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A Practical Study to Predict Uniaxial Compressive Strength of Turkish Marbles after Freeze Thaw Test

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Abstract **-**Natural stones have been used as construction and decoration materials for centuries. They have been used for these purposes because they are both durable and aesthetic. However they are constantly exposed to external influences such as excessive cold and excessive hot due to climatic conditions. For this reason freeze– thaw characteristic of stone is important because it will determine performance of stone during climatic changes. Freeze– thaw test is performed to determine the deteriorations of stones due to freeze– thaw cycling. The amount of strength loss is an important parameter which shows deterioration amount. Freeze– thaw test very reliable to determine strength loss but it is demanding and time consuming. Because of this hardness, predicting the after test strength (strength loss), previous studies were reviewed and a model constructed from 50 different natural stones. Moreover freeze– thaw tests were applied on 6 samples for controlling the model. In addition, 12 different natural stones from previous studies are also held as control group. All samples are from different places of Turkey. A statistical model developed to predict after freeze thaw test uniaxial compressive strength (UCS) values from UCS values. This model is simple and reliable (R^2 = 0.85) and this model can be functional for predetermination of uniaxial compression strengths of lime stones after freeze–thaw test without testing.

Keywords**:** Natural stone, Building material, Freeze– thaw test, Statistical model, Uniaxial compression strength

1. Introduction

Natural stones satisfy certain qualitative requirements and refer to any rock that is capable of being quarried in large blocks and being processed into specified or indicated shapes or sizes for specific applications. It includes many different origins of rock types such as marble, limestone, and andesite, which are widely used as building materials for construction and decoration purposes especially for outdoor applications such as paving, flooring and cladding. The most important issue in outdoor applications of natural stones is how long a stone endure and maintains its essential and distinctive characteristics of strength and appearance with relation to climate and environmental conditions (Yavuz et al., 2008; Bayram, 2012).

The physical, mechanical, chemical and petrographical properties of stones are very important to select the materials used as paving, flooring and cladding. The mechanical strength (uniaxial compression strength) of stones is one of the important parameters which affect their usages in cold regions. For example, natural stones used in cold regions are exposed to at least one freezing and thawing cycle every year. In the freezing period, the stone is frozen and water in micro pores expands about 9% of the original volume. This expansion induces tensile stress concentration and damages the micro pores; when the rock is thawed, water flows through the fractured micro pores which increase the damage. Rock damage in cold regions is the result of the number of freeze–thaw cycle, temperature, rock type, applied stress and moisture content (Chen et al., 2004; Tan et al., 2011; Bayram, 2012).

Many researchers studied freezing and thawing of natural stones by using numerous laboratory tests. Most of researchers interested what kind of relationship between freeze–thaw and properties of natural stones such as strength, compressibility, porosity, pore size distribution, permeability and the mineral content. Matsuoka (1990) investigated the freezing behaviour and frost shattering of rocks in the laboratory and dwelled on that the main cause of frost shattering depends on the relative magnitude between the two positive strains. Nicholson and Nicholson (2000) studied the sample weight loss in the course of freeze–thaw testing; a detailed graphic record was made of deterioration mode and its relationship to pre-existing rock flaws. Chen et al. (2004) studied the effect of water saturation on highly porous welded tuff due to freeze–thaw action and they found that rock damage significantly increases when the initial degree of saturation exceeds 70%. Mutluturk et al. (2004) presented a mathematical model describing the integrity loss process when a rock was subjected to freeze–thaw cycles and the model provided several meaningful parameters for rock disintegration or rock durability. Yavuz et al. (2006) developed a model equation predicting the index properties of rocks due to freeze–thaw and thermal shock treatment by multiple regression analysis. Karaca et al. (2010) experimentally investigated the Böhme abrasion and wide-wheel abrasion values after and before freeze–thaw cycles. They developed the statistical models for abrasion values after and before freeze–thaw. Saad et al. (2010) determined the influence of water flows into porous network on frost weathering of rocks. Tan et al. (2011) studied the degradation in the mechanical properties of granite as a function of freeze – thaw cycles by uniaxial and triaxial compression tests. Karaca et al. (2011). investigated the effects of surface-finishing forms and cement-filling on dry weights, porosities and Böhme abrasion loss values of two types of porous limestone that were exposed to freeze–thaw tests. Bayram (2012) developed a statistical model to predict percentage loss values in uniaxial compression strength. In this model impact strength, modulus of elasticity and water absorption were used as independent variables.

