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Suitability of the Fatha Limestone Formation rocks in Al-Mishraq Area, Ninavah Governorate, northern Iraq, for riprap stone purposes

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Abstract

Using natural materials for engineering purposes is less expensive compared to industrial materials, and taking advantage of the limestone found in abundance in Ninavah Governorate for the purpose of stone riprap. The research aims to evaluate the suitability of limestone rocks for Fatha Formation in the Al-Mishraq area, Ninavah Governorate, northern Iraq, for stone riprap purposes. Eight stations of limestone rocks were chosen in the study area. Geotechnical tests showed that the porosity values ranged between (5.401-16.362%), the dry density values It ranged between (2.177-2.601) g/cm3, mechanical abrasion values ranged from (37.7-53.8%), chemical abrasion values ranged from (2.1-9.8%), true specific gravity values ranged from (2.585-2.749), and absorption percentage values It ranged between (2.078-7.515%). By comparing the results of geotechnical tests with the standard specifications related to stones riprap, we found that the limestone rocks in the study area are suitable for use as riprap stones in stations (1, 2 and 8) and are not suitable in the rest of the stations according to the standard specification (F.D.O.T., 2000), (Florida Department of Transportation). Moreover, it is suitable for use as riprap stones in stations (1, 2, 7 and 8) and is not valid in the rest of the stations according to the Iraqi specification numbered 1387 (National Center for Laboratories and Construction Research, 1989). In addition, it is suitable for the same purpose in the stations (1, 2, 3, 4 and 6) and are not valid in the rest of the stations according to the standard specification (ASTM-D, 523, 2004) (American Society for Testing and Material). The difference in suitability is due to the difference in requirements of the standard specifications.

Introduction:

The study aims to assess the suitability of the Fatha Limestone Formation rocks in the Al-Mishraq Area for riprap purposes. It is necessary to search for natural materials suitable for engineering purposes, including riprap stones, in order to reduce financial costs in engineering projects. Despite the low prices of natural aggregates such as limestone, these materials have a significant impact on the financial activities of most countries, and the amount of their production and use of natural stones is one of the important factors that highlights the economic prosperity of those countries [1]. Besides, Iraq is distinguished by the presence of large quantities of Limestone suitable for engineering purposes [2]. The stones were used for various engineering and ornamental purposes [3] and they include different types of natural stones used in the exterior and interior improvements of buildings, such as granite, marble, sandstone, and limestone. The types of these stones are evaluated based on the possibility of extracting large pieces and the appearance of the stone when cut besides its polishing, accessibility to the site, and the mechanical properties of the stone [4]. The rock masses differ in their qualities, types, and characteristics from one region to another, as these rocks were formed at different ages and conditions [5]. Riprap stones are defined as a thin layer of angular, semi-angular, or semi-circular rocks of approximately equal sizes. This layer covers riverbanks and slopes [6]. [7] defined riprap stone as natural rocks that are paved on the banks of rivers and coasts, thus forming a shield or barrier to protect the soil beneath it from waves and water currents, as well as preventing the formation of holes resulting from strong waves. [8] noted that the riprap stone must be made of strong, solid rocks and resistant to erosion resulting from water. Therefore, it is often used in facilities located near valleys and rivers, such as roads, and bridges ripraps are one of the most employed defense mechanisms for several in-stream hydraulic structures such as embankment dams, spillways, streambeds, riverbanks, bridge piers, [9]. Rock riprap is divided into dumped riprap, hand placed riprap, and plated or keyed riprap. The effectiveness of the riprap can remain when some scattered stones are lost and can be easily repaired. Well-constructed riprap provides long-term protection, on condition that it is checked regularly and maintained, especially after floods[10]. The engineering properties of limestone rocks have been studied for use as riprap stones in the southeastern plunging area of the Khanuga anticline in northern Iraq, and it has been found that their suitability are for use as riprap stones after comparing geotechnical properties of limestone with the Iraqi standard of limestone rock in the Fatha formation [11]. [12] confirmed that the limestone rocks of several stations in Ninavah Governorate have weak to moderate strength resistance. This is consistent with many previous studies of limestone rocks in the governorate, in addition to the flexural and mechanical abrasion test (Los Angeles), which showed, according to Iraqi and international specifications, that the abundance of limestone rocks in Ninavah Governorate, as well as the variation in their properties, makes them suitable for widespread use for engineering purposes. **Figure 1** shows the importance of stone riprap in bridges.

