مجلة الدراسات التربوية والعلمية - كلية التربية - الجامعة العراقية
العدد الثالث والعشرون - المجلد السابع - علم الجغرافيا - تموز 2024م
doi.org/10.52866/esj.2023.07.23.17

A Study of Some Engineering Characteristics of The Injana and The Fat'ha Formations in Degala-Erbil, Northern Iraq

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ABSTRACT:

This research aims to analyzing the geotechnical properties of the The Injana and The Fat'ha Formations in Degala-Erbil. Another aim of the study is to evaluate the suitability of limestone rocks from the Fat'ha Formation in the Degala area in Erbil for construction purposes and Riprap. The engineering characteristics examined in this study encompass the water content, density, specific gravity, absorption ratio, porosity, saturation coefficient, and unconfined compressive strength determined using the point load test. A total of eight testing locations were selected for conducting the study, with two locations located within the The Fat'ha Formation and the remaining six locations situated within the The Injana Formation. Fat'ha Formation is exposed in the area as an outcrop, which consists of limestone, evaporites, claystone, and sandstone. And The Injana Formation is a sedimentary sequence of sandstone, silt, and mud. Two locations were selected on the southwestern limb of the Bina Bawi anticline, where limestone layers are exposed near the Degala Dam. The petrophysical results of tests showed that the specific gravity of the limestone rocks in the studied locations is 2.47 and 2.65. The chemical abrasion of the locations is 18.7% and 21.5%, while the mechanical abrasion is 31.2% to 32.6%. The absorption ratio ranged from 3.11% to 4.10%, and the dry density values of the two locations were 2.34 and 2.39. When comparing these results with the specifications for Riprap, it was found that they meet the requirements of the Iraqi specification [1]. However, when compared to the Lienhart specification [2], it was found that the first location is suitable, while the second location is not suitable. Comparing them with the American specification [3], it was found that the rocks are not suitable for Riprap purposes at the first location but acceptable at the second location. Regarding the suitability of limestone rocks for construction purposes, comparing the results with the specification indicates that the limestone rocks in the area are suitable for construction.

***Keywords*:** Building stones, Riprap, Degala, Fat'ha formation, Limestone.

دراسة بعض الخصائص الهندسية
لتكوين الفتحة و تكوين انجانة في ديكله / اربيل ، شمالي العراق

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مستخلص:

تركز الدراسة على تحليل الخصائص الجيوتكنيكية لتكويني انجانة والفتحة في منطقة ديكله-أربيل. تتضمن الخصائص الهندسية التي تم دراستها في هذا البحث المحتوى المائي والوزن النوعي ونسبة الامتصاص والمسامية ومعامل التشبع والمقاومة الانضغاطية غير المحصورة المحددة باختبار حمل النقطة ترجمة هذه المصطلحات. تم اختيار ثمانية مواقع لإجراء الدراسة بواقع عينة لكل موقع، حيث تقع محطتان منها ضمن تكوين الفتحة والست محطات الأخرى تقع ضمن تكوين انجانة. ينكشف تكوين الفتحة في المنطقة كمنكشف صخري، حيث يتكون من الحجر الجيري والمتبخرات والاطيان والحجر الرملي. ويعد تكوين انجانة تتابع رسوبي من الحجر الرملي والاطيان والغرين. كما تهدف هذه الدراسة الى تقييم صلاحة صخور الحجر الجيري من تكوين الفتحة في منطقة ديكله في اربيل كأحجار بناء ولاغراض التكسية تم اختيار محطتان تقعان على الجناح الجنوبي الغربي من طية بينا باوي المحدبة حيث تنكشف طبقات الحجر الجيري قرب سد ديكلة. اظهرت نتائج الفحوصات البتروفيزيائية ان الوزن النوعي لصخور لصخور الحجر الجيري في المنطقة المدروسة تساوي 2.47 و 2.65 اما التآكل الكيميائي فتتراوح نسبته بين ٪18.7 و ٪21.5 والتآكل الميكانيكي ٪31.2 و ٪32.6. بالاضافة الى نسبة الامتصاص التي تتراوح بين ٪3.11 و ٪4.10، اما قيم الكثافة الجافة فان قيم المحطتان كانت (2.34،2.39) .وعند مقارنة هذه النتائج مع مواصفات احجار التكسية فان المقارنة مع المواصفة العراقية[1] تبين صلاحيتها لأغراض الاكساء. وعند مقارنتها مع المواصفة لينهارت [2] تبين ان المحطة الاولى صالحة و الثانية غير صالحة. ومع المقارنة مع المواصفة الامريكية [3] وجد ان الصخور غير ملائمة كاحجار اكساء في المحطة الاولى و مقبولة في المحطة الثانية. ان صلاحية صخور الحجر الجيري لاغراض البناء فان مقارنة النتائج مع المواصفة تبين ان صخور الحجر الجيري في المنطقة صالحة لأغراض البناء.