The freeze–thaw test method is exceptionally demanding and time consuming. The prediction of after freeze–thaw without test uniaxial compression strength provides easy and quick predetermination without any test.

The main objective of this study is to predict the uniaxial compression strength after freeze–thaw cycles from uniaxial compressive strength. In this study a simple model developed using only UCS values are used to estimate after freeze–thaw UCS value.

2. Materials and Methods

In this study, various papers were reviewed and data was classified and divided into two groups. First one is the model group and second one is the control group. In Table 1 and Table 2 specifications of model group and control group are given. 68 different stones were used as database. Data of 50 dissimilar stones is used to construct a model. Data of 12 unlike stones from reviewed papers and 6 stones from laboratory studies (totally 18 samples) is used as control group to test constructed model. Then by using a simple regression method a model fitted and an empiric equation was obtained. Afterwards, this equation use to predict after freeze thaw value of unused control group. Once and for all, results were compared.

2. 1. Experimental Procedure of Freeze – Thaw Test

All reviewed and used data were performed according to ISRM Standards (UCS) and Turkish Standard (The freeze– thaw tests) TS 699. From six different stones, core samples were prepared from each stone for freeze–thaw tests. The samples were saturated under atmospheric pressure. The saturated samples were frozen in a deep-freezer and conditioned at − 20 °C for 2 h. Then they were taken out of the freezer and thawed in a deionized water bath at +20 °C for 2 h. This freeze–thaw cycle was repeated 25 times.

Table. 1. Specifications of Model Group

Commercial Name	Location	UCS (MPa)	UCS Freeze Thaw (MPa)
Marmara Marble [1]	Marmara Island	55.48	70.34
Crema Mare [1]	Bursa	106.92	109.13
Toros Black[1]	Kayseri	115.9	99.33
Burdur Beige$_a$[1]	Burdur	103.12	58.56
Emprador Light[1]	Bursa	93.55	92.53
Crema Likya [2]	Burdur	179	150.54
Burdur Travertine [2]	Burdur	65.79	57.42
Burdur Limra [2]	Burdur	53.2	49.54
Burdur Beige$_b$ [2]	Burdur	80	68.38
Grey Marble [3]	Konya	50.5	41.61
White Marble [3]	Konya	42.6	38.68
Çamlıbey Uşak [4]	Uşak	79.2	71.5
Karahallı White [4]	Uşak	45	24.7
Karahallı Light Green [4]	Uşak	52.1	52.9
Karahallı Dark Green [4]	Uşak	52.9	50.3
Kavacık White [4]	Uşak	69.7	57.5
Eldeniz White [4]	Uşak	75.1	69
Boşudamı White [4]	Uşak	106	105.3
Boşudamı Grey [4]	Uşak	71.1	65.1
Boşudamı Green [4]	Uşak	69.7	57.5
Afyon White$_a$ [5]	Afyon	89.7	62.7
Afyon Clouded [5]	Afyon	63.3	57.4
Bilecik Rosa Beige [5]	Bilecik	122.2	90.4
Bilecik Royal Beige [5]	Bilecik	90.7	63.2
Sivrihisar Beige [5]	Eskişehir	151.9	130
Afyon White$_b$ [6]	Afyon	70.1	59
Afyon Sugar [6]	Afyon	70.1	59
Afyon Bal [6]	Afyon	64.8	44.7
Eskişehir Süpren [6]	Eskişehir	68.8	53.5
Ege Bordo [6]	Muğla	52.2	47.9
Akşehir Black [6]	Konya	80.7	65.7
Uşak Green [6]	Uşak	69.7	57.5
Eldeniz White [7]	Uşak	75.1	69
Boşudamı White [7]	Uşak	106	105.3
Boşudamı Grey [7]	Uşak	72.1	65.1
Boşudamı Green [7]	Uşak	69.7	57.5
Kavacık White [7]	Uşak	69.7	57.5
Göktepe White Marble [8]	Muğla	88.5	86.1
Oruçoğlu White [8]	Muğla	73.6	67.5
Özer White [8]	Muğla	70.1	50.2
Mersan White [8]	Muğla	67.7	60.4
Rosso Levanto [9]	Elazığ	94.5	77.52
Elazığ Crem [9]	Elazığ	78.4	78
Kulp Beige [9]	Diyarbakır	135.6	98.42
Daisy Beige [9]	Diyarbakır	126.8	119.68
Verde Antico [9]	Malatya	82.2	63.81
Hazar Beige [9]	Diyarbakır	61.4	54.77
Cermik Beige [9]	Diyarbakır	76.9	67.31
Arapkır Beige [9]	Malatya	73.08	73
Akdağ Beige [9]	Elazığ	91.39	84.83

* Superscript numbers indicates the paper which data taken from.

