STRUCTURAL MODEL BASED ROOT CAUSE INVESTIGATION OF DAMAGE IN URLA HELVACILAR MOSQUE AND A PROPOSAL FOR STRENGTHENING

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ABSTRACT

STRUCTURAL MODEL BASED ROOT CAUSE INVESTIGATION OF DAMAGE IN URLA HELVACILAR MOSQUE AND A PROPOSAL FOR STRENGTHENING

The period when small independent beyliks (principalities) were founded in Anatolia in the 13th century is called the principalities period. The process of creating a new architectural style in Western Anatolia, as well as the works-built marks an important milestone in this period, which is defined as a transition period between the Seljuk architecture and the Ottoman architecture. The Aydın Dynasty, one of the important principalities of western Anatolia, had its capital at Birgi from 1308 to 1426. The dynasty is known for with its economic and political power and the important works it left behind.

Helvacılar Mosque is one of the important works of the Aydın Dynasty, which was built in the 15^{th} century and survives today. It is also an outstanding example to understand the single-domed mosque typology in western Anatolia. Helvacılar Mosque, located in the Kuşcular Neighborhood of the Urla District, is today derelict and abandoned. Heavy structural damage in the structure poses a grave risk for the structure to survive. This study compared and discovered the similarities and differences between Helvacılar Mosque and the similar-period structures situated in Urla and identified the architectural and structural characteristics of the structure with the aid of measured drawing projects.

This study used a combination of architectural restoration and structural engineering. For Helvacılar Mosque, the study carried out the self-weight analysis, modal analysis, settlement analysis, response spectrum analysis, time history analysis using three real earthquake records in a finite element model. The aim of engineering research is to identify the present causes of damages in the structure.

With the help of finite element analysis, the study put forward the essential repair and strengthening methods for Helvacılar Mosque to repair the damages observed in the structure, strengthen the structure, and obviate the causes of the damages based on the intervention methods offered in the guideline titled Earthquake Risk Management of Historical Structures issued by the General Directorate of Foundations.

ÖZET

URLA HELVACILAR CAMİ'NDEKİ HASARIN TEMEL SEBEBİNİN YAPISAL MODEL BAZLI ARAŞTIRILMASI VE GÜÇLENDİRME ÖNERİSİ

13. Yüzyılda küçük bağımsız beyliklerin kurulduğu zaman dilimi Beylikler Dönemi olarak adlandırılmıştır. Selçuklu mimarisi ile Osmanlı mimarisine arasında bir geçiş dönemi olarak tanımlanan bu dönemde; Batı Anadolu’daki yeni bir mimari üslup yaratma süreci ve ortaya çıkardıkları eserler önemli bir durak olarak kabul edilmektedir. Batı Anadolu’nun önemli beyliklerinden biri olan Aydınoğulları Beyliği 1308-1426 yılları arasında başkenti Birgi olan; dönemi içinde hem ekonomik ve politik gücüyle hem de bıraktığı önemli eserlerle anılan bir beyliktir.

Helvacılar Cami 15. yüzyılda yapılmış ve günümüze ulaşan önemli Aydınoğulları eserlerinden biridir. Batı Anadolu’daki tek kubbeli cami tipolojisini anlamak için de önemli bir örnektir. Urla ilçesinin Kuşçular Mahallesi’nde bulunan Helvacılar Cami, günümüzde metruk ve terk edilmiş durumdadır. Yapıdaki ağır strüktürel hasarlar, yapının ayakta kalması açısından büyük risk yaratmaktadır. Bu çalışma; Helvacılar Cami’nin Urla’da bulunan benzer dönem yapıları ile karşılaştırarak yapılar arasındaki benzerlikleri ve farklılıkları belirlenmekte ve çalışma yapısının mimari ve yapısal özelliklerini hazırlanmış rölöve projeleri yardımıyla tanımlamaktadır.

Mimari restorasyon ve yapı mühendisliği alanlarının ortaklaştırılması ile hazırlanan bu çalışmada, Helvacılar Cami’nin hasarsız sonlu elemanlar modeli ile kendi ağırlığı altında analizi, modal analizi, oturma analizi, tepki spektrumu analizi ve üç adet gerçek deprem kaydı ile zaman tanım alanında analizleri yapılmıştır. Mühendislik çalışmalarındaki amaç; yapıdaki mevcut hasar sebeplerinin neler olduğunu tespit edebilmektir.

Sonlu eleman analizlerinin de yardımıyla; yapıda gözlemlenen hasarların onarılması, yapının güçlendirilmesi ve hasarlara yol açmış sebeplerin ortadan kaldırılması amaçlı Vakıflar Genel Müdürlüğü’nün Tarihi Yapılar için Deprem Risklerinin Yönetimi isimli kılavuzundaki müdahale yöntemleri esas alınarak Helvacılar Cami için gerekli onarım ve güçlendirme yöntemleri ortaya konmuştur.

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CHAPTER 1

INTRODUCTION

1.1. Aim of the Study

This study aims to determine the architectural and structural features of Helvacılar Mosque, which has survived from the 15th century, and to understand the causes of the damages in the structure through engineering analysis. The study also aims to offer a strengthening proposal, which will contribute to the improvement of the impaired structural behavior mechanism. The strengthening proposal offered for the structure aims not only to repair damages in its existing condition but also to eliminate the causes of damages.

1.2. Methodology of the Study

The Charter "Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage" ratified by the International Council on Monuments and Sites (ICOMOS) in 2003, presents diagnosis and restoration methods for structures of architectural heritage, by their very nature and history (material and assembly), that restrict the use of modern legal codes and building standards.

The following are the rules that structural engineers should take as a reference in accordance with this charter:

1- The conservation, strengthening, and restoration of architectural heritage require an interdisciplinary approach.
2- The restoration of the load-bearing system should not be set as the single ultimate objective in the restoration of architectural heritage. The main objective is to preserve the entire building; the conservation of the structure is a means to reach the objective.
3- No intervention should be made to architectural heritage unless the potential benefit or harm is fully discerned, except in case of urgent safeguard measures to prevent the collapse of the load-bearing system (e.g. after

seismic damages). Irreversible intervention should be avoided as much as possible while undertaking such urgent measures.

4- The properties of the structure and materials should be entirely discovered and understood in conservation applications. Information is needed about the original, former and current conditions of the structure, the techniques used in the construction, changes and their effects, and events encountered.

5- Before the structural intervention, the causes of damage and decay should be identified, and the safety level of the structure should be then evaluated.

6- Structural safety levels that are generally applicable for new buildings require extreme, sometimes impossible measures. In such cases, special analysis and situation-specific conditions may justify a different approach to safety.

7- Where possible, interventions should be reversible so that they can be removed without causing harm to the structure and replaced with more appropriate interventions when new information is obtained. Irreversible interventions should not prevent possible future actions.

8- The properties of materials used in restoration (primarily new materials) and their compatibility with existing materials should be fully investigated and known. Long-term effects of materials used in restoration should be investigated to prevent undesired side effects.

9- Damaged structures should be repaired as far as possible and not all of them should be replaced.

10- Disassembly and reassembly should only be considered as an additional option when it is impossible or harmful to maintain the condition and material of the building by any other means.

11- Temporary safeguard systems used during the intervention should fulfill their aims and functions without damaging cultural values (ICOMOS, 2003).

In a study on seismic behavior assessment and engineering judgment for masonry structures, Lourenço and Karanikploudisa (2019) notes that the ICOMOS Charter (2003) has been used since 2005 and an integrated multidisciplinary approach has been established thanks to the charter. According to Lourenço and Karanikploudisa, the main objective is to achieve an in-depth understanding and knowledge of material characterization, overall structural behavior, level of connectivity between structural parts, and subsequent changes and decay that occurred throughout the lifespan of the structure.

This study was presented as a general scope based on the program "Structural Analysis of Monuments and Historical Constructions" conducted with 375 students in 70 countries for 12 years and it defines the steps related to structural safety and intervention methods (Figure 1.1).

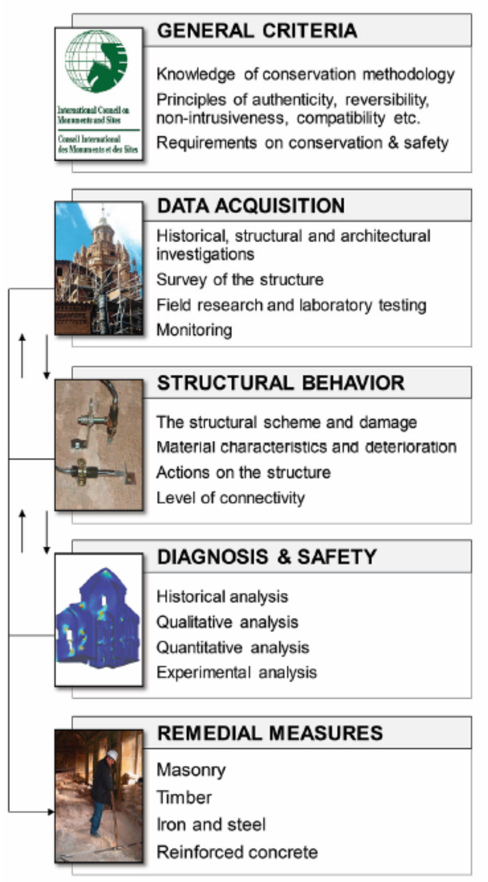


Figure 1.1. The ICOMOS methodology
(Source: Lourenço, 2019)

The ICOMOS Charter (2003) was accepted as the general criterion for Helvacılar Mosque which has a quite evident damage situation and requires urgent attention in terms of its structural safety due to these damages. The study was carried out with the method defined in Figure 1.1. It proceeded in the following steps: field survey, preparing of measured drawings; historical, architectural and structural investigations; settlement measurements on the structure, understanding the structural damages, analysis with the help of finite element software for understanding the behavior of the structure, and laying out the strengthening proposal for extending the lifespan of the mosque. Because the structure studied in this study is the property of the General Directorate of Foundations, strengthening proposals were made based on the recommendations offered in the guideline titled "Earthquake Risk Management of Historical Structures" issued by the General Directorate of Foundations in 2017.

1.3. Content of the Study

This study utilized architectural restoration and structural engineering together to understand the status of the structure studied. At the beginning of the study, the structure was described using architectural restoration techniques and its problems and engineering needs were identified. Later, the reasons for the structural problems were defined using engineering analyses and solutions were suggested.

The first chapter describes the aim, content, and methods of the thesis.

The second chapter examines the development of single-domed mosques during the principalities period to gain insights into the characteristics of the single-domed mosque in western Anatolia. It also presents detailed information on the single-domed mosques and masjids built in Urla in the 15th and 16th centuries and discuss the position of Helvacılar Mosque within the literature.

The third chapters include a detailed description of the architectural characteristics of Helvacılar Mosque based on the measured drawings and photographs. It also addresses the structural problems of Helvacılar Mosque.

The fourth chapter presents the engineering analyses performed on the finite-element model of the structure designed using SAP2000 software. These analyses include self-weight analysis, modal analysis, settlement analysis, response spectrum analysis, and time history analysis based on the accelerograms of three real-time earthquakes. With these analyses, the conditions under which the existing damages in the structure occurred were examined.

The fifth chapter presents proposals for repairing and strengthening Helvacılar Mosque in line with the guideline titled "Earthquake Risk Management of Historical Structures" issued by the General Directorate of Foundations.

The final chapter includes the results and discussion of the study.

CHAPTER 2

CHARACTERISTICS OF SINGLE DOMED MOSQUES' WITH PARTICULAR EMPHASIS ON 15^{TH}-16^{TH} CENTURY EXAMPLES IN URLA

2.1. Literature Review about Single Domed Mosques in West Anatolia

A transitional period of architecture called the Beyliks Architecture prevailed in Anatolia until the small independent beyliks (principalities) founded in Anatolia came under the Ottoman rule as a result of the weakening of the Seljuk authority after the second half of the 13th century. During this period, architectural works of different qualities were built in different regions in parallel with the political relations of the principalities and the effects of local traditions. While the architecture of the previous Anatolian Seljuk State was maintained in the architectural works in the regions of Anatolia, Southeastern Anatolia, and Central Anatolia, a new process of creating occurred in Western Anatolia, thereby leading to the emergence of a different style (Kolay, 1999, p. 1).

Apart from zawiyahs, which were built under the name of imaret (public soup kitchens) and later converted into mosques, and multi-domed mosques (also called ulu/grand mosques), which were generally built in city centers to serve for Friday prayers, there were also single-domed neighborhood mosques, which served as worship buildings for the daily prayers of the community. The earliest examples of single-domed mosques date from the 13th century and are found in Konya (Kuban, 2007, p 123) (Figure 2.1).

Kuban (2007) lists the architectural features of these first examples as follow:

1- A prayer hall (harim) wall was erected in the entrance facades of many early-dated mosques, thereby making the porch covered on the sides.
2- The Turkish triangle pendentive was the construction element for the transition to a single dome.

3- As seen in mosques such as İznik Hacı Özbek, Bilecik Orhan Bey, and Behramkale Hüdavendigar, a minaret is not an essential requirement.

4- The earliest minarets were generally built as a free-standing tower structure which was erected on a separate base but not resting on the walls of the masjid. However, the upper parts of most minarets over the base (pulpit) were destroyed by earthquakes and rebuilt; thus, the original forms of minarets other than those of plinths have been changed. The general trend is to build minarets to the left of the entrance. However, this is not a definitive rule. The mosques in Bursa have examples of minarets located to either the left or right.

5- All these mosques were built using the technique of alternating masonry, high drums, and a small number of windows.

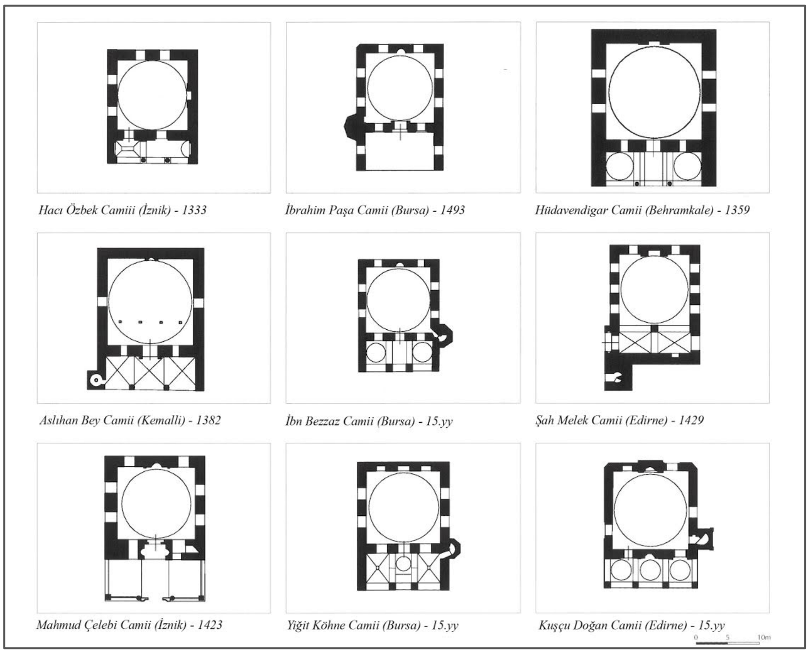


Figure 2.1. Early examples of single domed mosques in Anatolia
(Source: Kuban, 2007, s 124)

Kızıltan (1958) examined and classified the 14th-century mosques of the Anatolian principalities and reached the following conclusions:

a. A new approach to the understanding of mosques emerged, thereby leading to the construction of small single-domed mosques apart from grand (ulu) mosques. A portico was added to mosques and models of open yard began to be seen in the principalities in the 14th century.

b. An absolute simplicity was prevailing in the external architecture of the buildings. Although the style of the Seljuk architecture that used excessive ornamentation was still seen in some buildings, the ornamentation art began to be seen generally in parts that had no effect on the main system of the building but in parts that needed to look opulent.
c. Mosques were built based on the perception of the frontal, mass and special ratio in term of both their external appearance and internal volume. The first steps of classical Turkish architecture based on the same objectives were thereby taken in this period.

According to *Öney* (2007), the Beyliks period was a very colorful period in terms of Anatolian art history and interesting experiments were observed in western Anatolia during this period. The author explains this situation with the absence of a previously developed indigenous Islamic art tradition in this region.