الكلمات الدالة: احجار البناء، احجار الاكساء، ديكله، تكوين الفتحة ، الحجر الجيري.

1. Introduction

The physical, mechanical, and chemical tests are important examinations in the geotechnical assessment of rocks. Some laboratory tests were conducted on rock samples from the study area.

Limestone and sandstone rocks are abundant in the stratigraphic column of Iraq, making them one of the most prevalent sedimentary rock types. The Kurdistan region, in particular, boasts a diverse array of these rocks' units with distinct geological ages and depositional environments. The limestone rocks have served various purposes since ancient times, finding applications as building stones, paving stones, and numerous other practical uses[4]. Limestone, a sedimentary rock, is highly valued for its exceptional properties and wide range of applications in various industries. Its enduring beauty, durability, and abundant availability have made it a sought-after material worldwide for construction and infrastructure projects [5]. In the form of dimension stone, limestone undergoes a meticulous process of extraction, cutting, and shaping to create blocks or slabs of various sizes. Its natural allure enhances the visual appeal of building facades, flooring, countertops, and other architectural elements. The diverse colors and textures of limestone enable captivating designs that seamlessly blend with both modern and traditional aesthetics[6]. Beyond its decorative role, limestone's strength and resistance to weathering make it well-suited for applications such as riprap.

Large limestone stones strategically placed along shorelines act as a protective barrier against erosion caused by water currents and waves. This rugged yet visually pleasing solution effectively absorbs the forces of nature, preserving the integrity of the shoreline and maintaining its natural beauty[7]. Limestone also plays a crucial role in railway construction as railway ballast stone. Crushed limestone, known as ballast, forms a sturdy foundation beneath the tracks. This layer provides stability, ensures even distribution of the trains' weight, and facilitates efficient drainage. By utilizing limestone as railway ballast stone, the tracks remain securely in place, enabling safe and reliable transportation while reducing the risk of track shifts or deformations[8]. [9] Evaluated the validity of using The Fat'ha limestone rocks in the Sharqat Area for riprap purposes, and comprehensive assessment was carried out. The study specifically investigated the limestone rocks situated in nothewest plunge of the Makhul anticline. However, the findings revealed that the limestone rocks in this particular area were determined to be invalid for serving as riprap material. The study conducted in Koya, within the Pilaspi Formation, aimed to establish the relationship between the physical and mechanical properties of limestone rocks and their suitability as building materials. The engineering geological and geotechnical characteristics of the limestone rocks in the study area were thoroughly examined. The findings of the study align with national and international standards, demonstrating that the limestone rocks meet the criteria for being considered acceptable as building stones [10].

This research aims to analyzing the geotechnical properties of the The Injana and The Fat'ha Formations, also aims to evaluate the appropriateness of the Fat'ha Formation limestone for various engineering applications, including its potential as a building stone, and riprap material, by assess the relevant physical and mechanical properties of the limestone. The main reason for choosing the current study location is because there is a large limestone outcrop visible at the surface, and the limestone rock is quite thick, measuring around 10 meters.The study area is positioned on the southwest limb of Bina Bawi anticline in northeastern Iraq, , approximately 33 km east of Erbil. The study area is located within the coordinates (36° 11' 15")(36° 10' 10") longitudes and (44° 22' 40")(44° 27' 35") latitudes, according to the Geographic system, as shown in **Fig. 1**. And **Fig. 2.** Showing the limestone outcrop.

