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Armourstone Quality Analysis for Coastal Construction in Chabahar, Southeast Iran

Mohyeddin Ahrari-Roudi [1] and Mojtaba Zaresefat [2,*]

[1] Oceanography Department, Faculty of Marine Science, Chabahar Maritime University, Chabahar 99717-78631, Iran
[2] Copernicus Institute of Sustainable Development, Utrecht University, 3584 CB Utrecht, The Netherlands
* Correspondence: m.zaresefat@uu.nl; Tel.: +31-630499520

Abstract: Natural stones (armourstones) of varying sizes and qualities are frequently used to construct breakwaters to protect coastal engineering structures from wave actions for economic reasons. Time-related armourstone deterioration in the form of abrasion and disintegration may result in structural damage. Therefore, it is necessary to investigate the performance and quality of the armourstones, which should be robust and long-lasting. The study aimed to examine the quality of two distinct types of rocks from three breakwaters used as armourstones in the Chabahar region and compare the results to the observed field performance. This study aimed to illustrate why it is crucial to characterise rocks thoroughly before deciding which ones to use in a particular project and to evaluate how well current classification techniques account for the observed field performance of stones that may have complex geological compositions. The physical and mechanical properties of the rock were evaluated through both on-site observation and laboratory testing. The results indicated that the class of rocks used in the breakwater had a wide range of suitability ratings. It was discovered that sedimentary rocks have the best water absorption and porosity properties. In addition, age is a positive factor, as the rate of destruction decreases with age. Component and particle size can also play a role in lithology, which is a significant factor in the rock's durability. Also, the findings demonstrated that the marine organisms in the rock component play an important role in the stability of these structures, even though rock mass breakwaters are less qualified for breakwater construction as per international coastal engineering standards. According to the findings, a breakwater made of lumachel rock boulders, or alternatively sandstone boulders, will last the longest.

Keywords: breakwater; rock durability; lumachel rocks; quality; Chabahar

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1. Introduction

Stones' durability measures their ability to withstand wear and tear and maintain their initial physical-mechanical properties and aesthetics over time [1,2]. Greater durability in a rock mass means it can be used for longer. Several factors, including mineral make-up, rock fabric, chemical composition texture, porosity, pore structure properties, pore morphology, pore size distribution, water absorption, water absorption coefficient, bulk properties, strength, climate, and environmental conditions, all play a role in the variation in stone's durability [3–7]. Durability stone classification and evaluation have been debated since the early 1990s. CIRIA and CUR are pioneering methods for assessing European armourstone-quality rocks [8]. However, armourstone suitability for coastal structures is assessed in the quarry where the material is mined. As Erickson [9] notes, an experienced geologist must evaluate quality because the selected rocks affect armourstone longevity. Large blocks of magmatic and metamorphic rocks and dense sedimentary rocks with irregular shapes are commonly used for armourstones [10].

Rock properties and the abrasiveness of the stone's environment determine degradation [11]. Understanding the mechanism of stone deterioration involves numerous factors, ranging from environmental conditions to stone properties [11]. Evaluations require an appropriate geological composition, but index properties like water absorption, grading, specific gravity, weight, and visual inspections are also recommended. Thus, assessing a stone's durability requires skilled interpretation of multiple tests and consideration of its intended use and environment [11,12]. It implies that a stone's durability can hardly be determined by a single test or defined by a single value [11]. Rocks' field performance is their behaviour after being used in an engineering project, and they may perform differently in areas with different environmental factors [5]. However, all stones used in engineering projects as construction materials lose their original material properties like unit weight, water absorption, and uniaxial compressive strength over time [13].

Typical laboratory procedures for evaluating the performance of armourstones include hardness, durability, crushing strength, wetting-drying, and geometrical properties [14]. According to Smith [15], durability evaluations typically involve measuring the breakwater's resistance to abrasion and attrition, wetting–drying, thermal cycling, freeze-thaw, and salt crystallisation.

