# Comparison between site performance and index properties of the armourstones used in two harbours

BURCU ERTAS[1] & TAMER TOPAL[2]

[1] *Department of Geological Engineering, METU. (e-mail: borcey@yahoo.com)*
[2] *Department of Geological Engineering, METU. (e-mail: topal@metu.edu.tr)*

**Abstract:** Breakwaters are constructed in coastal areas to protect coastal engineering structures from wave action. For economic reasons, natural stone (armourstone) is frequently used for the construction of the breakwaters. The function of the stone in different zones of breakwater, various sizes and variable properties of the armourstones used in breakwaters are influential. Deterioration of armourstone with time, through abrasion and disintegration may cause damage to the costal engineering structures. It is therefore necessary to investigate the long term performance and quality of armourstones. In this study, index properties of three limestones used as armourstone in two harbours are compared with their site performances. Although two of the stones show good performance, one of them easily disintegrates.

**Résumé:** Les brise-lames sont construits dans les secteurs côtiers pour protéger les structures d'ingénierie côtières des actions de vague. Pour les raisons économiques, des pierres naturelles (armourstones) sont fréquemment utilisé pour la construction des brise-lames. Considérer la fonction des pierres aux zones différentes des brise-lames, les diverses tailles avec les propriétés variables du armourstones sont utilisées dans les brise-lames. La détérioration d'armourstones avec le temps, sous forme d'abrasion et la désintégration peut causer des dommages aux structures d'ingénierie côtières. C'est donc nécessaire d'examiner l'exécution à long terme et la qualité du armourstones. Dans cette étude, ces propriétés d'index de trois calcaire utilisés comme armourstones dans deux ports sont comparés à leurs exécutions de site. Bien que deux des pierres montrent de bonnes exécutions, un d'eux se désintègre facilement.

**Keywords:** durability, geomaterials, index tests, limestone, quarries

## INTRODUCTION

Rubble mound breakwaters are constructed in coastal areas to protect coastal engineering structures from wave action. It is common practice to use natural stone (armourstone) of different sizes, shapes and properties for the construction of breakwaters (Mather 1985; Latham 1991; Poole 1991; Erickson 1993; Smith 1999). In severe marine conditions, armourstone may deteriorate through abrasion and disintegration with time, resulting in damage to the costal engineering structures (Fookes & Poole 1981; Lienhart & Stransky 1981; Clark & Palmer 1991; Lienhart 1994; Latham 1998; Topal & Acir, 2004). It is therefore necessary to investigate the long term performance and quality of armourstones.

Armourstone used in Mersin harbour was taken from a quarry in Degirmencayi with an elevation of 486 m above mean sea level. It is located 15 km north of Mersin city center. However, for the construction of Kumkuyu harbour, armourstone from a quarry having an elevation of 54 above mean sea level near Tirtar village (55km northwest of Mersin and 20 km northeast of Silifke) was used (Figure 1). A typical Mediterranean climate is dominant in southern Turkey where both quarries are located. Summers are hot and dry, whereas winters are mild and rainy with very high relative humidity.

The three armourstones used in two harbours as part of rubble mound breakwaters in and near Mersin province (southern part of Turkey) show different durability. In this study, index properties of these limestones used in two harbours are compared with their known site performance. The index properties of the limestones and their field performances were also evaluated on the basis of CIRIA/CUR (1991) quality classification.

## GEOLOGICAL SETTING

Limestone is exposed in both quarries (Figure 2). In Degirmencayi quarry, the rock is beige, thick bedded to massive, slightly weathered, micritic fossiliferous limestone (Figure 3). Under the microscope, locally clayey lenses or veins exist within the rock. Fossil fragments and intraclasts are embedded within calcareous matrix. The limestone also contains solution cavities near the surface. It corresponds to Karaisali formation (Schmidt 1961; Ilker 1975; Yalçın & Görür 1984; Yeti  & Demirkol 1986). Based on the fossil content, the age of the limestone is Lower – Middle Miocene (Senol, Sahin, & Duman 1998).

