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Damage Assessment of Rock-Cut Ortahisar Castle in Cappadocia Region

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Abstract

Ortahisar Castle is one of the highest rock-cut structures in Cappadocia Region and there are some problems on its material and structure, which endanger its existence. The aim of this study is to analyse the problems of the rock-cut castle and to suggest solutions for damages according to the data obtained through in-situ dam-age assessment, laboratory and in-situ tests which were done during the winter and summer season in 2014. The mechanical, physical, chemical, petrographic and mineralogical characteristics of the rock samples were assessed and the deterioration of the rock material was researched. Finally, suggestions to overcome the problems were proposed.

1. INTRODUCTION

Cappadocia is located in the Central Anatolia, Turkey. Cabinet Council of Turkey identified the region as "The Privileged Region for Touristic Development" in 1973 and borders of the region were determined. Borders comprised the whole area of Nevsehir and Soganli Valley of Kayseri (Fig. 1).

Figure 1. *Cappadocia Region's approximate borders*

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Nature and history is integrated with man-made carvings and structures in that region for thousands of years. There are three types of structures according to construction types of buildings' structural systems. These structures are masonry, rock-cut&masonry and rock-cut. The building in the scope of this study is a rock-cut castle. Rock-cut structures were categorized according to their usage intend into three group. These are religious, military and civil architecture buildings (Fig. 2).

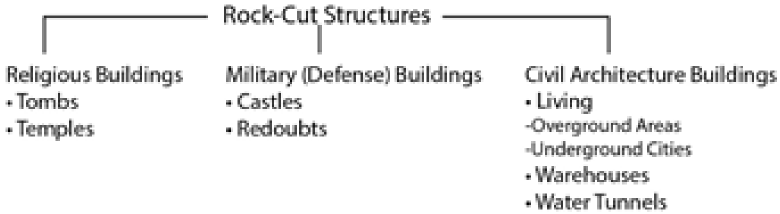

Figure 2. *Types of rock-cut structures according to their usage intend* [1]

The castle is in the military buildings group as seen in the Figure 2.

1.1. Ortahisar and Ortahisar Castle

Ortahisar is a town within the area of UNESCO World Heritage List, Göreme National Park and the Rock Sites of Cappadocia, and 15 km. far from Nevsehir (Fig.1). The town is very popular with its castle for tourists and there are hundreds of rock-cut warehouses for storing potato and citrus around the town.

Ortahisar is in the Urgup Formation of the Cappadocia Volcanic Province (CVP). The CVP is formed since 23, 5 million year [2]. The town is in the 3rd degree seismic zone and there has not been earthquake, which causes detrimental effects since 20th century.

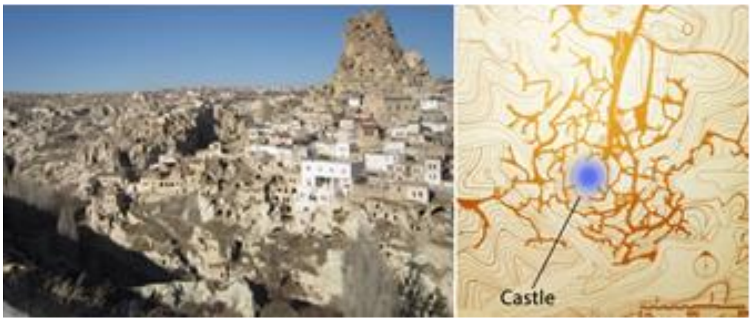

Figure 3*. Ortahisar Castle and its place in Ortahisar*

Ortahisar Castle is approximately in the middle of Ortahisar Town (Fig. 3.) and it is one of the highest rock-cut structures in Cappadocia Region with over 50 meters elevation. It was used for defensing and/or living. In 1916, it was the first town hall of Ortahisar. After a new town was built, it was left and was not used for years. The castle was closed at the beginning of 21th century and after 9 years of its closing, restoration was started in the castle. It was finished in 2013. Some parts of the castle were opened after restoration. There is neither fresco nor mural painting in the castle. The aim of restoration was to stop the rock fallings and to provide safe place for visitors firstly. Some parts of castle dropped in a controlled manner and some kind of additions like steel columns or masonry walls are designed for strengthening the structure. Some cracks are still monitored due to possible movement and some of them filled with mortar.

This castle is one of the worth preserving structure type among world heritage structures. Damages and deteriorations on this structure have to be determined and in-situ and laboratory tests for material characterization have to be done.

Therefore, this study is essential to assess damages on the rock-cut structures and to suggest and offer solutions for these damages and deteriorations by use of physical, mechanical, chemical, petrographic and mineralogical characteristics of rock material. In addition, the importance of material characterization on the suggesting compatible materials and preserving original material will come out with this study.

