DETERMINATION OF MATERIAL SPECIFICATIONS IN THE EXAMPLE OF TURGUTLU ANCIENT ARMENIAN CHURCH

Elif Ceren Müftüoğlu[1], Hakan Başaran[1*]

[1]Department of Civil Engineering , Celal Bayar University, Manisa, Turkey

ABSTRACT

Historic buildings are the most important components that constitute the cultural heritage of humankind. These buildings should be preserved and evaluated in the best way possible to hand this heritage down to the next generations. Preserving these buildings in their original forms means these are preserved successfully to the extent that they can survive. Restorations made periodically play a significant role in this preservation process. It is clear that these restorations require expertise. Basic principles with respect to the restorations of these historic buildings were determined with Venice Charter. Attention should be paid not to damage the aesthetic and historical value of the building, and to use original materials while performing these restorations. Before reinforcing a historic building, its floor properties, load-bearing system, materials used and historical qualifications should be scrutinized and the restoration to be made should be determined only after these studies. It is particularly important that the properties of the materials to be used in the restoration are in accord with the original materials composing the building. It is quite essential to determine the properties of the original materials the building is composed of. In this study, on-site and laboratorial experimental studies were performed with the aim of determining the properties of the materials used in Turgutlu Ancient Armanian Church example.

Keywords: Historic building, destructive test, non-destructive test

1. INTRODUCTION

Mankind built masonry constructions by preferring construction materials that could be found in the area where he lives in order to meet his housing need, which is one of his initial needs. Masonry construction is the name given to constructions which do not have any framed systems and whose bearing construction element is wall and foundation. Bearing walls are built by block-laying materials such as natural stones, adobe, bricks etc. on top of one another. The walls constitute the outer lines and partition of the building and they transfer horizontal and vertical loads to the foundation. Lime, mortar or mud is used as the binding material. This enables even load distribution amongst the binding blocks. Materials used when building the masonry construction are brittle materials whose ductility is small; therefore, they are resistant to pressure loads but not resistant to traction or bending loads. However, workmanship plays an important role in terms of strength of the building. Masonry constructions' resistant to vertical loads and horizontal earthquake loads is closely assosicated with the strength of the materials used, workmanship, wall geometry and the way the masonry blocks are stuck together. A masonry construction, whose geometry, material strength and workmanship is in accordance with the conditions, can remain standing for ages.

Masonry construction systems can be built simply. Another advantage of it is its aesthetic appearance. Masonry constructions are still built today because of their aesthetic appearances. In addition to this, they ensure heat and sound insulation; they are durable and fire-resistant.

Preservation of historic buildings has gained importance in recent years. In our country, a lot of projects regarding the preservation of historic buildings have been launched. Within the scope of these projects, extremely important buildings for our history have been brought to light, the necessary restorations have been made on them and this have made a contribution to the country's tourism. As many different materials were used when building historic buildings and they were exposed to quite a lot earthquakes and soil force, it is difficult to carry our structure analyses.

2. MATERIAL AND METHOD

The Historic Armenian Church building in Turgutlu, Manisa was examined in the study of determining the material properties of the historic masonry constructions. For this purpose, first of all, the history of the building was reviewed, a survey register was prepared, materials that constitute the building were examined, load-bearing system and damages of the building were determined. Then, samples were taken from the building. Material experiments were carried out with these samples and properties of the materials that constitute the building were determined.

2.1 Description of the building

The building, which is known as the Old Town Hall and located at the Atatürk Boulevard that is the artery of Turgutlu, is an old church that was enlarged through some regulations in the early years of the republic. Even though we do not have any documentation, considering the Armenian settlement in Turgutlu and the architectural properties of the building, it is estimated that it was built in the 17th century. The building, which is thought to have lost its function when the community centres were opened in the first periods of the republic, came into use as Turgutlu Community Centre the bays on the entrance facade side were added to it. According the information obtained, this modification was made in 1940s. It is known that after the community centres were closed and their assets were transferred to the revenue office, the building was sold to the municipality from the treasury for a fee when the Cevdet Öktem was the mayor between 1950-1955. The building had been used as a municipal services building until late 2003; after that, it played host to various events after our municipality moved to its new building. Internal and external views of the building can be seen in Fig 1.

Fig 1. Interior and exterios views of the building

2.2 Material tests on constituents of the building.

In the building, roughhewn andesite was used as the barrier. The average length of the stones is 50 cm and average height of them is 25 cm. Besides, building bricks used were partition tiles. Dimensions of the bricks are 30x20x5 cm approximately. Mortar (fibered plaster) mixed with hay was used as the binding material.