 


**Figure 1**. Location map of the study area

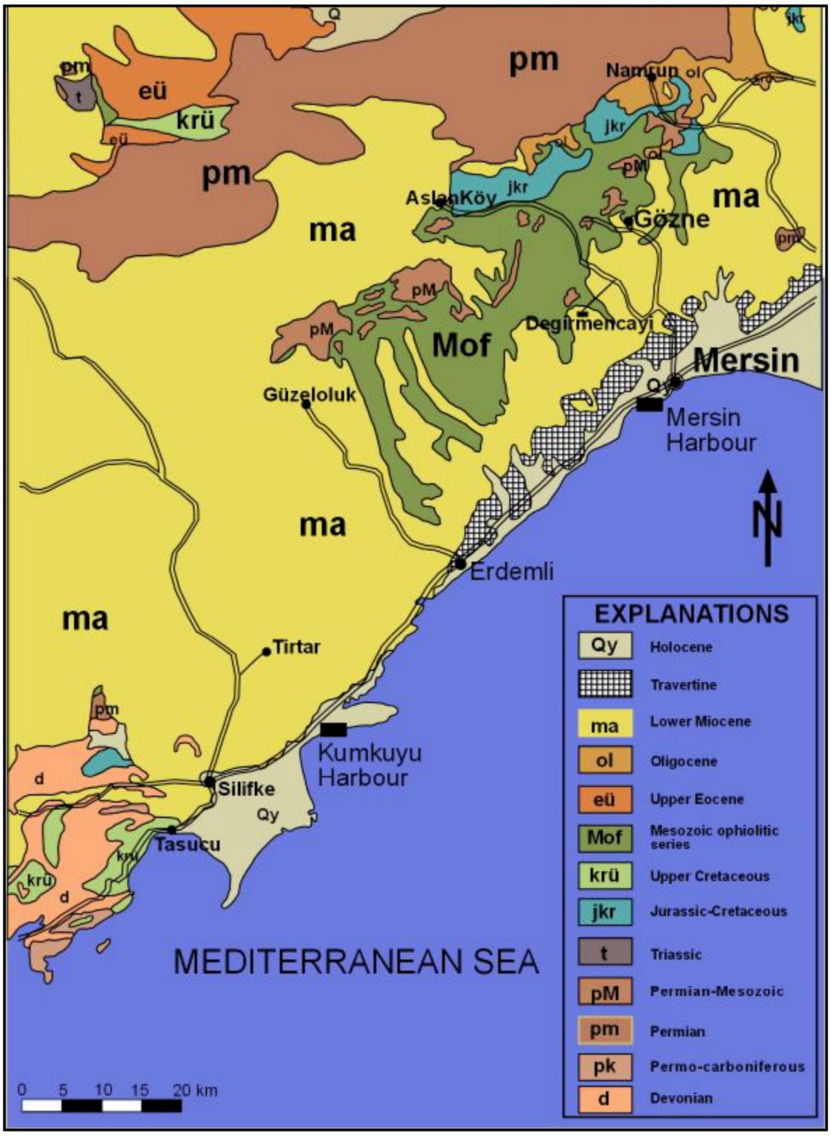


**Figure 2**. Geological map of the site vicinity

**Figure 3**. Photograph of the armourstone quarry in Degirmencayi area

In Tirtar quarry, there are two limestone levels (Figure 4). The upper level of the quarry includes light brown, fine grained, thick bedded, slightly weathered, microsparitic-sparitic fossiliferous limestone containing oolite, pisolite and other fossil fragments. These fragments are embedded in sparitic calcareous matrix. The limestone contains local solution cavities for the upper 1-2m of the quarry. No dissolution effects can be observed below this level. The total thickness of the upper limestone level ranges between 4-6 m. Although the lower level of the quarry also consists of limestone, it is weaker than that in the upper level. It is light brown to beige, fine grained, slightly weathered, biomicritic limestone with some fossil fragments. Oolite and pisolite content decreases at lower levels in the quarry. This unit locally contain clayey matrix. Bilgin, Oguz, Elibol, Güner, & Gedik (1994) indicated that the limestone is part of the Adras Formation and the age of the rock exposed in the quarry is Middle Miocene on the basis of contained fossils.

