Evaluation of the Material Durability and Classification of Rocks Used in the Anzali Port Breakwater

V. Tohidi Karandagh[1]; M. R. Nikudel, Ph.D.[2]; G. R. Lashkaripour, Ph.D.[3];
and B. Muhunthan, Ph.D., P.E., F.ASCE[4]

[1]Graduate Assistant, Dept. of Civil and Environmental Engineering, Washington State Univ., PO Box 642910, Pullman, WA 99163. E-mail: v.tohidikarandagh@wsu.edu
[2]Geology Dept., Faculty of Basic Sciences, Tarbiat Modarres Univ. of Tehran, Iran. E-mail: nikudelm@modares.ac.ir
[3]Dept. of Geology, Faculty of Sciences, Ferdowsi Univ. of Mashhad, Iran. E-mail: lashkaripour@um.ac.ir
[4]Dept. of Civil and Environmental Engineering, Washington State Univ., PO Box 642910, Pullman, WA 99163. E-mail: muhuntha@wsu.edu

ABSTRACT

Rock is one of the abundant materials widely used in the construction of breakwaters. Their performance is directly related to the durability of rock and its physical characteristics. In this paper, the durability and physical characteristics of eleven samples of rock masses used in the rubble-mound breakwater of Anzali Port, Iran, were evaluated to determine their service life. Suitability. Nine of these are igneous and the remaining two were sedimentary rock types. Standard tests such as Los Angles abrasion test, modified aggregate impact value, and Slake durability index were performed. The samples were classified based on the criteria provided by the Transportation Research Institute (TRI) of Ministry of Road and Urban Development of Iran. This classification, uses physical, mechanical, and chemical parameters based on indices. TRI criteria put samples into classes; for igneous rocks from A, the highest quality, to D, the lowest quality, and for sedimentary rocks and A to E. Rock quality is determined based on the scores that each sample attained for each test. The sum of these scores provides the total score of the sample. The results showed that the class of rocks used in the breakwater had wide variation in scores for suitability. In addition, it was found that sedimentary rocks to have the best properties for water absorption and porosity.

KEYWORDS: Rubble mound breakwaters, Durability, Material characteristics, Classification, Anzali Port

1. INTRODUCTION

Construction of breakwaters is key to protection of coastal lines. They include sea ports protection, protection of coastal erosion, and retention of coastal lines and recreational facilities. Breakwaters are effective to make maneuvering of ships more feasible at the entrance of the port. They also help the sedimentation balance using stream direction and allow for generation of areas with different degrees of turbulences. Protecting water inlet of power plants and coastal lines against Tsunami waves are other usages of breakwaters (Burcharth and Hughes, 2005). Rubble mound breakwaters are one of the most common marine structures and rock is used in huge volume in their construction. According to Clarck (1988), armor layer performance in a breakwater is directly related to durability of materials used. By utilization of durable material, the optimum life time of breakwaters can be extended resulting in reduction of probability of destruction and the need of rehabilitation.

Rock durability is defined as a stability factor in retaining physical, chemical, and mechanical properties during technical performance lifetime (Shafieefar et al., 2012). According to Latham et al. (2006), durability is a balance between strength of material and invasion of affecting forces during the service time. Poole (1991) divides essential rock properties in coastal engineering projects into two main groups: geometrical properties of the material including shape, size, and grading; and physical properties including density and mechanical strength related factors, strength against abrasion, porosity and durability. Armor layer is the most important layer in rubble mound breakwaters which is responsible to protect the other layers of breakwater. Although, armor layer with low weight is one of the important factors in instability of the structure, other factors like the length of the stone block in one direction as well as excessive smoothness and roundness of the stones may have significant negative effects (Latham and Poole, 1987). In addition, rock properties and characteristics are important factors in its reaction against invasive forces and parameters. Care should be taken in selecting armor layer rocks because the quality and durability of these rocks play an important role in optimum performance time and stability of breakwater. These rocks should have no foliation and weak plates and be resistant against wetting and drying, as well as frost and thaw, and wave impact and not become disintegrated (Talkhablou, 2007).

