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Damage Assessment and Mortar Identification in Beylerbeyi Palace

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ABSTRACT

The historical building stock and seismic risk of Anatolia draws considerable attention of the engineers for studying the construction techniques and the earthquake performance of these structures. This study is dealing with the 145 years old Beylerbeyi palace. Within the study architectural features and the construction technique of the palace are introduced and the existing condition of the structure is investigated. The observed damages are classified and the possible sources of these damages are discussed. The final stage is the chemical analyses, performed over the mortar of the structure. Thin section analyses, Scanning Electro microscope analyses, Energy Dispersive X Ray Analyses and X-Ray Diffraction Analyses have been applied over ruins of Beylerbeyi Palace. The results of the analyses have been used to determine the origin of the mortar.

Key Words: Historical structures, Damage evaluation, Horasan mortar, Mortar investigation.

1. INTRODUCTION

With its permanent occupancy, Anatolia is the cradle of civilization. There are many historical buildings and monuments spread over every corner. Every city in Turkey has many historical structures, built especially in Seljuk, Byzantine and Ottoman times. With their magnificence many structures are defying the centuries. For the modern engineers and architects construction techniques of the old structures are always in importance with respect to both the lessons taken from them and conservation work to make them stronger against aging and earthquake effects.

This study is grown up as the initial step of a broader one which aims to investigate the earthquake performance of Beylerbeyi palace. In this paper existing condition of the palace with respect to damage and the historical mortar investigation are explained. Identification of the existing damages would be very helpful for the assessment the necessity of the immediate restoration work and prevention of the propagation of the damages. Secondly mortar identification is essential for several reasons, such as, determination of origin of the material, mechanical properties of the material, and determination of appropriate restoration materials. Before starting to elaborate the damage and structural system of Beylerbeyi Palace it would be valuable to summarize the history and general architectural features of the structure.

2. HISTORY AND ARCHITECTURE OF THE STRUCTURE

Beylerbeyi Palace is the largest and the most elegant Ottoman palace on the Asian shore of the Bosporus. It was constructed between 1861 and 1865. The palace was generally reserved for summer use by the sultans or to accommodate foreign heads of state visiting the Ottoman capital. The palace is shown in Figure 1.

Figure 1. Beylerbeyi Palace.

The palace consists of two main floors and a basement containing kitchens and storage rooms. In the basement floor storey heights vary between 1.5 m. and 2.2 m. whereas in regular floors, storey heights change between 6 – 9 m. It has three entrances, six state rooms and 24 smaller rooms. The building has a 72 m length along the shore 48 m in the perpendicular direction [1]. It is divided to two parts as Mabeyn and Harem. Mabeyn is the name of the official part on which the imperial works were carried out while is the private part on which sultans live with their families. These two parts have different entrances.

The load bearing system is mainly made of masonry walls and timber slabs. The basement floor of the Harem part enables to identify the masonry which is composed of lime mortar, brick and stones. These walls are also forming the foundation system of the palace. The timber floor is also visible. It is determined that the slab of the structure is mainly composed of two types of timber cross-sections. 20*20 cm^2 beams (supporting beam) were located on the masonry walls and 8*40 cm^2 beams (slab beam) with 40 cm spacing lie between two walls perpendicular to wall direction. Oak was used for the supporting beam while slab beams were produced from fir. Figure 2 shows the details from that floor [1].

Figure 2. Foundation of the palace.

The first and second storey of the structure is made of masonry walls, consists of lime mortar and brick, marble and wood columns and timber slabs. The thickness of the walls in the first storey is generally 80 cm while it is 60 cm in the second floor. Cast iron clamps were used within the walls to increase the out of plane stability of the structure. The exterior face of the structure was covered by “küfeki” stone while interior faces were veneered with stucco and lime plaster and timber cover.

The roof of the palace verifies the slab configuration in the basement. On the other hand the first story slab configuration could not be examined. Figure 3 illustrates the interior side of the roof of the palace.

Figure 3. Structural wall and timber slab in the roof of the structure.

3. DAMAGE ASSESSMENT

A detailed damage survey was carried out in the palace. It should be emphasized that the structure is under the protection of the state establishment, Regional Directorate of National Palaces. The directorate has great effort and spends valuable time to save the structure against aging and atmospheric conditions. In that respect many minor restoration works have been carried out for both interior and exterior sides of the structure.

The basement floor of the structure is divided into two parts with different entrances. This floor is used as officers' room and storage purposes in the mabeyn part while in the harem a small portion of the basement is used as only storage purposes and other bigger portion is functionless. Damage survey of the basement floor is especially gathered on that functionless part on which the construction technique of the structure is clearly understood. Thicknesses of the walls are changing between 2 m and 1 m and it is often 1.4 m on that floor. High humidity existence is monitored on that part although it has several ventilation openings. Figure 4 illustrates one of the ventilation openings on the foundation while high humidity is shown in Figure 5. The high level of humidity affected both the timbers, forming the slab system by causing decay and the masonry walls by causing cracking. Figure 6 shows the chipped timber members in order to prevent the propagation of the decay. It is obvious that ventilation openings in Beylerbeyi Palace are not adequate to prevent high humidity. Recent studies have revealed that ventilation by using the appropriate machinery equipment can be used as a solution against high humidity [2].

Figure 4. Ventilation opening in the foundation floor.