Various studies and research have been conducted in marine protection structure construction, which can be classified into the relationship between identifying the type of rock materials, the engineering properties of rocks [16], and rock age [17] on rock durability. Evaluation of the effect of age on the strength and porosity of sedimentary rocks, such as argillite rocks with Paleozoic to Tertiary ages, showed that increasing the age of epistemology increases the strength of these rocks and decreases their porosity [18]. Also, increasing the samples' age increases the samples' dry density, and consequently, the compressive strength has increased to some extent [19]. Although detailed guidelines exist for characterising and evaluating armourstones, they are not implemented globally. In some parts of the world, design guidelines are not well established or enforced, and stones are selected based on accessibility and aesthetics rather than durability and quality.

The geopolitical and economic importance of the Makran coast has led the Iranian government to develop a wide range of strategic plans for developing and optimal inspection of the coastal structures in the Chabahar region [20]. Several large-size rubble mound breakwaters have been constructed around 25 to 40 m in width and 250 to 800 m in length (Figure 1). Furthermore, the optimal inspection plan was established based on a mixture of qualitative and quantitative maintenance decision-making approaches combined with time-dependent and condition-dependent maintenance. In the proposed maintenance strategy, inspections are event-driven or based on updates to previous observations. However, the breakwaters need to receive more attention, causing them to deteriorate over time, and unsuitable materials have caused significant financial losses.

This study examined breakwater rocks mined for quality and field performance. The goal was to demonstrate the importance of the initial characterisation/classification of rocks before their selection in a project and to evaluate existing classification methods for capturing the observed field performance of stones with complex geological compositions. The breakwater stones were considered years after their construction and use.

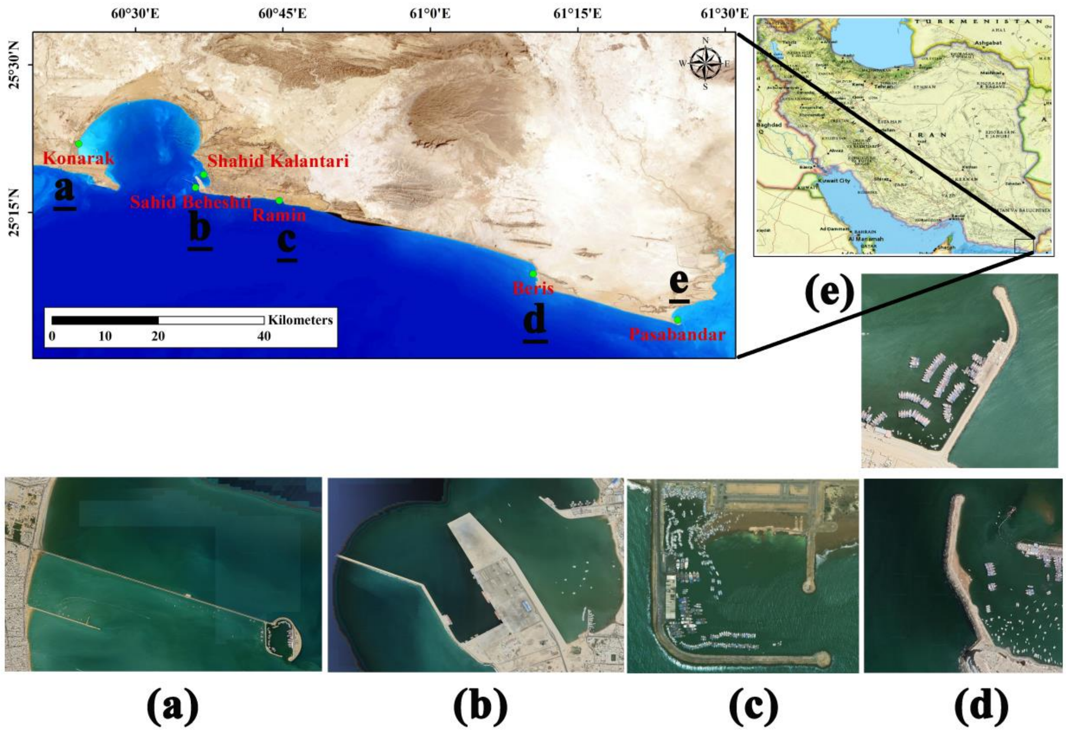

Figure 1. The study area location. A satellite view of all breakwaters in the study area is also presented. The lowercase letters represent the names and locations of the breakwaters, which include: (**a**): Konarak, (**b**): Shahid Beheshti, and Shahid Kalantari, (**c**): Ramin, (**d**): Beris, (**e**): Pasabandar.

