hand, dynamic elasticity represents the ratio between dynamic young's modulus calculated using

seismic velocities ($E_{dynamic}$) and the above static elastic parameter. Dynamic elasticity values for sites 2 and 4 indicate that rocks belong to these two sites are suitable for quarry operation and then after for cement industry requirements.

Table 4: Static and Dynamic Elastic Parameters Results.

Site No.	Sample No.	Type of Rocks	Elastic parameters ($N/m^2 \times 10^{10}$)		Dynamic Elasticity
			E_{Static}	E Dynamic	
1	4	Fossiliferous LST	2.18	4.737	2.172
2	6	Limestone	2.75	5.845	2.125
2	9	Friable LST	0.361	1.166	3.229
3	2	Marl	0.198	0.409	2.065
4	15	Limestone	1.621	5.421	3.344
4	16	Marl	0.139	0.455	3.273
5	1	Dolomite	2.063	4.832	2.342
5	9	Marl	0.727	1.592	2.189

GEOTECHNICAL PARAMETERS

Geotechnical parameters were measured for all dry rock samples in the area (Table 4).

Material Index (I_m) was calculated using the following equation:

$$I_m = 3 - (VP/V_s)^2 / (VP/V_s)^2 - 1 \dots\dots\dots 18$$

The Im values in the area are classified as a category II (this category ranged between 0 and -0.5) according to the international classification (Abdul Rahman, 1989). It represents highly fractured and highly porosity rocks. However, it means that this type of rocks have moderate efficiency for building purposes. A proportional linear relationship between VP, Vs values versus this parameter was observed.

Lateral Earth Pressure Parameter (K) is very important parameter used for detecting material strength at any depth interval against the subjected geostatic pressure, or it is the ratio between the effective horizontal and vertical stresses δ_h , δ_v respectively (Hunt, 1986).

$$K^0 = \delta_h / \delta_v \quad \text{or} \quad K^0 = \sigma / (1-\sigma) \quad \text{or} \quad K^0 = 1 - 2 (Vs / VP)^2 \dots\dots\dots 19$$

Table 4: Geotechnical Parameters Values for Rock Samples in the Sstudy Area.

From table-4, it reveals that values of this parameter were reduced due to the increasing of rock hardness and coherence of the investigated sites. Therefore, reverse linear relationship was noticed between VP, Vs and K values. Also, both K^0 and σ have similar behavior.

Equation 20 was used to determine the **Effective Internal Friction Angle (ϕ)** (Sjogren, 1984).

$$\text{Sin } \phi = 1 - K^0 \quad \text{or} \quad \text{Sin } \phi = 2 (Vs / VP)^2 \dots\dots\dots 20$$

Table-5 illustrates that hard limestone, dolomitic limestone and dolomite rock samples were recorded maximum values of this parameter, and however, marls are corresponding to the minimum one. A proportional linear relationship between VP and Vs versus ϕ was established.

The equation 21 below was used to calculate **Plasticity Index (Ip)** depending upon K^0 parameter (Bowels, 1984).

$$Ip = (K^0 - 0.4) / 0.007 \dots\dots\dots 21$$

Here, marls are recording maximum values of this parameter in the area and hence, the minimum one is belong to hard limestone, dolomitic limestone and dolomite. In comparison between Ip values mentioned in table-5 with the standard values demonstrated in table-5 below, it is clear that rocks in the study area are characterized by its highly to moderate plasticity index. Low values also detected in some limestone samples located at sites 4 and 5. A reverse linear relationship between VP, Vs versus Ip was recognized.

Table 5: Standard Values for Plasticity Index (Hunt, 1986)

Plasticity Index	Description
0	Not plasticity
< 7	Low plasticity
7 - 17	Moderate plasticity
> 17	High plasticity

MEASUREMENTS FOR SATURATED SAMPLES

Site four had been chosen to experience its rock samples under fluid saturation. Choosing site four for doing these measurements (Table 6) referred to the site itself. It contents most types of rocks and moreover, number of samples is almost good and satisfies.

After achieving water saturation for all 20 rock samples, it is observed that there is about 6.57% increasing percent occurs in **density** values for these samples relative to the individual dry samples. This percentage is mainly referred to marly limestone, friable and fossiliferous limestone. Marl samples (16, 17 and 18) were completely broken during laboratory measurements, and thenafter, these samples were removed from our calculation as shown in table-6 and figure 10.

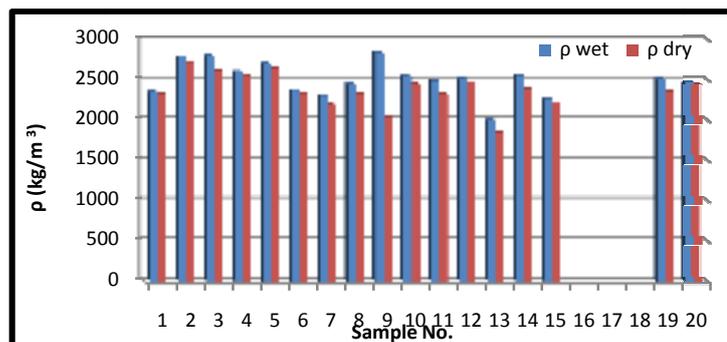


Fig.10: Comparison between Dry and saturated Densities for Samples in Site-4.

