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Evaluation of petrographic number methods efficiency in quality determination of some carbonates rocks

Mojtaba Kamani[1], Rassoul Ajalloeian*[2]

[1]*Department of Geology, Faculty of Science, University of Isfahan, Isfahan, Iran*
[2]*Department of Geology, Faculty of Science, University of Isfahan, Isfahan, Iran*

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ABSTRACT

Several regulations and manual have been presented for assessing the resources of rock aggregate for use of rock in breakwaters and shore protection structures. Although there are differences between these regulations, many experiments are required, which are often time-consuming, costly and sometimes difficult to implement in the early stages of the project. One of the fast, easy and low-cost methods is the Petrographic Number (PN) method, which according to rock thin sections, has suggestions for expressing the quality of rock materials. In this paper, the application of the PN method in some of the sources of rock aggregate in Iran has been addressed. For this purpose, 33 samples of carbonate rocks used in marine protection structures on the south coast and inland dams were collected. More than 350 experiments were carried out on these specimens. Also, in order to determine the PN, rock thin sections were prepared and the percentage of the components of the petrography including the type of allochem, porosity, cement and matrix, carbonate and non-carbonate minerals are obtained. Then, in order to evaluate the accuracy and efficiency of the PN method, correlation coefficient and comparison of the results of PN with the results of Iranian regulation has been used. Results have shown that a link between the PN with regulations and testing results. The results indicate a significant correlation between some of the engineering properties of samples with the PN. There is also a good correlation between the PN and the total score of the Iranian manual with R2=0.86. However, a single method cannot replace the set of experiments, but for the early stages of the aggregate resource study, it can provide a proper view of the quality of carbonate rock resources.

1. Introduction

Regarding the improvement in harbor facilities around the globe, building new marine protection structures and sea constructions in recent years increased significantly. Iran has a more than 1700 km beach and its need for using these lines for enhancing fishery, industry, trade, transportation, entertainment and also building infrastructure make it build various see and harbor constructions. Also, dams in the country are needed rock aggregates such as marine protection structures. Various manual and recommendations have been presented for analyzing rock aggregates used in see and hydraulically constructions by Iranian and foreign experts (Table 1).

However there are some differences between manuals and regulations regarding the number and type of experiments but for evaluating the rock aggregates according to the regulations, various experiments are needed that normally are expensive, time-consuming and difficult in terms of performing, especially in preliminary studies. One of the fastest, easiest and inexpensive methods in this area is using petrographic number (PN) that achieved by analyzing rock thin sections (McClellan et al., 2002). Using this method, if it's been applicable in Iran, could reduce time and expense in preliminary analyzing of rock aggregates.

*** Corresponding author.**
E-mail address: rasajl@sci.ui.ac.ir
Full Professor, Academic Staff.

The PN method gives valuable information regarding the efficacy of carbonate rock aggregates. Rogers (1990) and Bayne and Brownridge (1955) announced that PN could give a reasonable estimation regarding the efficacy of rock aggregates in concrete. Oyen et al. (1998) enhanced this method and recommended it for using in limestone aggregates. McClellan et al. (2002) used this method in evaluation of rock aggregates in protective see construction in Florida Province. In PN it is assumed that the strength and durability of rocks are due to the inherited properties (Oyenet al., 1998). Investigations on petrographic properties show the effect of it on engineering properties of rocks (Shakoor and Bonelli, 1991; Ulusay et al., 1994; Bell and Lindsay, 1999; Tugrul and Zarif, 1999; Tamrakar et al., 2007; Yılmaz et al., 2011; Tandon and Gupta, 2013; Yeşiloğlu Gültekin et al., 2013; Chitnarin, 2015). Ajalloeian and Kamani (2017) reported that abrasion properties of carbonate aggregate are related to the rock texture. In engineering geology point of view, mechanical, physical and chemical properties of intact rocks are related to texture and mineralogy of rocks and these factors will have a significant effect on engineering behavior of rocks. Due to the heterogeneity in different types of rocks with various texture and mineralogical properties, scientists recommended various methods for analyzing petrographical and textural properties (Howarth and Rowlands, 1986; Přikryl, 2001; Nishiyama et al., 2002; Åkesson et al., 2004; Öztürk et al., 2004; Jeng et al., 2004; Räisänen, 2004; Zorlu et al., 2004; Tandon and Gupta, 2013; Ündül, 2016).