Öney (2007) groups the mosques and masjids of the period of the principalities (Beyliks) period as follows:

1- Single domed, cube-shaped mosques
2- Hypostyle (also known as Kufa- or Kufic-type) mosques
3- Mosques with equivalent multiple units
4- Basilica-type mosques
5- Transept-type mosques
6- Mosques with zawiyahs
7- Central domed mosques

The earliest examples of single-domed mosques in Anatolia are found in the mosques and masjids of the Seljuk era, especially in Konya and around. This type of plan has its origins in Central Asia prior to the Beyliks period and is also available in the shrine architecture ranging from Iran to Anatolia. Single-domed mosques, which were the most typical examples of mosques and masjids in the Beyliks period, were found in every region of Anatolia in the 14^{th} and 15^{th} centuries. There are various examples including large or small, monumental or simple, with a portico or only a dome, with or without a minaret, and ornamented or unornamented. Examples of these simple types of mosques that laid the foundations of monumental, central-domed Ottoman mosques include Afyon Kubbeli Cami (lit., domed mosque) (1330), İznik Hacı Özbek Mosque (1333), İznik Hacı Hamza Mosque (1345), Bursa Alaaddin Mosque (1335), İznik Yeşil Mosque (1378-1398), Bilecik Orhan Mosque (the early 14^{th}

century), Gebze Orhan Mosque (the mid-14^{th} century), Milet İlyas Bey Mosque (the 15^{th} century) (Öney, 2007, pp. 1-7).

In Anatolian Turkish architecture, the first important attempt in facade plans, other than portals, is the porched entrances of the single-domed Seljuk masjids. The development of the entrance section during the principalities period prevented the monumental portal tradition. During the principalities period, portals lost their importance and the facade layout was changed and simplified. Another reason for the departure from this tradition is the economic weakness of western Anatolian principalities (Dilaver, 1971).

The Seljuk architectural style was effective in Anatolia until the late 14^{th} century and even the early 15^{th} century; however, many different styles appeared through new attempts in many Turkish states established at that time. Although the first works of Aydın Dynasty (also knows the Principality of Aydın) confirm the strength of the Seljuk influence, there are other works such as Birgi Ulu (Grand) Mosque, which show the emergence of new ideas towards the last years of the principality. In the architecture of the principalities period, increasing innovations especially in Western Anatolia and a strong will to improve reached a peak in the Ottoman period. The single-domed mosques with porticos built by Aydın Dynasty have no feature distinct from the within the general features of the architecture of the principalities period (Aslanapa, 1984).

The Ottoman State occupied the principalities in Anatolia one by one as from the mid-15^{th} century. According to O. Aslanapa, Iznik Yeşil Mosque, which was completed in 1392, is the most significant and monumental structure of the Ottoman period, which points to the first attempts to improve space in classical single-domed mosques. This monumental example represents a new attempt made by extending the single-domed space forward and creates the impression that both the inner space and the outer space are much larger (Figure 2.2).

The major examples of Ottoman architecture, which was started in Iznik and maintained in Bursa, continued to improve. After Aydın Dynasty in western Anatolia, buildings with different functions, many of which have survived until today, were constructed depending on the political and economic vitality of the region in the 15^{th} and 16^{th} centuries.[1] The single-domed mosques built during this period are important for

[1]for West Eagean Monuments between 15^{th} and 16^{th} century see below:
Reyhan K.,2004 (Seferihisar ve Urla baths), Aslanoğlu İ.,1978 (Tire mosques), Uğur, T.,2006 (Selçuk mosques)

understanding the architecture of the period and for explaining the transition to the process of creating Ottoman architecture.

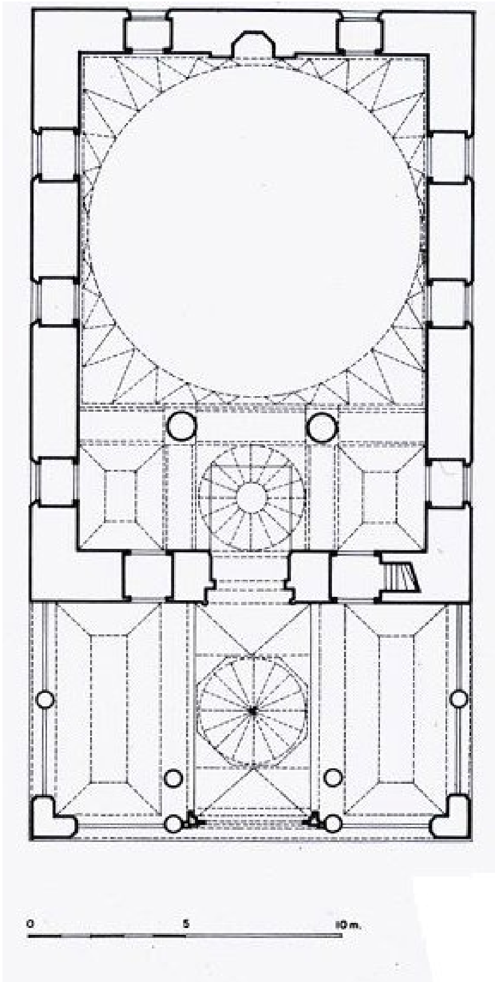


Figure 2.2. Plan of İznik Yeşil Mosque
(Source: Aslanapa, O.,1977)

2.2. Single Domed Mosque Examples in Urla

In the light of the remains found in the Iskele region in Urla, the city is considered to be a settlement dating from the prehistoric period. Throughout history, Urla was chronologically ruled by the Ionians, the Persian Empire, the Roman Empire, the Byzantine Empire, the Anatolian Seljuks, and Aydın Dynasty.

With the collapse of the Anatolian Seljuk State in 1308, the principalities period began in Anatolia. Among these principalities, the Aydın Dynasty was founded by Aydınoğlu Mehmet Bey, the Subaşi (lit., commander) of the Germiyanids, in western Anatolia in 1308. The Aydın Dynasty occupied Izmir and Urla in the 1320s. Aydın and its surroundings were annexed by the Ottomans in 1390. The region was later reannexed by Aydın Dynasty when Bayezid was defeated at the Battle of Ankara. When Aydın Dynasty was overthrown by Sultan Murad II, Urla was permanently annexed by the Ottomans.

The population statistics of the 15th century show that the population of Urla is larger than that of Izmir. In 1528, the total population was nearly 1194 in Izmir and nearly 3000 in Urla. In 1575, it was nearly 3345in Izmir and nearly 6000 in Urla (Atay, 2003, p. 36).

During the period of Aydın Dynasty, Urla was a major center in terms of population and urbanization. This can be seen from the diversity of cultural heritage in the district. Urla has major examples for investigating the single-domed mosque typology in western Anatolia.

Through six single-domed mosques and masjids in Urla, which date from the 15th and 16th centuries, the similarities and differences in buildings are compared below.

- *Kamanlı Mosque* is repaired today. The mosque is believed to be built in the early 15th century; however, it has no inscription panel (Figure 2.3). The building has three spaces including the prayer hall (harim), portico, and minaret. The two main walls of the portico are partially present before and after the repair, and the top cover is a timber porch. The prayer hall of the mosque has a square shape. The walls are built of pitch-faced stone, rubble, and brick. There are squinches filling in the upper corners of the prayer hall as a structural transition to the dome. The dome is built of brick and has a semi-circular shape. In the prayer hall, stone arches were built over the openings of some lower rows of windows, while brick arches were built over the openings of all upper rows of windows and the other lower rows of windows. Brick ornamentations on the brick window arches are remarkable in the facades. The minaret in the north-west corner of the building was repaired due to the local loss of material in its body. The minaret is on an octagonal base with blind niches. After the repair, the minaret remained uncompleted, and the upper part ends with a top balcony (serefe) that encircles the shaft (Figure 2.4).

Figure 2.3. Kamanlı Mosque

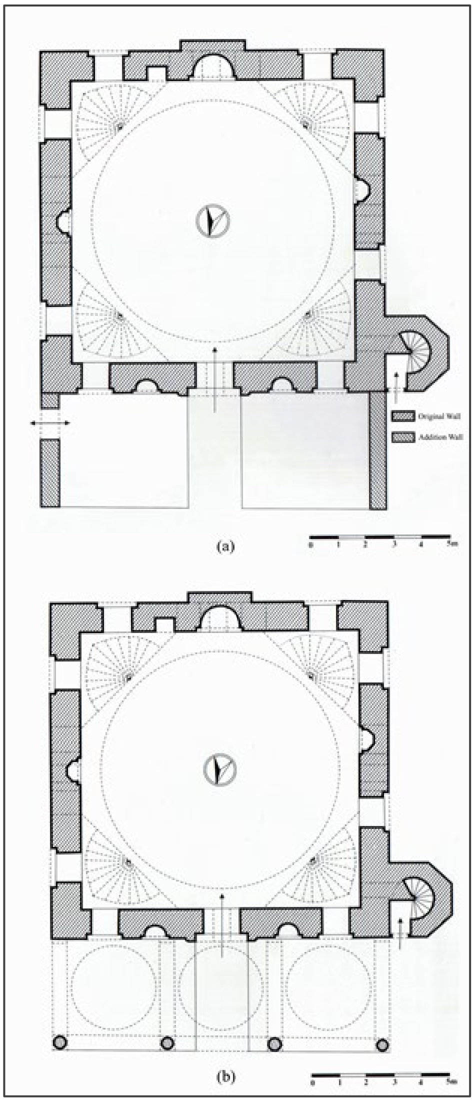


Figure 2.4.a) Kamanlı Mosque’s measured drawing plan, b) Kamanlı Mosque’s restitution plan (Source: Ünal R.H., Çağlıtütüncügil E., 2016)

- *Kütük Minaret Mo*sque is repaired today. The mosque is believed to be built in the 15th century; however, it has no inscription panel (Figure 2.5). The building has three spaces including the prayer hall, portico, and minaret. The portico is not in its original state. After the repair, it was covered with a flat timber roof resting on four columns on a single facade of the building. The mosque has a square prayer hall and the walls are built of pitch-faced stone. There are squinches filling in the upper corners of the prayer hall as a structural transition to the dome. The dome is built of brick and has a semi-circular shape. The arches and jambs of the entrance opening are marble. The openings of the upper row of windows are supported by brick arches. The minaret is situated in the south-east corner of the building. The base of the minaret is built of pitch-faced stone. There are niches in the semi-octagonal base. The arches of the base niches, the inner surface (intrados) of the arches, the pabuc section (the intermediate area between the shaft and base of the minaret), and the shaft are built of brick. The top balcony and the petek (upper part of body), which refers to the upper part of the minaret between the balcony and the cone, were plastered; therefore, the construction material was not identified (Figure 2.6).

Figure 2.5. Kütük Minare Mosque

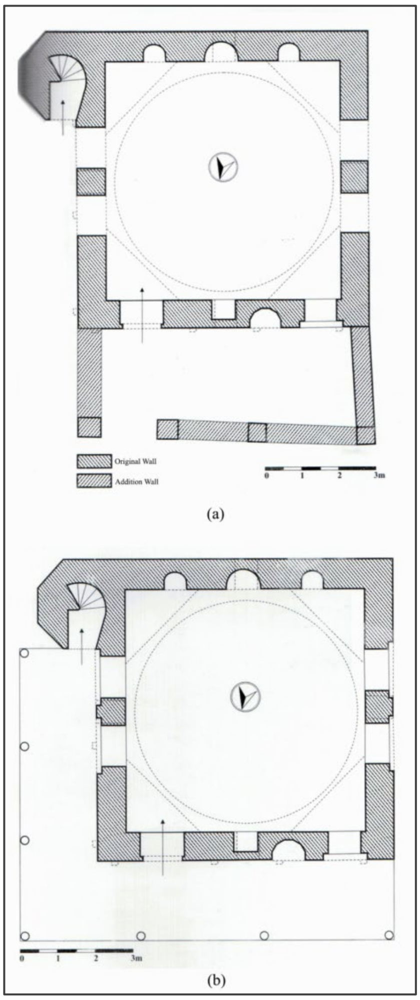


Figure 2.6.a) Kütük Minare Mosque’s measured drawing plan,b) Kütük Minare Mosque’s restitution plan (Source: Ünal R.H., Çağlıtütüncügil E., 2016)

- *Rüstem Paşa Mosque* is repaired today. The mosque is believed to be built in the 16^{th} century; however, it has no inscription panel (Figure 2.7). The building today has two spaces including the prayer hall and minaret, while the portico, which was originally present, is not present today. The prayer hall of the mosque has a square shape. The walls are built of pitch-faced stone and cut stone. There are squinches filling in the upper corners of the prayer hall as a structural transition to the dome. The dome has a semi-circular shape. The prayer hall has pointed arch windows, while some windows are square- framed and have pediments between the opening and the arch. The minaret is situated in the south-east corner of the building. The base, shaft, and top balcony of the minaret are built of pitch-faced stone. The five sides of the octagonal base are visible and there are niches in the base (Figure 2.8).

Figure 2.7. Rüstem Paşa Mosque

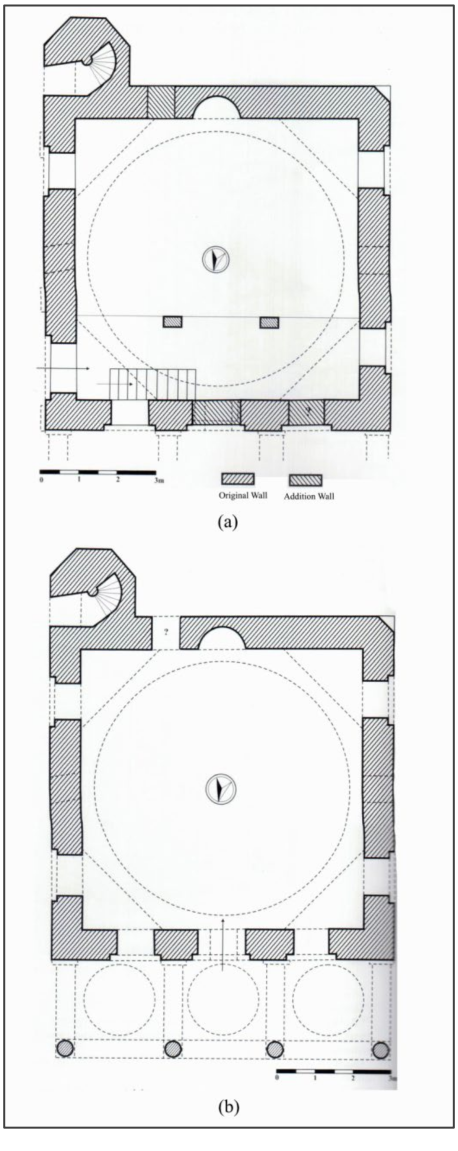


Figure 2.8.a) Rüstem Paşa Mosque's measured drawing plan, b) Rüstem Paşa Mosque's restitution plan (Source: Ünal R.H., Çağlıtütüncügil E., 2016)

- *Denizli Village Mosque* was restored in 2012 and opened for worship. The mosque is believed to be built in the 15th century or 16th century although it has no inscription panel (Figure 2.9). The building today has two spaces including the prayer hall and minaret. There are differences between the portico, which was originally present, and the spaces which can today be considered to be a yard. The building was built on land that steeply slopes from north to south. The northern wall of the yard serves as a retaining wall between the road running from the north of the yard and the stream running from the south. There is an external mihrab in the south wall of the yard. The prayer hall of the mosque has a square shape. The walls are built of pitch-faced stone. There are squinches filling in the upper corners of the prayer hall as a structural transition to the dome. There is structural evidence that the mosque originally had a portico; however, there is today no portico. The base of the minaret situated in the north-west corner of the building is built of pitch-faced stone. There are niches in the semi-octagonal base. The base is surmounted by triangle segments and the molding of pabuc (transition segment). The body of the minaret is constructed with brick and top of the body is surmounted by the petek (upper part of body) constructed with cut stone and cone at the top (Figure 2.10).

