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Engineering classification of argillite rocks with emphasis on laboratory tests in the Makran structural field

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Abstract
Argillite rocks are among the weak rocks that cause damage in the engineering project implementation due to stone swellability, high slake, and low strength and durability. South Makran structural zone is located in the southeastern part of Iran between the two thrust faults of Makran and Qasr-Ghand. Most of the sediments are Quartz fragments (silt size) with carbonate cement containing sub-minerals of calcite and fossil fragments, indicating a shallow and low-energy marine environment of the Neogene age. Based on the main faults south Makran is divided into four sub-areas, Makran, Zirdan, Chahan and Getivan. Field harvesting was used in each of the sub-areas for stone engineering classification and sampling for laboratory tests to determine the physical, mechanical and dynamic characteristics of the rock. According to rock engineering classification, most sediments are in weak and very weak classification. Petrology studies, determination of physical characteristics, durability test, point load strength and ultrasonic test were carried out. The results of the tests show that the sediments located in coastal Makran have more porosity and less cement due to the youngness of the sedimentation basin, and they have less strength characteristics in terms of durability. The results of the second stage cycle durability test show that porosity changes have the highest correlation with compressional wave velocity, uniaxial compressive strength, calcium carbonate percentage and SiO_2 percentage, and with the porosity increasing the efflorescence durability amount decreases (R^2=0.82). The durability of the second stage (I_{d2}) has a relationship between porosity percentage (n %) and compressive wave velocity (V_p) with a correlation value of (R^2=0.91) and calcium carbonate percentage (%$CaCO_3$) and compressive wave velocity (v_p) with a value correlation of(R^2=0.83). In order to determine the effective factors on the durability of argillite rocks, the experimental model of path analysis was used to determine the influencing coefficients, where porosity has a direct effect, and calcium carbonate percentage, dry density, and compressive wave velocity have an indirect effect.

Keywords: Weak Rocks, Qasr-Ghand Fault, Durability, Makran.

Introduction

In the international standards DIN, Ö-Norm, ASTM, or the methods recommended by IAEG, and ISRM, weak rocks are a group of rocks that are similar to hardened soils, and their difference from hard rocks is that in a short period of time (several years) when exposed to water and climatic changes, they break down that this loss of resistance is not reversible under normal conditions, while in cohesive soils it may be due to changes in water (Nikmann et al., 2006). The presence of anisotropy in argillite sandstones is considered an important factor in controlling weathering (Guang Sun et al., 2020). Due to the widespread use of marl rocks in many countries, an investigation of the physical and mechanical properties of this rock is

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necessary (Hooshmand et al., 2012). The conducted investigations show that the geomechanical parameters of marls are very diverse and their change range is greater than other rocks (Nikmann et al., 2006). Increasing the calcium carbonate amount in marl causes a decrease in the plastic and resistance indices of the soil. Several factors can be effective in evaluating the mechanical behavior of marl, which include the mineralogical characteristics of the rock constituents, the frequency ratio of clay materials to calcium carbonate, the cement type and the way particles are compacted to each other during the diagenesis process, the decalcification conditions caused by dissolution phenomenon and cracking of the stone structure (Tasiambaos., 1991). The mechanical properties of argillite sandstones are controlled by the influence of cement and clay matrix (Nie et al., 2021). strength and durability are two important parameters for evaluating weak rocks, which can be used to classify weak rocks due to the lack of core preparation for the uniaxial compression test, the point load strength test can also be used to estimate the uniaxial compressive strength (Ahmad et al., 2017). The durability of weak rock depends on various intrinsic and environmental conditions over time (days, months, and years). To study weak rocks in different countries, the international standards DIN, Ö-Norm, ASTM, or the recommended methods of IAEG, ISRM are used. The studies conducted on the durability of weak rocks show that the durability of rock is influenced by not only one parameter but also a combination of several parameters including compressive strength (boundary and matrix strength), grain size distribution (significant clay mineral content to water) and pore volume (water conductivity) (Nikmann et al., 2006). Nowadays, rock mass classification is one of the basic steps in the experimental design of engineering structures depended on the rock environment. Researchers have made a lot of efforts to provide a comprehensive and easy to understand classification method of the earth's environment, but depending on the application, there are several methods that need to apply coefficients and corrections in each project (Ghiasi et al., 2011). Among these methods, we can point to the Rock Quality distinctive (RQD), rock Structure Rating (RSR), rock geo-mechanical Rating (RMR), and rock Mass Quality Classification (Q) (Bieniawski., 1989). Classification systems enable engineering geologists to numerically introduce the characteristics and behavior of the Earth's environment to designers. The results of tests on an intact rock alone cannot express the characteristics of the rock mass well, so one of the methods is rock mass engineering classification. In tunnel design and maintenance (Bieniawski., 1989), stabilization and zoning of rocky slopes overlooking roads (Robert., 2002), reservoirs and dam foundations (Romana., 2004), buildings and open-pit mine ranges, in the stability analysis of trenches and excavations, Rock fracture criteria (Edelbro., 2004) using rock mass classification systems is common. The use of these rock engineering classification systems still has many limitations, so their efficiency becomes ambiguous when using these systems in fault zones and completely cut areas (Hosseinitoudeshki et al., 2012). Rock outcrops of southern Makran with clay, siltstone, sandstone, and limestone compounds called Argillite rocks that are in the weak rocks group. In the weak rocks group, there are different types of rocks from weak sandstones to mudstones and marlstones, all of which show different behaviors. Today, the rock mass classification is one of the basic steps in the experimental design of engineering structures depending on the rock environment. The unknown rock outcrops of South Makran and the wide spread of this problematic rock sediment type in most regions of the country, especially in the Chabahar region, provide an engineering classification model for the region based on the structural zones characteristics, conditions of the sedimentary environment and engineering geological indicators, can be a very suitable tool for field evaluations and engineering calculations of rock outcrops of the zone. Thus, based on the presented model, can separate the rocks of the region in terms of engineering indicators and identify areas with high potential for possible geology hazards in the construction project implementation site such as sensitive structures of the railway line. Most of the studies carried out in the Makoran structural zone have been focused on structural, petrological, age determination, sedimentology, and geochemical studies. The classification and investigation of engineering geological features of sedimentation units has been done with more focus on Chabahar units. Conducted investigations in this area show the complexity of this active structure, which plays different factors in the behavioral characteristics of these sedimentary units. Dividing South Makoran into different sub-areas and studying the properties of argillic sediments in each sub-area is considered an innovation of this research, for this purpose, the Chabahar-Nikshahr railway was chosen as a vertical cut on this structure so that can use its informational results. (Ghobadi et al., 2020 a) Geological properties of engineering rocks depend on mineralogical composition, texture, and weathering rate. In the following, (Ghobadi et al., 2020 b) in another research, by examining the engineering geological characteristics of peridotites in Harsin City, Kermanshah province, concluded that there is more compatibility between the characteristics in dry conditions than in saturated conditions. (Ghobadi et al., 2021) investigated the petrology characteristics and physical and mechanical characteristics of sandstones. The results showed that differences in the petrology and physical properties of sandstones has led to changes in their mechanical properties, and there is a good conformity between the results of the strength test with longitudinal wave velocity in dry and saturated conditions. The research was conducted by (Azarafza et al., 2019) on the engineering geological characteristics of Assalouyeh marls. The physical properties including porosity, density, liquid limit, and mechanical properties of Assalouyeh region marls including uniaxial compressive strength test, and durability test have been determined. In this research, they concluded that in sedimentary rocks with a lot of clay, such as marl, in the durability test, as the number of test cycles increases, a large weight loss occurs in the samples and vice versa. Research by (Rahimi Shahid et al., 2022) was conducted on Hamedan limestones, they worked on the engineering characteristics of limestone and using point load and porosity tests, presented a new parameter and obtained good experimental relationships. (Amiri et al., 2023) studied the petrology, Physical and mechanical characteristics of Ilam formation limestones and presented experimental relationships for the Ilam formation type section. Therefore, according to the importance of engineering characteristics, in this research, the engineering classification of argillite rocks with emphasis on laboratory tests on Makran structural subzones has been done.