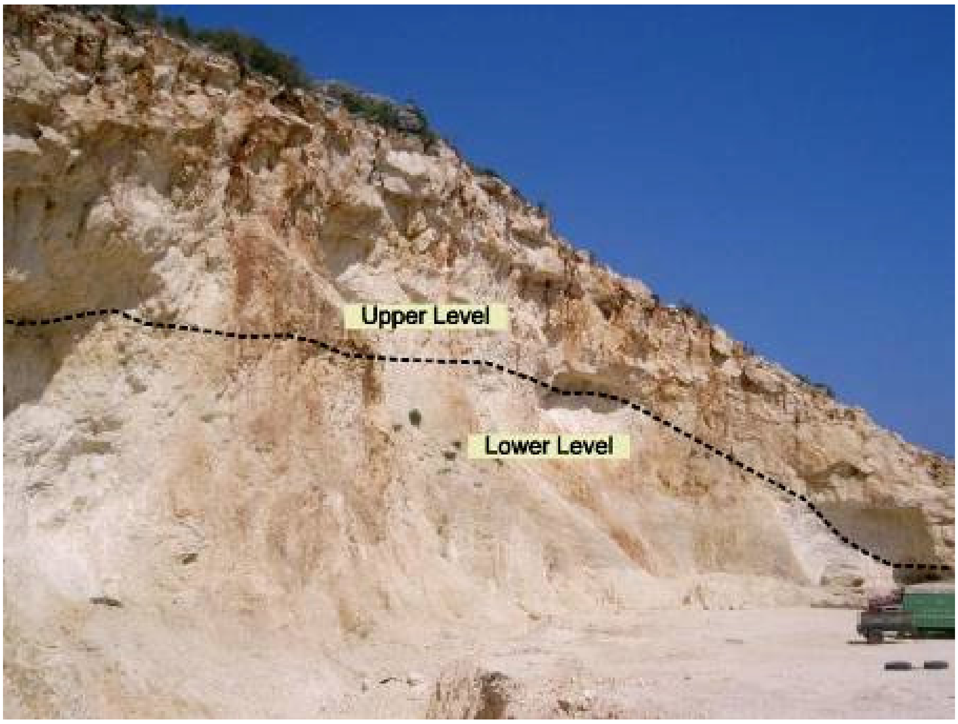


**Figure 4**. Photograph of the armourstone quarry in Tirtar area

# INDEX PROPERTIES OF THE ARMOURSTONES

The three limestones observed in the two quarries were used for the construction of the breakwaters. Forty block samples are also taken from the quarries. The index properties of the rocks were determined through laboratory tests. These included the determination of dry and saturated unit weights, effective porosity, water absorption, saturation coefficient, methylene blue adsorption, wet-dry resistance, freeze-thaw resistance, magnesium sulphate soundness, micro-deval abrasion, point load strength index, fracture toughness, and dry and saturated uniaxial compressive strengths. The test results for the three limestones are given in Tables 1-3.

**Table 1.** Index properties of the Degirmencayi limestone

| Properties | Standard used for testing | Number of tests | Test result Mean±SD* |
|---|---|---|---|
| Dry unit weight (kN/m$^3$) | ISRM (1981) | 180 | 23.71 ± 2.00 |
| Saturated unit weight (kN/m$^3$) | ISRM (1981) | 180 | 24.65 ± 1.80 |
| Effective porosity (%) | ISRM (1981) | 180 | 9.62 ± 5.82 |
| Water absorption by weight (%) | TS 699 (1987) | 180 | 3.31 ± 2.40 |
| Saturation coefficient | TS 699 (1987) | 180 | 0.81 ± 0.39 |
| Methylene blue adsorption value, MBA (g/100g) | AFNOR (1980) | 2 | 0.30 ± 0.05 |
| Wet – dry loss (%) | ASTM (1992) | 6 | 0.57 ± 0.16 |
| Freeze – thaw loss (%) | CIRIA/CUR (1991) | 6 | 1.25 ± 0.66 |
| Magnesium sulphate soundness value (%) | ASTM (1990) | 6 | 3.85 ± 1.24 |
| Micro-deval index, $M_{DE}$ (%) | TS EN (2002) | 2 | 18.10 ± 2.03 |
| Point load strength index, $I_{s(50)}$ (MPa) | ISRM (1985) | 8 | 4.39 ± 0.71 |
| Fracture toughness† (MPa.m$^{1/2}$) | Bearman (1999) | 8 | 0.92 ± 0.15 |
| Dry uniaxial compressive strength (MPa) | ISRM (1981) | 10 | 35.10 ± 1.99 |
| Saturated uniaxial compressive strength (MPa) | ISRM (1981) | 10 | 26.90 ± 3.51 |