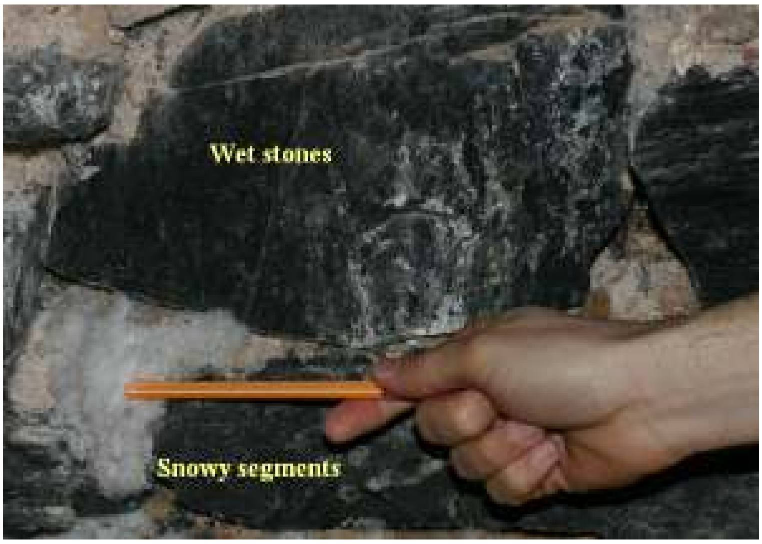

Figure 5. High humidity over stones and its effects.

Figure 6. Chipped timber beams due to decay on the foundation floor.

On the first and second floors of the structure several cracks were observed. Since no restoration process has been carried out in the mabeyn part of the palace, everything is original. On the other hand in the harem part of the palace repair works were performed to cover the cracks. For this reason most of the detected cracks are in the mabeyn part on the stucco plaster. Since the reproduction of stucco plaster is impossible nowadays, authorities do not touch the cracks to repair them. Similarly the timber coverings of the rooms in mabeyn part have very wide cracks which make it hard to interpret their effect over structural safety. If the cracks stem from the damage occurred on the wall beneath the covering, special care must be taken. Other wise these cracks are harmless and they only disturb the beauty of the rooms. Through Figures 7 – 9, the observed cracks are shown. The cracks can be classified into three categories as follows:

- The horizontal cracks,
- Vertical cracks on the side of the windows,
- Inclined cracks on the corners of the openings.

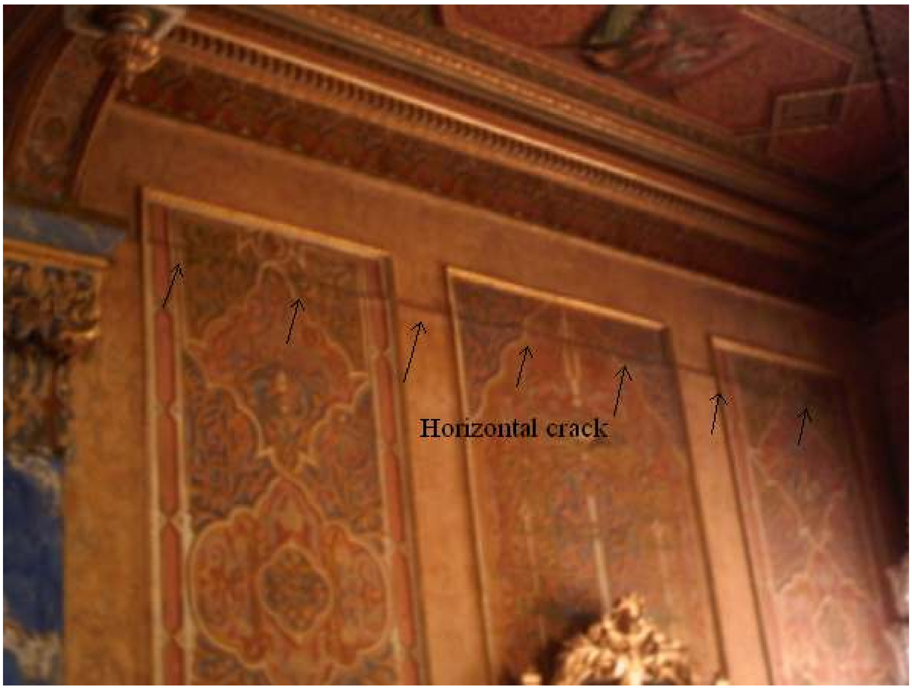

Figure 7. Horizontal crack in the Mabeyn part.

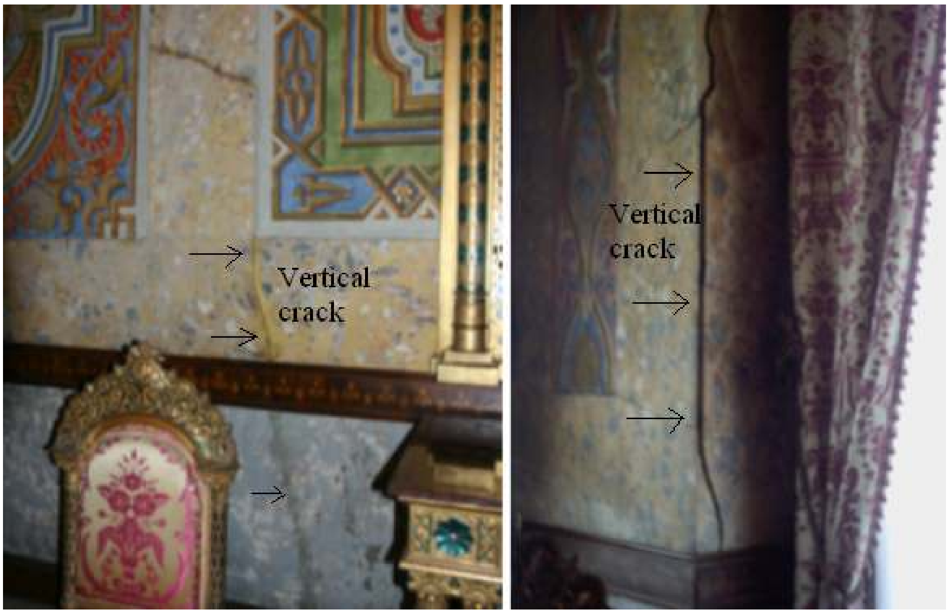

Figure 8. Vertical crack in Mabeyn part.