Samples were taken from the stones taken obtained from the building in a laboratory with a 54 mm core drilling bit and thus, cylindrical samples were obtained. Samples were cut in the cutting machine and emerged in the end trimming machine. Drilling cores with a diameter of 5.4 mm were taken from the bricks and thus, samples whose sizes were between 3-5 cm were obtained (Fig 2).

Fig 2. Interior and exterios views of the building

Uniaxial compression test, splitting tensile test (Brazil), ultra-sound test, density test and Schmidt hammer tests were performed by using these samples.

2.2.1 Schmidt Hammer test

The main mechanical properties of materials are strength, elasticity module, ductility, toughness and hardness. Hardness is the resistance shown by a material against a hard object stuck in its surface and it gives an idea about the strength of the material; but it does not fully represent a certain characteristic such as strength of ductility. Information about the origin of the materials is obtained through determining the hardness; it is understood if two different samples have the same origin. Hardness experiments are practical and materials are not destructed in the experiment. Hardness experiment can be performed at a laboratory or on-site on materials which are porous and which have a ceramic structure such as natural stones, bricks, mortar and concrete in the masonry buildings via portable tools. Schmidt hammer test is a test that can be applied both on-site and at the laboratory. This test was developed by Ernst Schmidt in 1948 [5]. In order to proceed from hardness value to the properties about the internal structure of the material, the object must be homogenous and its surface features must be same as the internal structure. Therefore, the surface of the sample should be emerged thoroughly before performing this test. In order to determine the hardness for materials that are porous and ceramic-structured, generally the N type, L type or P type Schmidt hammer is used, which are based on the principle of measuring the back-leaping (Fig 3). A rod for N and L types and a pendulum for P type is thrown to the surface with the help of an arch found at the back side. Generally, L type Schmidt hammer is used for masonry constructions. Rod or pendulum bounces back after striking the surface of the stone object; the higher the bounce is, the more the hardness is. After the plaster or coating on the surface of the element is removed, at least 10 strokes must be performed on different points (1 cm distance minimum); the difference between the maximum stroke value and the minimum stroke value must be less than 10 [1] - [3].

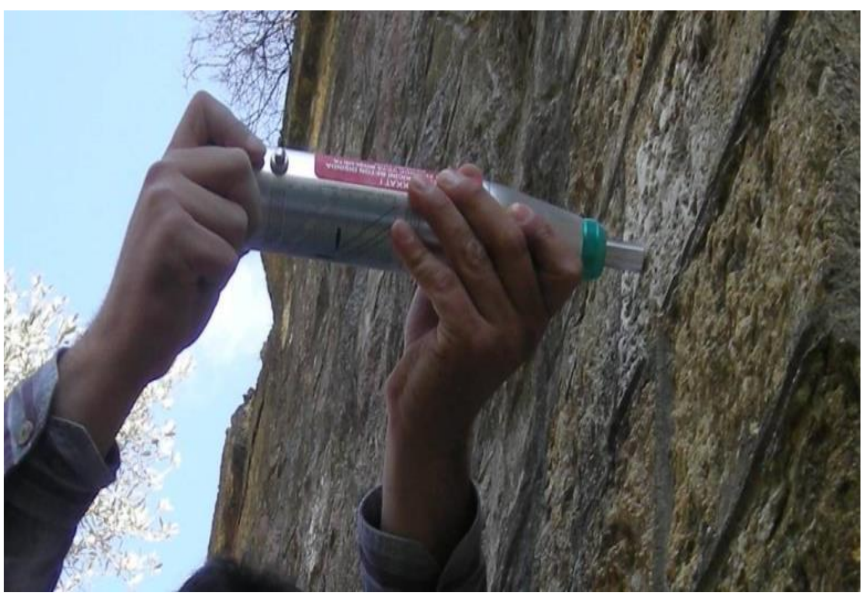

Fig 3. Schmidt Hammer Test

2.2.2 Uniaxial compression test

It is applied to core samples to be taken from stone or brick creating a concentration for Uniaxial Compression Test. For this reason, firstly the point is determined where the core to be taken from, or core is taken from falling structural materials. If this process is made from falling structural elements, taking core is realized on elements to be brought to laboratory. The samples are taken from selected areas with sufficient number, in diameter of 54 mm at least and in height of one or three times of diameter [2], [4].