Depuy in 1965 has divided rock material durability tests in 3 main groups including Physical tests, Mechanical tests, and Simulating tests. Fookes (1991) extended this classification and dedicated special tests for each class and added petrographical investigation. Table 1 shows a summary of these tests. To classify the rock samples of this research, the guide book by Shafieefar et al. (2012) was used. It was developed by the Transportation Research Institute (TRI) of Ministry of Road and Urban Development. Details of this criteria are discussed further.

Table 1. Durability engineering tests classification

Physical Tests	Mechanical Tests	Simulation Tests	Petrographical Investigations
-Density (Dry, Saturated and Bulk) (BS 812) **-Water Absorption % (BS 812)** **- Porosity**	**- Point Load Index (ISRM)** - 10% Fines Value (BS 812) - Schmidt hardness **- Aggregate Impact Value (AIV) (BS 812)** - Aggregate Abrasion Value (AAV) (BS 812) - Aggregate Crushing Value (ACV) (BS 812) **- Uniaxial Compression Test (ISRM)**	- Modified Aggregate Impact Value (Husking and Tubi 1969) **- Los Angles Abrasion Test (ASTM C535)** - Washington Degradation Test **- Sulphate Soundness (ASTM C88)** - Wetting and Drying - Freeze and Thaw **- Slake Durability Index (ASTM D 4644)**	**-Thin Section Petrology** **-** Clay Minerals Determination (Methylen Blue Absorption, Ethyl Glycol), (XRD)

*Parameters in bold indicate the tests performed in this research.
******BS Stands for British Standard.

2. RESEARCH AREA

Anzali port is one of the important and strategic ports in the north of Iran, playing a special role in the region. This port is located in 49 degrees and 28 minutes eastern longitude, and 37 degrees and 28 minutes northern latitude in the western part of the southern coastal line of the Caspian Sea, in the lowest elevation of vast plain of Guilan. Anzali County extends to Caspian Sea from north and Anzali lagoon from south. Breakwater arms are located at the sides of the outlet of the Anzali lagoon and, in fact, each of them has been built at one side of the city. Figure 1 shows the location of the breakwater.