Figure 2.9. Denizli Köyü Mosque

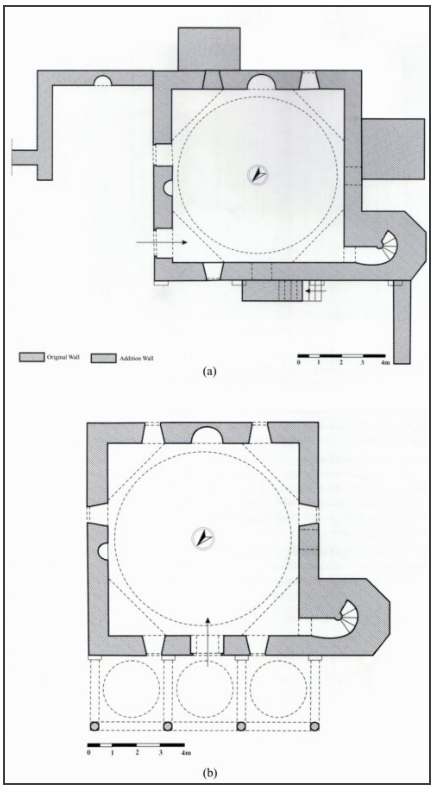


Figure 2.10.a) Deniz Köyü Mosque’s measured drawing plan, b) Denizli Köyü Mosque’s restitution plan (Source: Ünal R.H., Çağlıtütüncügil E., 2016)

- *Çarşı (Hoca Ali) Mosque* was repaired in 1992 and is today open for worship. The mosque is believed to be built in the 15th century although it has no inscription panel (Figure 2.11). The building today has three spaces including the prayer hall, portico, and minaret. The walls of the mosque are built of pitch-faced stone and brick. The portico has undergone many changes out of necessity. It was originally a three-unit space with the same length as the long side of the prayer hall; however, it has today turned to be a four-unit space with a unit overflowing the eastern facade. The roof is covered by four identical domes; the pendentives provide the transition to the dome. The eastern and western facades of the portico are also covered by walls. In the north, there are three reused columns on which the arches spanning from the dome rest. An iron canopy was recently attached over the front portico. In square prayer halls, four squinches across the corners support the spherical dome. The minaret is situated in the north-west corner of the mosque. The octagonal base of the minaret is built of stone. There are niches in the base and the transition from the stone to brick masonry begins in the upper parts of these niches. The pabuc, shaft, and top balcony are built of brick. Minaret bricks were laid to form a “Y” pattern horizontally (Figure 2.12).

Figure 2.11. Çarşı (Hoca Ali) Mosque

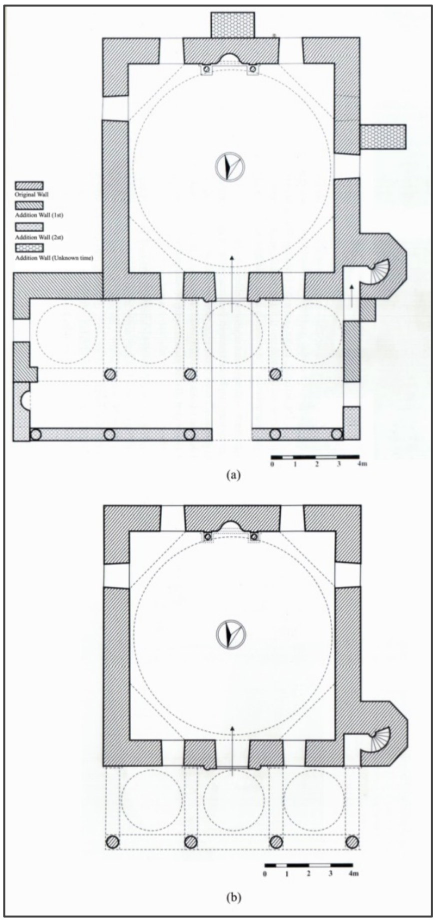


Figure 2.12.a) Çarşı (Hoca Ali) Mosque’s measured drawing plan, b) Çarşı (Hoca Ali) Mosque’s restitution plan (Source: Ünal R.H., Çağlıtütüncügil E., 2016)

- *Naibli Neighborhood Masjid* is in ruins today. The masjid is believed to be built in the 15th century or 16th century although it has no inscription panel (Figure 2.13). The dome and some main walls are not present. The building was built on land that slopes from east to west. The building has two spaces including the prayer hall and portico. The main walls generally built of rubble have also locally laid pitch-faced stone. The southern facade is completely built of pitch-faced stone. The window openings in the walls are also damaged. The pointed arches of the windows are visible in some parts, while in other parts, they are only evidenced by the remaining traces. The prayer hall today has no dome and elements of the transition zone. However, it is clear from the traces that squinches were used as a transition element in the north-east and north-west corners of the prayer hall (Figure 2.14).

Figure 2.13. Naibli Masjid (Source: Ünal R.H., Çağlıtütüncügil E., 2016)

Six different single-domed mosques and masjids in Urla, which date from recent periods, were examined in detail. It is clear that essential interventions have been made to maintain the buildings, including structural interventions such as local repairs and additions to support the load-bearing structural system, restoring functional needs such plaster and paint repairs, and changes in plan layouts such as spatial losses or space additions. These interventions have today led to a number of variations in the buildings. However, in comparison with the original situation of the buildings, the single-domed mosques and masjids examined in this study have similar characteristics in terms of space dimensions, architectural elements, structural solutions, and use of construction materials. The buildings in Urla, which are the subject of research, have important parallel characteristics that help gain insights into the typology of single-domed mosques built in the 15th and 16th centuries (Figure 2.15).

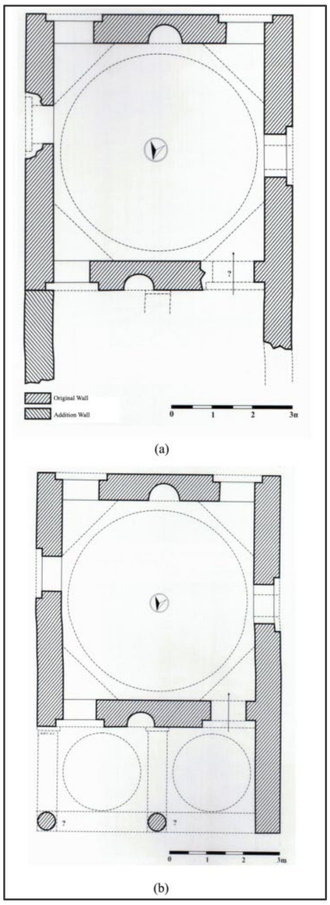


Figure 2.14.a) Naibli Masjid's measured drawing plan, b) Naibli Masjid's restitution plan (Source: Ünal R.H., Çağlıtütüncügil E., 2016)

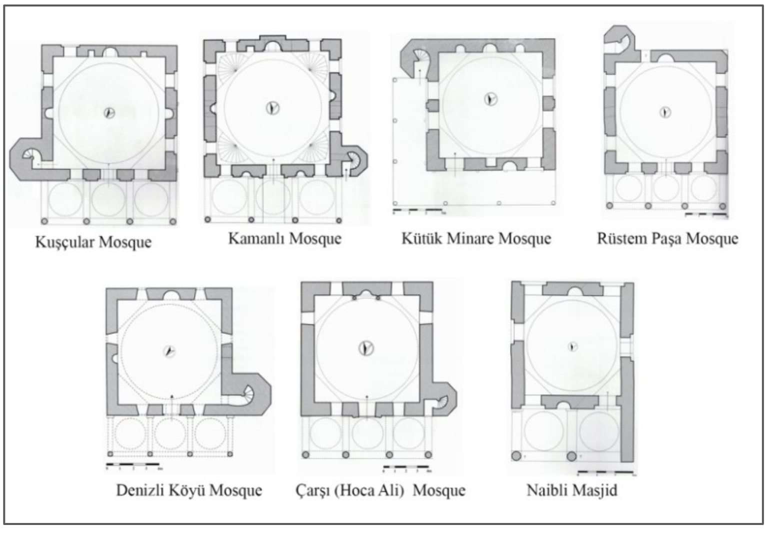


Figure 2.15. Restitution drawings of seven mosques in Urla (Source: Ünal R.H., Çağlıtütüncügil E., 2016)

CHAPTER 3

CHARACTERISTIC OF HELVACILAR MOSQUE

3.1. Location and Access

Helvacılar Mosque is located in the locality called Helvacılar Location in Kuşçular Village in Urla District, Izmir. The mosque is approximately 5 kilometers distant from the center of Urla and situated on the lot 384 and plot 30. The mosque built on a rough land away from the general village settlement area does not have a convenient location for transportation. There is no building around the mosque (Figure 3.1, Figure 3.2).

Figure 3.1. Location of Helvacılar Mosque on map
Source: Retrieved 25 April 2019 from http://kentrehberi.izmir.bel.tr/izmirkentrehberi)

3.2. Architectural Characteristic of Helvacılar Mosque

Helvacılar Mosque is referred to as Kuşçular Village Old Mosque in the records of the General Directorate of Foundations. The mosque is now derelict and ramshackle and suffers severe structural damages and losses. The mosque has a land area of 5,420 square meters. The plot of the mosque is leased by the Second Regional Directorate of Foundation for agricultural purposes. Helvacılar mosque is located at the eastern edge of the plot, which slopes from north to south (Figure 3.3).

The building has no inscription panel; however, it was built in the 15th century according to the registration slip issued by the General Directorate of Foundations in 2009.

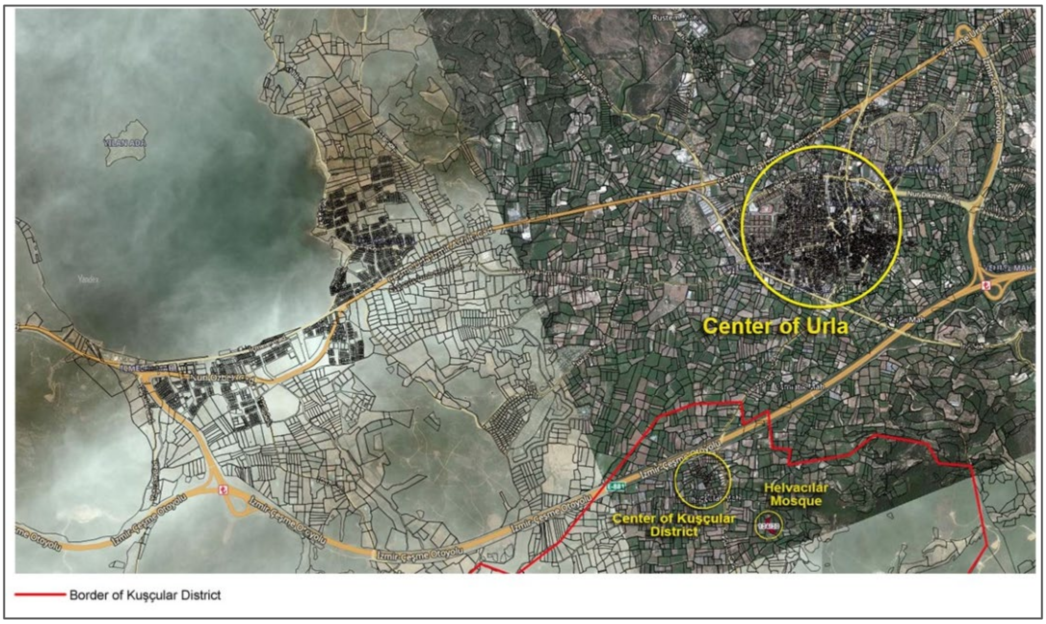


Figure 3.2. Access route of Helvacılar Mosque
(Source: Retrieved 25 April 2019 from www.tkgm.gov.tr)

Figure 3.3. General view of Helvacılar Mosque

3.2.1. Plan Characteristics

Helvacılar mosque consists of three spaces including the portico, prayer hall, and minaret (See Appendix A) (Figure 3.4).

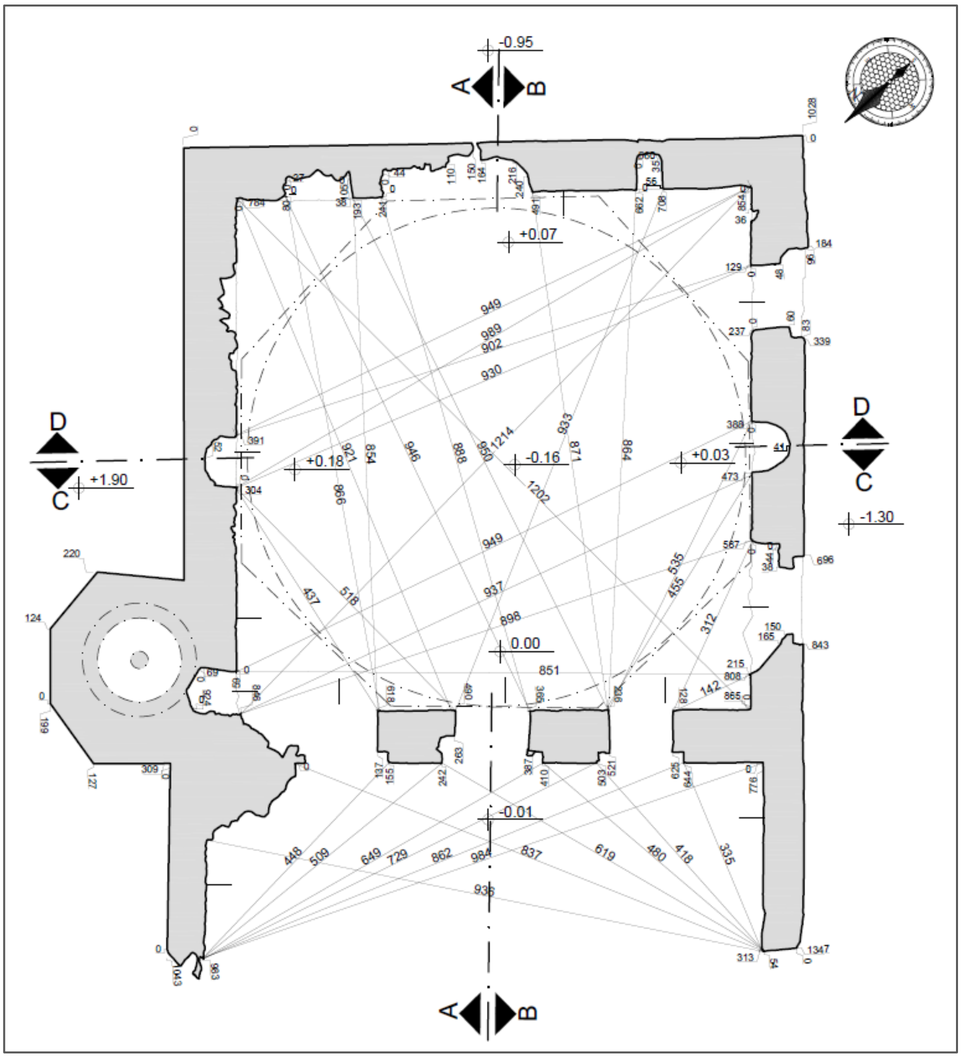


Figure 3.4. Ground floor plan of Helvacılar Mosque

3.2.1.1. Last Comers' Praying Hall (Portico/Son Cemaat Mahali)

The portico is not present today. Today, within the borders of the remaining walls, the portico is a rectangular space that measures 9.2 meters long x 3.5 meters wide. It is thought that when the mosque was usable, the entrance was from the portico, which led to the prayer hall. The northern and southern walls of the portico are partially present and there is no superstructure. However, the traces on the western wall of the portico suggest that the superstructure of the portico consisted of three identical domes. The thickness of the walls of the portico ranges from 64 to 67 centimeters and the walls are built of rubble. The length of the south wall is 3.65 meters at the bottom but decreases along the height of the wall and becomes 0.30 meters at the top. The length of the north wall is 3.23 meters at the bottom but drops to 1.65 meters along the height of the wall (Figure 3.5, Figure 3.6).

The north and south walls of the portico differ in masonry techniques and materials used, thereby suggesting that they might have been built later.

Figure 3.5. South wall of last comers' praying hall

Figure 3.6. North wall of last comers' praying hall

It is the west façade wall that separates the prayer hall and the portico. There is a door opening in the middle of the west wall for the entrance to the prayer hall. There are large window openings on both sides of the door, which have disintegrated stones at the bottom.

The floor of the portico is composed of soil covered with grass because it is not enclosed. There are stone and brick materials falling from the building on the floor. There is a heap of building materials on the northern side of the portico, which has been covered with soil over time.

3.2.1.2. Main Space (The Prayer Hall/ Harim)

The prayer hall (harim) is a square space that measures 8.6 meters on each side. The walls of the prayer hall (harim) are built of pitch-faced stone for a height of nearly

60 centimeters above the ground, which is surmounted by rubble for a height nearly 2.5 meters. The thickness of the walls of the prayer hall ranges from 85 to 92 centimeters and there are remains of plaster and paint locally on the walls. The walls bear traces of sections supported by timber beams at a height of nearly 2 meters above the ground, which are not present now.

In the middle of the west wall, there is a building entrance which extends to 2.8 meters above the ground and has two large window openings on both sides. The parts of the wall under the window are collapsed and the stones forming the wall are left as a heap of rubble at the bottom of the window openings (Figure 3.7).