2. DAMAGES AND DETERIORATION ON THE ORTAHISAR CASTLE

There are nine spaces in the castle, which is accessible for analyzing the inner and outer deteriorations and damages. All masonry arched walls and steel columns in the space 5, at the +91, 25 m. level, and in the space 6, at the +90, 53 m. level, were constructed during restoration (Figs. 4-5). Deterioration and damages in the space 5 is as follow. On its north wall there is spalling. On its west wall, crust exists. There are discolorations on the north, west and east walls (Fig. 4).

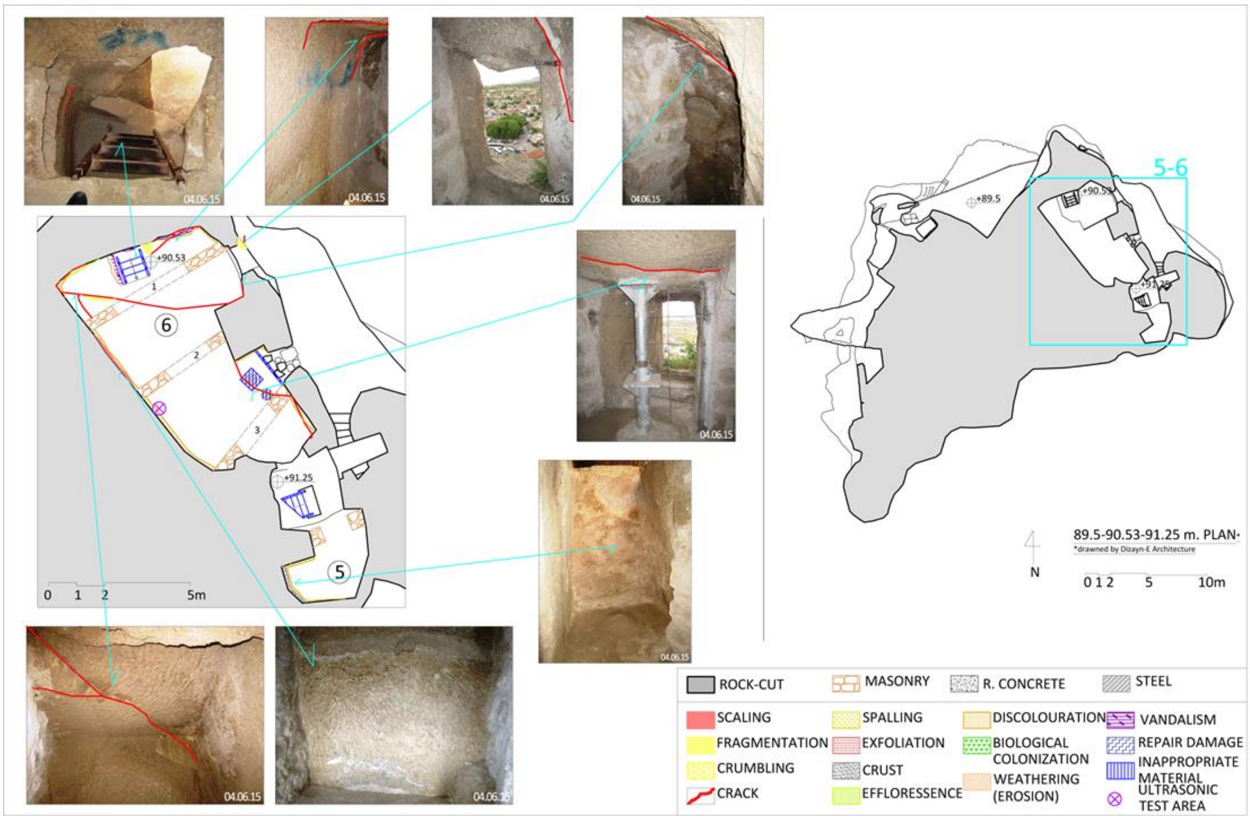

***Figure 4**. Damages and deteriorations in the space 5 and 6*

There are damages originating from Vandalism and discoloration on the west wall of tunnel in space 6. There are fragmentation and crack on the tunnel's east wall (Fig. 4). Masonry arched walls in the space 6 was numbered for defining the place of deteriorations apparently.

Damages and deterioration in the space 6 are as follow. There are various cracks, efflorescence, discoloration and vandalism effects on the north wall of the area until the first masonry wall. There are scaling and discoloration on the west wall of the area between the 1^{st} and 2^{nd} masonry walls. The fracture on the ceiling of this area continues along the border of the window of this area. The window has fragmentation, too. There is discoloration on the west and north walls of the area between 2^{nd} and 3^{rd} masonry walls and cracks exist on the ceiling. Window in the area is closed with inappropriate iron chains. There are inappropriate steel columns in front of the window. Discoloration on the east wall and cracks on the ceiling of the area between 3rd masonry wall and space 5 are seen (Fig. 4).