Taken core samples are cut with a stone cutting tool for being prepared to experiment in the way that diameter/height rate of its two heads which are parallel with each other is 1/1~1/3, and smoothed surface where the power applied on, by sandpapering its head surfaces with a stone sandpaper [4]. These samples are waited for average 48 hours in a laboratory environment with the temperature of 20±2 °C, relative humidity of %65±5. Diameter and height of samples are measured sensitively with caliper. If head surfaces are not smoothed with a sandpaper, after scaling process, a head in thickness of 5-6 mm is made with a dough which is a mixture of plaster and cement. After hardening of head, the height with head is measured. Uniaxial Compression Test is made on these samples (Fig 4). Height change occurred in effect of pressure, load-height change and breaking load are determined, compressive strength is calculated.

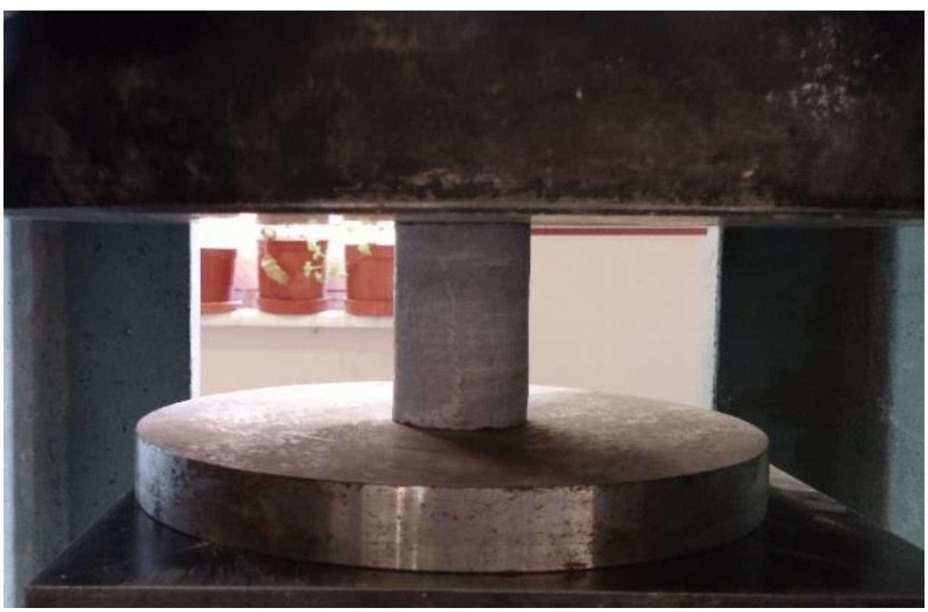

Fig 4. Single axis pressure test

2.2.3. Indirect tension (Brazilian) tests

This test method is used to determine the uniaxial tensile strength of the stones. It is a fairly easy method compared to the direct tensile test but the method gives a slightly greater tensile strength compared to the direct tensile test [2]. For the experiment, the cylinder cores with at least 54 mm diameter are taken from the stones that make up the masonry structures. The core samples firstly cut with stone cutting tool with two parallel head per diameter / height ratio of 1/1 ~ 1 / 0.5 for the experiment preparation. [2], [4]. Load, continuously and without shocks, is applied at a constant rate until the test sample is broken (Figure 5.19). This speed, depending on the test sample structure, should be between 1 minute to 10 minutes in order to break and about 3.5 minutes N / mm2 to 21N / mm2. The maximum load power indicator is recorded [4]. The execution of the experiment is shown in Fig 5.