Figure 3.7. West wall of the prayer hall (Harim)

In the middle of the north wall, there is a niche with a depth of nearly 60 centimeters. The entrance door of the minaret is situated in the west corner of the north wall. The debris of rubble walls at the bottom of and inside the minaret door hinders the entrance through the minaret. There is a window opening on the east side of the northern facade. The wall parts below the arch and the window are damaged. The north wall is the least damaged part of the building compared to the other walls (Figure 3.8)

Figure 3.8. North wall of the prayer hall (Harim)

In the middle of the east wall of the prayer hall, there is a mihrab which extends to 3.6 meters above the ground and has a depth of 55 centimeters. There is a small niche on both sides of the mihrab and a window opening on the north side of the east wall. The depth of the niche on the left side of the mihrab is 25 centimeters and that of the niche on the right side is 55 centimeters. There is a window opening on the left side of the mihrab, which starts at a height of nearly 1.2 meters above the ground. The masonry materials below the window and the borders of the window opening are disintegrated (Figure 3.9).

Figure 3.9. East wall of the prayer hall (Harim)

In the middle of the south wall, there is a niche with a depth of nearly 60 centimeters. There are two window openings on the right and left sides of the niche. The walls parts below the windows are not present. Window openings start at ground level as they stand. The biggest structural problems of the building are seen in the south wall of the prayer hall (Figure 3.10).

Figure 3.10. South wall of the prayer hall (Harim)

The prayer hall is covered by a brick dome. The drum of the dome starts at a height of 5.95 meters above the ground of the prayer hall and the apex of the dome ends at a height of 10.10 meters inside the building.

The structural symmetry of the prayer hall is evident, starting from the underside of the dome. Four equal squinches between the walls of the prayer hall and the corners of the dome aid in the transition to the dome. The transition to the dome on both sides of the squinches is supported by pendentives. In the pendentives, the relieving blocks (hafifletme küpleri) are clearly visible in the sections on the south wall. In the four walls of the prayer hall, there are arches in the middle of the inner walls at the same level as the squinches. The right and left ends of these arches join the corner squinches at the abutments. The springers embedded into the wall in the middle of each wall start at a height of 3.2 meters in the wall plane, and the keystones are at a height of 5.90 meters. There is an upper row of windows under the central arches of the four walls. The opening of the upper-row window under the mihrab in the south wall was completely closed with stone material, and half of the upper-row window in the north wall was closed with stone material.

No detail about the original material of the floor of the prayer hall was found in the building. The floor of the prayer hall is covered with soil at present and there are traces of excavations in the central part.

3.2.1.3. Minaret

In the north-west corner of the mosque, there is a minaret built adjacent to the building and the structural integrity of the minaret body is impaired today. The entrance to the minaret is through a small door inside the prayer hall.

The sections of the minaret are listed, from bottom to top, as the base, base niches, pabuc, and body. The inner radius of the minaret body is 70 centimeters and the outer radius is 95 centimeters. The minaret starts at a level of +1.68 meters and the apex of the minaret is +13.65 meters high.

Almost half of the minaret body is ruined. As it can be understood from the registration form, until recently, the minaret had a top balcony and the underside of the top balcony was decorated with brick motifs (Figure 3.11).

Figure 3.11. Minaret of the mosque

3.2.2. Facade Characteristics

The east wall of the portico is the western facade of the building (Figure 3.12). The minaret located to the north side of the facade is adjacent to the facade. The standing parts of the north and south walls of the portico are in the wall borders of the facade. There are four openings on the facade. In the lower row, there is the entrance door of the prayer hall, which is an arched opening in the middle of the western facade. There are large window openings on both sides of the door, which have disintegrated stones at the bottom. The width of the middle entrance door is greater than that of the windows. The traces of the lintels above indicate that the door and window openings are rectangular. There are the pediments of marble arches over the openings, which are highlighted by four courses of bricks. Simple brick decorations over the four courses of bricks are evident from the remains of plaster. The decoration on the window on the southern facade is clearly visible (Figure 3.13). The masonry of pitch-faced stone starts where the brick decoration ends. Circular holes at the level of marble jambs are the holes of timber beams. There is a piece of timber lintel, which is the only timber remnant of the building, in the space in the upper left corner of the door. Above the decorations, there are symmetrically arch-shaped moldings in the masonry of pitch-faced stone over the door and window openings. There is a brick wall above the moldings. The inside of the arch over the door entrance to the prayer hall, which is likely to hold the inscription panel, is empty today. In the upper row, there is a window with a brick arch in the center of the facade, and half of its opening is closed with the wall material. There are plants intensively growing on the border of the drum.

There are three openings in the southern facade, including two lower-row windows and one upper-row window (Figure 3.14). The lower rows of windows are the same in size and the easternmost window is destroyed. The traces of the timber lintel above indicate that both windows are rectangular. The pediments of both windows are highlighted by four courses of bricks (Figure 3.15). There are two stone corbels at a similar level with the upper level of the lower row windows. The last opening in the facade is an upper-row window with a brick arch in the center of the facade. The upper-row window has brick decorations similar to those in the lower-row windows on the western facade.

Figure 3.12. West facade of the mosque

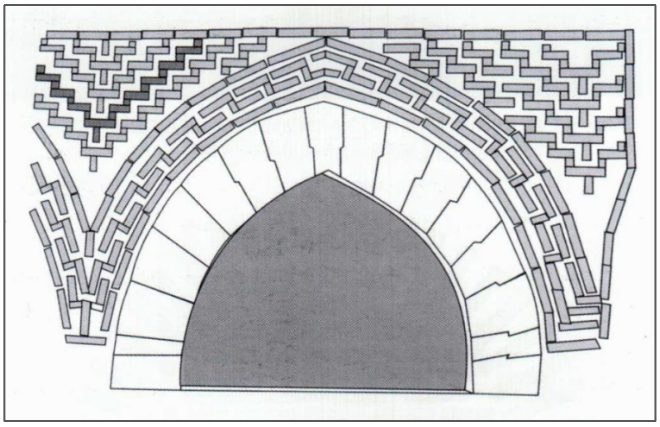


Figure 3.13. Drawing of decoration on west facade
(Source: Ünal R.H., Çağlıtütüncügil E., 2016)

Figure 3.14. South facade of the mosque

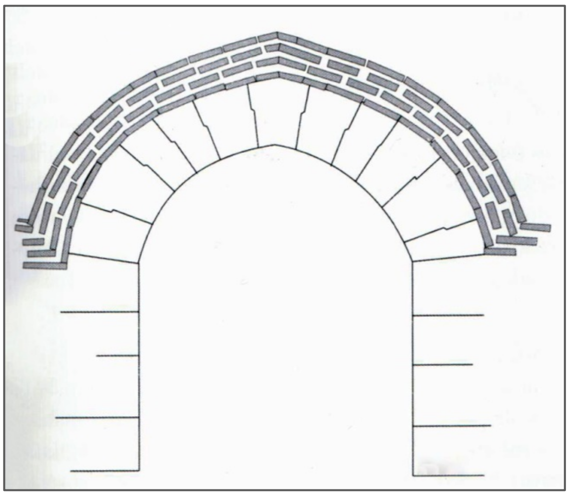


Figure 3.15. Drawing of upper level window decoration on south facade
(Source: Ünal R.H., Çağlıtütüncügil E., 2016)

As the northern and eastern facades are covered with trees, it is not possible to examine them as thoroughly as the other facades. However, like the walls on the other facades, the walls on the northern and eastern facades are built of pitch-faced stone in the corners and of rubble in the other parts. Unlike other facades, the northern and eastern facades have one lower-row window. In both the northern and southern facades, the window arches are worn out. In both facades, there are upper-row windows with brick arches, which are equal in position and size to those in the other facades. In both facades, there are plants intensively growing on the border of the drum (Figure 3.16, Figure 3.17).

Figure 3.16. North facade of the mosque

Figure 3.17. East facade of the mosque

3.2.3. Architectural Elements

The architectural elements in Helvacılar Mosque are examined in five main sections: door openings, window openings, mihrab, niches, and minaret (See Appendix B).

3.2.3.1. Door Openings

There are two doors with different characteristics.

Type 1: The main entrance door to the prayer hall is in the northern facade. It is 2.8 meters long x 1.2 meters wide. There is a pointed arch of cut stone over the main entrance door.

Type 2: The entrance door of the minaret is in the north corner of the east wall inside the prayer hall. There is a pointed arch of cut stone over the minaret door, which is approximately 90 centimeters long x 65 centimeters wide.

3.2.3.2. Window Openings

The mosque has five different types of windows. The first four types of windows are identified as lower-row windows and are in the prayer hall wall. The fifth type of window is an upper-row window.

Type 1: It is seen on both sides of the door at the entrance of the prayer hall. There is a pointed arch of cut stone over the windows, which are approximately 2.3 meters long x 1.2 meters wide. The windows start at nearly 50 centimeters above the ground. However, the under-window wall sections are collapsed and the wall rubble lays in a heap on the floor at the bottom of the windows.

Type 2: There are two windows in the south wall of the prayer hall, which can be described as the same type because they have similar dimensions. There is a pointed arch of cut stone over the westernmost window, which is approximately 3.1 meters long x 1.6 meters wide. The windows start at ground level in the interior. The under -window wall sections are collapsed, and the masonry materials lay on the ground outside the building. The window to the east of the south wall is severely damaged. Only the abutment of the window arch is visible. The wall sections to the left and right of the window are also disintegrated.

Type 3: It is in the east wall, which the mihrab is located in, to the north of the mihrab. It is nearly 1.6 meters long x 1.4 meters wide. However, the stone wall, which forms the outer borders of the window, is damaged and the under-window wall sections are disintegrated. The arch over the window is not present. It is seen from the stone masonry above that it was a pointed arch.

Type 4: It is to the east of the north wall of the prayer hall. It is nearly 1.6 meters long x 1.4 meters wide. However, the stone wall, which forms the outer borders of the window, is damaged and the below-window wall sections are disintegrated. The arch over the window is not present. It is seen from the stone masonry above that it was a pointed arch.

Type 5: The upper-row windows are located below the arches in the middle of the four walls of the prayer hall. Their widths range from 80 to 85 centimeters. None of the four windows are similar in height. The window arches are pointed arches built of brick. The window opening above the mihrab in the east wall was completely closed with stone material, and half of the upper-row window in the west wall was closed with stone material.

3.2.3.3. Mihrab

It is located in the middle of the east wall and is 3.3 meters long x 1.25 meters wide. The mihrab niche is semi-circular and the kavsara (the upper inner part of the niche) is worn-out and simply decorated with brick muqarnas.

3.2.3.4. Niches

There are three different types of niches in the mosque.

Type 1: It is into the middle of the north and south walls of the prayer hall. The niches with a depth of 55 to 60 centimeters have pointed stone arches. They face opposite each other inside the prayer hall.

Type 2: It is into the east wall of the prayer hall and to the left of the mihrab. It is small and nearly 25 centimeters in depth. It has a pointed brick arch. It is worn out.

Type 3: It is into the east wall of the prayer hall and to the left of the mihrab. With a depth of 55 cm, the niche has a pointed cut-stone arch.

3.2.3.5. Minaret

The architectural elements of the minaret include, from bottom to top, the base, base niches, pabuc, and body.

Base: The minaret base is octagonal. The five sides of the base built of pitch-faced stone are visible when looking from the facades, while the two sides are adjacent to the prayer hall wall. As can be seen from the masonry, the minaret base was built together with the adjacent wall of the prayer hall on the northern facade. In the upper part, there are blind niches built with pointed arches. The masonry material of the niches is brick. There is an alternate bond pattern with one course of stone and two courses of brick between the niches. The niches have geometric decorations built of bricks.

Base Niches: From north to south in order from 1 to 5;

The niche 1 has three distinct geometric stripes separated by one course. The lowermost stripe is in the composition of a diagonal line of rhombuses. The middle stripe is a zencirek motif in the "Z" pattern. The uppermost stripe is two horizontal rows of zencirek motif.

The ***niches 2 and 4*** have "Y" patterned zencirek lines, the open edges of which are alternately arranged with one looking rightward and one leftward.

The ***niche 3*** has courses of bricks laid in the form of steps ascending to both sides.

The ***niche 5*** has a 90-degree rotated version of the pattern in the niches 2 and 4 (Figure 3.18, Figure 3.19).

Pabuc: It is built of brick in the form of triangle segments. There is a brick molding of circular shape on the segments.

Body: It is cylindrical and simply built of brick. The upper part of the body is collapsed. Starting from the minaret entrance in the prayer hall, the staircase ascends upwards, with the rest in the inner side of the body.

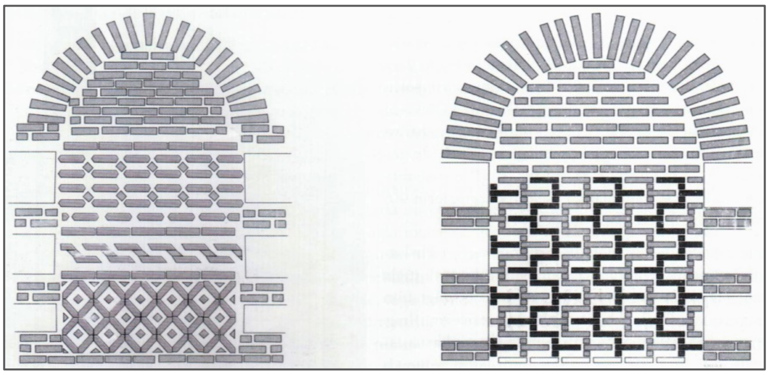


Figure 3.18. Drawing of pulpit niches decorations (No:1 on Left, No:2 on Right) (Source: Ünal R.H., Çağlıtütüncügil E., 2016)

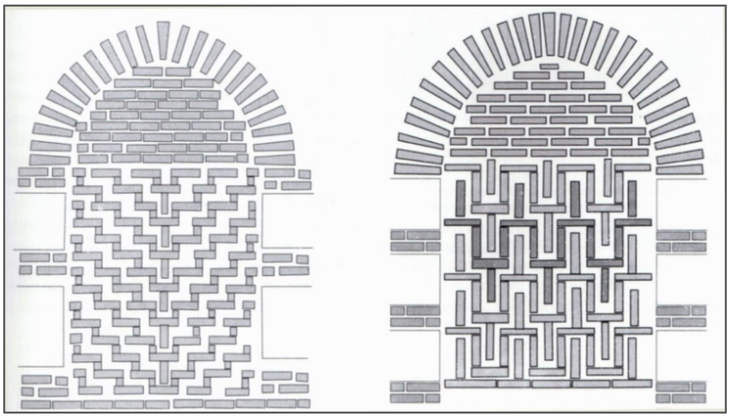


Figure 3.19. Drawing of pulpit niches decorations (No:3 on Left, No:5 on Right)
(Source: Ünal R.H., Çağlıtütüncügil E., 2016)

3.3. Structural System, Construction Technique and Material Usage

The load-bearing components of Helvacılar Mosque are examined under four main sections: vertical load-bearing walls, transition elements, superstructure, and minaret. Because there is no information on the foundation of the mosque, the foundation was excluded from the classification (See Appendix C).

3.3.1. Vertical Elements

The mosque has two different types of walls.

Wall 1: They are the walls of the prayer hall, with a thickness ranging from 85 to 92 centimeters. The wall sections of 60 centimeters above the ground and 120 centimeters from the corners are built of pitch-faced stone along the height of the wall. The remaining sections are built of rubble. Lime mortar was used for bonding. There are remains of plaster and paint locally on the interior walls. The walls of the prayer hall have large holes nearly 2 meters above the ground, which go all the way through the walls and appear to be the area on which the timber lintel sat. There are no timber elements inside the holes.

Wall 2: The northern and southern walls of the last comers' praying hall, whose thickness ranges from 64 to 67 cm, are partially standing. They are built of rubble and bonded by lime mortar in a bonding pattern different to the walls of the prayer hall.

3.3.2. Transition Elements

Three different types of transition elements are used including squinches, arches, and pendentives (Figure 3.20).

Squinch: The cubic prayer hall has four squinches symmetrically constructed in the upper corners where the walls join the dome drum. The thickness of the squinches, built of brick and lime mortar, was not exactly measured. Both sides of the pointed arched squinches are composed of two separate pendentives.

Arch: The abutments of the brick arches embedded into the wall in the middle of each wall start at a height of 3.2 meters in the wall plane, and the keystones are at a height of 5.90 meters. Brick and lime mortar were used in the construction of arches. The pointed wall arches join the corner squinches at the abutments. These abutments built of cut stone are slightly projecting beyond the wall surface. The intrados (soffit) of the arch is built of rubble in a patter following the wall pattern. Under the arches, there are upper-row windows in the middle of the wall.

