



GEOTECHNICAL CHARACTERIZATION OF MARL OF FA'THA ROCKS FOR ZURBATIYAH REGION, EAST IRAQ

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ABSTRACT

An investigation into the geotechnical properties of marl rocks from the Zurbatiyah zone was conducted. Characterization of physical attributes revealed dry densities spanning 2.120 g/cm³ to 2.370 g/cm³, specific gravity from 2.50 to 2.660, porosity from 8.7% to 19.23%, and water absorption from 3.69% to 8.99%. Chemical compositions, focusing on major oxides (MgO, CaO, Fe₂O₃, SiO₂, Al₂O₃, SO₂, and LOI), confirmed that their proportions fall within the acceptable ranges for cement industry raw materials, supported by Chaterjee (2018) and Iraqi standard specification (IQS-5:1984). The engineering properties assessment indicated a moderate strength profile, with uniaxial compressive strength values ranging from 21.80 MPa to 45.50 MPa.

KEYWORDS

Zurbatiyah; Fatha Formation; Uniaxial compressive strength; Marl; Major oxides.



1. INTRODUCTION

The rocks' geotechnical properties are an important indicator of their suitability as raw materials in industry. These properties provide ideal solutions for obtaining a clear and complete picture of the nature and components of these rocks and evaluating these properties for use in the cement industry. These geotechnical properties consist of physical, chemical, and mineralogical characteristics (Hadi & Al-Zubayidi, 2020; Ahmed et al., 2022). The study area was located between 46°05'034" and 46°05'285" north and 33°16'276" and 33°16'464" east, regarding nineteen kilometers away from the city of Badra Fig. 1. A previous study, such as Al-Mashaikie et al. (2018), has reported on the mineralogy and geological chemistry of the Al-Jariba Formation from specific areas in the Kirkuk-Dezful and Zurbatiyah areas of eastern Iraq. Omar et al. (2018) stated a unique study on the evolution of basins in the Middle Miocene and sedimentology of the Zurbatiyah region, eastern Iraq.

The study of Hadi and Al-Zubaydi (2020) was analyzed the geochemical properties of marl. They reported that the oxide content of these marl rocks is close to the limits and requirements set for cement production. A new material can be used for cement without further processing. Abdulrahman and Awad (2021) examined the Ibrahim Formation and its depositional environment, defining the Oligocene-Early Miocene boundary in eastern Iraq. Ahmed et al. (2022) investigated the thermal conductivity of limestone from the Nfiyal Formation in the Bahr al-Najaf depression. Mustafa et al. (2023) conducted a structural analytical study and evaluation of slope stability for selected sites in Wadi Shorshirin, in the Zurbatiya region, eastern Iraq. The research aims to evaluate the geotechnical properties of marl deposits, study and determine their physical, chemical, engineering, and mineralogical properties, and their suitability for the cement industry. This study is being conducted for the first time in Wasit Governorate. It lacks a cement factory, despite the presence of advanced rock detection equipment to manufacture all types of cement.

2. GEOLOGICAL SETTING

The geological characteristics of the study area include the formations that occur in the rock outcrops within the study area.

2.1. Euphrates Formation

Bellin stated the Euphrates Formation for the first time in 1959. The typical section was located in Wadi al-Fahimi, on the stable escarpment near Ana. The typical section comprises a thickness of about 8 meters, which may extend to 100 meters. Some of the rock components have been altered. The rocks of this formation are compact limestone, recrystallised limestone,

and clay. This formation dates back to the Early Miocene.

2.2. Fatha Formation

The Middle Miocene occurs when the Fatha Formation first appeared. Its type section goes through Jabal Makhoul-Hamrin as well as 15 kilometres from Baiji. Layers of gypsum, anhydrite, and limestone are regarded at the Tigris River's source (Jassim and Goff, 2006; Hadi and Al-Zubaydi, 2020). The Euphrates and Jeriba formations are linked with the lower reaction., which are its basic units. At the first gypsum layer, the Al-Jariba Formation begins. The upper layer of the Fatha Formation was traditionally formed and is compatible with the Injana Formation, when sandstone and the top of the gypsum layer where this upper reaction occurred (Ahmed et al., 2022). The Fatha Formation is characterized at its bottom by the presence of neritic limestone, which can be transformed into silty clastic rocks (Al-Naqib, 1959).

