Iraqi National Journal of Earth Science

www.earth.mosuljournals.com

Evaluation of the Validity of the Rocks of the Pila Spi Limestone Formation in Duhok Anticline, Northern Iraq for Riprap Purposes

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Article information

Received: 29- May -2023

Revised: 17- Aug -2023

Accepted: 05- Sep -2023

Available online: 31- Dec – 2023

Keywords:
Pila Spi formation
Dohuk fold
geological survey
Engineering geology
Building stone

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ABSTRACT

The research aims to show the validity of limestone rocks of Pila Spi Formation in the fold of Duhok, northern Iraq for Riprap purposes. The formations of Pila Spi, Fatha and Injana in addition to the Quaternary sediments are mainly exposed in the study area. Five stations are selected in the northeastern limb of Duhok anticline, in which the limestone rocks belonging to Pila Spi Formation are exposed. The petrophysical tests show that the dry density ranges between (2.46-2.08) g/cm3, the absorption ratio ranges between (3.15-10.90%) and the specific weight values range between (2.66-2.74). While the mechanical tests show that the percentage of mechanical abrasion ranges between (20.06-58.42%) and the percentage of chemical abrasion ranges between (6.87-21.25%), and when comparing the properties with the specification Florida standard, it is found that is the Pila Spi rocks are valid for Riprap purposes in stations (1 and 2) and invalid in stations (3, 4, and 5) because the values of absorption ratio and mechanical abrasion are beyond the limits of the specification. By conducting a comparison between the properties of the rock samples and the specifications Iraqi standard, it is believed that they are valid for riprap purposes in stations (1, 2, and 3) and not valid in stations (4 and 5) because the percentage of mechanical abrasion is beyond the boundaries of the specification. In comparison with the properties with the specification American standard, it is found to be valid for riprap purposes at stations (1 and 2) and not valid at stations (3, 4, and 5) because the absorption ratio values are out of specification limits.

DOI: 10.33899/earth.2023.140666.1090,

تقييم صلاحية صخور الحجر الجيري لتكوين بلاسبي في طية دهوك, شمالي العراق لأغراض التكسية

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معلومات الارشفة

تاريخ الاستلام: 29- مايو-2023

تاريخ المراجعة: 17- أغسطس -2023

تاريخ القبول: 05- سبتمبر -2023

تاريخ النشر الالكتروني: 31- ديسمبر -2023

الكلمات المفتاحية:

تكوين بلاسبي

طية دهوك

الجيولوجيا الهندسية

احجار بناء

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الملخص

يهدف البحث الى بيان صلاحية صخور الحجر الجيري لتكوين بلاسبي في طية دهوك, شمالي العراق لاغراض التكسية حيث تنكشف تكوينات بلاسبي وفتحة وانجانه بالاضافة الى ترسبات العصر الرباعي. وتم اختيار خمس محطات في الجناح الشمالي الشرقي لطية دهوك المحدبة التي تنكشف فيها صخور الحجر الجيري العائدة لتكوين بلاسبي. أظهرت الفحوصات البتروفيزيائية ان الكثافة الجافة تتراوح بين(2.46-2.08)غم/سم^3 ونسبة الامتصاص تتراوح بين (3.15-10.90%) وقيم الوزن النوعي تتراوح مابين (2.66-2.74)، في حين اظهرت الفحوصات الميكانيكية ان نسبة التآكل الميكانيكي تتراوح مابين (20.06-58.42%) ونسبة التآكل الكيميائي تتراوح مابين(6.87-21.25%), وعند مقارنة الخواص مع المواصفة الخاصة بقسم فلوريدا تبين انها صالحة لأغراض التكسية في المحطات (1 و2) وغير صالحة في المحطات (3، 4، و5) لان قيم نسبة الامتصاص والتآكل الميكانيكي خارج حدود المواصفة. وعند مقارنة الخواص بالمواصفة العراقية تبين انها صالحة لأغراض التكسية في المحطات (1، 2، و3) وغير صالحة في المحطات (4 و5) لان نسبة التآكل الميكانيكي خارج حدود المواصفة. وعند مقارنة الخواص مع المواصفة الامريكية، تبين انها صالحة لأغراض التكسية في المحطات (1 و2) وغير صالحة في المحطات (3، 4، و5) لان قيم نسبة الامتصاص خارج حدود المواصفة.