Figure 9. Inclined cracks on the corners of the door.

Not only is the existence of the damage but also their reasons are in importance. The existing damages may stem from the horizontal earthquake loads, ground settlements, or aging and atmospheric conditions. The palace experienced two strong earthquakes (1894 and 1999) since it was built. As mentioned the palace has timber floor system which is not adequate to supply rigid diaphragm action on the floor levels. In this condition the horizontal cracks can be induced by the out of plane movement of the walls whereas the inclined cracks at the corner of the openings like windows and doors are the sign of in-plane action under horizontal loads. In this respect it can be concluded that these cracks are probably induced by the horizontal earthquake load. On the other hand stress analysis by using an efficient computer package program is essential for a certain conclusion.

The site on which the palace is sitting has a detailed site investigation report prepared in 2005. The report identifies three different layers of the soil at the inspected site. From top to bottom layers were addressed as C type, B type and A type soil in NEHRP classification. It is guessed that the weaker soil was removed at the construction phase and the structure was built on stronger soil which is classified as B type [3]. Construction of the palace on such a strong soil reduces the chance of ground settlement as a possible source of observed damages.

Another type of damage is caused by the metal clamps placed within the masonry walls. The oxidation of cast iron clamps used within the masonry caused swelling and finally cracking of the wall in a room and stair case in harem part. This damage ended up with the separation of about 50*50 cm^2 wall part in the room as seen in Figure 10. The same fact has repeated the damage in the staircase of harem part. This crack formation is shown in Figure 11. Together with the damages observed of foundation floor, the damages induced by the oxidation of metal clamps can be named as damages caused by aging and atmospheric conditions.

Figure 10. Damage induced by the oxidation of metal clamps before and after the separation of wall part in the room.

Figure 11. Damage induced by oxidation of the metal clamps in the staircase of Harem part.

4. MORTAR IDENTIFICATION

The damages, induced by the oxidation of metal clamps used within the masonry enabled to determine the masonry configuration and have ruins from the original mortar of the structure. Both mortar and plaster particles were taken to analyze the origin of the mortar. The average mortar thickness is about 18 mm and brick height was measured as 65 mm.

More recently developed mortar characterization schemes have optical microscopy as the first step in identifying the aggregates, of various mineral additions, binder type, and binder-related particles and in describing the pore structure. Optical microscopy is also a valuable aid for damage diagnosis of degraded historic mortars and for the study of the interfacial zone, the bonding and possible reaction rims between aggregates, brick or stone and the mortar [4].

A Scanning Electro Microscopy (SEM) analysis together with an X-Ray Diffraction (XRD) analysis is the most valuable second step in the characterization process of historic mortars. SEM analysis can be performed on mortar fragments or on polished epoxy-impregnated sections. With a scanning electro microscope, equipped with an Energy Dispersive X-Ray (EDX) -detector, valuable information can be obtained on the mineral phase composition [4].

For these reasons chemical and mineralogical composition of mortar from Beylerbeyi Palace was determined by Thin-Section analysis, Scanning Electron Microscope-Energy Dispersive X-Ray (SEM-EDX) analysis and X-Ray Diffraction (XRD) analysis.

4.1. Thin Sections, Under Polarizing Microscope

For the characterization of mortar, the study of thin sections under the polarizing microscope is a very efficient analytical technique. A thin section is made by grinding down a slice of rock which has been glued to a glass slide until it reaches a thickness of about 0.03mm (30 microns). At this thickness most minerals become more or less transparent and can therefore be studied by a microscope using transmitted light. In this study five thin sections were prepared and investigated. Figure 12 shows three enlarged views of the prepared thin sections and Figure 13 shows the photograph of a thin section, taken under petrography microscope.

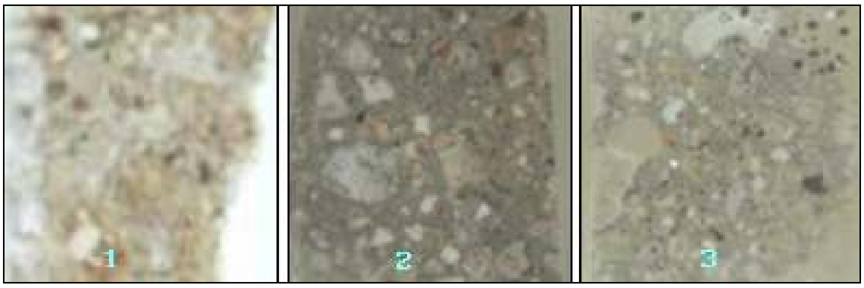

Figure 12. Thin-sections.

Thin-section analysis showed that, about 60% of the mortar is binding material and remaining part is the grains. The general grain size is about 500 µm and less. It occasionally reaches to 1 mm. These grains contain mineral particles, quarts particles and clearly identified brick powder particles. Table 1 summarizes the identified ingredients of the thin-sections.