2. Materials and Methods

2.1. Study Area and Geological Setting

Chabahar is located in the northern portion of the Gulf of Oman, in the Iranian province of Sistan and Baluchestan (Figure 1). The study area is a free port with many commercial and political investment opportunities, persuaded the government to approve a strategic plan for the southern Makran Coast's sustainable development and, in turn, benefit its Indigenous people while reducing social and environmental damage; consequently, this region was chosen for study. Due to the economic importance of coastal ports and facilities in south Iran, it is necessary to evaluate the engineering properties of rocky construction materials in such structures. Chabahar's climate is hot and humid, with winter temperatures of 7 °C and summer temperatures of 47 °C. Precipitation amounts vary from year to year, typically falling within the range of 150 mm [21]. Two types of Indian Ocean monsoons affect this region: one from the northeast (during the winter) and one from the southwest (during the summer). There is widespread upwelling and high surface productivity along the coasts during the summer monsoon season because of the wet winds.

On the other hand, the sea water's biological productivity is low during the winter due to the dryness of the monsoon winds [22]. Hydrodynamic modelling shows that Chabahar's coast is vulnerable to storm surges [23], and the frequency of severe storms has increased [24]. From 1980 to 2008, Hoarau and Chalonge recorded 21 intense storms [25]. As a result, breakwaters and marine construction were damaged.

Lumachel, a bio-sedimentary rock sandstone abundant and easily extracted in the coastal strip's Miocene to Pliocene formations, is used in constructing Chabahar coastal structures. Although these quarries were not far apart geographically, the stones produced by each quarry were distinct due to the study area's geology complexity. The study area is geologically located within Makran Trench in the Oman Sea basin in the northern Indian Ocean. The Makran Trench forms in the subduction zone of the Arabian and Eurasian plates at the base of the Pakistani continental margin, in the zone of northward subduction of the high-velocity Arabian Plate to the continental crust of the slow-moving Eurasian Plate [26–28], which makes numerous active faults, seismotectonic events, and morphotectonic features, common on the Iranian plate [29–31]. Makran, one of the most active zones, is located south of the Jazmourian depression. Its western boundary is the Minab fault [32]; to the south, it is restricted by the Oman Sea, and to the east, it extends into Pakistan. The dominance of east-west trending faults characterises the northern part, the Bashagard fault being the most important one [33]. Along these faults lies a large section of the ophiolite series. The oldest rocks in this zone are the ophiolites of the late Cretaceous-Paleocene overlaid by a thick sequence (about 5000 m) of sandstone, shale, and marl. The whole sequence is deformed before the Early Miocene [34]. A thick sequence of Neogene rock units above 5000 m covers the older series [34,35]. According to recent studies [36,37], the Chabahar coast, as a part of coastal Makran, was divided into two central units, which are extremely common and consist of light grey medium-thick bedded marls or thin-medium bedded calcareous sandstones, partly with polymictic conglomerate and rarely with gypsum. The Dar Pahn and Jaghin unit's lower stratigraphic boundary is faulted, and the upper limit with the marine terrace deposits is not observed or unconformable with the Nahang unit. Recent studies introduced Pliocene-Pleistocene shallow water sediments (Chabahar unit) for the Pliocene-Pleistocene deposits cropped out in minor occurrences along the coast. This unit was previously identified as marine terraces composed of light grey sandstones and conglomerates with silty marls. Previous geologists proposed Pliocene-Pleistocene continental deposition (Nahang unit) for fluvial conglomerates cropped out on the 1:250,000 scale Pishin and Nikshah geological maps (Figure 2).