Pendentive: The pendentives built of stone and brick are at the intersection of the corner squinches, arches, and the drum. Lime mortar was used in the pendentives. There are holes of relieving blocks in the area of pendentives in four sections. Those in the southern facade are clearly noticeable and larger compared to those in the other facades. These relieving blocks are likely to have been used to reduce the weight of these geometrically challenging transition zones and to increase the contact with the air to ease mortar strength during the construction.

3.3.3. Superstructure

The dome forming the top cover of the prayer hall is hemispherical, 35 to 40 centimeters in thickness and built of brick. The dome was bonded by lime mortar. The octagonal drum starts at a height of 5.95 meters above ground level. The extrados of the drum was framed with pitch-faced stone. The interior apex of the dome is 10.10 meters high from the ground. The drum’s frame is not in its entirety. The northern, western and southern sides of the dome have conspicuously but sparsely the parts of the frame. The parts in the remaining sides are torn apart due to external factors.

Figure 3.20. Squinches, arch and pendentives on transition zone of north wall

3.3.4. Minaret

The load-bearing components of the minaret include the base, pabuc, and body.

Base: The minaret base has an octagonal shape with five sides facing outside and the others adjacent to the prayer hall. It starts at a height of 1.65 meters above the ground and ends at 6.30 meters. The base, built of pitch-faced stone and lime mortar, was built together with the adjacent wall of the prayer hall. The side lengths of the base range from 125 to130 centimeters. The base has five niches of brick between the 4.3-meter level and 6.30-meter level.

Pabuc (Transition Segment): The pabuc changes from polygonal to circular between the base and the body. It is built of brick in the form of triangle segments between the 6.30-centimeter level and 7.20-centimeter level. There is a circular ring when the pabuc joins the body.

Body: The minaret body is built of brick and lime mortar is 25 centimeters in thickness. The body starts at a height of 7.2 meters and ends at 13.65 meters. The internal radius of the body is 70 centimeters. The minaret staircase inside the body is stone. It is not possible to determine whether there is a core section that fills the center of the staircase. The stone stairs are underpinning bricks underneath. The staircase was constructed by bonding underpinning bricks to the minaret body.

3.4. Structural Failures

The building examined in this study has serious structural problems and its structural integrity and load transfer mechanism are almost destroyed, especially in the southern facade. The identification of structural problems will help map out a course of action to reveal the problems of the mosque and to identify interventions that the mosque needs.

Structural problems are addressed under four main sections: mass collapse, cracks, losses of timber element, and ground settlement (See Appendix D).

3.4.1. Mass Collapse

Mass collapse are divided into six different categories, starting with the structurally most important losses.

The Mass Collapse in the South-Eastern Corner of the Prayer Hall:

The corner squinch, the wall section below this squinch, and the arch abutment in this wall are all lost. They represent the most important mass collapse in the structure. This loss has resulted in both cracks in surrounding sections and significant loss of stability in the south wall of the structure (Figure 3.21).

The Mass Collapse in the Minaret Body:

The southern portion of the minaret body, which comprises nearly one-third of the minaret body, is missing. Because the original height of the body is unknown, there is no precise information about how much mass collapse there is on the body over the top level. The structural integrity of the minaret is impaired by these losses and the deterioration mechanism continues to increase (Figure 3.22, Figure 3.23, Figure 3.24).

Mass Collapses/Deformations in the Walls under Window Openings:

All lower-row windows labeled as type 1,2, 3, and 4 suffer mass collapses or wall disintegration under the openings. In type 1 and 2 windows, wall fillings are missing. In type 3 and 4 windows, the fillings are not suitable in terms of load-bearing capacity although they are in their place (Figure 3.25).

The Collapses of the Over-Lintel Blocks and Relieving Arches over Window and Door Openings:

These losses include the losses of wall blocks on the lintels over the openings of the main entrance door and all lower-row windows labeled as type 1, 2, 3, and 4 and the losses of relieving arches which are supposed to be rest on them. The traces of arches are clearly visible in the walls (Figure 3.25).

Collapses in Keystone Areas:

The losses in keystone areas are seen in the arch in the south wall, the south-west and north-east squinches, and the upper-row windows in the north and east walls. These losses can be described as the loss of two or three courses of bricks in the keystone area of the arches. The losses in the center and corners of the south wall should not be considered locally as they are associated with other structural problems, but rather should be addressed in terms of the ripple effect of all damages in the southern wall on each other.

Figure 3.21. Mass collapse on the southeast part of the south wall of Harim

Figure 3.22. Mass collapse of minaret (dated on 1985)
(Source: Ünal R. H personal archive)

Figure 3.23. Mass collapse of minaret (dated on 2016)

Figure 3.24. Mass collapse of minaret (dated on 2019)

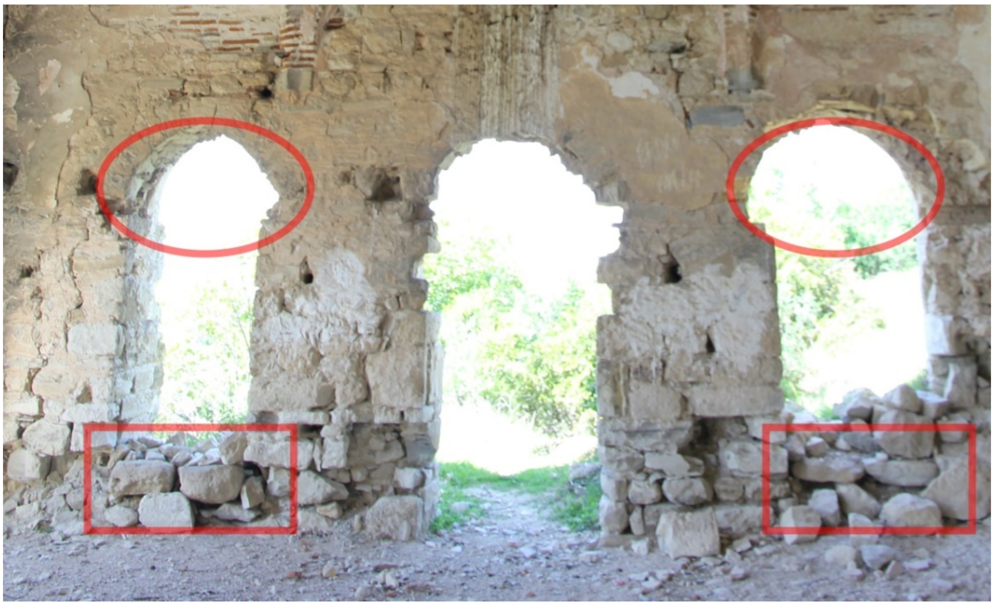


Figure 3.25. Mass collapse of different level of window openings on west wall of Harim

3.4.2. Cracks

Cracks in the Dome:

The three main cracks in the southern side of the dome are the most important structural cracks in the structure. These three cracks originate from the squinches and the keystone of the central arch, run up through the dome and intersect at some point. The dome cracks go all the way through the dome surface. Looking up to the ceiling, the sky can be seen through the cracks. These cracks and other structural problems in the south wall should be handled together (Figure 3.26).

Cracks in the Squinches:

These cracks originate from the joining line in the center of the north-east and south-west squinches and go downwards to the corners of the walls under the squinches. The crack in the north-east corner continues along the squinch, narrowing upwards to the dome. The crack in the south-west corner goes downwards to the wall as a continuation of the main crack originating from the dome. While the cracks in the squinches are clearly visible inside the structure, no cracks are observed in the facade (Figure 3.27).

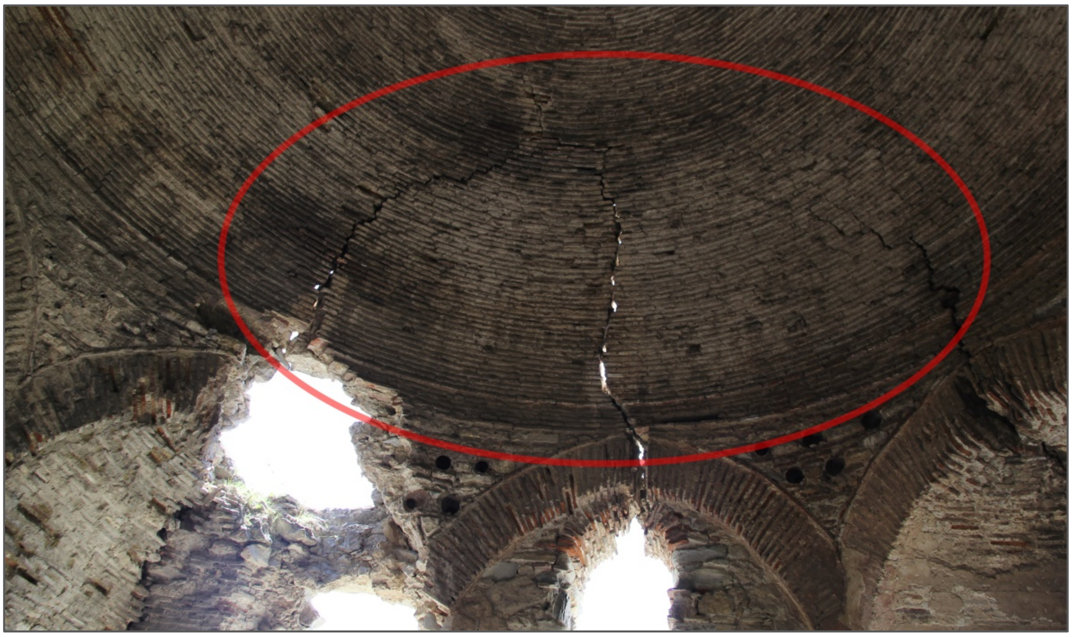


Figure 3.26. Crack on the south part of the dome

Figure 3.27. Cracks on the southwest corner of harim

3.4.3. Loss of Timber Elements

The wooden lintels embedded into the walls of the prayer hall at a height of 2 meters above the ground and the wooden lintels over the window openings are not visible in any wall or window. Lintel holes are clearly seen in the north, south and west walls of the prayer hall (Figure 3.28).

Figure 3.28. Loss of timber elements on north and west walls of harim

3.4.4. Settlement

Two measurements were performed on the west wall of harim and the plan to determine the degree of the settlement in the structure.

First, inside the prayer hall, a laser line, considered to be the 0.00 level, was set up at a height of 115 centimeters above the ground, and a line was drawn by horizontally stretching out a rope between the lower levels of the lintel spaces in the north, south and west walls of the prayer hall (Figure 3.29). The vertical distance between the laser line and the horizontal rope was measured at certain vertical distances from the north wall to the south. As can be seen in Table 3.1, the distance between the levels from the north wall to the south wall decreased. In other words, the building had a settlement of 14.5 centimeters from inside the north wall to inside the south wall.

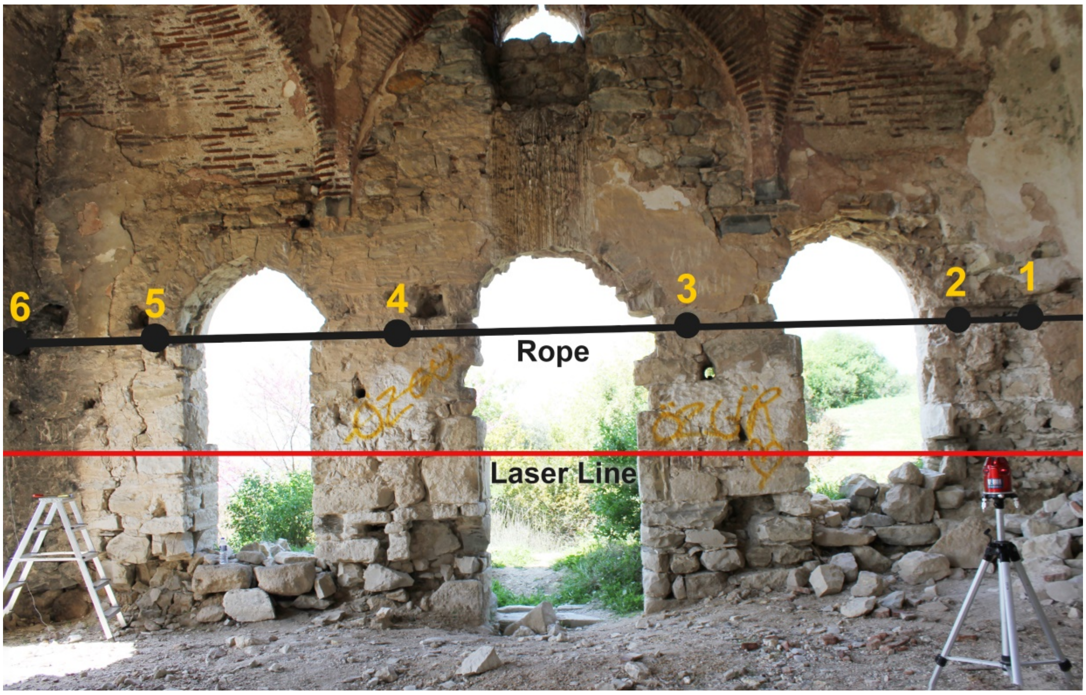


Figure 3.29. Settlement measurement between north and south walls of harim

Due to material deterioration and structural losses in the building, it is extremely hard to find points that can be considered as reference points in horizontal and vertical dimensions. For the measurements made in the plan, the laser line was placed at a height of 115 centimeters. The arches and the joining abutments where the squinches were thought to be theoretically at the same level; therefore, the distance between the laser line and the beginning levels of the seven abutments in the structure was manually measured and compared with the measures on the measured drawings. The thicknesses of abutment stones also vary (Figure 3.30) (Table 3.2).

Table 3.1. Settlement measurements on aa section

POINT	DISTANCE FROM STARTING POINT (NORTH WALL)	RANGE BETWEEN TWO LEVEL (cm)	SETTLEMENT (cm)
1	0 m	113	0
2	0.4 m	112.5	0.5
3	3 m	107	6
4	5 m	104	9
5	7 m	100.5	12.5
6	8.5 m	98.5	14.5

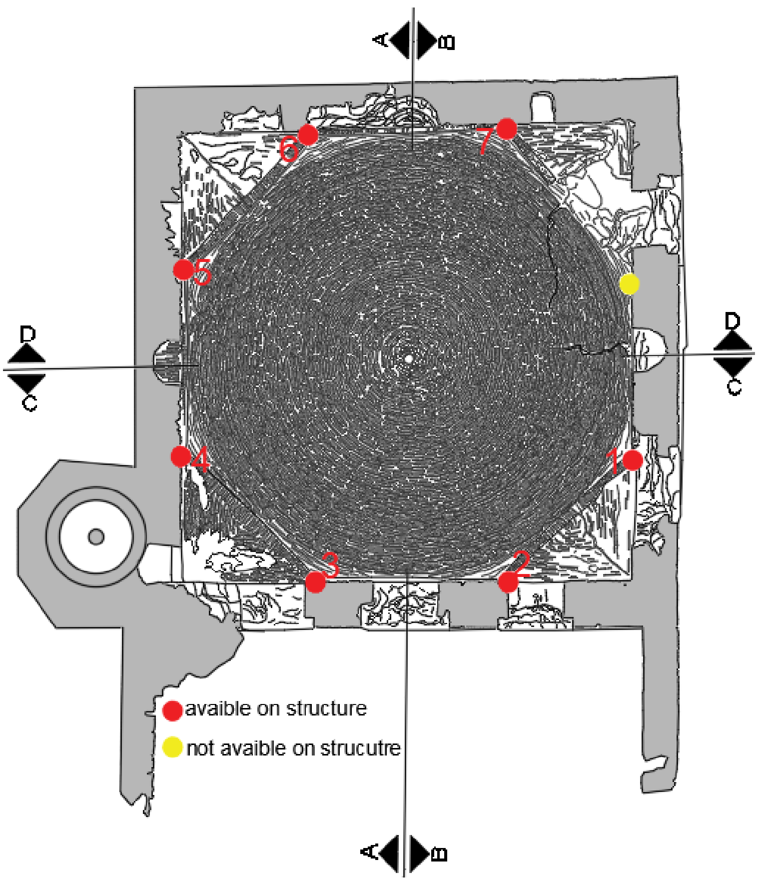


Figure 3.30. Location of abutments on plan

Table 3.2. Settlement measurements on plan

ARCH ABUTMENT	**LOCATION**	**TOP OF ABUTMENT (cm)**	**HEIGHT OF ABUTMENT STONE (cm)**	**ELEVATION FROM LAZER LINE (cm)**	**LOCAL ELEVATION (MEASURED BY HAND) (cm)**	**LOCAL ELEVATION (ON MEASURED DRAWING) (cm)**	**LAPSE BETWEEN TWO MEASUREMENTS (cm)**
1	*SOUTH*	211.5	18	193.5	308.5	311	-2.5
2	*WEST*	214.5	16	198.5	313.5	315	-1.5
3	*WEST*	216.5	13	203.5	318.5	317	1.5
4	*NORTH*	214.5	11	203.5	318.5	316	2.5
5	*NORTH*	226.5	17.5	209	324	326	-2
6	*EAST*	229.5	20.5	209	324	330	-6
7	*EAST*	224	17	207	322	324	-2

The measurement made by taking the abutment stones as a point of reference was performed on March 22, 2019, and the measurement made using the measured drawings was performed on February 10, 2016. The difference between the manually measured values and the values measured by a tool might be due to both the margin of error of the manual measurement and the ongoing settlement mechanism in the structure for 3 years. As can be seen from the signs on the abutment stones, the settlement in the structure is also westwards.