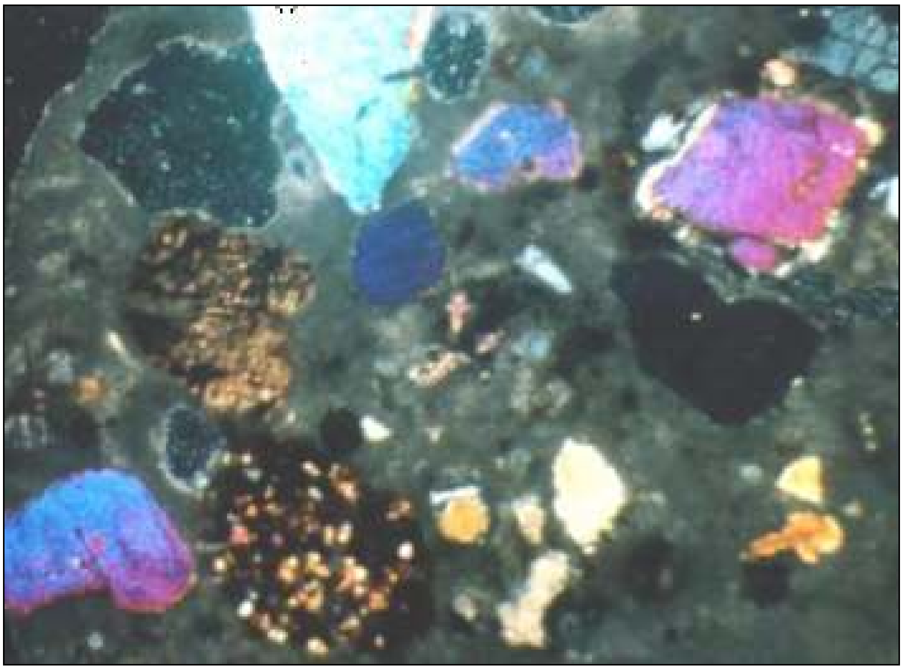

Figure 13. Photograph of thin-section under microscope.

Although the brick powder can be recognized in thin-section analysis, it is hard to say that the determined ratios are the initial proportion of the brick powder since the quarts particles may come from the brick grains. Brick aggregates also contain Calcite [5].

Table 1. Mortar ingredients according to thin-section analysis.

Sample Code	**Components**		
	Binding Material %	Quarts and Calcite Particles %	Brick Particles %
TS-1	50	45	5
TS-2	50	35	12
TS-3	60	30	8
TS-4	65	25	6
TS-5	67	25	6
Average	58.4	32	7.4

4.2. Scanning Electron Microscope Views and Energy Dispersive X-ray Analysis

Scanning Electron Microscope is a widely used technique to study surface topography. The mortar specimens were searched under Philips XL30ESEM-FEG&EDAX, Environmental Scanning Electron Microscope and Energy Dispersive X-Ray device. Figure 14 shows the polished specimens. The first two specimens with bigger grain size belong to the mortar taken between the bricks and the third one is the plaster mortar. Mineralogical structure of the ingredients of the mortar were tried to be identified on enlarged views thanks to EDX.

Figure 14. Mortar specimens, prepared for SEM and EDX analysis.

Good connection between particles and binding material was observed through the SEM views. No gap or cracks were determined. Particle size distribution can easily be determined from SEM views (Figures 15 – 17). It is seen that the grain particle size, used in mortar is grater than that used in plaster. According to SEM views the maximum size is determined as about 1800 µm.