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Introduction

Riprap stone is defined as a layer of rocks of approximately equal sizes angled or semi-circular through which slopes and river channel banks are covered to protect them from erosion (Jerome et al., 2021). Is also known as a layer of naturally occurring rocks found along riverbanks and coastlines, because of the large weight of rock masses, they withstand the waves and act as barriers that protect the soil under them and prevent the formation of pits as a result of strong waves (Lagasse et al., 2006). When the water flows it leads to erosion of river banks, streams, dams, and slopes, removal of crumbling materials from their place and transfer them to the bottom of the river of the lower soil or removal of vegetation that increases the process of erosion, it is very necessary to resort to the use of riprap that prevent or reduce erosion (Abdalla et al., 2022).

The design of Riprap is based on the knowledge of the slope of the river bank, the speed of flow, the depth and direction of the water, and the characteristics of the cladding stones in terms of density, durability, bonding, availability, the direction of the piers and supports, their dimensions, location, the direction of storage, the material that connects the stones and the

foundation on which they rest (Lagasse et al., 2006). In the Kurdistan region, there are huge quantities of limestone rocks suitable for engineering uses (Khudhur and Aqrawi, 2022).

Location of the Studied Area

The study area is located in northern Iraq within the administrative boundaries of Duhok Governorate, between longitudes (43°0'52") and (43°1'18") East and latitudes (36°50'02") and (36°50'24") North. The study area is located on the northeastern limb of the fold, where the length of the fold is about 15km, and its width is about 3-5 km (Fig.1).

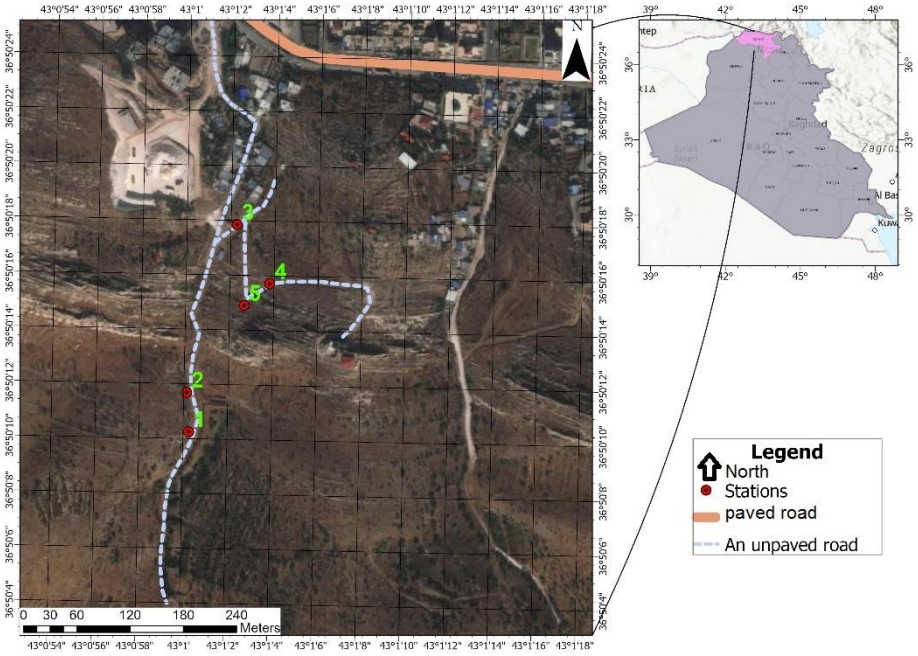

Fig. 1. Site map of the study area

Aim of the study

The study aims to find out the validity of limestone rocks belonging to Pila Spi Formation in Duhok anticline for riprap purposes by studying their geotechnical properties related to riprap after comparing them with standard specifications.

Stratigraphy of the Study Area

The Pila Spi, Fatha and Injana formations are exposed in the study area, in addition to the deposits of the Quaternary period. The Pila Spi Formation is one of the important formations that form continuous ridges in the Kurdistan region, and the thickness of the formation ranges from 15 to 110 meter. The Pila Spi Formation is one among the primary formations in northern of Iraq of old (Middle-Upper Eocene) and it forms the structure of the most folds (Varoujan et al., 2020), and controls the geological and geomorphological structure of the region. Its typical section is located in the village of Pila Spi, southeast of Sulaymaniyah, and as a result of the disappearance of this section because it submerged in water of Derbandikhan lake, an additional section was chosen for it in the Kashti area near the original section. The lower contact of this formation with the formation of Avana is sometimes overlapping and other times separated by the basal conglomerate (Bellen et al., 1959). The upper contact of the Pila Spi Formation is unconformable determined by appearance of basal conglomerate bed of different thickness, and these conglomerates may disappear in some areas. The Pila Spi Formation was deposited in a

lagoon environment (Sardar and Kurdistan, 2021) consisting of a sequence of layers of limestone and marly limestone and interspersed with layers of marl and dolomitic limestone and nodules of chert (Irfan, 2022). Plate (1), (Fig.2).