Geology of the study area

According to Fig. 1, Makran includes 4 main states of North Makran, Inner Makran, Outer Makran and Coastal Makran with different sedimentary and igneous accumulations that reflect different stages in the development of the accretionary prism (Dolati., 2010). Due to the location of the studying region between the two Makran and Qasr-Ghand faults the investigation has been done under the name of South Makoran (outer-Makran, coastal Makran). Outer Makran contour of two Ghasr-Ghand faults is located in north of the Nikshahr and Chah Khan faults, its age is middle Miocene, which includes Qasr Ghand units (Lower Miocene marl), Vaziri unit (Lower Miocene sandstone), Roksha unit (Lower Miocene shale and sandstone) are located at the boundary between Getiwan and Qasr Ghan thrust fault (Figure 2). Pir Sohrab unit (Turbidie and shallow water sediments of middle Miocene age) are located between the Chah Khan fault and the Gativan fault (Figure 2). Coastal Makran to the south of Outer Makran is the boundary between the coastline and the Chah Khan fault, which consists of continental sediments and a shallow sequence of continental slope to the coast marls. This part is located in the sedimentary unit that includes the wide valley units (Upper Miocene surface waters) including two dominant marl members and dominant calcareous sandstone members, Nahang unit (detrital discontinuity (conglomerate) Pliocene-Pleistocene)), Chabahar unit (Pliocene-Pleistocene surface sediments).

The Makran subduction system is located in the southeast of the country and the southern half of Sistan and Baluchistan province. The very low subduction angle causes the distance between the beginning of the accretionary wedge and the volcanic arc is more than 400 km. Currently, the oceanic crust of Oman is subducting under Iran at a rate of approximately two centimeters per year (Vernant et al., 2004).

Materials and Method

In this study, in order to determine the topic and research method, the library method was used at first. For this purpose, a number of different sources were collected and studied. In the next step, 13 points were studied, and 24 samples were prepared from the investigated area. After transferring samples to the laboratory, the laboratory tests were performed. Sampling has been done along the axis of the Chabahar-Nikshahr railway and based on the difference in each geological unit from all layers of weathered and intact argillite rocks (Figure 2). The structures and units that were selected in the study cut is according to (Figure 2, Table 1). Due to the looseness of the samples and their sensitivity to water, it was not possible to core in some samples, and tests were performed on the lumps.

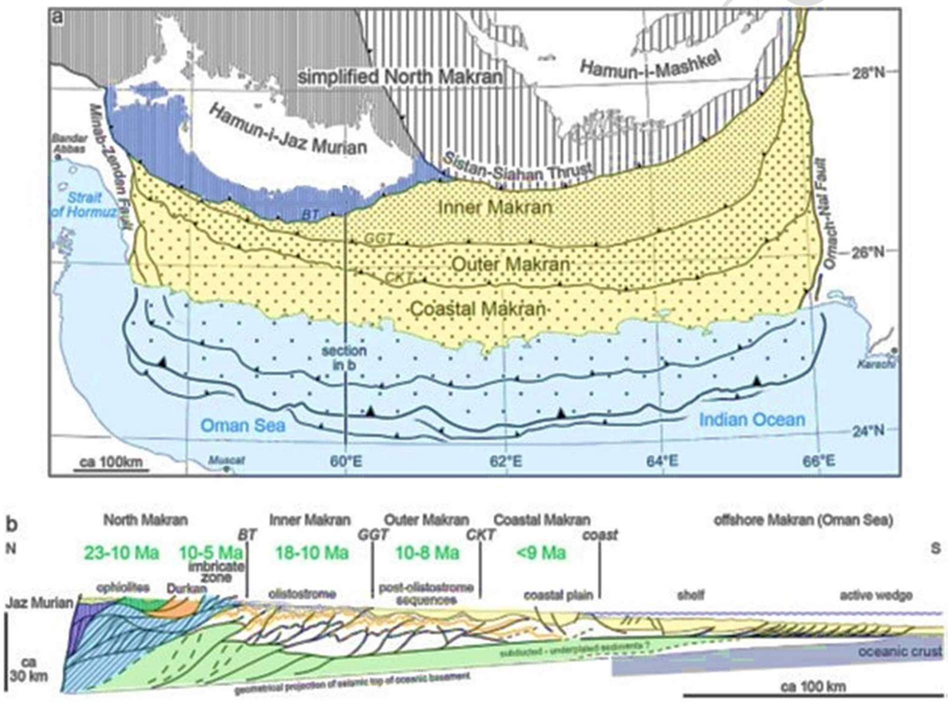

Figure 1. (a): General setting and simplified structural map of the Makran accretionary wedge, with different patterns representing the different tectono-stratigraphic zones discussed in the text. Yellow: emerged accretionary wedge; Violet: North Makran, partly ophiolitic backstop region. Offshore structures from Ellouz- (Zimmermann et al., 2007b), Grando and McClay (2007) and the National Iranian Oil Company, (unpublished). (b): General, synthetic profile (traced in a) across the Makran accretionary system modified after Burg et al. (2013). Fission track apatite ages (green numbers) interpreted as indication of tectonic activity after (Dolati, 2010). Note generally in sequence (southward) younging but necessary reactivation of the imbricate zone with its 10-5 Ma ages. Folded green line in profile: Cretaceous sediments; Folded orange line: Eocene-Lower Miocene sediments. Doted: Olistostrome. Pale yellow: Upper Miocene-Quaternary deposits. Ophiolites, Durkan Complex and imbricate zone coloured as in Fig. 6. In both a and b: BT=Bashakerd thrust; GGT=Ghasr Ghand Thrust; CKT=Chah Khan Thrust. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article)

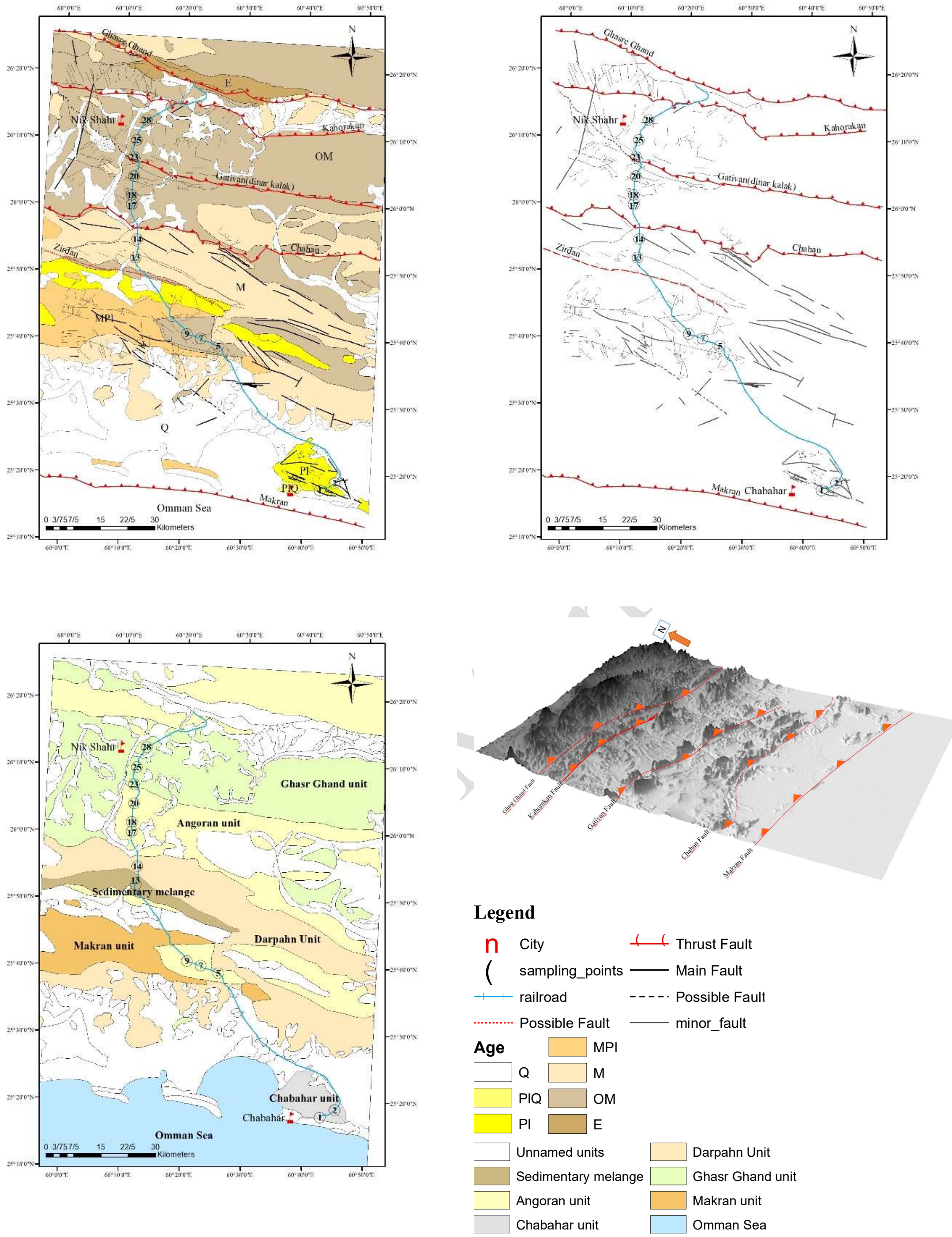

Figure 2. Geological map of the studied area (adapted from Dolati., 2010, Aghanabati et al., 1996, Eshraghi et al., 1996, Jafarian et al., 2004)

