Repair and Maintenance of Historical Buildings of Cyprus Made of Natural Building Stones

Enç Yılmaz

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science
in
Civil Engineering

Eastern Mediterranean University
February 2022
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Ali Hakan Ulusoy
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science in Civil Engineering.

Prof. Dr. Umut Türker
Chair, Department of Civil Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Civil Engineering.

Prof. Dr. Özgür Eren
Supervisor

Examining Committee

1. Prof. Dr. Özgür Eren
2. Assoc. Prof. Dr. Tülin Akçaoğlu
3. Asst. Prof. Dr. Ali Mosaberpanah

ABSTRACT

Cyprus is the third biggest Island located at Mediterrenean Sea. It is located between three continents; Europe, Asia and Africa. Because of its' geogrophical importance lots of empires ruled Cyprus accross the centuries. Therefore, Island has huge cultural heritage as well as historical monuments. In this study conservation works of Archangelos Micheal Church in Yeni Erenköy investigated detailly. During conservation projects of historical monuments, new natural stones that are going to be used instead of missing or damaged ones, should have similar characteristics with them. Information about these original natural stones are very limited.

In this study, samples are collected from new and old parts of Archangelos Michael Church in Yeni Erenköy and Sourp Magar Monastery in Alevkayası to determine their properties by experiments. From the results of experiments, stones at new part of Archangeos Michael Church (Group Y) have the highest coefficient of water absorption by capilarity (C) and the highest water absorption capacity (A_b) at atmospheric pressure by 351,85 g/m^2.s$^{0.5}$ and 19,74% respectively. Stones of Group Y also have the highest open porosity and total porosity values (29,59% and 39,29%). In addition, stones at old part of Archangelos Michael Church (Group E) have the highest uniaxial compressive strength (R) and pulse velocity values by 16,27 MPa and 3,31 km/sec respectively. Stones at Sourp Magar Monastery in Alevkayası (Group A) have the highest real density and specific gravity values (2732 kg/m^3 and 2,75). Also, stones at Sourp Magar Monastery are the most resistive group against to salt crystallization.

Keywords: Historical monuments, natural stones, conservation works, porosity, water absorption, compressive strength, Archangelos Michael Church

ÖZ

Kıbrıs Akdeniz'in en büyük üçüncü adasıdır. Avrupa, Asya ve Afrika kıtalarının arasında konumlanmıştır. Coğrafik öneminden dolayı yüz yıllar boyunca birçok imparatorluk tarafından yönetilmiştir. Bu yüzden, çok büyük bir kültürel mirasın yanında tarihi eserlere sahiptir. Bu çalışmada Yeni Erenköy'deki Archangelos Michael Klisesi'nin tamir ve koruma çalışmaları detaylı bir şekilde incelenmiştir. Tarihi eserlerin koruma ve tamir projelerinde, kayıp veya zarar görmüş doğal taşların yerine kullanılan doğal taşlar, orjinal doğal taşlarla benzer özelliklere sahip olmalıdır. Öte yandan ise maalesef tarihi eserlerde kullanılmış olan orjinal doğal taşlar hakkında çok kısıtlı bilgiler mevcuttur.

Bu çalışmada numuneler Yeni Erenköy'deki Archangelos Michael Klisesi'nin yeni ve eski taraflarından, Alevkayası'ndaki Sourp Magar Manastırı'ndan mühendislik özelliklerinin belirlenmesi amacıyla toplandı. Deney sonuçlarına göre, Archangelos Michael Klisesi'nin yeni tarafındaki taşlar (Grup Y) 351,85 $g/m^2.s^{0.5}$ ve 19,74% ile en yüksek kılcal etkiye bağlı su emme katsayısı (C) ve atmosfer basıncında su emme kapasitesine (A_b) sahiptir. Grup Y taşları 29,59% ve 39,29% ile en yüksek açık ve toplam gözenek değerlerine sahiptir. Archangelos Michael Klisesi'nin eski tarafındaki taşlar (Grup E) 16,27 MPa ve 3,31 km/s ile en büyük tek eksenli basınç dayanımı (R) ve geçiş hızına sahiptir. Alevkayası'ndakı Sourp Magar Manastırı'nın taşları (Grup A) en fazla gerçek yoğunluk ve özgül ağırlık değerlerine sahiptir (2732 kg/m^3 ve 2,75). Sourp Magar Manastırır'nın taşları tuz kristalleşmesine karşı en dirençli gruptur.

Anahtar Kelimeler: Tarihi eserler, doğal taşlar, koruma ve tamir çalışmaları, gözeneklilik, su emme, basınç dayanımı, Archangelos Michael Klisesi

ACKNOWLEDGEMENT

I would like to thank to my supervisor Prof. Dr. Özgür Eren for his help and support during the study and to Civil Engineering Department of EMU. I also would like to thank to my family and to all members of the Kayas Construction for their supports.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

1.1 General Information

Cyprus is the third largest island located in the Mediterranean after Sicily and Sardinia. It is ruled by several empires such as Eastern Roman Empire, French Lusignan dynasty, Venetians, Ottoman Empire and British Empire over the centuries. So island has very rich cultural heritage such as classical Greek temples, Roman theatres and villas, Early Christian basilicas, many Latin and Byzantine churches and monasteries, Crusader castles, Gothic cathedrals, Frankish and Venetian fortifications, Moslem mosques and British colonial-style buildings.

At this study, investigations have been done for some of these historical buildings during the phase of their conservation works. Research has done on two historical monuments, Archangelos Michael Church (located in Yialousa/Yeni Erenköy) and Sourp Magar Monastery (located in Alevkayası/Chartzia).

1.2 Aim of the Study

Historical buildings at Cyprus were mainly constructed with natural building stones. During the conservation projects of these historical monuments, some damaged, heavily weathered or loss natural stones at structures have to be replaced with new ones. But the new ones should have similar characteristics (texture, hardness, colour, size, etc.) as original ones.

Main objective of this study is to obtain informations about natural stones at historical monuments by performing physical and mechanical tests on them.

Therefore, it is expected that outcomes of the study will be beneficial for restoration, rehabilitation and conservation works of historical buildings/structures.

1.3 Works Done

- Research about the conservation projects of historical monuments at Cyprus.
- Collecting of specimens from Sourp Magar Monastery at Alevkayası and Archangelos Michael Chucrh at Yeni Erenköy, both from old part and new part of the Church.
- Experiments for determination of water absorption coefficient of the specimens by capillarity according to standard TS EN 1925.
- Experiments for determination of water absorption of the specimens at atmospheric pressure according to standard TS EN 13755.
- Experiments for determination of uniaxial compressive strength of the specimens according to standard TS EN 1926 and pulse velocity.
- Experiments for determination of real density, apparent density, total porosity, open porosity and specific gravity of the specimens according to standard TS EN 1936.
- Experiments for determination of resistance of the specimens to salt crystallisation according to standard TS EN 12370.

1.4 Guide for Thesis

- Chapter 2 deals with literature review historical monuments and their importance, conservation of historical monuments, masonry, natural stone, historical monuments in Cyprus and conservation works of historical monuments in Cyprus. Chapter 2 also deals with specifically conservation works of Archangelos Michael Church in Yeni Erenköy.

- Chapter 3 is related with the experimental procedures for the samples collected from new and old parts of Archangelos Michael Church and Sourp Magar Monastery (located in Alevkayası/Chartzia).
- Chapter 4 is related with the results and discussions of the experiments
- Chapter 5 deals with conclusion and further recommendations.

Chapter 2

LITERATURE REVIEW AND CONSERVATION WORKS AT ARCHANGELOS MICHAEL CHURCH

2.1 Historical Monuments and Their Importance

"Cultural heritage" statement is mentioning sites and historical structures that have unique global worth from the viewpoint of science, art and history by UNESCO (The United Nations Educational, Scientific and Cultural Organization) [1].

Historical structures are priceless, by this reason they have to be respected for their cultural importance. Importance of those structures is coming from their artistic, ancient, symbolic and moral values. Therefore, these historical buildings should be maintained [2].

Due to their architectural worth and proof of structural techniques, historical buildings are crucial part of the cultural heritage. Their conservation and maintenance to keep them alive as much as possible should be commitment of people, for the purpose of transferring to next generations [3].

2.2 Conservation of Historical Monuments

The UNESCO has established on 16th November 1945 in United Kingdom. Focusing on to studies started years ago by League of Nations, loyalty of UNESCO expressed in its organization to the idea of mutual cultural heritage, as well as fortification and preservation of that heritage with international team work and unity [4].

The conservation of historical monuments classified as exact approach to protect a historical monument by maintenance and rehabilitation jobs. Maintenance of structure is specific method in preserving historic buildings by extending their lifetime [5].

Slow and unavoidable aging case could influence the present structural stability due to various reasons such as element degradation, humanitarian alterations especially in civic areas or climate and ecological alterations [3].

Protection of historical monuments is mainly carried out by the method called maintenance. Maintenance is a principle for protecting of the original texture of the historical monuments. Appropriate maintenance generally improves condition and worth of historical structures [6].

Maintenance contains pragmatic and specialized methods that are supposed essential to provide situation of monument where that is placed is conserved similarly to its' authentic. In addition to this, jobs in progress do not deteriorate monument's worth and importance [7].

Analysis of current conditions of historical buildings can be done fully by interdisciplinary understanding by using technological survey, ancient records, non-destructive experiment processes and analysis of deteriorate traces [3].

Conservation is not alone necessary for notes and authentications to be undertaken, in meantime, necessities include scheduling methods and rehabilitation jobs [8]. Usually, body and structure substances of the historical monuments deteriorate along years. Furthermore, facilities and places of buildings where they exist are two extrinsic circumstances which affects deteriorate condition of structures and appearance of decays [9].

2.3 Masonry

Masonry wall construction supplies miscellaneous benefits. For example; only one element can accomplish various functions including structure, fire protection, weather protection, thermal and sound insulation, and sub-division of space. The second main advantage of masonry wall is durability of the material. By suitable choice, among small preservation it can last usable in long terms. In addition, by tectonic perspective, masonry supplies benefits from the standpoint of various design opportunities and display of external walls. Substances exist in miscellaneous types of characteristics. Challenging wall designs for example, arcuated walls, can be built by not using high-priced formworks. Due to characteristic of masonry, building process can be done by not needing of pricy and weighty site, machinery and equipment [10].

Circumstances such as movement, humidity, durability, fire resistance, thermal and acoustic properties should be considered while designing of masonry walls [11].

Movement can occur in all masonry materials due to chemical reactions, exerted forces, humidity and heat difference [12]. Apart from that factors, damaging of masonry may result from foundation motions [13].

Stress from loading can be led to motions at masonry elements, which is so important at multistorey structures, and can occur instantly at later the appliance of forces or afterwards of particular time. In addition, movement in close elements may influence the masonry wall. For example, bending of beams can result in tensile stresses at touching walls or motions at beam which may end up with cracking [11].

Thermal movement is related with amount of exposed heat and extension coefficient of substance. Since the amount of exposing heat is directly related with various factors, it is very hard to calculate it during the designing stage. [11].

2.4 Natural Stone

Since approximately 5000 BC from the Middle East, natural stone is using as main building substance. At the beginning, this high-priced substance was using at chapels, graves, castles, mansions and civic structures as well as ornaments and art objects [14].

Before the 20th century, main material that used in large-scale building construction was natural stone. Nowadays, it is still in use but not as much as previously. As well as structural material, natural stone is using as exterior cladding and interior finish of walls at nowadays. Disadvantage of working with natural stone appears from heavy weight of stone walling and therefore requirements for foundation. Also, it needs skilled labours while working with natural stones. On the other hand, appearance and durability are main advantages of stone masonry [15].

Natural stone is necessity at conservation and rehabilitation of anciently, and socially significant monuments to avoid degradation because of environmental factors and weathering and usage. Generally, these structures may need overall restoration, rehabilitation or conservation. The stone that is going to be used, has to be suitable characteristic with previously existing one [14].

2.5 Types of Natural Stone

There are lots of type of natural stone, but only few types of natural stone are appropriate for building masonry walls. As well as accessibility and effortless quarrying, the stone have to supply properties such as strength, workability, hardness, durability and appearance. Stones that supply these properties are limestone, granite and sandstone. Marble and slate are generally used for particular aims. Quartzite and serpentine are used rarely, they are used locally or regionally [15].

Granite is an acid igneous rock and does not have many range of composition, it is very limited. The granite group consist of members which includes different amount of quartz, alkali plagioclase feldspar, potash feldspar and dark-coloured ferromagnesian mineral, usually either biotite mica or hornblende. Colour type is relevant with amount and type of secondary minerals.

Limestone is a sedimentary rock. It is durable, worked without difficulty and extensively spread throughout the earth's crust. Limestone mainly made up of calcium carbonate (CaCO3). It is very fossiliferous.

Sandstone is a sedimentary rock build up with sand or quartz grains cemented together by matrices of various compositions. The most frequent mineral grains are quartz, micas, feldspar and clays. As well as within the grains, porosity also observed between the grains. Hardness and durability of sandstone is directly related with the type of cementing agent present [15].

2.6 Historical Monuments in Cyprus

Cyprus is the third largest island located in the Mediterranean after Sicily and Sardinia. It is located between three continents, Europe, Asia and Africa. This geographic feature played significant role in the island's tumultuous history. Island ruled by several empires such as Eastern Roman Empire, French Lusignan dynasty, Venetians, Ottoman Empire and British Empire over the centuries. So island has very rich cultural heritage such as classical Greek temples, Roman theatres and villas, Early Christian basilicas, many Latin and Byzantine churches and monasteries (see Figure 2.1), Crusader castles, Gothic cathedrals, Frankish and Venetian fortifications, Moslem mosques and British colonial-style buildings [16].


Figure 2.1: Sourp Magar Monastery in Alevkayası

2.7 Conservation Works at Historical Buildings in Cyprus

The Agreement of 21 March 2008 reached between Greek Cypriot leader Demetris Christofias and Turkish Cypriot leader Mehmet Ali Talat under the aegis of the United Nations (UN), paved the way for the founding of the Technical Committee on Cultural Heritage, which aims to the repair and protection of historical monuments of Cyprus.

The Committee is backed at its work by an Advisory Board which is made up of archaeologists, architects, art historians civil engineers and town planners from both communities.

The Technical Committee on Cultural Heritage studies to supply a mutually satisfactory mechanism for the implementation of practical actions for the suitable preservation, physical conservation and restoration (including research, study and survey) of the cultural heritage of Cyprus [17].

2.8 Conservation Works at Archangelos Michael Church

2.8.1 General Information about the Church

Archangelos Michael church (can be seen at Figure 2.2) is located in Yeni Erenköy/Yialousa and known as the principal church of the area. It is a twin church which are two churches attached to each other, older part is located at northern side and made up of two basic parts main church and narthex to the west. According to researches, it is believed that old part church is constructed at Byzantine times in Cyprus (A.C 395-1195). It is assumed that new church is constructed in 1794 to the south side of Byzantine church. More details about the church are given at the Appendix A.

Figure 2.2: Archangelos Michael Church, view of the southern side (new part) before conservation works

2.8.2 External Walls

- Existing Portland cement or other plaster types were removed from external walls of church and belfry (see Figure 2.3).

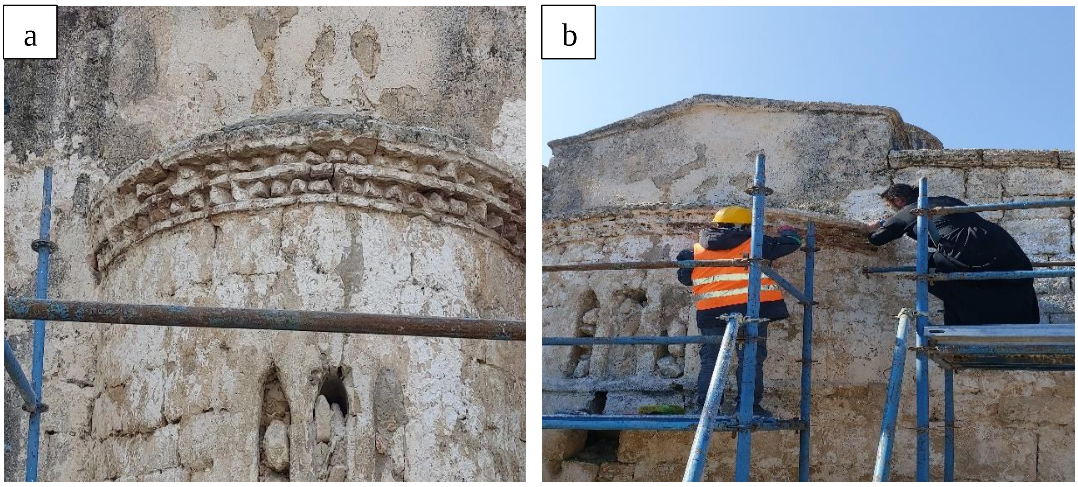


Figure 2.3: a) Initial condition b) Removal of plaster from external walls of the church

- Surface deposits were cleaned from stone surfaces using flat brushes, natural fibre brooms and sandblasting (see Figure 2.4).

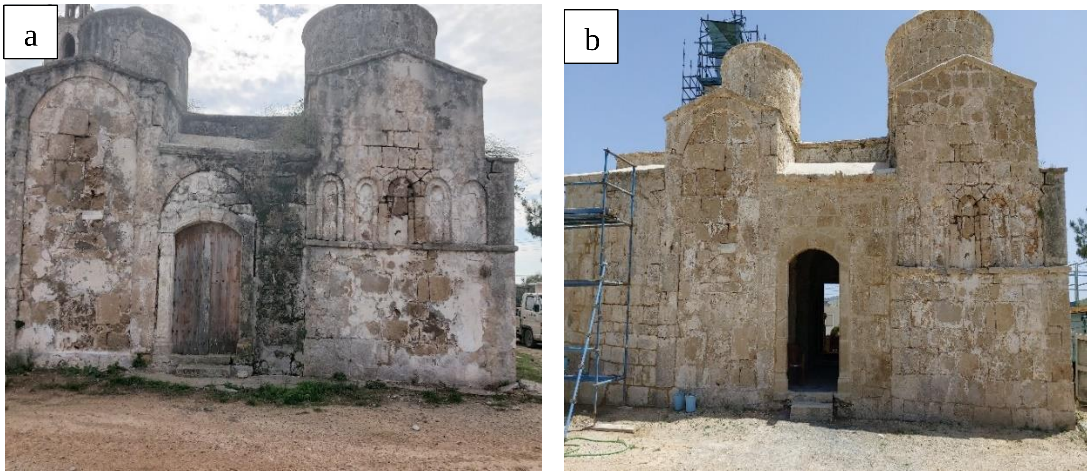


Figure 2.4: a) Initial condition b) Condition after cleaning of surface deposits from stone surfaces

- Vegetation (roots etc.) removed from walls after application of approved biocide (see Figure 2.5).

Figure 2.5: a) Vegetation removal stage 1 b) Stage 2

- Existing pointing was removed and joins of external walls of church cleaned (see Figure 2.6).

Figure 2.6: a) Pointing removal 1 b) Pointing removal 2

- The external walls of church were repointed with lime mortar in same colour and hardness as the original (see Figure 2.7).

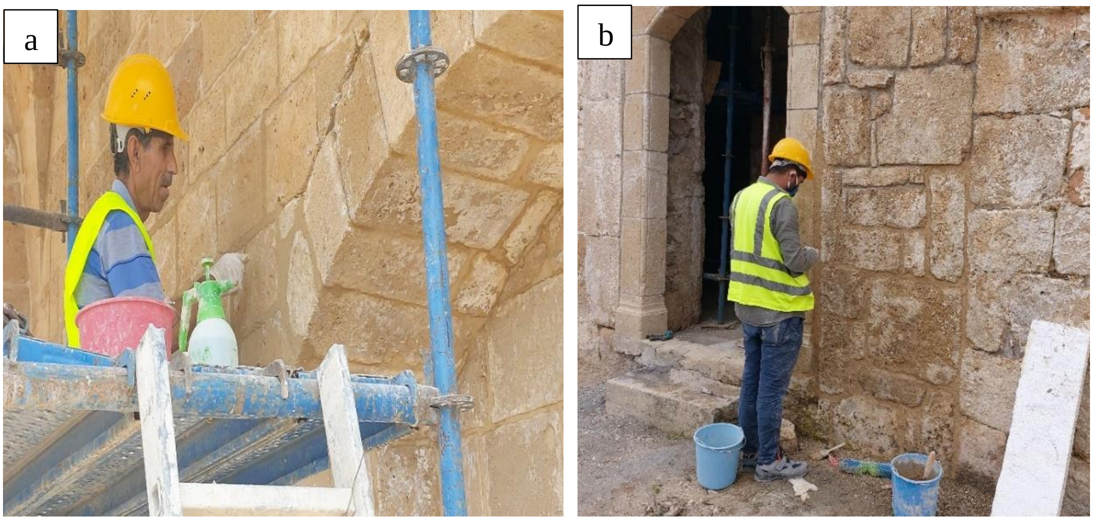


Figure 2.7: a) Repointing 1 b) Repointing 2

2.8.2.1 Important Points while Render Removal

Portland cement or other plaster type were used in previous repair works in extended areas of walls. Being incompatible with the stone structure, as was harder than the stones underneath and as it did not allow breathing of the wall (moisture could not escape), it was needed to be removed.

Work was proposed to be done by hand tools (chisels, hand hammers) and only if absolutely necessary to use heavier machinery. The work was done carefully in order to prevent affecting the adjacent stones or stones below. After removal of the cement mortar, wall was cleaned by means of low water pressure. The work was initially done at a test area for the approval of the Engineer.