Table. 2. Specifications of Control Group

Commercial Name	Location	UCS (MPa)	UCS Freeze Thaw (MPa)
Bilecik Beige [10]	Bilecik	103.00	93.00
Mugla White [10]	Muğla	72.00	59.00
Burdur Brown [10]	Burdur	141.00	102.00
Konya Travertine [10]	Konya	70.00	56.00
Yesilova Green [10]	Burdur	100.00	95.00
Korkuteli Beige [10]	Antalya	139.00	129.00
Yesilova Beige [10]	Burdur	126.00	92.00
Bucak Travertine [10]	Burdur	43.00	34.00
Milas Lilac [10]	Muğla	46.00	41.00
Finike Limra [10]	Antalya	52.00	34.00
Bilecik Rose [10]	Bilecik	96.00	78.00
Karamanlı Beige [10]	Burdur	120.00	120.00
Crystal Emprador [11]	Adıyaman	65.33	59.61
Botticino Royal [11]	Diyarbakır	52.81	44.26
Breccia Adonis [11]	Adana	69.26	68.60
Perlato Giallo [11]	Malatya	71.46	63.16
White Onyx [11]	Ağrı	64.79	54.55
Cream Karaman [11]	Karaman	84.47	68.02

* Superscript numbers indicates the paper which data taken from.

The uniaxial compression strengths of limestone samples were measured after freeze–thaw test. The uniaxial compression strength tests were applied using an ELE ADR-AUTO 3000 which is computer controlled hydraulic press. Before testing, all the test samples were conditioned in the oven at 105 °C and cooled until to steady state. The test results are given in control group and numbered as ‘’11’’

3. Statistical Analysis

First of all, summary statistics of all groups were determined. In Table 3 and Figure 1 basic statistics and histograms are given.

Table. 3.Summary Statistics

	UCS (model group)	UCS Freeze Thaw (model group)	UCS (control group)	UCS Freeze Thaw (control group)
Mean	81.48	70.34	84.23	71.73
Standard Error	3.84	3.41	7.38	6.63
Median	73.34	64.46	71.73	65.59
Mode	69.70	57.50	#N/A	34.00
Standard Deviation	27.17	24.13	31.29	28.14
Sample Variance	738.43	582.12	979.33	792.05
Kurtosis	2.83	1.90	-0.84	-0.48
Skewness	1.49	1.25	0.57	0.56
Range	136.40	125.84	98.00	95.00
Minimum	42.60	24.70	43.00	34.00
Maximum	179.00	150.54	141.00	129.00
Count	50	50	18	18
Confidence Level (95.0%)	7.72	6.86	15.56	14.00

Then the relation between UCS and freeze thaw UCS was checked and a linear relationship drew attention. (Figure 2a) By applying regression analysis two simple and quick equations were produced

(Equation 1 and Equation 2). While Equation 1 contains interception Equation 2 does not. Equations are given below:

$$y = 0.83x + 2.12 \tag{1}$$

$$y = 0.86x \tag{2}$$

To test reliability of models ANOVA was performed and results are given as Table 4, Table 5 and Table 6.

Table. 4. Regression Statistics

Regression Statistics	intercept	no intercept
Multiple R	0.928	0.993
R Square	0.861	0.985
Adjusted R Square	0.858	0.964
Standard Error	9.184	9.112
Observations	49	49

Table. 5. ANOVA

		df	SS	MS	F	Significance F
intercept	Regression	1	24560.06	24560.06	291.21	0.00
	Residual	47	3963.84	84.34		
	Total	48	28523.89			
no intercept	Regression	1	266948.59	266948.59	3215.25	0.00
	Residual	48	3985.23	83.03		
	Total	49	270933.82			

Table. 6. Constructed Equations and Confidence Levels

		Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
intercept	Intercept	2.12	4.21	0.50	0.62	-6.34	10.58	-6.34	10.58
		0.83	0.05	17.06	0.00	0.73	0.93	0.73	0.93
no intercept	Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
		0.86	0.02	56.70	0.00	0.82	0.89	0.82	0.89

After ANOVA it can be clearly seen that both of constructed models are reliable (low standard error, low P values high F values). However, model without interception is better. Therefore Equation 2 was chosen to predict after freeze thaw UCS values.