There are repair damages resulting from cement mortar on the staircase, which gets people to space 15. In addition, the pipe railings on the staircases are inappropriate. There is biological colonization on the outer surface of the space 15. Algae, lichens, mosses and plants are main colony types on the surface. There are

inappropriate attachments like iron chains out of the window and pipe railings. Other damages, degradations and deteriorations in space 15 are as follow (Fig. 5).
There are two different levels in the space 15. At the level +82, 6 m, north wall has discoloration; west wall has fragmentation and discoloration. At the lev-el +83, 2 m, there are spalling and discoloration on the ceiling. There are two different area in the space 17, at the +75, 65 m level. Cracks in these areas sometimes convert into fractures and continue on the outer sur-face of the space. A masonry-arched wall was constructed during restoration to avoid rock falling due to fractures and fractures filled with mortar (Fig. 5).

The space 17 is divided into east and west parts based upon the rock wall in the middle of the space. At the west area, there are crusts on the ceiling and south wall of it and fragmentation on the east wall. Fractures exist on the ceiling and floor. At the east area, all walls have discoloration. There are spalling on the south wall and fractures on the ceiling (Fig. 5).

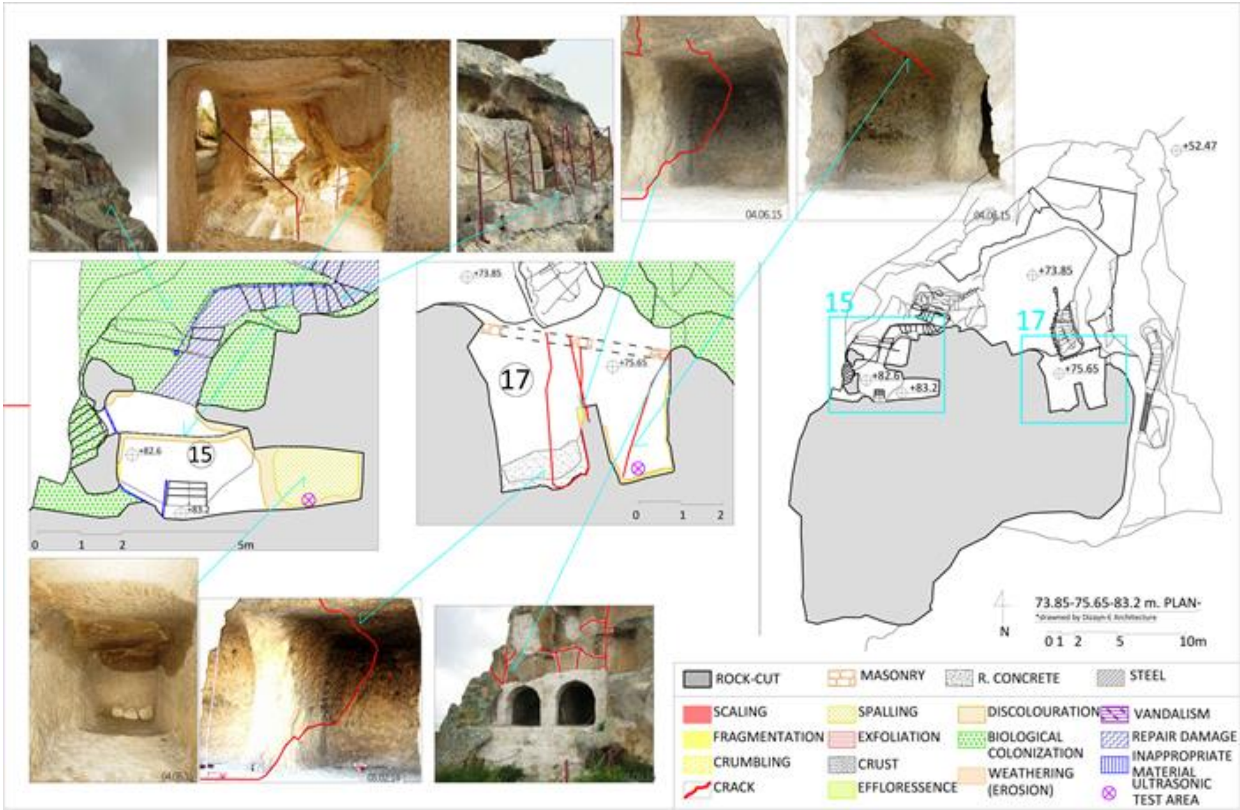

***Figure 5**. Damages and deteriorations in the space 15 and 17*

In the space 19, at the +71, 05 m level, discoloration and the scaling are seen on the west wall; spalling and discoloration exist on the north wall (Fig. 6). The space 20, at the +71, 05 m level, is divided into north and south parts based upon masonry-arched wall in the middle of the space. At the north area, cracks on the ceiling continue on the ceiling of the corridor, which is at the +70, 8 m level. There are crusts on the west wall, spalling on the ceiling, efflorescence and discoloration on the north wall of this area At the north area of the space 20, there are cracks on the ceiling, south and west walls. Crusts exist on the west wall, too. All walls have discoloration and spalling in the space 21. There are fragmentation and cracks on the ceiling (Fig. 6).