Fig. 1: Slope resulting from the construction of the newly built Al-Shohadaa Bridge on the Tigris River/Ninavah Governorate, (A) the condition of the slope before (stones riprap), (B) the condition of the slope after (stones riprap) with limestone rocks.

Location of the study area:

The study area is located in Ninavah Governorate, 45 km southeast of the city of Mosul, between two longitudes (43° 21′ 2.8″ - 43° 17′ 38.1″) east and two latitudes (35° 57′ 55.5 - 36° 01′ 12.1″), north as in **Figure 2**. It is bordered by the Tigris River to the east and to the west by the General Mishraq Sulfur Company. The area of the study area is about (4) km^2, represented by some (out crop) located in the Mishraq Anticline and its adjacent areas. This area is generally called (Al-Mishraq 1), (M1) **[**13**]**.

Tectonically, the study area is located in the low folded zone within the foot hill zone belonging to the unstable shelf according to the classification of **[**14**]**. Most of the folds of this region extend from the Makhul Hamrin mountain series in the NW-SE direction, gradually changing to the E-W direction in the northwestern regions. Many geomorphological phenomena also appear in the study area, where the most important of which are the Mishraq Anticline, the Tigris River, the Great Zab River, and the hills, as the Mishraq Area is characterized by undulating land and low hills. The Fatha formation in the study area consists of several depositional cycles between 10-16 cycles, with cycle thickness ranging from 1-20 m. It consists of a homogeneous arrangement of clay, marl, gypsum and limestone. Some of these cycles are complete and another portion is missing one or more of the mentioned components, **[**15**]**.

