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Rock mass rating system with application to construction of breakwaters, southeast of Iran

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Abstract

A tremendous amount of rock is used in constructing shoreline protective structures on which the influence of marine environments is totally different from other areas. These materials must be classified according to particular size, shape and grading as specified by marine structure designers. Other properties of rock such as density are needed to be incorporated in design equations. Moreover, tough conditions prevailing marine environments cause the durability of rock to assume quite a peculiar and important stature. Durability is defined as the ability of rock to maintain its physical and mechanical properties for the period of time that it is present in an engineering structure. Hence, durability is a function of rock properties and the environment or conditions surrounding it.

This study attempts to look further into rock materials of Pozm, Tis, Chabahar, Ramin, Briz, and Pasabandar's breakwaters in the southeast of Iran from the view point of their durability and degradation in the armour layer. Also, it is aimed at setting forth appropriate criteria to quickly evaluate quality and durability of regional rock materials by considering samples of durable and indurable rocks of breakwaters, paying attention to field observations and durability evaluation engineering tests as well as introducing the most proper rock material deposits of the region.

Key words: armour layer, Breakwaters, durability, marine structures.

سیستم امتیازدهی توده‌ی سنگ جهت کاربرد در ساخت موج‌شکن‌های جنوب شرق ایران

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چکیده

برای احداث اکثر سازه‌های حفاظتی سواحل مقادیر زیادی سنگ به مصرف می‌رسد که تأثیر شرایط محیط دریا بر روی آن‌ها با دیگر مناطق کاملاً متفاوت است. این مصالح می‌بایست به اندازه، شکل و دانه‌بندی ویژه، مشخّص‌شده توسّط طرّاحان سازه‌های حفاظتی، طبقه‌بندی شوند. خصوصیّات دیگر سنگ نظیر دانسیته نیز برای استفاده در معادلات طراحی مورد نیاز است. علاوه بر این شرایط سخت حاکم بر مناطق دریایی موجب

می‌شود که دوام و مقاومت سنگ مورد مصرف نیز از جایگاه و اهمّیّت ویژه‌ای برخوردار شود. دوام عبارتست از توانایی سنگ در حفظ ویژگی‌های فیزیکی و شیمیایی خود در مدّتی که در یک سازه‌ی مهندسی از آن استفاده می‌شود. بنابراین دوام تابعی از ویژگی‌های سنگ و محیط یا شرایطی است که در آن قرار می‌گیرد.

در این پژوهش سعی شده است که مصالح سنگ مصرفی در لایه‌ی حفاظ موج‌شکن‌های نواحی پزم، تیس، چابهار، رمین، بریس و پسابندر در جنوب شرق ایران از دیدگاه دوام و زوال آن‌ها مورد بررّسی قرار گیرد. همچنین ضمن معرّفی مناسب‌ترین منبع قرضه‌ی مصالح سنگی در ناحیه‌ی مذکور با بهره‌گیری از نمونه‌های سنگ بادوام و بی‌دوام مشاهده شده در موج‌شکن‌های مذکور و توجّه به نتایج حاصل از بررّسی‌های مشاهده‌ای و آزمایش‌های مهندسی سنجش دوام معیارهای مناسبی برای ارزیابی سریع کیفیّت و دوام مصالح سنگی دراین منطقه ارائه شود.

واژه‌های کلیدی: سازه‌های دریایی، دوام، لایه‌ی حفاظ، موج شکن

1. Introduction

The importance of analyzing rock material durability before being utilized in engineering structures becomes better apparent when one glances at the considerable list of ruined structures due to the application of low grade and indurable materials. In the mean time destructions and incidents inflicted on great rubble mound breakwaters along coastal lines of the Atlantic and the Pacific like Sines in Portugal, Tripoli in Libya, Giola Tauro in Italy and Skikda in Algeria concede the vitality of analyzing and recognition of rock material durability(CIRIA/CUR 1991).

Numerous reports of marine structures destruction made of rock especially rubble mound breakwaters are also available in Iran. In recent years many breakwaters have been or are being constructed along the southern coast line of Iran and several islands, most of which are of rubble mound type, and the Armour layers of a majority of such breakwaters have been destroyed after a while due to improper choice of materials causing huge financial loss.