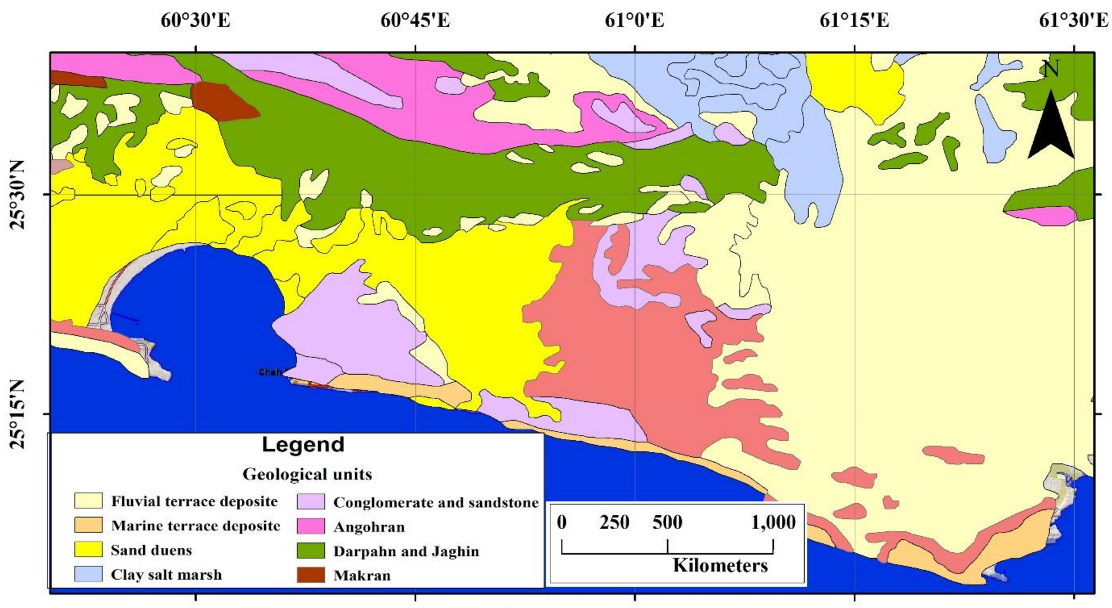

Figure 2. The surface geology of the study area.

2.2. The Erosion Evaluation

Impacts, abrasion, and physicochemical weathering can cause the armourstone to change shape and size quickly, which can be disastrous for the stability of the armourstone [38]. Resistance to abrasion in service is especially important for sites where suspended sand from wave action can attack the armourstone. On the other hand, abrasion is the most crucial factor in determining the service life of an armourstone, which is related to the durability of a stone in seawater [39]. A suitable armourstone with the proper physical characteristics and resistance to erosion is necessary for harsh marine conditions (such as wave loads, chemical weathering, physical erosion, etc.) [40]. Here, regarding the field observation, commonly observed erosion processes include chemical dissolution, roundness, exfoliation, lamination, and fracture (Figure 3).

(**a**)

(**b**)

(**c**)

(**d**)

Figure 3. Erosion patterns varied across the studied breakwaters' armourstones. The corresponding lowercase letters represent the erosion types observed; (**a**): chemical dissolution,(**b**): lamination, (**c**): fracture, and (**d**): exfoliation.

Chemical dissolution is the process whereby chemical reactions dissolve rocks. The deterioration of rocks is due to atmospheric water, humidity, and air pollution on water-soluble salt sand [40,41]. Roundness is a process where sedimentary particles have been smoothed by abrasion [42]. Exfoliation is a type of mechanical weathering in which curved plates of rock are peeled away from the rock beneath [43]. In sedimentary rocks, lamination is a small-scale sequence of fine layers (laminae; singular: lamina). A fracture is any separation in a geologic formation that divides the rock into two or more pieces, such as a joint or a fault [44].