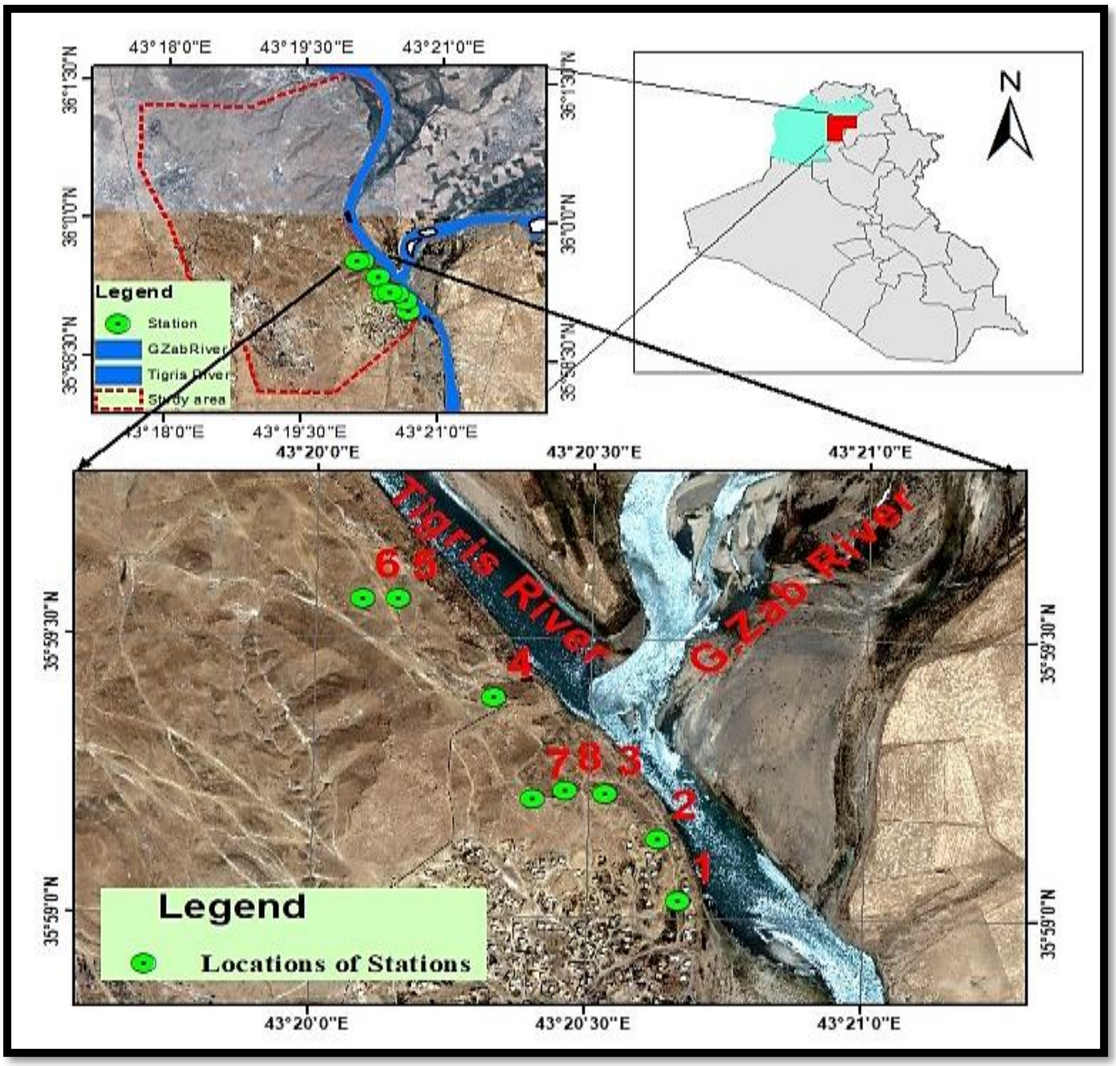

Fig. 2: Site map of the study area and selected stations

Methodology:

Engineering geological survey of study stations:

The engineering geological survey is very important for the purpose of determining the suitability of rock mass for engineering purposes and classifying them by finding the field properties of the rocks. A comprehensive engineering geological survey of the limestone rocks in the study area was

conducted and described according to the report of the Geological Society in London**[**16**]**, **[**17**]**. It states that the name of the rock alone without a description is useless for engineering purposes, as there must be an accurate description of the rock.
The proposal of the Geological Society in London states that the system for describing rocks should be according to color, distance between discontinuities (joints), field rock resistance, and layer thickness (bedding), according to**[**16**]** , **[**17**]** as well as describing the state of weathering according to **[**18**]**, as in **Table 1**. The thickness of the limestone layers to form the opening for the study stations is shown in **Figure 3**.

Table1: Engineering geological description of the limestone rocks belonging to the Fatha Formation in the study area.

Station No.	Dip direction/dip amount	Color according to **[**16**]**	The distance between the joints according to **[**16**]**	Weathering according to **[**18**]**	Bedding according to **[**16**]**	Resistance of rock material according to **[**17**]**
1	040°/28°	Light yellow	Very wide	Light weathering	Thick layers	Moderately strong
2	110°/8°	Light yellow	Wide spaced	Light weathering	Thick layers	Moderately strong
3	160°/20°	Light yellow	Wide spaced	Light weathering	Thick layers	Moderately strong
4	170°/20°	Light yellow	Wide spaced	Light weathering	Thick layers	Moderately strong
5	070°/30°	Light yellow	Wide spaced	Light weathering	Thick layers	Moderately strong
6	230°/25°	Light yellow	Wide spaced	Light weathering	Thick layers	Moderately strong
7	022°/32°	Light yellow	Wide spaced	Light weathering	Thick layers	Moderately strong
8	050°/20°	Light yellow	Wide spaced	Light weathering	Thick layers	Moderately strong