In order to test Equation 2 a separate group (control group) was used. In Table 7 real UCS freeze thaw values and predicted UCS freeze thaw values are given and in Figure 2b correlation between real UCS freeze thaw and predicted UCS freeze thaw are shown.

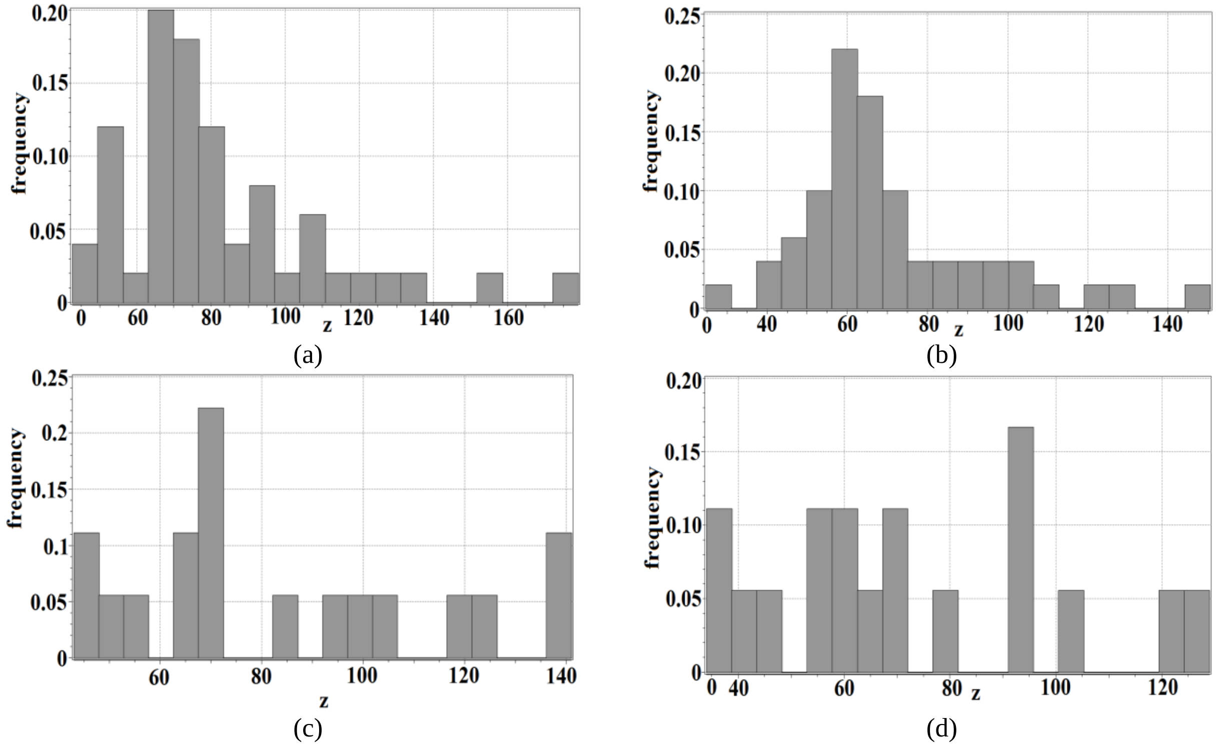

Fig. 1. Histograms of Data; (a) Histogram of UCS Values (Model Group), (b) Histogram of Freeze Thaw UCS Values(Model Group), (c)Histogram of UCS Values (Control Group), (d) Histogram of Freeze Thaw UCS Values(Control Group)

Table. 7. Real UCS Freeze Thaw Values and Predicted UCS Freeze Thaw Values

UCS Freeze Thaw Real (MPa)	93.00	59.00	102.00	56.00	95.00	129.00	92.00	34.00	41.00
UCS Freeze Thaw Predicted(MPa)	88.58	61.92	121.26	60.20	86.00	119.54	108.36	36.98	39.56
UCS Freeze Thaw Real (MPa)	34.00	78.00	120.00	59.61	44.26	68.60	63.16	54.55	68.02
UCS Freeze Thaw Predicted(MPa)	44.72	82.56	103.20	56.18	45.42	59.56	61.45	55.72	72.65