2.3. Sample Design and Data Collection

Classifying stones according to their durability is essential for assessing their suitability and predicting their behaviour in service life when used as construction materials in coastal structures. In the literature, investigations were conducted while visiting them to determine the quality of the armourstones used in constructing the Chabahar breakwaters; 25 samples of their rocky materials were collected for laboratory evaluations. Following the procedures outlined by Priest [45], a scanline survey was carried out alongside the production bench to detect and document the existence and characteristics of the discontinuities. Based on field observations and laboratory tests, the stones were classified following CIRIA/CUR [8] and Rock Engineering Rating System(RERS) [46]. The results of numerous researchers utilising these guidelines, consisting of different evaluation methods for all factors affecting the intrinsic properties of armourstone [11,20,47], persuaded us to use them as well. Detailed laboratory evaluations, including physical properties, mechanical properties, and durability testing, were performed to investigate the following tests: porosity (%), specific weight (N/m^3), dry density (g/cm^3), saturation density (g/cm^3), slake durability index, water absorption (%), Los Angeles abrasion (%), impact value (%), and sulfate health (%), which are all used by many researchers so far [48–53]. All laboratory tests were conducted at the Chabahar Maritime University within the facilities located as part of the engineering geology and mining engineering departments.

Accelerated weathering tests, such as freezing-and-thawing, wetting-and-drying, and salt crystallisation tests, particularly in humid conditions, predict rock field performance by evaluating stone durability and long-term field performance [54]. Wetting-and-drying tests benefit limestone and other rocks with a relatively high water expansion coefficient. In addition, crystallisation pressure, dependent on porosity and degree of supersaturation, is the principal decay mechanism during a salt attack and is used to simulate harsh environmental conditions [55]. In addition to the results of accelerated weathering tests, classifications of stone durability, such as a saturation coefficient and durability index, are essential for determining their suitability and estimating their service life in engineering projects [56].

2.4. Statistical Analysis and Correlation Analysis

The results of one set of tests can be used to predict or estimate the outcomes of another set of tests since there is always a relationship between physical properties, resistance, and durability. Specifically, regression equations and their respective determination Pearson correlation coefficient (r) are calculated with the aid of IBM SPSS Statistics. Also, we used SPSS to conduct mean values for all samples collected per station. Pearson correlation coefficient (r) can be calculated according to the formula (Equation (1)).

$$r = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}} \quad (1)$$

where r is the correlation coefficient of the two variables (x and y), and its value ranges from 1 to 1. The variables' averages are x and y. A result of r < 0 denotes a negative correlation between x and y, while $r > 0$ denotes a positive correlation between x and y. When $r = 0$, however, it indicates no linear correlation between the variables. A greater absolute value of the correlation coefficient indicates a higher degree of association between the variables under investigation.

Also presented are the maximum and minimum acceptable tolerances for rock sample characteristics. If any of the characteristics of a rock sample falls below the specified tolerance, the sample is deemed unsuitable and should not be used. Table 1 displays the acceptable tolerance levels for each parameter of sandstone and limestone.

Table 1. Rock Manual test values and guidelines for using sandstone and limestone as armourstone.

Test	Rock Manual Guideline Values				Source
	Excellent	Good	Marginal	Poor	
Porosity	<2	2–6	6–20	>20	[57]
Specific weight	>2.55	2.2–2.55	2.2–1.8	<1.8	[58]
Wet–dry (% loss)	<0.5	0.5–1	1.0–2	>2	[59]
Slake durability index	>80	65–80	35–65	<35	[60]
Water absorption	<0.5	0.5–2.0	2.0–6.0	>6.0	[61]
Los Angeles abrasion	<15	15–25	25–35	>35	[62]
Impact value	>60	50–60	40–50	<40	[63]
Sulfate health	<2	2–12	12–30	>30	[8]
Point load	>8	4–8	1.5–4	>1.5	[64]
Brazilians	>10	5–10	2–5	<2	[65,66]
uniaxial	>150	100–150	50–100	<50	[67]