Declaration of Chabahar as a free trade zone and the attention of government authorities to the economic and civil progress of this port has enhanced the construction of numerous civil and commercial structures which necessitate the existence of coastal facilities, especially breakwaters. For this same reason many breakwaters have been constructed in the region the Armour layer of which is made of rock.

This case study attempts to look further into rock materials of these breakwaters from the view point of their durability. Also it is aimed to set forth appropriate criteria to quickly evaluate quality and durability of regions rock materials by considering samples of durable and indurable rocks of breakwaters, paying attention to field observations and durability evaluation engineering tests.

2. Results of petrological studies

Petrological studies and surveys have been conducted on the region's mines rock materials, used in the construction of region's breakwaters, in order to recognize their characteristics. The results are shown in Table 1.

Figure 1 shows the geological map of the region and location of the mines.

Table 1. Results of petrological studies on the mines rock materials

Name of the mine	Position and distance from Chabahar	Name of the breakwater	Rock	Minerals and particles
Pozm (Po1, Po2)	45 kms west of Chabahar	Pozm Konarak	Biosparodite	Sedimentary rock fragments, Igneous rock fragments,Quartz & plagioclase particles
Tis (T)	10 kms north of Chabahar	Tis & Beheshti	Limy sandstone	Quartz & plagioclase particles, Igneous rock fragments
Pirsohrab (PS), (PK)	80 kms northeast of Chabahar	Kalantari & Sepah	Gray wacke	Quartz & feldspar particles, Igneous & Sedimentary and metamorphic rock fragments
Ramin (R)	12 kms east of Chabahar	Ramin	Biosparodite	Shells, Sedimentary rock fragments, Quartz particles
Briz (B)	70 kms east of Chabahar	Briz	Coquinite	Shells, Quartz particles
Pasabandar (PA)	130 kms east of Chabahar	Pasabandar	Biosparodite	Shells, Quartz particles, Sedimentary rock fragments,

3. List of durability evaluation tests

The following durability evaluation engineering tests have been performed on rock materials used in breakwaters so as to assess their quality and durability.

Water absorption test (ASTM C127-01)

Porosity determination test (ISRM 1981)

Saturated and bulk specific gravity determination test (BS 812)