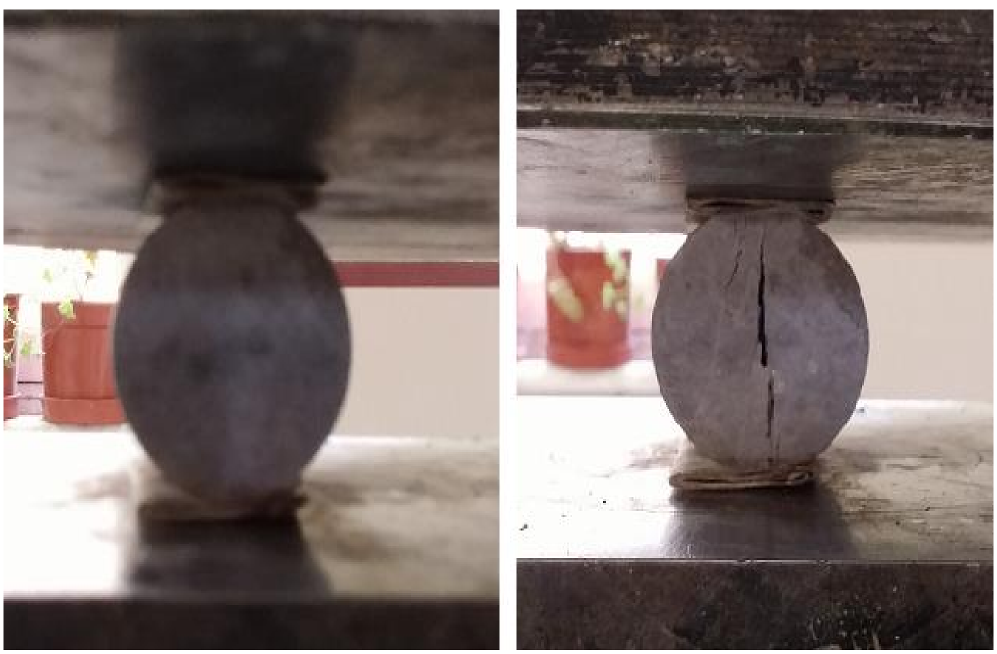

Fig 5. Indirect tension (Brazilian) tests

2.2.4. Density and porosity tests

The elements that constitute the masonry structure help us to obtain comprehensive information about the freeze thaw resistance, the apparent density and the actual unit weight and porosity determination, durability of these elements, decay time, and freeze thaw resistance.

Properly shaped or irregular shaped samples taken for these tests are dried in accordance with TS 699 in oven until the constant weight is left and then weighed (Fig 6). Afterwards, the samples are suspended in water in accordance with TS 699 to become water-saturated and weighed out in water and out of water, the saturated state of the sample in water and the saturated state of the sample in air as mass is obtained. By using these values, volumetric mass, specific gravity and porosity are determined.

Fig 6. Drying in the oven and measuring the weight of samples

2.2.5. Ultra sound test

Modulus of elasticity of the elastic constants of stone-like material and Poisson ratio can be determined by means of said pressure through material and glide ultra-sound waves speed [6]. According to the determination of elastic constants found by this method with uniaxial compressive modulus of elasticity test usually gives greater values [2]. For ultra sound test, cylindrical core samples are used with diameter greater than 31 mm and greater than height, both sides of the cylinder lubricated with grease and the sender and receiver of ultrasound tester surface is touched.

Lubricating oil fills the micro cavities on the surface and provides a full contact between the receiver and the transmitter and the surface of the stone. Pressure and shear ultra-sound waves transition time through the sample is measured in seconds (Fig 7). The modulus of elasticity is determined by using the obtained values.

Fig 7. Ultra sound test

3. Results

Experiments conducted on the rough-hewn stone bearing andesite values obtained as a result of the structure are given in Table 1. Moreover, the values obtained from the tests on the construction bricks are given in Table 2.

Table 1. Stone values

Number	Sample Name	Height (cm)	Dry Weight (gr)	Weight in water (gr)	Volumetric mass (dh)	Specific weight (do)	Porosity (P %)	Surface hardness R	Ultra sound time µs	Ultra sonic speed V (m/s)	Breakage load (kN)	Pressure resistance (Mpa)	Pressure resistance from R (Mpa)	Elasticity Module u (Mpa)	Elasticity Module from V(Mpa)	Fracture pattern
1	STONE1	6,7	280	178	2,30	2,75	16,39	53,8	15,9	4213,84	137,1	59,89	84	4760	43301155,82	KS
2	STONE2-1	3,5	138	93	2,38	3,07	22,41	50,6	16,4	2134,15	132,1	57,71	81	4750	12407984,37	KS