3. Result and Discussion

The durability of materials used in constructing engineering structures in corrosive environments is a crucial aspect of the structure's service life. Due to the climatic and regional conditions of the country's coastlines, the stone is one of the primary materials used in the construction of breakwaters, which should be of high quality and have a long lifespan. The evaluations included field observation and laboratory testing, including physical, mechanical, and durability assessments. The outcomes of these analyses are as follows:

3.1. Field Observation

The construction of ports and breakwaters in the Chabahar region primarily uses lumachel extracted from local mines. Based on the investigated geological maps, the sequence of formations, and the researchers' earlier work, the age of the collected stone was computed in millions of years, as shown in Table 2. These objects are modern since they are Cenozoic. Most of these materials (95%) contain carbonate compounds and comprise limestone and biodegradable stones (Lumachel), except the Shahid Kalantari breakwater, where sandstone is the predominant material. Due to their low density, high percentage of wear, and low resistance after saturation by seawater, the Lumachelic stone components utilised in most breakwaters are easily rounded. They have vast and numerous voids between the components, particularly in the tidal zone. It decreases the quantity of locking and fastening of stone components. Parts of the sandstone used in the Shahid Kalantari breakwater are not durable because, on the one hand, they contain numerous calcite vessels that dissolve, which causes the entire rock mass to be crushed, and, on the other hand, they undergo rounding, scaling, and excessive erosion when in contact with water. According to the field observations obtained from the rock samples of the region, combining them with the results of quality measurement experiments of the samples and a comparison with the stone selection criteria, the performance of each rock in the region was determined as follows:

- **Marl limestone:**

Table 2. The geological age of materials used in the construction of breakwaters.

Breakwaters	Lithology	Geological time	Age
Pasabandar	lumachel	Miocene	6
Beris	lumachel	Miocene	9
Ramin	lumachel	Pleistocene	2
Sahid Beheshti	lumachel	Pliocene	4
Shahid Kalantari	sandstone	Miocene	12
Konarak	lumachel	Miocene	15

The water absorption, porosity, and specific gravity range from weak to very weak, and the rock is in good health. In addition to physical characteristics, field observations indicate that the performance of these rocks is more influenced by the particles that make up the rock. Weathering and onion skin (scaling) erosion contribute to these rocks' erosion, but the fracture zone's breakdown is much more pronounced than in the crown zone. Here, similar to other rocks, the erosion rate of these rocks rises as their porosity and water absorption rise. Fossil particles increase rock resistance and change scaling erosion to pitting erosion. Pitting erosion is much preferable to scaling erosion. Furthermore, poor performance in the tidal and flood zones causes these rocks to be severely eroded and highly rounded in the tidal zone, as well as drastically reduced resistance, allowing marine organisms to penetrate the rock easily.

- **Calcareous conglomerate**

The rock's specific gravity is low, its water absorption and porosity are average, and its health is excellent. Although the physical properties of this rock are nearly ideal, field observations indicate that the performance of these rocks is also dependent on the particle size of the rock's constituent particles. The fine-grained conglomerate has superior physical properties to a coarse-grained conglomerate, as well as greater grain particle adhesion to the main body of the rock, allowing it to perform better in fracture and tidal zones and not even round in the tidal zone. Nonetheless, this difference is diminished due to the accumulation of algae on the rock in the tidal and submerged zone, and both rocks exhibit excellent performance.

3.2. Physical and Mechanical Properties

One of the most important methods for evaluating the durability of materials is the impact value test and sulfate health test. Rock materials in marine environments, especially on shores, are highly exposed to shocks caused by waves and chemical compounds, salts, and salts in the water composition. The relationship between water absorption and the porosity parameter is direct and considerable, suggesting the utility of porosity in rocks. The rock's porosity is a weakness factor and decreases the rock's engineering qualities. As porosity and water absorption rise, mechanical parameters such as uniaxial compressive strength and Brazilian tensile strength decrease, and the percentage of drop resulting from the test increase the impact value.