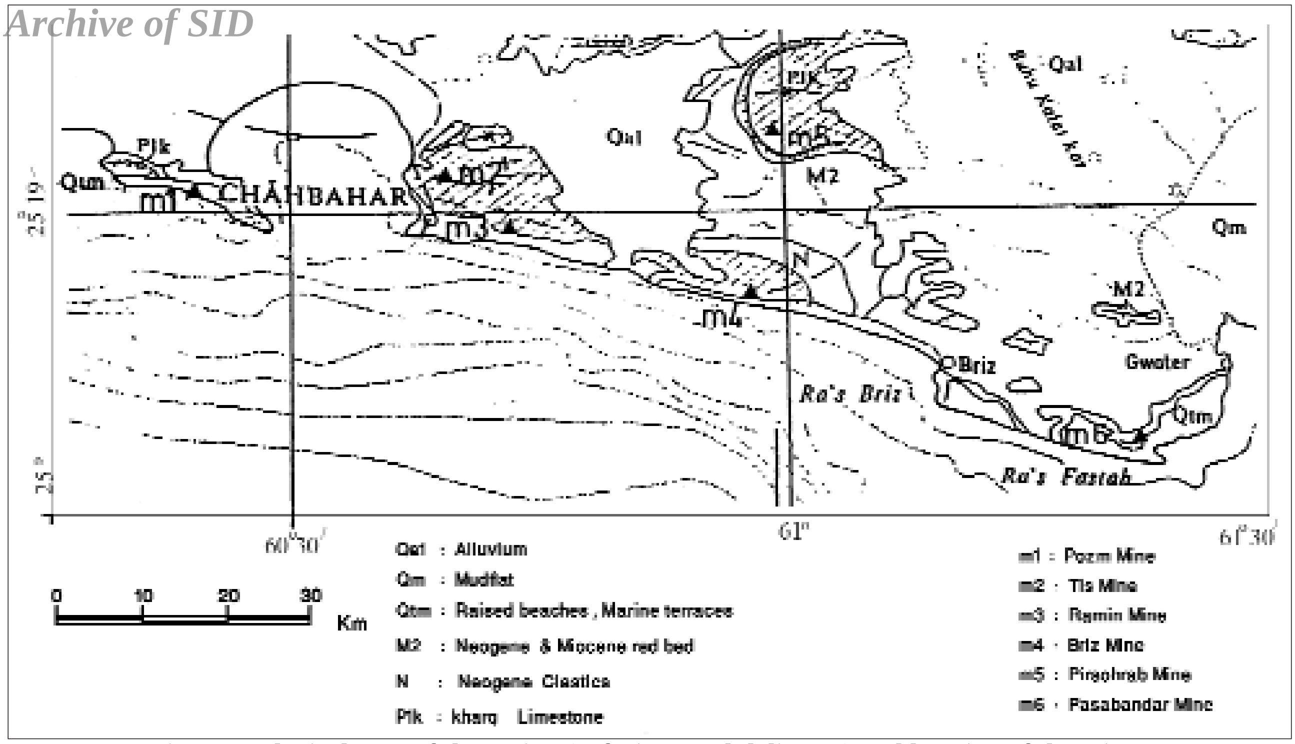


Fig. 1. Geological map of the region (Jafarian & Abdoli 1996) and location of the mines

Los Angeles abrasion test (ASTM C535-01)

Aggregate impact value test (BS 812)

Point load index test (ISRM 1988) in dry, saturated conditions and different cycles of hydration and dehydration using saturated sodium sulphate solution

Sulfate soundness test (ASTM C 88)

Slake durability test (ISRM 1981)

Fracture toughness test (ISRM 1988) using indirect method-brazilian test (Guo et al. 1993)

Uniaxial compressive strength test on dry and saturated samples (ISRM 1981)

Summary of results of durability evaluation engineering tests are shown in Table 2.

4. Variations in point load index

In order to realize the effect of saline solutions on mines materials along with determination of influences posed by tensile stresses caused by salt crystallization in the pores of these materials, point load index was determined in different hydration and dehydration cycles with saturated sodium sulphate solution.

Afterwards, durability index (Di), which is the ratio of point load index after twenty such cycles to point load index of materials before hydration and dehydration cycles, was calculated for all samples according to

$$Di = Is/Is_0 \quad (1)$$

Figure 2 shows variations of durability index (Di) against different hydration and dehydration cycles. As glance at the figure reveals that sample Po1has undergone the smallest reduction in tensile strength after twenty cycles, while samples PK and PS show the highest reduction, in such a way that PS faces degradation and collapse at the end of the seventh cycle with a durability index of 0.29 at this stage. PK

Table 2. Summary of results of durability

Sample	Wab (%)	Porosity (%)	Specific Gravity		Los Angles Abrasion (%)	A.I.V (%)	Point load Index (Mpa)		S.S (%)	S.D (%)	Fracture Toughness (MN/M1.5)		Uniaxial Compressive Strength (Mpa)	
				Sat.			Dry	Sat.			Dry	Sat.	Dry	Sat.
Po1	۱.۴۴	۳.۴	۲.۴	۲.۴۲	۸.۰	۱۴.۰	۴.۴	۴.۱	۰.۰	-	۰.۹۸	۰.۸۰	۵۲.۵	۴۴.۴
Po2	۱۴.۸	۲۷.۷	۱.۸	۲.۰۹	۲۰.۸	۳۷.۳	۱.۷	۱.۷	۰.۰	۶۹.۹	۰.۳۱	۰.۱۸	۱۶.۶	۱۱.۹
T	۲۰.۰	۳۵.۰	۱.۷	۲.۱۰	۴۵.۰	۵۷.۴	۰.۶۸	۰.۳۸	۱۰.۴	۹۲.۱	۰.۲۳	۰.۱۰	۷.۲	۳.۹
PK	۲.۷	۷.۰	۲.۵	۲.۵۸	۶.۵	۱۰.۵	۵.۴	۴.۲	۱۸.۲	-	۲.۱۰	۰.۹۱	۱۴۵.۰	۱۲۰.۹
PS	۳.۲	۸.۱	۲.۴	۲.۵۸	۸.۵	۱۱.۰	۲.۳	۱.۶	-	-	۱.۶۰	۰.۷۰	۰.۵۳	۴۳.۰
R	۲۲.۵	۳۶.۶	۱.۶	۲.۰۶	۳۹.۲	۶۱.۲	۰.۵۵	۰.۴۳	۸.۲	۹۲.۹	۰.۱۹	۰.۱۵	۵.۰	۳.۱
B	۱۷.۰	۳۰.۰	۱.۸	۲.۱۵	۳۶.۰	۶۲.۸	۰.۱۲	۰.۸۵	۷.۵	۹۱.۰	۰.۱۸	۰.۱۴	۵.۹	۴.۶
PA	۲۰.۴	۳۴.۵	۱.۷	۲.۰۹	۴۵.۰	۵۶.۶	۰.۹۶	۰.۶۶	۸.۴	۹۳.۳	۰.۲۴	۰.۱۲	۷.۴	۴.۹