Petrology

The study of thin sections shows two categories of coarse-grained clastic sediments (carbonate sandstone, and siltstone), and fine-grained clastic sediments (marl, sandy limestone, and silt limestone) (Table 2). These sediments were formed in a shallow and low-energy environment that was mostly associated with detrital minerals. The distribution of grains are mainly silty and angular in a mainly carbonate field with the calcium carbonate percentage of less than 15%. XRD results show the composition of quartz, calcite, albite, clinochlore, muscovite and dolomite minerals (Figures 3 and 4).

Table 1. Structural divisions, stratigraphy units of the studied area and sampling locations

Sample No	Zone		Sub zone	Mechanism	Epoch	Stage	Unit
23,25, 28	Outer Makran	Gativan	Kahorakan-Gativan	Thrust fault	Miocene	Burdigalian	**Ghasr Ghand unit**
17,18, 20		Chahan	Gativan-Chahan	Thrust fault	Miocene	Burdigalian	**Angoran unit**
14	Coastal Makran	Zirdan	Chahan-Ziradan	Normal Fault	Miocene	Tortonian	**Makran unit**
13						Tortonian	**Sedimentary Melange**
5, 7		Makran	Zirdan-Makran	Normal Fault	Miocene	Tortonian	**Angoran unit**
9						Messinian	**Angoran unit**
-					Miocene-Pliocene	-	**-**
1, 2					Pliocene	-	**Chabahar**
-					Pliocene-Quatrnary	-	**Chabahar**
-					Quatrnary	-	**-**

Table 2. Study of thin sections of the studying area

km	Rock name	Description
1-S	Calcareous sandstone (hybrid)	Silt-level quartz fragments with carbonate background and calcite veins formed in a shallow and low-energy environment.
1-M	Silt Mudstone	Fossil fragments along with detrital quartz grains scattered in silt with carbonate background formed in a marine (open sea) environment with low energy.
2-S	Calcareous sandstone (hybrid)	Quartz fragments and skeletal pieces in the silt limit with carbonate background and calcite veins formed in a shallow and low energy environment.
2-M	Silt Mudstone	Fossil fragments along with detrital quartz grains scattered in silt with carbonate background that formed in a marine (open sea) environment with low energy.
5-S	Siltstone - a mixture of carbonate + clastic silica	Quartz fragments and calcite crystal grains formed in a shallow, low-energy environment.
7-S	detrital lime	Detrital Quartz grains with angular surfaces along with feldspar, rock fragments (volcanic, chert) formed in a low energy environment.
7-M	marl	Clay minerals with calcite, autogenic pyrites, detrital quartzes with a clay background that formed in a low-energy marine environment.
7	Carbonate silicate is an intermediate level rock (detrital -carbonate)	Quartz detrital grains, feldspar, stone fragments (volcanic, chert)

		which are mostly angular and without rims formed in a spar calcite cement field of low energy environment.
9-M	Calcareous sandstone (hybrid)	Silt-level quartz fragments with carbonate background and calcite veins formed in a shallow and low-energy environment.
9-S	siltstone	Silt-size quartz fragments with a carbonate background formed in a low-energy environment.
9-V	marl	Clay minerals that boil with acid and only clay remains, along with fine grains of quartz, lime oxides, and clay minerals.
13-M	siltstone	Silt-size quartz grains with bio disturbance effects along with fine plant fragments and iron oxides formed in the coastal to shallow marine environment with low energy.
14-S	siltstone	detrital quartz grains in the silt limit with a carbonate background formed in a marine environment
14-Sh	Lime sandstone	Silt-size quartz grains with bio disturbance effects along with fine plant fragments and iron oxides formed in the coastal to shallow marine environment with low energy.
17-S	Quartz siltstone with laminated structure	Fine quartz grains are formed along with fine carbonate grains and clay minerals in the shallow marine environment.
18-S	siltstone	Angular detrital grains of silt-size quartz with clay, calcite, and plant fragments formed in a continental environment.
20-Sh	Quartz siltstone	Silt-size quartz grains with bio disturbance effects
20-M	Sand lime	Quartz grains with a carbonate and clay background formed in a low-energy marine environment.
23-Sh	Quartz siltstone	Silt-size quartz grains with bio disturbance effects
23-S	Sand lime	Detrital Quartz grains along with non-skeletal fragments and calcite formed in a coastal environment (mixed carbonate and detrital rock).
25-Sh	Quartz siltstone	Fine quartz grains with high angular and no roundness to the extent of silt, which were formed in shallow marine environment.
25-S	detrital lime	Quartz grains with a calcium carbonate background formed in a shallow environment.
28-S	Lithic Arenite	Angular quartz grains formed in a low energy environment.
28-Sh	Stone silt lime	Detrital quartz grains in the silt size, which autogenic pyrites effects extend to a large amount in a carbonate field.