Table 3 presents the average laboratory results for the physical and mechanical properties of each station's collected stones. According to the test results, the porosity of the stones ranges between 5.2% and 42.7%, placing them in the category of poor quality, except the Shahid Kalantari breakwater, which is of good quality. The specific weight result reveals that all stones are categorised as excellent and good. The all wet–dry (% loss) is less than 0.5, indicating all stones have an excellent classification. The slake durability index results suggest that all stones belong to the excellent group. However, the water absorption results indicate that all stones belong to the poor group, except Shahid Kalantari's samples, which are of marginal quality. Shahid Kalantari's samples are good quality, whilst others are in poor, marginal condition, according to the Los Angeles abrasion test results. The impact values also indicate that the samples from Sahid Beheshti and Konarak are of high quality, whereas those from Pasabandar and Ramin are of poor quality. The quality of the Beris and Shahid Kalantari samples is rated as poor.

Table 3. Physical and mechanical properties of the stones tested in this study. The code description is as follows: P: Porosity(%), S_W: Specific Weight, W_D: Wet–dry (% Loss), D_I: Durability Index (%), W_A: Water Absorption (%), L_{AA}: Los Angeles Abrasion (%), I_V: Impact Value(%), S_H: Sulfate Health (%).

Breakwaters	P	S_W	W_D	D_I	W_A	L_{AA}	I_V	S_H
Pasabandar	30.43	2.62	0.34	94.50	17.60	-	47.50	28.50
Beris	26.20	2.3	0.26	91.55	14.80	41.35	38.70	14.26
Ramin	32.20	2.71	0.32	94.70	17.60	-	46.60	4.18
Sahid Beheshti	31.10	2.65	0.3	91.85	17	88	51.30	-
Shahid Kalantari	5.22	2.54	0.06	99.04	2.18	23.26	15.60	8.60
Konarak	42.70	2.74	0.44	93.52	29.60	28.83	54.30	19.60

Comparing Tables 2 and 3 reveals that as the age of carbonate rocks has increased, all engineering metrics have improved due to the sedimentary environment. Samples of younger rocks have been formed mainly in the intertidal zone, and older ones have settled in deeper environments such as the neritic and oceanic zones. A positive correlation exists between the geologic age of rock materials and their wet and dry density. Due to a decline in cavity formation with time, the water absorption capacity of stone materials declines with age. The porosity parameter meets this requirement as well. The age of rock materials older than 20 million years causes a dramatic reduction in the volume of pores, and this reduction is exponential in nature. It shows that the rock density increases due to the potential of petrification to diminish rock pores or the formation of overburden.

However, although there is a general trend toward enhanced engineering capabilities with age, this is only sometimes the case, and limestone has superior technical characteristics to lumachel rocks. Additionally, despite their young age, terrigenous rock samples like sandstone show adequate physical and mechanical characteristics similar to older carbonate rocks. This highlights the significance of lithology, as it is attributable to differences in the rock's mineral composition. For instance, the sandstone samples from Shahid Kalantari port, which date back to the Miocene, have very few pores due to the effect of rock mineralogy and have a distinctive sandstone texture. In contrast to porosity and density, the impact value and sulfate health test have an inverse correlation with age and increase the rate of destruction. However, the age impact is more significant on carbonate rocks.

One should consider that Hafezi Moghaddas et al. [68] evaluated the engineering properties of rock used in such structures at local mines. Comparing Table 5 and Table 6 from their work outcome with Table 3 from our work outcome reveals that our physical and mechanical properties did not change significantly over time.

3.3. The Correlation Analysis Result

The Pearson correlation coefficient (r) result is presented in Table 4. Here, relationships with extreme significance (>0.7) and strong significance (>0.5) levels are shown in italic bold formatted and bold formatted, respectively. Strong relationships have higher correlation coefficients.