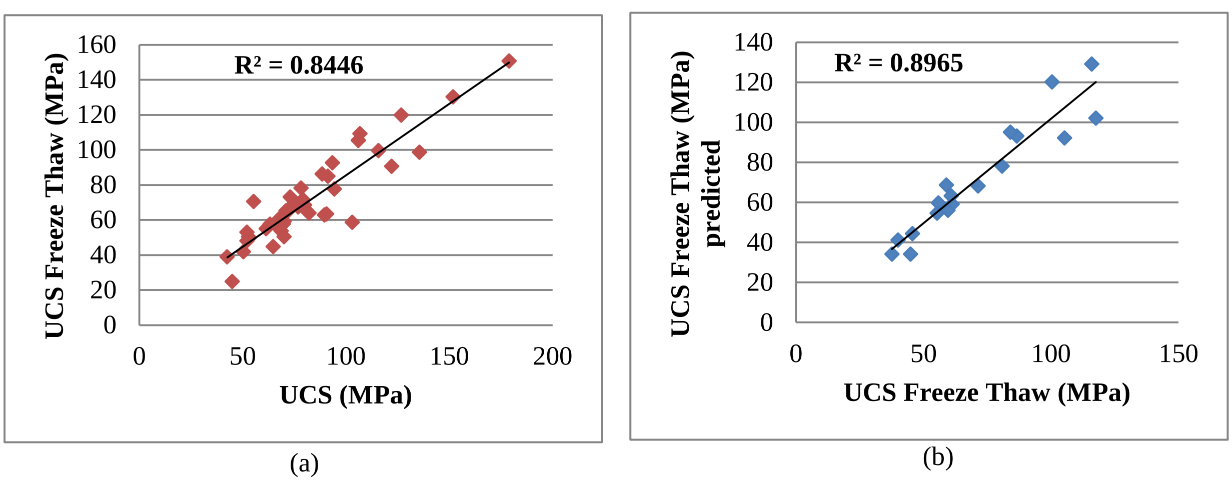

Figure 2.(a) relation between UCS and UCS freeze thaw (b) relation between real UCS freeze thaw and predicted UCS freeze thaw

4. Conclusion

The freeze–thaw test is a notable test for the identifying of the strength loss in uniaxial compressive strength after freeze–thaw cycles, for building stones. Nevertheless, this test is extremely laborious and a practical and comprehensive prediction model was needed. In this paper a large number of data used to construct a model and a second data set used to test the model. The results can be summarized as:

- UCS values and after freeze thaw UCS values are in a strong relationship. ($R^2 = 0.8446$)
- This relationship can be expressed by Equation 1 (=0.83x + 2.12) and Equation 2 (y = 0.86x)
- By using Equation 2, after freeze thaw UCS values can be predicted approximately to real values. ($R^2 = 0.8965$)
- Even though this model can give a reliable result about UCS loss after freeze thaw test, it does not give a reliable result for predicting UCS loss percentage after freeze thaw test.

References

Aysal, N., & Korkanç, M. (2002). Geological And Engineering Properties Of Sivaslı Marble Deposits. *Sivaslı Mermer Yataklarının Jeolojik ve Mühendislik Özellikleri, İstanbul Üniversitesi Mühendislik Fakültesi Yerbilimleri Dergisi*, 15(2), 1-10.

Bayram, F. (2012). Predicting Mechanical Strength Loss Of Natural Stones After Freeze– Thaw In Cold Regions. *Cold Regions Science and Technology*, 83–84, 98–102.

Bodur, B. (2009). *Bazı mermerlerin mekanik özelliklerinin araştırılması***.**

Chen, C.H., Yeung, M.R., & Mori, N. (2004). Effect Of Water Saturation On Deterioration Of Welded Tuff Due To Freeze– Thaw Action. *Cold Regions Science and Technology*, 38, 127– 136.

Çelik, Y,M., & Emrullahoğlu, F,Ö. (1999). Mermer Atıklarından Polyester Bağlayıcılı Suni Mermer Blok Ve Levha Üretiminin Araştırılması. *Afyon Kocatepe Üniversitesi Fen Bilimleri Dergisi*, 1, 35-50.

Çelik, Y,M., & Kırılıveren, S. (2012). Çamlıbel - Ulubey (Uşak) Beyaz Mermerinin Jeolojik ve Fiziko - Mekanik Özelliklerinin Araştırılması. *Yapı Teknolojileri Elektronik Dergisi*, 8(1), 44-53.