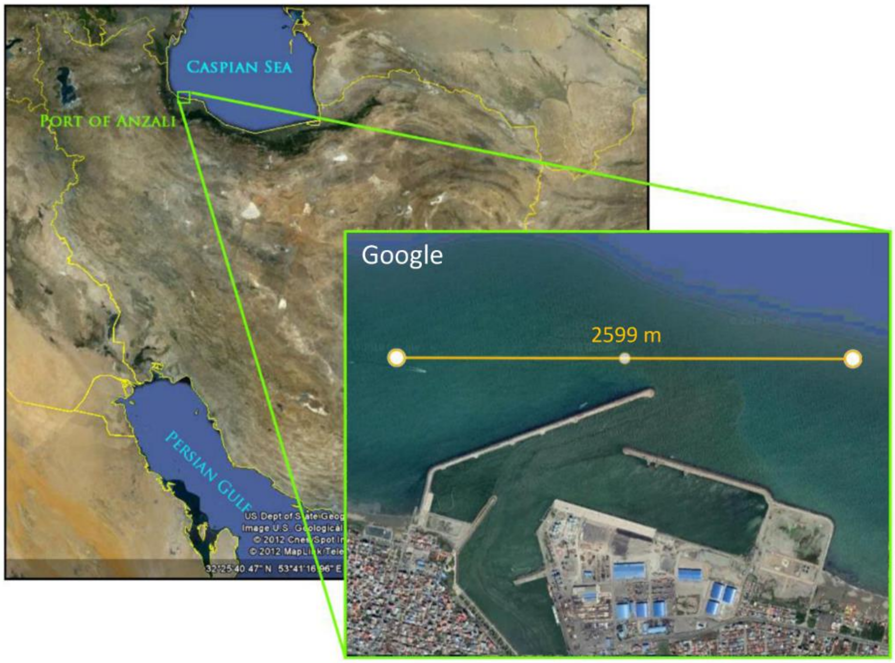

Figure 1. Location of the breakwater, Google earth image

Table 2. Sampling location and types of rocks

Sample No.	Sampling Location	Rock Type	Quarry Location	Quarry Name
1	Eastern arm of breakwater	Hialo-Andesite	Lowshan	Chegini
2	Eastern arm of breakwater	Andesite	Lowshan	Fakouri
3	Eastern arm of breakwater	Hialo-Andesite Porphyry	Lowshan	Shahsavari
4	Eastern arm of breakwater	Tuff Andesite	Ardabil	Namin
5	Eastern arm of breakwater	Andesite	Ardabil	Kelar
6	Eastern arm of breakwater	Andesite	Khalkhal	Andabil
7	Eastern arm of breakwater	Andesite	Khalkhal	Sanj-badleh
8	Isargaran Quarry	Trachyandesite	Rudbar	Isargaran
9	Parham Quarry	Trachyandesite	Lowshan	Parham
10	Western arm of breakwater	Biomicrite	Ardabil	Marly Limestone
11	Western arm of breakwater	Biopel Sparite	Ardabil	Namin's Limestone

3. SPECIFICATIONS OF SELECTED SAMPLES

Samples 1 to 9 are igneous and samples 10 and 11 are sedimentary. According to the place of quarry and microscopic sections, Igneous rocks belong to Eocene epoch volcanic activities.

Carbonate rocks, based on microscopic sections and Rudist fossils, belong to Cenomanian age. 1/100000 geological map of Ardabil indicates their stratigraphic units of K_2^{11} (Thick layer of Rudisti-bearing Limestone) and K_2^{12} (Thin layer of Marly Limestone) (Khoda Bandeh and Amini Fazl, 1997). In Table 2, lists of the sampling location and rock types are reported. Different parts of Figure 2 show the steps from sampling to a prepared thin section under microscope.

Figure 2- a) Sampling at one of the arms of the breakwater. b) Sampling at Isargaran Quarry. c) Coring of rock samples. d) Samples prepared for different experiments. e) Thin section of sample 2 (2.5X enlarged).

4. RESULTS

In this research, physical characteristic tests conducted include density, unit weight, water absorption and porosity. Strength tests include uniaxial compressive test, Point load test, and Brazilian (shear test). Moreover, simulating tests including Aggregate Impact Value (AIV), Los Angeles Abrasion test, Slake durability test, and Sulphate Soundness (Magnesium Sulphate) are performed. In addition, microscopic sections are prepared and studied during the research. In Table 3, the results of physical characteristics of samples, and in Tables 4 and 5 the results of strength and simulating tests are presented. Figure 3 shows the Uniaxial Compressive Strength of samples.

Table 3. Physical Characteristics of Samples.

Sample No.	Porosity (%)	Water Absorption (%)	G_s	γ_d (gr/cm^3)
1	3.76	1.86	2.47	2.42
2	1.50	0.78	2.50	2.48
3	1.77	0.74	2.44	2.40
4	5.82	2.81	2.46	2.44
5	4.98	2.40	2.37	2.31
6	6.47	3.08	2.50	2.43
7	2.38	1.16	2.45	2.41
8	7.03	3.34	2.48	2.40
9	0.90	0.50	2.46	2.46
10	0.83	0.44	2.44	2.43
11	0.41	0.21	2.45	2.45

Table 4. Mechanical Strength Characteristics.

Sample No.	Point Load Index (MPa)(I_{s50})	Uniaxial Compressive Strength (MPa)	Brazilian Tensile Strength (MPa)
1	4.86	103.80	14.60
2	7.14	124.00	12.35
3	4.50	154.80	17.00
4	3.20	138.26	1.94
5	0.62	60.35	3.98
6	2.88	68.82	7.56
7	2.61	26.18	7.58
8	2.05	99.82	6.06
9	5.10	166.58	13.87
10	2.71	111.19	16.56
11	2.06	66.00	9.12

Table 5. Simulation Tests Results.