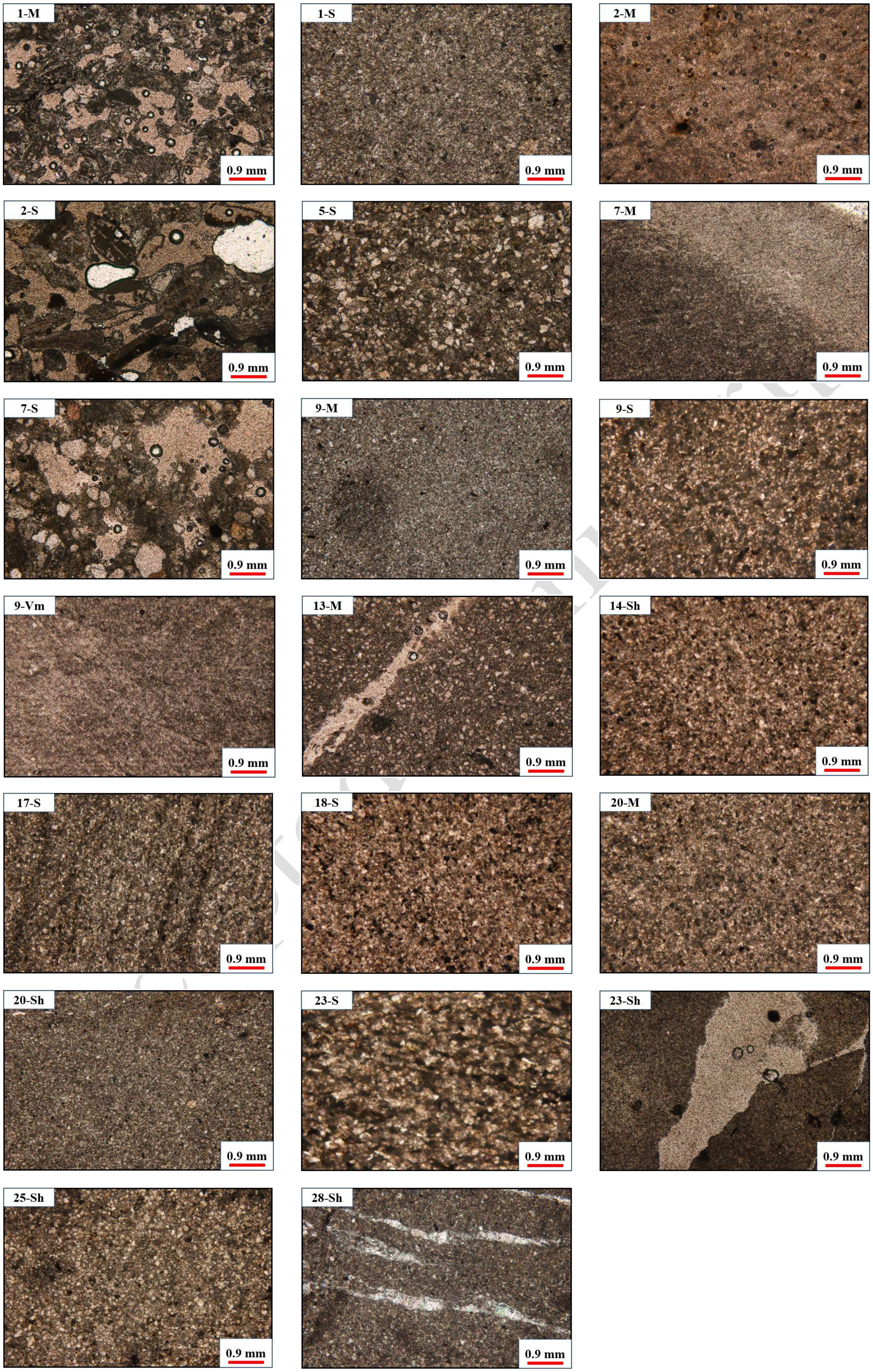

Figure 3. Microscopic images of lithological thin sections

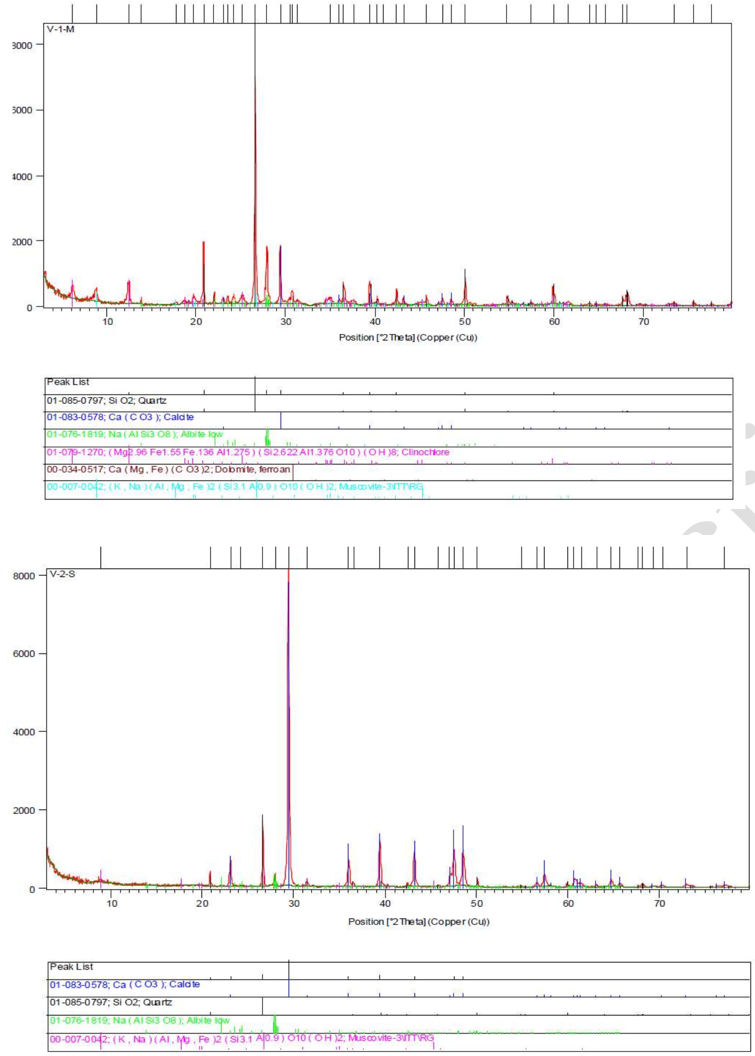

Figure 4. X-ray diffraction (XRD) results for two samples 1-M and 2-S

Chemical analysis

The XRF analysis of the samples results show that the main constituent oxides are SiO2, Al2O3, Fe2O3, and Cao (Table 3). The characteristic features of marl rocks such as Atterberg limit, uniaxial compressive strength, and point load are closely related to the amount of calcium in the rock. The percentage of calcium carbonate in the argillite samples has been determined by using the calcimetry test using the back titration method. In this method, one normal hydrochloric acid solution and half normal soda solution are used, the results of which are according to Table 5.

Results

Physical, mechanical and engineering properties

Physical characteristics

Anon (1979) classified rocks based on dry density and porosity percentage. In this category, the more porous the rock is and has lower the dry density, the weaker the rock is (Table 4). The percentage of porosity is one of the indicators for identifying weak rocks, and if the percentage of porosity is between 40-60%, the rock can be considered as a weak rock. The physical characteristics of rocks according to the ASTM (D2216-80, 1989) and ISRM, 1981 standard, and the results of tests on coarse-grained and fine-grained clastic sediments are given in Table 5.

Slake durability test

The slake durability test is one of the most important parameters of weak rocks (especially rocks containing clay). This index is used to design and analyze the stability of structures built in or on weak rock mass. This test measures the strength of weak rocks to physical, mechanical, and chemical weathering, which helps engineers predict the future behavior of the rock under natural conditions.

Table 3. The results of x-ray diffraction (XRF)

Sample No	L.O. I	Na2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	Fe_2O_3
1-S	29/74	0/61	6/01	3/45	22/46	0/67	34/37	1/95
1-M	8/71	1/44	4/21	12/78	52/73	2/34	9/16	7/12
2-S	36/57	0/25	0/71	1/23	7/05	0/27	52/32	1/16
2-M	11/42	0/72	4/73	14/73	49/94	2/94	8/18	6/16
5-S	9/49	1/30	3/52	10/68	56/81	1/84	11/76	3/75
7-S	16/48	1/04	2/40	5/11	43/17	1/09	27/27	2/51
7-M	8/53	1/19	4/17	14/75	56/64	2/76	4/85	5/90
9-M	17/10	1/51	3/37	7/46	42/43	1/05	22/07	4/09
9-S	8/24	1/14	4/11	15/13	56/88	3/04	4/29	5/89
13-M	7/45	1/10	3/86	14/87	58/71	2/94	4/47	5/62
14-S	12/21	1/63	2/26	8/22	51/93	1/22	18/88	2/70
14-Sh	7/57	1/16	4/97	17/55	51/87	3/31	5/07	7/01
17-S	7/84	1/21	4/00	14/86	57/60	2/86	5/54	6/04
18-S	8/99	1/73	2/56	9/45	59/85	1/29	12/40	2/97
20-M	10/80	1/40	3/45	11/60	55/57	1/79	10/69	4/51
20-Sh	6/98	0/92	4/48	16/40	56/97	3/36	2/87	6/99
23-S	11/22	1/68	1/60	6/15	57/21	0/80	18/70	2/03
23-Sh	7/00	0/86	4/25	16/24	57/63	3/52	2/90	6/62
25-S	12/41	1/95	2/88	10/95	48/50	1/71	16/92	3/66
25-Sh	7/76	1/09	4/09	15/84	56/51	3/30	3/90	6/53
28-S	8/24	1/59	3/20	11/30	59/98	1/64	9/54	3/75
28-Sh	11/24	1/13	3/74	13/33	51/52	2/52	10/00	5/53

Table 4. Classification of dry density and porosity of rocks based on LAFG (Anon., 1979)

Porosity description	Sample number	%n	Density description	Sample number×	ρ_d (gr/cm3)	Class
Very high	**2-S, 2-M**	>30	Very low	**2-S, 2-M, 1-M**	1.8<	1
high	**5-S, 1-M**	15-30	low	**5-S**	1.2-8.2	2
Medium	**13-M**, 18-S, **9-M, 7-S, 1-S**, 28-Sh, 23-Sh, **14-Sh, 7-M**	5-15	Medium	18-S, **9-M, 7-S, 1-S, 7-M**	2.2-2.55	3
low	28-S, 25-S, 23-S, 17-S, 14-S, 9-S, 20-M	1-5	high	28-S, 25-S, 23-S, 17-S, **14-S, 13-M**, **9-S**, 28-Sh, 23-Sh, 20-M, **14-Sh**	2.55-2.75	4
Very low	-	1>	Very high	-	2.75>	5

× The samples marked in bold are located in the coastal area of Makran.