*SD-standard deviation
†Assessed from $I_{s(50)}$ using correlation factor

**Table 2.** Index properties of the Tirtar limestone (upper level)

| Properties | Standard used for testing | Number of tests | Test result Mean±SD* |
|---|---|---|---|
| Dry unit weight (kN/m$^3$) | ISRM (1981) | 155 | 25.57 ± 1.31 |
| Saturated unit weight (kN/m$^3$) | ISRM (1981) | 155 | 25.92 ± 1.22 |
| Effective porosity (%) | ISRM (1981) | 155 | 4.41 ± 2.79 |
| Water absorption by weight (%) | TS 699 (1987) | 155 | 1.38 ± 0.93 |
| Saturation coefficient | TS 699 (1987) | 155 | 0.73 ± 0.14 |
| Methylene blue adsorption value, MBA (g/100g) | AFNOR (1980) | 2 | 0.30 ±0.05 |
| Wet – dry loss (%) | ASTM (1992) | 6 | 1.48 ± 0.58 |
| Freeze – thaw loss (%) | CIRIA/CUR (1991) | 6 | 1.95± 0.25 |
| Magnesium sulphate soundness value (%) | ASTM (1990) | 6 | 8.59 ± 1.18 |
| Micro-deval index, $M_{DE}$ (%) | TS EN (2002) | 2 | 19.20 ± 0.21 |
| Point load strength index, $I_{s(50)}$ (MPa) (Dry-Sat) | ISRM (1985) | 8 | 4.08 ± 1.09 |
| Fracture toughness† (MPa.m$^{1/2}$) | Bearman (1999) | 8 | 0.84 ± 0.22 |
| Dry uniaxial compressive strength (MPa) | ISRM (1981) | 10 | 32.80 ± 2.94 |
| Saturated uniaxial compressive strength (MPa) | ISRM (1981) | 10 | 25.25 ± 3.79 |

*SD-standard deviation
†Assessed from $I_{s(50)}$ using correlation factor

**Table 3.** Index properties of the Tirtar limestone (lower level)

| Properties | Standard Used for Testing | Number of Tests | Test result Mean±SD* |
|---|---|---|---|
| Dry unit weight ($kN/m^3$) | ISRM (1981) | 110 | 22.31 ± 1.67 |
| Saturated unit weight ($kN/m^3$) | ISRM (1981) | 110 | 23.53 ± 1.40 |
| Effective porosity (%) | ISRM (1981) | 110 | 16.39 ± 7.21 |
| Water absorption by weight (%) | TS 699 (1987) | 110 | 5.58 ± 2.75 |
| Saturation coefficient | TS 699 (1987) | 110 | 0.95 ± 1.18 |
| Methylene blue adsorption value, MBA (g/100g) | AFNOR (1980) | 2 | 0.71 ± 0.05 |
| Wet – dry loss (%) | ASTM (1992) | 6 | 5.14 ± 0.90 |
| Freeze – thaw loss (%) | CIRIA/CUR (1991) | 6 | 11.51 ± 1.25 |
| Magnesium sulphate soundness value (%) | ASTM (1990) | 6 | 27.35 ± 3.96 |
| Micro-deval index, $M_{DE}$ (%) | TS EN (2002) | 2 | 54.40 ± 3.83 |
| Point load strength index, $I_{s(50)}$ (MPa) | ISRM (1985) | 8 | 3.11 ± 1.16 |
| Fracture toughness† ($MPa.m^{1/2}$) | Bearman (1999) | 8 | 0.65 ± 0.24 |
| Dry uniaxial compressive strength (MPa) | ISRM (1981) | 10 | 14.70 ± 2.97 |
| Saturated uniaxial compressive strength (MPa) | ISRM (1981) | 10 | 9.20 ± 1.39 |