has the worst condition next to PS with a Di of 0.4 after the 20th cycle which is too small. Samples Po2, T, R, B and PA have relatively similar conditions (Nasehi 2007). Graphs of correlations among the results of durability evaluation tests are shown in Figure 3.

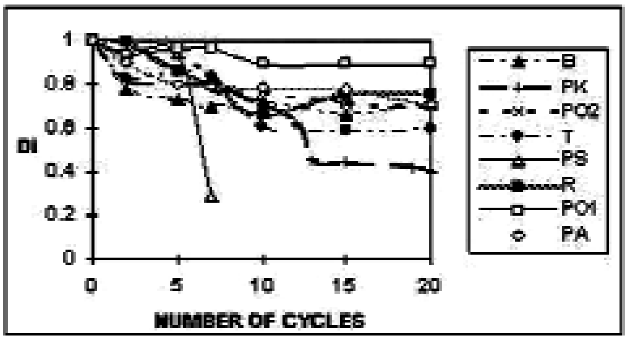


Fig. 2. Variations of durability index

5. Correlations among results of tests

Establishment of relations and correlations among results acquired from durability evaluation tests facilitates prompt and easy recognition of tests which can be regarded as substitutes for lengthy and complicated tests. Table 3 depicts correlations among durability evaluation test results of the mines rock materials.

Table 3. Correlations among the results of durability evaluation tests

Correlation among	Equation	R2
Los Angeles abrasion (Los) and bulk specific gravity (BSG)	Los= 449.47 BSG-3.849	0.85
Los Angeles abrasion (Los) and aggregate impact value (AIV)	Los= 0.97 AIV+5.99	0.93
Los Angeles abrasion (Los) and point load index (IS(50))	Los= 13769 Is(50) -0.809	0.84
Los Angeles abrasion (Los) and uniaxial compressive strength (qu)	Los= 177.09 qu-0.562	0.93
Aggregate impact value (AIV) and bulk specific gravity (BSG)	AIV= 772.49BSG-4.614	0.97
Aggregate impact value (AIV) and fracture toughness (KIC)	AIV= 16.7 KIC -0.811	0.97
Point load index (Is (50)) and aggregate impact value (AIV)	Is(50)= 36.77 AIV-0.915	0.80
Uni. compressive strength (qu) and aggregate impact value (AIV)	qu= 3223.1 AIV -1.518	0.95
Sulphate soundness(SS) and water absorption (Wab)	SS= -0.51 Wab+ 19.0	0.84
Sulphate soundness (SS) and aggregate impact value (AIV)	SS= -0.19 AIV+ 20.3	0.97