In brief, the settlement in the structure reaches a maximum degree in the south-west corner of the south and west walls caused by ground settlement. Additionally, this settlement concurrently led to the rotation of the eastern wall of the building. Starting from the north corner of the eastern wall of the prayer hall and increasing along the length of the wall, there is a rotation of about 20 centimeters in the south corner.

CHAPTER 4

ENGINEERING ANALYSES OF HELVACILAR MOSQUE

4.1. Finite Element Modeling Strategies and the Structural Model of the Case Study

Structures, which were built with the knowledge and experience of builders in the past and have developed and changed over the centuries, are today modeled using computer-based analysis with the development of technology to understand their current situation and describe their structural problems.

The finite element method is a numerical method for solving problems of engineering and mathematical physics. For problems involving complicated geometries, loadings, and material properties, it is generally not possible to obtain analytical mathematical solutions. Analytical solutions generally require the solution of ordinary or partial differential equations, which, because of the complicated geometries, loadings, and material properties, are not usually obtainable. Hence, we need to rely on numerical methods, such as the finite element method, for acceptable solutions. This process of modeling a body by dividing it into an equivalent system of smaller bodies or units (finite elements) interconnected at points common to two or more elements (nodal points or nodes) and/or boundary lines and/or surfaces is called discretization. In the finite element method, instead of solving the problem for the entire body in one operation, we formulate the equations for each finite element and combine them to obtain the solution of the whole body (Logan.2012).

Masonry structures are non-anisotropic and non-homogeneous complex structures and analysis methods should be carefully selected in the light of this information. According to Lourenço (1996), modeling strategies depend on structural problems as much as they depend on the characteristics of the structure. The general structural behavior of complex structures can be examined using a simplified model and the stress-strain relations of mortar-stone interfaces can be examined using more complex modeling approaches.

Lourenço (1996) notes that there are three main modeling methods for masonry structures:

1. Detailed Micro-modeling: It involves modeling units of mortar and stone/brick individually. The connection between the unit and the joint is also defined as an interface. Separate mechanical properties are defined for the unit, joint, and interface. Units and mortars in the joints are represented by continuum elements whereas the unit-mortar interface is represented by discontinuous elements. Rather than modeling the entire structure, it is more convenient to use some of the smaller parts of the structure during the detailed analysis. It ensures modeling very close to real behavior.

2. Simplified Micro-modeling: It is a more simplified method compared to the detailed modeling. In this method, mortar units are accepted together with units and joint interfaces are defined between units. Expanded units are represented by continuum elements whereas the behavior of the mortar joints and unit-mortar interface is lumped in discontinuous elements.

3. Macro Modeling: It is more an aggregated model of constituents of masonry and more frequently used in studies in which the entire structure is modeled. Units, mortar, and unit-mortar interfaces are naked out in the continuum. The mechanical properties of a masonry structure are defined by means of meshes of certain sizes in the single and continuum elements. This modeling method yields more general results compared to the detailed modeling method.

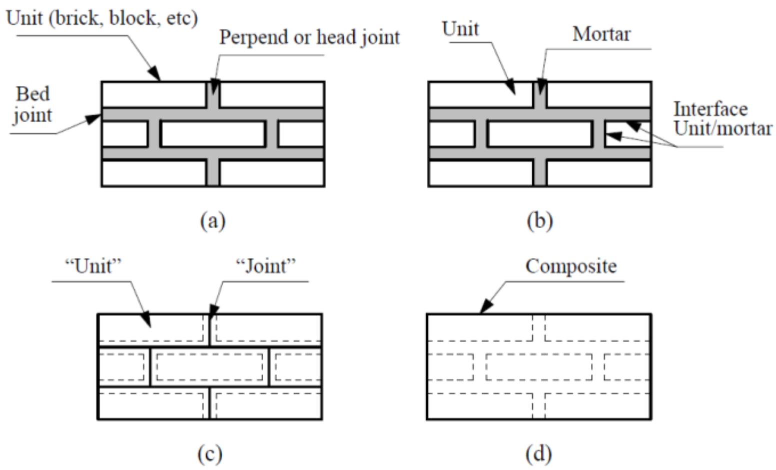


Figure 4.1. Modeling strategies for masonry structures: (a) masonry sample;
(b) detailed micro-modeling; (c) simplified micro-modeling; (d) macro modeling.
(Source: Lourenço,1996)

The question of how to model a damaged masonry structure is a really important engineering question for structures like Helvacılar Mosque. The most important engineering inquiry should be to discover the causes of damage in the structure in which the load-bearing system is damaged and the load transfer mechanism is not its original condition (Figure 4.2).

Figure 4.2. Failure mechanism of load bearing system

Because Helvacılar Mosque is a structure that cannot be preserved with its existing damages, the most basic structural need of the structure is to restitute its original load-bearing system. Which methods to use in which parts of the structure will be evaluated according to the results of the examination.

Therefore, the finite-element model generated for the analyses does not contain structural damages. The finite-element model was designed as a macro model with shell elements in the same geometry as the structure in undamaged form and in the dimensions of the load-bearing components based on the measured drawings.

Considering the differences in modeling methods and the advantages and disadvantages of the analyses to be made, a finite element (FE) model was created with shell elements for Helvacılar Mosque using SAP2000 v. 20 software (Figure 4.3).

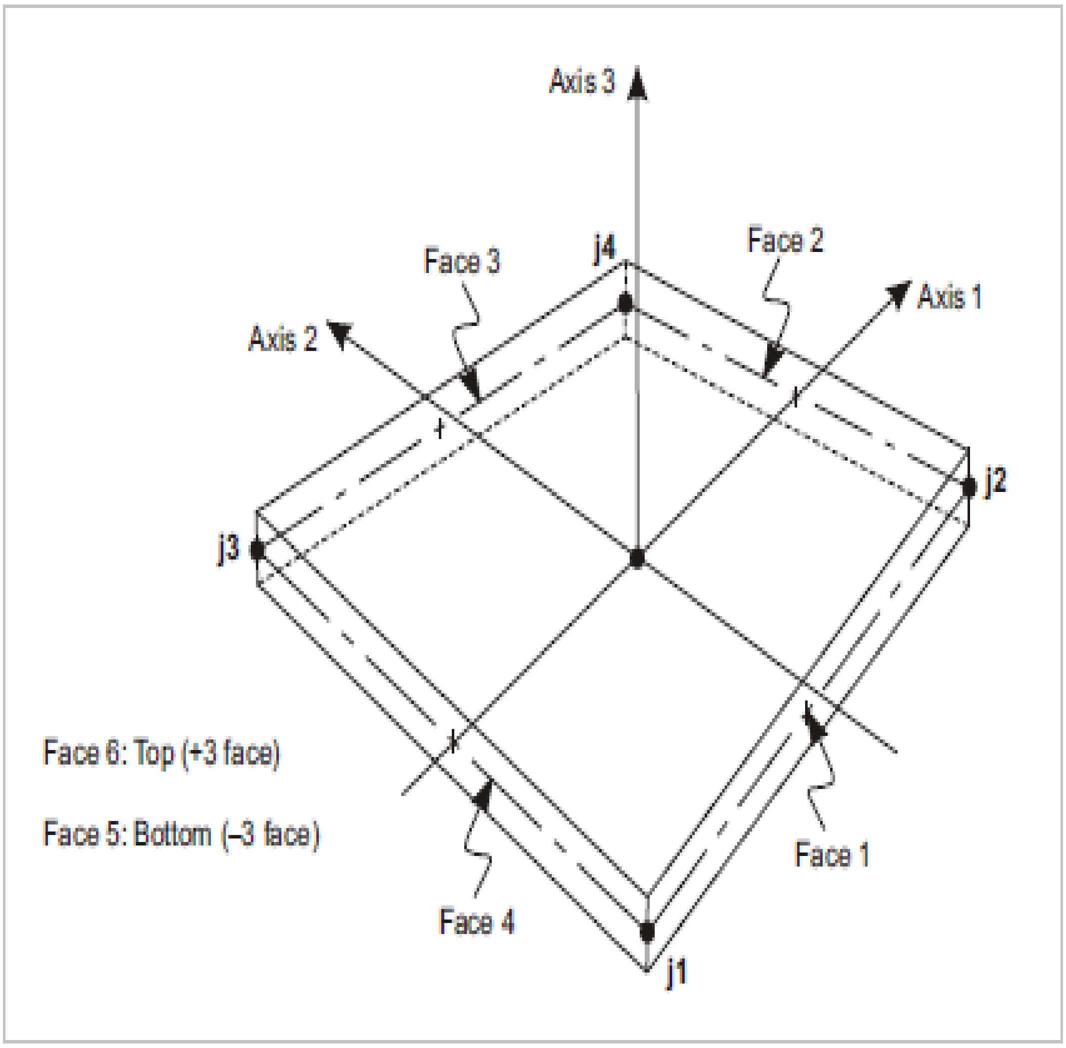


Figure 4.3. Shell element on SAP2000
(Source: csiamerica)

According the SAP200 manual; Figure 4.4 below illustrates the positive directions for shell element internal stresses S11, S22, S12, S13 and S23. Also shown are the positive directions for the principal stresses, S-Max and S-Min, and the positive directions for the maximum transverse shear stresses, S-Max-V.

Shell elements of different thickness were used in the finite element model (Table 4.1) (Figure 4.5). The basic approach to the analysis of this undamaged model will focus on the identification of boundary conditions based on material strengths and the understanding of the stress distributions in the structure.

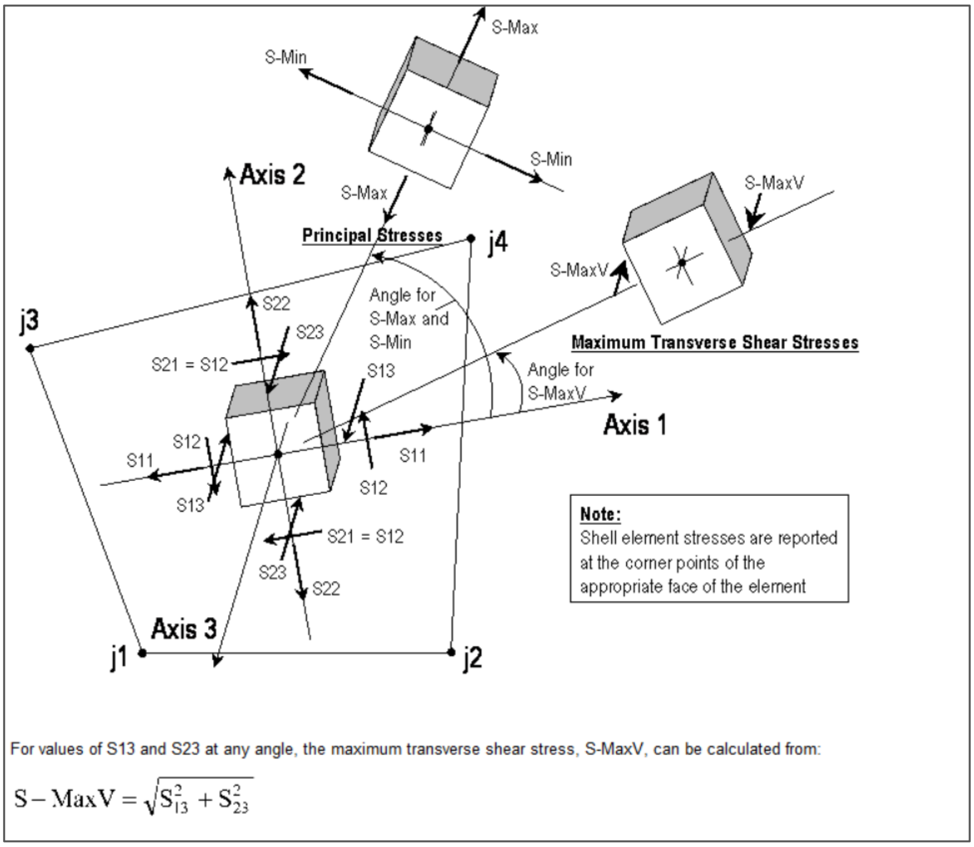


Figure 4.4. Shell stress' direction on SAP2000
(Source: SAP2000 manual)

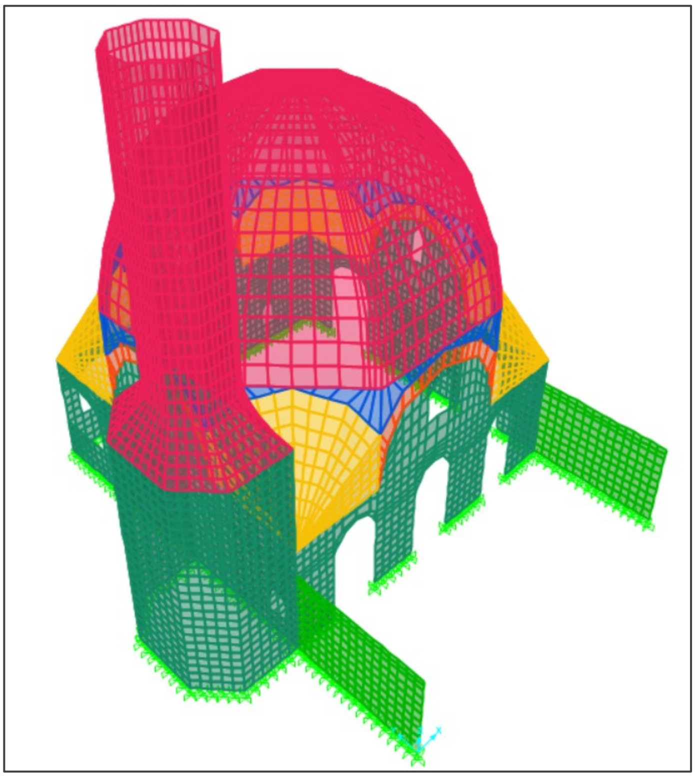


Figure 4.5. Finite element model of Helvacılar Mosque

Table 4.1. Finite element thickness of Helvacılar Mosque's structural elements on SAP2000

Structural Element Type	Thickness
Wall of Harim	85 cm
Wall of Last Comers' Praying Hall	65 cm
Squinch	40 cm
Arch	85 cm
Pendentive	40 cm
Dome	35 cm
Niche/Mihrap	25 cm

4.2. Selection of the Mechanical Properties of the Materials

Because neither laboratory nor in-situ tests could be carried out in the structure, material mechanical properties were selected from literature for use in the finite element analysis. While making this selection, studies on historic buildings in the nearby region were evaluated using the operational model analysis (OMA) method. Tables 2 and 3 show five studies in the Aegean Region with the mechanical properties of material obtained in their results.

Because the material of the historic masonry structure is heterogeneous, it is clear that there are a variety of physical elements that affect the strength. Kamanlı Mosque was selected from five nearby structures examined in previous literature studies because the mosque is known to be built in the same period within the boundaries of the same district as Helvacılar Mosque and to have similar structural forms. Therefore, the mechanical properties derived from the tests performed in Kamanlı Mosque were accepted as reference values for the analyses in Helvacılar Mosque.

Because the work carried out for Kamanlı Mosque does not provide a value for shear strength, the comparison of shear strength will be determined by reference to the values written in the guideline "Earthquake Risk Management of Historical Structures" issued by the General Directorate of Foundations. According to the guideline, shear strength for pitch-faced stone masonry walls ranges from 35 to 51 kPa, while that for lime mortar brick masonry walls ranges from 60 to 92 kPa (VGM, 2017).