Sample No.	Los Angeles Abrasion (%)	Slake Durability Cycle2 (%)	Slake Durability Cycle15 (%)	AIV (%)	Sulphate Soundness (%)
1	15.98	99.26	98.47	7.69	-1.998
2	13.81	99.58	98.73	6.79	-2.408
3	17.19	99.38	98.61	8.16	-3.624
4	21.59	99.11	96.52	10.78	-3.046
5	44.92	97.98	93.41	20.83	-0.201
6	26.12	99.34	95.7	12.89	0.318
7	38.9	99.08	96.05	15.67	-2.065
8	23.4	99.40	97.21	12.96	-1.678
9	16.78	99.31	98.48	9.18	0.582
10	22.67	99.44	98.59	13.47	0.068
11	26	99.15	97.61	10.94	-0.028

*The minus in Sulphate Soundness column shows the weight increase.

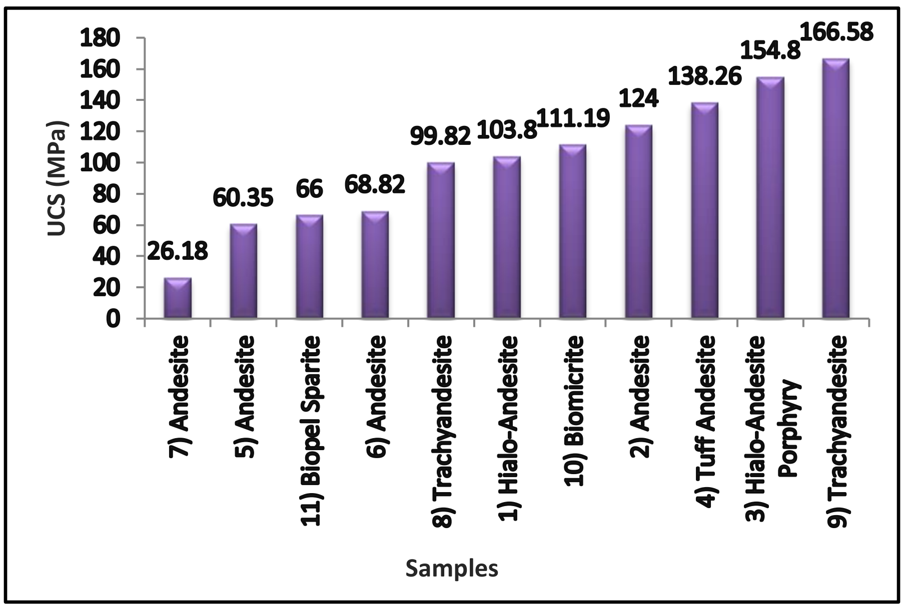

Figure 3- Uniaxial Compressive Strength

5. DISCUSSION

Tests and criteria for evaluating materials have been presented by researchers of different countries for the process of selecting materials. Acceptable tolerance point for the results of tests is different. In Table 6, a summary of these criteria has been presented. As mentioned before, to classify the rock samples of this research, the guideline by Shafieefar et al. (2012) was used. In this classification, parameters are divided into 4 categories including some tests as indices:

- Physical Parameters (Dry Density, Water Absorption, Porosity)
- Strength Parameters (Uniaxial Strength, Point Load Index)
- Mechanical Durability Parameters (Los Angeles Abrasion, Aggregate Impact Value

(AIV), Franklin Slake Durability)

- Chemical Durability Parameters (Magnesium Sulphate Soundness)

Table 6. Summary of different criteria

Criteria/Researcher		Sulphate Soundness (%)	(AIV) (%)	Los Angeles Abrasion (LA) (%)	Water absorption (%)	Dry Density)gr/cm^3(
Wakeling (1977)		18>	<30	-	<3	>2.6
Poole & Fookes (1984)		12>	<16	-	<2.5	>2.6
Lutton (1991)		2>	-	<35	<2.1	>2.6
BS (1989)		18>	<30	<18	<3	>2.6
Jalali (1990)		-	<13	<18	<3	>2.55
CUR 2000	Excellent	2>	-	-	0. 5>	>2.9
	Good	2-12	-	-	0.5-2	2.6-2.9
	Medium	12-20	-	-	2-6	2.3-2.6
	Weak	>20	-	-	>6	<2.3
Nikudel (1990)	Very High Ranking	<1	<10	<10	<1	>2.7
	High Ranking	1-2	10-13	10-14	1-2.5	2.5-2.7
	Medium Ranking	2-3	13-15	14-18	2.5-4	2.3-2.5
	Low Ranking	3-5	15-18	18-24	4-6	2.1-2.3
	Very Low Ranking	>5	>18	>24	>6	<2.1

Considering the importance of chemical durability in overall performance of rocks and the lack of a systematic relation between chemical durability and other characteristics of rocks, this parameter is used individually in categorization. In this classification, three different scoring tables have been offered for igneous rocks, sedimentary rocks (sandstones and limestones), and loam shell rocks. In this research igneous rocks and limestones have been investigated, thus classification table of igneous rocks and sedimentary rocks have been presented in Tables 7 and 8, respectively.