Spalling and crack exist on the ceiling of the space 22. A masonry wall was constructed in front of the northeast wall of this space. Southeast wall has discoloration and efflorescence. There is discoloration on the southwest and northwest walls (Fig. 6).

Two gaps in the space 23 were closed with masonry walls. Fragmentation exists on the entrance gap. There are spalling on the west wall and discoloration on the north and east walls. Discolorations exist on

the ceiling, west and east walls of the corridor, at the +70, 8 m level. There is spalling on the east wall, too. Staircase that gets people to upper parts of the corridor has repair damage due to using cement (Fig. 6).
In addition, ladder gets people from lower parts to corridor and railings are inappropriate due to its material and style. Inappropriate steel columns exist in the space 21, 21, 22 and 23 to avoid rock fall by reason of cracks (Fig. 6).

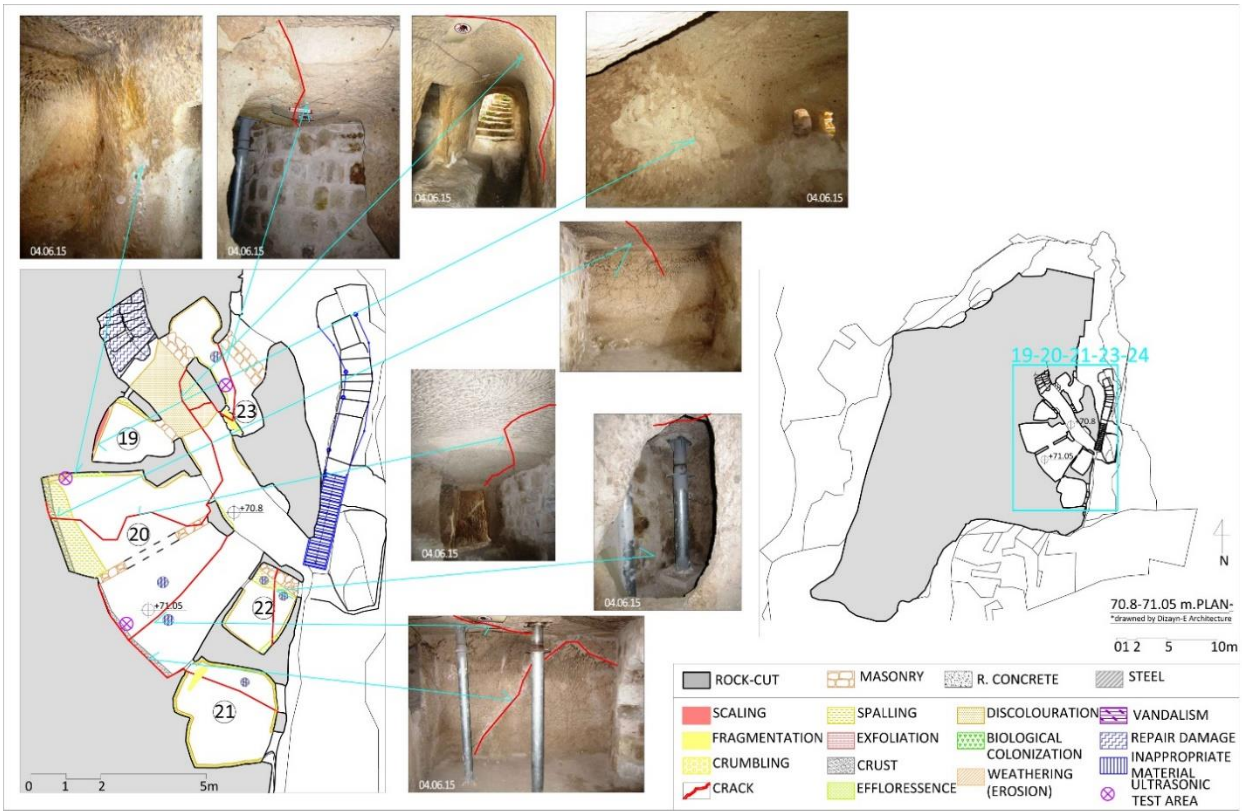

Figure 6. *Damages and deteriorations in the space 19-20-21-22 and 23*

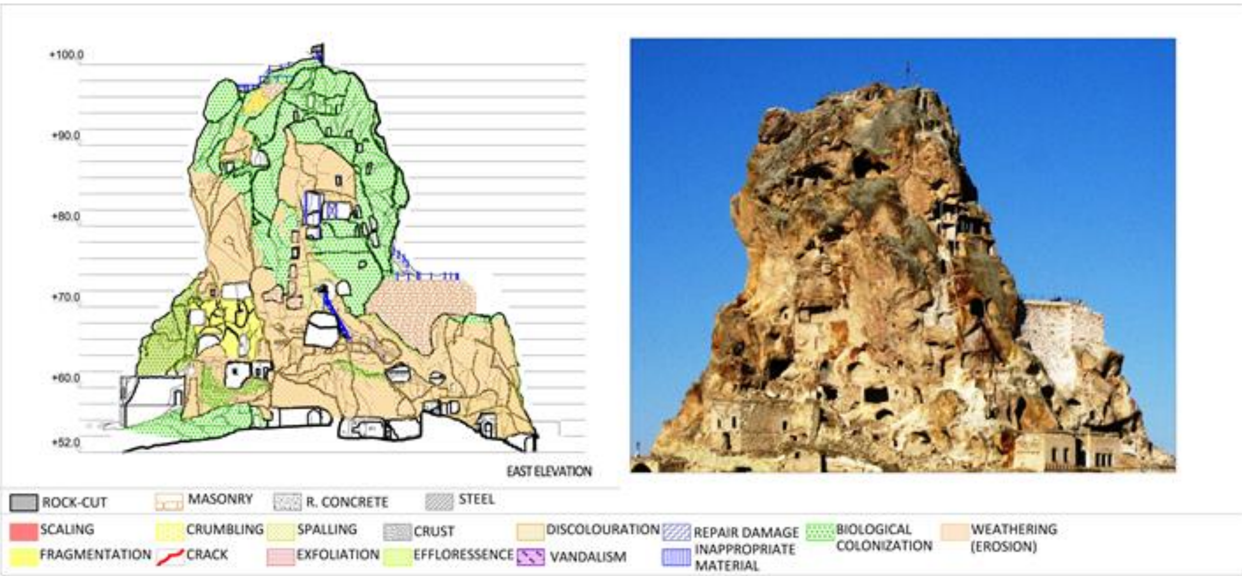

Figure 7. *Damages and deteriorations on the east elevation*

On the east elevation of the castle, biological colonization like algae, lichens, mosses and plants, weathering (erosion) and spalling exist between the +52, 0-60, 0 m levels. Between the +60, 0-90, 0 m

levels there are biological colonization, discoloration, fragmentation, spalling, weathering and inappropriate steel columns (Fig. 7).
Some windows on the elevation were closed with masonry walls. Crumbling, weathering, spalling, biological colonization and inappropriate annexes are seen between the +90,0-100,0 m levels. Walls of the terrace between +64, 0-74, 0 m levels were renewed during restoration (Fig. 7). Other elevations have similar deterioration and damages on.