2.8.2.2 Important Points During Cleaning of Dressed Stones Surface

Extended areas of the church external walls were either lime washed (several layers) or present natural weathering, staining, biological growth and other dirt. The work of cleaning had to be carried out by means of low-pressure clean water spraying and soft brushes. In case of soft stone material, work had to be done with maximum care in order to prevent crumbling of the stone surface.

2.8.2.3 Important Points at Pointing Removal and Repointing

Existing pointing (either modern cement or else) was removed from all external wall surfaces. The work was carried out on all types of stonewalls (irregular masonry, ashlar etc) where original mortar lost or present failure (soft or crumbling) or where modern cement pointing applied.

The cleaning work had to be carried out by means of basic mason's tools, clean water with pressure and brushes. Cleaning of joints went as deep as possible but not less than 5 cm. The new pointing material had to be lime-based mortar and must match existing (original) one in colour and hardness. The mortar was applied in layers and each one compacted thoroughly.

Mortar slightly recessed into stone surface carefully, to avoid spread on stone surface. Excess mortar was cleaned before drying. Mortar was protected from rapid drying by regularly spraying with water to be kept humid and to dry slowly.

2.8.3 Grouting

- Cracks on the walls, arches, vaults and domes repaired by injecting fine hydraulic lime mortar (see Figure 2.8, 2.9, 2.10 and 2.11).

Figure 2.8: Cracks at roof

Figure 2.9: Cracks at roof

Figure 2.10: Repaired cracks at roof

Figure 2.11: Repaired cracks at roof

2.8.3.1 Important Details about Grouting

Cracks on the walls, arches and vaults were existing. Few of those were considered as more serious (eg. Byz. church NE corner internally and externally) and some were minor. Also, mortar failure and wash out along with plants' (roots) growth lead to voids in the walls and vaults. All of them treated by grouting in order to strengthen and improve the mechanical properties of the building.

Areas in need of grouting specified by the engineer, after removal of plaster, plants removal (walls), vaults and dome cleaning.

Grouting material used was Albaria Masterinject BASF (property of material is given at Appendix C). Other materials necessary for the work execution were: mixing and injection machinery, plastic tubes 10 mm in diameter (to be penetrated 30 cm in to the wall).

The work has been executed as the following steps:

1) Cleaning of crack or area to be treated,

2) Insertion of plastic injection tubes at a distance of about 50 cm,

3) Sealing of crack/joints with mortar,

4) Injection with fluid mortar starting from bottom to top of wall,

5) Sealing of first point of injection when material comes out from the second etc.

6) If the work was applied to an extended area, the work was done from bottom to top in rows of about 1m each. Material of first row must be dry before going to the upper one.

7) Cleaning of stone surface, removal of plastic tubes and sealing of holes.

2.8.4 Internal Walls

- Existing lime or gypsum or cement removed from internal surfaces except areas with frescoes. Work had been done by hand tools only. Without use of heavy machinery. Loose deposits were removed by air under pressure (see Figure 2.12).

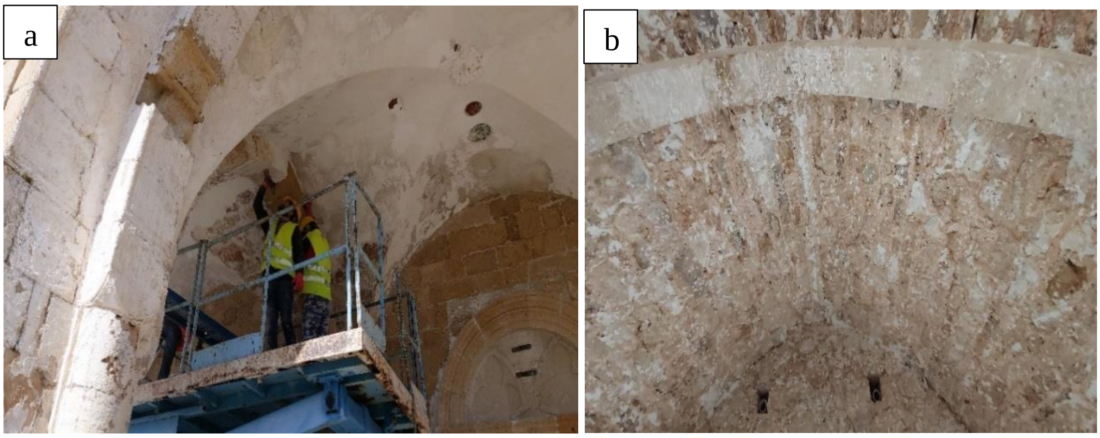


Figure 2.12: a) Initial condition b) After of cement removal

- Cleaning of surface deposits using flat brushes natural fibre brooms (see Figure 2.13).

Figure 2.13: Cleaning of stone surfaces with brushes

- Vegetation (roots etc.) was removed from walls after application of approved biocide.
- New plastering applied to internal surfaces (wall, arch, etc.) with Hydraulic lime mortar (material property of Hydraulic lime mortar is given at Appendix D) (see Figure 2.14, 2.15, 2.16 and 2.17).

Figure 2.14: Plastering stage 1

Figure 2.15: Plastering stage 2


Figure 2.16: Plastering stage 3


Figure 2.17: Plastering stage 4

- New wooden tie beams (be of class C22 or higher, which means minimum bending strength value of wood should be 22 N/mm^2) were inserted at the places where the original ones were cut off or removed at the east, west and north dome base/arch (see Figure 2.18 and 2.19).

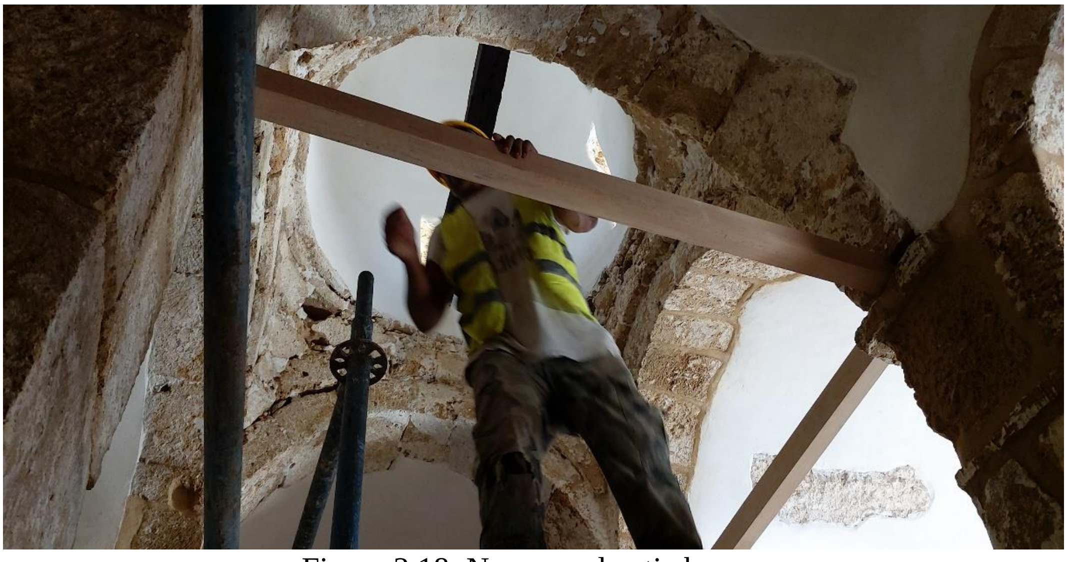


Figure 2.18: New wooden tie beams

Figure 2.19: New wooden tie beams

2.8.4.1 Important Points while Working at Internal Walls

Internal surfaces were covered with lime or gypsum mortars. Due to severe cracking and defect, renders had to be removed where needed. Removal of renders gave chance to a better and close check of the masonry and vaults status (cracks, defected stones etc.). Initially, the most seriously damaged areas removed. After that, it was up to the Architect to check again and decide whether certain areas of original plaster was strong enough to remain or not.

Work had to be done by hand tools only (chisels, hand hammers) without any use of heavy machinery. Loose deposits had been removed by air under pressure and the surfaces have washed with water under pressure.

Some areas of the walls have wall paintings (frescoes). The conservation work on those areas was carried out by a specialized and experienced conservator and at no circumstances unskilled personnel carried out any work close to the frescoes. The removal of renders had to be done under the continuous supervision of a professional conservator as it was highly possible that other wall paintings might be hidden underneath.

2.8.4.2 Important Points about Insertion of Wooden Tie Beams

In order to improve the diaphragmatic function of dome base, the original system of tie beams restored. Thus, new wooden tie beams inserted where the original ones had been cut off or removed. Three new tie beams constructed in the east, west and north dome base/arch.

New tie beams had to be inserted into walls/arches by removing existing wood remnants and the stones from one side so as to allow access. New tie beams inserted into walls/arches for at least 20 cm and be built and fixed properly.

The new wooden beams had to be of hard wood class C22 or higher (which means minimum bending strength value of wood should be 22 N/mm^2).

2.8.5 Stone Replacement and New Stone Carving

- Existing cornice stones were removed, then area was cleaned and new cornice stones added, including lime mortar and small stones to fill gaps and voids (see Figure 2.20 and 2.21).

Figure 2.20: Existing cornice stones


Figure 2.21 New cornice stones

- Existing column drums at south Porch semi columns were removed, then area was cleaned and new column drums added, including lime mortar and small stones to fill gaps and voids (see Figure 2.22 and 2.23).

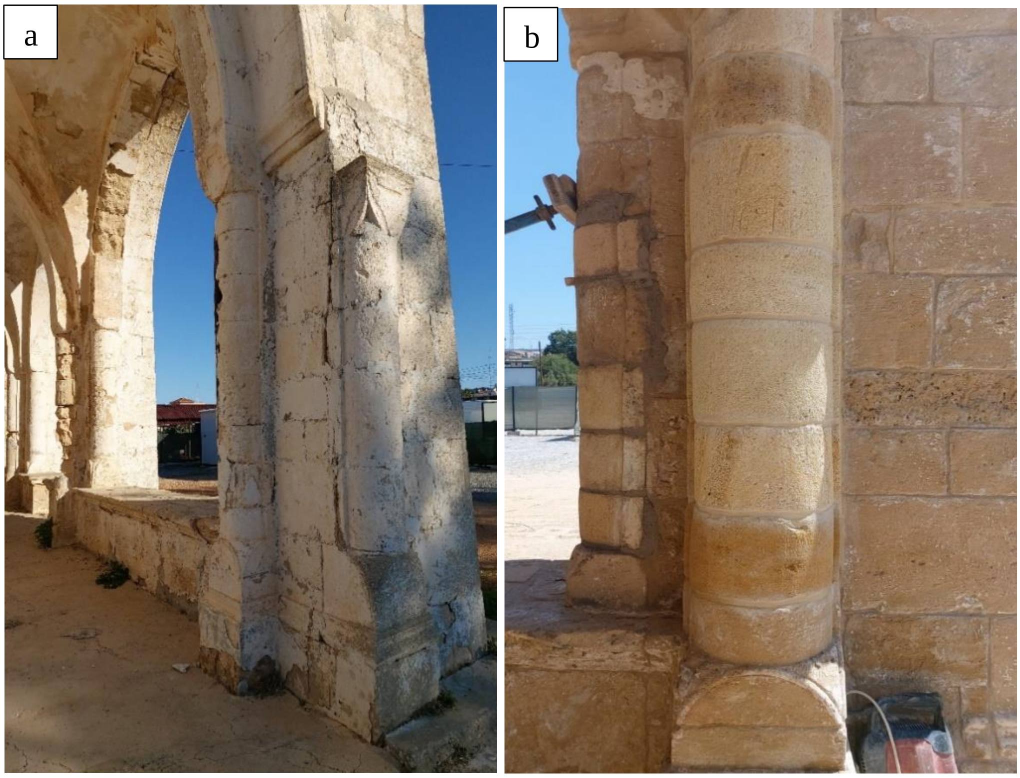


Figure 2.22: a) Initial condition of column drum 1 b) Final condition

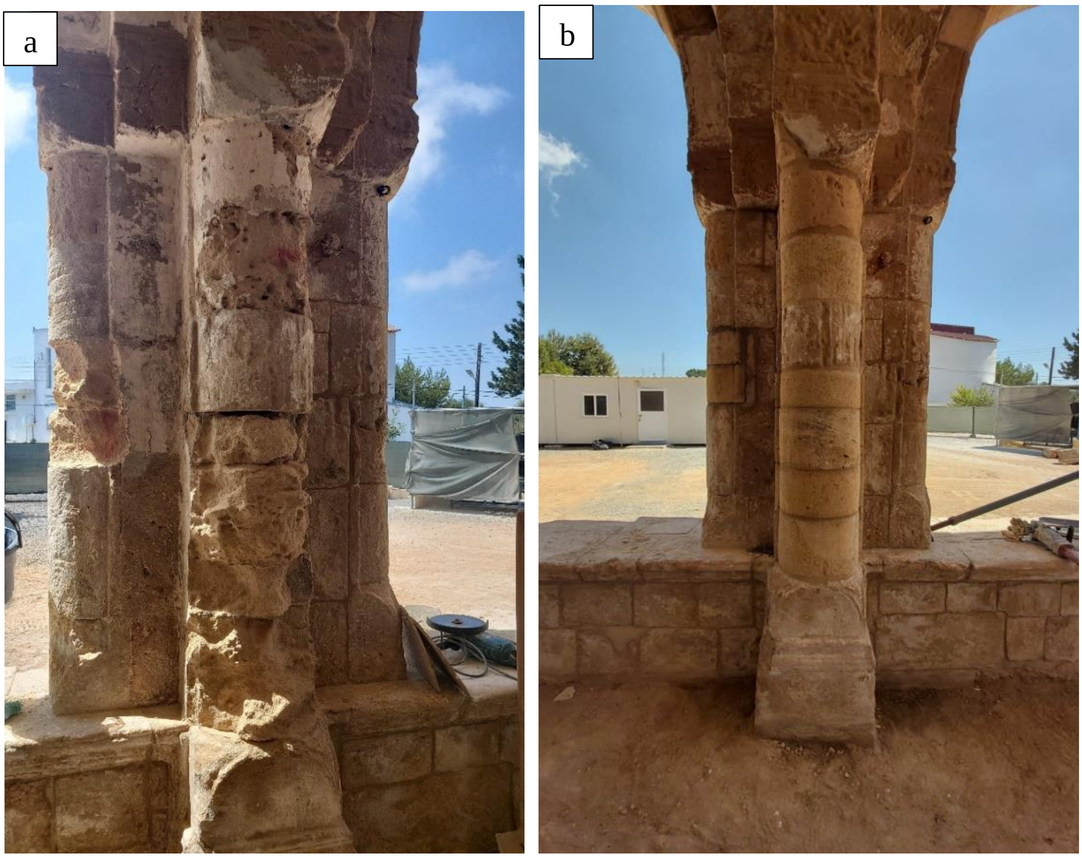


Figure 2.23: a) Initial condition of column drum 2 b) Final condition

- Existing arch stones from south porch arches were removed, then area was cleaned and new ones added, including lime mortar and small stones to fill gaps and voids (see Figure 2.24).

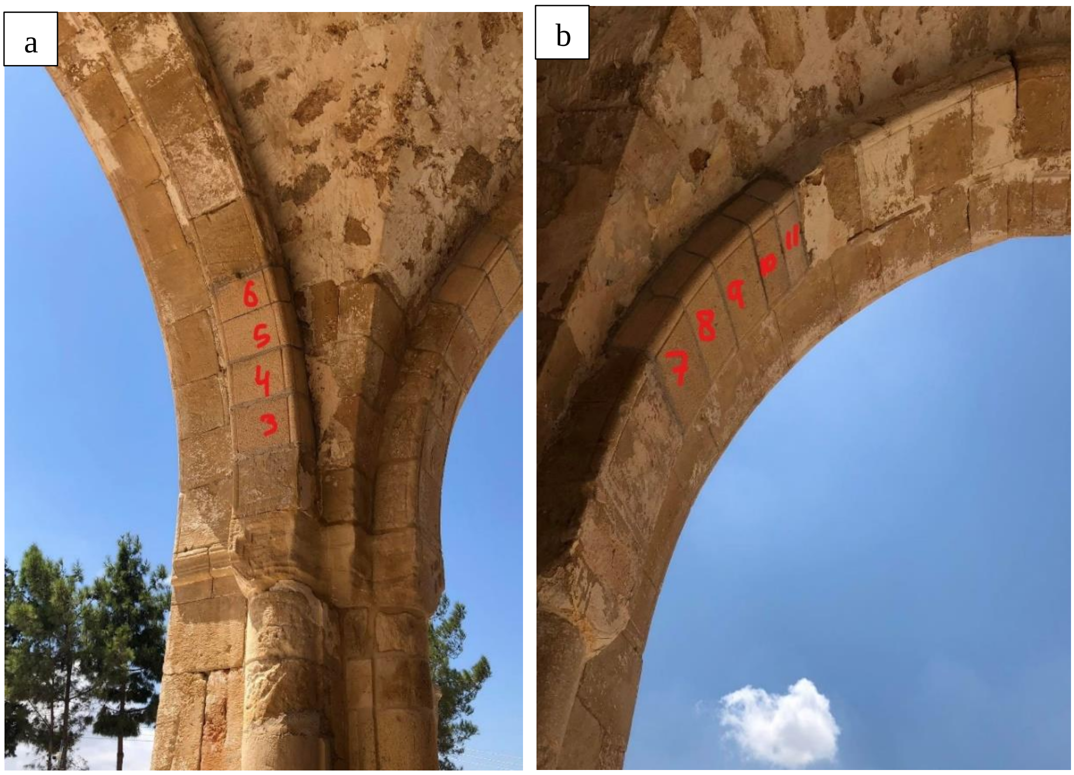


Figure 2.24: a) Replaced arch stones 1 b) Replaced arch stones 2

- Existing simple rectangular stones from several locations and different sizes were removed, then area was cleaned and new ones added, including lime mortar and small stones to fill gaps and voids (see Figure 2.25).

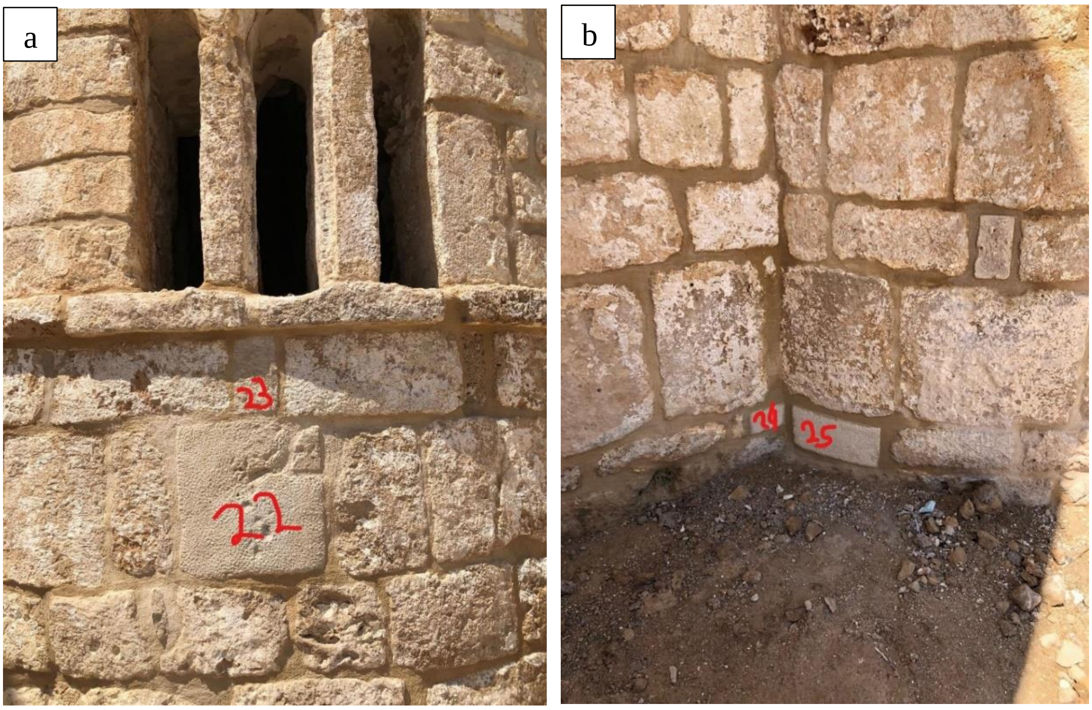


Figure 2.25: a) Replaced simple rectangular stones 1 b) Replaced simple rectangular stones 2

2.8.5.1 Important Points at Stones Replacement

Broken (cracked) or heavily weathered stones (mainly dressed stones) replaced in several positions. New stones had to be similar characteristics as the stone to be replaced (colour, texture, hardness, size etc.)

Some damaged stones were hidden under modern cement plaster. Thus, the number of those to be replaced could only be specified after plaster or paint removal, either internally or externally.

2.8.5.2 Important Points about Stone Wall or Vault Dismantling and Rebuilding

The work was carried out in specific areas where an extended damage, distortion or failure of wall was observed. It was expected to be carried out in areas where thick roots of plants penetrated into wall or vaults and possibly in other areas which might be revealed after renders removal.

Same stone material could be reused after removal, or material of same nature (irregular stone, dressed stone) had to be used. Reconstruction had been done with using lime mortar and small stones to fill gaps and voids. If needed, before the work, adjacent structures supported properly with scaffoldings.

