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Durability Characterization of Abderaz Marly Limestone in the Kopet- Dagh Basin, NE of Iran

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***Abstract*— Durability is one of the most important engineering properties of weak and clay-bearing rocks. Weathering can induce a rapid change in rock material from initial properties to soil-like properties. The sensitivity of a rock type against weatherability is usually described by a durability parameter. This paper deals with the relationship between durability tests results and physical and mechanical properties such as water absorption, point load index, dry density and carbonate content. These tests have been carried out on 16 samples of marly limestone of Abderaz formation in the north east of Iran. The samples were subjected to 4 cycles of slake durability. The obtained results show that all tested samples have high to very high durability. Furthermore, the relationship between durability and point load is poor due to the granular texture in the samples. It seems that the calcium carbonate content of these samples is more related to the lime particles rather than the cement.**

***Keywords*- Slake durability index, marly limestone, Abderaz Formation, Point load, Carbonate content**

I. INTRODUCTION

Abderaz Formation is one of the lithostratigraphic units remained from Late Cretaceous in Koppet Dagh sedimentary basin (Afshar Harb, 1994). The main lithology of this Formation in the study area includes marly limestone. Marly limestone is a clay-bearing rock type. One of the main problems in construction on and of clay bearing rocks is their susceptibility to degradation or weathering upon exposure. Weathering can induce a rapid change from an initial rock material to a soil-like one. The sensitivity of a rock type against weatherability is usually described by a durability parameter, such as the slake durability index. The slake durability index is typically used for mud rocks, marls, ignimbirites, conglomerates, sandstones with weak bonds (cementing material) and etc. (Czerewko and Cripps, 2001; Erguer and Ulusay, 2009; Sabatakakis et al., 1993; Santi, 1998). The durability behavior of these rocks is responsible for slope stability problems due to rapid slope degradation by the loss of strength of the surface material, unexpected additional settlements and failures of embankments, long term loss of intact strength affecting the stability of underground openings and etc. (Athmania et al., 2010; Hornig, 2010; Frydman et al., 2007; Johnston and Novello, 1994; Anagnostopoulos et al., 1991; Maekawa and Miyakita, 1991; Fookes et al., 1988; Olivier, 1979).

In the majority of studies, the assessments for durability are based on the second cycle slake durability index. ISRM (1979) and ASTM (2004) suggest that 2 cycles can be used in the determination of the slake durability index. However, many authors like Koncagul and Santi (1999), Condan and Husnu (2000) and Lashkaripour and Ghafoori (2003) emphasize that two-cycle slake durability testing does not offer an acceptable indication of the durability of clay-bearing rocks.

Slaking is one of the most common physical degradation mechanisms affecting the rocks which contain clay. Marly limestone may contain various amounts of clay and non-clay minerals. The particular type of slaking is strongly controlled by clay mineralogy and the concentration of exchangeable sodium ions (Dhakal et al. 2002). The common types of slaking in pure clay are as follows: dispersion slaking, swelling slaking, body slaking and surface slaking (Moriwaki and Mitchell, 1977). Mixtures of various clay minerals lead to different combinations of slaking modes. The mineralogy and the geometric arrangement of particles also affect the slaking and the strength of the marl (Tsiambaos, 1991; Youn and Tonon, 2010). However, since determination of mineralogy is time consuming and expensive, practicing rock engineers need to be able to assess durability with faster and cheaper test methods.

The scope of the presented study is to discuss and identify the physical properties that can affect the slake durability index of tested marly limestone samples. In this paper, the slake durability tests were carried out over the course of 4 cycles and the obtained index values were correlated with the amount of carbonate minerals, point load strength, water absorption and dry density.

II. GEOLOGY

Abderaz Formation is a major formation in Koppet Dagh basin on north east of Iran which is dated upper Cretaceous (Fig. 1).

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The age of Abderaz Formation is determined from Turonian to early Campanian (Shafiee Ardestani et al., 2012).