By performing this test on rock samples and determining the durability and slake index in the second cycle, weak rocks can be identified. If the slake characteristics of rocks containing clay minerals are examined to time, it can be seen that their durability is strongly dependent on the reaction between rock and water (Hadak., 1982). The result of the reaction between rock and water is called deposition, which is often the result of dissolution, creation of fractures and destruction of surface layers of rock (Santi et al., 1996). Due to the dependence between durability and deposition, the durability of shales and marls is often determined by slake test (Santi, 1998). Rock slake is an important index in evaluating the rock mass engineering behavior and the use of rock materials in geotechnical works. The slake durability, especially for weak rock groups, is an important engineering parameter in relation to the stability of surface and subsurface drilling, as well as the stability of natural and artificial roofs (Khanleri et al., 2019). The second stage slake durability test (Id2) is widely used in determining physical changes or slake behavior of rocks due to wet and drying processes (ISRM, 1981, ISRM, 2007, Franklin and Chandra., 1972). If the index of durability in the second cycle of a rock is determined based on the ASTM D4644-87 standard and its value is less than 60%, the rock is considered a weak rock (Tables 5 and 6) (Santi et al., 1997).

Table 5. The results of laboratory tests for coarse-grained clastic sediments

Sample No	Is_{50} (Mpa)	$\%Id_2$	$\%Id_1$	$CaCO_3$ (%)	n (%)	Iv (%)	ρ_d (gr/cm3)
28-S	0.27	98.57	99.47	12.5	2.29	0.26	**2.63**
28-Sh	_	_	_	12.5	5.74	0.79	**2.66**
25-S	6.47	99.02	99.35	2.33	3. 97	0.38	**2.59**
25-SH	_	_	_	2.33	_	_	**_**
23-S	0.31	99.61	99.74	2.45	2.25	0.14	**2.61**
23-Sh	_	_	_	2.45	9.22	0.95	**2.67**
20-M	0.38	_	_	3.01	2.1	0.39	**2.62**
20-Sh	_	_	_	2.59	_	_	**_**
18-S	0.05	97.77	98.64	12.44	10.09	0.43	**2.37**
17-S	0.18	99.28	99.56	4.19	4.93	0.35	**2.57**
14-S	5.72	99.46	99.63	9.96	3.03	0.25	**2.56**
14-Sh	_	_	_	8.11	8.01	0.72	**2.57**
13-M	0.07	95.18	98.07	5.95	7.30	0/63	**2/62**
9-S	0.31	99.53	99.70	3.55	2.58	0.14	**2.59**
9-M	0.30	98.85	99.25	9.43	6.70	0.41	**2.52**
7-M	1.71	_	_	4.6	10.05	1.21	**2.45**
7-S	0.03	92.31	95.35	33.29	13.47	0.27	**2.28**
5-S	0.02	0.14	7.95	9.59	23.35	0.44	**2.13**
2-M	0.02	_	_	16.64	37.53	2.45	**1.77**
2-S	0.02	87.32	92.88	90.44	35.99	0.15	**1.62**
1-M	0.01	3.91	10.15	15.01	33.62	0.85	**1.86**
1-S	0.10	98.70	99.06	71.85	12.64	0.26	**2.27**

Table 6. Classification of rocks based on slake durability index of the first and second cycle (Santi et al., 1997)

slake durability index of the second cycle (%) (Gamble., 1971)	classification	slake durability index of the first cycle (%) Franklin and Chandra., 1972)	Classification
0-30	Very low	0-25	Very low
30-60	low	25-50	low
60-85	Medium	50-75	Medium
85-95	Slightly strength	75-90	strength
95-98	strength	90-95	Very strength
98-100	Very strength	95-100	Extremely strength

Mechanical properties

point load Strength test

The uniaxial compressive test that use in order to determine the rock strength is used due to the long time for preparation and supplying the sample, the high cost of the test, the limitation of use in argillite rocks due to the lack of rock cores supplying, and alternative tests such as the point load strength test have been used, which causes significant reduction in the cost and time of studies. The point load strength test is used to determine the point load index (Is50) of rock samples (Bieniawski., 1973) (ASTM., 1995, Dear., 1968). The rocks have been clssified based on the point load strength. According to Beniawski classification, weak rocks have a point load index of less than 2.5 and 2 MPa respectively (Table 7).

Point load test is used as an index test for classification and estimation of uniaxial compressive strength. Various researchers have presented ratios for the relationship between uniaxial compressive strength and point load index, which have a wide range. The reasons for this can be the use of rocks with different petrology, porosity, degree of weathering and other factors affecting the rock's strength. For some samples, due to excessive weathering and crushing, it was not possible to prepare samples even in the form of lumps, which are marked with dashes in the results table (Table 8), in order to determine the uniaxial compressive strength, Equation 1 was used for weak rocks. (Table 8).

$$\begin{aligned} &UCS=24.4\ PLI\ \text{(Strong rocks)} \\ &UCS=3.86(PLI)^2 + 5.65PLI\ \text{(Weak rocks)} \end{aligned} \quad \text{(Quane and Russel., 2003)} \qquad (1)$$

Table 7. Classification of rocks based on point load Strength

Sample number	point load Strength (MPa) Beniawski(1973)	Sample number	Deer (1968)	description	classification
25-S	>8	-	>10	Very high	A
14-S	4-8	25-S, 14-S	5-10	high	B
-	2-4	-	2.5-5	medium	C
7-M	1-2	7-M	1.2-5.5	low	D
1-S, 1-M, 2-S, 2-M, 5-S, 7-S, 9-M, 9-S, 13-M, 17-S, 18-S, 20-M, 23-S, 28-S	0-1	1-S, 1-M, 2-S, 2-M, 5-S, 7-S, 9-M, 9-S, 13-M, 17-S, 18-S, 20-M, 23-S, 28-S	0.5-1	Very low	E

Table 8. Determining uniaxial compressive strength using point load results indirectly for coarse and fine-grained clastic sediments

28-S	**25-Sh**	**23-Sh**	**20-Sh**	**18-S**	**17-S**	**14-S**	**13-M**	**9-S**	**9-M**	**7-S**	**5-S**	**2-S**	**1-S**	**Sample code**	**coarse-grained**
1.84	-	-	-	0.31	1.12	158.73	0.44	2.13	2.08	0.18	0.09	0.12	0.61	**UCS(Mpa)**	
28-Sh	**25-S**	**23-S**	**20-M**	-	-	**14-Sh**	-	-	**9-V**	**7-M**	-	**2-M**	**1-M**	**Sample code**	**fine-grained**
-	1.45	2.15	2.71	-	-	-	-	-	-	20.96	-	0.09	0.06	**UCS(Mpa)**	

Determination of uniaxial compressive strength and wave velocity

Uniaxial compressive strength and wave velocity are important properties of rock, which are time-consuming and difficult to measure in the laboratory, but compressive wave velocity and shear wave velocity are considered non-destructive tests to determine the physical and engineering properties of rock. The wave velocity measurement on the samples was done according to the ISRM standard (ISRM.., 2007), which was obtained using the Vp and Vs values of the dynamic modulus of the rock using the following equation (Deliormnli et al., 2007). Table 9 shows the results of mechanical and dynamic characteristics.

$$E_{dry} = \frac{\rho V_s^2 (3V_p^2 - 4V_s^2)}{V_p^2 - V_s^2}$$

The following equation has been used to determine the uniaxial compressive strength (Kaharaman and Yeken, 2008).

$$UCS = 0.258 V_p^{3.543}$$

Rock engineering classification

In order to classify rock mass engineering field harvesting was done in different units according to (Figure 2) and then classification was done by RMR (Bieniawiski., 1989), Q-System (Barton., 1987) and GSI (Marinos & Hoek., 2001) method that its results are given in table 10.

Most of the studies conducted in the Makran structural zone have been focused on structural, lithology, age determination, sedimentology and geochemistry. The classification and investigation of engineering geological features of sedimentation units has been done with more focus on Chabahar units. The variety of studies conducted in this area shows the complexity of this active structure, which plays different factors on the behavioral characteristics of these sedimentary units. Investigating and classifying these sedimentation units requires comprehensive information in creating various dimensions. For this purpose, Chabahar-Nikshahr railway was chosen as a vertical cut on this structure so that its information results can be used.