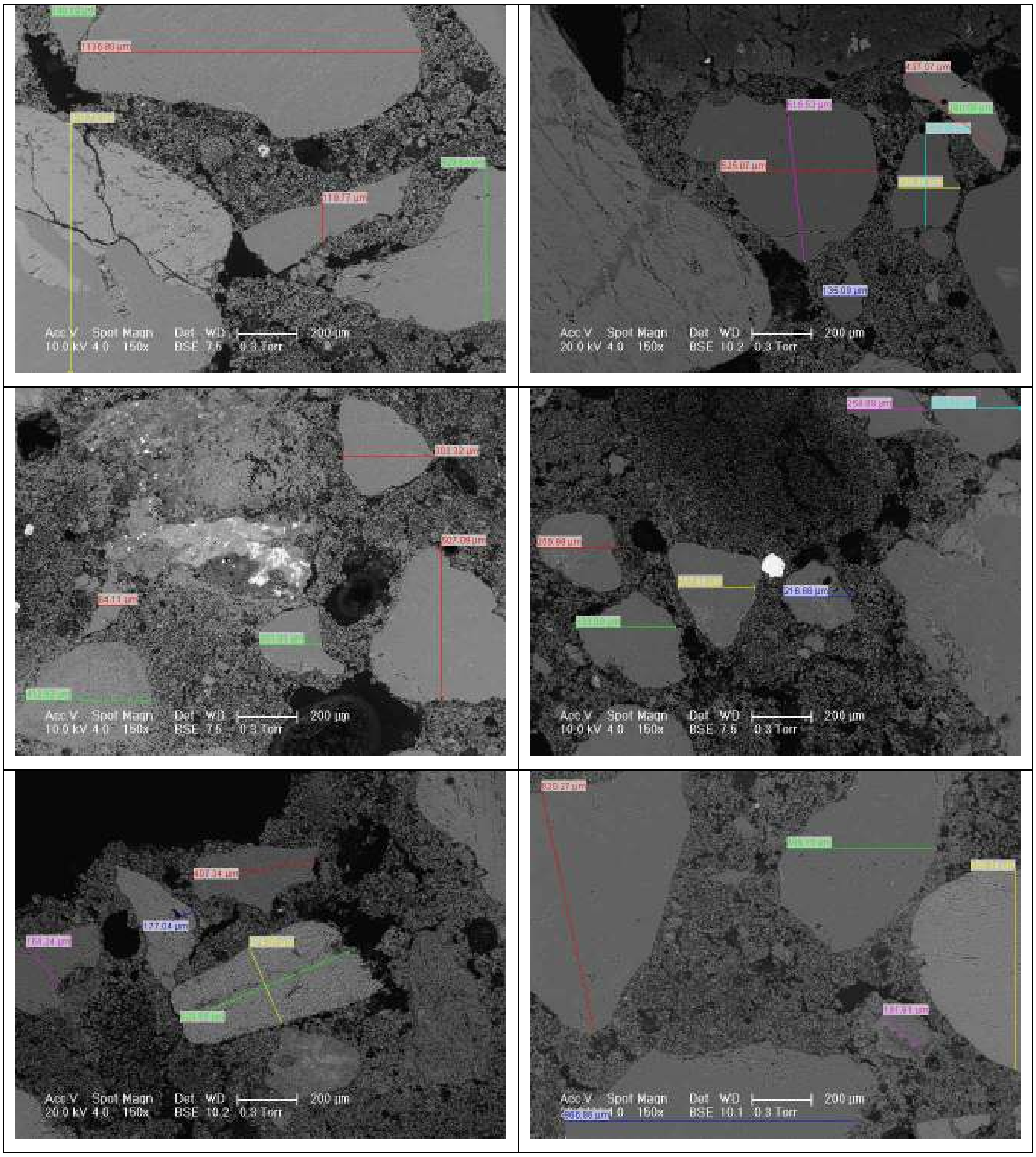

Figure15. SEM views from the mortar between the bricks.

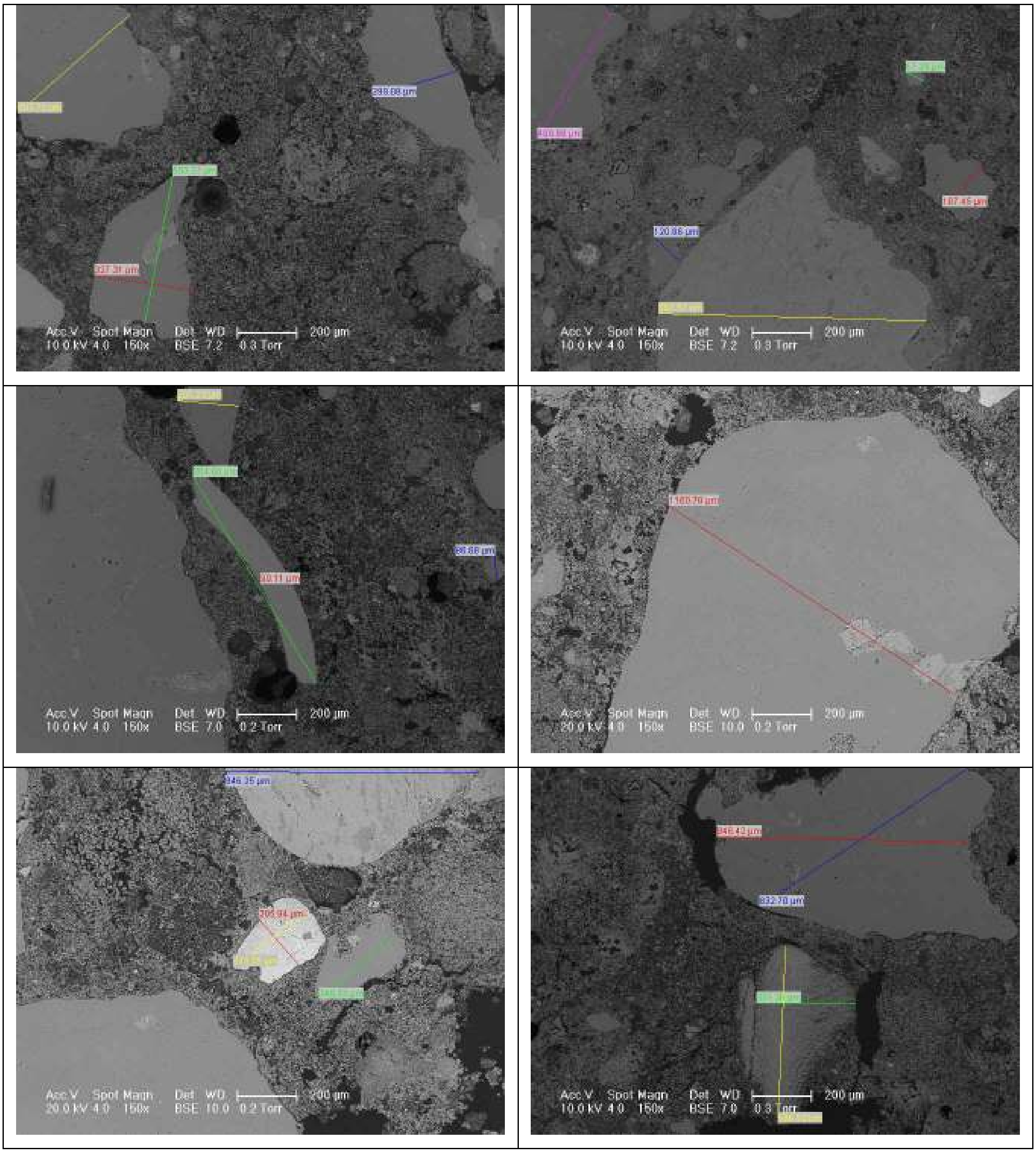

Figure 16. SEM views from the mortar between the bricks.