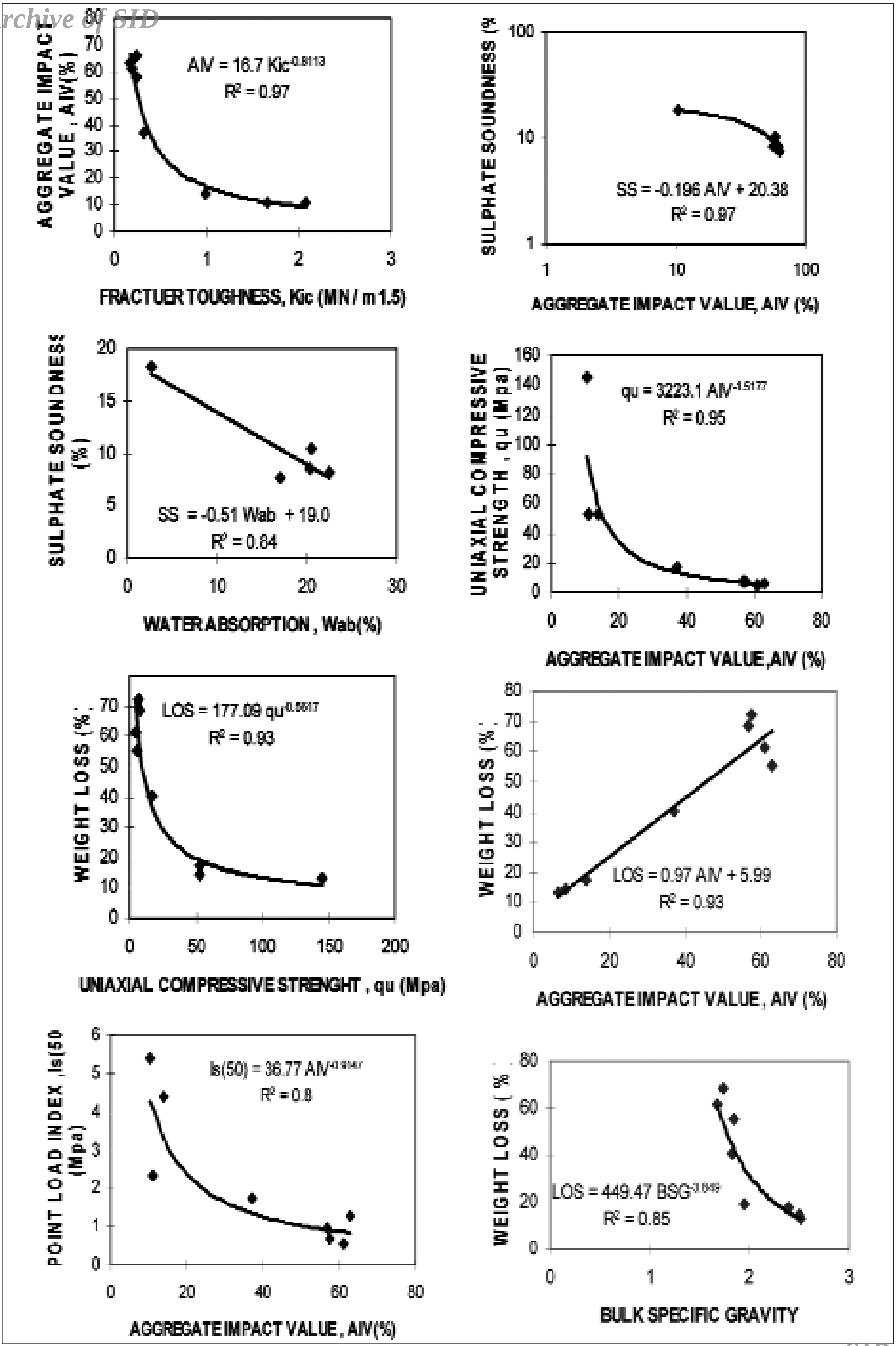
6. Conclusion

None of engineering tests can individually be introduced as a criterion for assessment of rock materials durability. A combination of results obtained from different engineering tests such as percentage of water absorption, specific gravity, point load

Table 4. The rating assessment system for the use of rock in marine structures -south east of Iran

Test	Classified results of the test				
	Excellent	Good	Fair	Weak	Very weak
Bulk specific gravity	>2.7	2.5-2.7	2.2-2.5	1.9-2.2	<1.9
Point	10	8	6	3	1
Water absorption (%)	<	1-3	3-6	6-10	>10
Point	10	8	6	3	1
Sulfate soundness test (%)	<2	2-5	5-12	12-15	>15
Point	15	12	7	3	1
Modified Los Angles test (%)	<10	10-5	15-20	20-30	>30
Point	10	8	5	2	1
Rock fracture toughness (MN/m105)	>2.2	1.5-2.5	0.8-1.5	0.3-0.8	<0.3
Point	15	12	8	4	2
Durability index (Di)	0.9-1	0.75-0.9	0.5-0.75	0.25-0.50	<0.25
Point	12	8	6	3	1
Aggregate impact Value (%)	<10	10-12	12-18	18-25	>25
Point	10	7	5	3	1
Uniaxial compressive strength(MPa)	>140	70-140	20-70	5-20	<5
Point	6	4	2	1	0
Petrology	Compact igneous rock without joints		Moderately compact & weathered igneous & metamorphic rocks with joints, moderately strong sedimentary rocks	Highly weathered & jointed rocks with Soluble minerals	Highly weathered rocks with soluble minerals & more than 15 percent of porosity
Point	12	Compact igneous & metamorphic rocks with low grade weathering & without joints, strong sedimentary Rocks	5	3	2
Sum of the points	100	75	50	25	10
Classification	Excellent	Good	Fair	Weak	Veryweak
Rating bound		75-90	50-75	25-50	<25

strength, impact value and sulphate soundness can be recommended as the mentioned criterion. Durability index (Di), as discussed, is the most proper parameter which one can use to recognize durability or