One of these methods for determining petrographical properties and quantification is a PN (Oyen et al., 1998) that applied in this research. According to the increase in usage of limestone in civil engineering projects, more investigations have been performed in this type of rock (Chitnarin, 2015; Ghobadi and Naseri, 2016). In this research according to the vast limestone aggregates in sought and center of Iran and increase in using them in civil projects, the efficacy of PN for determining the quality of carbonate aggregates are evaluated.

2. Material and methods

The 33 samples of carbonate rocks used in breakwater projects includingHasanAbad-Lenge mine, Sarsho-Gheshm, Pasabandar mine and also limestone used in Behesht-Abad Dam are gathered. Samples classified according to Dunham classifications (Dunham, 1962). According to this classification, the samples are included three samples of crystalline limestone, four grainstone, eleven wackestone, four packstone, seven mudstone, two mixed carbonates, one bafflestone and one dolostone.General experiments for evaluating the quality of these rock aggregates are conducted. Experiments are including Aggregate Impact Value (BS 8812), Point Load Index (ASTM D5731-ISRM), Uniaxial Compressive Strength (ASTM D2938-ISRM), Durability Index (ASTM D4644–08 ISRM), Los Angeles Abrasion (ASTM C131, C535), sodium sulfate soundness (ASTM C88), Porosity and Water Absorption (ISRM, ASTM D2216-10). Also, for each sample rock thin section is prepared and petrographical studies for obtaining PN are done.

One of the problems associated with an evaluation of rock aggregates is that one experiment couldn't be used solely for evaluating mechanical and physical properties of rock aggregates. On the other side, properties of rock are due to its inside and petrographic properties. In PN which is based on microscopic analysis of thin sections, it's tried to consider percentage and type of mineralogy, porosity, cementation, and matrix, simultaneously. Also using a numeric system, petrographic properties of rocks will be quantified. Parameters used in PN methods are including the type of allochem or grain, type of porosity, cement or matrix and non-carbonates minerals. In this method for each main parameter, there is a factor weight (FW) used in the process of evaluation. Finally, these factor weights are multiplied by percentage value of each parameter and by summation of them the PN will be obtained. The value of the FW is relative to its strength or resistance to physical and chemical weathering (Oyen et al., 1998). FW of 1.0 represents an ideally durable grain, while progressively larger FWs are indicative of a poorer quality material with regard to potential durability. In the method proposed by Oyen et al. (1998) assigned non-fossil grains, such as peloids, ooids, intraclasts and aggregate grains, an FW of 1.0 due to their dense nature and potentially greater strength. This PN system assigns an FW of 1.3 to fossil grains because the majorities of fossils are composed of aragonitic and thus, are more susceptible to weathering and altering to more permanent phase. This is particularly important in younger limestone. Moreover, fossils are typically thin-walled and have a lower strength and resistance. In this system cement-matrix component of the carbonate are considered by separating differences in potential chemical reactivity according to grain size. For micrite (smaller than 4 microns) is assigned an FW of 1.5 because micrite commonly occurs as an accumulation of biogenic carbonate with free grain boundaries that are subject to chemical and physical reactions. Conversely, sparite due to larger calcite crystal than micrite has a lower potential chemical reactivity due to a decreased surface area. Sparite which typically precipitates directly from solution has tightly bonded crystal boundaries. As a result, sparite and microsparite were assigned an FW of 1.0. Porosity also is one of the important factorsin durability and stability of aggregates. According to the method proposed by Choquette and Pray (1970), there are five main types of porosity in limestone rocks. FW values were assigned to each porosity type based upon typical pore sizes. The larger the average pore size, the larger the assigned FW will be. It is due to the potentially lower physical durability of such grains. For example, for Vuggy pores that normally formed by solution enlargement processes have the largest typical pore sizes, larger than 1.5mm, FW assigned 3.0. For moldic pores which are formed by the dissolution and removal of fossil grains FW assigned 3.0. For interparticle porosity that is formed between individual allochems and creating large pores in sedimentation process FW assigned 3.0. For Intraparticle pores and intercrystalline pores having lower size, FW assigned 2.0.