Table 4. The Pearson correlation coefficient (r) between physical, mechanical, and durability parameters. The code description is as follows: D_D: Dry Density, S_D: Saturation Density, D_I: Durability Index, W_A: Water Absorption, P: Porosity, P_L: Point Load, B: Brazilians, U: Uniaxial, I_V: Impact Value, D: Durability, S_H: Sulfate Health, L_{AA}: Los Angeles Abrasion.

	D_D	S_D	D_I	W_A	P	P_L	B	U	I_V	D	S_H	L_{AA}
D_D	1											
S_D	***0.85***	1										
D_I	***0.82***	0.009	1									
W_A	***−0.803***	***−0.753***	0424	1								
P	***0804***	**−0.540**	0.388	***0.995***	1							
P_L	**0.699**	**0.688**	0.105	−0.484	0.495	1						
B	***0.826***	***0.767***	0.164	***−0.713***	***−0.77***	0.488	1					
U	***0.745***	**0.658**	0.119	***−0.756***	***−0.785***	**0.65**	***0.897***	1				
I_V	***−0.845***	***−0.759***	0.249	***0.88***	***0.87***	**−0.623**	***−0.818***	***−0.74***	1			
D	**0.573**	***0.500***	0.192	−0.296	−0.426	0.215	0.485	0.307	**−0.55**	1		
S_H	−0.385	−0.345	0.287	0.445	0.480	−0.156	−0.43	−0.493	**0.54**	0.218	1	
L_{AA}	***−0.748***	−0442	0.026	**0.689**	**0.655**	−0.28	**−0.51**	−0.499	**0.516**	**−0.515**	−0.335	1

The mechanical parameters are predominantly correlated in such a way that as the integrity and compressive strength of the stone increase, so does its tensile strength. Consequently, this increase in resistance reduces the erosion and loss of stone caused by physical and chemical interactions. There is a direct relationship between dry density and saturated density, point load strength, Brazilian tensile strength, and uniaxial compressive strength, and an inverse relationship between dry density and water absorption, porosity, and the impact value test. The relationship between water absorption and the porosity parameter is direct and significant, indicating the utility of porosity in rocks. Porosity is a weakening factor in stone and decreases the stone's engineering properties. With increased porosity and water absorption, mechanical parameters such as uniaxial compressive strength and Brazilian tensile strength decrease, whereas the weight loss percentage increases.

The smallest regression relationship between the data is associated with the specific weight, durability of deposition, and sulphate health. Numerous pores and the looseness of the Lumachelic rocks, which comprised most of the samples, are primarily responsible for the disparate results of the durability tests and sulphate health. Also, the relationship between specific weight and other mechanical properties displays the greatest degree of dispersion among the physical properties. The primary reason may be that the samples' specific weights are comparable, so their variations do not significantly affect the results of other characteristics. Among the results that can be inferred, we can mention the inverse relationship between the age of stone materials and the weight loss percentage resulting from the impact value test. Like other results, the amount of loss of sandstone materials according to their age has a significant difference compared to other materials.

4. Conclusions

This study examined the quality of four distinct types of armourstones extracted from three distinct quarries. These stones were used to construct breakwaters in the region of Chabahar. Stones from these quarries have been analysed in-depth, characterised through extensive laboratory testing, and ranked according to several criteria. The study's findings were compared to field observations after the stones were used. This study found that the CIRIA/CUR [8] and RERS [46] classification methods are good predictors of field performance in most cases but not always. This research also demonstrated the significance of thorough stone evaluations before selecting stones for use as armourstones. The study also suggested that standard (traditional) classification methods may not always be adequate for capturing the complexities associated with geological origins. For example, this study concluded that breakwaters, which are morphologically less qualified for breakwater construction according to international coastal engineering standards, rely heavily on marine organisms attached to the rock mass for stability. So, it is best to use as many different methods as possible when classifying. Furthermore, the results of this research showed that even though rock mass breakwaters are less qualified for breakwater construction according to international coastal engineering standards, the marine organisms that attach themselves to the rock play a crucial role in the stability of these structures. Thus, the research also indicates that lumachel rock boulders, followed by sandstone boulders, are the best option for constructing long-lasting jetties.

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