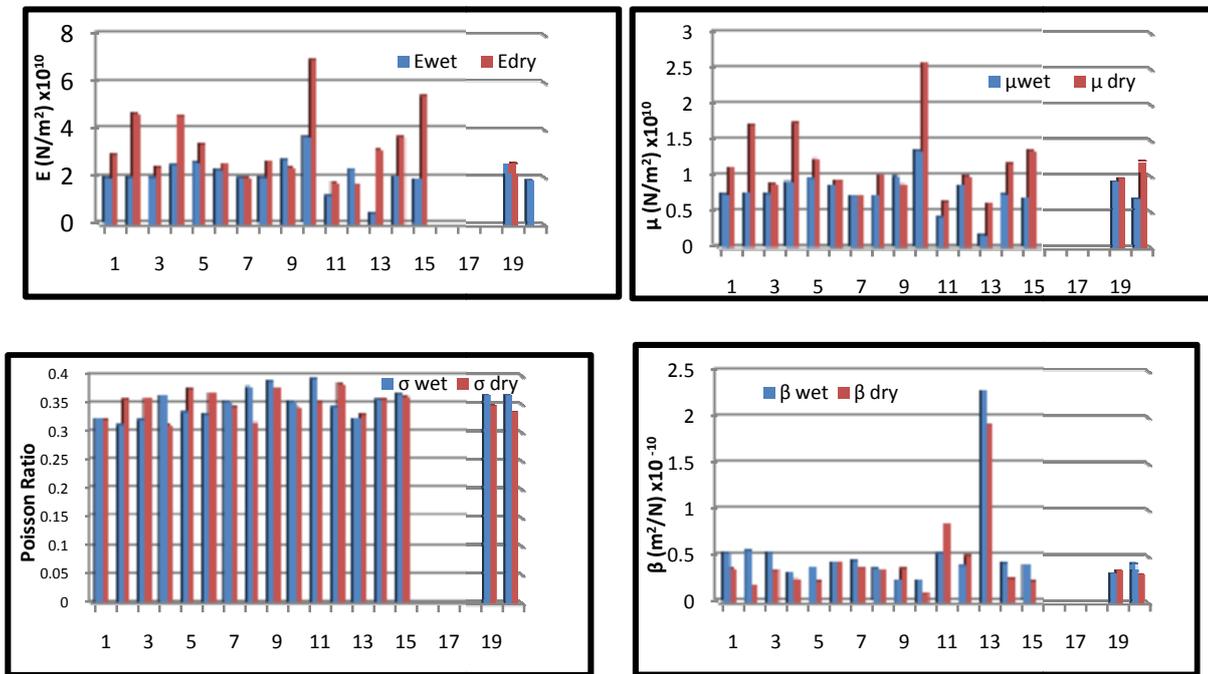
On the other hand, average values for both **VP** and **Vs** that measured in three directions were reduced in saturated rock samples. VP and Vs values were ranged between (1832-4867) m/sec and (931-2310) m/sec respectively. There is a 19.7%

decrease percent was recognized in rock samples due to saturation process relative to dry samples (Fig 11).



Fig. 11: Comparison between VP and Vs Values for Dry and saturated Samples in Site-4.

Elastic moduli were extremely affected by this step. Generally, all types of these moduli values were declined in saturated rock samples as shown in Fig. 12.



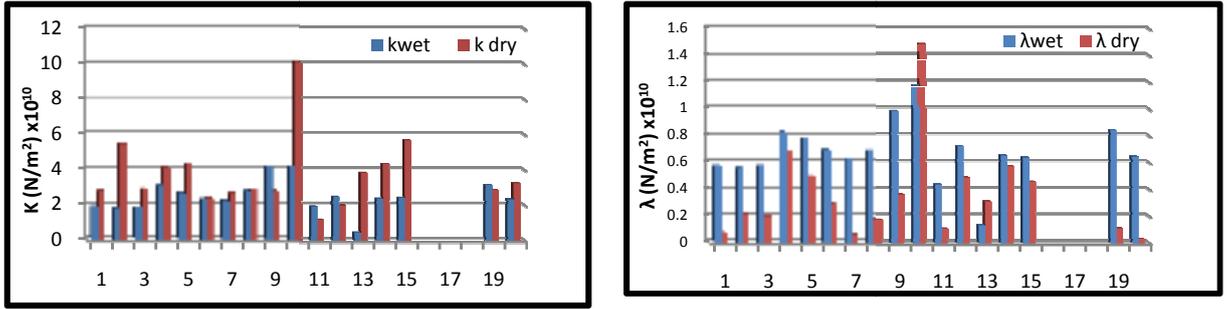


Fig. 12: Comparison between young's, shear, bulk, compressibility, lame's and poisson's moduli for dry and saturated samples in site-4.