Table 1 Some of the investigations and regulations presented by Iranian and foreigner scientists

Reference	Country	Explanations
Mather (1985)	Australia	Characteristics of rocks that needed for the outer line of breakwater are analyzed and investigated.
CUR (2000)	General	General factors for evaluation of rocks used in see constructions are presented. Rocks are classified according to physical, strength and chemical parameters into four groups of excellent, good, moderate and poor.
McClellan et al. (2002) ASTM STP-1061	America (Florida)	Numerical petrographicalmethod for evaluation of aggregates is presented for Florida rocks.
BS (2000)	Britain	Factors for selection of appropriate rock for using in the outer line of breakwater are presented.
OCDI (2002)	Japan	Acceptable physical and mechanical ranges of rocks are presented.
Jalali (1989)	Iran	Introduced criteria for using igneous rocks of Gachin salt dome (if microscopically and durably confirmed)
Nikudel, 1989)	Iran	Introduced a system for evaluation of Igneous rocks used in Breakwater.
Amini-Mazraeno (2007)	Iran	Determined a factor for selecting rock aggregates of sought harbors of Iran.
Talkhablo (2007)	Iran	Introduced different factors for selection of limestone, Igneous and Lomashelrespectively
MRUD, The Ministryof Road and Urban Development (2010)	Iran	Rocks used in a harbor and see constructions were classified into three groups of limestone- sandstone, Lomashel and Igneous and determined evaluation factors for each group.

In this method the effect of noncarbonated grains also considered. These include chert, quartz, clays and opaque minerals. With the exception of chert and quartz, all other noncarbonated grains are assigned an FW of 6.0. This designation is due to their substantial weakening effect in rock aggregates. Opaque minerals can be oxidizing severely and clays can cause weakening via expansion (McClellan et al., 2002). According to the aforementioned data,it's possible to calculate the PN with Equation 1 for each sample. The percentage of each parameter could be calculated using counting points methodusing microscope which is normal methods in petrographical studies.

$$PN=1.3S_{FG}+S_{NF}+3S_{HP}+2S_{SP}+1.5S_{M}+S_{S}+1.5S_{D}+S_{Q}+6S_{O}+6S_{C} \quad (1)$$

where, PN is petrographic number, S percentage of each parameter including: FG fossil grain, NF non-fossil grain, HP high porosity and large voids (vuggy, moldic, Inter-particle), SP small porosity and small voids (Intraparticle and Intercrystalline), M micrite, S sparite, D dolomitic grains and cement, Q quartz and chert, O opaque minerals and C clay minerals.

3. Results and discussion

Experiments results and their statistical parameters are presented in Table 2. Essential experiments for evaluating of rock aggregates are including four main groups: physical, mechanical, simulating and petrological analysis (Fookes et al., 1988). In this paper,at least two tests of each group are conducted (Table 2). Also, the petrographical analysis is performed in terms of determining thePN. Among 33 samples, the PNis ranged from 114.5 to 198.7 were presented in Table 2. With the increase in PN, quality of samples will be reduced. According to Rogers, 1990 (ASTM STP 1061), rock resources with PN lower than 140 are good, between 140 to 160 approximately good to poor and higher 160 are useless. Classification of samples regarding their PN is presented in Table 3.

In such a context, 36 percent of samples for using in protective marine constructions are useless. Physical experiments are including density (D) and water Absorption (WA). The percentage of WA in samples ranged from 0.15 to 21.20. 18.2% of samples have WA higher than 15% and their PN is higher than 176. Mechanical experiments including determining weight loss in impact value (IV), point load index (PLI) and uniaxial compressive strength (UCS). Impact value is done for determining rock strength against impact during the construction process and also against destructive factors during the usage. Around 33% of samples have weight loss higher than 30% which according to the standard B.S. 812 (1990) are useless. PN in all of these samples is higher than 161. Results of point load experiments for standard diameter, 50 mm, are ranged between 0.54 to 5.15 MP. According to Broch and Franklin (1972) classification, 57.6% of samples have a very high strength, 36.4% are high strength and 6% have an average strength. Two samples with an average strength (point load index ranged between 0.3 to 1.0 MP) have PN 179.9 and 198.8. Results of uniaxial compressive strength ranged between 4.4 to 130.62 MP. 18.2% of samples have a strength lower than 10MP and PN in all of them is higher than 176.