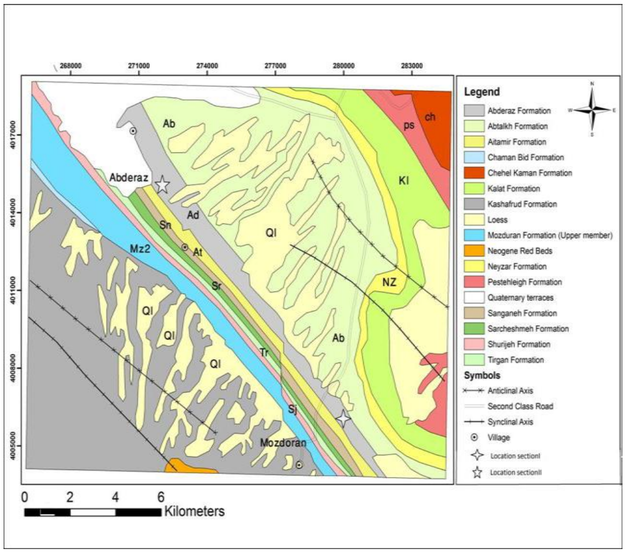

Fig. 1- Simplified geological map of the study area

The Abderaz Formation consists of marly limestone (Fig. 2A). Marly limestone of Abderaz formation includes bivalve fragments (Fig 2. B) and planktonic Foraminifera (Fig 2. C). This marly limestone has veins that are filled with spar calcite (Fig 2. D).

III. Materials And Methods

Cretaceous marly limestone is the dominant type of lithology in Abderaz Formation. Different samples of marly limestone with varying percentages of clay and carbonate mineral content were collected in two different sections from the benches of the slopes at a newly constructed trench for a road and from rock outcrops around the Formation. The location of section 1 is close to Mozduran city, whereas the location of section 2 is close to Abderaz village (Fig. 1). The dominant color of samples was gray to white. 16 samples were collected as blocks with approximate side dimensions between 20 cm and 30 cm, extracted using hammer from freshly excavated slopes or from about 0.2 m beneath the surface of outcrops. The significance of this procedure is that some of the surficial materials from the exposures were removed in order to obtain intact samples. For some kinds of marls, especially those with higher clay content; sampling was difficult because of their weak nature and frequent fractures.

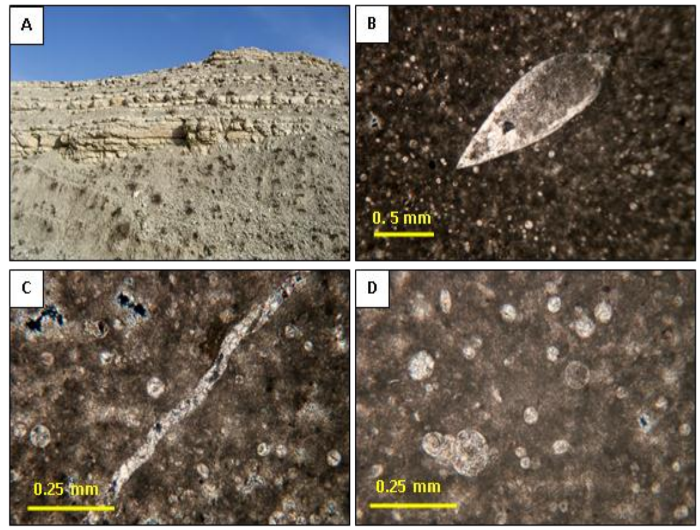

Fig. 2- (A) The Abderaz Formation (marl and chalky limestone). (B) Thin section of marly limestone including bivalve fragment and (C) planktonic Foraminifera. (D) Veins filled with spar calcite.

The slake durability test was first proposed by Franklin and Chandra (1972). The original test procedure was modified by ISRM (1979) and as a standard procedure (ASTM D4644-04 2004) was employed in this study. In this test, the apparatus simulates and combines the effects of both soaking and nearly equidimensional rock lumps. Ten pieces of about 45–55 gr each, were prepared and subjected to rotation for 10 min in a test drum made of a standard sieve mesh. The drum was half-immersed in a water bath at about $20^{\circ C}$. In order to assess the influence of the number of cycles on durability, the samples were subjected to 4cycles of soaking of rotation followed by oven drying. The slake durability index corresponding to each cycle was calculated as the percentage ratio of the dry weight of material left in the drum after each drying and 10 min rotation cycle. The oven temperature used for drying was $105^{\circ C}$. Because of difficulties anticipated with the preparation of cylindrical samples from laminated marl, the strength of the rock units studied was assessed by difficult because of its weak nature and frequent fractures. The slake durability index corresponding to each cycle was calculated as the percentage ratio of the dry weight of material left in the drum after each drying and 10 min rotation cycle. The oven temperature used for drying was $105^{\circ C}$. Because it was anticipated that there would be a lot of difficulties during the preparation of cylindrical samples from laminated marl, the strength of the studied rock units was assessed by point load testing.