3. MATERIAL CHARACTERIZATION OF ORTAHISAR CASTLE

Various on-site and laboratory tests were made for understanding and explaining the material characterization of Ortahisar Castle.

3.1. On-Site Tests and Results

On-site measurements were made during the February and July of 2014 for evaluating space and material features of the nine accessible space in the castle. Temperature and moisture measurements actualized on the rock surface, measurements of temperature and relative humidity in the space realized with on-site tests. In addition, ultrasonic pulse velocities (UPV) of material were measured in some spaces.

Naming of each test was made by adding OK in front of the space number like OK-15.

Rock surface temperature (T, ^{o}C) and moisture (R, %) were measured with the Protimeter Surveymaster device. Temperature (T, ^{o}C) and relative humidity (RH, g/m^3) in the space were measured with thermometer and moisture meter. Value of the test result is the mean of all measurement of test place. Outdoor mean temperature in February is 0, 9 ^{o}C, mean relative moisture is 68, 3 g/m^3. In July, the outdoor mean temperature is 20, 1 ^{o}C, mean relative moisture is 48, 0 g/m^3.

According to data of Table 1, surface temperature is more than space's during the winter and summer. Surface moisture is lower than space relative humidity. While outer mean relative humidity is higher than rock surface moisture and space humidity during February and July, outer temperature is lower than spaces' and surfaces'. In the spaces like OK-5, OK-6 and OK-23, which have discoloration and spalling on its walls or ceilings, have 100 percent surface humidity.