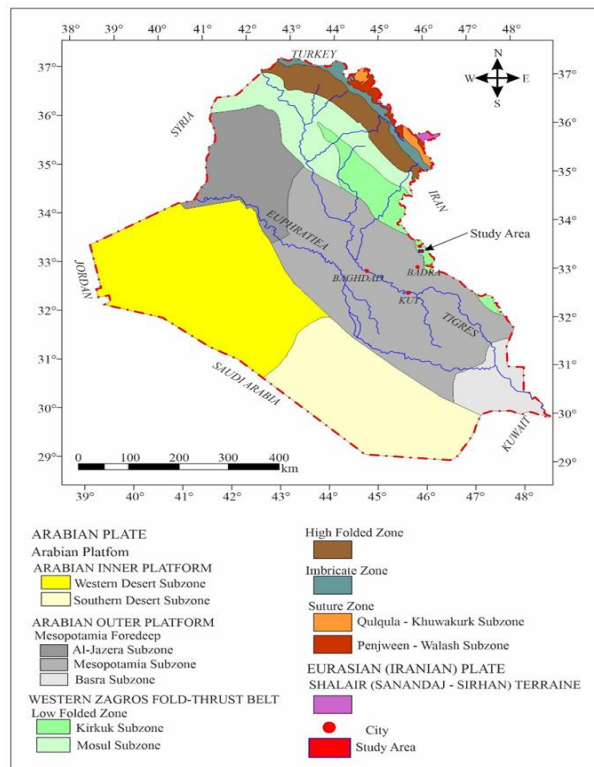


Fig.1. A tectonic map for Iraq (modified by Fattah et al., 2023)

2.3. Injana Formation

According to Bellin et al. (1959), the Injana Formation developed during the Miocene. It is prevalent throughout Iraq, along the Baghdad-Kirkuk Highway, and within the Hamrin Anticline; its typical section is in the Injana area (Bellin et al., 1959; Jassim and Goff, 2006). The beds of this formation comprise a mixture of siltstone, sandstone, and some limestone in the lower half, according to Al-Juboury (1994). Aslclastic series, sedimentary cycles, and

successive upwellings and ring formations of clay, marl, and sand composed the formation in northern Iraq (Al-Saady and Al-Zubaydi, 2019; Al-Sultani et al., 2022).

2.4. Muqdadiya Formation

This formation (Pliocene) is located within the unstable escarpment area that forms the exposed Al-Muqdadiya Formation. It consists of terrestrial clastics, mainly with grain sizes ranging from conglomerate to silt (Dikran, 2003). In the basin, especially in the central regions, we notice a gradual increase in the size of the terrestrial clastic grains towards the summit. On the foothills, there are deposits of mudstone and fine sandstone, while the extreme northeastern peripheral regions are characterized by the presence of gravel.

2.5. Bai Hassan Formation

The section of this formation is located in the village of Bai Hassan. Its characteristics are generally similar to the Muqdadiya Formation. The only differences between the two formations are their grain size and age. The Bai Hassan Formation consists of two components: the lenticular sandstone layer, which is the conglomerate member, and the sandy clay layers, which are the conglomerate member (Dikran, 2003; Mohammed and Sultan, 2022).

3. METHODS AND MATERIALS

The fieldwork includes integrated engineering geology and research fields. The rock characteristics are accurately described. Using the Global Positioning System (GPS), the thickness of the layers at 15 stations was selected and measured. According to the variation and difference of rock characteristics, rock samples were selected for engineering geological investigation. Fifteen rock samples were kept in sealed plastic bags, and field information was recorded and entered on them. This information shows the alternation of some secondary gypsum veins with the marl layer, with horizontal and sub-horizontal extension of the opening formation. Table 1 shows the locations of 15 stations within the opening formation. The details of the studied stations are shown in Fig. 2.