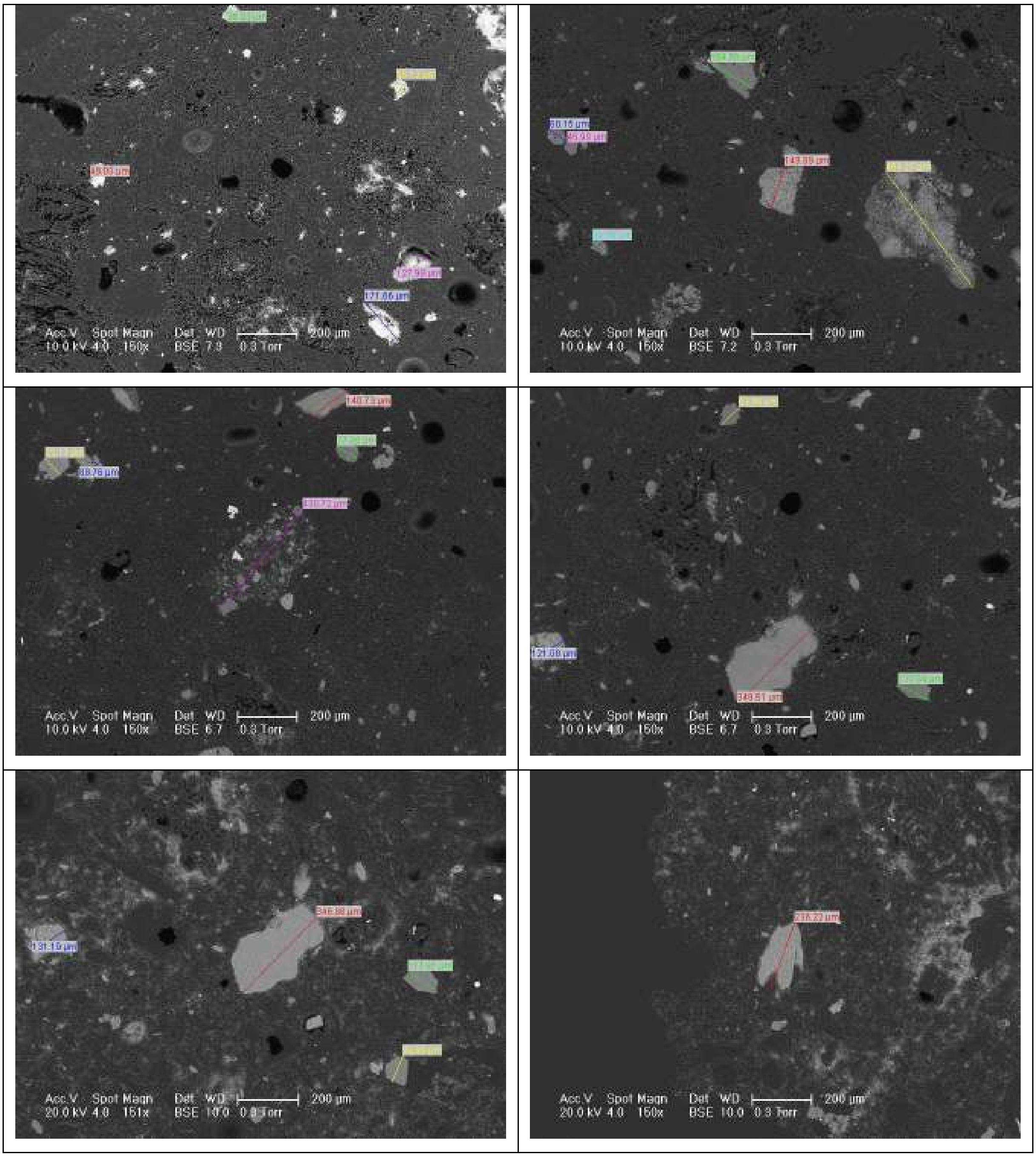

Figure 17. SEM views from the plaster.

The EDX analyses were performed simultaneously with the SEM. It was determined that the mineralogical origin of the particles is quartz, SiO_2 and derived from the aggregates containing sand and brick powder. Figure 18 represents the EDX analysis for a particle, seen in SEM view as in grey colour. Wt % column shows the weight ratio of the each element and oxides. Occasionally feldspar minerals were seen through the EDX patterns of aggregates (Figure 19).