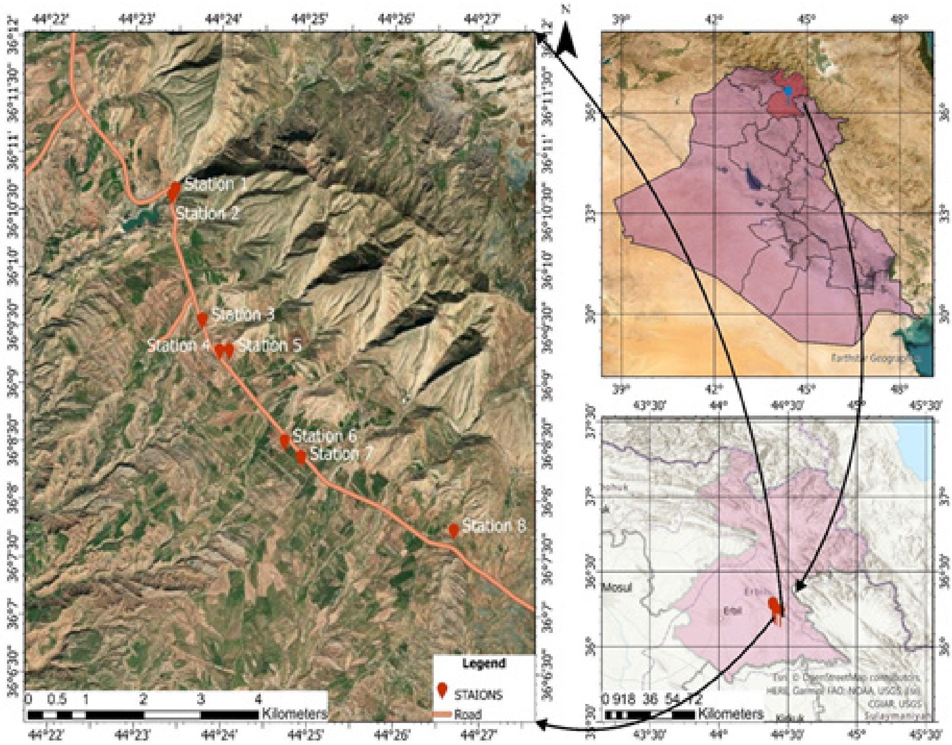

Fig. 1. Locations of the studied locations.

Fig. 2. The Fat’ha limestone outcrop.

The geological formations outcrop in the surveyed area comprises the The Fat’ha Formation (Middle Miocene) at locations 1, 2 and the The Injana Formation (Upper Miocene) in the last 6 locations. The The Fat’ha Formation is a predominant geological formation in Iraq and is composed of two distinct members. The lower member is comprised of evaporite rocks, namely gypsum and anhydrite, as well as mudstone and thick limestone. The upper member is typified by variable thicknesses of gypsum, marl, and limestone. On the other hand, the The Injana Formation is a sedimentary sequence of sandstone, silt, and mud [11]. The investigated region is situated in the Low Folded Zone, adjacent to Koya city, and is characterized by the southeastward plunge of the Bina Bawi anticline [12]. The northwestward plunge of the fold is intersected by the Great Zab River. This fold is classified as an asymmetrical anticline, with a northern limb dipping at 20 degrees towards the northeast and a southern limb dipping at 40 degrees towards the southwest [13].

2. Materials and Methods

2.1. laboratory tests.

When assessing the engineering properties of rocks, several crucial tests are indispensable. These tests encompass the determination of dry density, porosity, absorption rate, Saturation Coefficient, uniaxial compressive strength, and flexural strength. Collectively, these parameters offer important information on the performance and durability of rocks within the study area.

For evaluating the suitability of limestone as a building stone, some tests are required such as unit weight, absorption rate, flexural strength, and uniaxial compressive strength. These parameters collectively provide valuable insights into the performance and durability of limestone in construction applications.

In the assessment of limestone suitability for riprap applications, a set of significant geotechnical tests must be conducted. These tests encompass the determination of the absorption rate, mechanical abrasion rate, chemical abrasion rate, specific gravity, and dry density. The absorption rate evaluation provides insights into the stone's ability to resist water absorption, which is crucial for the long-term durability of riprap structures. The mechanical and chemical abrasion rates assess the limestone's resistance against physical and chemical deterioration, respectively, ensuring its ability to withstand harsh environmental conditions. Additionally, the measurement of unit weight aids in understanding the stone's density and stability, which are important factors for ensuring the effectiveness of riprap installations.