3.1. Basic Properties

The basic properties of rocks are considered important indicators in the evaluation process. They provide a detailed report on the suitability of these rocks for raw porosity. It includes water absorption, specific gravity, bulk density, and porosity according to (ASTM C568-03).

3.1.1. Specific Gravity and Dry Density

The mass of a sample divided by the volume of all voids, as well as solids, is referred to as its density (Duggal, 2008; Ahmed et al., 2022; Fadhil et al., 2023). This is also known as the

volume per unit weight and relies on a number of factors, such as the metal's porosity, hardness, and the volume of liquid that is present in the voids throughout measurement. As a result, density was identified with ASTM C568-03. According to [Al-Sultani et al. \(2023\)](#), specific gravity is calculated by separating the rock material weight for the water weight to the same volume, The basis for this study is true specific density, which is found by dividing the solid's weight by the weight of water it removes when submerged in water ([Saeed, 1997](#); [Ahmed et al., 2022](#)).

Table 1. The coordinates of the stations of the Marl rocks

Station No	Latitude	Longitude	Thickness (m)	Elevation above sea level (m)
1	46°.026'39"	33°.395'28"	3	336
2	46°.033'59"	33°.380'96"	2	356
3	46°.058'06"	33°.393'06"	8.5	362
4	46°.060'83"	33°.383'61"	3.5	347
5	46°.071'11"	33°.380'28"	2.5	332
6	46°.074'72"	33°.375'28"	3.5	322
7	46°.071'39"	33°.360'00"	2	320
8	46°.050'28"	33°.367'22"	5	324
9	46°.056'94"	33°.372'78"	4	326
10	46°.054'44"	33°.380'00"	5.75	333
11	46°.062'78"	33°.358'22"	2	319
12	46°.064'44"	33°.347'22"	3	311
13	46°.049'72"	33°.353'06"	2.5	328
14	46°.049'44"	33°.343'06"	3.5	352
15	46°.035'56"	33°.354'44"	3	306

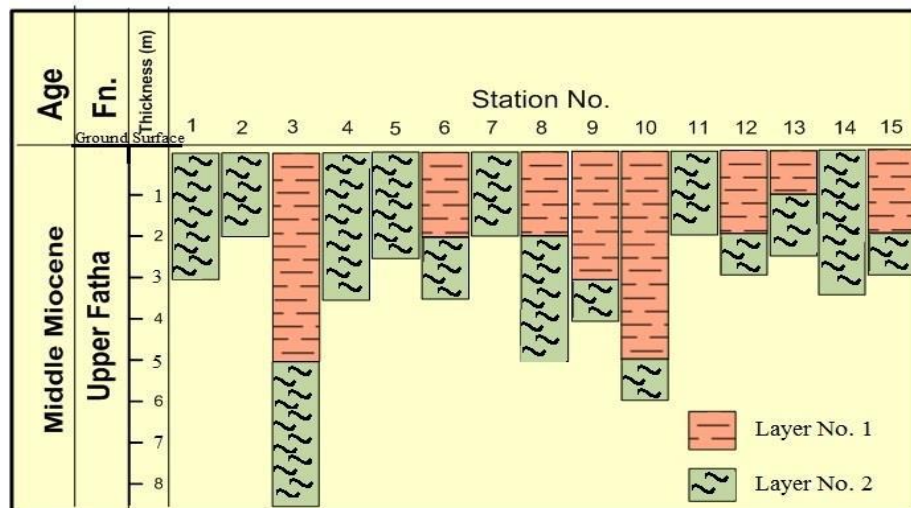


Fig.2. Thickness and stratigraphic sections of the studied stations

3.1.2. Porosity

The ratio of the volume of voids to the volume of the rock sample is regarded as porosity.