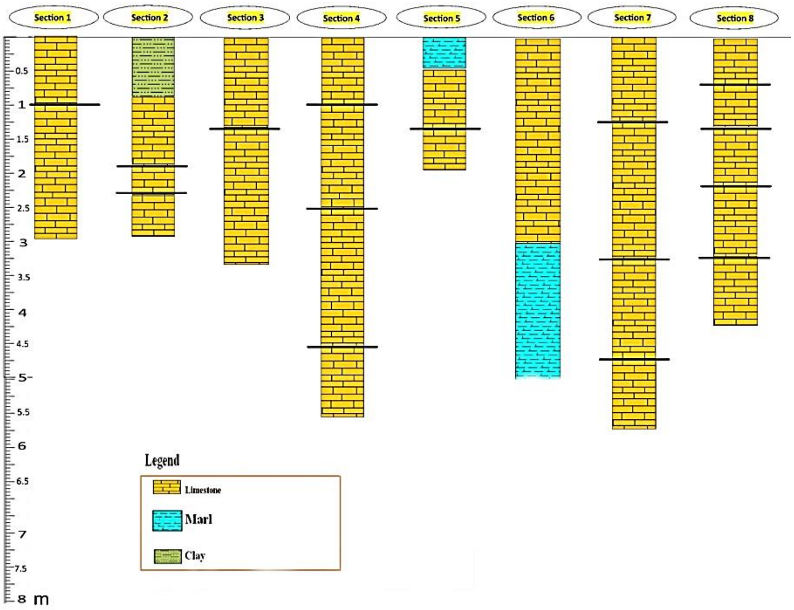

Fig. 3: Lithological successions of stations in the study area.

Laboratory tests

The required geotechnical tests were conducted to determine the properties that concern the suitability of limestone rocks in the Mishraq Area for riprap purposes according to the following American standard specifications **[**19**]**, **[**20**]**, and **[**21**]**. Tests include (porosity, dry density, mechanical abrasion, chemical abrasion, true specific gravity, and absorption percentage).

a. Porosity (n%)

It is defined as the ratio between the volume of voids in the rock to the total volume of the rock, which is measured when the pores are emptied of air **[**22**]**. Measuring porosity in the rock laboratory of the Department of Civil Engineering/University of Mosul according to specification **[**22**]**. The total porosity value is calculated with the following equation:

$$\boldsymbol{n}\% = \left(\frac{\boldsymbol{M_{sat}} - \boldsymbol{M_{dry}}}{\boldsymbol{M_{sat}} - \boldsymbol{M_{sub}}}\right) \mathbf{100} \ldots \mathbf{(1)}$$

Where (n) = porosity (%), (M_{sat}) = saturated mass in (gm), (M_{dry}) = dry mass in (gm), and (M_{sub}) = submerged mass in (gm).

The porosity values of the limestone rocks in the study area were described according to **[**23**]** as in **Table 2**.

Table 2: Porosity classification according to [23].

Porosity%	Description
(0-5%)	Neglected
(5-10%)	Weak
(10-15%)	Medium
(15-25%)	High
>25%	very high

Table 3: Total porosity values of the limestone samples in the stations of the study area

Station No	Porosity
1	5.911
2	5.676
3	5.601
4	5.912

5	16.362
6	5.401
7	12.813
8	10.963

b. Dry density (ρdry)

It is the mass of a unit volume, and its unit of measurement is (g/cm3), [24]. It depends on porosity and mineral composition [10]. Dry density was measured using the three-weight method (saturated, dry, and submerged) in the rock laboratory of the Department of Civil Engineering/University of Mosul. According to the American standard [19], the true dry density is calculated according to the following equation:

$$\boldsymbol{Dry\ Density(\rho dry)} = \left(\frac{\boldsymbol{Mdry}}{\boldsymbol{Msat-Msub}}\right)\boldsymbol{\rho_w} \ldots (2)$$

