Overview on geo-mechanical assessments of Denizli travertines in Turkey

S. YAGIZ[1]

[1] Pamukkale University. (e-mail: syagiz@pamukkale.edu.tr)

Abstract: The city of Denizli and its surrounding areas, located in western Turkey, have one of the marvellous travertine deposits, and quarries in the world. The areas have about forty travertine quarries and fifty factories, which are located approximately 10 to 20 kilometres away from the city centre. Travertines are also one of the main export products for Denizli and there are different and widespread travertine outcrops in the area, their common commercial usage can be listed as cladding sidewalls of buildings, in steps of buildings and water pools, other accessories for modern civil constructions. Both their colours and physical properties vary from location to location in the study area. The purpose of this paper is the investigation of geomechanical properties of Denizli travertine, on the basis of field and laboratory studies. In order to achieve the goal, from various travertine quarries and factories, travertine samples were collected and geomechanical tests were performed. It is concluded that although these travertines have a good quality and also nice commercial market, purposes of their usage can change due to various engineering properties of travertines. In the area, travertines have good quality and can be used for cladding of sidewall and other internal and external usage in modern building and structures.

Résumé: La ville de Denizli et de ses abords, situé dans la Turquie occidentale, ayez un des gisements merveilleux de travertin, et carrières dans le monde. Les secteurs ont environ quarante carrières de travertin et cinquante usines, ce qui sont situés approximativement 10 à 20 kilomètres loin du centre de la ville. Les travertins sont également l'un des produits principaux d'exportation et il y a différents et répandus affleurements de travertin dans le secteur, leur utilisation commerciale commune peut être énumérée comme parois latérales de revêtement des bâtiments, dans les étapes des bâtiments et des piscines de l'eau, d'autres accessoires pour les constructions civiles modernes. Leurs couleurs et propriétés physiques changent de l'endroit en l'endroit dans le secteur d'étude. Le but de cet article est à la recherche sur les propriétés geomechanical du travertin de Denizli, mise en oeuvre des études de champ et de laboratoire. Afin de réaliser le mais, de diverses carrières et usines de travertin, des échantillons de travertin ont été rassemblés et des essais geomechanical ont été réalisés. On le conclut que bien que ces travertins aient une bonne qualité et également un marché gentil, les buts de leur utilisation peuvent changer en raison de diverses propriétés de technologie des travertins. Dans le secteur, les travertins ont la bonne qualité et peuvent être employés pour le revêtement de la paroi latérale et de toute autre utilisation interne et externe en bâtiment et structures modernes.

Keywords: Mechanical properties, limestone, and quarries

INTRODUCTION

Turkey is one of the biggest travertine producers in the world. Since middle of the year 2002, travertine production and export values are becoming more than other total Turkish marbles export values. The United States comes first among exporting countries. Turkey provides 50% of travertine consumption of the United States, alone. In terms of travertine reserve and production, Denizli area takes first place in Turkey. Various companies are located in this area and export travertines to almost 60 countries around the world. More than 20% of Turkey's total natural stone production belongs to this area, production amount in some quarries reaches up to 25,000-30,000 m^3 per year (Yuzer, 2005). In Turkey, the other most important travertine-tufa localities take place around Burdur, Kayseri, Sivas, Konya, Afyon, Kutahya, Ankara, Kirsehir provinces. The natural stone, especially travertine production of Turkey reached to 1,148,000 tones in 2003 (Yuzer, 2005). Produced travertine in the area has been used for cladding of sidewall and other internal and external usage in modern building and structures. For this paper, the study was performed on travertine samples, collected from Ballık district that is located on the eastern side of Denizli city, to evaluate Denizli travertines in terms of geo-mechanical point. In order to accomplish the goal; field, factory studies and geo-mechanical laboratory tests were conducted.

PREVIOUS STUDIES

The Denizli extensional basin in western Turkey has widespread travertine accumulation including the famous modern Pamukkale travertines since Late Quaternary. The total area occupied by modern and old travertines is more than 100 km^2 and its thickness can reach up to 60 m (Ozkul et al. 2002). Travertine is a kind of limestone that forms where hot ground waters, rich in calcium and bicarbonate, emerge at springs. Most of the studies performed on the Denizli travertine are generally focused on Pamukkale and they are mainly related to hydrogeology of the hot waters, geothermal potential, wasting and conversion (Ekmekci et al. 1995). Altunel and Hancock et al. (1993a, 1993b, 1996, 1999) studied on morphological classification of travertine and relations between travertine and active tectonic-

seismicity of the region. Ozpinar et al. (2001) studied geological and petrologic properties of travertine. He stated that travertine, in Ballık district and surrounding is mostly composed of CaO (53.5-55.24%). Demirkiran and Calapkulu (2001) investigated geological and morphological characteristic of the travertine. They classified travertine in terms of geological feature and accumulation media in the basin. Akyol et al. (2005) studied on the geological properties, including travertine litho-type and its basic properties, of the Denizli travertine.