Several variables affect porosity, such as the size and form of the mineral crystals or grains that make up the rock (Ahmed et al., 2022; Fadhil et al., 2023), the type of bonding between these grains and the binding materials, and the arrangement of these grains.. The physical properties of rocks are controlled by porosity, which is a very important property (Hussein, 2010). Porosity is of two types: the first, which occurs during the formation of the rock, is called primary porosity. The second type, which occurs due to the rock's exposure to fractures, joints, and cracking, and due to the influence of solutions, is called secondary porosity (Wyllie et al., 1958; Fadhil et al., 2021). Through practical examinations, it has been shown that density and porosity are extremely important properties due to their direct relationship with each other, as well as their engineering properties and influence on the rock structure.

3.1.3. Water Absorption

The rock's ability to draw liquids and water into its pores and around its surface is recognized as water absorption. Numerous factors that affect porosity affect its absorption capacity. Moisture content is one factor that affects rock resistance; a slight increase in water content is the cause of any notable decrease in resistance and formability (Fattah et al., 2018; Ahmed et al., 2022). The size of the mineral grains and their arrangement within the same type of mineral aggregate determine how much water a sample absorbs. The size of the grains, their interconnectedness, and their abundance and presence all have a major impact on the absorption rate.

3.2. Engineering Properties

Uniaxial compressive strength means a rock's capacity to withstand stress. It can be determined by continuously applying a load to a body in two opposing directions until it reaches the point of collapse. The material's hardness, water absorption, texture, and mineral makeup all affect its resistance (Anon. 1977 and Piteau ,1970).

3.3. Chemical properties

The determination of the major oxide ratios in marl rocks was obtained from chemical tests: CaO, MgO, SiO₂, Al₂O₃, Fe₂O₃, SO₃, and LOI. These tests were conducted at the Department of Applied Geology, University of Babylon.

4. RESULTS AND DISCUSSION

Fifteen samples were examined for dry density through stations in the study area. With an average of 2.24 g/cm³, the lowest value was 2.12 g/cm³, which correlated to station 14, and the highest value was 2.37 g/cm³, which corresponded to station 9. Water absorption and porosity are two instances of the physical characteristics of the rocks that cause the small variations in

the maximum and minimum dry density values. With only minor deviations, this suggests that every station in the research region is nearly identical [Table 2](#).

The three-weight method was utilized to determine the specific gravity of 15 samples; the lowest value was 2.5, corresponding to station 14, and the highest value was 2.66, that referred station 5, with an average of 2.58. [Table 2](#) shows that the variation between dry density and specific gravity of 2.66 is low, indicating medium porosity for the studied samples. Porosity tests were carried out on 15 samples that were scattered among the stations in the study area; the lowest value was 8.71% obtained at station 9, and the highest value was 19.24% at station 3. The average was about 13.6%.

High compressive strength leads to low porosity, causing the process of grinding and crushing marl rocks to be difficult. Water absorption was gained from the 15 samples that were distributed across 15 stations used in this study. The minimum value was 3.69%, and the maximum value was 13.6%. 8.99%, with an average of 6.12% [Table 2](#).

Table 2. The Physical characterization of marl.

Station No.	Dry Density (gm/cm ³)	Specific gravity	Partial Porosity%	Water absorption%
1	2.1950	2.570	14.80	6.70
2	2.170	2.510	13.540	6.230
3	2.130	2.640	19.230	8.990
4	2.220	2.590	14.020	6.280
5	2.220	2.660	16.410	7.380
6	2.250	2.630	14.40	6.380
7	2.340	2.630	10.80	4.60
8	2.30	2.570	11.50	5.110
9	2.370	2.6070	8.70	3.690
10	2.220	2.560	13.090	5.870
11	2.190	2.530	10.120	4.230
12	2.2160	2.530	15.970	6.570
13	2.360	2.60	12.140	5.170
14	2.120	2.50	15.720	7.80
15	2.320	2.630	13.670	6.850
Average	2.24140	2.58380	13.6070	6.1230

Based on fifteen samples that were scattered among the study area's stations, the uniaxial compressive strength was discovered to be 28.298 MPa on average, with a minimum value of 20.24 MPa at station 12 and a maximum value of 45.51 MPa at station 9 ([Hadi and Al-Zubaydi 2020](#)). Marl rocks are therefore divided as medium strength.