Where (ρdry) = dry density in (g/cm3), (M_{dry}) = dry mass in (gm), (M_{sat}) = saturated mass in (gm), (M_{sub}) = submerged mass in (gm), (ρ_w) = density of water in (g/cm3).
Dry density values of limestone rocks in the study area ranged between (2.177-2.601) g/cm3 as in **Table 4.**

c. Mechanical abrasion

This property is considered a qualitative indicator of different sources of aggregates that are similar in mineral composition [20]. It is also an important measure of the extent of resistance of coarse aggregate to abrasion and friction that affect the outer surface of the aggregate grains. This test is often used to test aggregates that it is used in concrete and surfaces exposed to severe friction as a result of traffic, including roads, where a tangential force and a vertical force are applied simultaneously to determine the extent of the aggregate's resistance to abrasion. Special metal balls are used for this purpose in the test device [25]. This test was carried out in the rock laboratory of the Department of Applied Geology/University of Tikrit according to the standard specification [20]. The percentage of mechanical wear is calculated according to the following equation:

$$\boldsymbol{A.b}\% = \left(\frac{\boldsymbol{A-B}}{\boldsymbol{A}}\right)100 \ldots (3)$$

Where: (A.b) = abrasion percentage (%),(A) = total dry weight in (gm), (B) = dry weight remaining on sieve No. (12) diameter (1.7) mm. Mechanical abrasion values for limestone rocks in the study area ranged between (37.7-53.8)% as in **Table 4**.

d. Chemical abrasion

This test is used to predict the durability of rocks and to know the effect of water on the age of rocks (The resistance of rocks to water over time) and weathering characteristics [26]. Weathering affects the durability of the aggregate. As the size of the voids increases and the bond between the grains becomes weaker, the aggregate becomes more susceptible to disintegration in solutions, especially sulfate solutions, due to crystal growth. When sodium or magnesium sulfate crystals penetrate into the aggregate or when the phenomenon of hydration occurs, this causes the emergence of stresses that affect the surface. A stability test was conducted according to the American Standard [21] by using a sodium sulfate solution (Na_2SO_4). This test was performed in the rock laboratory of the Department of Geology/Tikrit University, and the percentage loss was calculated according to the following equation:

Percentage of loss = $\frac{\boldsymbol{A-B}}{\boldsymbol{A}}$ ***100…(4)**

Where: (A) = mass of the sample before the test in (gm), and (B) = mass of the sample after the test (gm).

Chemical abrasion values for limestone rocks in the study area ranged between (2.1-9.8)%, as in **Table 4**.

e. True specific gravity (True G.S)

It is the weight of the solid substance present in a certain volume of that substance to the mass of distilled water present in the same volume at a temperature of 20°C **[**19**]**. This test was conducted in the rock laboratory of the Department of Civil Engineering/University of Mosul, according to specification **[**19**]** and is calculated according to the following equation:

$$\boldsymbol{True\ G.s} = \frac{M_{dry}}{M_{dry} - M_{sub}} \ldots(5)$$

Where True (G.s) = True Specific Gravity.
(M_{dry}) = dry mass in (gm).
(M_{sub}) submerged mass in (gm).
The true specific gravity values for the models selected from the study area were calculated and found to range between (2.585-2.749) as in Table (4)

f. Water absorption ratio (W_{abs})

It is the ratio of the mass of water in the voids (M_w) absorbed within 48 hours to the total dry mass of the rock (M_{dry}), which is a percentage **[**24**]**. The absorption percentage was calculated in the rock laboratory of the Department of Civil Engineering/University of Mosul. According to the specification **[**19**]** according to the following equation:

$$W_{abs}=\left(\frac{Mw}{Mdry}\right)100 \ldots (6)$$

Where (W_{abs}) = water absorption rate (%), (M_w) is the mass of water in (gm), (M_{dry}) = dry mass in (gm). The values of the water absorption percentage of limestone rocks in the study area ranged between (2.078-7.515) %, as in Table (4).