Existing loose or detached stones and mortar removed and the wall cavity cleaned from dust and loose material. The wall was rebuilt with the same, if in good condition, stone material with same technique using hydraulic mortar.

Areas in need of such treatment were the NE corner of the byzantine church, the north side vaults and other areas. The area to be dismantled also specified after the cleaning of the areas (pointing, plaster etc.).

2.8.6 Works at the Ceilings

Existing lime or gypsum or cement removed from internal surfaces except areas with frescoes. Work has been done by hand tools only (chisels, hand hammers), without use of heavy machinery. Loose deposits were removed by air under pressure and the surfaces washed with water under pressure. Then new plastering applied to surfaces with Hydraulic mortar (see Figure 2.26 and 2.27).

Figure 2.26: a) Plastering of ceiling stage 1 b) Plastering of ceiling stage 2

Figure 2.27: Final stage of plastering at ceiling

2.8.7 Works at the Roof

- Loose deposits were cleaned and removed, loose roof materials near cracks cleaned with brush and water under pressure (see Figure 2.28, 2.29 and 2.30).

Figure 2.28: Cleaning of loose deposits stage 1


Figure 2.29: Cleaning of loose deposits stage 2


Figure 2.30: Cleaning of loose deposits stage 3

- Vegetation and roots removed and approved biocide applied (see Figure 2.31).

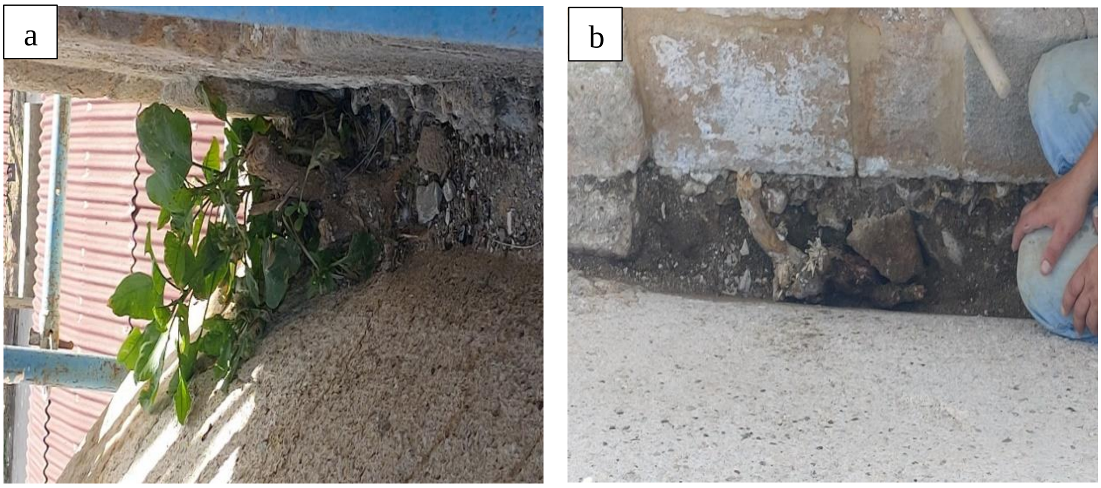


Figure 2.31: a) Vegetation cleaning stage 1 b) Vegetation cleaning stage 2

- Lime mortar material were removed from defected areas up to depth minimum 15cm. Cleaned with water and soft brushes (see Figure 2.32).

Figure 2.32: a) Removed lime mortar up to a depth of 15 cm 1 b) Removed mortar up to depth of 15 cm 2

- Seriously damaged stone build areas totally dismantled and rebuilt (see Figure 2.33).

Figure 2.33: a) Dismantling and rebuilding of seriously damaged part stage 1 b) Stage 2 c) Stage 3 d) Stage 4

- Cracks and voids repaired with grouting. (see more detailly at Chapter 2.8.3)
- New stone crosses constructed and placed (see Figure 2.34).

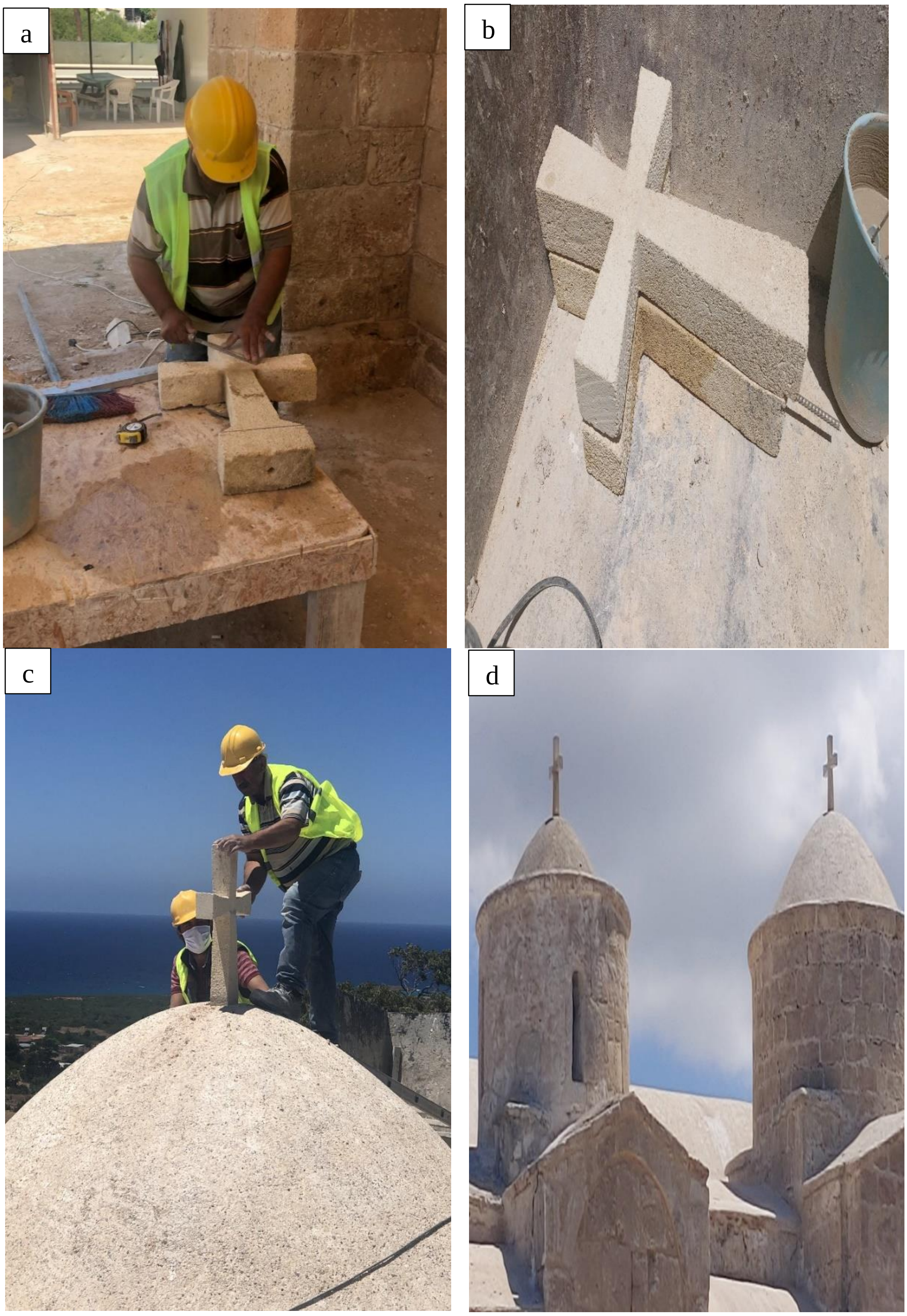


Figure 2.34: a) Construction and placing of new stone crosses stage 1 b) Stage 2 c) Stage 3 d) Stage 4

2.8.7.1 Church's Roof and South Arcade Roof

The roof of the church was entirely covered by the traditional "lime-mortar" material. In certain areas the material was presenting surface failure and/or cracks. Defected surfaces have removed, and the same material reconstructed.

Defected areas (loose or cracked material) cleaned up to a depth of min 15cm. The area cleaned with clear (salt free) water, the new "lime-mortar'' reconstructed in layers of about 5 cm each. The material had to be remained wet and protected by direct sun to dry slowly. It sprayed regularly for at least 15 days and be protected by damp cloth.

All roof surface cleaned from bio deteriorating organisms. Antimould biocide (Kimistone BIOCITA) applied with brush, roller or spray. After the completion of this work a new roofing insulating material was applied.

2.8.8 Works at Belfry

Existing modern cement repairs in joints or surfaces were removed. Surface deposits on the stone surfaces were cleaned using flat brushes, natural fibre brooms vacuum cleaners and water under pressure.

Upper part of belfry from row 19th to 23rd (the top small cupola with four columns, the stone/cement rail with four corner posts, the cornice and five row of stones) dismantled and rebuilt. Then cracked cornice stones at row 23rd were removed and new ones added in same style and dimensions (see Figure 2.35 and 2.36).

Figure 2.35: a) Initial condition b) Dismantling of upper part of belfry

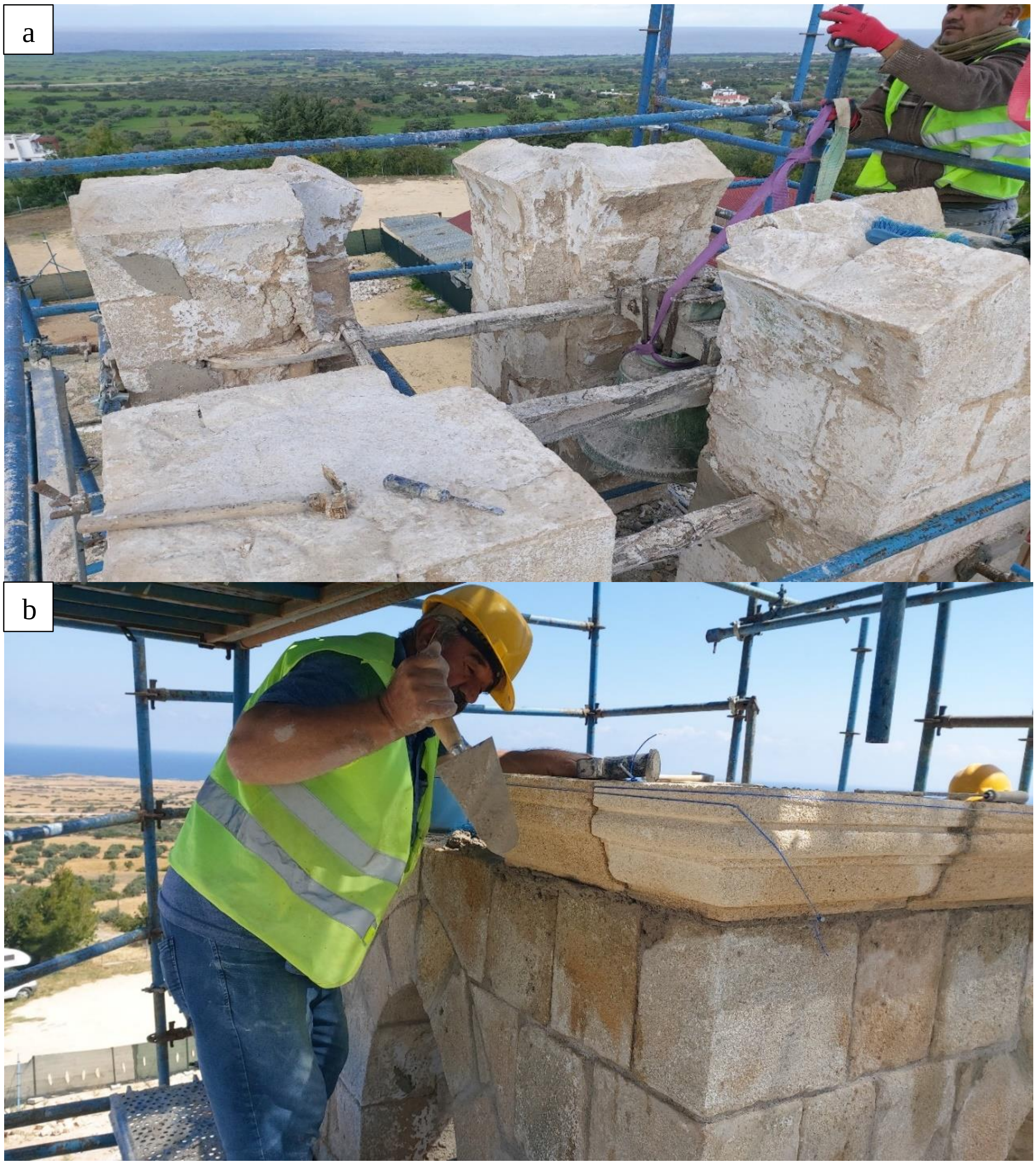


Figure 2.36: a) Dismantled condition b) Adding new cornice stones at 23^{th} row of belfry

- New stone corner posts and new stone rail were constructed in same pattern and dimensions as original (see Figure 2.37).

Figure 2.37: a) Initial condition b) Construction of new stone rail and corner posts

- Rebuilding of new stone columns and arches (from row 25th to 29th) (see Figure 2.38).

Figure 2.38: a) Rebuilding of new stone columns and arches b) Rebuilding of new stone coupole

- Cracked stones were removed and replaced with new ones on different locations (see Figure 2.39).

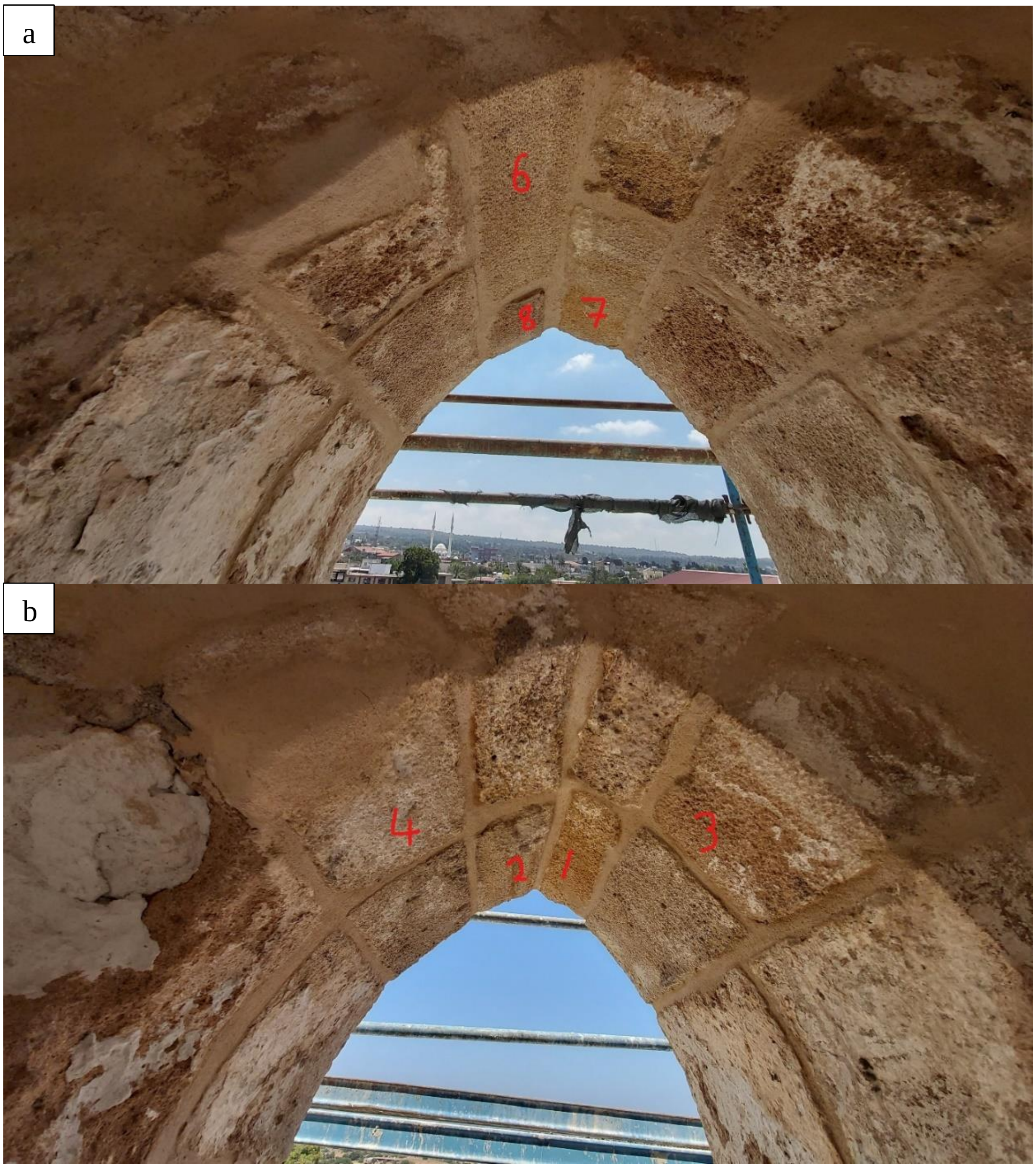


Figure 2.39: a) Replaced cracked stones 1 b) Replaced cracked stones 2

- Missing stones replaced at different locations (see Figure 2.40)

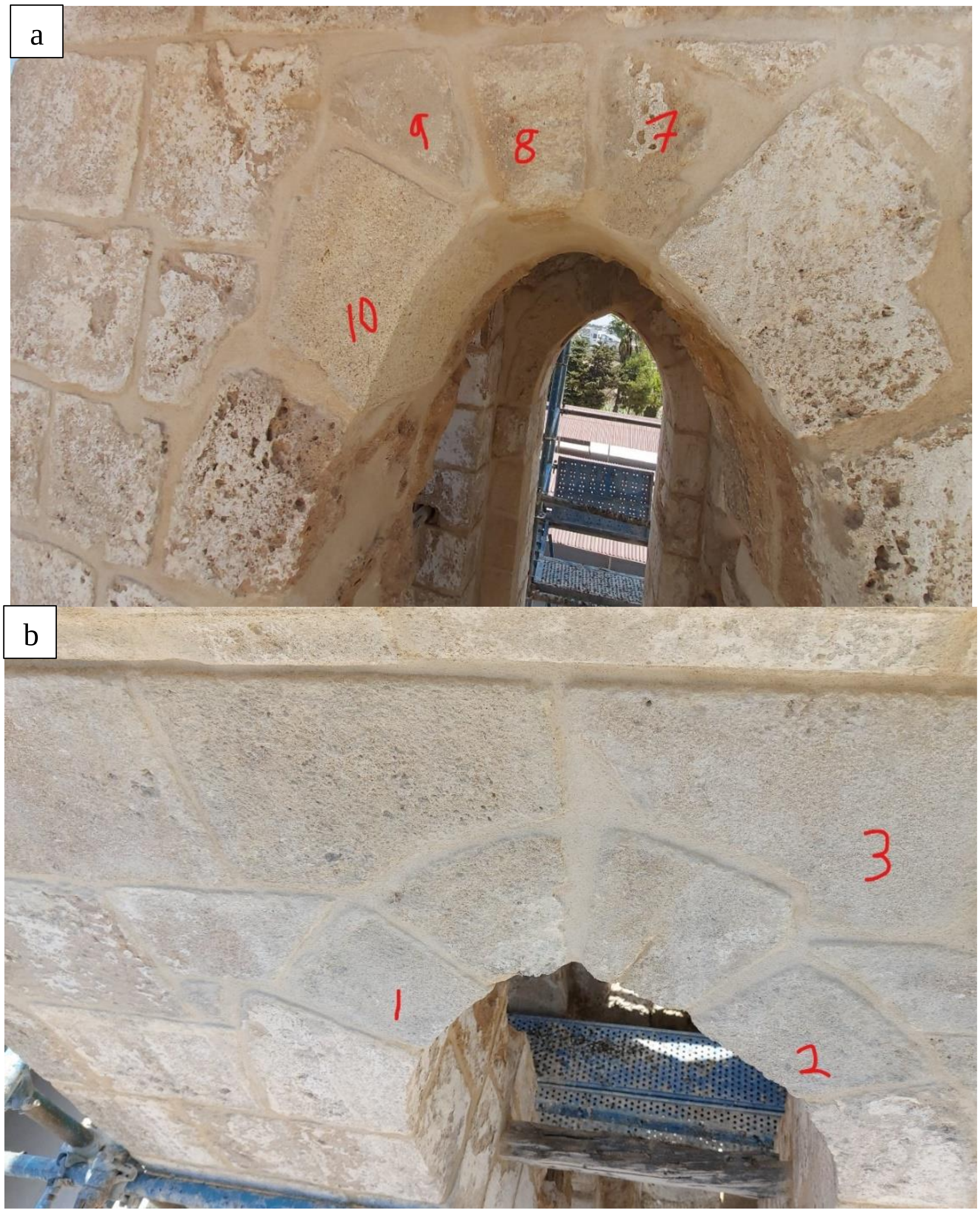


Figure 2.40: a) Replaced missing stones 1 b) Replaced missing stones 2

- Rotten wooden ties rods were removed and replaced into belfry columns in three different levels (row 4th, 11th, 20th).
- Internal sides of columns were repaired (from row 2nd to 18th) (see Figure 2.41).

Figure 2.41: a) Repairing internal sides of columns 1 b) Replacing of internal sides of columns 2

- Repointing of belfry (from row2nd to 29th) (see Figure 2.42).

Figure 2.42: a) Repointing of belfry 1 b) Repointing of belfry 2

- Bell and its’ mechanism were removed, repaired and placed back in order to function properly (see Figure 2.43).