Table 3. Results of chemical analyses (wt %) of the studied marl

Station No	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	LOI	Total%
1	15.76	3.82	5.1	41.00	0.66	0.39	0.23	0.12	31.16	98.24
2	18.32	4.6	0.93	42.47	0.96	0.3	0.34	0.21	30.54	98.67
3	13.11	3.64	3.92	42.11	0.71	1.5	0.05	0.03	33.21	98.28
4	16.66	4.32	0.68	44.98	0.94	0.29	0.06	0.043	31.26	99.233
5	13.93	4.38	4.21	45.9	0.46	0.03	0.11	0.24	29.59	98.85
6	15.11	6.64	3.36	43.41	0.44	0.06	0.23	0.39	29.32	98.96
7	19.54	2.59	3.4	41.39	0.31	0.13	0.41	0.63	31.27	99.67
8	21.38	5.81	0.74	37.12	0.96	0.14	0.43	0.31	32.61	99.5
9	16.76	3.62	3.04	42.67	0.83	0.49	0.67	0.06	32.27	100.41
10	14.13	6.36	4.36	38.79	0.88	0.1	0.73	0.29	32.43	98.07
11	17.47	5.4	3.21	41.29	0.35	0.14	0.45	0.43	29.73	98.47
12	15.61	2.81	5.96	42.61	0.96	0.3	0.29	0.17	30.12	98.83
13	20.12	2.23	3.38	40.11	0.56	0.12	0.16	0.22	31.22	98.12
14	19.25	2.19	2.4	40.32	0.51	0.42	0.25	0.31	34.27	99.92
15	23.4	4.6	2.4	37.19	0.13	0.31	0.54	0.67	30.13	99.37
Average	17.37	4.2	3.14	41.42	0.64	0.31	0.33	0.27	31.27	98.97

Table 4. The chemical analysis of marl-free LOI as well as contrast to oxide limits for typical raw mix elements (Chatterjee, 2018).

Oxides	Minimum	Maximum	Average	Typical Oxides boundaries
CaO	53	65.430	60.270	63-65
SiO ₂	19.621	33.493	25.282	20-23
Al ₂ O ₃	9.411	3.242	6.113	4-8
Fe ₂ O ₃	0.981	7.41	4.56	3-5
MgO	0.182	1.422	0.944	2-3
SO ₃	0.082	2.243	0.463	2.0-3.5
(Na ₂ O+K ₂ O)	0.072+0.042	1.082+0.952	0.482+0.392	0.42-1.22

Table 5. Chemical assessment of limestone samples from the surrounding region.

Station No	SiO ₂	CaO	MgO	SO ₃	Al ₂ O ₃	Fe ₂ O ₃	LOI	K ₂ O	Na ₂ O	Total%
1	4.62	51.08	0.97	0.33	1.38	0.59	40.54	0.30	0.23	99.93
2	4.22	52.72	0.62	0.32	1.03	0.49	41.08	0.24	0.23	100.85
3	3.5	51.86	1.03	0.35	1.68	0.78	39.32	0.36	0.38	99.26
4	3.98	51.9	0.46	0.1	0.89	0.46	41.53	0.25	0.36	99.93
Average	4.07	51.88	0.76	0.26	1.24	0.575	40.604	0.28	0.29	99.98

In marl rock, the calcium oxide (CaO) was the most common element. Calcium oxide content possesses the highest percentage of silica across all tested stations, with an average of 41.42% and a range of 37.12 to 45.9% Table 4. The percentages shown are near the typical ranges, as stated by Chatterjee (2018) in Table 5. Because of its interactions with other oxides like Al₂O₃, SiO₂, and Fe₂O₃, calcium oxide (CaO) is the most frequently used oxide in the production of cement. Low lime presence was due to low early strength, while lime mineralisation outcomes