Table 4: Results of geotechnical tests of limestone rock samples belonging to the Fatha Formation in the study area

Station No.	Dry density(gm/cm3)	Mechanical abrasion(%)	Chemical abrasion(%)	True specific gravity	Water absorption ratio(%)
1	2.477	37.7	4.8	2.633	2.385
2	2.549	44.4	4	2.703	2.226
3	2.507	53.8	2.1	2.655	2.234
4	2.503	48.8	4.4	2.661	2.361
5	2.177	50.1	9.8	2.603	7.515
6	2.601	48.2	6.8	2.749	2.078
7	2.267	46.4	7.6	2.600	5.650
8	2.301	38.8	2.3	2.585	4.763

Result and discussion

1. The variation in the water absorption rate is caused by the variation in the porosity values of the limestone rocks in the study area, as in the **Figure 4**.
2. Mechanical abrasion values were high (It was higher than the limits required in the specifications in some stations) due to the nature of the texture and mineral components of the limestone rocks in the study area.
3. Chemical abrasion values varied due to the nature of the chemical composition of the limestone rocks in the study area.

4. The specific gravity values were low due to the high porosity of the limestone rocks in the study area, as in the **Figure 5**.
5. The dry density values were low due to the low values of the specific gravity of limestone rocks in the study area, as in the **Figure 6**.