Kadane, J.B., & Lazar, N.A. (2004). Methods And Criteria For Model Selection. *Journal of the American Statistical Association*, 99, 279– 290.

Karaca, Z., Deliormanli, A.H., Elci, H., & Pamukcu, C. (2010). Effect Of Freeze– Thaw Process On The Abrasion Loss Value Of Stones. *International Journal of Rock Mechanics and Mining Sciences*, 47, 1207– 1211.

Karaca, Z., Oztank, N., Gokce, M.V., & Elci, H. (2011). Effects Of Surface-Finishing Forms And Cement- Filling On Porous Dimension Limestone Deterioration In Cold Regions. *Cold Regions Science and Technology*, 68, 124– 129.

Kıncal, A. (2012). Burdur Yöresinde üretilen mermerlerin bazı mekanik özelliklerinin belirlenmesi ve kullanım alanlarının analizi.

Matsuoka, N. (1990). Mechanisms Of Rock Breakdown By Frost Action: An Experimental Approach. *Cold Regions Science and Technology*, 17, 253– 270.

Mutluturk, M., Altindag, R., & Turk, G. (2004). A Decay Function Model For The Integrity Loss Of Rock When Subjected To Recurrent Cycles Of Freezing-Thawing And Heating Cooling. *International Journal of Rock Mechanics and Mining Sciences*, 41, 237– 244.

Nicholson, D.T., & Nicholson, F.H. (2000). Physical Deterioration Of Sedimentary Rocks Subjected To Experimental Freeze– Thaw Weathering. *Earth Surface Processes and Landforms*, 25, 1295– 1307.

Osmanlıoğlu, EA., & Ersoy, FT. (1993). Determination Of Geomechanical Properties and Utilization of Konya - Ladik Marbles, Konya - Ladik Mermerlerinin Jeomekanik Özellikleri Ve Kullanım Olanaklarının Belirlenmesi. *Türkiye 13. Mining Congress*, 367-374.

Saad, A., Guedon, S., & Martineau, F. (2010). Microstructural Weathering Of Sedimentary Rocks By Freeze– Thaw Cycles: Experimental Study Of State And Transfer Parameters. *Comptes Rendus Geoscience*, 342, 197– 203.

Tan, X., Chen, W., Tian, H., & Cao, J. (2011). Laboratory Investigations On The Mechanical Properties Degradation Of Granite Under Freeze– Thaw Cycles. *Cold Regions Science and Technology*, 68, 130– 138.

Tirnakçioğlu, G. (2014). Farklı bölgelerdeki bazı mermerlerin fiziksel ve mekanik özelliklerinin boyut parametresine göre incelenmesi.

TSE (1987). Methods of Testing for Natural Building Stones (TS 699). *TSE Publication, Ankara.*

Uysal, Ö., Akçakoca, H., & Topal, İ. (2003). The Technical-Mechanical Specifications of Some Natural Stones and the Determination of Suitable Usage Areas, Bazı Doğal Taşların Tekno-Mekanik Özellikleri ve Uygun Kullanım Alanlarının Belirlenmesi, Türkiye 4. *Mermer Sempozyumu (Mersem'2003) Bildiriler Kitabı*, 343 – 351**.**

Yavuz, H., Altindag, R., Sarac, S., Ugur, I., & Sengun, N. (2006). Estimating The Index Properties Of Deteriorated Carbonate Rocks Due To Freeze– Thaw And Thermal Shock Weathering. *International Journal of Rock Mechanics and Mining Sciences,* 43, 767– 775.

Yavuz, H., Ugur, I., & Demirdag, S. (2008). Abrasion Resistance Of Carbonate Rocks Used In Dimension Stone Industry And Correlations Between Abrasion And Rock Properties. *International Journal of Rock Mechanics and Mining Sciences*, 45, 260– 267.

Yavuz, A. B., & Elçi, H., (2007). Geological Parameters Influencing Use of Göktepe (Muğla) White Marbles As Natural Building Stone, Göktepe (Muğla) Beyaz Mermerlerinin Doğal Yapı Taşı Olarak Kullanılabilirliğini Etkileyen Jeolojik Parametreler, S.Ü. Müh.-Mim. Fak. Derg., C.23, S.3, J. *Fac.Eng.Arch. Selcuk Univ.*, 23(3), 57 – 68.