The geotechnical tests were conducted at the geological laboratory affiliated with the Geology Department of Tikrit University. The determination of specific gravity was performed following the American standard [14], utilizing Equation 1. The obtained results are presented in Table 1.

$$\text{True. G.s} = Md/(Md - Msub) \quad (1)$$

Dry density refers to the mass of the rock per unit volume, In accordance with the American standard [14], Equation 2 was employed to calculate the dry density. The obtained results of the dry density measurements are presented in Table 1.

$$\text{Dry density} = Md/(Msat - Msub) \;/\; \rho m \quad (2)$$

The absorption rate refers to the ratio of the mass of water (Mw) absorbed in the rock's voids during a 24-hour period to the total dry mass of the rock (Md). This property holds significance as rocks with lower absorption rates exhibit greater resistance to fluctuations in dryness, humidity, freezing and thawing, and other environmental conditions. Therefore, the absorption property is a crucial factor in determining the suitability of rocks for engineering purposes[15]. The absorption rate was determined in accordance with the American Standard, utilizing Equation 3, and the corresponding results are presented in Table 1.

$$W.ab = (Msat - Md)/Md \times 100\% \quad (3)$$

The porosity of a rock is defined as the ratio of the void or pore volume to the total volume of the rock specimen, expressed as a percentage. The equation (4) of determining porosity is according to [14].

$$n\% = (Vv / Vt) \times 100\% \quad (4)$$

Where:

Vv is the volume of voids or pores within the rock specimen.

Vt is the total volume of the rock specimen.

the Saturation Coefficient, also known as the Saturation Index, is a parameter used to quantify the degree of saturation of a porous material, The ratio between partial porosity (n') and total porosity (n), Saturation Coefficient determined by equation (5) according to [16].

$$Sc\% = n` / n \quad (5)$$

Chemical abrasion resistance refers to the weight loss percentage observed in a sample due to chemical abrasion, typically carried out using saturated sodium sulfate. This test holds great importance when evaluating rock aggregates for applications in building and road construction. In accordance with the American standard[17], the test involves immersing the rock sample in a saturated sodium sulfate solution for 16-18 hours, followed by 8 hours of drying, repeated for five consecutive cycles. The results of this test, as per the American standard, are tabulated in Table 1.

Mechanical abrasion resistance refers to the weight loss percentage experienced by a sample due to mechanical abrasion. This test evaluates the ability of a material to withstand physical wear and tear. The results of this test, determined in accordance with the American Standard[18], are presented in Table 1. **Fig. 3.** Show the los angles device that had been used to calculate the mechanical abrasion.

Fig. 3. The los angles device.

The determination of uniaxial compressive strength involved the utilization of the point load test method, following the guidelines set by the International Society for Rock Mechanics (ISRM) standard [19]. The results obtained from the point load test can be employed to calculate the uniaxial compressive strength using the equation provided by Das (reference) in Equation 6-9. **Fig. 4.** Show the point load device.

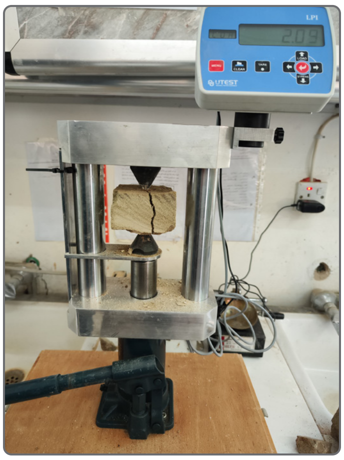

Fig. 4. The point load device.

Is=F/(De)2=π F/4A=

π F/4*D*W (6)

Where: Is: coefficient of uncorrected resistance.

F: The Force applied on the sample.

D: Sample hight

De: The equivalent base diameter, which is extracted from De= (4A/ π)

W: the sample width

The Is was corrected to the equiva-ldiametereter 50 mm using the Eqi. 3.