Table 4.2. Material parameters for stone masonry from literature research

	MATERIAL PARAMETRES FOR STONE MASONRY								
	CASE STUDY	LOCATION OF CASE STUDY	AUTORS	COMPRESSIVE STRENGTH (MPA)	TENSILE STRENGTH (MPA)	MODULUS OF ELASTICITY (MPA)	SHEAR MODULUS (MPA)	DENSITY (KG/M3)	POISSON RATIO
1	İSA BEY MOSQUE	SELÇUK/İZMİR	MISIR S. et al.,2018	2.3	0.23	4530	-	2200	-
2	KAMANLI MOSQUE	URLA/İZMİR	TEOMETE E., 2004	10.77	1.08	1100	440.00	2200	0.17
3	SULTAN MOSQUE	MANİSA	NOHUTÇU H.,et al.,2014	7.42	0.74	1500	600	2200	0.17
4	HACI MAHMUT MOSQUE	AFYON	DEMİR A., et al, 2016	10.86	1.05	2591	1036.40	2100	0.17
5	VEZİRAĞA AQUEDUCT	İZMİR	ERCAN E. et al., 2014	10.49	1.05	871	326.00	2100	0.17

Table 4.3. Material parameters for brick masonry from literature research

	MATERIAL PARAMETRES FOR BRICK MASONRY								
	CASE STUDY	LOCATION OF CASE STUDY	AUTORS	COMPRESSIVE STRENGTH (MPA)	TENSILE STRENGTH (MPA)	MODULUS OF ELASTICITY (MPA)	SHEAR MODULUS (MPA)	DENSITY (KG/M3)	POISSON RATIO
1	İSA BEY MOSQUE	SELÇUK/İZMİR	MISIR S. et al.,2018	-	-	-	-	-	-
2	KAMANLI MOSQUE	URLA/İZMİR	TEOMETE E., 2004	4.25	0.43	270	110.00	1700	0.17
3	SULTAN MOSQUE	MANİSA	NOHUTÇU H.,et al.,2014	-	-	-	-	-	-
4	HACI MAHMUT MOSQUE	AFYON	DEMİR A., et al, 2016	7.31	0.73	132	52.80	1780	0.17
5	VEZİRAĞA AQUEDUCT	İZMİR	ERCAN E. et al., 2014	3.62	0.36	201	80.40	1750	0.17

4.3. Linear Elastic Self-Weight Analysis

This analysis was performed to understand the situation under the self-weight of the structure in the case of its undamaged condition. This analysis, which is the first phase of analysis, investigated how the structural integrity was and what degrees of stress changes were observed which parts of the structure.

The contour plot of the global z direction displacements (DZ) is given in Figure 4.6. The vertical displacements of the structure under its own weight increase towards the upper levels from the ground, as expected. The maximum vertical displacement is 3 millimeters to the negative Z direction, at the top of the keystone of the dome.

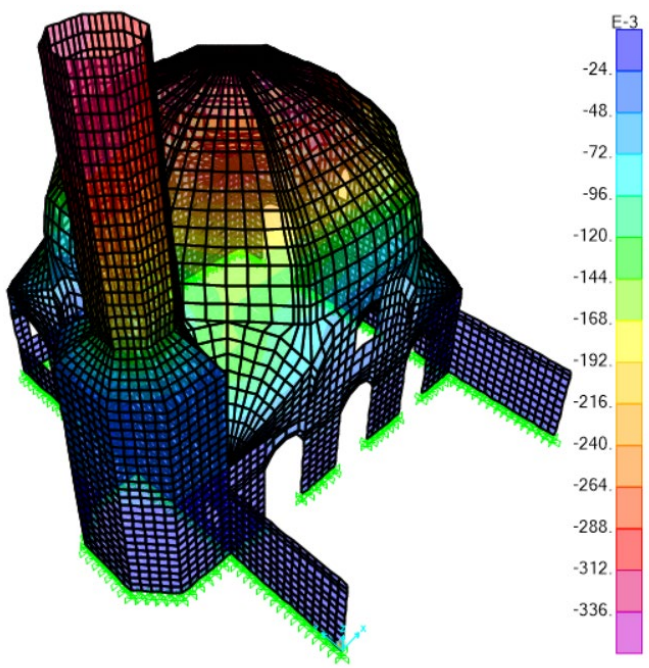


Figure 4.6. DZ (cm) displacement contours of self-weight analysis

Considering the tensile stresses under the self-weight of the structure, the stresses in the walls are in the wall-squinch joints. The maximum values of tensile stresses are seen at 0.02 kN/cm^2 (0.2 MPa) in the south-east corner. They are below 1.08 MPa, the maximum tensile stress value for stone masonry structures, and 0.43 MPa, the maximum tensile stress value for brick masonry structures (Figure 4.7)

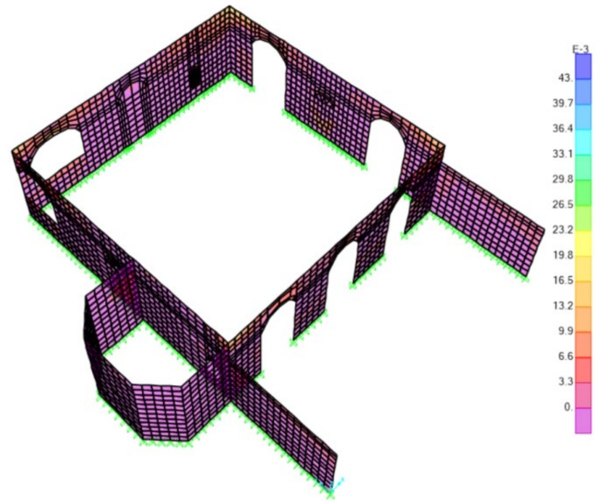


Figure 4.7. Tensile stress (absolute Smax) contours of self-weight analysis on walls (kN/cm^2)

The stresses in the arch, squinch, and pendentive line, which constitutes the transition zone, gradually increase towards the dome drum and the maximum stresses are concentrated on the drum line. The maximum average is 0.030 KN/cm^2 (0.30 MPa) along the drum line, but the highest stress value is 0.069 kN/cm^2 (0.69 MPa) above the south-east squinch. The arch and squinch sections are built of brick masonry and the pendentive sections are built of brick-stone masonry; the values found in the analysis were over the maximum tensile strength of brick masonry (0.43 MPa) (Figure 4.8). For the dome, tensile stresses are read in the lower sections; however, the maximum values of these stresses are 0.004 kN/cm^2 (0.04 MPa) (Figure 4.9).

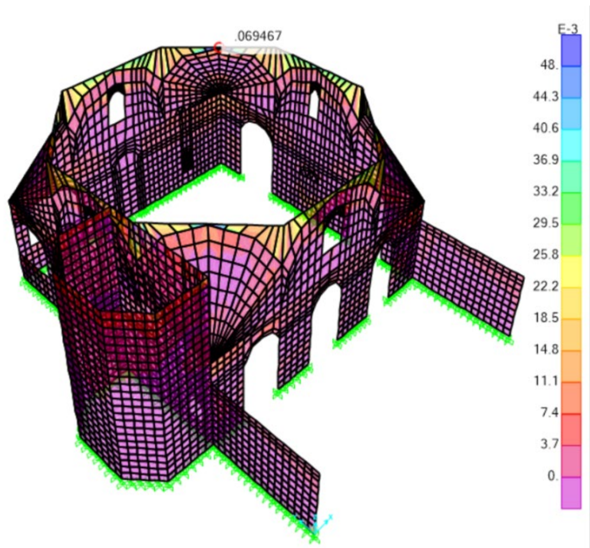


Figure 4.8. Tensile stress (absolute Smax) contours of self-weight analysis on transition zone (kN/cm^2)

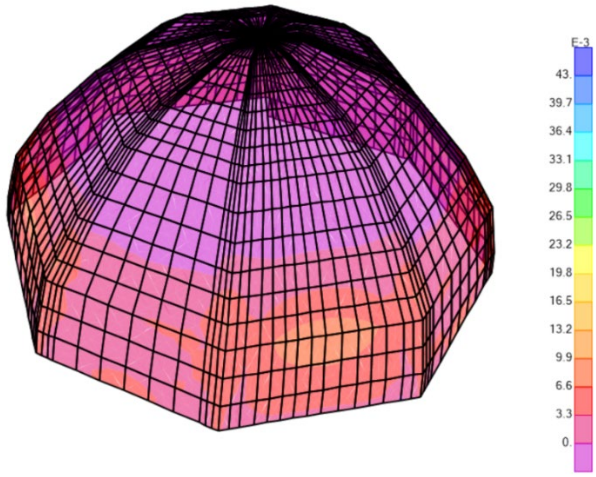


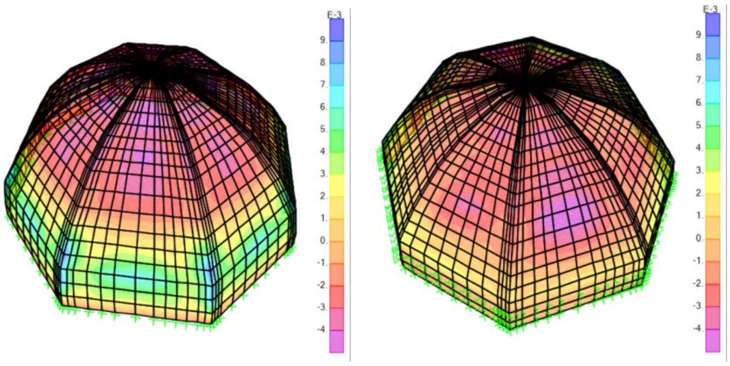
Figure 4.9. Tensile stress (absolute Smax) contours of self-weight analysis on dome (kN/cm^2)

The structure has a drum frame that has today lost its integrity and locally encircles the dome. The whole structural model does not include the drum frame. Rigidity calculation was made using Equation 4.1 to discuss how the frame element enclosing a solid dome drum affects the strength of the element. Among the entire structural model, only the dome geometry was used; the rigidity effect of the frame at 0.50 centimeters and 100 centimeters at approximately 1 meter high where the frame it is placed was applied to the dome by spring elements. The rigidity value which would be applied at all points and was generated by using Equation 1 was calculated using Equation 2.

$$y(x) = \int_0^H \frac{\propto V}{AG} dx \qquad \text{(Eq 4.1)}$$

$$k = \frac{AG}{\propto x} \qquad \text{(Eq 4.2)}$$

The frame cross section used in Equation 4.2. was (A) 40 centimeters x 30 centimeters (distance between each node), the shear modulus was (G) 110 MPa, and the $\propto$ value (maximum shear stress /mean shear stress) was 1.5. X (distance) varying throughout the height was found to be 50 centimeters and 100 centimeters. The rigidity values derived from the equation were applied to the dome. It was found that the low-level tensile stresses at the bottom of the dome approached zero and the dome was completely fulfilling the compression stress due to the rigidity effect of the drum in the dome in which tensile stresses are not above the boundary values even without the drum effect (Figure 4.10).



(a) (b)

Figure 4.10. Tensile stress (absolute Smax) contours of self-weight analysis on dome (kN/cm^2) a) without drum's frame effect, b) with drum's frame effect

Looking at the entire structure, it is evident that tensile stresses that pose a risk to the masonry structure caused by the effects of geometric forms and window openings on stress variations occurred in the transition to the dome and along the drum line. Therefore, these areas in the mosque should be observed more carefully under possible risks (Figure 4.11).

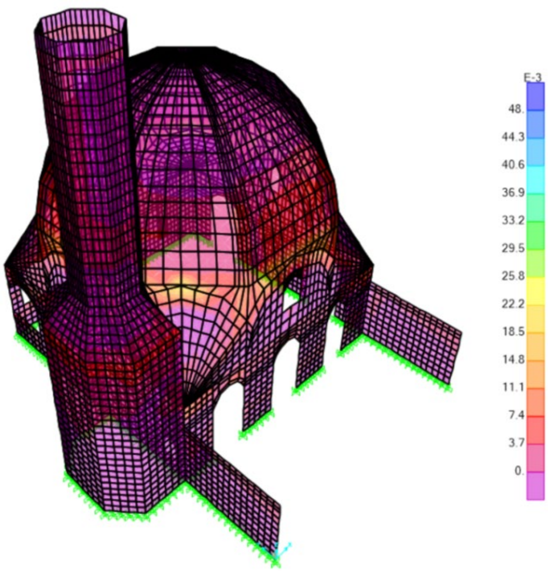


Figure 4.11. Tensile stress (absolute Smax) contours of self-weight analysis of the structure (kN/cm^2)

4.4. Modal Analysis

Modal analysis is the analysis of the vibration frequencies of a system in free vibration and mode shapes corresponding to these frequencies. This analysis was performed to understand the dynamic characteristics of the structure and to find vibrational periods and mode shapes to use in the analysis of the earthquake behavior of the structure at the next stages. Vibration frequencies and mode shapes are derived from the solution of the motion equation of the system in free vibration.

Twelve modes were taken into account in the modal analysis. The first two modes, as expected, are observed in directions x and y of the minaret (Figure 4.12, Figure 4.13). Considering the first three modes of the entire structure, the modes 4, 5, and 6 are seen in direction y, direction x, and as torsion, respectively (Figure 4.14, Figure 4.15, Figure 4.16). Due to the structural symmetry, the two main direction modes of the entire structure are very close to each other. The period, frequency, eigenvalue, and modal participating ratios of the twelve modes are given in Table 4.4.

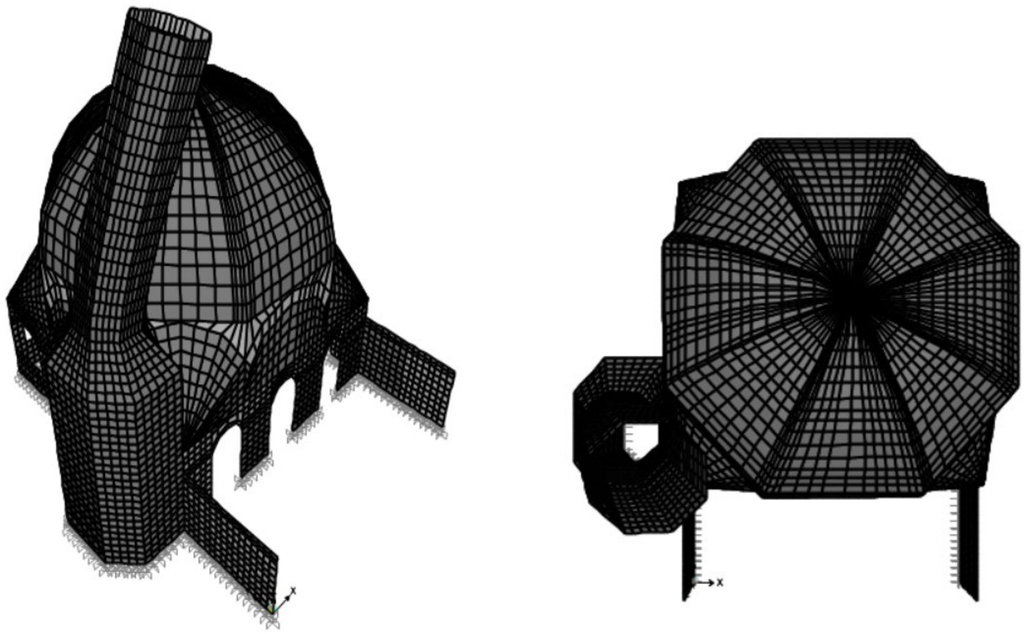


Figure 4.12. 1st mode shape of the structure (on minaret)

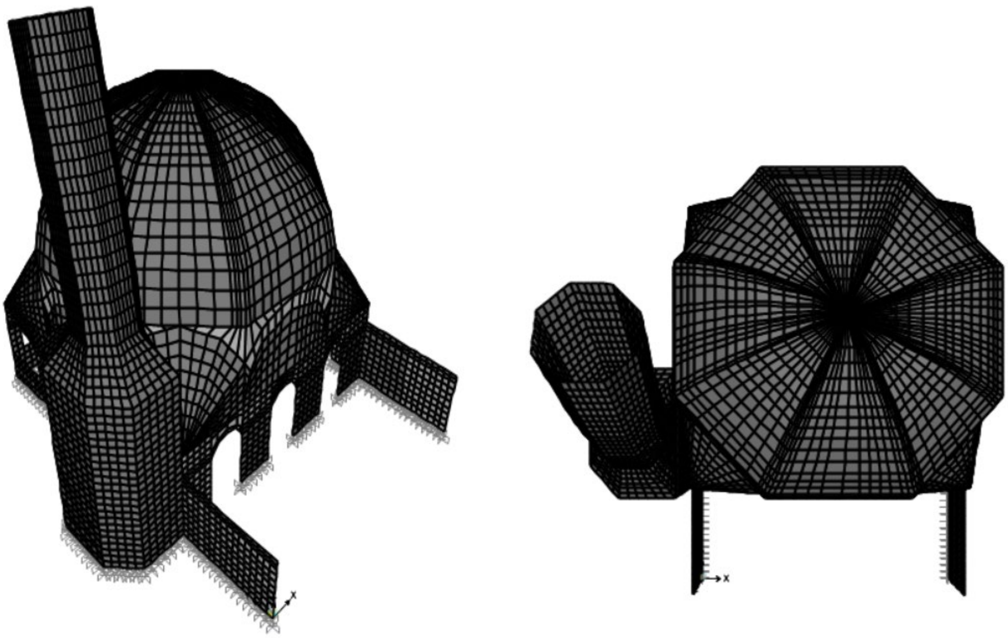


Figure 4.13. 2nd mode shape of the structure (on minaret)