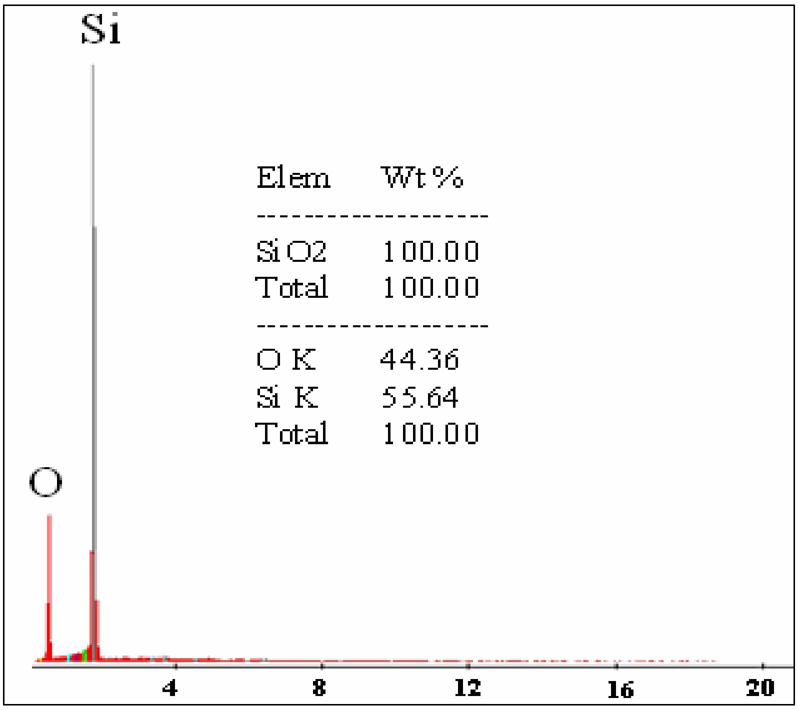

Figure 18. EDX analysis of particle in SEM view.

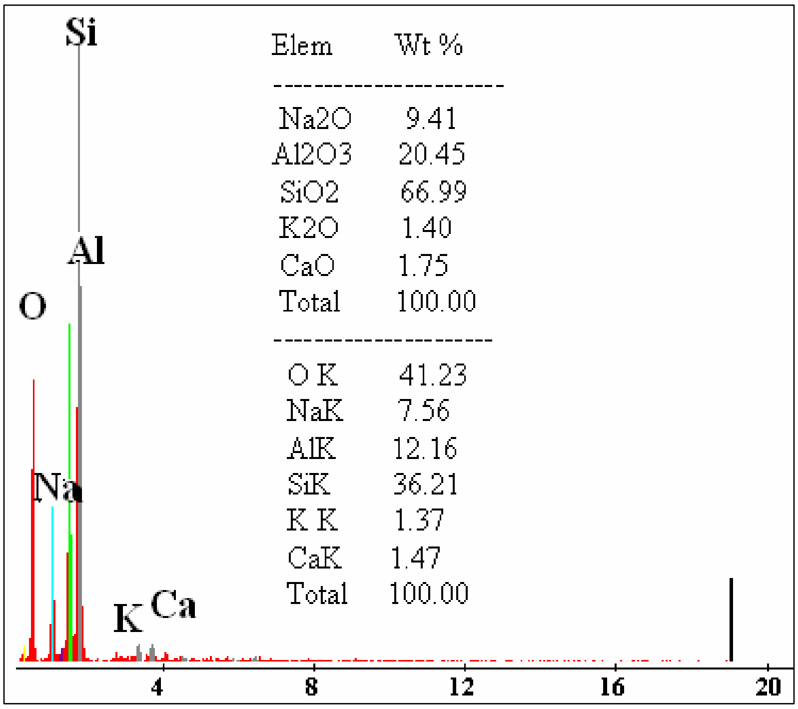

Figure 19. Identified feldspar elements, EDX analysis of particle.

EDX analysis showed that the origin of the binding material between the particles is calcite minerals. Calcite is originated from carbonated lime [5]. Figure 20 shows the EDX analysis, applied to the darker region (binding material) on the SEM view.

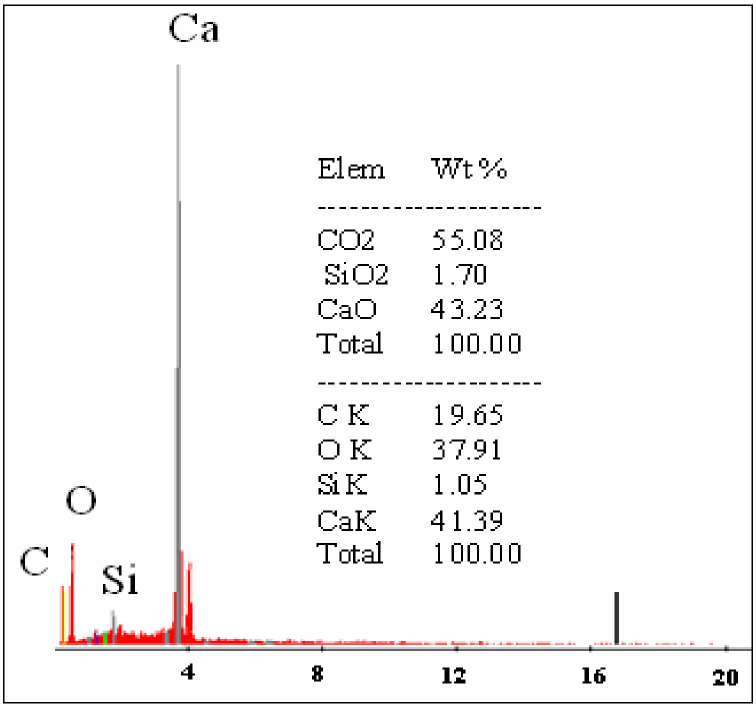

Figure 20. EDX analysis of binding material in SEM view.