Figure 2.43: a) Initial condition of bell b) Bell and its’ mechanism were removed and repaired

2.8.8.1 Important Points about Belfry Works

The problems were, stone cracking (due to corroded iron or else), stones displacement and joints’ widening (upper parts), loose of pointing, iron items corrosion, wooden ties defect and problematic upper part due to past failure,

Because of the extended damage, it is proposed that the upper part of belfry should be dismantled and rebuilt. The area to be dismantled was including the top small cupola with four columns, the stone/cement rail with four corner posts and five (5) rows of stones (including the cornice).

It was a necessity to maintain as much as possible of the existing original stone material which would be put back. It was a necessity to maintain and put back all decorative stones. The final decision on how many of those could be reused or not has taken after dismantling. Amount of ten (10) cornice stones, all four (4) corner posts, all four (4) columns at top and all top arches were replaced (existing ones removed and new ones carved and placed).

It was pointed out that dressed stones (simple dressed or with carvings and decorations) only exists on the external surfaces of the belfry. Internal surfaces were plastered and were built with irregular stones. These internal sides thoroughly checked and if necessary dismantled and rebuild. Then they were plastered.

Severely defected dressed stones (below dismantling area) were replaced with new ones. Around twenty (20) stones of any type (corner stones, simple rectangular or else) replaced. All new stones had to match with existing ones in colour, dimensions and style.

All wooden tie beams replaced with new ones of similar dimensions and built into belfry columns. All wooden beams were treated with preservatives. The hard wood class was C22 or higher.

The cement railing on top (all 4 sides) was removed and reconstructed exclusively with stone in the same pattern. Bell and bell mechanism were removed, maintained, repaired and placed back.

For the execution, proper scaffolding installed from ground level to top on east side and from church vaulting to top on south, north and west sides. Special care had been given to the scaffolding supports for not to cause any damage to the roof lime mortar material.

2.8.9 Works at Floors

2.8.9.1 South Arcade Floor

- Removal of existing floor materials and substructures and construction of new floor using local stones (see Figure 2.44 and 2.45).

Figure 2.44: a) Removal of existing floor stage 1 b) Stage 2

Figure 2.45: a) Construction of new floor with Local stone stage 1 b) Stage 2

2.8.9.2 Gynaikonitis (Women's Gallery) Floor

- Existing floor material and substructure were removed (see Figure 2.46).

Figure 2.46: Removal of existing substructure floor

- Wooden structure (planking and beams) was checked and damaged elements were removed and replaced (see Figure 2.47, 2.48, 2.49 and 2.50).

Figure 2.47: Damaged elements

Figure 2.48: New wooden beam

Figure 2.49: New wooden beam

Figure 2.50: New floor

- All beams and parapet were cleaned with paint remover and new water-based varnish applied (see Figure 2.51).

Figure 2.51: Cleaning of beams and parapet with paint-remover and applying of water-based varnish

- Stairs were cleaned and repaired (see Figure 2.52).

Figure 2.52: a) Initial condition of stairs b) Final condition of stairs

2.8.9.2.1 Important Points about Gynaikonitis (Women's Gallery) Floor

The existing floor structure was made of Cyprus marble slaps on top of wooden planking and twenty supporting beams underneath. All beams rest on a big wooden beam along the N-S axis. The floor was covered by carpet. After removing the carpet, all marble slabs have been numbered and carefully removed.

The wooden structure (planking, beams) checked thoroughly and damaged elements were removed. All replaced rotten wooden beams had similar dimensions and same type as existing ones. Also, the new wooden beams had to be of class C22 or higher. All new beams had to rest into the walls for at least 30 cm. All beams cleaned thoroughly with paint-remover, proper preservative applied along with water-based varnish.

2.8.10 Doors and Windows

- New doors and windows were constructed at different locations of church (see Figure 2.53, 2.54 and 2.55).

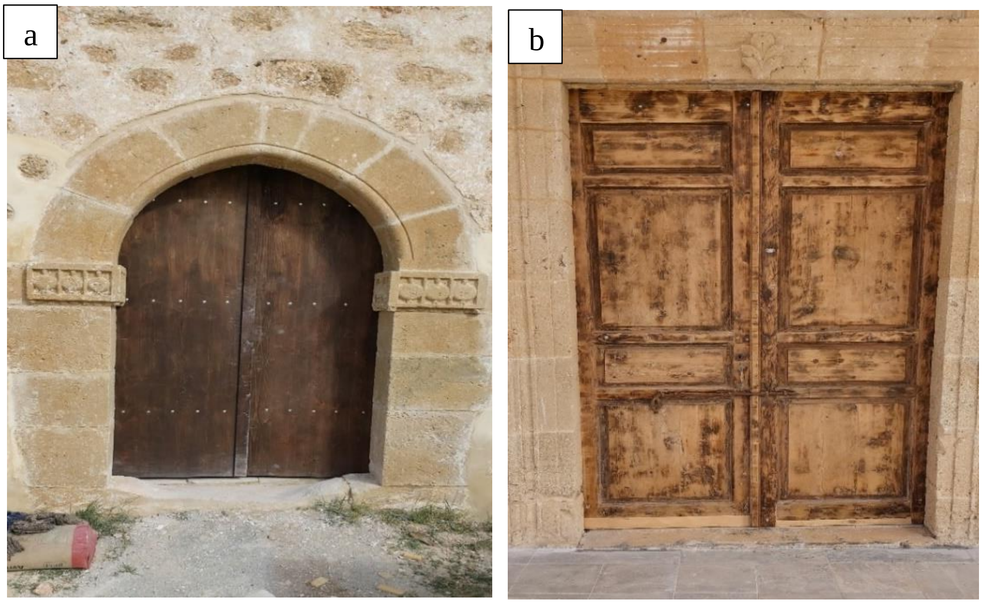


Figure 2.53: a) New door 1 b) New door 2

Figure 2.54: a) New door 3 b) New door 4

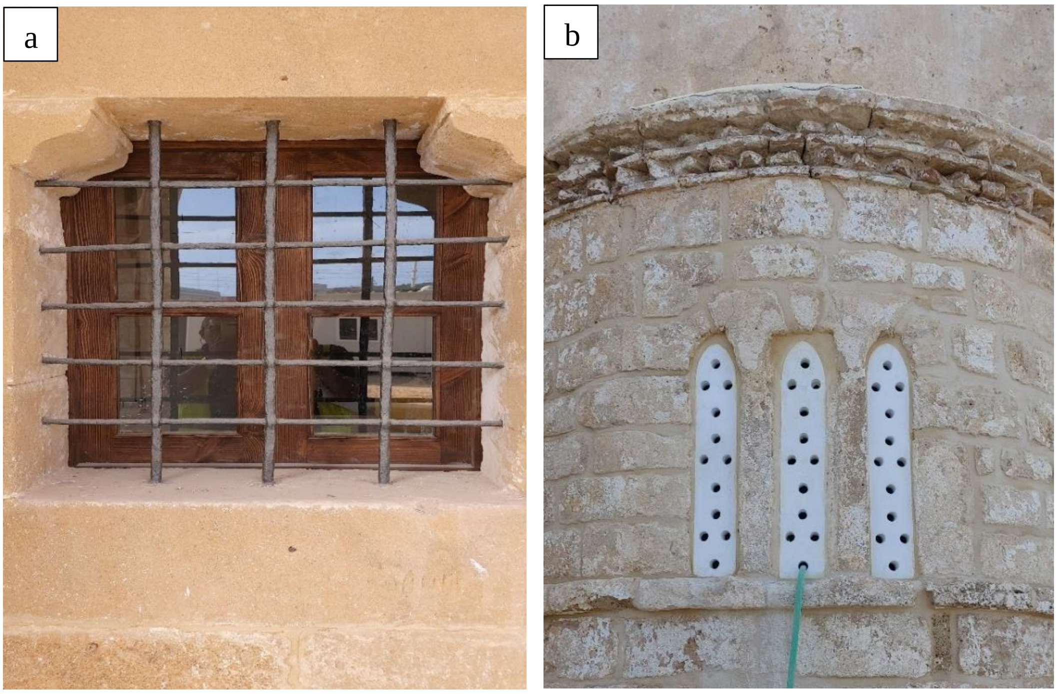


Figure 2.55: a) New window 1 b) New window 2

2.8.11 Before and After Figures from All Around the Church

Figure 2.56: View of south facade

Figure 2.57: View of north facade

Figure 2.58: View of the belfry

Figure 2.59: View of the new church (southern part) east facade

Figure 2.60: View of the old church (Byzantine/north part) east facade

Figure 2.61: View of the west facade

Figure 2.62: View of the roof from northern facade

2.9 Other Techniques at Similar Works

Nowadays, during the rehabilitation works of historical buildings, at the stage of replacement of missing or deteriorated stones some challenges have appeared. Due to lack of availability of distinct natural stone types, expensiveness of transportation and stone quarrying, other methods became popular. For example, using of artificial stones. Artificial stones have obtained by mixing of particular amount of cement, hydraulic lime, sand, clay and aggregates in order to supply criteria of original natural stones [23]. By the design of a mortar with similar properties to the specific natural stone type, environmentally friendly and low cost product of adjustable dimensions, texture and high reproducibility can be achieved.

This technique used at The Archeological site of Pella, Ancient theatre Maronia which is located in Greece and Fortress of Saint Nicolaos of the Medieval city of Rhodes (see Tables 2.1, 2.2 and Figures 2.63, 2.64 and 2.65).

Table 2.1: Properties of natural stones from archeological site of Pella [23]

Sample deterioration degree	Compressive strength (MPa)	Porosity (%)	Apparent specific gravity	Absorption (%)
Healthy	30.0–45.0	1.5–3.5	2.35–2.60	0.64–1.50
Medium deteriorated	15.0–30.0	4.0–9.0	2.30–2.40	1.50–2.50
Heavily deteriorated	11.5–15.0	9.0–11.0	2.17–2.27	2.50–4.85

Table 2.2: Properties of artificial stone of archeological site of Pella [23]

Samples	Porosity (%)	Ap. specific gravity	Compressive strength (MPa)	Dynamic modulus of elasticity (GPa)
Natural stone	5.13	2.300	41.25	26.8
Artificial stone (28d)	5.78	2.365	45.8	27.4
Artificial stone (after 40 cycles of freeze-thaw)*	5.81	2.368	41.4	25.6

Figure 2.63 Artificial stones at archeological site of Pella [23]

Figure 2.64: Natural and artificial stone (at right) of ancient theatre of Maronia [23]

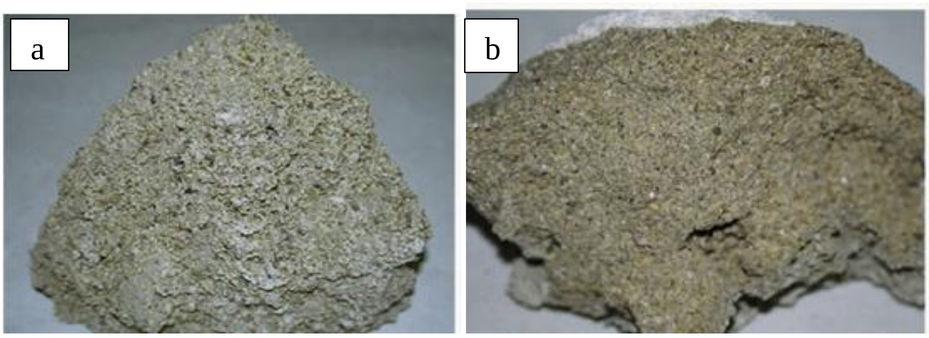


Figure 2.65: a) Natural stone b) Artificial stone at Fortress of Saint Nicolao [23]

At some cases, mortar is used for repairing of historical natural stones. Mortar repair term indicates the use of mortars to repair missing parts of facades, historical monuments and archaeological remains that made of various materials such as natural and artificial stone. Surface repair mortars are used for the compensation, or repair, of lost portions of surface materials in historic masonry buildings [24]. (see Figures 2.66, 2.67, 2.68 and 2.69)

Figure 2.66: Example of mortar application (light parts) as a mortar repair of deteriorated stone units in Glasgow. Scotland [24]

Figure 2.67: Mortar used to repair deteriorated stone parts and detailing of the main entrance portal of the cathedral in Évora. Portugal [24]

Figure 2.68: Mortar repair of degraded bricks [24]

Figure 2.69: Mortar repair carried out on multi-coloured degraded sandstone blocks Palazzo Piccolomini, Pienza, Italy [24]

Due to cultural worth of the structures, they need restoration and conservation processes. During repair, strengthening and rehabilitation of historical stone masonry walls, strengthening mortar with modern technology is applying to tensile joints in irregular external faces of stone walls. Techniques include introducing small diameter steel tie-rods and fibre composites into wall joints in conjunction with replacement of mortar [25] (see Figures 2.70 and 2.71).

Figure 2.70: Cord locking device inside the wall joint before application of steel cords and mortar [25]

Figure 2.71: Stainless steel cord inside opened three leaf masonry wall joint [25]

Chapter 3

EXPERIMENTAL PROCEDURES

3.1 Testing Samples

Samples are collected from two historical monuments. From Sourp Magar Monastery which is located in Alevkayası (Beşparmak Mountains region) and from Archangelos Michael Church located in Yeni Erenköy/Yioulasa (Karpaz region). Archangelos Michael Church is composed of two parts, new part and old part. Samples obtained from old part are labelled as "E" and samples obtained from new part are labelled as "Y", can be seen at Figure 3.1. Specimens from Sourp Magar Monastry are labelled as "A". (Information about specimens can be seen at Table 3.1 more detailly)

Therefore, testing samples are divided into 3 groups,

- Samples from old part of Archangelos Michael Church (E)
- Samples from new part of Archangelos Michael Church (Y)
- Samples from Sourp Magar Monastery (A)

Figure 3.1: Samples from Archangelos Michael Church

Cylindrical samples removed from natural stones by coring machine, can be seen at Figure 3.2 and 3.3. Then cut to dimension of approximately 64x64 mm cylinders by stone saw machine, can be seen at Figure 3.4.

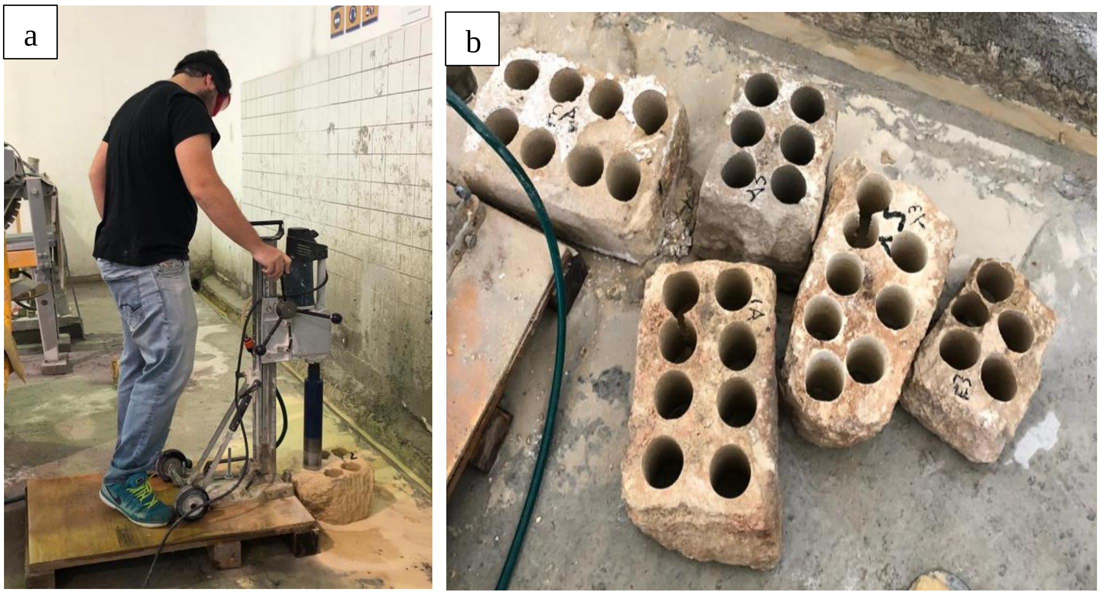


Figure 3.2: a) Removing of testing samples from natural stones stage 1 b) Stage 2

Figure 3.3: Removed samples from natural stones by coring machine

Figure 3.4: a) Cutting samples to approximately 64x64 mm cylindrical shape stage 1 b) Stage 2

Table 3.1: Meaning of sample names

Sample Name	Y	2	C
Y-2-C	Stone collected from new part of Archangelos Michael Church (built in 1794)	2nd collected stone of Group Y	Specimen from that stone which is notated as "C"
Sample Name	E	1	A
E-1-B	Stone collected from old part of Archangelos Michael Church (built at Byzantime time in Cyprus A.C 395-1195)	1st collected stone of Group E	Specimen from that stone which is notated as "A"
Sample Name	A	3	B
A-3-B	Stone collected from Sourp Magar Monastery	3rd collected stone of Group A	Specimen from that stone which is notated as "B"

3.2 Water Absorption at Atmospheric Pressure

This experiment determines the water absorption of the specimens at atmospheric pressure according to standard TS EN 13755. Eighteen cylindrical shaped testing samples (6 from each of 3 groups) have dried to constant mass (m_d) and weighed to accuracy of 0,01 g. After this procedure samples placed into a tank on the supports provided. Firstly, tap water (20 ± 10 °C) filled into tank until the half height of specimens (see Figure 3.5). After 60 mins water level at the tank increased to three-quarter height of the samples. Then, after 120 mins from initial, water level in the tank increased until the samples are totally immersed about 25 ± 5mm (see Figure 3.5). After 2 days, samples are removed from water, quickly wiped and weighed to an accuracy of 0,01 g and samples are Immersed again into water. Finally, every day specimens are removed from water and weighed until they reach to a constant mass (m_s). Constant mass is reached when the difference between two successive weightings is not bigger than 0,1 % of the first of the two masses.

The water absorption at atmospheric pressure A_b of each specimen is calculated by the equation below:

$A_b = (m_s - m_d).100 / m_d$

where;

m_d is mass of the dry sample, in grams;

m_s is mass of the saturated sample (after immersion in water when the constant mass is reached), in grams;

A_b is water absorption at atmospheric pressure, expressed as a percentage.

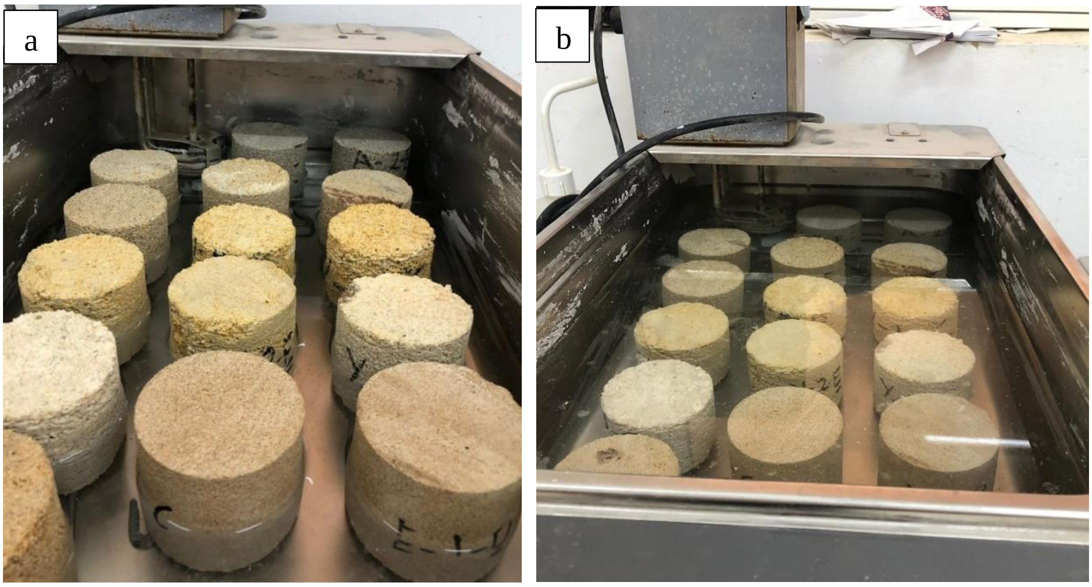


Figure 3.5: a) Water level is at half height of samples b) Samples are totally immersed into water

3.3 Salt Crystallisation Test

This experiment determines resistance of the specimens to salt crystallisation according to standard TS EN 12370. Cylindrical shaped testing samples (6 from each of 3 groups) have dried to constant mass (m_d) and weighed to accuracy of 0,01 g (constant mass is obtained when the difference between two weightings at an interval of 24 ± 2 hrs is not bigger than 0,1 %). After that samples are labelled with durable tag and again weighed (m_{d1}) (see Figure 3.6).

Specimens are placed into a container and immersed into solution of 14% sodium sulphate decahydrate by depth of 8 ± 2 mm above the top of the samples. At the container, there should be a minimum space of 10 mm between samples and at least 20 mm between the samples and the sides of the container. After 2 hours of immersion at 20 ± 0,5 °C samples are removed from solution and dried. The initial humidity in the oven during drying process obtained by placing a tray of water into an oven before placing samples into oven.

Samples are dried in the oven minimum for 16 hours. Then, they are removed from oven and left to cool at room temperature for 2 ± 0,5 hours. Finally, they are re-immersed into new sodium sulphate solution. This cycle repeated 15 times. Samples which are broke up before the 15th cycle have noted.

At the end of the 15th cycle, the samples are removed from the oven and kept in water at 23 ± 5 °C, for 24 hours. Then they are washed with fresh water. Finally, they are dried to constant mass and weighed to accuracy of 0,01 g (m_f) (see Figure 3.7).