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Point load strength is intended as an index test for the strength classification of rock materials. The test procedure was proposed by ISRM (1985). For this study, rock specimens in the form of different core sizes were used.

Point load strength varies with the water content of the specimens. Water can soften the bonds or interact with mineral surfaces and alter their surface properties. Moreover, with the aid of pore water pressure, water may cause instability along weakness planes. Calcite dissolves when in contact with water and hydration forces destroy structural integrity by disrupting bonds. Such soft minerals also fail easily even under light loads in the point-load strength test. For this reason, all specimens should be tested with similar and well-defined water content. Though oven dried specimens are usually much stronger than moist ones, they were used in this study in order to eliminate the influence of moisture. Density, Immersion Method (ISRM) describes the procedure for using the saturated surface dry immersion volume method to determine the dry density of cores and formed specimens. In this method, density of rock specimens was determined using water displacement techniques and then when oven-dried and immersed in water. The specimens were weighed and then immersed in water, and their volume was determined from the volume of displaced water. Carbonate percentages of the samples were determined by calcimetry test. The test procedure was applied according to ASTM C97-02 (2004).

Laboratory test results are listed in Table 1 for the marly limestone samples.

For determination of sample mineralogy, the x-ray diffraction (XRD) test was applied by a Philip X Pert diffractometer system. The X-ray diffraction studies on the bulk limestone show that all the studied samples are mainly composed of quartz, albite and clinochlore. The principal clay mineral is illite (Fig 3).

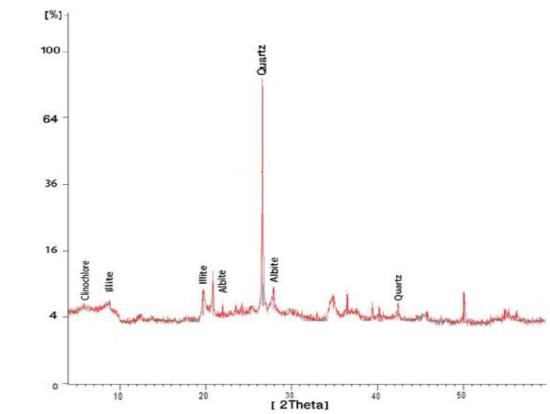

Fig .3- X-ray diffraction pattern after the delete of calcite (sample 9)

Table 1- Laboratory test results: carbonate content (gasometrical method), dry density, water absorption, point load index in dry state, slake durability index after second cycle (Id2) and after fourth cycle (Id4).

Sample no.	section	Carbonate Content (%)	Dry density γd (Mg/m3)	Absorption (%)	Point load index(dry state) IS(50) (MPa)	Id2 (%)	Id4 (%)
01	I	87.6	2.05	5.17	3.674	98.7	98.0
04	I	82.9	2.501	3.03	6.139	99.5	99.02
06	I	85.7	2.49	2.955	1.820	98.9	98.4
07	I	88.7	2.50	2.954	4.249	99.3	99.0
08	I	86.41	2.52	2.923	3.431	99.2	98.6
09	I	86.1	2.46	3.937	2.073	98.9	98.4
010	I	93.5	2.53	2.673	4.09	99.3	98.9
011	I	87.3	2.48	3.280	2.073	98.7	98.1
1	II	87.31	2.42	4.007	5.266	98.7	98
3	II	87.3	2.4	3.59	4.71	99.1	98.6
4	II	**84.6**	**2.47**	3.444	4.293	99	98.4
5	II	**84.5**	**2.49**	2.780	2.202	99.1	98.5
7	II	86.98	1.77	3.985	1.578	99	98.5
8	II	87.4	2.47	3.675	5.236	98.8	98.0
9	II	80.5	2.48	3.417	2.552	99.1	98.4
10	II	84.41	2.46	3.529	3.241	98.8	98.3

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IV. DISCUSSION

Gamble (1971) suggests that slake durability index values taken after three or more cycles of slaking and drying may be useful when evaluating rock durability. Depending on factors such as porosity, permeability, texture and mineralogy, complete failure may not take place during the span of the standard two-cycle slake durability test. Therefore, in this study, 4 cycles were applied to each sample. Slake durability was calculated using the following equation:

$$Id2 = \frac{C-A}{D-A}$$

Where:

Id2= slake durability index

C = the weight of drum plus the retained portions of sample

D = the weight of drum brushed clean

A = the weight of drum plus sample

The plot of results of 4-cycle slake durability tests is presented in Fig. 4. By a visual inspection of sample remains after the second and fourth cycle, according to the procedure (ASTM D4644-04 2004), samples are divided into two groups. Fig. 5 presents a photograph of each type. It is interesting to observe that in presented study all analyzed samples were classified as the same type either after second and fourth cycle of the slake durability test. The first group (section I) are samples with practically unchanged pieces and with a high value on the slake durability index. The second group (section II) includes samples with an amount of smaller pieces. In the present study a characteristic of these samples is that the slake durability index after second cycle is still higher than approximately 98%. Following Gamble (1971), these samples can be categorized of ‘‘high’’ to ‘‘very high’’ durability, The durability indicated with the condition of sample remains after the test is in accordance with behavior of analyzed material observed in the engineering practice. The same conclusion, according to previous explanation, can be observed in Fig. 4 for samples tested in this study. According to test results, as illustrated in Fig. 5, it could be inaccurately concluded that it is easy to separate samples into groups based on a visual inspection of sample remains after the slake durability test.

Fig. 6 illustrates the interrelationship between carbonate content and the slake durability index after the fourth cycle of the tested samples. The results indicate that there are meaningful correlations between durability and carbonate content.

It is obvious that marly limestone with carbonate content greater than about 87%, exhibit a higher resistance to slaking (i.e. Id4 values greater than %99).In Fig. 7 the correlations between the carbonate content and dry density of the tested samples are plotted. Groups of samples are marked with the same marks as in previous figures. The results indicate that the sections I and II include materials with carbonate content approximately higher than 80% and a dry density approximately higher than 2.4 gr/cm3.

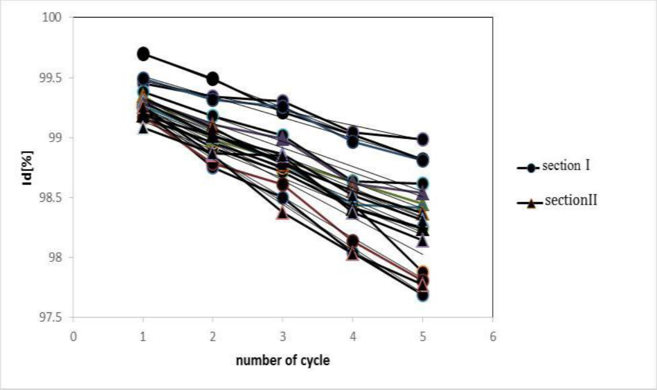

Fig. 4- Influence of the number of slaking cycles on the slake durability index

Fig. 5- Remaining samples after fourth cycle for two types of samples

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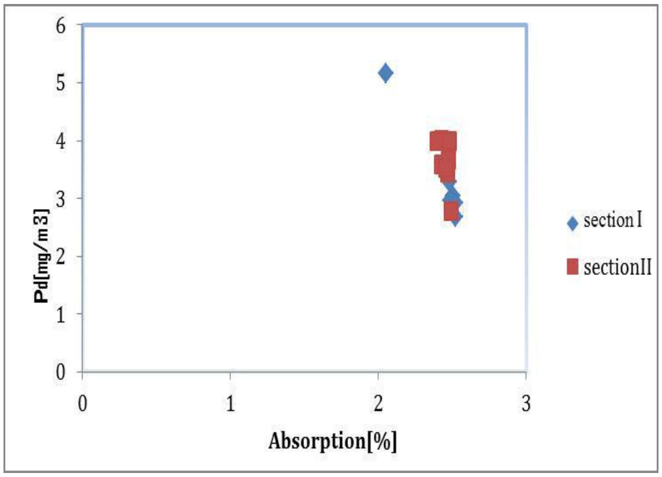

Fig. 6- Plot of the interrelationship between carbonate content and the fourth cycle slake durability index: a)sample of section I; b) sample of section II