Is(50mm) =*f(F/De2) =*f**Is (7)**

And Size correction factor calculated with Eqi. 4.

$$f=(De/50)^{0.45} \quad (8)$$

where: f is the Size correction factor.

And according to (Das, 1995) the unconfined compressive strength calculates by Eqi. 5.

$$= k * Is_{(50)} = 21 * Is_{(50)} \quad (9)$$

3. RESULTS AND DISCUSSION

Table 1. The values of Petrophysical and Mechanical tests of rock samples belonging to the Fat'ha and The Injana Formations in the study area.

Location NO.	Specific gravity	Dry density	Absorption rate %	% Porosity	Saturation Coefficient	Chemical abrasion %	Mechanical abrasion %	Uniaxial compressive strength (Mpa)	Flexural strength
1	2.65	2.39	3.11	4.95	0.83	18.7	31.2	64.379	13.59
2	2.47	2.34	4.10	9.79	0.87	21.5	32.6	55.577	11.10
3	2.65	2.13	9.15	19.49	0.94	-	-	1.653	-
4	2.62	2.11	9.25	19.52	0.87	-	-	10.081	-
5	2.66	2.06	10.89	22.45	0.84	-	-	2.018	-
6	2.62	2.12	8.86	18.83	0.93	-	-	3.170	-
7	2.62	2.27	5.89	13.19	0.92	-	-	2.115	-
8	2.63	2.27	5.93	13.50	0.87	-	-	1.017	-

The suitability of limestone rock for building purposes can be determined by comparing its test results with the Standard Specification for Limestone Dimension Stone[20]. Limestone is classified into three distinct categories as a building stone, based on its flexural strength, dry density, and unconfined compressive strength. The first category, characterized by low density, is considered acceptable for use in construction. The second category, displaying medium density, is recommended as a suitable option. The third category, designated as high specification, is specifically intended for construction purposes the categories shown in Table 2. By doing the comparison, it becomes possible to identify the category into which the limestone belongs, the category corresponding to the limestone sample can be found in Table 3,

Table 2. Specifications of Building Stones by[20].

Category	**Physical Requirement**		**Engineering Requirement**	
	Absorption rate %	**Dry density (gm/cm^3)**	**Uniaxial compressive strength (Mpa)**	**Flexural strength (N/mm^2)**
I	12 More than	2.16> - 1.76	28> - 12	3.4>-2.9
II	12-7.5	2.56> - 2.16	55> -28	6.9>-3.4
III	7.5-3.0	2.56 more than	55 more than	More than 6.9

Table 3. The evaluation of limestone rocks in the area as building stone[20].

Location NO.	Dry density	Absorption rate %	Uniaxial compressive strength	Flexural strength
1	II	III	III	II
2	**II**	III	III	II

Riprap is an individual rock fragment that must possess characteristics such as high density, minimal porosity, hardness, absence of fractures, cracks, and potholes, as these features contribute to the reduction and facilitation of the weathering process. Additionally, the rocks should exhibit well-defined sharp edges and angular or semicircular forms. Furthermore, the proportion of riprap stones with a long axis to a short axis (2.5) should not exceed 30%, while those exceeding this threshold are either lamellar or longitudinal in shape. The determination of dimensions and mass for each rock piece is a complex task influenced by the force exerted by water, making it challenging to precisely ascertain the weight of aggregates in field conditions.

The suitability of limestone rocks taken from the first and second locations in the study area has been evaluated as Riprap by comparing the geotechnical properties of the limestone rocks with the standard specifications set by the Florida Department of Transportation [21] shown in Table 4, the specifications of the National Centre for Laboratories and Construction Research (1989)[1] shown in Table 6, the specifications set by [2] shown in Table 8, and the ASTM standard specification [3] shown in Table 10. Limestone rocks are commonly utilized as cladding stones, provided they satisfy the specified mechanical and chemical requirements outlined in the relevant specifications.

Table4 . Specifications of Riprap by**[21].**

Geotechnical property	Accepted Value
True Specific gravity	Shores and Beaches:2.3 Trenches and Canals:1.9
Water absorption ratio	Less than 5%
Mechanical Abrasion	Less than 12%
Chemical Abrasion	Less than 45%

The geotechnical properties of the rocks have been evaluated in accordance with the specifications mentioned above, and the resulting assessment of the limestone in the examined locations has been documented in Table 1.