Table 1. *Mean temperature, moisture, relative humidity and ultrasonic pulse velocity (UPV) values*

Place	Rock Surface				Space				Ultrasonic Pulse Velocity (m/s)	
	Mean Surface Temperature(°C)		Mean Surface Moisture (%)		Mean temperature (°C)		Mean Relative Humidity (%)			
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
OK-05	3	31	28	21	1,3	27,5	57	31	-	-
OK-06	3,5	30	34	19	0,6	28,2	57	30	1833,7	1016,3
OK-15	3	30	24	22	0,3	28,1	58	28	857,6	968,9
OK-17	3,4	30	16	16	0,6	27,1	57	27	2149	1152,9
OK-19	2,9	31	27	22	0,8	25,4	62	28	112	874
OK-20	2	30	22	14	0,8	28	59	25	111,9	1369,9
OK-21	2	30	16	14	0,7	25,7	59	29	-	-
OK-22	1,5	30	24	14	0,7	25,7	59	30	-	-
OK-23	4	29	45	24	1,9	25,7	58	30	1163,7	1166,4

Situation of gaps (voids) in the material was evaluated with ultrasound pulse velocity (UPV) test. The places of UPV test are shown on the Figures 4-5-6. The test was made with a device, which is identified in ASTM D2845 [3]. Tests could not be done on some surfaces. Whole values are seen on the Table 1.

According to Table 1, UPV values of rocks (except OK-06 and OK -17) in winter are lower than values in summer. Accordingly, it was supposed that gaps (voids) of OK-06 and OK-17 are more filled during winter than during summer. On the contrary, gaps of OK-15, OK-19 and OK-20 are more filled in summer than in winter. OK-23 has a balanced gaps filling in winter and summer.

3.2. Laboratory Tests and Results

Three samples, OK-15, OK-20 and OK-23, were taken from different levels of Ortahisar Castle. Samples' physical and mechanical tests were done in the Yıldız Technical Building (YTU) Material Laboratory. Chemical, petrographic and mineralogical characterization tests were made by the Istanbul Technical University Geological Survey Laboratory (ITU JAL) team.

3.2.1 Physical and Mechanical Characterization and Results

Methods defined in TS EN 1936 [5] was used to determine physical features as apparent and real density, compactness, total and open porosity of samples. Obtained results are shown on the Table 2. Saturation (open porosity / total porosity) was found with the values of open and total porosity [6]. Color values specified with Konica Minolta CM, defined in the TS EN 15886 [7], and Munsell Color Chart.

Table 2. *Features of physical and mechanical characteristics of OK-15-20 and 23*

Sample	Physical Characteristics							Mechanical Characteristics
	Apparent density (β,g/cm^3)	Real density (γ,g/cm^3)	Compactness (k, %)	Total porosity (p, %)	Open porosity (A_h, %)	Saturation (D_d, %)	Color (value)	Compression strength, MPa
OK-15	1,5	2,3	64,74	35,26	20,37	57,78	orange-yellow	9,55
OK-20	1,6	2,3	70,78	29,22	17,79	60,90	orange-yellow	31,77
OK-23	1,5	2,3	66,48	33,52	24,74	73,82	orange-yellow	14,23

Capillary water absorption capacities of samples, on the Table 2, were found according to methods of TS EN 15801 [8]. Samples' water desorption (Table 2) specified with the method in the ICCROM Laboratory Handbook [9]. One of the mechanical properties of samples, uniaxial compression stresses, were determined with the methods defined in TS EN 1926 [10]. Values of them are on the Table 2.

According to physical and mechanical data, the apparent density of the castle's material is between 1, 5-1, 6 g/cm^3 and real density of it is 2, 3 g/cm^3. OK-23 sample has the highest open porosity with the amount of 24, 74 %. The highest total porosity belongs to OK-15 sample. In that case, it is clear that sample OK-15 has closed pores than other samples. Also, OK-15 has the lowest compactness with the percentage of 64, 74. Saturation level is important for deciding on freeze-thaw resistance of materials. The saturation ratio under 80 % means durability against freeze-thaw cycles [6]. Accordingly, all samples have freeze-thaw durability. In addition, color values of all samples are orange-yellow.

Capillary water absorption capacity (Q_i, kg/m$^2\sqrt{s}$) of samples were obtained from the graphic curves of the changing amount of water absorption of each sample from unit area (kg/m^2). Ascending sort of samples' capillary water absorption capacity is OK-20 (0, 086) < OK-15 (0, 104) < OK-23 (0, 136). Open porosity values support this result.