Plate 1. Limestone Rocks for Pila Spi Formation at Study Area Stations

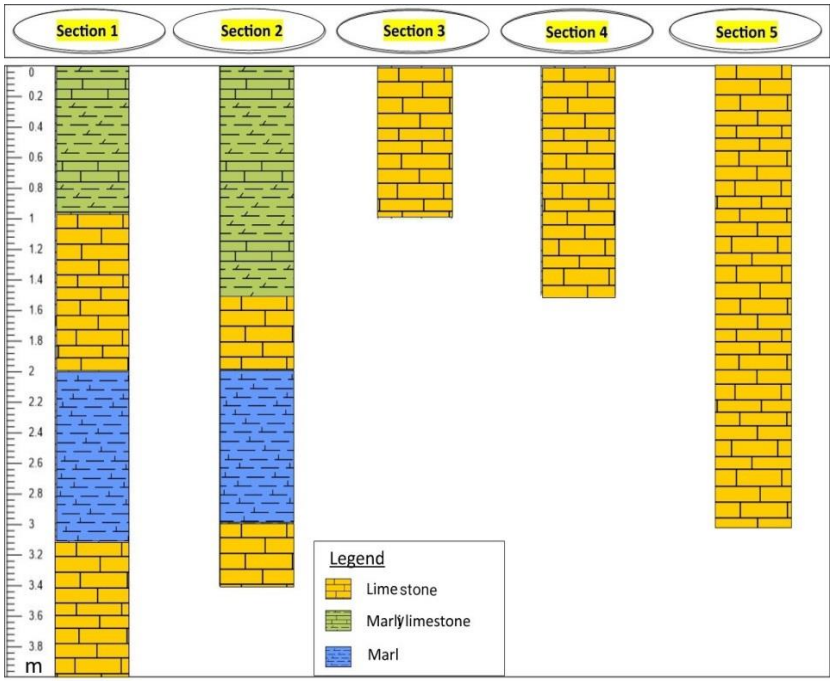

Fig. 2. Stratigraphic sequences of limestone Pila Spi Formation rocks at each station in the study area.

Structure and tectonics of the Study Area

Duhok anticline is structurally defined as an asymmetrical anticline fold, as the northeast limb is about (80 degrees). It is one of the large geological structures and its axis extends toward (northwest - southeast), its length about 15 km and its width is about 3 km (Al-Kadhim, 2009).

The study area is located tectonically within the high folds zone according to the modern division of Jassim and Goff (2006), who dealt with the theory of plate tectonic, and they divided Iraq into three main parts, namely the stable shelf and the unstable shelf (high folded zone and low folded zone) and the zone of the Zagros suture. The studied fold was formed in the second phase of the alpine movement in the Pliocene as a result of the collision of the Arabian plate with the Turkish and Iranian plates and the formation of the folds of its axes in a northwest-southeast direction, including the fold of the study area, which returns to the direction of the folds of Zagros, as for the folds whose axes are east-west resulting from the collision of the Arabian plate with the Turkish plate (Buday and Jassim, 1987). Fouad (2012) mentioned a division of Iraq based on modern concepts of tectonic plate (Fig.3).