Simulating experiments performed in this research are including weight loss percentage in sodium sulfate soundness (S), durability index (DI) and Los Angeles abrasion Loss (LAL). The purpose of these experiments is simulating the condition of the project area for better evaluation of properties of a sample in situ. However these experiments could simulate the condition up to a point but none of them can represent the whole condition of an area (Fookes et al., 1988). Results of weight loss in sulfate ranged from 0.1 to 58.0. Also, durability index ranged from 55.25 to 98.15. Approximately 18.2% of samples have a durability index lower than 70% which PN in all of them is higher than 169.8. In addition, 24.3% of samples have a more than 52% weight loss in Los Angeles experiment and all of them have a PN higher than 169.

Table 2 The results and its statistical parameters

Tests Codes	Physical tests			Mechanical tests		Simulation tests			Petrological study
	D (KN/m^3)	WA (%)	IV (%)	PLS (MPa)	UCS (MPa)	S (%)	DI (%)	LAL (%)	PN
1	24.2	3.07	15.6	3.35	61.53	58	90.12	26.3	148.9
2	20.5	6	16.1	4.8	82	12.7	92.1	43.6	141
3	19.6	5.1	15.2	3.29	49.8	9.85	93	34.9	139.7
4	18.2	15.4	55.57	1.2	8.74	11.47	87.1	73.1	176.15
5	19.1	11.5	14.06	2.13	14.9	13.4	83.8	32.85	146.05
6	17.8	17.4	41.66	1.2	8	53.2	74.8	66.7	183
7	19.2	9.8	38.2	3.48	40	9.35	88.3	46.2	161.05
8	17.2	7.6	38	1.48	17.5	12.1	82	47.1	162.7
9	18.1	15.2	59.4	1.05	6.4	52.4	77.6	69.1	180.58
10	25.3	1.1	9.65	3.1	82.7	0.1	98.15	19.18	136.3
11	24.1	1.89	11.71	4.09	72.44	2.9	97.14	21.59	129
12	24.6	1.23	10.81	3.35	68.19	1.3	97.14	20.2	136.5
13	24	2	9.2	5.15	61	2.1	94	22.14	114.1
14	23.4	3.5	16	3.3	54.8	4.25	91.29	26.01	128.7
15	24	2.18	15.6	5.12	44.63	3.3	96.15	23.26	134.6
16	24.1	1.17	11.21	3.56	38.17	3.6	96.26	20.02	118.9
17	21.5	7.4	23.4	2.04	37.3	9.6	87.8	36.98	152
18	17.2	13.5	34.25	1.36	17.88	16.18	83.1	49.21	173.2
19	16.1	19.1	45	0.95	6.89	21.2	76.95	63.87	179.9
20	20.4	7.61	37.62	1.07	28.56	42.9	84.38	76.89	175.2
21	22.58	4.6	11.3	4.8	50	6.12	91.52	23	132
22	25.51	1.8	12.51	3.1	49.44	5.07	94.32	32.8	140.36
23	25.55	2.56	15.43	1.43	59.63	4.07	83.56	37.2	165.5
24	15.21	21.2	65.5	0.54	4.4	21.55	55.25	74.55	198.8
25	26.7	0.19	8.77	3.41	116.22	7.61	94.23	26.1	135.81
26	20.51	8.1	22.7	3.1	34.15	11.13	88.6	38.25	146.1
27	18.35	13.6	38.3	1.93	16.64	15.48	78.03	52.4	169.8
28	16.82	18.9	51.4	1.42	7.1	18.86	69.2	62.63	186.2
29	26.7	0.15	8.72	3.73	98.44	20.45	95.58	26.6	131.32
30	23.6	0.98	10.53	4.14	67.2	0.7	98.15	17.03	134.7
31	26.6	0.28	8.89	3.83	122.5	15.47	95.12	22.6	133.45
32	24.36	2.03	12.97	3.18	60.07	12.8	91.21	22.7	146.8
33	26.39	0.45	9.17	4.49	130.62	10.5	91.85	20.8	140.19
Statistical analysis									
Mean	21.74	6.86	24.07	2.85	49.02	14.83	87.81	38.66	148.9
Std. Dvn.	3.53	6.5	17.05	1.35	34.85	15.23	9.46	18.89	21.59
Min	15.21	0.15	8.72	0.54	4.4	0.1	55.25	17.03	114.1
Max	26.7	21.2	65.5	5.15	130.62	58	98.15	76.89	198.7

D: density, WA: water Absorption, IV: impact value, PLI: point load index, UCS: uniaxial compressive strength, PN: petrographic number, S: sodium sulfate soundness, DI: durability index, LAL: Los Angeles abrasion Loss, PN: petrographic number.