The results are calculated by the equation below and expressed as %

$\Delta M = (M_f - M_{d1}).100 / M_d$

where;

M_d is the initial mass of the dried sample, in grams

M_{d1} is the initial mass of the dried sample with labelled tag before first cycle, in grams

M_f is the final mass of the dried specimen with labelled tag, after 15th cycle, in grams

ΔM is the relative difference between the mass of sample before and the mass of sample after testing, in percent.

Figure 3.6: sample Y-3-C labelled before the first cycle

Figure 3.7: sample Y-3-C after 15th cycle

3.4 Uniaxial Compressive Strength

This experiment determines the uniaxial compressive strength of the specimens according to standard TS EN 1926. Cylindrical shaped testing samples (6 from each of 3 groups) have been used for this experiment. Their average diameters (d) are measured to calculate their cross-sectional areas (A). Then, samples are capped and dried to constant mass in an oven. After that, samples are loaded with an applied stress of 1 ± 0,5 MPa/s and failure load (F) recorded (see Figure 3.8).

Uniaxial compressive strength (R) calculated for each sample with using the equation below;

$R = F / A$

where;

F is the failure load of sample, in kN

A is the cross sectional area of the sample, in mm^2

R is the uniaxial compressive strength of the sample, in MPa

Figure 3.8: Sample Y-2-D during test

3.5 Water Absorption by Capillarity

This experiment determines water absorption coefficient of the specimens by capillarity, according to standard TS EN 1925. Cylindrical shaped testing samples (6 from each of 3 groups) have dried to constant mass (m_d) and weighed to accuracy of 0,01 g (constant mass is obtained when the difference between two weightings at an interval of 24 ± 2 hours is not bigger than 0,1 %). After that, the area of the base of samples that are going to be immersed in water is measured (A). Then samples are placed into tank on the thin supports provided, at the depth of 3 ± 1 mm of water (see Figure 3.10). Finally, at time intervals t_i: 1, 3, 5, 10, 15, 30, 60, 480 and 1440 minutes after immersion of samples, they are removed from tank and weighed quickly with accuracy of 0,01 grams (m_i). If the difference of weight of sample between two measurements are not bigger than 1%, experiment ends for that sample.

Calculation of coefficient of water absorption by capillarity is explained at below;

Graph of absorbed water mass in grams divided by area of immersed section in square metres against square root of time is drawn. If the correlation coefficient between the measured points of the first part of graph and the regression straight line for that part is bigger than 0,90 (for the first 5 measurements) or bigger than 0,95 (for the first 4 measurements) like Figure 3.9 at below, coefficient of water absorption by capillarity C (in grams per square meter per root of time in seconds) obtained by slope of regression line also with the equation below.

$C = (M_i - M_d) / A.\sqrt{T_i}$

where;

M_i is the mass of the sample at that specific time, in grams

M_d is the dried constant mass, in grams

A is the area of the side immersed in water, in square meter

T_i is the time elapsed from the starting of test to when the mass of sample weighed, in minutes

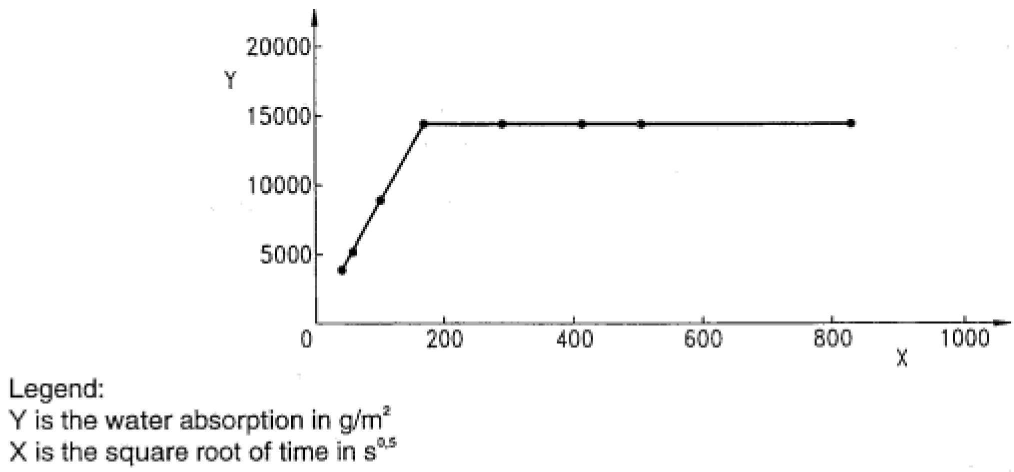


Figure 3.9: Example of graph of water absorbed by capillarity [22]

If the correlation coefficient between the measured points of the first part of graph and the regression straight line for that part is **NOT** bigger than 0,90 (for the first 5 measurements) or bigger than 0,95 (for the first 4 measurements), C is calculated by the formula below.

C = a.b

where;

$a = (m_f - m_d)/A$ (m_f is final mass of sample and m_d is initial dry mass in grams)

$b = 1/\sqrt{t_i}$

Figure 3.10: Samples of group A during water absorption by capilarity test placed on thin supports

3.6 Real Density, Apparent Density, Total Porosity, Open Porosity and Specific Gravity

This experiment determines real density, apparent density, total porosity, open porosity according to standard TS EN 1936 and specific gravity of the specimens. Cylindrical shaped testing samples (6 from each of 3 groups) have dried to constant mass.

3.6.1 Procedure for Determining of Open Porosity and Apparent Density

After determining of constant dried mass of samples (m_d), samples are placed into evacuation vessel and pressure decreased slowly to 2,0 ± 0,7 kPa. This pressure kept about 2 hours for elimination of air that in open pores of samples. Then, demineralized water at 20 ± 5°C slowly added into vessel (it should not take more than 15 minutes for samples to immersed fully in water). During addition of water pressure should be maintained at 2,0 ± 0,7 kPa (see Figure 3.11). Vessel turned back to atmospheric pressure when the all samples covered fully with water and left samples under water about 24 hours at atmospheric pressure. Finally, each sample weighed under water (m_h), then wiped quickly and weighed again to obtain saturated mass of sample (m_s).

Apparent density and Open porosity of samples can be found using equations below;

$\rho_b = (m_d).\rho_{rh} / (m_s - m_h)$

where;

m_d is mass of the dried sample, in grams;

m_s is mass of the saturated sample, in grams;

m_h is mass of the sample immersed in water, in grams;

ρ_{rh} is density of water, in kilograms per cubic metre;

ρ_b is apparent density of the sample, in kilograms per cubic metre;

$p_o = (m_s - m_d).100 / (m_s - m_h)$

where;

m_d is mass of the dried sample, in grams;

m_s is mass of the saturated sample, in grams;

m_h is mass of the sample immersed in water, in grams;

p_o is open porosity of the sample, as a percentage;

Figure 3.11: Addition of water into vessel while keeping pressure at 2 kPa

3.6.2 Procedure for Determining of Real Density

After determining of apparent density and open porosity of samples, each sample grind individually for particles to pass through a sieve with 0,063 mm mesh (see Figure 3.12). Ground samples are dried to constant mass and approximately 10 grams of these samples collected individually (m_e). Then collected 10 grams of sample added into pycnometers which are half full with deionized water and shaked well for dispersion of solid matter (see Figure 3.13 and 3.14). After that, vacuum of 2 ± 0,7 kPa is applied to pycnometers until finishing of rising of air bubbles. Finally, pycnometers filled completely with deionized water and weighed with accuracy of 0,01 g (m_1). Pycnometers are cleared and washed, then filled fully only with deionized water and weighed with accuracy of 0,01g (m_2).

Real density of the sample is calculated with using equation below;

$\rho_r = (m_e).\rho_{rh} / (m_2 + m_e - m_1)$

where;

m_e is mass of the dried ground sample for tests using the pycnometer approximately 10g, in grams;

m_1 is mass of the pycnometer filled with deionized water and the ground specimen, in grams;

m_2 is mass of the pycnometer filled with deionized water only, in grams;

ρ_{rh} is density of water, in kilograms per cubic metre;

ρ_r is real density of the sample, in kilograms per cubic metre;

Total porosity of the sample is calculated with using equation below;

$P = [1 - (\rho_b / \rho_r)].100$

where;

ρ_b is apparent density of the sample, in kilograms per cubic metre;

ρ_r is real density of the sample, in kilograms per cubic metre;

p is total porosity of the sample, as a percentage

Figure 3.12: a) Grinding of samples and passing through sieve stage 1 b) Stage 2

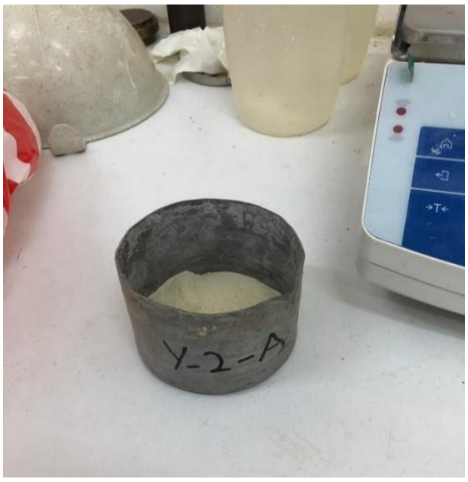


Figure 3.13: sample Y-2-A that is grinded and dried


Figure 3.14: Pycnometers containing dried ground samples, approximately 10g and half fully with deionized water

In addition, volume of open pores and apparent volume can be found using these equations below;

$V_o = (m_s - m_d).1000 / \rho_{rh}$

where;

m_d is mass of the dried sample, in grams;

m_s is mass of the saturated sample, in grams;

ρ_{rh} is density of water, in kilograms per cubic metre;

V_o is volume of open pores of the sample, in millilitres

$V_b = (m_s - m_h).1000 / \rho_{rh}$

where;

m_d is mass of the dried sample, in grams;

m_s is mass of the saturated sample, in grams;

ρ_{rh} is density of water, in kilograms per cubic metre;

V_b is apparent volume of the sample, in millilitres

Specific gravity of samples from pycnometer method at real density test can also be found using equation below;

$S.G = (m_e).G_t / [m_e - (m_1 - m_2)]$

where;

m_e is mass of the dried ground sample for tests using the pycnometer approximately 10g, in grams;

m_1 is mass of the pycnometer filled with deionized water and the ground specimen, in grams;

m_2 is mass of the pycnometer filled with deionized water only, in grams;

G_t is the specific gravity of water at that room temperature;

S.G is the specific gravity of the sample

3.7 Pulse Velocity

This test determines the ultrasonic pulse velocity of samples. Cylindrical shaped testing samples (6 from each of 3 groups) have dried to constant mass and their height (body length where the signal will travel) measured in milli meters (X). Then samples are placed horizontally between two electro-acoustic transducers by applying surface contacts. By this way, pulse of vibrations at an ultrasonic frequency from one transducer reach other one. Time taken (t) for pulse to travel through sample is measured by apparatus in micro seconds with an accuracy of $\pm$ 0,1 μsec. Samples used in this test, also used later at uniaxial compressive strength test.

Ultrasonic pulse velocity can be calculated by using equation below;

$U = x / t$

where;

x is length of path the pulse is travelled, in milli meters

t is time taken for pulse to travel, in micro seconds

U is the pulse velocity, in km/sec

Chapter 4

RESULTS AND DISCUSSION

4.1 Water Absorption at Atmospheric Pressure

Results of water absorption test at atmospheric pressure for 18 cylindrical shaped test samples (6 from each group) are given in Table 4.1 and Figure 4.1. Group A is samples from Sourp Magar Monastery which is located in Alevkayası. Group Y is samples from a new part of Archangelos Michael Church located in Yeni Erenköy and Group E is samples from an old part of Archangelos Michael Church.

In light of the results below, samples from the new part of Archangelos Micheal Church (Group Y) has the highest water absorption capacity (A_b) with an average of 19,74%. It is followed by the samples from the old part of Archangelos Michael Church (Group E), with a result of 15,83%. Samples from Sourp Magar Monastery (Group A) has the lowest water absorption capacity at 11,63%.

Özçelik and Güven [19], and Ünal [20], highlighted that there is a high correlation between the porosity and water absorption capacity of stone. From Figure 4.8 and Table 4.6 in Chapter 4.5, it can be observed that Group Y is highly porous when compared to the other groups, therefore it was expected for Group Y to have a higher water absorption capacity.

From Bahalı's study [18], the oven dried condition of Karpaz stone has a 20,5% water absorption capacity. Since Yeni Erenköy is a location that neighbours Karpaz , it was expected to have similar results. As was expected, Group Y's water absorption capacity result of 19,74% is very close to the Karpaz stone.

Table 4.1: Results of water absorption at atmospheric pressure test

Sample	Mass of the dry sample m_d (g)	Mass of the saturated sample m_s (g)	Water absorption capacity A_b (%)	**Average A_b (%)**
A-1-C	358,99	389,57	8,52	Group A 11,63
A-1-E	362,69	396,54	9,33	
A-2-E	355,86	407,27	14,45	
A-2-F	377,69	427,04	13,07	
A-3-A	336,15	384,66	14,43	
A-3-F	334,1	367,49	9,99	
Y-1-B	271,84	334,94	23,21	Group Y 19,74
Y-1-C	273,7	341,28	24,69	
Y-2-D	329,33	383,56	16,47	
Y-2-E	333,7	388,57	16,44	
Y-3-D	308,5	368,75	19,53	
Y-3-G	315,18	372,14	18,07	
E-1-C	376,53	414,19	10,00	Group E 15,83
E-1-D	367,84	408,54	11,06	
E-1-E	360,8	409,5	13,50	
E-2-A	279,99	352,16	25,78	
E-2-E	296,79	365,63	23,19	
E-3-A	370,8	413,18	11,43	

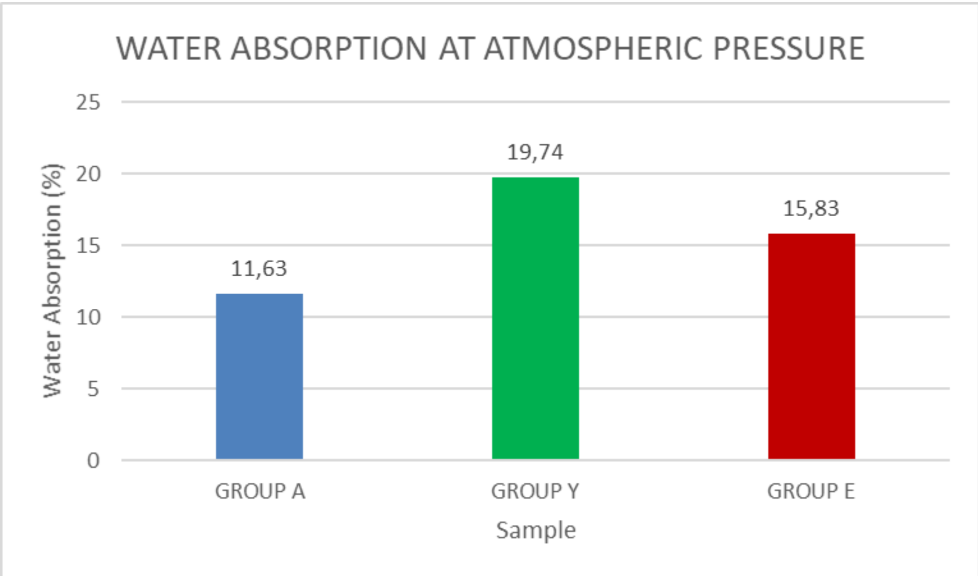


Figure 4.1: Water absorption at atmospheric pressure test results

4.2 Salt Crystallisation Test

Results of the resistance to salt crystallisation test of stones from the Sourp Magar Monastery (Group A), and the new and old parts of Archangelos Michael Church (Group Y and Group E) are given in Table 4.2 and Figure 4.2, respectively.

It can be observed that most resistant group to salt crystallisation is Group A with only -2,27% of average mass change. It is followed by Group E with an average -7.63% mass change. On the other hand, the least resistant group to salt crystallisation is Group Y. 2 of the samples Y-2-B and Y-2-C could not reach to the 15th cycle and broke up at cycles 12 and 9 respectively. The remaining samples of the group have an average change in mass of -17,24%.

Maximum value of resistance to salt crystallisation is observed in Group A, which only had a change in mass of -0,06%, in sample A-1-B. Additionally, the least resistant sample can be seen in Group Y, by the breaking up of sample Y-2-C in the 9th Cycle.

Table 4.2: Results of resistance to salt crystallisation test

Sample	Initial Mass of Sample **M_d (g)**	Initial Mass of Sample with Labelled Tag **M_{d1} (g)**	Final Mass of the Dried Sample **M_f (g)**	Change in Mass **ΔM (%)**	**Average ΔM (%)**
A-1-B	347,151	350,301	350,106	-0,06	Group A -2,27
A-1-D	374,868	378,405	345,880	-8,68	
A-2-B	326,411	329,797	323,552	-1,91	
A-2-C	374,467	377,878	377,585	-0,08	
A-3-A	334,154	337,808	330,993	-2,04	
A-3-F	333,671	337,264	333,982	-0,98	

Y-1-C	279,679	282,804	198,814	-30,03	Group Y -17.24 (also 2 samples broke up before Cycle 15)
Y-1-E	266,741	270,282	238,559	-11,89	
Y-2-B	345,421	348,556	Cycle 12		
Y-2-C	324,831	327,88	Cycle 9		
Y-3-C	318,999	322,217	263,769	-18,32	
Y-3-C	308,488	312,020	285,171	-8,70	
E-1-A	361,600	365,500	338,698	-7,41	Group E -7,63
E-1-B	372,951	376,382	337,279	-10,48	
E-1-C	376,507	380,130	355,475	-6,55	
E-2-A	275,979	279,842	279,181	-0,24	
E-2-B	287,250	290,505	288,425	-0,72	
E-3-C	381,966	385,035	307,338	-20,34	

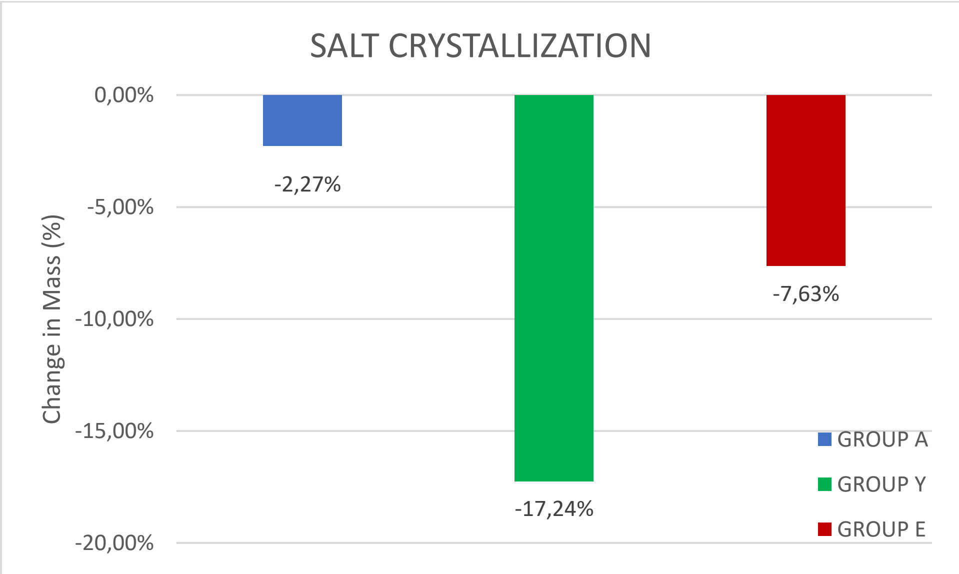


Figure 4.2: Demonstration of resistance to salt crystallisation test results

4.3 Uniaxial Compressive Strength

Results of the uniaxial compressive strength test for samples from the Sourp Magar Monastery (Group A), and the new and old parts of Archangelos Michael Church (Group Y and Group E) are given in Table 4.3 and Figure 4.3 respectively.

In light of the results below, we can see that Group E has the greatest average compressive strength value (R) at 16,27 MPa, which is approximately double the second highest group, group A; at 7,97 MPa. On the other hand, Group Y has the lowest average compressive strength of 4,96 MPa.

The highest compressive strength value is seen in sample E-1-B from Group E at 27,00 MPa, and the smallest value is observed in sample Y-1-F, at 1,78 MPa.

According to Bahalı's study [18], oven dried Karpaz stone has an average compressive strength of 5,03 MPa, which is very similar to Group Y, the stones of the new part of Archangelos Michael Church, located in Yeni Erenköy.