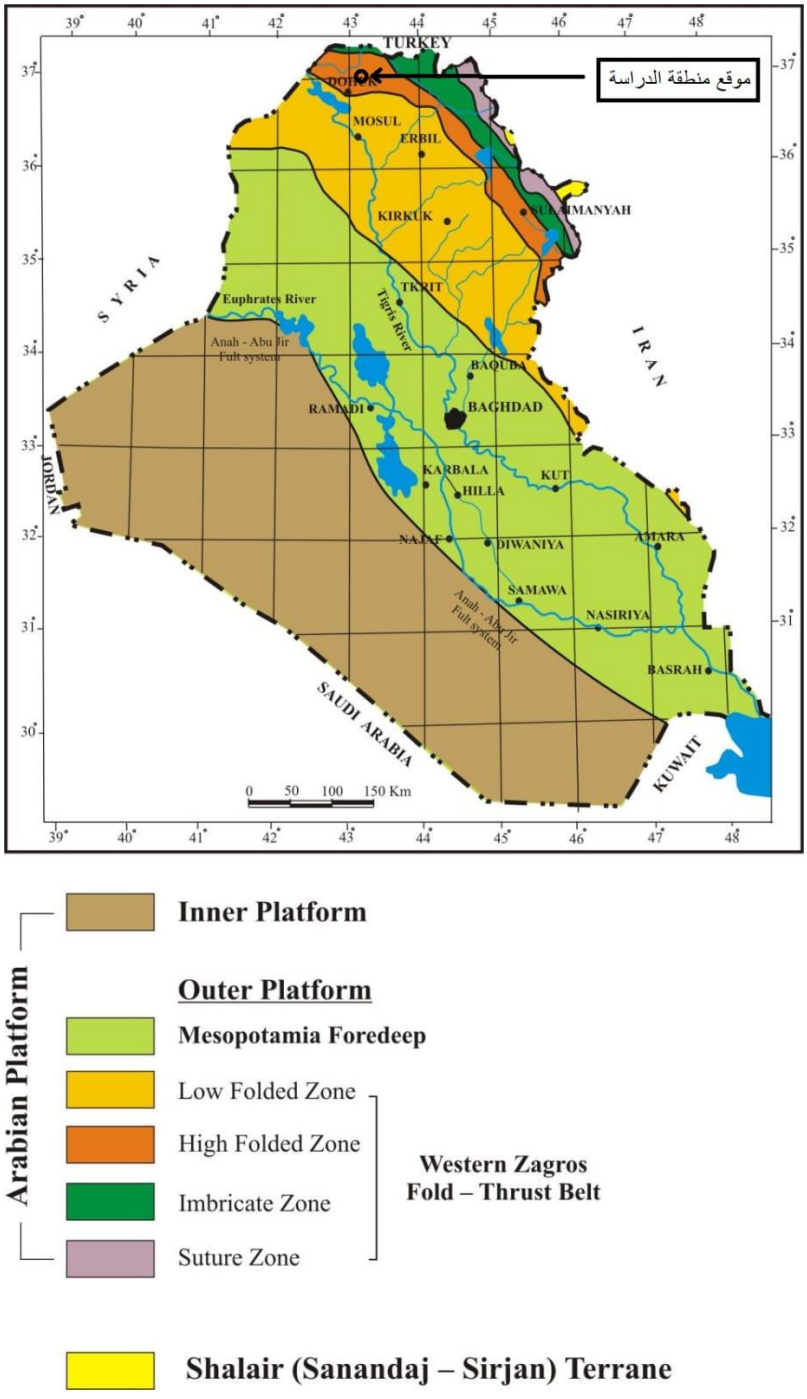

Fig. 3. Tectonic map of study area, (Fouad,2012).

Geomorphology of the Study Area

The study area is marked by a variety of topographical and geomorphological features with high, medium and low altitude terrain. The terrain with high and medium altitude is characterized by its resistance to weathering, while the low terrain is almost even due to its low resistance to erosion, and the geomorphological phenomena observed in the field are: (Hogback ridges) and transverse valleys that are perpendicular to the strike line, and the toppling and rock fall resulting from the erosion of limestone rocks and their fall down of the slope (Plate2).

Plate 2. Geomorphological features, 1-Toppling, 2-Rock fall, 3-valley, 4-Ridge.

Engineering Geological Survey

The engineering geological survey is very important in the classification of rock masses and their suitability for various engineering purposes through the explanation of the field properties of rocks, a comprehensive engineering geological survey of limestone rocks in the study area was conducted and engineering description according to the report of the Geological Society Committee of London. Which states that the name of the rock alone without description is not useful for engineering and stratigraphic purposes and that there must be an accurate description of the rock, and that the proposal of the Committee of the Geological Society of London that the system of the rocks description according to: color, spaces between joints, field rock strength, thickness of bedding, according to Anon (1972, 1977) and the weathering condition as Hawkins (1986) stated (Table1).

Table 1: The engineering field description of the limestone rocks belonging to the Pila Spi Formation in the study area (Anon,1972), (Anon,1977), and (Hawkins,1986).