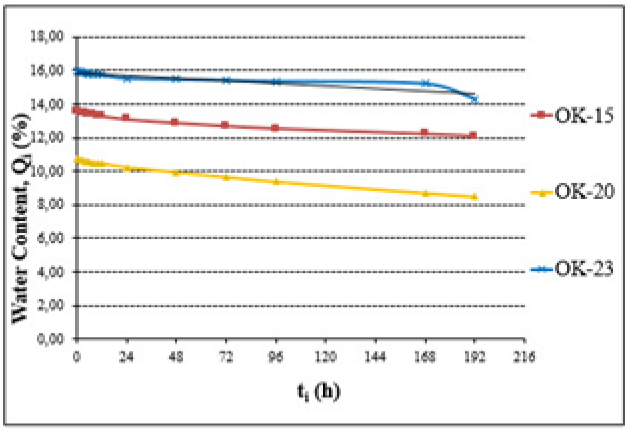

Figure 8. *Water desorption of OK-15, OK-20 and OK-23*

The changing percentage of water desorption of each sample in unit of time is shown on the Fig. 8. According to Fig.8, quickest water desorption ratio belongs to OK-20 and OK-23 has slowest desorption. If the sample has low open porosity, its water desorption is high.

Uniaxial compression stresses of samples are changing between 9, 55 and 31, 77 MPa. OK-20 has the highest one. According to Yıldırım and Gökaşan's [11] classification of rock compression strength, OK-20 is in the semi-hard rock group, OK-23 and OK-15 are in the weak rock group.

3.2.2 Chemical-Petrographic and Mineralogical Characterization and Results

Chemical, petrographic and mineralogical characteristics of OK-15, OK-20 and OK-23 samples were investigated through thin section, X-ray diffraction (XRD) and X-ray fluorescence (XRF) analyzes.

OK-15 macroscopic analysis: The sample is very breakable and its hardness is varying. When aqueous solution with 10 percent HCl dripped onto the sample, there was no reaction. It is a sign of non-being of carbonate group minerals like calcite and dolomite [4].

OK-15 microscopic analysis: Sample has a volcanic porphyritic-glassy tuff texture, contains slight amount (30-35 %) of mineral and rock spall (aggregates), more of it is matrix (binder). Aggregates consist of plagioclase, amphibole, quartz low and sanidine (a type of K- feldspar) and biotite. Most of the matrix possesses a similar characteristic with volcanic glass. Volcanic glass has secondary conversions (Silica-Mika- Chlorite conversion) (Fig. 9)[4].

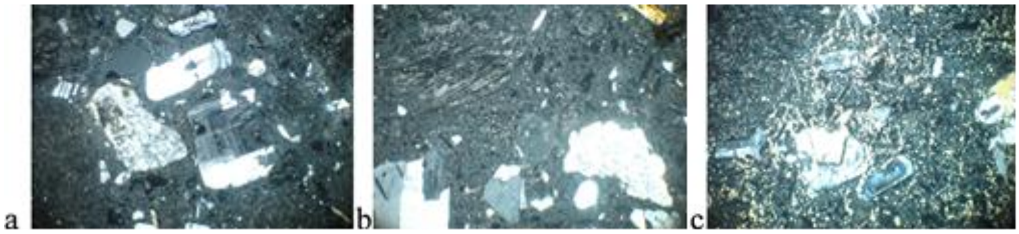

Figure 9. *Photomicrograph of OK-15 **(a)** OK-20 **(b)** and OK-23 **(c)** sample (double Nicol, width 4mm)* [4]

OK-20 macroscopic analysis: The sample has various grain sizes. There was no reaction when aqueous solution with HCl dripped onto the sample as a sign of non-being calcite and dolomite [4].

OK-20 microscopic analysis: Sample has a characteristic of tuff. It contains approximately 30 percent of mineral-crystal spall and 70 percent of matrix. There are secondary conversions in matrix. It consists of microlites of plagioclase and volcanic glass. Aggregates consist of quartz low, quartz, plagioclase, sanidine, mica, and opaque (nontransparent) minerals. All aggregates are eroded and lost lose their original shapes (Fig. 9) [4].

OK-23 macroscopic analysis: The sample has medium grain size and is very breakable. After dripping the aqueous solution with HCl, there was no reaction, which is a confirmation of non-being calcite and dolomite [4].

OK-23 microscopic analysis: Sample has a volcanic porphyritic texture. The proportion of matrix is around 75-80 percent and comprises microlites and volcanic glass. Aggregates consist of quartz, quartz low, plagioclase, biotite, amphibole and sanidine (Fig 9) [4].

Table 3. *Mineral ratios of the rock samples OK-15, OK-20 and OK-23*

Sample	Opal	Quartz	Albite	İllite	Amorphous Mineral
OK-15	~5	~2-3	~75-~80	~3-5	~10
OK-20	~70-~75	~5-~10	~3-~5	~3-~5	~10
OK-23	~75	~5	~10	-	~10

Mineral ratios of the rock samples of Ortahisar Castle, were obtained with XRD analyses, are seen on the Table 3.