Table 4.3: Results of uniaxial compressive strength test

Sample	Avg. Diameter (mm)	Failure Load **F (kN)**	Cross Sectional Area **A (mm²)**	Uniaxial Compressive Strength **R (MPa)**	**Average R (MPa)**
A-1-B	63,95	25,7	3211,96358	8,00	Group A 7,97
A-1-F	63,275	27,4	3144,5161	8,71	
A-2-D	63,875	43	3204,43407	13,42	
A-2-E	63,575	20,6	3174,4044	6,49	
A-3-D	63,475	16,6	3164,42592	5,25	
A-3-D	64,025	19,2	3219,50192	5,96	
Y-1-D	62,9	9,5	3107,35452	3,06	Group Y 4,96
Y-1-F	63,25	5,6	3142,03179	1,78	
Y-2-A	63,6	25	3176,90147	7,87	
Y-2-D	63,9	16,4	3206,94293	5,11	
Y-3-A	63,75	20,7	3191,90453	6,49	
Y-3-B	63,725	17,3	3189,40156	5,42	
E-1-B	64,2	87,4	3237,12575	27,00	Group E 16,27
E-1-D	64,2	86,5	3237,12575	26,72	
E-1-E	64,15	62,2	3232,08546	19,24	
E-2-C	63,775	15,7	3194,40847	4,91	
E-2-D	63,9	18,7	3206,94293	5,83	
E-3-B	63,95	44,7	3211,96358	13,92	

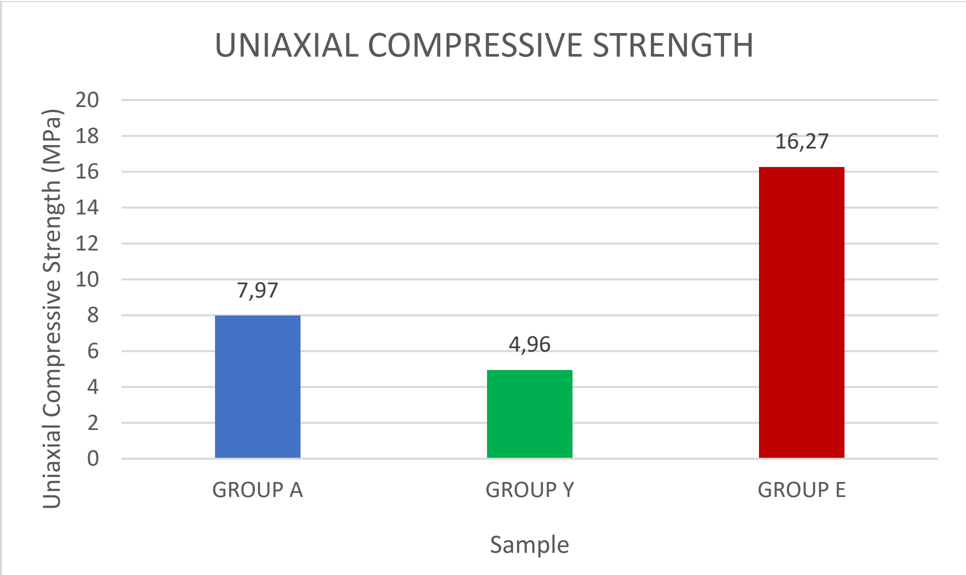


Figure 4.3: Demonstaration of uniaxial compressive strength test results

4.4 Water Absorption by Capillarity

Results of the water absorption by capillarity test of samples from the Sourp Magar Monastery (Group A), and the new and old parts of Archangelos Michael Church (Group Y and Group E) are given in Figure 4.4, 4.5, 4.6, 4.7 and Table 4.4.

The correlation coefficient between the measured points of the first part of the graph, and the regression straight line for that part is bigger than 0,90 (for the first 5 measurements) or bigger than 0,95 (for the first 4 measurements) at samples A-1-B, A-1-F, Y-2-A, Y-2-D, Y-3-A, E-1-B and E-1-D (can be seen at Figure 4.4, 4.5 and 4.6). Therefore, their coefficient of water absorption by capillarity (C) values (in grams per square meter per root of time in seconds) are obtained through the slope of the regression line (can be seen in more detail at Appendix B). C values of the remaining samples are calculated according to their final masses.

From Table 4.4 and Figure 4.7, it can be seen that Group Y has the highest average coefficient of water absorption by capillarity (C) value, at 351,85 $g/m^2.s^{0.5}$. It is followed by Group E with a value of 331,07 $g/m^2.s^{0.5}$. Conversely, Group A has the lowest average coefficient of water absorption by capillarity (C) value, at 327,20 $g/m^2.s^{0.5}$.

That sequence is also the same as the sequence from the water absorption at atmospheric pressure test. In Chapter 4.5, it was observed that Group Y was highly porous when compared to other groups. Therefore, it can be concluded that as the samples become more porous, the absorption coefficients of the samples increase.

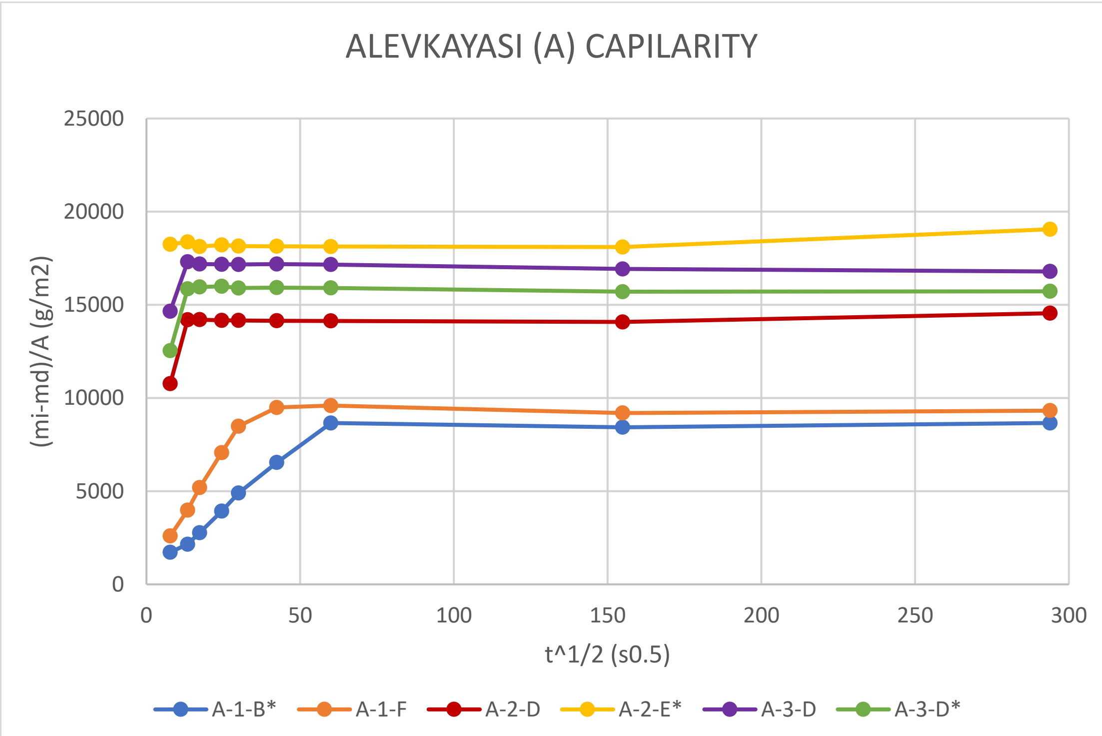


Figure 4.4: Graph of water absorbed by capillarity for Group A

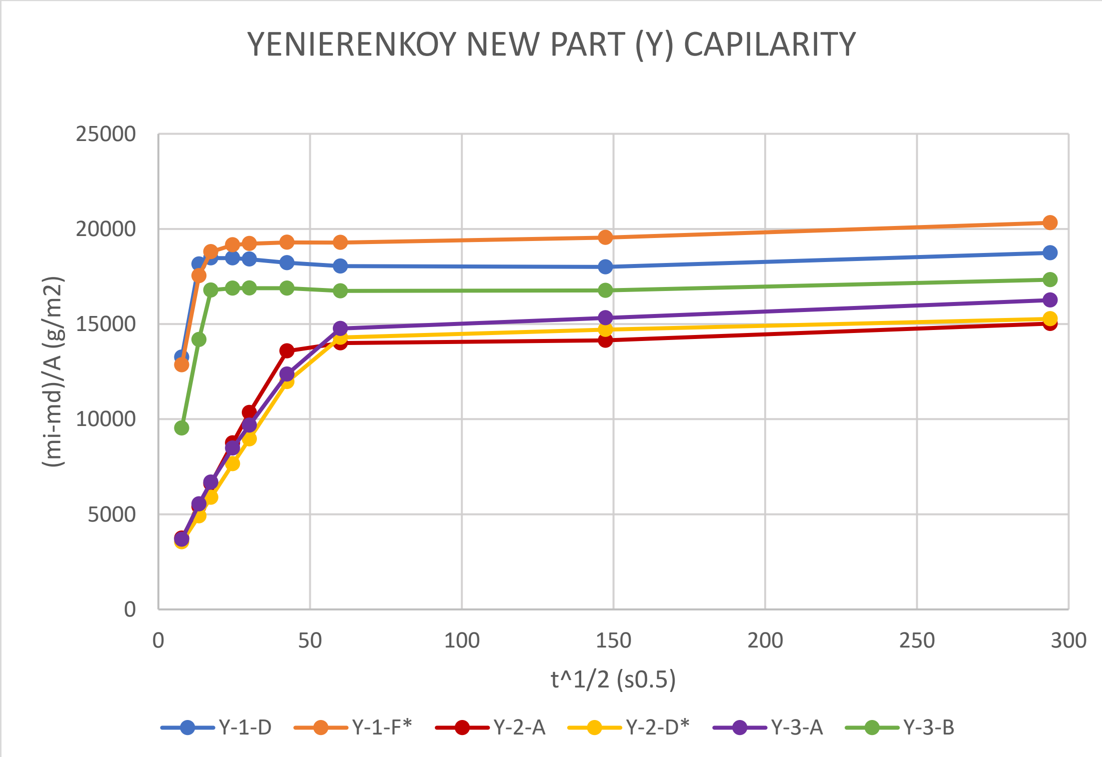


Figure 4.5: Graph of water absorbed by capillarity for Group Y

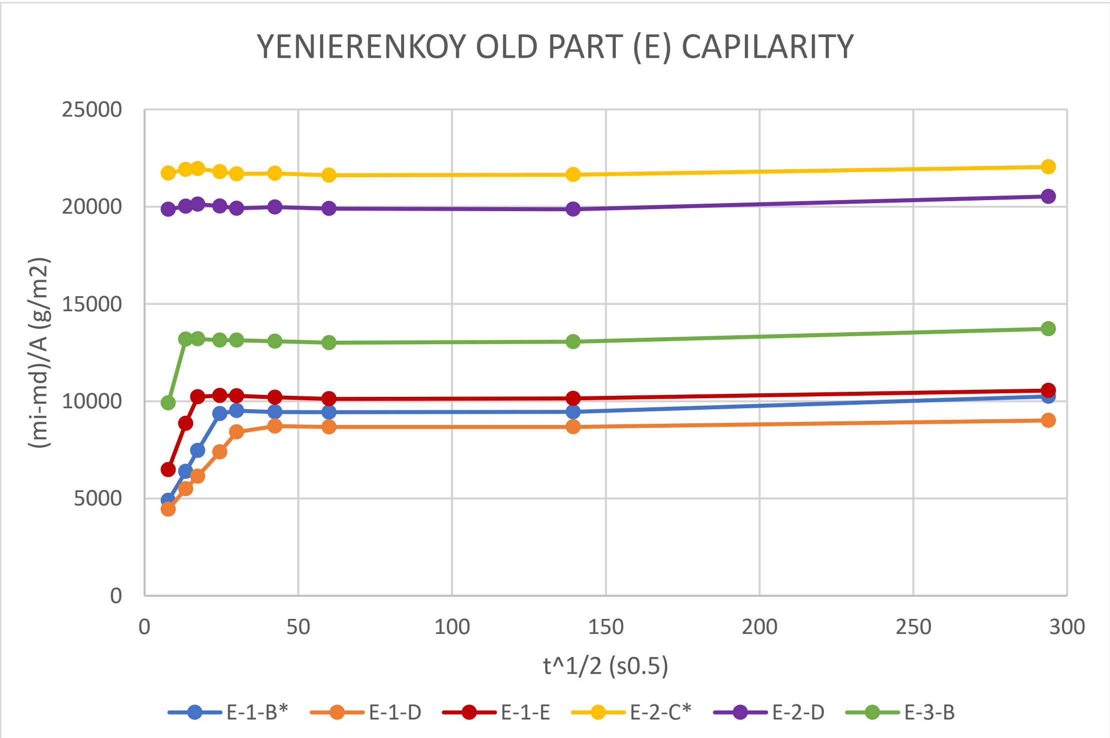


Figure 4.6: Graph of water absorbed by capillarity for Group E

Table 4.4: Results of water absorption by capillarity test

Sample	Coefficient of Water Absorption by Capillarity C ($g/m^2.s^{0.5}$)	**Average C ($g/m^2.s^{0.5}$)**
A-1-B	266,98	Group A 327,20
A-1-F	147,08	
A-2-D	334,82	
A-2-E	433,03	
A-3-D	405,12	
A-3-D	376,15	
Y-1-D	435,32	Group Y 351,85
Y-1-F	453,09	
Y-2-A	297,58	
Y-2-D	243,99	
Y-3-A	285,62	
Y-3-B	395,52	
E-1-B	266,76	Group E 331,07
E-1-D	176,96	
E-1-E	242,62	
E-2-C	517,46	
E-2-D	471,85	
E-3-B	310,77	

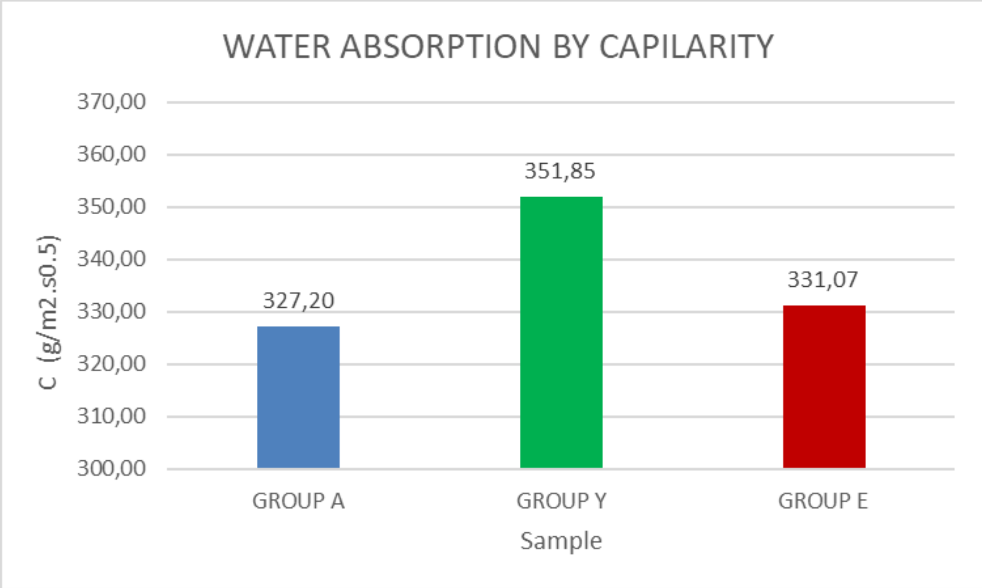


Figure 4.7: Demonstration of water absorption by capillarity test results

4.5 Real Density, Apparent Density, Total Porosity, Open Porosity and Specific Gravity

Results of the real density, apparent density, total porosity, open porosity and specific gravity tests for samples from the Sourp Magar Monastery (Group A), and the new and old parts of Archangelos Michael Church (Group Y and Group E) are given in Table 4.5, 4.6, Figure 4.8, 4.9 and 4.10.

From the results below, it can be seen that Group Y is more porous than the other groups. It has an average of 29,59% open porosity and 39.20% for total porosity. Group A has the lowest average open porosity at 22,88%, and Group E's average open porosity value is 23,93%. In terms of total porosity, Group E has the lowest average value with 32,91% and Group A's average total porosity value is 36,70%.

In addition, Group E has the highest average apparent density at 1746 kg/m^3, Group A has a slightly lower value than Group E at 1732 kg/m^{3,} and Group Y has the lowest average apparent density at 1592 kg/m^3. On the other hand, in terms of real density, Group E has the lowest average value with 2601 kg/m^3. Group A has the highest value with 2732 kg/m^3, followed by Group Y with 2622 kg/m^3.

Finally, Group A has the highest average specific gravity value at 2,75. Group Y has second highest value with 2,63 and the lowest average specific gravity value is seen in Group E at 2,61.

When comparing the specific gravity and porosity values of Group Y stones with the oven dried condition of Karpaz stone at Bahalı's study [18], some remarkable similarities were found again. For the oven dried condition of Karpaz stone, specific gravity was obtained at 2,68, and the stones from the new part of Archangelos Michael Church (Group Y) had an average of 2,63. Furthermore, open porosity and total porosity values of the oven dried condition of Karpaz stone was obtained at 28,3% and 43,55% respectively in Bahalı's study [18]. In our study, Group Y had 29,59% and 39,20% for the open and total porosity values, respectively.

Table 4.5: Results of measurements for real density, apparent density, total porosity, open porosity and specific gravity tests

Sample	Mass of the Dried Sample **m_d (g)**	Mass of the Sample Immersed in Water **m_h (g)**	Mass of the Saturated Sample **m_s (g)**	Mass of the Dried Ground Sample **m_e (g)**	Mass of Pycnometer with Water and Ground Sample **m_1 (g)**	Mass of the Pycnometer Filled with Deionized Water Only **m_2 (g)**
A-1-B	349,11	184,4	377,84	10,28	163,48	157
A-1-F	373,87	199,37	404,47	10,3	154,14	147,61
A-2-D	376,34	220,48	423,54	10,18	162,9	156,43
A-2-E	330,14	192,7	388,93	10,35	153,87	147,27
A-3-D	317,2	174,54	372,14	10,54	150,75	144,04
A-3-D	320,72	177,42	372,32	10,39	161,05	154,42
Y-1-D	269,03	149,61	333,85	10,34	163,45	157
Y-1-F	267,79	145,46	330,3	10,42	154,15	147,61
Y-2-A	329,68	185,3	378,98	10,45	162,88	156,4
Y-2-D	322,38	179,3	373,32	10,39	153,7	147,26
Y-3-A	338,5	193,2	391,73	10,49	150,6	143,99
Y-3-B	306,45	172,06	364,06	10,51	160,65	154,42

E-1-B	395,06	224,47	428,47	10,2	88,67	82,36
E-1-D	392,67	223,08	422,44	10,09	86,31	80,11
E-1-E	387,07	219,5	422,16	10,27	88,68	82,37
E-2-C	275,85	152,2	347,84	10,37	86,47	80,08
E-2-D	279,72	155,58	346,69	10,19	88,74	82,5
E-3-B	347,16	199,27	391,67	10,15	88,39	82,08

Table 4.6: Results of open porosity and total porosity tests

Sample	Open porosity po (%)	Total porosity p (%)
A-1-B	14,85	33,29
A-1-F	14,92	33,28
A-2-D	23,24	32,46
A-2-E	29,96	39,04
A-3-D	27,80	41,67
A-3-D	26,48	40,45
Average values for group A	**22,88**	**36,70**
Y-1-D	35,18	45,07
Y-1-F	33,82	46,05
Y-2-A	25,45	35,33
Y-2-D	26,26	36,83
Y-3-A	26,81	36,93
Y-3-B	30,01	35,00
Average values for group Y	**29,59**	**39,20**
E-1-B	16,38	26,14
E-1-D	14,93	24,06
E-1-E	17,31	26,35
E-2-C	36,80	45,88
E-2-D	35,04	43,26
E-3-B	23,13	31,74
Average values for group E	**23,93**	**32,91**

Table 4.7: Results of real density, apparent density and specific gravity tests

Sample	Apparent density ρ_b (kg/m3)	Real density ρ_r (kg/m3)	Specific gravity
A-1-B	1801	2700	2,71
A-1-F	1819	2727	2,73
A-2-D	1850	2738	2,75
A-2-E	1679	2754	2,76
A-3-D	1602	2746	2,75
A-3-D	1642	2758	2,77
Average values for group A	**1732**	**2737**	**2,75**
Y-1-D	1457	2653	2,66
Y-1-F	1446	2680	2,69
Y-2-A	1699	2627	2,63
Y-2-D	1658	2625	2,63
Y-3-A	1702	2698	2,71
Y-3-B	1593	2451	2,46
Average values for group Y	**1592**	**2622**	**2,63**
E-1-B	1933	2617	2,62
E-1-D	1966	2589	2,60
E-1-E	1906	2588	2,60
E-2-C	1407	2600	2,61
E-2-D	1461	2575	2,58
E-3-B	1801	2638	2,65
Average values for group E	**1746**	**2601**	**2,61**