No.	Dip direction/ Dip amount	Color (Anon, 1972)	Spacing (Anon,1972)	Weathering (Hawkins, 1986)	Rock strength (Anon,1977)	Bedding thickness classification (Anon, 1972)
1	010\80	Yellowish	Moderately wide spaced	Slightly weathering	Moderately strong	Thickly bedded
2	031\84	Yellowish	Moderately widely spaced	Slightly weathering	Moderately strong	Medium bedded
3	010\86	Yellowish	Widely spaced	Slightly weathering	Moderately strong	Medium bedded
4	016\75	Yellowish	Moderately wide spaced	Slightly weathering	Moderately strong	Thickly bedded
5	010\78	Yellowish	Very widely spaced	Slightly weathering	Moderately strong	Very thickly bedded

Sampling

Five stations representing the study area are selected in the northeastern limb of the Duhok anticline, and the positioning of the stations using a GPS device is determined, and sampling was done so that the samples are representative of the limestone rocks in the area, and sufficient to conduct all the required tests.

Properties of Building stone

Individual rock pieces must be of high density, very low porosity, hard, free of fractures, cracks and potholes that increase and facilitate the weathering process, and rocks should have sharp edges and angular forms. or semicircular (ASTM-D,4992, 2004). Also, it should not exceed more than 30% riprap stones with a long axis to a short axis (2.5), while the stones that have more than this percentage are either lamellar or longitudinal. The dimensions and mass of each individual piece are determined by the force of the water, making it challenging to ascertain the weight of the aggregates in the field. There exists a correlation between the size and weight of the rock fragments, and this equation assumes the shape of the rock pieces between the cube and circular.

$$Wn = 0.75 * \gamma * Dn3$$

where

Wn: the percentage of the total weight of a rock when its percentage is small.

γ: unit of weight of the rock.

Dn: the representative diameter of the rock when its ratio is small.

Laboratory tests

The geotechnical test of the stones are conducted in Department of Applied Geology, University of Tikrit according to the required engineering specifications such as dry density, specific gravity, absorption ratio, mechanical abrasion and chemical abrasion. Each test is briefly explained below.

1- **Dry density (ρ_{dry}):** is defined as the mass of a unit volume and its units (g/cm3) (ASTM-C,127-01, 2004), and depends on porosity, and mineral composition, and the mass of the unit volume of the samples measured by the method of three weights (dry, saturated, and submerged) by (ASTM-C,97-09, 2010) and the true dry density is calculated following the equation:

$$\boldsymbol{Bulk\ Density(\rho dry) = \frac{Mdry}{Msat - Msub} \cdot \rho w}$$

2-True Specific gravity (True G.s): is the ratio between the weight of a certain volume of solid to the weight of the same volume of distilled water at a temperature of (20 °C), (ASTM-C,97-09, 2010) and is calculated by applying the equation:

True G.s = M dry / (M dry – M sub)

where:

True G.s: True specific weight.

M dry: dry mass (gm).

M sub: submerged mass (g)

3-Water absorption ratio (A): 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 (Mdry), which is a percentage (ASTM-C,127-01, 2004), and it is calculated according to the following equation:

$$*100A = \frac{Mw}{Mdry}$$

4-Mechanical abrasion Test (Los Angeles): Mechanical abrasion test measures the weight reduction percentage of the sample caused by mechanical abrasion, which is a measurement of the resistance of coarse aggregates with small scales less than (37 mm) to abrasion and friction that affects the outer surface of the granules (ASTM-C131-96, 2004).

5-Chemical abrasion Test: The percentage of weight loss in the sample is determined by the chemical abrasion using sodium sulfate and is one of the important tests for the purpose of predicting the long durability of rock samples and knowing the weathering properties of rocks as well as evaluating the effect of water on the duration of the rock (ASTM-C,88, 2004).

Assessment the Suitability of limestone rocks for Riprap

When using limestone rocks as Riprap stones, geotechnical specifications (mechanical, physical) must meet the following specifications.

1-Florida Department of Transportation (F.D.O.T.) (2000). Specifications for the properties identified for the suitability of limestone rock as riprap stones as shown in Table (2).

Table 2: Riprap properties according to (F.D.O.T., 2000).

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%

By comparison of the geotechnical characteristics of the rocks of the study area with the above specifications, it is found that stations 1and2 are suitable as riprap stone, while the rocks of stations 3, 4 and 5 are not suitable as riprap stone, (Table3).