AGGREGATE IMPACT VALUE , AIV(%)
AIV = 16.7 Kic^-0.8113
R² = 0.97
FRACTUER TOUGHNESS, Kic (MN / m1.5)
SULPHATE SOUNDNESS (%
SS = -0.196 AIV + 20.38
R² = 0.97
AGGREGATE IMPACT VALUE, AIV (%)
SULPHATE SOUNDNESS (%)
SS = -0.51 Wab + 19.0
R² = 0.84
WATER ABSORPTION , Wab(%)
UNIAXIAL COMPRESSIVE STRENGTH , qu (Mpa)
qu = 3223.1 AIV^-1.5177
R² = 0.95
AGGREGATE IMPACT VALUE ,AIV (%)
WEIGHT LOSS (%)
LOS = 177.09 qu^-0.5617
R² = 0.93
UNIAXIAL COMPRESSIVE STRENGHT , qu (Mpa)
WEIGHT LOSS (%)
LOS = 0.97 AIV + 5.99
R² = 0.93
AGGREGATE IMPACT VALUE , AIV (%)
POINT LOAD INDEX ,Is(50) (Mpa)
Is(50) = 36.77 AIV^-0.9047
R² = 0.8
AGGREGATE IMPACT VALUE, AIV(%)
WEIGHT LOSS (%)
LOS = 449.47 BSG^-3.849
R² = 0.85
BULK SPECIFIC GRAVITY

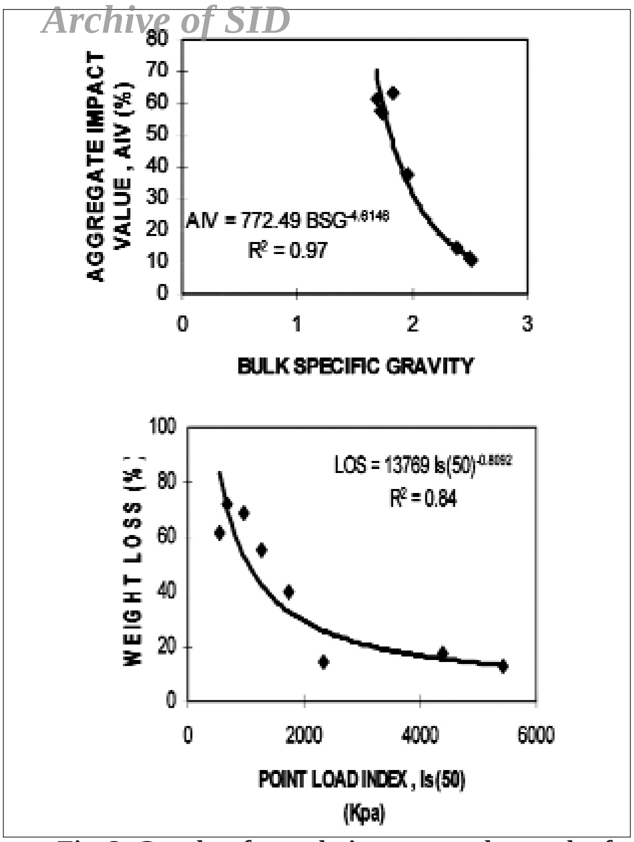


Fig. 3. Graphs of correlation among the result of durability evaluation tests

indurability of rocks along the coast line of Persian Gulf. As there is no need to spend a great amount of capital to study this parameter and rock durability is understood with a high degree of precision using it, hence its application is strongly recommended for any research on durability of rocks along the Persian Gulf.

According to Figure 2, sample Pol has the best quality in the region while samples PK and PS show the highest reduction in tensile strength and have the worst quality.

A rating system for prompt assessment of rock materials durability and their application in the region's breakwaters can be proposed as in Table 4. However, more extensive research is needed to finalize this proposition. According to this classification, materials with excellent to good quality can be recommended for the construction of armour layers and protective ramps and those with good to intermediate quality for use as materials of under layers and cores of such structures.

7. Acknowledgment

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