Geotechnical parameters: measurements for saturated rock samples within site-4 were also determined (Table 6). Behavior of these parameters against water saturation is variable depending upon the individual rock type as illustrated in Fig. 13.

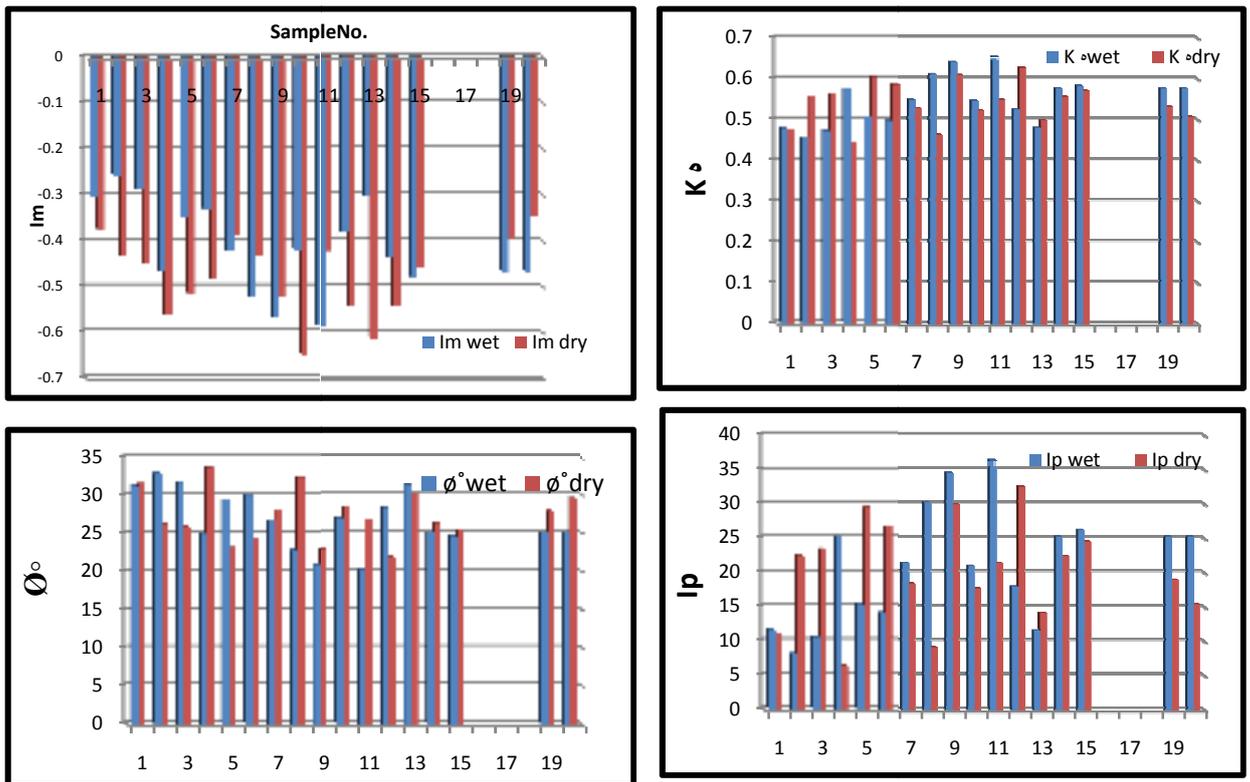


Fig.13: Comparison between Material Index, Lateral Earth Pressure, Effective Internal Angle and Plasticity Geotechnical Parameters for Dry and Saturated Samples in Site-4.

CONCLUSIONS AND RECOMMENDATION

- 1- It is found that porosity values calculated using VP were not satisfied for both dry and saturated rock samples in the investigated area. Whereas porosities determined depending upon Vs were close to those porosities extracted using laboratory method.
- 2- Anisotropy between rock types in the selected sites was existed due to velocity differences occurred in three directions within samples. Velocities measured perpendicular to the bedding plane of dry rocks in the area indicate that this direction may represents the weakness one. This direction therefore is considered as suitable for quarrying operation. Moreover, velocity and elastic module results obtained for saturated rock samples also indicate that quarry technique is being easier and cheep.
- 3- Average acoustic impedance in the area is found to be equal to 941 gm.sec/cm³. So, the convenient explosive charge type recommended for this area is "50% Nitro-glycerin + 2.3% Gumcotton + 40.3% Ammonium Nitrate + 5.5% Cellulose + 1.9% others".
- 4- E_{static} and dynamic elasticity values were measured for eight rock samples had been chosen randomly in the area under study. It shows that results obtained using ultrasonic viewer instrument give close results for those obtained by static method.
- 5- VP and Vs measurements for some saturated rock samples reveal district anomaly in their physical and geotechnical properties. This is because of its differences occurred in lithology, vugges, fractures and fossils contents. Moreover, high porosity existed in marl samples might causes this anomaly.

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