Table 7. Scoring the parameters for igneous rocks from class A to D

Parameter	Characteristic	Class			
		A	**B**	**C**	**D**
Physical	Water Absorption(%)	<1	1-2	2-4	>4
	Density(KN/m^3)	>26	24-26	22-24	<22
Score		25	20	15	10
Strength	Point Load Index (MPa)	>10	7-10	4-7	<4
	Uniaxial Compression (MPa)	>150	-150 100	-100 50	<50
Score		25	20	15	10
Mechanical Durability	AIV (%)	<5	5-10	10-15	>15
	Slake Durability Index 15th Cycle (%)	>99	98-99	97-98	<97
	Los Angeles Abrasion (%)	<12	12-16	16-20	>20
Score		25	20	15	10
Chemical Durability	Sulphate Soundness (%)	<1	1-2	2-5	>5
Score		25	20	15	10
Sum of Scores		80-100	60-80	40-60	20-40

A: Very Durable
B: Durable
C: Moderate
D: Weak

Also, maximum and minimum acceptable tolerance for rock sample characteristics is presented. If any of the characteristics of rock samples is below the presented tolerance, regardless of all other characteristics of the samples, the sample is deemed not suitable and should not be used. Table 9 shows acceptable tolerance points for each of the parameters of igneous rocks and sedimentary and limestone.

In Table 10, results of scoring and classification of investigated samples is presented according to the criteria of Transportation Research Institute (TRI) of Ministry of Road and

Urban Development. Initially, according to the resulting values of tests, scoring is done in each of the 4 described parameters (Physical Parameters, Strength Parameters, Mechanical durability parameters, Chemical durability parameters). Final score for each sample equals the sum of resulting scores in each category. Finally, samples are classified based on their overall score.

Here is an example of reading the data from Table (10) for each sample. Sample No.1: According to the microscopic investigation, this sample is a Hialo-Andesite. It shows relatively acceptable physical characteristics and is placed in classes B and C. It gains the same classes in strength parameters. For mechanical durability parameters, it is placed in class B and in class A in chemical durability. The overall score of this sample equals 80. So, according to Table 7, it is placed in class A in final classification. In addition, according to Table 9, all parameters cover acceptable tolerance point.

Table 8. Scoring the parameters for limestones and sandstones from class A to E

Parameter	Characteristic	Class				
		A	B	C	D	E
Physical	Water Absorption(%)	<3	3-6	6-12	12-18	>18
	Density(KN/m^3)	>24	22-24	18-22	16-18	<16
Score		25	20	15	10	5
Strength	Point Load Index (MPa)	>4	3-4	2-3	1-2	<1
	Uniaxial Compression (MPa)	>60	40-60	20-40	8-20	<8
Score		25	20	15	10	5
Mechanical Durability	AIV (%)	<10	10-20	20-35	35-45	>45
	Slake Durability Index 15th Cycle (%)	>95	90-95	85-90	80-85	<80
	Los Angeles Abrasion (%)	<25	25-35	35-50	50-65	>65
Score		25	20	15	10	5
Chemical Durability	Sulphate Soundness (%)	<4	4-8	8-16	16-20	>20
Score		25	20	15	10	5
Sum of Scores		80-100	60-80	40-60	20-40	0-20

A: Very Durable
B: Durable
C: Moderate
D: Weak
E: Very Weak

Table 9. Acceptable tolerances for parameters of igneous rocks and sandstone-limestone