Table 3 PN class of samples

PN range	<140	140-160	160<
Class description	Good	Fair	Poor
Number of samples	15	6	12
Percentage	45.45	18.18	36.36

4. Evaluating of PN methods efficiency

Results of aggregate tests and PN methods are determined so it is needed to investigate the accuracy of PN method in determining the quality of limestone resources in breakwater and marine protective constructions. Therefore, two methods including 1) analyzing correlation coefficients between PN and other aggregate tests and 2) comparing the Iranian regulation (the Ministryof Road and Urban Development, MRUD 2010) with PN method are used.

4.1. Correlation coefficient analysis

In order to investigate whether any meaningful correlations exist or not between PN with results of the rock tests correlation coefficient and t-test are analyzed (Table 4). If any meaningful correlations between PN and results of rock tests exist, it could be possible to use this method in order to determine the quality of rock aggregates for using in hydraulic structures. With analyzing results of the correlation coefficient (R) and P value in hypothesis testing experiment by 95% accuracy, significant correlations between PN and some engineering properties of rocks are found (Table 4).Overall, all of the rock tests including D, WA, IV, PLI, UCS, S, DI, LAL and PN have been used for correlation coefficient matrix and presented in Table 4. The correlation coefficient is a statistical method for determining the type and amount of correlation between two or more quantitative variables. The correlation coefficient of R is one of the parameters used in determining the correlation of two variables showing the intensity and type (direct or reverse) of the correlation. Its range is between 1 to -1 and if there will be no correlation between two variables it will be equal to zero. Also, Significances of R were evaluated by hypothesis testing (P-value) which is presented by Johnson (1998). If the P-value lowers than 0.05, it means that is statistically significant at 95% confidence level. This method is used by many researchers such as Prikryl (2006) and Tiryaki and Dikmen (2009). The correlation coefficient between PN with density is -0.788, water absorption is 0.880, impact value is 0.912, point load index is-0.881, uniaxial compressive strength is -0.690, sodium sulfate soundness is 0.557, durability index is -0.887 and Los Angeles is 0.913. The lowest correlation coefficient exists between PN and Soundness. By increasing PN the impact value, Los Angeles, water absorption and Soundness will increase, however, durability, density, point load index and strength will decrease. In other words, as it was mentioned before, by increasing PN the quality of samples decreased.

4.2. Compared PN with other regulations

The investigations indicate that using an international regulation in analyzing rock aggregate resources of Iran is neither useful and nor efficient in the breakwater and marine protection structures. Amini-Mazraeno (2007) and Shafieefaret al. (2010) recommended using special criteria according to the conditions of Iran. In this section, the efficacy of PN by using domestic criteria is analyzed. For this purpose, manual of the Ministry of Road and Urban Development (MRUD, 2010) is selected. The reason for applying this manual is having a grading system and considering limestone. Also, this manual is commonly used in Iran. For instance, however Nikudel (1989) criteria have a grading system but it's obtained for igneous rocks; consequently, it doesn't use in this investigation.