Table 5. The evaluation of limestone as riprap according to the standard of [21]

Location NO.	Specific gravity	Absorption rate %	Chemical abrasion %	Mechanical abrasion %	Evaluation
1	(-)2.65	(+)3.11	(-)18.7	(+)31.2	Invalid
2	(-)2.47	(+)4.10	(-)21.5	(+)32.6	Invalid
(+) accepted		(-) unaccepted			

Table 6. Specifications of limestone rocks when used as cladding stone Riprap es according to[1].

Geotechnical properties	Evaluation		
	Successful	**acceptable**	**unacceptable**
Dry density (g / cm^3)	More than 2.2	2-2.2	Less than 2
Water absorption ratio%	Less than 10%		More than 10%
Chemical Abrasion%	Less than 18%	18-45	More than 45%
Mechanical Abrasion%	Less than 45%		More than 45%

The geotechnical properties of the rocks have been evaluated in accordance with the specifications mentioned above, and the resulting assessment of the limestone in the examined locations has been documented in Table 7.

Table 7. The evaluation of limestone as riprap according to the Iraqi standard [1].

Location NO.	Dry density	Absorption rate %	Chemical abrasion %	Mechanical abrasion %
1	Successful	Successful	acceptable	Successful
2	Successful	Successful	acceptable	Successful

Table 8. Specification of Riprap according to[2].

Geotechnical properties	Evaluation			
	Poor	**Moderate**	**Good**	**Excellent**
Uniaxial compressive strength (pa)	Less than 2000	2000-6000	6000-10000	More than 10000
Specific gravity	Less than2.5	2.5-2.6	2.6-2.9	More than2.9
Absorption rate %	More than6%	2-6%	0.5-2%	Less than 0.5%
Chemical abrasion %	More than 30%	10-30	2-10%	Less than2%

The geotechnical properties of the rocks have been evaluated in accordance with the specifications mentioned above, and the resulting assessment of the limestone in the examined locations has been documented in Table 9.

Table 9. The evaluation of limestone as riprap according to standard [2].

Location NO.	Specific gravity	Absorption rate %	Chemical abrasion %	Uniaxial compressive strength
1	Moderate	Moderate	Moderate	Excellent
2	Poor	Moderate	Moderate	Moderate

Table10 . Specification of riprap according to[3].

class	True Specific gravity	Water absorption ratio%	Chemical Abrasion%	
			Sodium sulfate	Magnesium sulfate
I	2.5<	2>	10≥	15≥
II	2.5-2.3	2-4	11-19	16-24
III	2.3>	4<	20≤	25≤

The geotechnical properties of the rocks have been evaluated in accordance with the specifications mentioned above, and the resulting assessment of the limestone in the examined locations has been documented in Table 11.

Table 11. The evaluation of limestone as riprap according to standard [3].

Location NO.	Specific gravity	Absorption rate %	Chemical abrasion %	Evaluation
1	I	II	II	unacceptable
2	II	III	III	acceptable

4. CONCLUSIONS

The test results were conducted on eight rock samples collected from the study locations, the analyzed various geotechnical properties of rocks from eight different locations. Locations 1 and 2 exhibit relatively higher specific gravity and dry density for limestone rocks, On the other hand, the sand rocks at locations 3 to 8 exhibited higher absorption rates, porosity, and saturation coefficients, the assessment of the suitability of the Fat'ha formation rocks for use as a building stone and for riprap purposes. The rocks from both locations were categorized as the second category which is recommended as a suitable option in terms of suitability as a building stone, which is considered a recommended option. However, for riprap purposes, the rocks from the locations were classified as unacceptable according to [21]due to chemical abrasion and specific gravity values that exceeded the standard limits. The Iraqi standard indicated that the studied rocks were generally successful, except for the chemical abrasion, which was considered acceptable. According to [2] standard, the average rating for the rocks' suitability was moderate, while the specific gravity was categorized as poor for the second location. Finally, based on [3]standards, the rocks in the studied locations were deemed unacceptable for riprap in the first location and acceptable in the second location.

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