Table 9. Results of mechanical and dynamic properties

Sample code	**Vp(m/s)**	**Vs(m/s)**	UCS(Mpa)
1-S	5136	2608	84.99
2-S	2254	2766	4.59
5-S	1566	1798	1.26
7-S	1771	1501	1.95
9-M	3722	3102	27.16
9-S	4317	3241	45.93
13-M	2600	1146	7.62
14-S	4270	4108	44.18
17-S	4435	2173	50.53
18-S	2896	2252	11.16
28-S	5000	2154	77.28
1-M	1434	2786	0.93
2-M	1615	1146	1.41
23-S	4770	1740	65.40
25-S	4257	2292	43.71

Table 10. The results of rock engineering classification by RMR, Q-System and GSI methods in the studied units

Sample No	RMR	GSI	Q-system	Age
28	53	40-45	2.89	**M**
25	39	45-50	0.36	**M**
23	28	15-20	0.12	**M**
20	32	15-20	0.23	**OM**
18	43	25-30	0.3	**OM**
17	47	35-40	1.22	**OM**
14	31	20-25	0.26	**M**
13	53	35-40	0.72	**PL**
9	40	30-35	0.67	**OM**
7	40	30-35	0.65	**OM**
5	56	65-70	2.73	**OM**
1	47	40-45	1.05	**PL**
2	30	10-15	0.6	**PlQ**

In order to investigate behavioral changes in southern Makran (coastal and outer Makran) and the structure type of accretionary wedges in subduction zones, this zone was divided into four structural sub-zones (Figures 1 and 2) to consider the effects of changes in sedimentation areas due to structural conditions dominate the region. Sampling of Angoran, Sabzeh and Qasr-Ghand, Dareh Pahan and Jaqin and Chabahar units of Oligomiocene, Miocene, Pliocene and Quaternary ages was carried out in a way that the age of sediments becomes younger in the north to south direction. The engineering geological impressions for the purpose of rock engineering classification show weak and very weak classification (Table 10). Investigations of thin sections show quartz fragments at the limit of silt with a carbonate background that has calcite sub-minerals and fossil fragments and indicates a shallow and low-energy marine environment (Table 2). In order to compare sedimentary units, after studying them, they are divided into coarse-grained and fine-grained clastic (Table 2) that can compare their physical, mechanical and behavioral characteristics (Table 8). The results of XRF analysis of the samples show that the main constituent oxides are SiO2, Al2O3, Fe2O3 and Cao (Table 3). The characteristic features of marl rocks such as Atterberg limit, uniaxial compressive strength and point load are closely related to the amount of calcium in the rock. The percentage of calcium carbonate in the argillite samples has been determined by using the calcimeter test using the back titration method. In this method, one normal hydrochloric acid solution and half normal soda solution have been used, the results of which are according to Table 5.

The characteristic features of argillite rocks, such as point load and slake durability, are closely related to the amount of calcium carbonate in the rock. The percentage of calcium carbonate in coarse- and fine-grained clastic sedimentary units that are of Miocene and Mio-Pliocene age is between 2 and 30%, and the samples of coarse-grained clastic in coastal Makran and near the sea are of Pliocene and Quaternary age, due to the presence of sprite calcite, its amount is between 70 and 80%. This amount of calcium carbonate for fine-grained samples is 15% on average. Review the results of physical tests (Table 5) shows that sediments are divided into three categories of very low, low and medium density according to Anon classification (Table 4); and in terms of porosity, they are divided into four categories: low, medium, high and very high

Porosity shows the highest value of correlation with the change in the sub-zones considering the age of the samples and the samples located in coastal Makran (samples 1-M, 1-S, 2-S, 2-M, 5-S, 7- M) have high and very high porosity, so that limestone (hybrid) sandstones and silt - mudstones located near the coast have very high porosity (Figure 5).

Due to the large amount of time required to prepare and supply the sample for the uniaxial compressive test, which are used to determine the rock strength, and the limitation of using argillite rocks due to the lack of rock cores preparation, alternative tests such as the point load strength test have been used to use the results indirectly to estimate the uniaxial compressive strength of the rock (Eq. 1), however, some samples could not be tested due to weathering and crushing conditions. Determining the uniaxial compressive strength indirectly using equations (Tables 8 and 9) shows that most of the samples have a uniaxial strength of less than 20 MPa, and the samples located in coastal Makran have the lowest strength value. In order to establish a correlation between porosity and indirect results of uniaxial compressive using the Quane and Russel (2003) relationship which is used for weak rocks, the results of samples with the lowest and highest strength were removed, which indicates a high correlation (R2=0.96). So that the samples with high and very high porosity have lower strength (Figure 8). The results of the slake durability test (Table 5) show that coarse-grained clastic samples based on the classification (Gamble, 1971, Franklin and Chandra, 1972) (Table 5) classified to three categories of slightly strength, strength and very strength, and for mudstone sediments, they are classified as extremely weak category. Other samples lacked standard lumps due to excessive weathering and crushing, and it was not possible to perform durability cycle test (Figure 6).

In order to study the parameters affecting the durability, the results of the correlation value were used (Table 12).

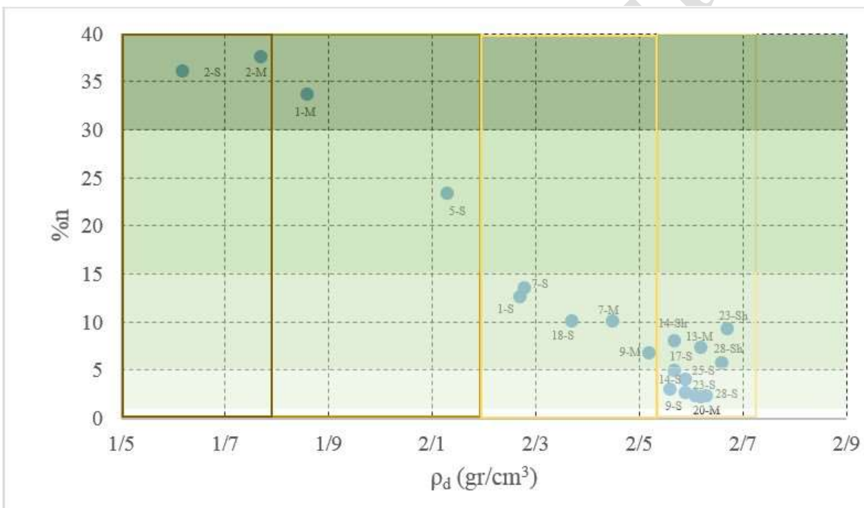

Figure 5. Classification of samples based on dry density and porosity of rocks based on LAFG (Anon, 1979)

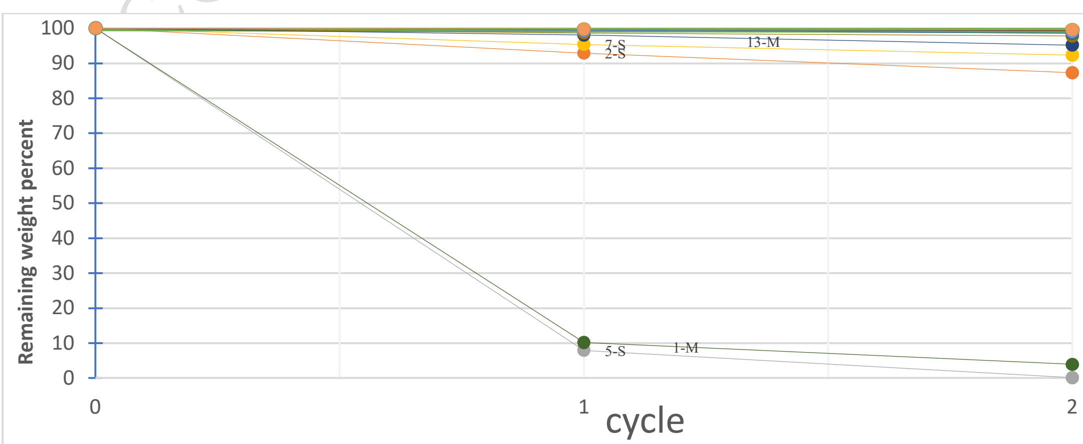

Figure 6. The percentage of weight loss in the two stages of the efflorescence durability test cycle

Table 12. Determining the correlation value of parameters affecting the slake durability index (second cycle)

	R^2				
	$\%SiO_2$	%n	$\%CaCO_3$	UCS(MPa)	V_p(m/s)
$\%Id_2$	0.58	0.84	0.52	0.30	0.58

The results of the cycle durability test of the second stage show that the changes in porosity have the highest correlation with the uniaxial compressive strength, percentage of calcium carbonate and percentage of SiO2, and as the porosity increases, the durability value decreases with the correlation value of (R2=0.84) (Figure 7-12).