GEOLOGY OF STUDY AREA

The city of Denizli and its surroundings are located at the eastern edge of the Aegean region extensional province. It is a graben, which is bounded by normal faults from north and south and intersects the Gediz and B. Menderes graben in the west. The basin is composed of Neogene fluvial and lacutrain sediments and Quaternary alluvium-colluvium. In the study area, Ozkul et al. (2002) investigated this travertine in terms of its age, color and geological settlement. Ozkul et al. (2002) stated that age of this travertine in the study area is Neogene and overlays both Paleozoic including marble, schist and Mesozoic age limestone; Paleocene age limestone, dolomite and evaporates. In the Denizli basin, Pamukkale-Karahayıt and Ballık masses are important for travertine precipitation and also quarrying. More than 50 quarries in Ballık region have been intensively quarried by natural stone industry. Geological map of the investigated area is shown in Figure 1.

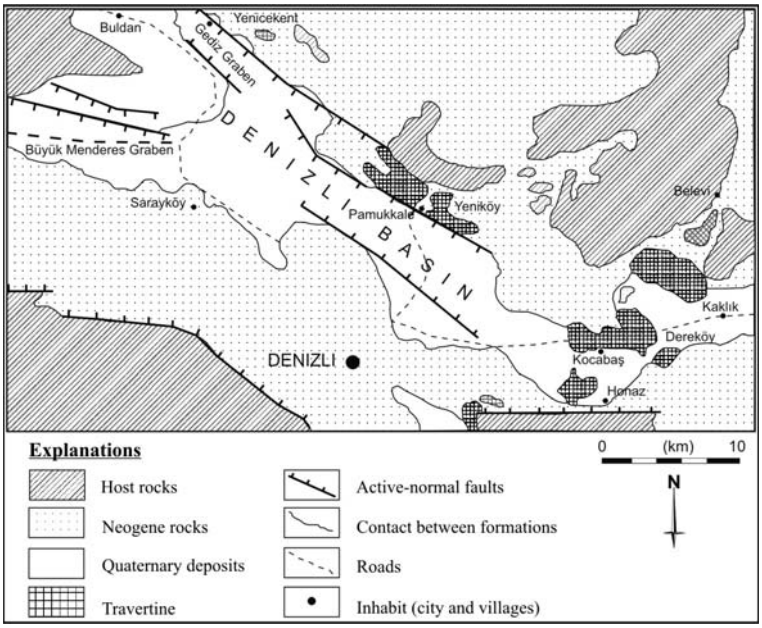

Figure 1. General geological map of the Denizli basin (Modified from Altunel, 1996)

EVALUATIONS OF TRAVERTINES IN THE FIELD, FACTORY AND LABORATORY

Travertine quarrying is such an expensive investment and it needs considerable effort to get high production rate. The rate of production depends on rock type, machines and the classification of labour working in factories and field. Thus, operation and long term scheduling are important parameters to increase profit. In the Ballık travertine basin, annual travertine production is about 277,000 m^3. Total travertine reserve is 550-million m^3 in Denizli City. In the following section, influence of some parameters including field study, rock properties, machines used in the field and factory, are discussed in detail. Ballık district and surrounding in Denizli basin have been chosen for evaluating geotechnical aspect of the travertines and their quarry operations.

Field studies on travertine quarries

Field studies and production on the quarries depend not only on the machine being used for operation but also labours and engineer performance. Additionally, in the quarry, efficiency depends on operation, production and long term scheduling. An example of the typical quarry in Ballık district is demonstrated in Figure 2. In the district, most of the quarries use diamond wire cutting tools which is recently common and preferable in the field and chain cutter to pull apart blocks from the travertine mass in the field and uses truck for transportation (Figure 3 and 4). In the field, dimensions of the travertine blocks depend upon the discontinuities, micro-fractures and faults. Most of the quarries produce 1 to 2m^3 blocks (Figure 5).

Figure 2. Typical travertine quarry operated in Ballık district (Alimoglu Quarry)

Figure 3. Diamond-wire cutter in the Quarry

Figure 4. Chain cutter in the quarry (Courtesy of Basaranlar quarry)

Figure 5. Dimension of the typical block produced in the quarry

Performance evaluation of cutting machines in the factory

Travertine factories are located in Denizli surroundings where most of the travertine quarries are operated. Travertine quarries and factories were visited and the large diameter circular sawing machine was observed during the cutting travertine blocks. Sawing machine has two saws, one of which is vertical and the other one is horizontal, working at the same time to cut the travertine block in Figure 6. In order to record sawing machine performance and related rock properties and features, the performance study form was prepared. However, this performance measurement was conducted for only one factory that was chosen as a pilot for the study. The form showing in Table 1 includes observation number, factory name and location, ST machine specification, rock type besides, any other observations and remarks during the cutting process.