Group of Rock Type	Max. Water Absorption (%)	Min. Dry Density (KN/m^3)	Min. Point Load Index (MPa)	Min. Dry Uniaxial Comp. Strength (MPa)	Max. Los Angeles Abrasion (%)	Max. AIV (%)	Max. Weight Loss in Sulphate (10 Cycles) (%)	Max. Weight Loss in 15 Cycles of Slake Durability (%)
Igneous Rocks	6	23	4	50	30	15	7	90
Sandstone- Limestone	15	17	1.5	14	50	35	18	80

Table 10. Scoring and classification of samples of this research

Parameter Category		Chemical Durability Parameters	Mechanical Durability Parameters			Strength Parameters		Physical Parameters	
Sample/Sum of Scores		Sulphate Soundness	Los Angeles Abrasion (%)	Slake Dur. in 15 Cycles	AIV (%)	Uniaxial Com. strength (MPa)	Point Load Index (MPa)	Dry Density (KN/m^3)	Water Abs. (%)
1) Hialo-Andesite	Value	-1.998	15.98	98.47	7.69	103.80	4.86	23.74	1.86
	Class	A=25	B=20	B=20	B=20	B=20	C=15	C=15	B=20
80	Score	25	20			17.5		17.5	
2) Andesite	Value	-2.408	13.81	98.73	6.79	124.00	7.14	24.33	0.78
	Class	A=25	B=20	B=20	B=20	B=20	B=20	B=20	A=25
87.5	Score	25	20			20		22.5	
3) Hialo-Andesite Porphyry	Value	-3.624	17.19	98.61	8.16	154.80	4.50	23.54	0.74
	Class	A=25	C=15	B=20	B=20	A=25	C=15	C=15	A=25
83.33	Score	25	18.33			20		20	
4) Tuff Andesite	Value	-3.046	21.59	96.52	10.78	138.26	3.20	23.93	2.81
	Class	A=25	D=10	D=10	C=15	B=20	D=10	C=15	C=15
66.66	Score	25	11.66			15		15	
5) Andesite	Value	-0.201	44.92	93.41	20.83	60.35	0.62	22.66	2.40
	Class	A=25	D=10	D=10	D=10	C=15	D=10	C=15	C=15
62.5	Score	25	10			12.5		15	
6) Andesite	Value	0.318	26.12	95.7	12.89	68.82	2.88	23.84	3.08
	Class	A=25	D=10	D=10	C=15	C=15	D=10	C=15	C=15
64.16	Score	25	11.66			12.5		15	
7) Andesite	Value	-2.065	38.9	96.05	15.67	26.18	2.61	23.64	1.16
	Class	A=25	D=10	D=10	D=10	D=10	D=10	C=15	B=20
62.5	Score	25	10			10		17.5	
8) Trachyande-site	Value	-1.678	23.4	97.21	12.96	99.82	2.05	23.54	3.34
	Class	A=25	D=10	C=15	C=15	C=15	D=10	C=15	C=15
65.83	Score	25	13.33			12.5		15	
9) Trachyande-site	Value	0.582	16.78	98.48	9.18	166.58	5.10	24.13	0.50
	Class	A=25	C=15	B=20	B=20	A=25	C=15	B=20	A=25
85.83	Score	25	18.33			20		22.5	
10) Biomicrite	Value	0.068	22.67	98.59	13.47	111.19	2.71	23.84	0.44
	Class	A=25	A=25	A=25	B=20	A=25	C=15	B=20	A=25
90.83	Score	25	23.33			20		22.5	
11) Biopel Sparite	Value	-0.028	26	97.61	10.94	66.00	2.06	24.03	0.21
	Class	A=25	B=20	A=25	B=20	A=25	C=15	A=25	A=25
91.66	Score	25	21.66			20		25	

*To score samples 1 to 9, Table 7 and to score samples 10 and 11, Table 8 has been used.