in poor safety (Duda, 1985). The proportion of silica (SiO_2) is acceptable following the addition of different materials for the production of Portland cement, according to Chatterjee (2018). The percentages of silicon dioxide (SiO_2) varied from 13.11% to 23.4%, with 17.37% on average. The mean amount of alumina oxide in marl was 4.2%, with a range of 2.19% to 6.64%. These percentages align with the norms of the industry. Building damage is caused by high concentrations of iron oxide (Fe_2O_3), which is an impurity that occurs in marl and oxides in sulphide forms (Amin et al., 2008). The Fe_2O_3 concentrations identified in marl rock samples ranged between 0.75% and 5.97%, with an average of 3.15%, based on Chatterjee (2018) Table 4. These values are therefore appropriate. Magnesium oxide (MgO) appeared in most samples at low concentrations, with the ratios ranging from 0.14% to 0.97%, with an average of 0.645, which is consistent with the national standards for Portland cement production (I.Q.S., No. 5, 1984). In marl rocks, sulfur dioxide content was low, averaging between 0.11% and 1.6%. Based on Chatterjee's (2018) investigation, this finding percentage was acceptable.

Table 6. Chemical oxide analysis of the limestone as calculated for free LOI.

Oxides	Minimum	Maximum	Average
CaO	85.862	89.422	87.35
SiO_2	5.762	7.742	6.852
Al_2O_3	1.522	2.762	2.081
Fe_2O_3	0.782	1.282	0.961
MgO	0.79	1.682	1.291
SO_3	0.18	0.582	0.451
($\text{Na}_2\text{O}+\text{K}_2\text{O}$)	0.37+0.40	0.63+0.0.49	0.49+0.48

Limestone and clay rocks are the primary sources of alkalis, as potassium and sodium join the crystal structure (Al-Samarrai, 2010). Volatile materials during combustion are alkalis, and the dust produced by cement kilns contains a higher alkalinity than the raw mix fed to the kiln. Following Chatterjee (2018), the alkalinity is within the legally permissible range. The X-ray diffraction analysis was applied to find the main minerals in marl rocks. When analyzing a single sample of marl, station 10 was selected, from the analysis of quartz, calcite, and clay minerals using X-ray diffraction (XRD) Fig 3.

5. CONCLUSIONS

- A high specific gravity was observed in all samples in physical tests, along with dry density, moderate porosity, and water absorption values, all within the standard levels required for the cement industry.
- Marl has relatively high uniaxial compressive strength values, requiring reasonable force during crushing and extraction, thus reducing costly quarrying operations.
- The oxide content of marl rock is close to the permissible limits for cement production.

- Raw material quality in the cement industry can be optimized by adding a specific percentage of limestone to achieve the ideal oxide ratios for kiln feed. Additionally, marl serves as a valuable raw material in cement production, enhancing both the cement and its properties.
- Finally, it is necessary to conduct a geotechnical model to validate the current results in future work.

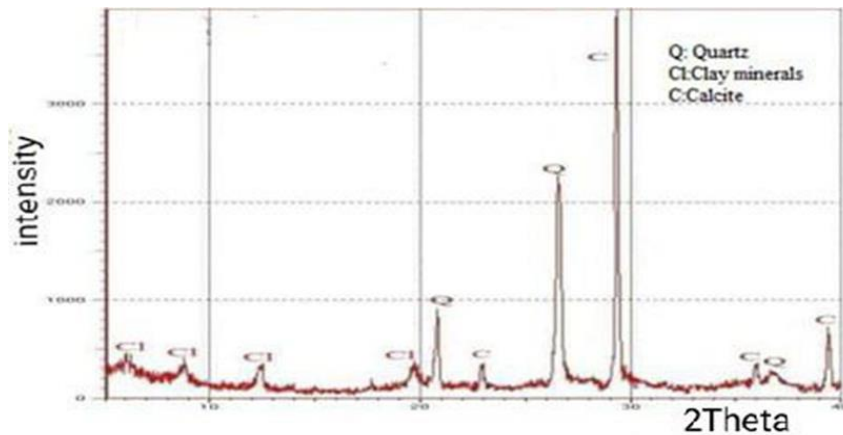


Fig.3. X-ray diffract gram of marl in station ten.

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