Regression

Multiple variable linear regression

In the regression subject, the goal is to find a relationship between dependent and independent variables. This relationship may be linear or non-linear. SPSS Version 26 software was used to perform regression. The way it works is that by specifying the independent variables as input in the software and the dependent variable as output, the software engine creates an equation according to the amount of input and output values, by which the amount of the dependent variable can be estimated according to the input parameters (independent variables). The solutions of the created equation compared to the real values (dependent variable) have a correlation coefficient (R) of the engineering confidence level. The closer the correlation coefficient is to 1, the more accurate the equation created by the software is. Since it is possible that in addition to the independent variables, many other unknown factors also play a role in determining the value of the dependent variable, we consider the regression model with the most appropriate number of independent variables and consider the error rate as a representative of other random factors that could not be identified, which is expected to play a lesser role in the changes of the dependent variable. The mean sum of squared errors (MSE), which is also known as the mean squared deviations, and the smaller its number is, the higher the accuracy of the equation is. The significance level (Sig) of the mentioned test shows whether the entry of the variable into the model is significant or not, the significance level of the statistical test should be less than 0.05, which is significant as a result. By using simple regression, can apply it to determine the correlation between the mechanical properties of rock (Sharman et al, 2018).

Backward model

In this method, first all the variables are used to make the model. Then, in each step, the change that has a lower impact is removed and finally the model is presented with a smaller change of changes with a greater impact (SPSS 18, 2010). In multi variable linear regression analysis, we intend to predict the linear relationship between independent and dependent variables; but the issue that arises in the implementation of the regression analysis method is that we could only predict the direct effect of each independent variable on the dependent variable and it was not possible to identify the indirect effects of the independent variables on the dependent variables. In such condition, we cannot test the conceptual and theoretical model of research, which is usually a theoretical model consisting of making relationships between independent variables. To solve such a problem, we can use the path analysis method; therefore, path analysis, which was first developed by Sowell Wright in 1934, is a generalization of the multivariate regression method in relation to the development of causal models. Path analysis is an advanced statistical method that by using it can identify, in addition to direct effects, the indirect effects of each independent variable on the dependent variable; therefore, the most important advantage of using the path analysis method compared to the regression method is that in the regression analysis method, we were only able to identify the direct effect of each independent variable on the dependent variable, but in the path analysis method, in addition to the identify direct effect, we are also able to identify indirect effects of each independent variable on dependent variable. Therefore, in path analysis, we are faced with several standardized regression line equations, while in regression analysis, we have only one standardized regression line equation. In path analysis, the arrows indicate causal effects from independent variables to intermediate and final dependent variables. Path analysis determines how direct and indirect the effect of each variable is. In other words, the path analysis technique is used to determine the direct and indirect effect and ineffectiveness between the variables in the causal system, as well as the degree of conformity of the theoretical model with a set of data; therefore, in path analysis, the theoretical model of the research based on the causal relationships pattern between the variables is tested and this theoretical model becomes the experimental model of the research after the implementation of the test. The most important part of path analysis is designing and testing the path diagram, which consists of several basic components. The path diagram is actually a prior or pre-empirical structural model with a set of structural equation that describe possible scientific relationships between variables. This path diagram is always designed by the researcher after reviewing the theoretical foundations and formulating the selected theoretical framework of the research, which is finally tested experimentally in the path analysis. The path diagram is a combination of the total paths that connect the independent variables to the dependent variable in the form of one-way arrows. Each of these paths is characterized by a path coefficient. The path coefficient is Beta, which expresses the contribution or weight of each independent variable in explaining the variance of the dependent variable. In the path diagram, each independent variable has a path coefficient that shows the amount of expected change in the dependent variable as a result of a unit change in the independent variable; that is, it shows how much change is made in the dependent variable per one unit of the independent variable; so, in such an effect, the first variable is called the cause and the second variable is called the effect. In path analysis, the R statistic is used to evaluate the model. This statistic shows the dependent variable variance amount that the independent variables in the model have been able to explain it. As mentioned before, in path analysis, we put a theoretical model to the test, and finally, by performing the analysis, this theoretical model should lead to an experimental model; therefore, it is natural that the made of causal relationships between variables in the empirical model obtained from path analysis is always different from the theoretical model obtained from the theoretical framework. The general rule is that when performing path analysis, we remove from the model the variables whose beta value is not significant at a level smaller than 0.05; so, the path of these variables is also removed from the model. Of course, the larger the sample size, the more likely the smaller path coefficients will be significant.

In order to determine the relationship between durability and other parameters, the described regression method was used. According to the investigations, it was found that the porosity percentage, the calcium carbonate percentage, and the velocity wave are suitable parameters for estimating the durability index, and it is possible to avoid costly and time-consuming tests to estimate these values. The statistical analysis of these parameters showed that there is a suitable and acceptable linear relationship between the slake durability index and other parameters with correlation coefficients of 0.91 and 0.83, respectively. Also, the investigations showed that the value of the durability index increases with the decrease of porosity and calcium carbonate and increases with increasing of the compressional wave velocity. The relationships presented in this article are simple and accurate enough, and by using them, costly and time-consuming experiments can be avoided to determine rock mechanics parameters (Table 13).

Making an experimental model of factors affecting the slake durability

It is concluded that the porosity has a direct effect on the durability index, and the dry unit weight, the percentage of calcium carbonate, and the compressional wave velocity have an indirect effect. Other measured factors had no significant effect on the Slake durability index (Sig<0.05) and were removed from the model. To obtain the indirect effect coefficients, the beta coefficient of each path is multiplied together. The amount of the total effect is obtained from the sum of the direct effect and the indirect effect (Table 14).

Table 13. Relationships between slake durability and variables using multivariable regression

Statistics VIF	Durbin-Watson	Sig. F Change	MSE	R Square	Equations
1.461	2.142	0.000	1.53	0.912	$\%Id_2 = 95.197 - 0.279^{*}\%n + 0.001^{*}\ \%V_p$
1.089	2.123	0.000	2.881	0.835	$\%Id_2 = 91.353 - 0.068^{*}\%CaCO_3 + 0.002^{*}\ \%V_p$

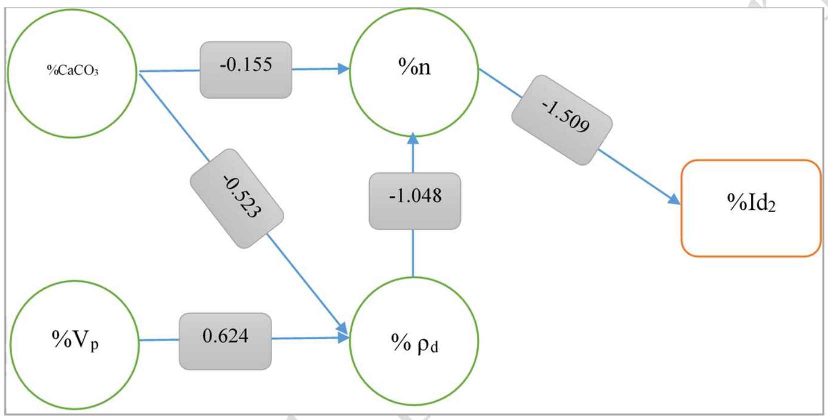

Figure 7. Experimental model of factors affecting the durability of argillite rocks using path analysis

Table 14. Determining the values of direct and indirect impact on durability using the path analysis empirical model

Total effect	Indirect effect	Direct effect	
-1.509	-	-1.509	%n
0.9868	0.9868	-	$\%\ \rho_d$
1.5814	1.5814	-	$\%CaCO_3$
0.2338	0.2338	-	$\%V_p$