*SD-standard deviation

†Assessed from $I_{s(50)}$ using correlation factor

# QUALITY EVALUATION OF THE ARMOURSTONES

Performance of armourstone in a breakwater is directly related to its long-term structural durability when used in coastal protection (Clark 1988). This long-term durability can be assessed through field observations and experimental laboratory data (CIRIA/CUR 1991; Smith 1999). In this study, quality evaluation of the armourstones is done on the basis of CIRIA/CUR (1991) criteria, saturation coefficient of Schaffer (1972), and wet-to-dry strength ratio of Winkler (1986). The results obtained are compared with the field performances of the three armourstones.

Degirmencayi limestone was used for the construction of the Mersin harbour. Both upper and lower levels of the Tirtar limestone were used for the Kumkuyu breakwater. Among these, both Degirmencayi and Tirtar upper level limestones showed good performance. However, the Tirtar lower level limestone became almost completely disintegrated in the Kumkuyu breakwater.

CIRIA/CUR (1991) classification is based on the laboratory and field tests of the armourstone. This system represents the outlines of the marginal values of rocks for different tests. In this study, the index properties of the armourstones are studied because the stone blocks are generally massive. Therefore, the comparison is only based on the laboratory test results. The strength-related parameters used for the classification belong to saturated conditions. An example of the CIRIA/CUR (1991) classification for the Degirmencayi limestone is given in Table 4. The CIRIA/CUR (1991) classification for the three limestones belonging to two quarries indicates that both the Degirmencayi and Tirtar upper level limestones are marginal to excellent in quality, whereas the Tirtar lower level limestone is poor to marginal. These findings are in good agreement with the field performance of the armourstones.

**Table 4.** CIRIA/CUR (1991) classification for Degirmencayi limestone

| TEST PROPERTIES | CIRIA/CUR (1991) CRITERIA | | | | Degirmencayi limestone |
|---|---|---|---|---|---|
| | Excellent | Good | Marginal | Poor | |
| Dry rock density ($t/m^3$) | ≥2.9 | 2.6-2.9 | 2.3-2.6 | ≥2.3 | 2.42 |
| Water absorption-by weight (%) | ≤0.5 | 0.5-2.0 | 2.0-6.0 | ≥6.0 | 3.31 |
| Magnesium sulphate soundness (%) | ≤2 | 2-12 | 12-30 | ≥30 | 3.85 |
| Freeze-Thaw (%) | ≤0.1 | 0.1-0.5 | 0.5-2.0 | ≥2.0 | 1.25 |
| Methylene blue adsorption (g/100g) | ≤0.4 | 0.4-0.7 | 0.7-1.0 | ≥1.0 | 0.30 |
| Fracture toughness ($MPa.m^{1/2}$) | ≥2.2 | 1.4-2.2 | 0.8-1.4 | ≤0.8 | 0.92 |
| Point load strength index (MPa) | ≥8.0 | 4.0-8.0 | 1.5-4.0 | ≤1.5 | 4.39 |
| Mill abrasion resistance index*, $k_s$ (%) | ≤0.002 | 0.002-0.004 | 0.004-0.015 | ≥0.015 | 0.003 |

*Assessed from micro-deval index using a correlation factor of Latham (1998)

The saturation coefficient is another parameter used to assess the durability of stone (Schaffer 1972). A value greater than 0.90, indicates "poor" durability in terms of freeze-thaw activity. Although the temperature in the study area is well above 0°C, this property can also be used in relation to salt crystallization where pressures expected within the pores of the stone are very similar to frost activity. The saturation coefficients of the Degirmencayi, Tirtar upper and lower limestones are 0.81, 0.73, and 0.95, respectively (see Tables 1-3). Therefore, the Degirmencayi and Tirtar upper limestones may be considered to be "durable", but the Tirtar lower limestone is "not durable".