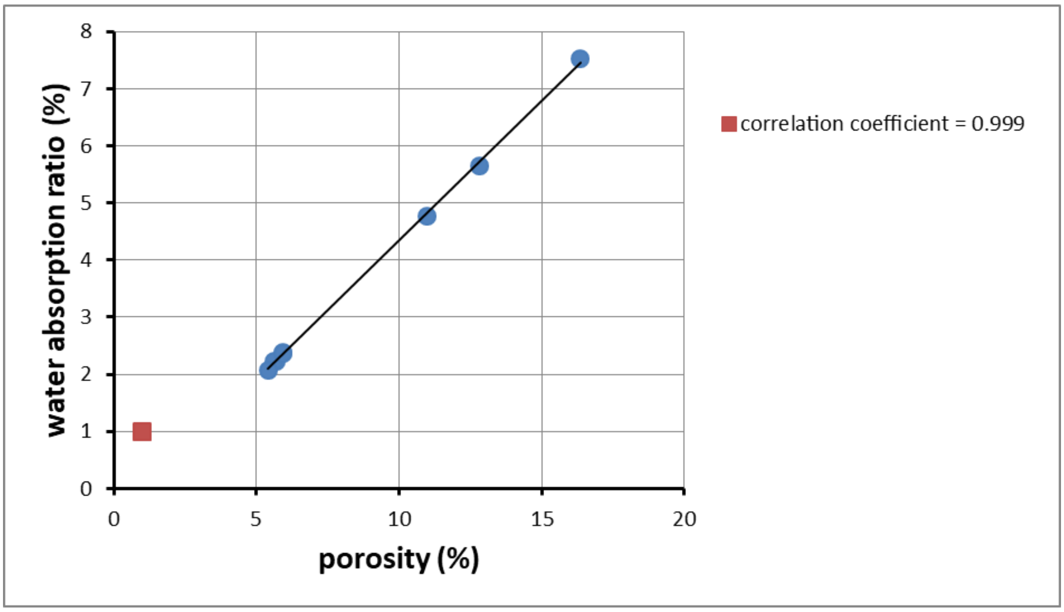

Fig. 4: Relationship between the porosity and water absorption ratio

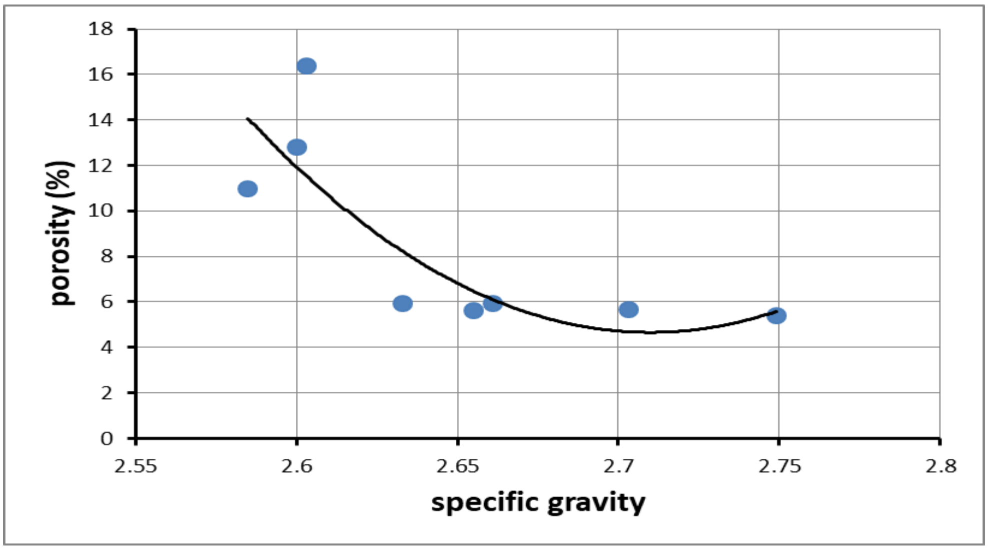

Fig. 5: Relationship between the specific gravity and the porosity (correlation coefficient = - 0.721)

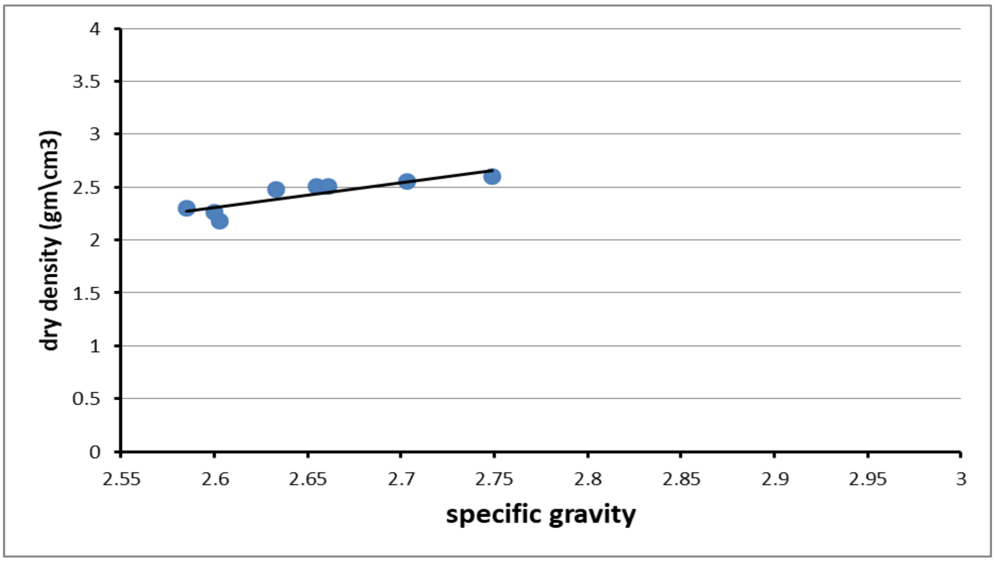

Fig. 6: Relationship between the specific gravity and the dry density (correlation coefficient = 0.866).

Assessment the suitability of limestone rocks for riprap

<u>Properties of the riprap stone</u>

The standard specification **[6]** specifies some properties for riprap stones.

<u>Features of the riprap stone</u>

The most important characteristic of riprap stones is that they are easy to install, use and maintain, in addition to their surface roughness, which thus protects slopes from erosion and thus increases the stability of slopes resulting from projects **[27]**. Geotechnical specifications must be available according to each specification for limestone rocks used as riprap stones, as follows:

First: The specifications determined by **[**28**]**.
Second: Specifications specified by the National Center for Laboratories and Construction Research for limestone rocks when used to cover riverbanks according to Specification **[**29**]**.
Third: The specification **[**30**]**, which in turn divided the rocks into three classes, Class I, Class II, and Class III, based on the different geotechnical properties.

By comparing the results of the geotechnical properties of the limestone rocks belonging to the Fatha Formation. They were taken from the study area, as in Table (4), with the specifications set by **[**28**]**, and with the Iraqi specification **[**29**]**, and the standard specification **[**30**]**, where the suitability of these rocks for use as riprap stones was evaluated, as in **Tables (5), (6), (7), (8).**
a. Evaluation based on Florida Department of Transportation **[**28**]**.