4.3. X-ray Diffraction Analysis

X-ray Diffraction (XRD) clarifies the nature of the mineralogical phases present in the sample [6, 7, and 8]. Pulverized mortar specimen were analyzed under Rigaku D/Max-Ultima+/PC XRD device and diffractogram were obtained for each specimens. Figure 21 shows one of the XRD diffractograms. Mineral ratios for each specimen were estimated by using line magnitudes and areas. The results verified the existence of calcite and quarts elements. Six specimens were analyzed and it is seen that each of them consists of quarts, calcite and feldspar minerals with varying ratios. Table 2 summarizes identified component ratios for each specimen. These specimens were taken from the two different room of the palace and all specimens belong to mortar between bricks. The average of ratios indicates that, about 65% of the horasan mortar is calcite derived from carbonated lime, 30% of the mortar is quartz, derived from aggregates, and 5% is feldspar, (Na, K, Ca), $(Si_3Al)O$ elements.

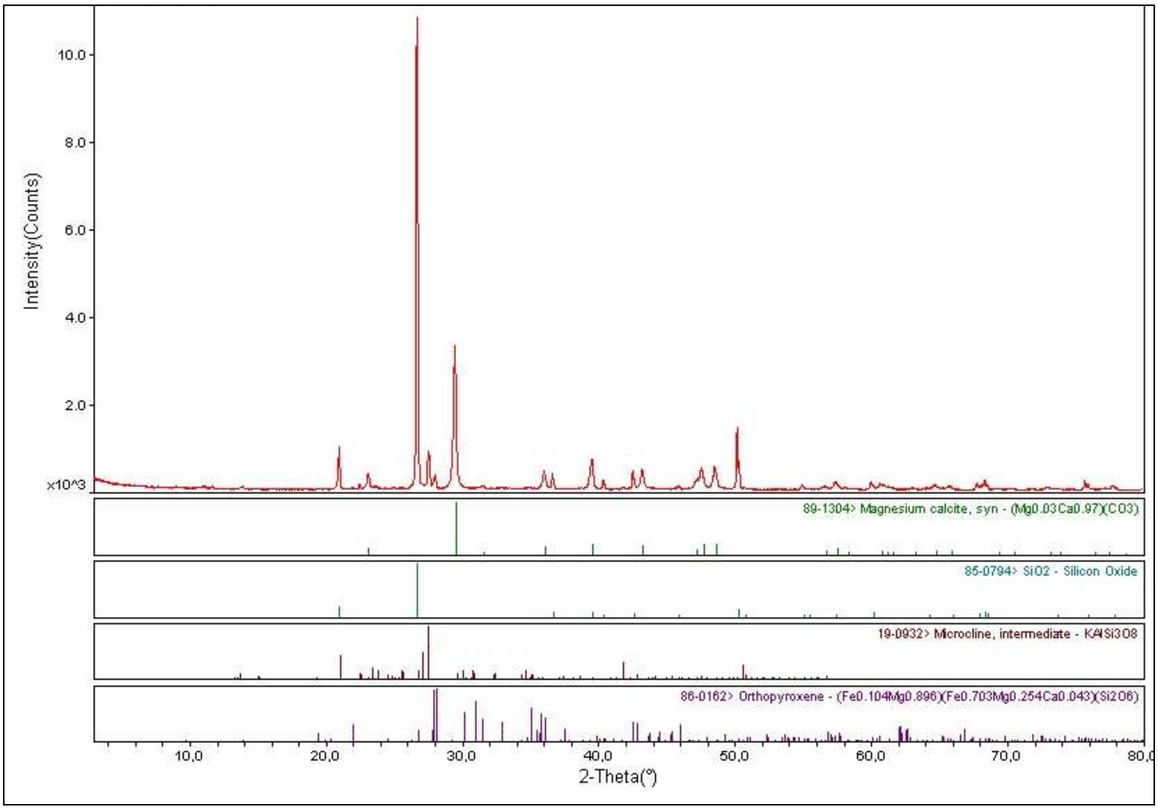

Figure 21. XRD diffractogram of W-02 specimen in Table 2.

Table 2. Mineralogical components of the specimens according to XRD analysis.

Sample Code	**Mineralogical Component**		
	Calcite %	Quartz %	Feldspar %
W-01	60	30	10
W-02	30	65	5
W-03	53	43	4
W-04	85	10	5
T-01	75	20	5
T-02	90	5	5
Average	65.5	28.8	5.7

The findings of the chemical analyses may be compared to similar survey for mortar ruins of Dolmabahçe palace which was built in the same period as Beylerbeyi palace. The analyses showed the ingredients of the mortar of Dolmabahce palace as lime, crushed brick, fine sand marble powder and a type of fibre (in a very small percentage) [9]. In Byzantine, Seljuk and Ottoman time the binding material of construction mortar is carbonated lime while as aggregate, river sand, pebbles, brick pieces and powder have been used together with hay, horse hair and rope which have served as fibres [10]. Although no fibre was found in the mortar of Beylerbeyi palace, the mineralogical components of the mortar of two palaces are the same.

5. CONCLUSION

Damage observations through Beylerbeyi Palace has showed the damages can be categorized into four categories, namely, horizontal cracks, vertical cracks, inclined cracks and damages due to aging and atmospheric conditions. Although the first three categories are the sign of earthquake oriented damages, numerical analyses are required for certain a conclusion.

In order to characterize the mortar of Beylerbeyi Palace, built between 1861 and 1865, Thin Section, SEM-EDX and XRD analyses have been used. When the findings of the employed methods are assessed, it is seen that there is a good trustworthiness. These three methods gave the mineralogical ingredients of the mortar as quartz, calcite and feldspar. This mineralogical structure and the construction period of the palace indicate the mortar as lime mortar, known as Horasan Mortar.

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