3	STONE2-2	2,6	127	76	1,90	2,49	23,88	48,4	16,8	1547,62	128,4	56,09	80	4675	5298439,137	KS
4	STONE3	9,4	563	350	2,23	2,64	15,48	56,7	14,7	6394,56	147,3	64,35	97	4865	96014340,17	KS
5	STONE4	9,62	566	349	2,19	2,61	15,89	54,5	15,1	6370,86	145	63,34	85	4850	94045759,79	KS
6	STONE5	9,2	485	297	2,26	2,58	12,56	58,7	13,1	7022,90	153,7	67,15	110	4885	113032471,9	KS
7	STONE6	9,15	511	310	2,19	2,54	13,73	58,3	13,8	6630,43	150,6	65,79	110	4880	99287626,9	KS
8	STONE7	9,84	547	330	2,35	2,52	6,87	65,3	11,9	8268,91	161,4	70,51	140	5225	153112320,7	KS
9	STONE 8	10,3	556	339	2,37	2,56	7,66	61,4	12,6	8174,60	157,3	68,72	125	5100	152101917,6	KS
10	STONE 9	9,56	572	354	2,32	2,62	11,74	61,3	12,8	7468,75	154,6	67,54	125	4900	130023440,3	KS
11	STONE10	9,54	425	263	2,23	2,62	15,18	56,8	14,5	6579,31	149,4	65,27	97	4865	100883684	KS

No	**Northeast Wall**	**Southeast Wall**	**Southwestern Wall**	**Southeast Wall**	**East Wall**	**First Floor Western Wall**	**First Floor Southwestern Wall**
1	24	70	66	72	6	0	74
2	38	66	69	68	8	8	71
3	30	68	66	38	0	2	70
4	20	67	72	53	2	0	72
5	28	60	68	60	4	0	73
6	28	61	59	63	5	9	68
7	26	61	59	53	0	8	72
8	32	64	58	67	4	0	71
9	27	67	61	62	5	0	68
10	24	58	74	59	4	6	73
Average	***27,7***	***64,2***	***65,2***	***59,5***	***3,8***	***9,625***	***71,375***

Table 2. Bricks values

No	Sample name	Height L (cm)	Dry Weight (g)	Water Weight (g)	Volumetric mass (dh)	Specific weightk (do)	Porosity (P %)	Surface hardness R	Ultra sound time µs	Ultra sonic speed V (m/s)	Breakage load (kN)	Pressure resistance (Mpa)	Elasticity Module (Mpa)	Elasticity Module from V (Mpa)	Fracture pattern
1	BRICK 1	4,0	80	37	1,38	1,86	25,86	15,4	15,7	2547,77	7,2	3,15	1480	10728240,03	KS
2	BRICK 2	3,4	95	39	1,44	1,70	15,15	24,7	12,3	2764,23	10,2	4,46	956	11515146,35	KS
3	BRICK 3	3,8	84	36	1,35	1,75	22,58	21,3	14,0	2714,29	9,5	4,15	1020	11453426,76	KS
4	BRICK 4	3,2	91	38	1,30	1,72	24,29	19,4	11,8	2711,86	9,0	3,93	1025	11217284,56	KS
5	BRICK 5	3,9	91	37	1,26	1,69	25,00	16,8	14,7	2666,67	8,4	3,67	1320	10645630,05	KS

No	Northeast Wall	Southeast Wall	Southwestern Wall	Southeast Wall	East Wall	First Floor Western Wall	First Floor Southwestern Wall
1	18	21	13	25	9	8	12
2	10	20	14	18	15	11	10
3	12	14	15	21	24	10	12
4	16	20	13	26	18	8	14
5	10	17	9	20	21	9	9
6	14	19	12	15	17	9	11
7	8	18	13	16	19	9	16
8	13	20	9	15	11	11	14
9	9	21	9	10	26	8	16
10	17	16	17	20	21	15	16
Average	***12,7***	***18,6***	***12,4***	***18,6***	***18,1***	***9,8***	***13***

4. CONCLUSIONS

Historical Armenian Church is composed of composite masonry system. The following formulas are used to determine the mechanical properties of the material forming the stone and brick masonry structures. Compressive strength of masonry systems were obtained from the following equation (Eurocode 6, 1995).

$$f_k = \mathrm{K}\ f_b^{0.65}\ f_m^{0.25} \qquad (1)$$

Here, K, α and β are constant, fb (MPa); refers to the stone and brick compressive strength, FM (MPa); refers to the grout compressive strength. The value of constant K, takes values ranging from from 0.4 to 0.6 according to the morphological structure of the stacking system with 0.05 difference. As for α and β, values of 0.7 and 0.3 respectively for the regular-shaped masonry, and masonry built in coarse values of 0.65 and 0.25 are suggested. The maximum value that can be taken for fm is twice the value of fb or 20 MPa (Eurocode 6, 1995). The formula used in masonry systems with very thin grout (between 0.5 mm to 3 mm) is below.