Table 5: Evaluation of limestone belonging to the Fatha formation as riprap stones by comparing its properties with [28]

Station No.	Geotechnical properties of limestone rocks in the study area				Evaluation
	Specific gravity	Absorption percentage (%)	Mechanical abrasion(%)	Chemical abrasion(%)	
1	2.633	2.385	37.7	4.8	Suitable
2	2.703	2.226	44.4	4	Suitable
3	2.655	2.234	53.8	2.1	Not suitable
4	2.661	2.361	48.8	4.4	Not suitable

5	2.603	7.515	50.1	9.8	Not suitable
6	2.749	2.078	48.2	6.8	Not suitable
7	2.600	5.650	46.4	7.6	Not suitable
8	2.585	4.763	38.8	2.3	Suitable

b. Evaluation based on Iraqi Standard No. 1387 (National Center for Laboratories and Construction Research, 1989) **[**29**]**.

Table 6: Evaluation of limestone rocks as riprap stones according to [29]

Station No.	Geotechnical properties of limestone rocks in the study area				Evaluation
	Dry density(gm/cm3)	Absorption percentage (%)	Mechanical abrasion(%)	Chemical abrasion(%)	
1	2.477	2.385	37.7	4.8	successful
2	2.549	2.226	44.4	4	successful
3	2.507	2.234	53.8	2.1	unacceptable
4	2.503	2.361	48.8	4.4	unacceptable
5	2.177	7.515	50.1	9.8	unacceptable
6	2.601	2.078	48.2	6.8	unacceptable
7	2.267	5.650	46.4	7.6	acceptable
8	2.301	4.763	38.8	2.3	successful

c. Evaluation based on the American standard (ASTM-D, 523, 2004) **[**30**]**.

Table 7: Evaluation of limestone rocks as riprap stones according to specification [30].

Station No.	Geotechnical properties of limestone rocks in the study area			class	Evaluation
	Specific gravity	Absorption percentage	Chemical abrasion(%)		
1	2.633	2.385	4.8	III	Suitable
2	2.703	2.226	4	III	Suitable
3	2.655	2.234	2.1	III	Suitable
4	2.661	2.361	4.4	III	Suitable
5	2.603	7.515	9.8	-	Not suitable
6	2.749	2.078	6.8	III	Suitable
7	2.600	5.650	7.6	-	Not suitable
8	2.585	4.763	2.3	-	Not suitable

Table 8: final evaluation of the limestone rocks in the study area for use as riprap stone and the extent of their suitability with standard specifications.

Station No.	Standard specification		
	(F.D.O.T., 2000)	Iraqi Standard No. 1387	(ASTM-D, 523, 2004)
1	Suitable	successful	Suitable
2	Suitable	successful	Suitable
3	Not suitable	unacceptable	Suitable
4	Not suitable	unacceptable	Suitable
5	Not suitable	unacceptable	Not suitable
6	Not suitable	unacceptable	Suitable
7	Not suitable	acceptable	Not suitable
8	Suitable	successful	Not suitable

6- Conclusions:

• Through the engineering geological survey, we found that the limestone rocks in the study area are light yellow in color, with wide to very wide intervals, light to moderate weathering, thick layers and moderately strong resistance.

• The limestone rocks in the study area are suitable for use as riprap stones in stations (1, 2, 8) and are not suitable in the rest of the stations according to the standard specification (F.D.O.T., 2000).

• The limestone rocks in the study area are suitable for use as riprap stones in station (1, 2, 7, 8), and are not suitable in the rest of the stations according to the Iraqi specification numbered 1387 (National Center for Laboratories and Construction Research, 1989).

• The limestone rocks in the study area are suitable for use as riprap stones in stations (1, 2, 3, 4, 6) and are not suitable in the rest of the stations according to the standard specification (ASTM-D, 523, 2004).

7- Recommendations:

• Identifying limestone rock reserves in stations (1, 2, 3, 4, 6, 8), and investing them for riprap purposes.

• Quarrying rocks according to the mining method for investment in single or multiple terraces**.**

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