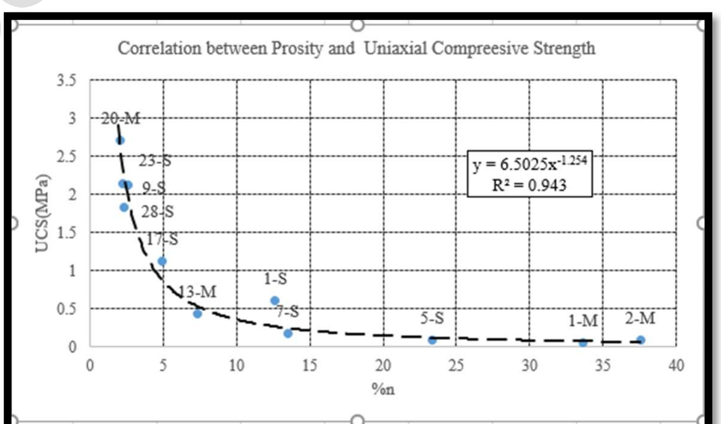

Figure 8. Correlation of the uniaxial compressive strength and porosity percentage

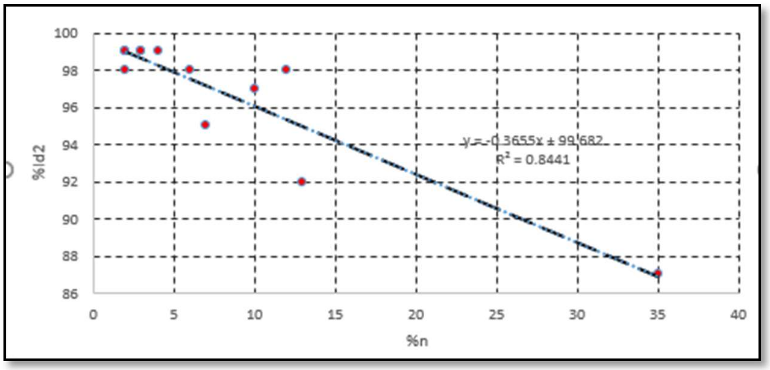

Figure 9. Correlation between slake durability index and porosity percentage

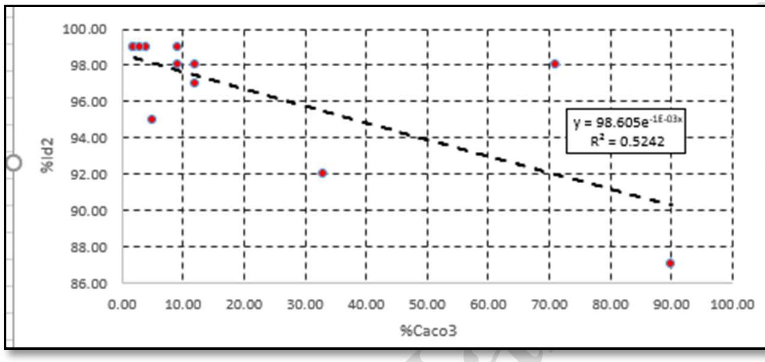

Figure 10. Correlation of the slake durability index of the second cycle with the percentage of calcium carbonate

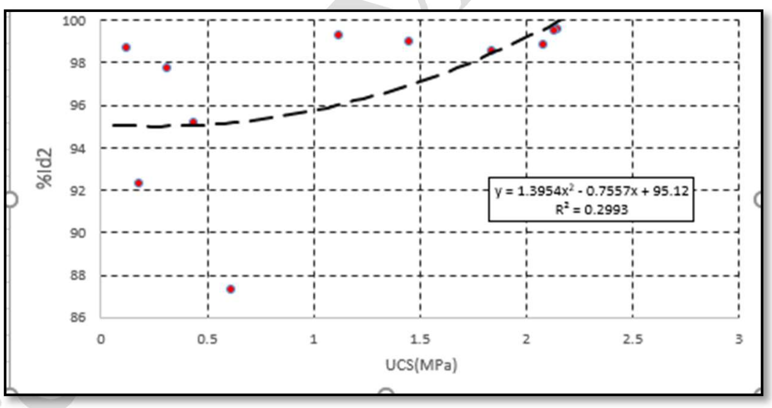

Figure 11. Correlation of durability index and uniaxial compressive strength

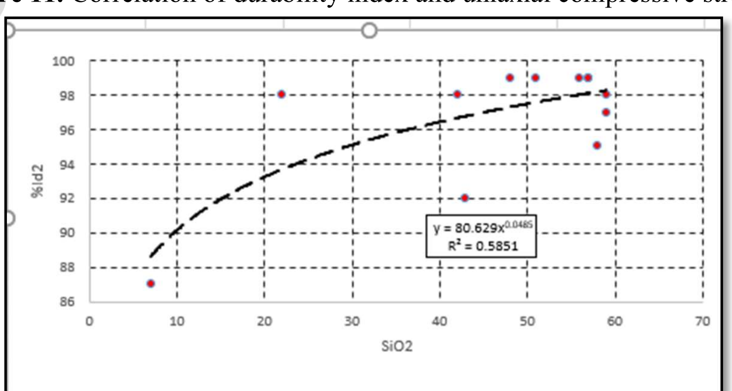

Figure 12. Correlation of durability index and SiO_2 percentage

The findings regarding the physical and mechanical properties of argillite rocks in the South Makran structural zone have significant implications for construction practices, hazard mitigation strategies, and geological modeling. The identification of argillite rocks as having different classifications indicates that they may not be suitable as primary construction materials in critical structural applications. Instead, alternative materials or reinforcement strategies should be employed when building in areas with significant argillite deposits. Given the porosity and low strength characteristics of these sediments, structures built over such formations may require adjusted design parameters. Structures might also integrate flexible designs capable of accommodating ground movements or settling associated with potential land instability linked to weak rock substrates. With insights into the swellability and low durability of argillites in coastal zones like South Makran, urban planners can better assess risks related to landslides or subsidence events during heavy rainfall or seismic activity. The relationships identified among porosity percentages, compressional wave velocity (Vp), uniaxial compressive strength (UCS), and calcium carbonate content offer valuable data inputs for enhancing predictive modeling efforts concerning ground stability under varying loading conditions.These findings advocate for a multidisciplinary approach where geology informs engineering practices directly impacting urban planning initiatives aimed at heightened community resilience amid environmental vulnerabilities. With all the above explanations, it is important to recognize and classify argillaceous rocks, considering the development of infrastructure in coastal areas. Also, differences in depositional and diagenesis conditions in these types of rocks have caused argillitic rocks to exhibit different resistance. Classifying argillite rocks based on durability by considering factors affecting durability can predict problems caused by weathering and rock collapse. This study shows that examining the strength alone in rocks containing clay and lime compounds is not enough, which doubles the importance of a criterion for evaluating the strength of argillite rocks. As mentioned, the percentage of calcium carbonate, porosity, and SiO_2 percentage can have a direct and indirect effect on durability. By establishing the aforementioned relationships, the extent of the effect on durability can be determined. This study, in line with previous studies by Miran, shows the impact of parameters affecting durability, directly or indirectly.

Conclusion

Most of the argillite sediments under the structural zones of southern Makran are composed of quartz fragments at the silt level with carbonate background along with calcite sub-minerals and fossil fragments, which indicate a shallow and low-energy environment. Rock engineering classification by Q-System, RMR and GSI methods shows that most of the sediments are in weak and very weak classification. The results of the point load test show that most of sediments have a strength of less than 20 MPa, which has a high correlation with the amount of porosity (R^2=0.95). Petrological studies, determination of physical characteristics, slake durability test show that the sediments located in coastal Makran have higher porosity and higher percentage of calcium carbonate due to the youngness of the sedimentation area and have less strength characteristics in terms of slake durability. The results of the cycle slake durability test of the second cycle show that porosity changes have the highest correlation with compressive wave velocity, uniaxial compressive strength, calcium carbonate percentage and SiO_2 percentage, and as porosity increasing, the value of deposition durability decreases with the correlation value of (R^2=0.82). In order to classify the rocks of the region, the results of the slake durability test were used, which shows that in the direction towards the south and the younger age of the samples, the amount of porosity increases and the trend of durability is also decreasing. The durability of the second cycle (I_{d2}) has a relationship between porosity percentage (%n) and compressive wave velocity (Vp) with correlation value of (R^2=0.91) and calcium carbonate percentage ($CaCO_3$%) and compressive wave velocity (Vp) with correlation value of (R^2=0.83). The results of the path analysis show that the porosity has a direct effect and the percentage of calcium carbonate, dry density and compressive wave velocity have an indirect effect and the percentage of SiO_2 has no significance on the durability.

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