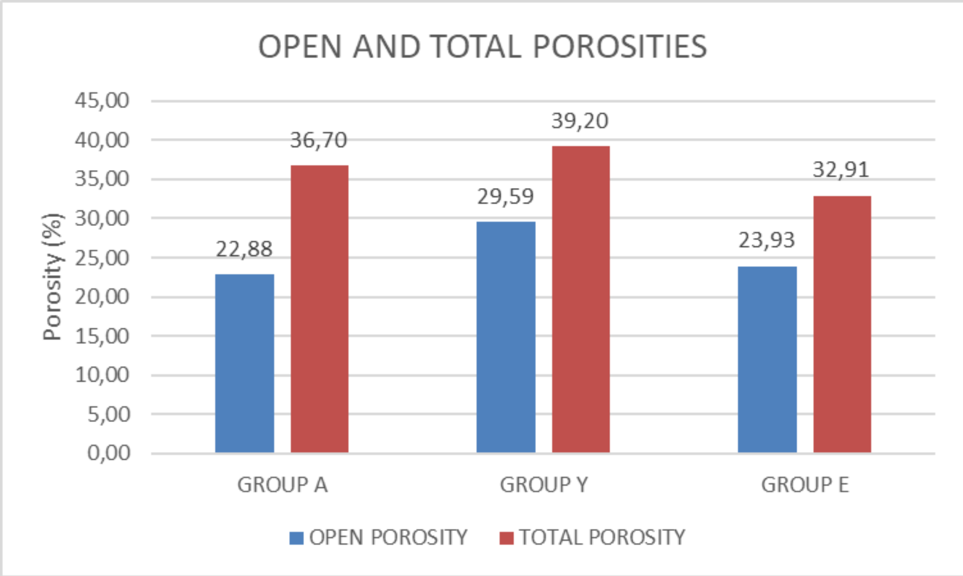


Figure 4.8: Demonstration of results of open and total porosity test

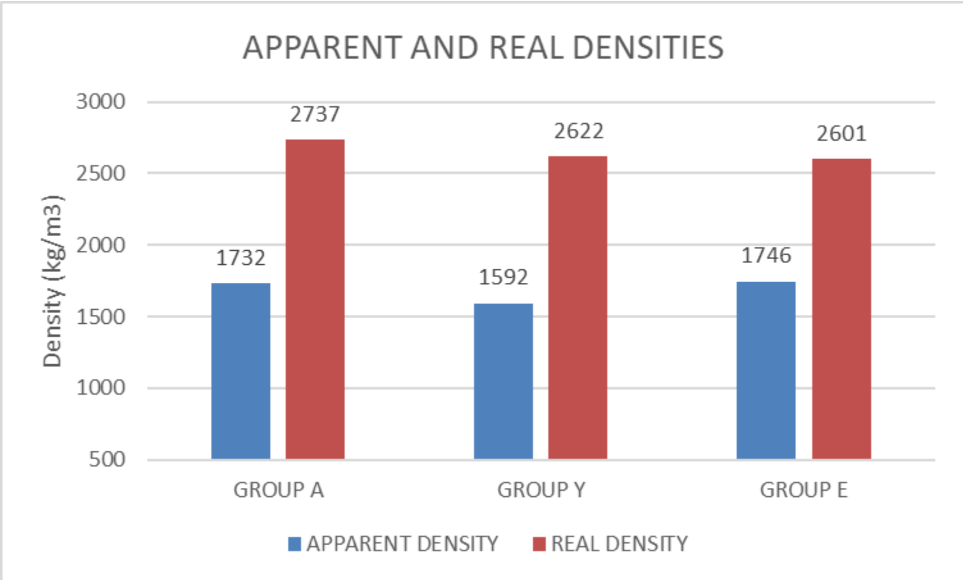


Figure 4.9: Demonstration of results of apparent density and real density tests

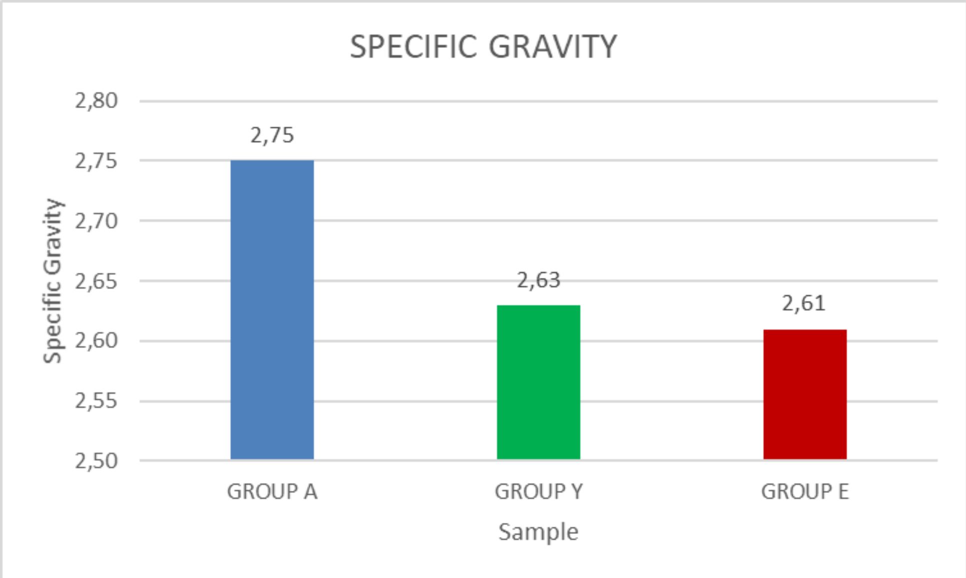


Figure 4.10: Demonstration of results of specific gravity values

4.6 Pulse Velocity

Results of the pulse velocity test for samples from the Sourp Magar Monastery (Group A), and the new and old parts of Archangelos Michael Church (Group Y and Group E) are given in Table 4.7 and Figure 4.11, respectively.

From the results below, it can be seen that Group E has the highest average pulse velocity with 3,31 km/sec. Group A has the second highest with 2,64 km/sec, and Group Y has the lowest with 2,25 km/sec. This sequence is exactly same as the sequence of uniaxial compressive strength test (can be seen in part 4.3). This situation was also obtained in Aliabdo's study [21], which showed that the pulse velocities of stones are highly correlated with their compressive strengths. From Figure 4.12 and 4.13, it can be seen that the acceptable regression coefficient values (R^2) of 0,82 and 0,80 have been obtained from Group E and Group Y separately, and 0,74 for all of the pulse velocity and compressive strength values.

The maximum pulse velocity is obtained from Group A, as 3,05 km/sec, from sample A-1-B (the sample which has also shown the highest compressive strength value). On the other hand, the lowest pulse velocity value is observed in Group Y sample Y-1-F at 1,88 (the sample which has also shown the minimum compressive strength value).

Table 4.8: Results of pulse velocity test

Sample	Length (mm)	Pulse time (microsecond)	Pulse velocity (km/sec)	Average pulse velocity (km/sec)
A-1-B	62,5	20,5	3,05	**Group A 2,64**
A-1-F	64,7	23,4	2,76	
A-2-D	64,2	22,8	2,82	
A-2-E	63,45	23,4	2,71	
A-3-D	64,45	28,5	2,26	
A-3-D	64,5	29,1	2,22	
Y-1-D	63,7	32,8	1,94	**Group Y 2,25**
Y-1-F	65	34,6	1,88	
Y-2-A	63,4	24,4	2,60	
Y-2-D	63,1	31	2,04	
Y-3-A	62,3	23,1	2,70	
Y-3-B	62	26,6	2,33	
E-1-B	63,85	18,3	3,49	**Group E 3,31**
E-1-D	64,7	16,9	3,83	
E-1-E	64,25	18,5	3,47	
E-2-C	64,75	23,6	2,74	
E-2-D	63,9	22,3	2,87	
E-3-B	61,55	17,7	3,48	

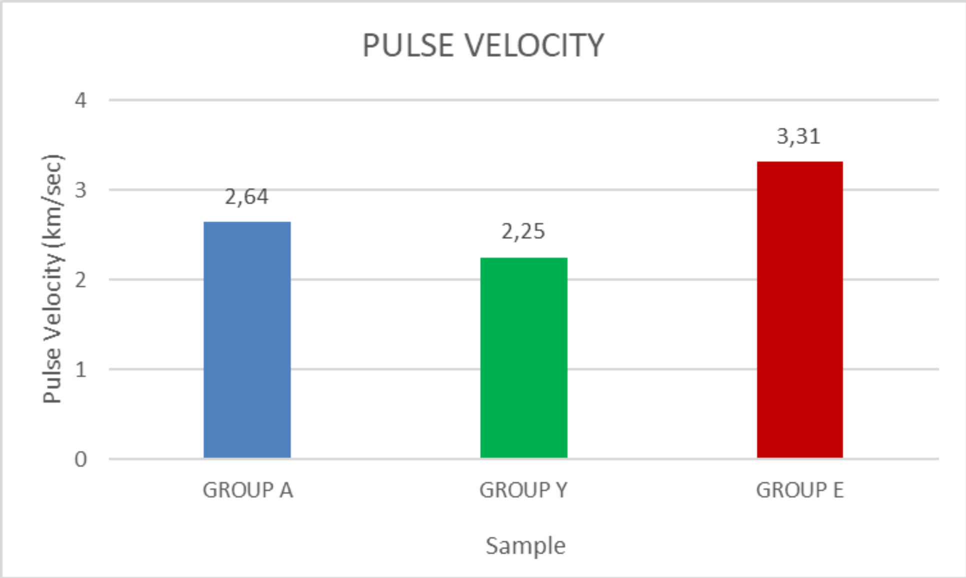


Figure 4.11: Demonstaration of pulse velocity test results

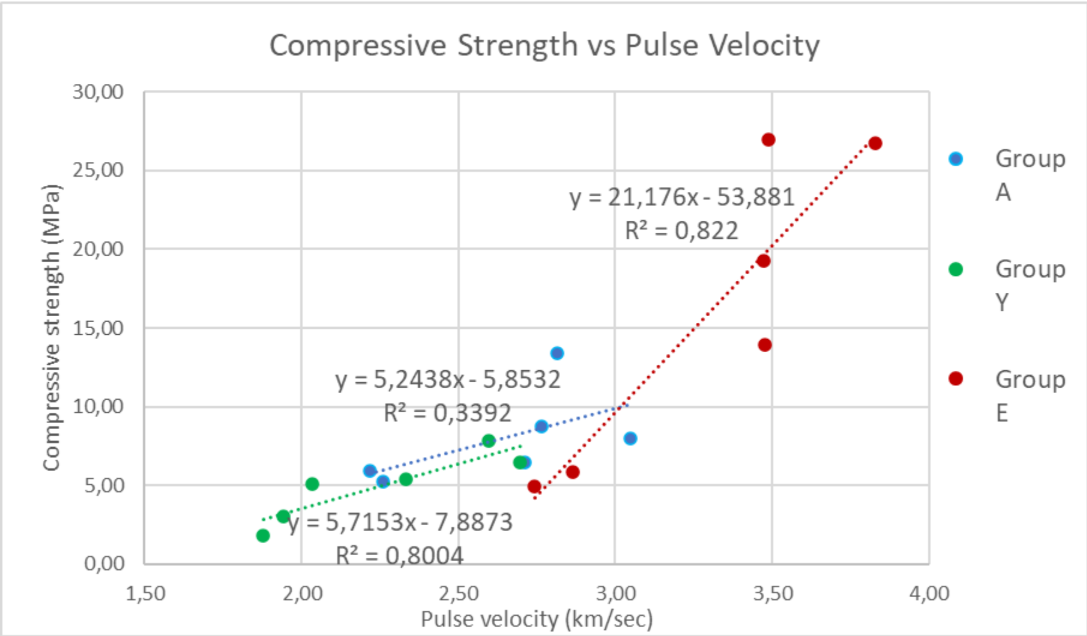


Figure 4.12: Relationship between pulse velocity and compressive strength values separately for Group E, Group Y and Group A

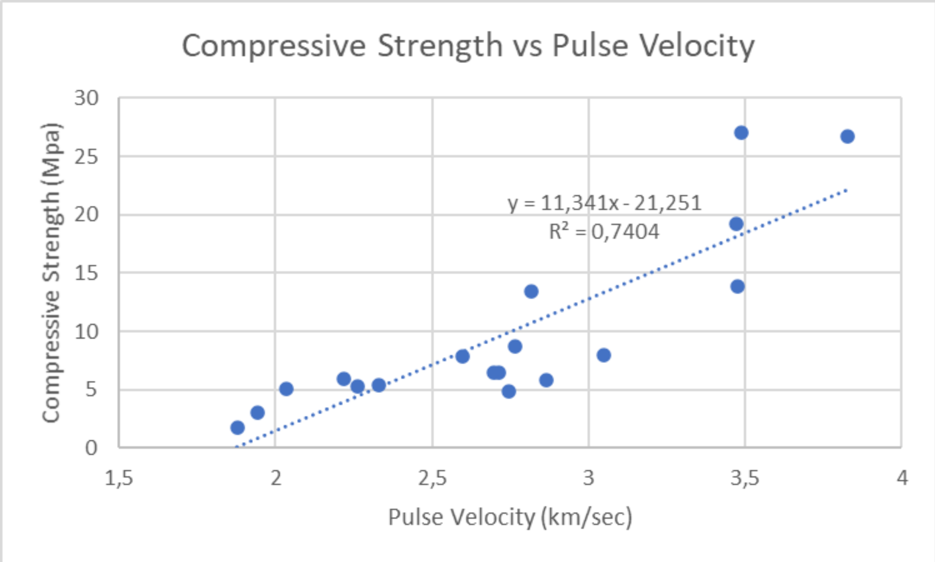


Figure 4.13: Overall relationship between all pulse velocity and compressive strength values

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Generally, during conservation projects of historical monuments, trustworthy information about the stones of the structures is very crucial. In the cases of replacing missing or damaged parts of the natural stones, new ones should be extremely similar to the originals that were used. Should that situation arise, this would be very helpful for all the stakeholders that partake in conservation projects of historical monuments. Unfortunately, at the moment, resources about the characteristics of natural stones is hard to find and very lacking. The main aim of this thesis was to more widely spread such information.

From the results of the experiments that were carried out, the stones from the new part of Archengelos Michael Church in Yeni Erenköy (Group Y) have the highest coefficient of water absorption by capilarity (C) and the highest water absorption capacity (A_b) at atmospheric pressure. This characteristic of Group Y comes from its porous condition. Group Y also has the highest open porosity and total porosity values.

During the conservation project, most of the replaced deteriorated stones were in the new part of the Archangelos Michael Church (Figures 2.25 and 2.29). This situation can be explained by the results of experimentation of the Group Y stones. More specifically, their high porosity and capillarity values are the main reasons for the extent of the stones' deterioration over time, due to environmental factors (rain, wind, high temperature, etc.).

In addition, the stones from the old part of the Archangelos Michael Church (Group E) had the highest uniaxial compressive strength (R) and pulse velocity values. An acceptable correlation between uniaxial compressive strength and pulse velocity has also been observed in this study. Furthermore, Group E has the biggest apparent density.

Stones from the Sourp Magar Monastery in Alevkayası (Group A) have the highest real density and specific gravity values. At the same time, these stones are also the most resistive group against salt crystallization.

On the other hand, the stones from the new part of the Archengelos Michael Church in Yeni Erenköy (Group Y) were least resistive group against salt crystallization. They also had the lowest uniaxial compressive strength value.

Yenierenköy is a region that lies very close to sea, therefore, a low resistance to salt crystallization is a major disadvantage for stones in the new part of the Archangelos Michael Church (Group Y). Consequently, a significant amount of the replaced deteriorated stones were also from that part of the church.

Finally, when comparing the properties of the oven dried condition of Karpaz stone from Bahalı's study [18] to the stones from the new part of the Archengelos Michael Church in Yeni Erenköy (Group Y), a large number of similarities have been observed. Their compressive strength, open porosity, total porosity, specific gravity and water absorption capacity values were all very close to each other.

5.2 Recommendations

1. Historical monuments in Cyprus should be investigated as much as possible to determine the properties of their natural stones.
2. Research should be done on products from all of the stone quarries in Cyprus as much as possible.

3. A study should be done to determine which stone quarry has the most suitable products for conservation works of different historical monuments.

REFERENCES

[1] UNESCO. (1972). *Convention concerning the protection of the world cultural and natural heritage.* General Conference Seventeenth Session 135–145.

[2] Fielden, B. M. (2003). *Conservation of Historic Buildings (3rd Ed)*. United Kingdom: Architectural Press.

[3] Vicente, Romeu & Lagomarsino, Sergio & Ferreira, Tiago & Cattari, Serena & Mendes Silva, Raimundo. (2018). *Cultural Heritage Monuments and Historical Buildings: Conservation Works and Structural Retrofitting.* 10.1007/978-981-10-5858-5_2.

[4] Titchen SM. (1995). *On the construction of outstanding universal value: UNESCO's World Heritage Convention (Convention concerning the Protection of the World Cultural and Natural Heritage, 1972) and the identification and assessment of cultural places for inclusion in the World Heritage List,* Phd Thesis, Australian National University.

[5] Abdul Rashid, Robiah & Ahmad, A.G.. (2011). *Overview of Maintenance Approaches of Historical Buildings in Kuala Lumpur* – A Current Practice. Procedia Engineering. 20. 425-434. 10.1016/j.proeng.2011.11.185.

[6] Dunn, N. (2000). *Maintaining Europe's Built Cultural Heritage*. Conference of Planned Preservation, Milano, Italy.

[7] Fielden, B. M., & Jokilehto, J. (1993). *Management Guidelines for World Cultural Heritage Sites*. Rome: ICCROM.

[8] Ahmad Ghafar, A. (1994). *Building Maintenance*. Benkel Conference, Taiping.

[9] Ahmad Ghafar A. (1994). *Pengenalan Kepada Bangunan dan Monumen Lama di Malaysia.* Benkel Conference, Taiping.

[10] Hendry AW, Khalaf FM. (2000) *Masonry wall construction*. London: Spon Press.

[11] Hendry, A.W. (2001). *Masonry Walls: materials and construction*, Construction and Building Materials, Vol 15, pp 323-330, 2001.

[12] Grimm CT. (1999). *Design for masonry volume change*. The Masonry Society, Boulder Co.

[13] Building Research Establishment. (1966). *Cracking in buildings*. Watford: Building Research Establishment.

[14] Pereira, D. & Marker, B. (2016). *The Value of Original Natural Stone in the Context of Architectural Heritage*. Geosciences. 6(1). 10.3390/geosciences6010013.

[15] Hendry, A.W., and Khalaf, F.M. (2001). *Masonry Wall Construction.* London: Spon Press.

[16] Cyprus Tourism Organization. (2015). *Cyprus 10000 Years of History and Civilization.*

[17] UNDP Cyprus. (2013). *Support to Monuments of Great Importance for the Communities of Cyprus Phase 2.* https://www.cy.undp.org/content/cyprus/en/home/projects/CulturalHeritage2.html (May 2021).

[18] Eren, Özgür & Bahali, Mustafa. (2005). *Some engineering properties of natural building cut stones of Cyprus*. Construction and Building Materials. 19. 213-222. 10.1016/j.conbuildmat.2004.05.011.

[19] Ozcelik, Yilmaz & Ozguven, Ahmet. (2014). *Water absorption and drying features of different natural building stones*. Construction and Building Materials. 63. 257-270. 10.1016/j.conbuildmat.2014.04.030.

[20] Ünal, Murat & Altunok, Erhan. (2019). *Determination Of Water Absorption Properties Of Natural Building Stones And Their Relation To Porosity*. E-journal of New World Sciences Academy. 14. 39-45. 10.12739/NWSA.2019.14.1.1A0429.

[21] Aliabdo, Ali & Abd Elmoaty, Abd Elmoaty. (2012). *Reliability of using nondestructive tests to estimate compressive strength of building stones and bricks*. Alexandria Engineering Journal. 51. 193–203. 10.1016/j.aej.2012.05.004.

[22] Turkish Standard Institution. (2000). *Natural Stone Test Methods - Determination of water absorption coefficient by capillarity*. TS EN 1925.

[23] Stefanidou, Maria & Pachta, Vasiliki & Papayianni, Ioanna. (2015). *Design and testing of artificial stone for the restoration of stone elements in monuments and historic buildings.* Construction and Building Materials. 93. 10.1016/j.conbuildmat.2015.05.063.

[24] Válek, J., Hughes, J. J., Pique, F., Gulotta, D., van Hees, R., & Papayiani, I. (2019). *Recommendation of RILEM TC 243-SGM: functional requirements for surface repair mortars for historic buildings*. Materials and Structures, 52(28). https://doi.org/10.1617/s11527-018-1284-y

[25] Jasieńko, Jerzy & Logoń, Dominik & Misztal, Witold. (2016). *Trass-lime reinforced mortars in strengthening and reconstruction of historical masonry walls*. Construction and Building Materials. 102. 884-892. 10.1016/j.conbuildmat.2015.08.098.

APPENDICES

Appendix A: Archangelos Michael Church

Archangelos Michael Church

This is a project of the Technical Committee on Cultural Heritage

PROJECT OVERVIEW

Start Date: **October 2019**

End Date: **October 2020**

Type of intervention: **Conservation Works**

Total cost: **320,000 USD**

The church of Archangelos Michael, located in the Karpasia/Karpaz area, constitutes the principal church of the area.

The church is the result of several construction phases dating from the Byzantine period to the middle of the 20th century. It is a twin church; a composition of two churches attached to each other with an additional open portico to the south side.

The older part of the church on the northern side consists of two basic parts, the main church and the narthex to the west. While scholars have proposed slightly different dates for its construction, it has been generally dated to the Byzantine period.

The church is of the cross-in-square type with four piers on which a cylindrical dome is resting. The central and side aisles are roofed by cylindrical vaults. To the east, there is a projecting semicircular apse. Interesting features of the apse are the triple-light window and the double sawtooth brick cornice which are common characteristics of Byzantine architecture but are relatively scarce in Cyprus. The north facade is formed by three large blind arches which is also a typical characteristic of Byzantine architecture.

One of the original entrances to the church, which was located in the middle of the north wall, was blocked and replaced by a new entrance further to the west in the late 19th century.

Internally, remnants of at least two different periods of wall paintings are visible. On the south wall, there is a large wall painting of Archangelos Michael and small remnants of other paintings are visible on many locations within the church. Above the north entrance there was part of another wall painting of Archangelos Michael which due to water penetration collapsed recently. Remains of the collapsed painting were collected during the works, are safely kept and will be restored as soon as possible.

The church was extended to the west in the late Byzantine period, and a narthex was created. The narthex is of the cross-in-square compressed type and is also covered by a cylindrical dome in the center and cylindrical vaults to the north and south sides. The dome of the narthex does not have any windows. On the external side of the north wall there is a series of five recessed flat blind arches over a horizontal string-course. The external flat blind arch is a characteristic feature of Byzantine architecture which is met only in few churches in Cyprus.