Based on the durability classification of Winkler (1986), the wet-to-dry uniaxial compressive strength ratio of the Degirmencayi and the Tirtar upper limestones are 0.75 and 0.77, respectively. Thus, these may be considered to have "very good to good" durability. However, the corresponding ratio for the Tirtar lower limestone is 0.63, which corresponds to "fair (unsafe)" rock quality. A significant large reduction in the strength due to saturation is observed for the Tirtar lower limestone. This is attributed to the existence of the clayey matrix within the limestone.

As a general evaluation, the laboratory test results, the quality evaluations using CIRIA/CUR (1991), saturation coeffecient and wet-to-dry strength ratio are are in good agreement with the field performance of the armourstones. No significant further deterioration is expected for the Degirmencayi and Tirtar upper level limestones in the harbours. However, Tirtar lower level armourstone with poor field and laboratory performances should not be used for the protection of any marine structures. This study demonstrates how systematic testing and quality evaluation procedures are very useful in predicting the long term performances of the armourstones.

## CONCLUSIONS

Three limestones were used as armourstone in Mersin and Kumkuyu harbours. While the Degirmencayi and Tirtar upper level limestones show good performance, Tirtar lower level limestone presents rather poor performance. Some index tests performed in this study were used to assess the quality of the armourstones, and to compare field and laboratory performances of the rocks. Based on the test results, the Degirmencayi and Tirtar upper level limestones were shown to have marginal to very good durability but the Tirtar lower limestone had poor to marginal durability. In general, the index test results and the quality evaluation of the stones through CIRIA/CUR (1991) classification, saturation coefficient and wet-to-dry strength ratio were found to be in good agreement with the field performance of the armourstones. Therefore, systematic testing and quality evaluation of the stones should be performed for the selection of the armourstones.

**Acknowledgements:** This study is financially supported by TUBITAK Project (104Y178). The authors gratefully acknowledge Muge Akin for drawing some of the figures.

**Corresponding author:** Dr Tamer Topal, Department of Geological Engineering, METU, Eskisehir yolu, Ankara, 06531, Turkey. Tel: +90 312 210 26 90. Email: topal@metu.edu.tr.

## REFERENCES

AFNOR 1980. *Essai au bleu de methylene.* 18-592. AFNOR 80181. Paris La Defence.

ASTM 1989. Standard test method for resistance to degradation of large-size coarse aggregate by abrasion and impact in the Los Angeles Machine, C535, *Annual Book of ASTM Standards,* American Society for Testing and Materials, West Conshocken, PA., 285-287.

ASTM 1990. Standard test method for soundness of aggregates by the use of sodium sulphate or magnesium sulphate, C88, *Annual Book of ASTM Standards,* American Society for Testing and Materials, West Conshocken, PA., 37-41.

ASTM 1992. *Standard test method for evaluation of durability of rock for erosion control under wetting and drying conditions, D5313, Annual Book of ASTM Standards,* American Society for Testing and Materials, West Conshocken, PA., 1347-1348.

BEARMAN, R.A. 1999. The use of the point load test for the rapid estimation of Mode I fracture toughness: *International Journal of Rock Mechanics and Mineral Sciences*, 36, 257-263.

BILGIN, A., OGUZ, M., ELIBOL, E., GÜNER, E., & GEDIK, I. 1994. *Mut-Silifke-Gülnar Yöresinin ( çel ili Jeolojisi),* MTA, 120p.

BSI 1990. *Testing aggregates-Methods for determination of aggregate impact value, BS 812: Part 112.* British Standards Institution. London.

CIRIA/CUR 1991. *Manual on the use of rock in coastal and shoreline engineering*. Construction Industry Research and Information Association, CIRIA Special Publication 83/ CUR Report 154.

CLARK, A.R. 1988. The use of Portland stone rock armour in coastal protection and sea defence works*. Quarterly Journal of Engineering Geology*, 21, 13-136.