In the manual of MRUD (2010) there are some recommendations about maximum or minimum of allowable values (criteria) of different tests. The criteria values for limestone with some of the samples which don't have the criteria value are presented in table 5. In addition to number and percentage of unaccepted samples in each experiment, the lowest PN related to those samples is given. By analyzing Table 5 it is obtained that samples with PN lower than 161, have the minimum requirement for selecting as breakwater aggregates, except soundness test. Although, samples 1 and 29 having lower PN than 160, 148.9 and 131.32 respectively, however, results of their soundness test are higher than their limit in regulation, 58 and 20.45 respectively. According to PN method, probably this method doesn't have the necessary accuracy for analyzing sodium sulfate soundness of aggregate. Results of performed rock mechanic tests on samples and their PN shows a meaningful correlation exists between them. Also, by analyzing limited of allowable values it is proved that samples with PN lower than 161, have the minimum requirement according to limited of allowable values of the manual of MRUD, except soundness test. But it's not the reason of gaining required merit according to a suggestion of other researchers or present regulations in this regard. As a consequence, analyzing samples according to the manual of MRUD are essential. According to this manual, rocks used in a harbor and marine constructions are classified into three groups and special criteria are presented for each group respectively. Regarding the purpose of this research, only limestone-sandstone sedimentary rocks are analyzed. In Table 6, grading to parameters in five sections A to E for limestone and sandstone rocks are presented which approximately 6% of samples are very poor with mean of PN 189.35, 12% is poor (class D) with mean of PN 181.48, 15% is class C with mean of PN 165.39, 24% is high or tough, (class B) with mean of PN 148.19 and 42% are very high, very tough, (class A) with mean of PN 132.96 (Table 7). In these criteria, by increasing PN, the summation of the score will decrease and rock will be situated in very poor and poor class (Table 7, Fig. 1). It is possible to estimate the summation score with PN and reasonable accuracy (R^2= 0.86) Using Equation 2. Correlations cross refereeing between estimated values by this equation and observed values are presented in Fig. 2.

$$MRUD=-1.1092\times PN+234.33 \quad (2)$$

In this equation, PN is a petrographic number and MRUD is the summation of score regarding MRUD manual.

Table 4 The results and its statistical parameters

*		D	WA	IV	PLS	UCS	S	DI	LAL	PN
D	R	1	-0.93	-0.859	0.691	0.859	-0.363	0.791	-0.822	-0.788
	Sig. (2-tailed)	*	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
WA	R	-0.93	1	0.915	-0.769	-0.82	0.454	-0.889	0.879	0.88
	Sig. (2-tailed)	0.00	*	0.00	0.00	0.00	0.01	0.00	0.00	0.00
IV	R	-0.859	0.915	1	-0.793	-0.771	0.492	-0.853	0.932	0.912
	Sig. (2-tailed)	0.00	0.00	*	0.00	0.00	0.00	0.00	0.00	0.00
PLS	R	0.691	-0.769	-0.793	1	0.703	-0.473	0.782	-0.818	-0.881
	Sig. (2-tailed)	0.00	0.00	0.00	*	0.00	0.01	0.00	0.00	0.00
UCS	R	0.859	-0.82	-0.771	0.703	1	-0.332	0.69	-0.724	-0.69
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	*	0.06	0.00	0.00	0.01
S	R	-0.363	0.454	0.492	-0.473	-0.332	1	-0.474	0.568	0.557
	Sig. (2-tailed)	0.04	0.01	0.00	0.01	0.06	*	0.01	0.00	0.00
DI	R	0.791	-0.889	-0.853	0.782	0.69	-0.474	1	-0.813	-0.887
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.00	0.01	*	0.00	0.00
LAL	R	-0.822	0.879	0.932	-0.818	-0.724	0.568	-0.813	1	0.913
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*	0.00
PN	R	-0.788	0.88	0.912	-0.881	-0.69	0.557	-0.887	0.913	1
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	*

Table 5 Limited of allowable values and their PN values

Test	Min of D (KN/m^3)	Max of WA (%)	Max of IV (%)	Min of PLS (MPa)	Min of UCS (MPa)	Min of S (%)	Min of DI (%)	Max of LAL (%)
limited of allowable values	17	15	35	1.5	14	18	80	50
Statistical analysis								
Number of rejected samples	3	6	10	10	6	8	6	8
Percentage	9.1	18.18	30.30	30.30	18.18	24.24	18.18	24.24
Min of PN	179.9	176.15	161.05	162.7	176.15	131.32	169.8	169.80

D: density, WA: water Absorption, IV: impact value, PLI: point load index, UCS: uniaxial compressive strength, PN petrographic number, S: sodium sulfate soundness, DI: durability index, LAL: Los Angeles abrasion Loss, PN: petrographic number.