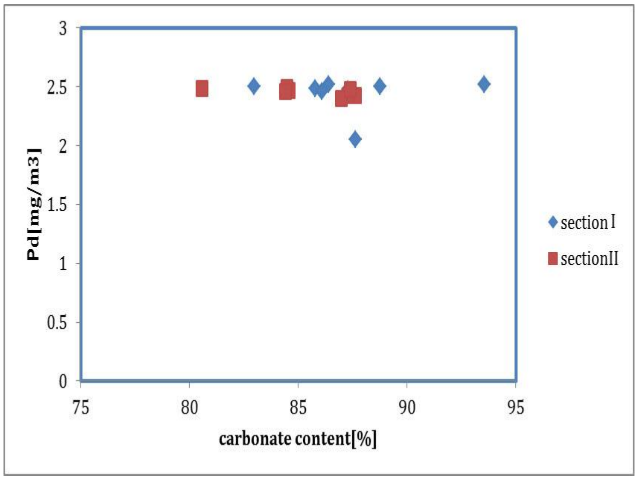

Fig. 7- Carbonate content plotted versus dry density

Fig. 8 shows the correlation between carbonate content and water absorption. It can be seen that there is a weak relationship between these two parameters. However, almost all samples that are classified as section I and II materials present values for the absorption of water higher than approximately 3%.

Very similar results can be observed in Fig. 9, which shows the correlations between dry density and water absorption. These correlations indicate that for these examined samples of marls, section I and section II materials can be considered as materials with carbonate content lower than approximately 87% or a dry density lower than 2.5 $^{gr/cm3}$ and water absorption values higher than 3%.

Most of researches have focused on strength, deformability and durability of weak rocks while studies that compare strength and durability are very limited (i.e. Koncagul and Santi 1999), especially for marly rocks. From the analysis of test results, it is concluded that no meaningful relationship between point load strength, and slake durability index can be drawn. The correlation between the fourth-cycle slake durability index and point load index is illustrated in Fig. 10. Then the carbonate content and point load index values were employed in order to investigate if there is a relationship between these two. Only a trend of increasing point load strength with an increase in carbonate content can be observed (Fig. 11). Generally, it is expected that samples with higher carbonate content are stronger. However, from the presented results, it may be concluded that besides the level of carbonate intergranular bonds, strength can also be defined by cementation capacity. Moreover, if the results are displayed as samples belonging to the proposed types, it is also evident that the correlation between the investigated values is not useful in establishing an accurate description of durability.

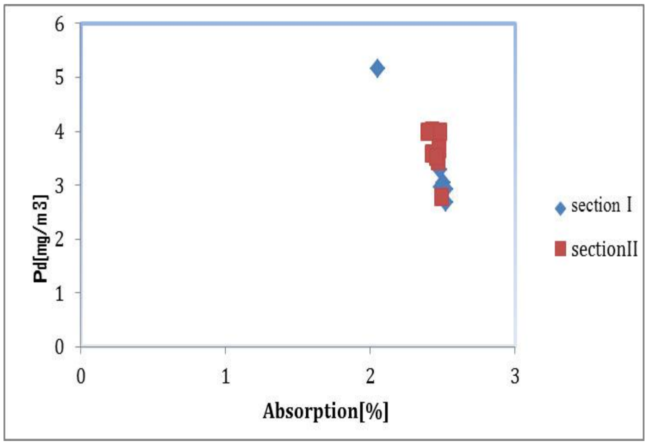

Fig. 8- Carbonate content versus water absorption

V. CONCLUSIONS

The primary purpose of this research is to establish fast and inexpensive tests that can be used as additional criterion for better classification of marl durability. Durability is one of the most important engineering properties of weak and clay bearing rocks. In the present research, the collected samples were subjected to 4 cycles of slake durability, point load tests, and tests to determine dry density, carbonate content, and absorption of water of the samples is applied.