6. CONCLUSIONS

To determine the best fit quarry materials to be used in breakwater construction, a set of specified tests were determined by the classification criteria. To find the strength and durability characteristics of rocks of new breakwater of Anzali port, tests are done according to the TRI criteria. Based on the tests done in this research and their comparison with the existing criteria, following results are derived:

- Sedimentary samples show the best results in water absorption and porosity with minimum values. In strength tests, sample No. 10 (Biomicrite) shows better results in comparison with sample No.11 (Biopel Sparite). In total, sample No.11 gains a higher score (91.66), but both the samples are in class A and according to Table 9, all parameters cover acceptable tolerance point.
- Igneous samples 1, 2, 3, and 9 show the best results and all four are in class A and according to Table 9, all parameters cover acceptable tolerance point.
- Sample No.2 (Andesite of Fakouri quarry, Lowshan) with the score of 87.5 gains the highest score among igneous rocks and sample No.11 (Biopel Sparite of Ardebil quarry) with score of 91.66 gains the highest score in sedimentary rocks.
- Sample No.5 (Andesite of Kelar Ardebil) and sample No.7 (Andesite of Sanj-badleh, Khakhal quarry) with equal score of 62.5 gain the lowest scores among all the samples. According to Table 9, these samples do not reach to an acceptable tolerance point in 4 parameters and thus, should not be used as armour layer of breakwaters.
- According to the fact that the highest destructive load is imposed to armour layer of breakwater in tidal region, samples that show the best results are more suitable for such places. Samples with weaker results are better to be used in other parts of the breakwater such as filter.
- As the number of the cycles of Sulphate Soundness test increases, it shows a better relationship with Uniaxial Compressive Strength test.

Regarding the similar studies and researches on breakwaters and utilized materials in the south of Iran, this research may be considered as an attempt towards more investigations of rock materials in the north of Iran. The data of this research along with those of researches on the south of Iran and future studies, can provide a comprehensive information about breakwaters of Iran and available materials. Also, the data provided in this research can be used to correlate the relationships among different tests or existing models.

ACKNOWLEDGEMENT

This research has been done using the facilities and devices of Tarbiat Modarres University of Tehran.

REFERENCES

Burcharth, H.F., and Hughes, S.A. (2005). Types and functions of coastal structures. EM 1110-2-1100, Part VI.

CIRIA/CUR. (2000). Manual on the use of rock in coastal and shoreline engineering. Construction Industry Research and Information Association, London, CIRIA Spec Publ 83/ CUR report 154.

Clark, A.R. (1988). The use of Portland stone rock armour in coastal protection and sea defense works. Quarterly Journal of Engineering Geology & Hydrogeology, 21, no. 2, 113-136.

Fahimifar, A., and Soroush, H. (2001). Rock mechanics tests, theoretical aspects and standards. Vol. I, Laboratory tests, Amirkabir University of Technology Publishing Center (Tafresh).
Fookes, P.G. (1991). Geomaterials. Quarterly Journal of Engineering Geology and Hydrogeology, London, 24, 3-15.
Jalali, H. (1990). Importance of durability of rocks in stability of rubble mound breakwaters. First International Conference of Port Construction and Marine Structures, Vol.2, 407-443.
Khoda Bandeh, A., and Amini Fazl, A. (1997). Geological report of 1/100000 map of Ardebil. Geological Survey of Iran.
Latham, J.P., and Poole, A.B. (1987). Pilot study of an aggregate abrasion test for breakwater armourstone. Quarterly Journal of Engineering Geology, London, 20, 311-316.
Latham, J.P., Meulen, J.V., and Dupray, S. (2006). Prediction of in situ block size with distributions with reference to armourstone for breakwater. Engineering Geology, 86, 18-36.
Nikudel, M.R. (1990). To determine criteria for degradation and durability of rocks. M.Sc. thesis, Tarbiat Modarres University of Iran.
Poole, A.B. (1991). Rock quality in coastal engineering. Quarterly Journal of Engineering Geology, London, 24, 85-90.
Shafieefar, M., Nikudel, M.R., and Hafezi Moghaddas, N. (2012). The guide to use rocks in breakwaters and coastal protection structures. Transportation Research Institute (TRI), Ministry of Road and Urban Development, Department of Marine Transportation Research.
Talkhablou, M. (2007). Evaluation the engineering properties of rocks and suggesting a criterion to use in marine protection structure construction (Southern Coast of Iran). PhD Thesis, Tarbiat Modarres University of Tehran, Iran.
Wakeling, H.L. (1977). The design of rubble mound breakwater. Symp. on Design of Rubble Mound Breakwaters, British Hovercraft Corp.