Table 6 Comparing the samples with Iranian manual and PN method

Parameters	properties	Class				
		A	B	C	D	E
Physical	WA (%)	<3	3-6	6-12	12-18	18<
	D (KN/m^3)	24<	22-24	18-22	16-18	<16
	Score	25	20	15	10	5
Strength	PLS (MPa)	4<	3-4	2-3	1-2	<1
	UCS (MPa)	60<	40-60	20-40	8-20	<8
	Score	25	20	15	10	5
Mechanical durability	IV (%)	<10	10-20	20-35	35-45	45<
	DI_{15} (%)	95<	90-95	85-90	80-85	<80
	LAL (%)	<25	25-35	35-50	50-65	65<
	Score	25	20	15	10	5
Chemical durability	S (%)	<4	4-8	8-16	16-20	20<
	Score	25	20	15	10	5
	Sum of score	80-100	80-60	40-60	20-40	20-0
Comparing manual with PN method						
PN method	Number of samples in each class	14	8	5	4	2
	Percentage	42.42	24.24	15.15	12.12	6.06
	Mean of PN	132.96	148.19	165.39	181.48	189.35
	Min of PN	114.10	131.32	146.05	176.15	179.90
	Max of PN	146.80	165.50	175.20	186.20	198.70

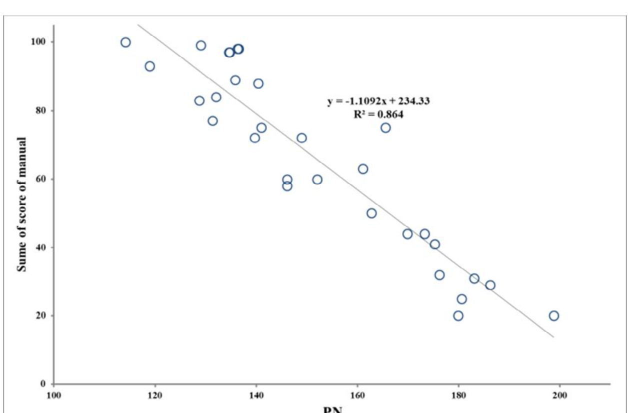

Figure. 1. The relationship between PN and the sum of score of MRUD manual

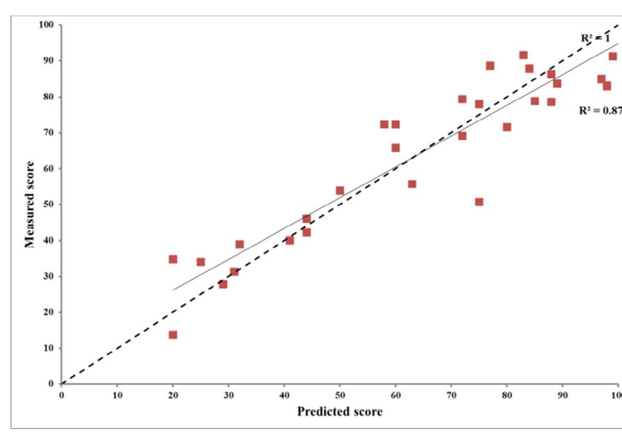

Figure. 2. Cross-correlation of the predicted score by PN and measured score by MRUD manual

5. Conclusion

In this investigation, the efficacy of PN method as an easy, fast and inexpensive method for determining the quality of some limestone resources used in hydraulic construction is analyzed. Recommended regulations and manual in this regard need various experiments that are expensive, time-consuming and need special laboratory facilities. Determining inappropriate resources, omitting them and basic evaluation of them in preliminary steps of a project would be quite beneficial for engineers in terms of estimating the time of construction and expense of the project. Investigations performed in this study shows a good correlation exists between results of aggregate tests and manual of MRUDwith PN. There is a reverse correlation between PN and some of the aggregate properties including DI, PLS, D, and UCS. Also, there is a direct correlation between PN and some of the aggregate properties including LAL, IV, and WA. Overall, when PN increased, quality of rock aggregate decreased. The samples which have PN lower than 161 have the minimum requirement for selecting as breakwater aggregates, except soundness test. In addition, the relationship between PN and sum of score of this manual is obtained with R2=0.86. However, one method shouldn't consider as a replacement for all experiments but it can give a good view regarding the quality of carbonate aggregate resources in preliminary steps of projects. However, further data and studies are needed.

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