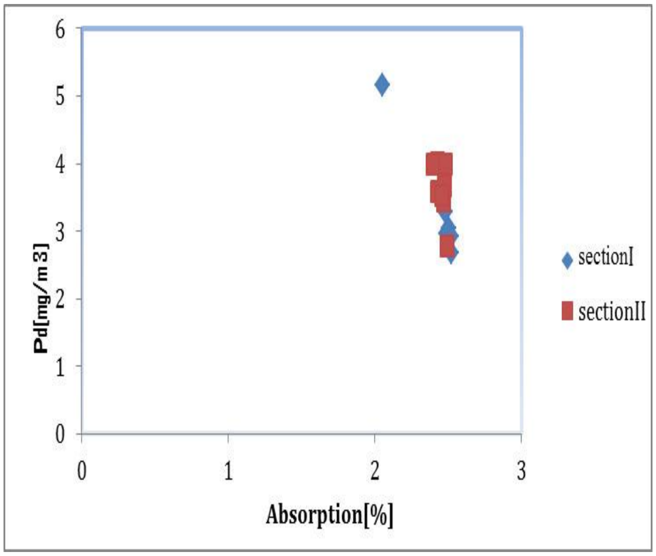

Fig. 9- Dry density versus water absorption for different types of marls

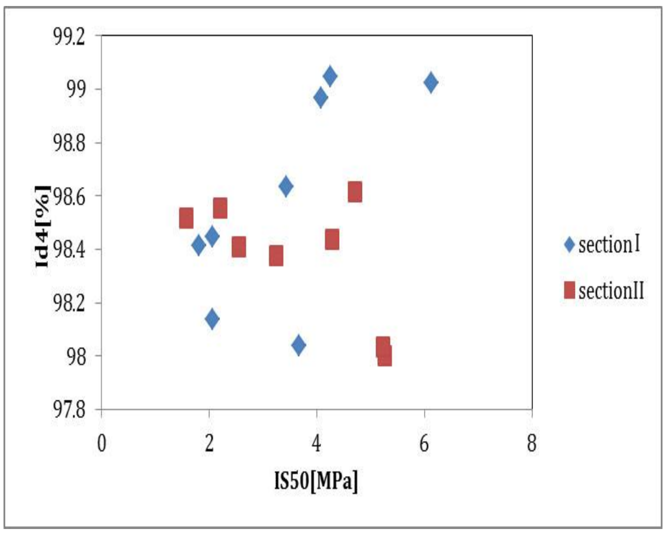

Fig. 10- Point load index values plotted against slake durability index values after fourth cycle

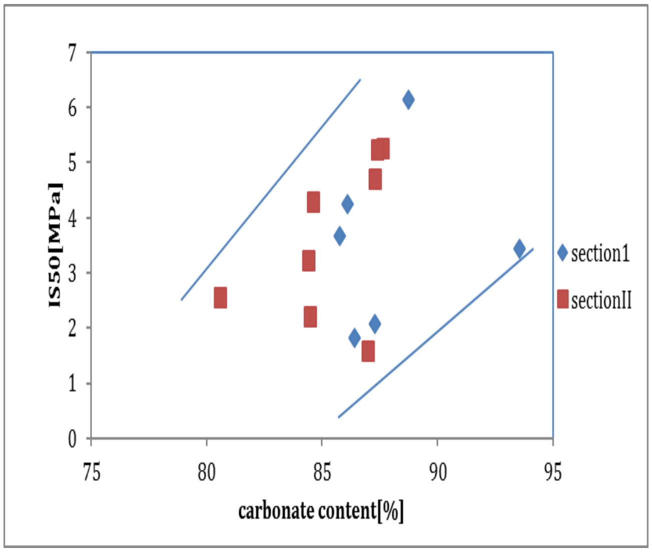

Fig. 11- Carbonate content plotted against point load index

The results of this study are obtained from a limited number of marly limestone sections of the Abderaz Formation in the Koppet-Dagh basin, NE Iran. The scatter of data suggests that strength probably has no influence on the durability of marly limestone. The test results also show that the samples have carbonate content of higher than approximately 80%, dry density of higher than 2.4 $^{gr/cm3}$ and water absorption of higher than 3%. The tested samples were categorized as materials with''high" to very ''high'' durability. From Fig. 2 can be observed that similar results for this separate group can be achieved if the Gamble's classification is applied on the durability index after the fourth slaking cycle. The mineral composition and textural features of argillaceous rocks greatly affects it's slake durability. The mineralogy and the geometric arrangement of particles also affect the strength of marly limestone, but analyses are time consuming and expensive. Furthermore, the relationship between durability and point load is poor due to the granular texture in the samples. It seems that the calcium carbonate content of these samples is more related to the lime particles rather than the cement.

The present research was made as an effort for a better understanding of the durability of marls by using additional test methods, taking into account the carbonate content of these marls. The authors suggest that additional data and studies on marls from other regions are needed to verify the proposed criterions.

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