Table 3: The evaluation of limestone of the Pila Spi Formation as riprap stones by comparing with the standard (F.D.O.T., 2000) for evaluation.

No. Station	Geotechnical properties				Evaluation
	True Specific gravity	Water absorption ratio%	Mechanical Abrasion%	Chemical Abrasion%	
1	2.68	3.15	20.06	6.87	Valid
2	2.74	4.77	29.00	8.31	Valid
3	2.71	6.61	43.08	11.63	Invalid
4	2.66	8.30	55.06	17.47	Invalid
5	2.69	10.90	58.42	21.25	Invalid

2-The Iraqi Standard (National Center for Laboratories and Structural Research, 1989) The properties are determined by the National Center for Laboratories and Structural Research of limestone rocks when are used in cladding the river banks according to the specifications of the (Iraqi Standard, 1989) as illustraed in Table (4).

Table 4: Specifications of limestone rocks when are used as cladding stones according to (Iraqi Standard,1989).

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%

By comparison of the geotechnical characteristics of the rocks in the study area with the above specifications, it is found that they are in stations 1, 2, and 3 are acceptable, while the rock of stations 4 and 5 are unacceptable (Table5).

Table 5: shows the evaluation of limestone rocks as riprap stones according to (the Iraqi standard,1989).

Station No.	Geotechnical properties				Evaluation
	Dry density (g / cm^3)	Water absorption ratio%	Mechanical Abrasion%	Chemical Abrasion%	
1	2.46+	3.15+	20.06+	6.87+	Acceptable
2	2.40+	4.77+	29.00+	8.31+	Acceptable
3	2.30+	4.61+	43.08+	11.63+	Acceptable
4	2.17+	8.30+	55.06-	17.47+	Unacceptable
5	2.08+	10.90-	58.42-	21.25+	Unacceptable

+ acceptable; - unacceptable

3-ASTM-D.523,2004 Rocks are divided according to Standard Specification into three classes, Class I, Class II and Class III, depending on the difference in geotechnical properties as shown in Table (6).

Table 6: Geotechnical properties according to the standard (ASTM-D,523,2004).

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≤

By comparing the geotechnical characteristics of the rock in the study area with the above specifications it is found that stations 1and2 are acceptable for riprap stone while the rocks at stations 3,4 and 5 are unacceptable (Table7).

Table 7: The evaluation of limestone rocks according to standard (ASTM-D,523,2004).

Station No.	Geotechnical properties			Evaluation
	True Specific gravity	Water absorption ratio%	Chemical Abrasion% (Sodium sulfate)	
1	2.68+	3.15+	6.87+	Acceptable
2	2.74+	4.77-	8.31+	Somewhat acceptable
3	2.71+	6.61-	11.63+	unacceptable
4	2.66+	8.30-	17.47+	unacceptable
5	2.67+	10.90-	21.25-	unacceptable

Conclusions

- The geological survey of the area shows that the geological formations exposed in the research location are the Pila Spi, Fatha and Injana formations and with deposits of the Quaternary period.

- The engineering geological survey in the study area shows that the limestone rocks are yellowish in color. The bedding is medium, thick to very thick, moderately strong strength, and spaces between joints are wide to very wide.
- Petrophysical tests showed that the dry density ranges between weak to high, and the specific gravity values are high, and the absorption rate is uneven.
- Mechanical tests show that the values of mechanical abrasion range between weak to high, and the values of chemical abrasion are uneven.
- It is found that the limestone rocks of the Pila Spi Formation in the study area are suitable for riprap purposes in stations (1 and 2) when compared with the standards and are not valid in stations (3, 4, and 5) because the values of the absorption ratio and mechanical abrasion are beyond the limits of the Florida specification standards.
- It is found that the limestone rocks of the Pila Spi Formation in the study area are suitable for riprap purposes in stations (1+, 2, and 3) and unsuitable in stations (4 and 5) because the mechanical abrasion values are outside the boundaries of the standard when compared with the Iraqi specification standards.
- Based on the observation made, it can be concluded that limestone rocks of Pila Spi Formation are suitable for riprap purpose at stations (1 and 2), and they are not suitable in other stations due to their absorption ratio exceeding the standard boundaries when comparing to American specification standards.

Recommendations

- Study of the reserve of limestone rock layers in stations (1,2,3) for use for various riprap purposes.
- Encouraging ministries and departments related to conduct studies in this field to benefit from them in construction work.

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