CLARK, A.R. & PALMER, J.S. 1991. The problem of quality control and selection of armourstone. *Quarterly Journal of Engineering Geology*, 24, 119-122.

ERICKSON, R.L. 1993. *Evaluation of limestone and dolomite armor stone durability from observations in the Great Lakes regions.* Rock for Erosion Control, 88-93.

FOOKES, P.G. & POOLE, A.B. 1981. Some preliminary considerations on the selection and durability of rock and concrete materials for breakwaters and coastal protection works. *Quarterly Journal of Engineering Geology*, 14, 97-128.

ILKER, S. 1975. *Adana baseni kuzeybatısının jeoloji ve petrol olanakları.* T.PA.O. Raporu, Arama Ar iv No:973, 63p.

ISRM 1981. *Rock characterization, testing and monitoring.* International Society for Rock Mechanics, Suggested Methods, Pergamon Press, Oxford. Brown, E.T. (ed.)

ISRM 1985. Suggested method for point load strength*. International Journal of Rock Mechanics, Mineral Sciences and Geotechnical Abstracts,* 22, 51-60.

LATHAM, J.P. 1991. Degradation model for rock armour in coastal engineering. *Quarterly Journal of Engineering Geology*, *24*, 101-118.

LATHAM, J.P. 1998. Assessment and specification of armourstone quality from CIRIA/CUR (1991) to CEN (2000). *In: Advances in Aggregates and Armourstone Evaluation.* The Geological Society, Engineering Geology Special Publication No.13, 65-85.

LIENHART, D.A. 1994. Durability issues in the production of rock for erosion control. *In: Proceedings of the 1st. North American Rock Mechanics Symposium on Rock Mechanics, Models, and Measurements, Challenges from Industry*, Balkema, Rotterdam, 1083-1090.

LIENHART, D.A. & STRANSKY, T.E. 1981. Evaluation of the potential sources of rip-rap and armourstone-methods and considerations. *Bulletin of the Association of Engineering Geologists*, 18, 323-332.

MATHER, R.P. 1985. Rock for breakwater construction in western Australia-its availability and influence on design. *Engineering Geology*, 22, 35-44.

POOLE, A.B. 1991. Rock quality in coastal engineering. *Quarterly Journal of Engineering Geology*, 24, 85-90.

SCHAFFER, R.J. 1972. *The weathering of natural building stones.* Department of Scientific and Industrial Researches, Special Report, No.18.

SCHMIDT, G. 1961. *VII. Adana petrol bölgesinin stratigrafik nomenklatürü*, Petrol DernegiYayini, 6, 47-63.

SENOL, M., SAHIN, S., & DUMAN, T. 1998. Adana-Mersin dolayının jeoloji etüt raporu (1/100.000 Ölçekli Mersin O 33 Paftası, MTA, 46p.

SMITH, M.R. 1999. *Stone: Building stone, rock fill and armourstone in construction*, The Geological Society. Engineering Geology Special Publication, No.16.

TOPAL, T. & ACIR, O. 2004. Quality assessment of armourstone for a rouble mound breakwater (Sinop-Turkey), *Environmental Geology*, 46, 905-913.

TS 699 1987. *Methods of testing for natural building stones.* Turkish Standards Institute (in Turkish)

TS EN 1097. *Tests for mechanical and physical properties of aggregates-Part 1: Determination of the resistance to ware(Micro deval).* Turkish Standards Institute (in Turkish), 8p.

WINKLER, E.M. 1986. A durability index for stone. *Bulletin of the Association of Engineering Geologists*, 30, 99-101

YALCIN, N.M. & GORUR, N. 1984. Sedimentological evolution of the Adana Basin. *In: International Symposium on the Geology of the Taurus Belt*, Ankara, 165-172.

YETIS, C. & DEMIRKOL, C. 1984. Adana baseni kuzey-kuzeybatı kesiminin temel stratigrafisine ili kin bazı gözlemler. *T.J.K .38 .Bilimsel ve Teknik Kurultayı Bildiri Özetleri*. Ankara, 59-61.