Table 4. *Major oxide ratios of OK-15, OK-20 and OK-23*

Formula	Major Oxide Ratio		
	OK-15	OK-20	OK-23
SiO_2	72,20	78,50	66,10
Al_2O_3	11,91	8,86	9,76
Fe_2O_3	1,55	0,86	5,02
MgO	0,34	0,20	0,23
CaO	1,58	1,32	1,05
Na_2O	1,19	1,12	1,27
K_2O	4,69	3,95	4,40
TiO_2	0,19	0,16	0,16
P_2O_5	0,03	0,02	0,02
MnO	0,06	0,05	0,05
Ba	839 PPM	1095 PPM	985 PPM
LOI	5,67	4,56	8,27

The major oxide amounts of samples, were supplied with XRF analyses, are shown on Table 4.

According to chemical, petrographic and mineralogical analyses, SiO_2 amount is the highest of major oxides in the three samples of Ortahisar Castle. According to igneous rock type classification of Helvacı and Ersoy [12] if the rock has an amount of SiO_2 more than 66 % of total major oxide, it is an acidic (felsic) rock. Therefore, all samples are acidic due to their SiO_2 ratio. It is foreseen that albite (a kind of Na-Feldspar), opal, quartz, illite or amorphous minerals that contain silica constitute the SiO_2 amount in the samples. Al_2O_3 has the second highest ratio in the major oxides of the samples. It is perceived that albite and amorphous minerals constitute Al_2O_3 ratio and the proportion of other oxides in the samples.

Samples do not contain smectites, are known to be swelling clays. In addition, there is not calcite or dolomite in the samples as it was foreseen after samples were checked with HCl during the macroscopic analysis.

Illite has the feature of swelling due to water or cation exchange but the illite ratio of the samples around 3-5 percentage. Due to little amount of illite, swelling possibility is low for the samples, but cannot be ignored. OK-23 does not have illite and there were not secondary conversion within that sample. Namely, it was thought that biotites in the sample have not converted into illite yet. OK-15 and OK-20 samples have porphyritic texture and this may induce or accelerate the process of deteriorations like crumbling, weathering, spalling and exfoliation. Moreover, existence of quartz low indicates that the rock was formed at various temperatures below 573°−1000°C [13].

4. CONCLUSIONS

Rock-cut structures are one of worth preserving structure type among world heritage structures. They have outstanding value confirmed by UNESCO and need the attention of people for their preservation and sustainability. Damages and deteriorations on these structures have to be minimalized and be transferred to the next generations safely.

To minimize the type of deterioration like spalling, weathering (erosion) and discoloration on the rock structures, it should be checked whether the cation absorbent minerals or water in the structure. If these damages occurred outside of the structure, it should not intervene for oxidation shell, which occurs naturally. Then a surface with (less) harmless lichens should be provided to decrease spalling and weathering. Applying water-repellent agent to the rock surface not beneficial for rock and causes cracks [14]. Although mosses, algae and lichens cause biological deterioration on the rock-cut structures, removing them from the surface is not recommended. Some biological formations especially lichens constitute only 1 cm thick in 300 years [15] prevent spalling, exfoliation, crumbling and weathering. It should be checked whether the absorbent minerals or water in the rock-cut structure to prevent the structure from crust and efflorescence.

Cracks in the rock-cut structures are very important damages in terms of rock falls and any kind of damage or deterioration around cracks affect it adversely. To decrease crack damages, first should be looked at another kind of damage-deterioration around the crack. The reason of cracks may be intrinsic properties of the crack, ground subsidence or natural disasters. The reason should be identified with endoscopic examinations if necessary. After the cause of cracks identified, the condition (status) of crack should be monitored with movement meter whether movement exist or not. If cracks are moving can be used temporarily annex underpinning. If necessary to construct annexes, it should be made of compatible materials with rocks such as stone. It is not recommended to use the materials, which can corrode, due to moisture like steel and thermal expansion coefficient is not the same with rock. In that case, it is not recommended to use steel materials in rock-cut structure [16]. Bolting or pricking cracks with steel plaques is not recommended due to low hardness of rock and non-compatibility between steel and rock [17]. If there is risk of freezing water inside the cracks, it is suggested that cracks should be filled with a compatible mortar. After and before this process, cracks must be checked.

Fragmentation usually occurs around the cracks. Movement meter can be used for monitoring it and an appropriate underpinning should be made if necessary or fragment should be dropped in a controlled manner. Controlled dropping is the last option for fragmentations. To avoid the repair damage, intervention decisions should be taken under the supervision of experts. Grouting, covering and part completion applications made with plaster should not be used in rock-cut structures if they have any kind of salty content. It must be taken care of each repairs have to be reversible. It should not be forgotten that especially rocks including illite and smectite, moisture retention might occur. Limiting the number of visitors in places is useful in reducing damage resulting from moisture.

Rock-cut structure is a structure type continued to function in Anatolia and all over the World. Rock-cut building regulations and standards must be established for transferring the historical value to the future generations, ensuring cultural continuity and creating sustainable spaces provide new life opportunities for people with history.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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