Figure 6. Large diameter ST-circular sawing machine (Courtesy of Komurcuoglu Factory)

Table 1. A sample of the machine performance form

Observation number	1
Date	3rd of May 2005
Factory name and location	Kömürcüo lu
Machine model	ST1400-four footed
Diameter of vertical saw (mm)	1400
Direction of Sawing	Parallel to layer
Diameter of horizontal saw (mm)	450
Rotational speed of vertical saw	700 rpm
Advanced rate of saw (cm/s)	3.57
Motor current for saw	110 A
Horizontal motor power – (Kw)	11
Max. Water required (lt/min)	60-80
Rock type	Travertine
Rock location	Ballık - Denizli
Slab dimension (cm^2)	130x30
Slab production per hour (m^2/hr)	21.9
Dimension of Block - (m^3)	1-2.5

Geomechanical studies in the laboratory

Geomechanical properties of rock including uniaxial compressive strength, water absorption, measurement of densities, flexural (bending) strength, measurement of P wave velocity of travertine, Schmidt hammer rebound values are fundamental tests for evaluation of natural stone properties. In order to investigate these properties in the study area, the samples are collected from the quarries. After the sample arrived to the laboratory, the following tests were performed according to the Turkish and European (TSE and EN) Standard Institute regulations. Determination of uniaxial compressive strength (UCS) of the rock is relatively simple and common test for investigation of the strength properties of rock. Therefore, UCS was performed on 20 cubic samples with 7x7x7cm dimension for each quarry (Figure 7).

Figure 7. Prepared sample for geomechanical tests in the laboratory

The test was performed according to TS EN 1926 with loading rate of 10 kg/sec. In order to measure travertine unit weights including natural, dry and saturated unit weight, specific gravity and water absorption percentage of the travertine; from each quarry, 10 samples with 7x7x7cm dimension were prepared and tested according to TS 699, and results were discussed.

DISCUSSIONS AND CONCLUSIONS

In the laboratory, geomechanical testing was performed and the results were evaluated from the scope of technological and commercial usage of travertine. In the study area, in order to investigate average physical properties of the travertine, from each type of travertine enough samples were collected, prepared and tested according to related testing standard and summary of the test results are given in Table 2.

Table 2. Geomechanical properties of travertine in Ballık district

Quarries Name	γ_n kN/m^3	γ_d kN/m^3	σ_c MPa	ω by W %	n %	G_s
Alimoglu	22.8	22.6	58	1.42	2.92	2.46
Cakmak	22.7	22.4	56	1.18	1.81	2.52
Ece	24.3	24.0	59	1.31	4.22	2.46
Ege	22.9	22.6	56	1.06	3.03	2.52
Emek	22.7	22.4	53	1.80	1.64	2.48
Erdem	22.7	22.5	58	1.22	2.13	2.62
Faber	22.3	21.9	46	2.32	2.75	2.55
lik	23.4	23.2	44	1.87	2.24	2.42
K.oglu	25.8	25.7	57	1.64	2.26	2.48
K.oglu	23.3	23.1	67	2.64	2.28	2.42
Ozhan	23.8	23.7	54	0.91	2.96	2.38
Reisoglu	22.1	21.6	50	1.55	1.71	2.47
Zeybek	23.7	23.5	70	1.41	1.45	2.59
TS10449	-	-	>50	<3	-	-
TS2513	-	-	>35	-	-	-
TS1910	-	-	-	<7.5	<12	>2.3

Based on measurements and findings, some geomechanical properties of travertine can be summarized as follows:

Natural unit weight of travertine in Ballık district varies from 22 through 26 kN/m^3 and dry unit weight of travertine varies from 22 to 25 kN/m^3.

For travertine, water absorption by weight was also investigated and the percentage of water absorption is about 0.9 to 2.5. That means the water absorption is less than the value of 7.5% recommended by TS 1910 for travertine. Specific gravity of the travertines varies from 2.4 to 2.6.

Porosity of the travertine is less than the value of 12% recommended by TS 1910 standard. Specific gravity of travertine was also investigated according the TS 1910 standard and it was concluded that specific gravity of travertine is more than 2.3 for all the quarries in the district.

Uniaxial Compressive Strength (UCS) of travertine for Ballık district varies from 44.5 to 70 MPa. These values are very good for travertines according to TS standard mentioned in Table 2.

It is concluded that, quarried travertines in the area are of high quality according to TS and EN Standards used in this research. Colour of travertine varies from white to yellow and brownish. In the Ballık district, produced travertines can be used for cladding sidewalls of modern building and structures both in internal and external areas. The district has good quality travertine; however, quarries and factories should be operated so carefully by using technological tools to improve production in the field and factories.

Corresponding author: Dr. Saffet Yagiz, Pamukkale University, Engineering Faculty, Department of Geological Engineering, Denizli, 20020, Turkey. Tel: +90 258 213 4030. E-mail: syagiz@pamukkale.edu.tr

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