$$f_k = \mathrm{K}\ f_b^{0.85} \qquad (2)$$

Reference [3], has proposed in his work that the tensile strength of the masonry work system can be 10% compressive. Reference [7], for the modulus of elasticity of masonry systems and used the expression of the Eurocodes.

$$E = \frac{t_m + t_u}{\frac{t_m}{E_m} + \frac{t_u}{E_u}}\rho \qquad (3)$$

Here, ρ is a constant and varies according to the adherence between the stone or brick and grout with Reference [7]. Other parameters tm, tu, Em and Eu are respectively represents the average thickness of the grout, the average height of the stone or the brick, the modulus of elasticity of the grout, and the modulus of elasticity of the bricks. Eurocode 6 has offered the following equation for modulus of elasticity.

$$E = 1000\ f_k \qquad (4)$$

He has proposed the 40% of modulus of Elasticity can be taken for shear modulus for Eurocode G (Eurocode 6, 1995). Poisson's ratio for masonry structures have been proposed as 0,17 by Reference [7]. The compressive strength to the walls of the historic Armenian Church consisting of stone and grout;

$$f_k = 0.5 \times 64.21^{0.65} \times 6.5^{0.25} = 11.94\ \mathrm{MPa}$$

was obtained. The tensile strength of the stacking system according to the recommendation of Koçak, compressive strength is considered to be 10%;

$$f_{ts}=0.1x11.94=1.194\,MPa$$

was obtained. The elasticity modulus of the masonry system using the equation 3;

$$E=\frac{0.02+0.81}{\frac{0.02}{0.85}+\frac{0.81}{4.887}}x0.5=1.515\,GPa.$$

found as a result. Shear modulus was obtained from the equation given in Eurocode 6.

$$G=0.4x1515=606\,MPa$$

If the average apparent density of the stones forming the masonry is considered as 2225 kg / m3 and grout density is considered as 1700 kg / m3, the apparent density of the stacking system can be considered as 1963 kg / m3. The compressive strength to the walls consisting of bricks and grout of the historic Armenian Church;

$$f_k=0.5\,x\,3.87^{0.65}\,x\,6.5^{0.25}=1.92\,MPa$$

has obtained. According to the proposal of Reference [3], the tensile strength of the masonry system;

$$f_{ts}=0.1x1.92=0.192\,MPa$$

has been found. The elasticity modulus of the masonry system using the equation 3,

$$E=\frac{0.02+0.37}{\frac{0.02}{0.185}+\frac{0.37}{1.160}}x0.5=0.46\,GPa.$$

has been found as a result. Shear modulus, according to Eurocode 6, was obtained from the following equation.

$$G=0.4x460=184\,MPa$$

If the average apparent density of the bricks forming the masonry arch is considered as 1350 kg / m3 and the grout density is considered as 1700 kg / m3, the apparent density of the stacking system can be obtained as 1525 kg / m3.

Table 7.1 The material parameters of the historical Armenian Church

	Stone Masonry	Brick Masonry
Pressure Resistance (Mpa)	11,94	1,92
Tensile Strength (Mpa)	1,194	0,192
Modulus of Elasticity(Mpa)	1515	460
Shear Modulus(Mpa)	606	184
Apparent Density (kg/m3)	1963	1525

REFERENCES

[1] Postacıoğlu,,B. Cisimlerin Yapısı ve Özellikleri-İç Yapı ve Mekanik Özellikler, Cilt 1, İTÜ Matbaası, İstanbul, 1981.

[2] Ulusay, R. Gökçeoğlu, C. Binal, A. Kaya Mekaniği Laboratuar Deneyleri, TMMOB Jeoloji Mühendisleri Odası Yayınları, 2001,

[3] Koçak A., Tarihi Yığma Yapıların Doğrusal ve Doğrusal olmayan Statik ve Dinamik Analizi: Küçük Aya Sofya Camisi , doktora tezi, Yıldız Teknik Üniversitesi, İstanbul, 1999.

[4] TS 699 (Turkish standards) , Doğal Yapı Taşlarının Test Edilmesi, Türk Standartları Enstitüsü, Ankara, 1987, 197.

[5] Schmidt, E., Investigations with the new concrete test hammer for estimating the quality of concrete, Schweiz. Archivangew. Wiss.Tech. (Solothurn), 17(5), 1951, 139.

[6] ASTM, D2845-69, Standard Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock, 1969.

[7] Lourenço P.B., Assessment of the Stability Conditions of a Cistercian Cloister, 2nd International Congress on Studies in Ancient Structures, Istanbul, 2001.