It is hypothesized that the new church was constructed on the south side of the byzantine church in 1794; the two churches were connected as one complex. Three arched openings were arranged along the south wall of the byzantine church to facilitate communication between the two churches. The new church is of the single-nave type covered by a pointed vault, which is a typical feature of this period. It is wider, longer and higher than the first one and has a five-sided apse to the east.

To the west there is a women's gallery, also known as "gynaikonites," on the second level, access to which is provided by narrow and steep stone and wooden stairs.

On the southeast corner of the 18th century church, a belfry was erected towards the end of 19th century. To the south side of the complex an open portico was added in the late 19th or early 20th century.

Other, more recent, architectural interventions include a new doorway on the south side of the church (1944) which was modified and became the main entrance, reformation of the 18th century apse window, possibly of the same period and the construction of a new mosaic floor in the 18th century church above the original marble one.

Main interventions for this site include:

- Removal of incompatible renders, cleaning of the masonry, and replastering where needed;
- Revealing and conserving historical plasters and wall paintings by a conservator;
- Conserving of original doors and windows;
- Structural consolidation of the church fabric, including:
    - Replacing and dismantling of stones and rebuilding where needed;

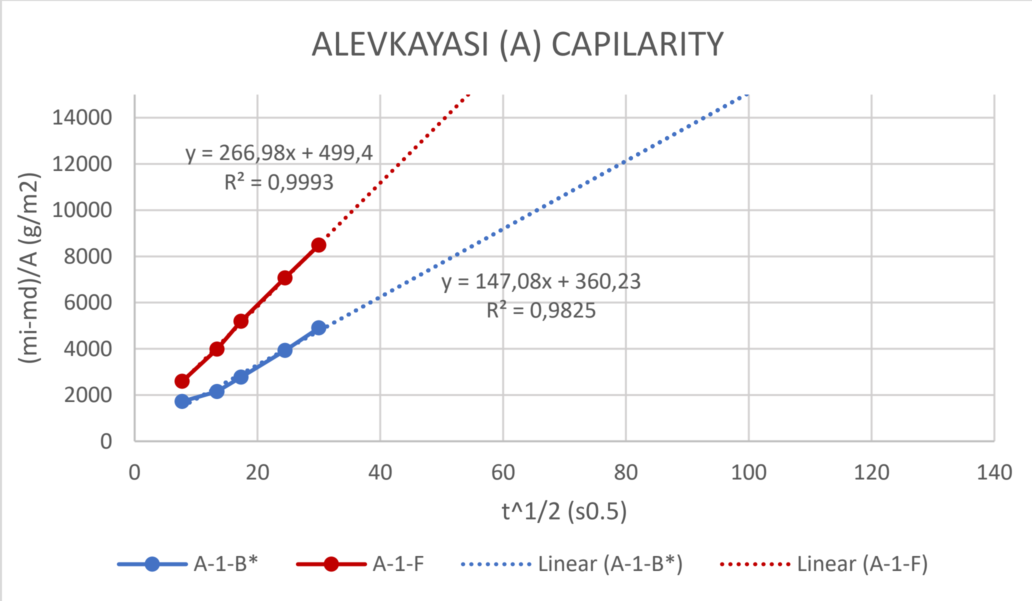
- Grouting;
    - Restoring the original system of timber beams;
    - Replacing inappropriate cement interventions.
- Conserving the byzantine church floor;
- Removing the 20th century floor from the 18th century church and revealing the historical floor;
- Installing new floor at the south arcade;
- Conserving the women's gallery;
- Cleaning, treating the cracks and applying waterproofing on the roof;
- Treating metal items;
- Conserving timber iconostasis and timber ambon by a conservator;
- Minimal electrical installation.

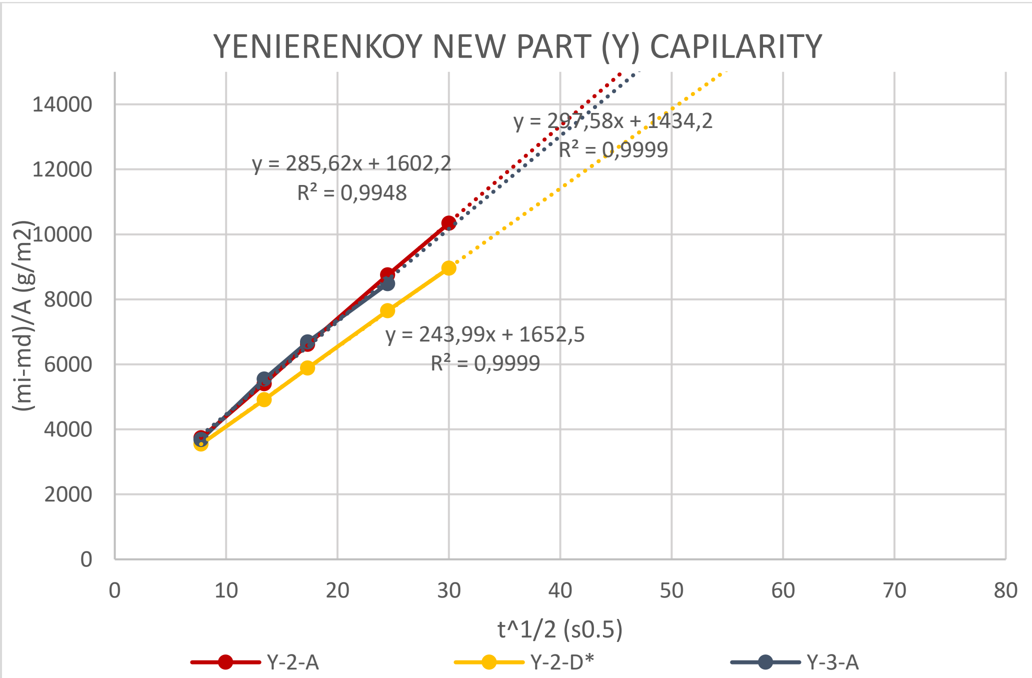
This project is financed under the scheme of the TCCH self-funded projects and implemented by UNDP in partnership with the Technical Committee on Cultural Heritage. Since 2012 approximately €27 million has been invested by several donors, benefiting over 100 Cultural Heritage Sites across Cyprus to implement the priorities of the Technical Committee on Cultural Heritage for the preservation of the island-wide cultural heritage in Cyprus.

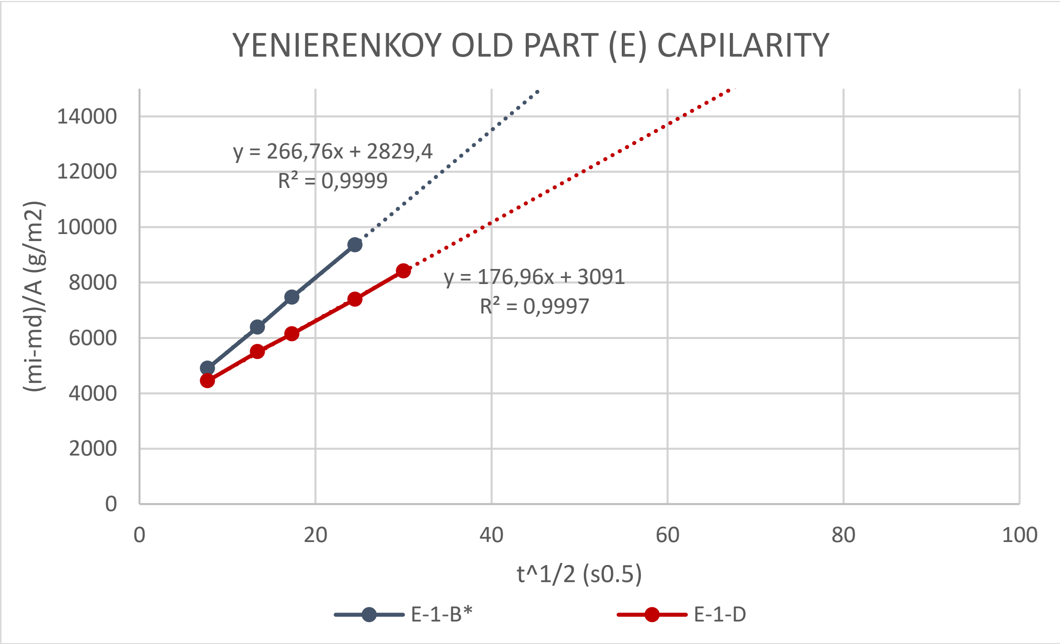
***

The Technical Committee on Cultural Heritage
The Technical Committee on Cultural Heritage works in line with the mutually agreed mechanism for the preservation of the island's common heritage. In 2009, the Advisory Board was set up by a decision of the Technical Committee on Cultural Heritage and approved by the two leaders as the consultative body of the Committee. The aim of the Board is to protect, preserve and facilitate the preservation, physical protection and restoration (including research, study and survey) of the immovable cultural heritage of Cyprus. This mechanism allows for the practical aspects of preservation to be considered in a non-political manner so that practical measures can be taken to improve the situation on the ground.

Appendix B: Obtaining of C Values from the Slope of Regression Line






YENIERENKOY OLD PART (E) CAPILARITY
y = 266,76x + 2829,4
R² = 0,9999
y = 176,96x + 3091
R² = 0,9997
(mi-md)/A (g/m2)
14000
12000
10000
8000
6000
4000
2000
0
0
20
40
60
80
100
t^1/2 (s0.5)
E-1-B*
E-1-D

Appendix C: Properties of Grouting Material Albaria Masterinject BASF

MASTER®
» BUILDERS
SOLUTIONS

MasterInject® 222

Puzolanic Lime Based Injection Mortar Designed For Historical Masonry Buildings

DESCRIPTION OF PRODUCT

MasterInject® 222 is an injection mortar that is used in the crack repair and consolidation of the masonry elements that contains puzolanic lime and micronized carbonates.

FIELDS OF APPLICATION

MasterInject® 222 is an injection mortar that is used for repair purposes in brick, stone or tufa containing historical buildings especially in places where cracks have been formed and supporting capacity has been lost.
MasterInject® 222 is used in;

- Consolidating themasonry walls under sulphate attacks,
- Consolidating the masonry domes and vaults,
- In the filling of small or large voids in the walls,
- Cracks repairs in masonry elements,
- Consolidating the masonry foundations.

FEATURES AND BENEFITS

- Cement free
- Can be used in environments under sulphate attacks
- It doesn't react with original building materials neither physically, nor chemically
- The superior hydraulic nature of the binder enables the injection mortar to penetrate into the building deeply With the assistance of the medium elasticity modulus, it is ideal in the filling of small and large voids even in bearing problems due to the high moisture content of the original building material
- Does not affect the vapour and moisture permeability of the existing building
- It shows limited expansion that does not cause to any additional internal stresses in the masonry elements
- Does not bleed
- Easy to inject even under low pressures
- Water-born salts (alkalis, sulphates, chlorides or nitrates), are limited

APPLICATION PROCEDURE

Preparation of Substrate

The surfaces should be free of frost, curing membranes, waterproofing treatments, oil stains, laitance, friable material and dust. The surfaces should be wetted before application. If there is a water leakage it must be drained or properly plugged.

Cracks with a width of 1- 5 mm

Depending on the crack width the holes should be drilled in both two sides of the crack line with an angle of 45° to the surface. The holes should be 5-10 cm away from the crack line and deep enough for passing across the crack plane and reach opposite side. Through the crack line, the holes should have a distance of 30-50 cm from each other. The holes have to be cleaned by air compressors to remove all dust and loose particles. Injection packers should be installed in to the holes, then screwed and fixed to the holes. All the cracks and packer sides should be sealed with **MasterEmaco® N 275 TIX** by using a steel spatula or trowel to prevent the leakage of injection mortar from the crack openings. Allow 24 hour (at 20°C) for curing the cap.

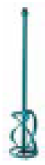
Cracks with a width of > 5 mm

Depending on the crack width and depth, the pneumatic hoses should be installed in to the crack opening with a distance of 75-100 cm from each other. All the cracks and hoses should be sealed with **MasterEmaco® N 275 TIX** by using a steel spatula or trowel to prevent the leakage of injection mortar from the crack openings. Allow 24 hour (at 20°C) for curing the cap.

Mixing

Add enough water into a clean mixing bucket by using a proper water gauge. Add the powder into the bucket slowly and continously. Mix the fresh mortar with a proper electrical mixer (300-600 rpm) for 4minutes until having a

TECHNICAL DATA

Product Chemistry	Includes Puzolanic Lime and Micronized Carbonates	
Color	Off white – Light brow	
Grain Size of Injection Mortar	0,1-30 µm D_{50}=15 µm	KR
Compressive Strength (20°C) TS EN 196 7 days 28 days	>7,0 N/mm² >13 N/mm²	
Flow (DIN Cup, No.6) At the Beginning 20 Minutes Later	<35 sn <45 sn	
Application Temperature	+5°C +35°C	
Pot Life (20°C)	30 minutes	

Typical values are obtained from the test results of 4x4x16 mortar prism in 23°C and 50% relative humidity conditions. High temperatures shortens the curing and working time, lower temperatures extends the durations.

MASTER®
BUILDERS
SOLUTIONS

MasterInject® 222

Puzolanic Lime Based Injection Mortar Designed For Historical Masonry Buildings

homogenous consistency. Let the mortar have rest for 4 minutes and re-mix for 30 seconds.

Mixing Ratio

MasterInject® 222	1 kg Powder	15 kg Bag
Water Quantity	0,30 liter	4,5 liter
Mixed Density	1,93 kg/liter	

APPLICATION METHOD

Tie the pneumatic pipe of the pump to the lowest hose/packer fixed to the cracked surface. Start pumping the mortar into the crack until it comes out from upper hose/packer. Remove the pipe from the current hose/packer and close/lock its opening by screwing or by steel wires. Follow the same instruction to the hose/packer fixed at the top of the surface. When the mortar leaks out from the upper hose/packer it is understood that the whole crack plane has been fully filled with **MasterInject® 222** and finishes the application. At least 24 hours after the application all the hoses/packers could be cut or pull out and surface could be finished with proper mortar in **MasterEmaco®** range.

COVERAGE

1.50 kg/lt

WATCH POINTS

- During the application the substrate and environment temperature should be between 5°C-35°C.
- Injection works should be run by expert applicators.
- Mixing should be made with proper mixers and do not allow mixing by hand.
- Injection pressure is defined due to crack width, crack depth and material properties of the existing structure. It should be defined according to the project.

CLEANING OF TOOLS

After the application all tools should be cleaned with water. **MasterInject® 222** can be cleaned with only mechanical abrasion after hardening.

PACKAGING

15 kg bag

STORAGE

Store in original container in cool (+5°C-+25°C) and dry indoor conditions.

SHELF LIFE

12 months under proper storage conditions after production date.

HEALTH AND SAFETY PRECAUTIONS

It is dengerous to approach the application sites. During the application, a protective apparel, protective gloves, goggles and masks which comply with the Occupational Healt and Safety Rules should be used. Due to the irritaion effect of the uncured materials, the mixtures should not come into contact with skin and eyes; in case of contact, the affected area should be washed with plenty of water and soap; in case of swallowing, a physician should be consulted immediately. No food or beverages should be brought to the application area. The product should be stored and kep out of reach of children. For detailed information please colsult the Material Safety Data Sheet.

DISCLAIMER

The technical information given in this publication is based on the present state of our best scientific and practical knowledge. **Master Builders Solutions Yapı Kimyasalları Sanayi ve Ticaret Ltd. Şti.** is only responsible for the quality of the product **Master Builders Solutions Yapı Kimyasalları Sanayi ve Ticaret Ltd. Şti.** is not responsible for results that may occur because the product is used other than advised and/or out of instructions regarding the place and the method of use. This technical form is valid only till a new version is implemented and nullifies the old ones.

CONTACT INFORMATION

Master Builders Solutions Yapı Kimyasalları Sanayi ve Ticaret Ltd. Şti.
Adres: Barbaros Mah. Begonya Sok.
Nidakule Kuzey Ataşehir, C Kapısı
No:3 E/5, 34746 Ataşehir İstanbul / Türkiye
Tel: 0216 217 88 00
Mail: mbs.tr@mbcc-group.com
Web: www.master-builders-solutions.com/tr-tr

MasterInject® 222 Technical Data Sheet -Revision Date: 12/2020

CE
1020 **Master Builders Solutions Yapı Kimyasalları Sanayi ve Ticaret Ltd. Şti.** Adres: Barbaros Mah. Begonya Sok. Nidakule Kuzey Ataşehir, C Kapısı No:3 E/5, 34746 Ataşehir İstanbul **20** **1020 – CPR – 040 065835** **DOP NO: 02.998.2.001.1**
MASTERINJECT 222 **EN 998-2:2016** **Kâgir Harcı - Özellikler - Bölüm 2: Kâgir Harcı** **(Specification for mortar for masonry - Part 2: Masonry mortar)** **G(Genel Kullanım Tasarlanmış Harç)** **G(General Purpose Designed Mortar)**

Basınç Dayanımı (Compressive Strength)	Sınıf M(10) (Class M(10))
Bağ Dayanımı (Bond Strength)	>0,15 N/mm²
Klorür İçeriği (Chloride ion Content)	≤0,1%
Su absorbsiyonu (Water absorption)	<0,5 kg/m²√h
Su buharı geçirgenliği (Water vapour permeability)	15/35 µ
Isıl iletkenlik (Thermal conductivity)	(λ10,dry) 0,83 W/(m.K)
Yangına tepki (Reaction to fire)	A1

Appendix D: Properties of Hydraulic Lime Mortar

MASTER®
» BUILDERS
SOLUTIONS

MasterEmaco® A 265 (Formerly known as Albaria® Calce Albazzana)

Natural Hydraulic Lime

DESCRIPTION OF PRODUCT

MasterEmaco® A 265 is cement-free, natural hydraulic lime burnt at low temperatures (900°C) for lime mortar production.

FIELDS OF APPLICATION

MasterEmaco® A 265 is used in following cases as binder of lime mortar;

- Plastering production
- Building of masonry walls
- Building of masonry and natural stone joints

FEATURES AND BENEFITS

- Cement free
- Burnt with traditional methods at low temperatures
- Can be used in production of different lime mortars compatible with existing building materials
- Does not affect the vapour and moisture permeability of the existing building

APPLICATION PROCEDURE

Preparation of Substrate

The surfaces should be free of frost, curing membranes, waterproofing treatments, oil stains, laitance, friable material and dust. The surfaces should be wetted before application. If there is a water leakage it must be drained or properly plugged.

Mixing

The work instructions of the restoration project should be followed.

APPLICATION METHOD

Fresh mortar should be applied to the prepared surface by using a trowel as mentioned application thickness in instructions. After the mortar finishes its first setting, some water should be sprayed onto the mortar and the surface should be finished with using steel or wooden trowel. For thicker applications first layer should be wetted after it hardens. Then the new layer application can be done. Open areas should be protected from the rain, wind, etc. Aggressive whether conditions during the first 24-48 hours after finishing repair by using wet clothes, curing membranes etc.

COVERAGE

Depends on the mix design of lime mortar.

WATCH POINTS

- During the application the substrate and environment temperature should be between 5°C-40°C.
- For full curing of material, both the substrate and environment temperature shouldn't be under allowed application temperature.
- Open areas should be protected from the rain, wind, etc. Aggressive whether conditions during the first 24-48 hours after finishing application.

CLEANING OF TOOLS

After the application all tools should be cleaned with water. **MasterEmaco®** A 265 can be cleaned with only mechanical abrasion after hardening.

PACKAGING

25 kg bag

STORAGE

Store in original container in cool (+5°C-+35°C) and dry indoor conditions.

SHELF LIFE

12 months under proper storage conditions after production date.

HEALTH AND SAFETY PRECAUTIONS

It is dengerous to approach the application sites. During the application, a protective apparel, protective gloves, goggles and masks which comply with the Occupational Healt and Safety Rules should be used. Due to the irritaion effect of the uncured materials, the mixtures should not come into contact with skin and eyes; in case of contact, the affected area should be washed with plenty of water and soap; in case of swallowing, a physician should be consulted immediately. No food or beverages should be brought to the application area. The product should be stored and kep out of reach of children. For detailed information please colsult the Material Safety Data Sheet.

TECHNICAL DATA

Product Chemistry	Natural Hydraulic Lime
Color	Light Brown
Application Temperature	+5°C - + 40°C

MasterEmaco® A 265 (Formerly known as Albaria® Calce Albazzana)

Natural Hydraulic Lime

DISCLAIMER

The technical information given in this publication is based on the present state of our best scientific and practical knowledge. **Master Builders Solutions Yapı Kimyasalları Sanayi ve Ticaret Ltd. Şti.** is only responsible for the quality of the product **Master Builders Solutions Yapı Kimyasalları Sanayi ve Ticaret Ltd. Şti.** is not responsible for results that may occur because the product is used other than advised and/or out of instructions regarding the place and the method of use. This technical form is valid only till a new version is implemented and nullifies the old ones.

CONTACT INFORMATION

Master Builders Solutions Yapı Kimyasalları Sanayi ve Ticaret Ltd. Şti.
Adres: Barbaros Mah. Begonya Sok.
Nidakule Kuzey Ataşehir, C Kapısı
No:3 E/5, 34746 Ataşehir İstanbul / Türkiye
Tel: 0216 217 88 00
Mail: mbs.tr@mbcc-group.com
Web: www.master-builders-solutions.com/tr-tr

MasterEmaco® A 265 Technical Data Sheet -Revision Date: 12/2020