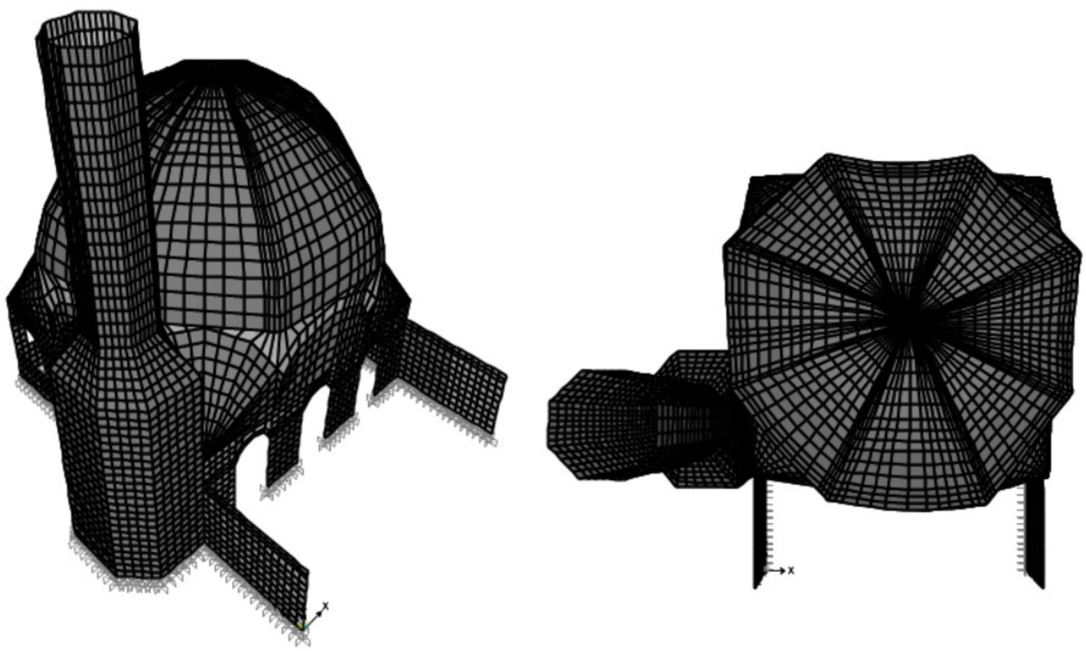


Figure 4.14. 3rd mode shape of the structure

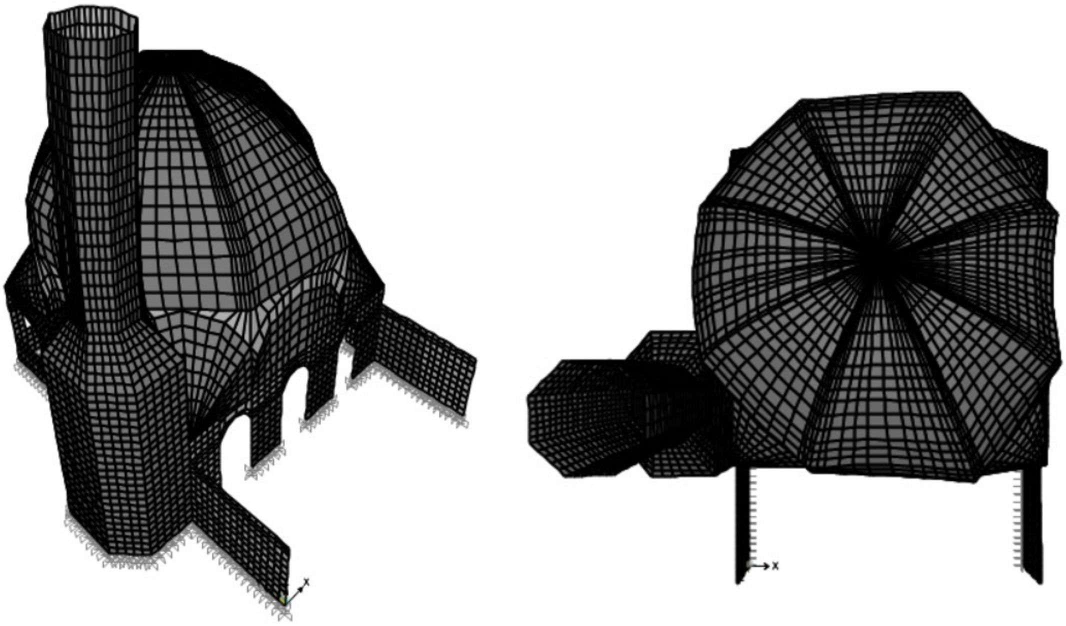


Figure 4.15. 4th mode shape of the structure

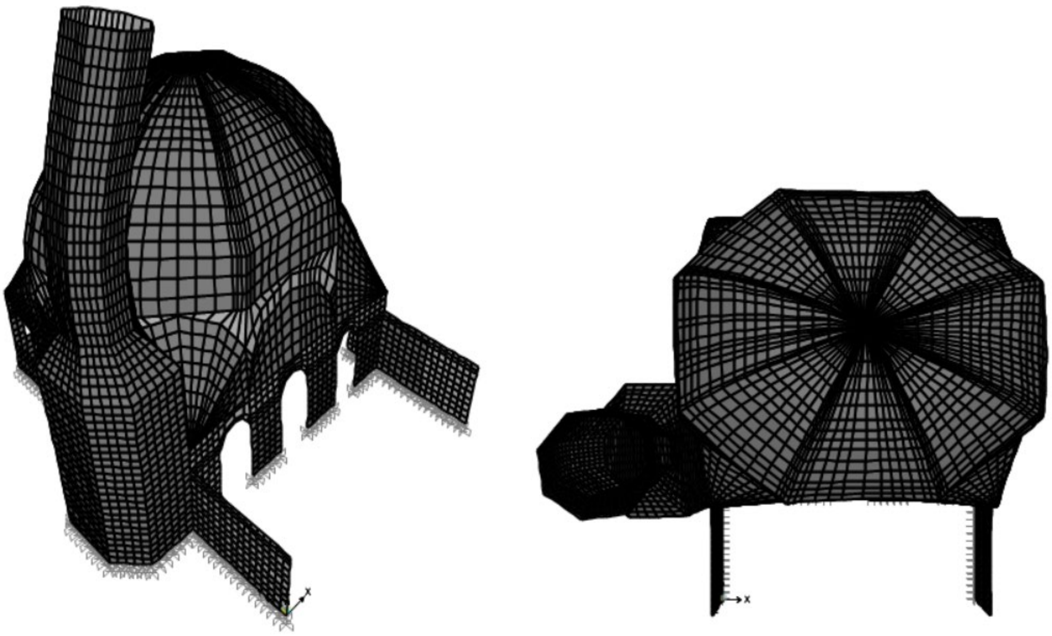


Figure 4.16. 5th mode shape of the structure

Table 4.4. Modal frequencies and mass participation factors.

Mode	Period	Frequency	Eigenvalue	Modal Participaiting Mass Ratios		
	Sec	Cyc/sec	rad2/sec2	**UX**	**UY**	**UZ**
1	0.529	1.889	140.898	0.040	0.004	3.50E-06
2	0.528	1.894	141.599	0.004	0.034	4.89E-08
3	0.194	5.157	1050.073	0.051	0.278	3.40E-05
4	0.189	5.275	1098.616	0.294	0.054	3.14E-05
5	0.142	7.032	1952.223	0.047	0.001	0.001
6	0.130	7.657	2315.1303	0.001	0.001	1.22E-05
7	0.126	7.949	2494.786	0.043	0.001	0.001
8	0.113	8.860	3099.063	0.002	0.013	0.008
9	0.112	8.892	3121.927	0.001	0.042	2.27E-06
10	0.110	9.013	3207.521	0.001	0.002	0.056
11	0.104	9.560	3608.050	0.001	0.002	0.011
12	0.101	9.940	3900.390	4.49E-05	0.001	0.001

4.5. Settlement Analysis

The most critical damage mechanism of the structure is observed in the southern wall and the squinches and dome section in this wall. The structural settlements described in Chapter 3.4 in which structural problems are defined are thought to be the main cause of the damage mechanism in this area. In the light of the documents obtained from Rahmi Hüseyin Ünal's personal archive, similar losses were observed in the southern wall of the building in 1985 and the squinch in this wall had a wide crack along the intersection line with no mass collapse (Figure 4.17, Figure 4.18). According to Ertuğrul (1995), the structure has four corner squinches. In light of this information, when the damage in the wall occurred is unknown; however, but it is clear that the damage grew towards the squinch during the period of nearly twenty years after 1995.

To understand whether or not the cause of the damage in the southern wall of the building was due to the settlement, the manually taken measurements of the building and the values read from the measured drawings were combined and the settlement scenario was constructed. For this scenario, the vertical displacements applied to the structure are shown in Figure 4.19.

Figure 4.17. South facade (dated on 1985)
(Source: Rahmi Hüseyin Unal’s personal archive)

Figure 4.18. East wall of Harim (dated on 1985)
(Source: Rahmi Hüseyin Unal’s personal archive)

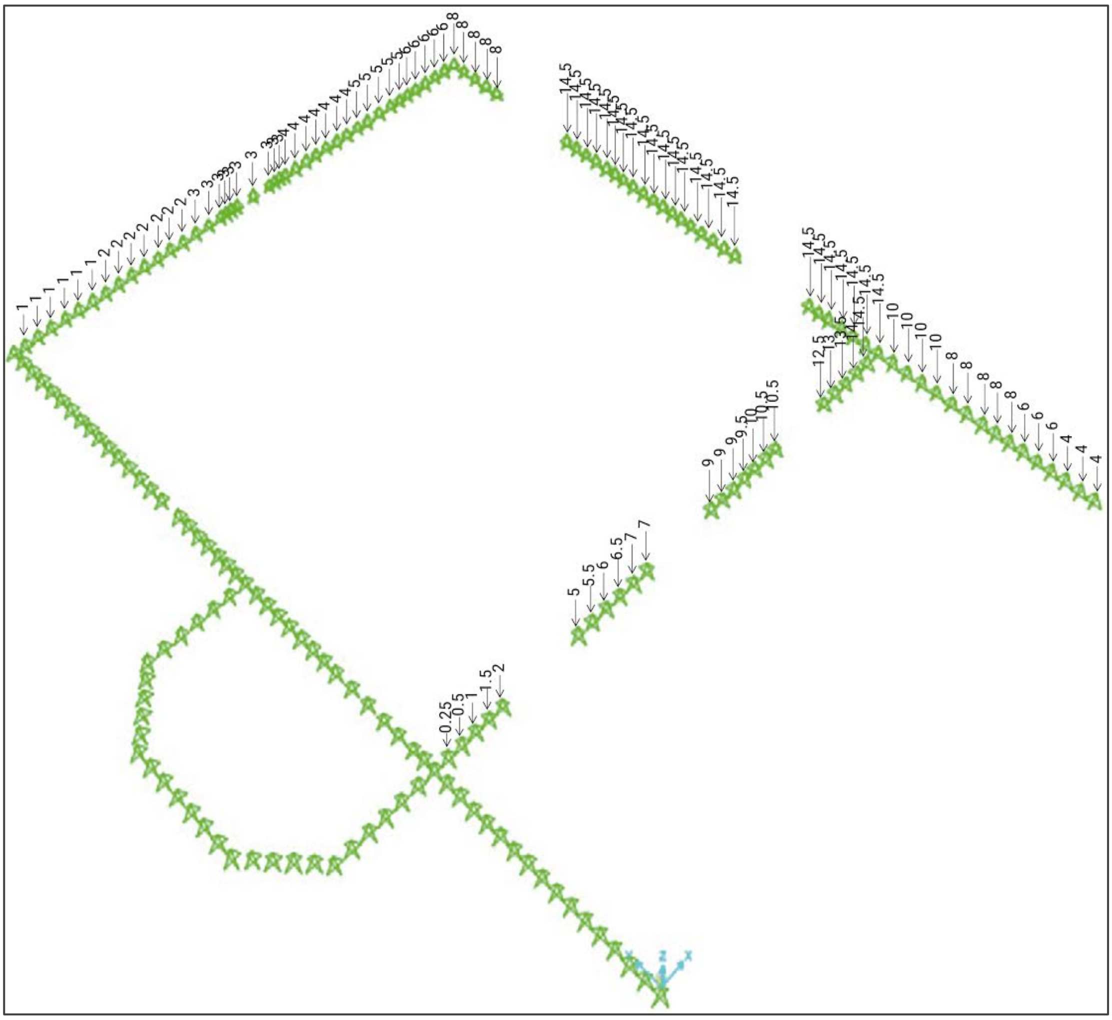


Figure 4.19. Displacement scenario for settlement analyses (cm)

According to the settlement analysis scenario with the vertical displacements, the stress conditions in the southern wall and the southeast squinch are shown in Figure 4.20 and Figure 4.21. The stresses in the walls are greater than the tensile stress boundary value 0.108 kN/cm^2. With respect to the southeast squinch, the stresses in the south half of the squinch range from 0.3 to 0.5 kN/cm^2 and are greater than the tensile stress boundary value 0.043 kN/cm^2.

This result supports the idea that a settlement caused by ground motion for years in accord with this scenario has led to the damage mechanism in the southern side of the building.

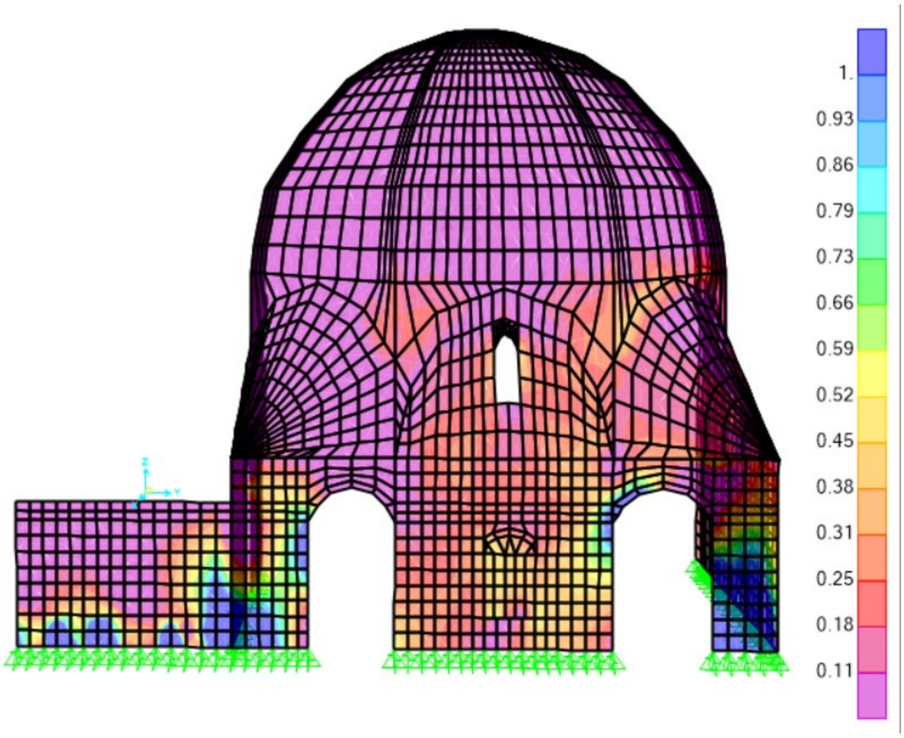


Figure 4.20. Tensile stress (absolute Smax) contours of settlement analysis on south facade of the structure (kN/cm^2)

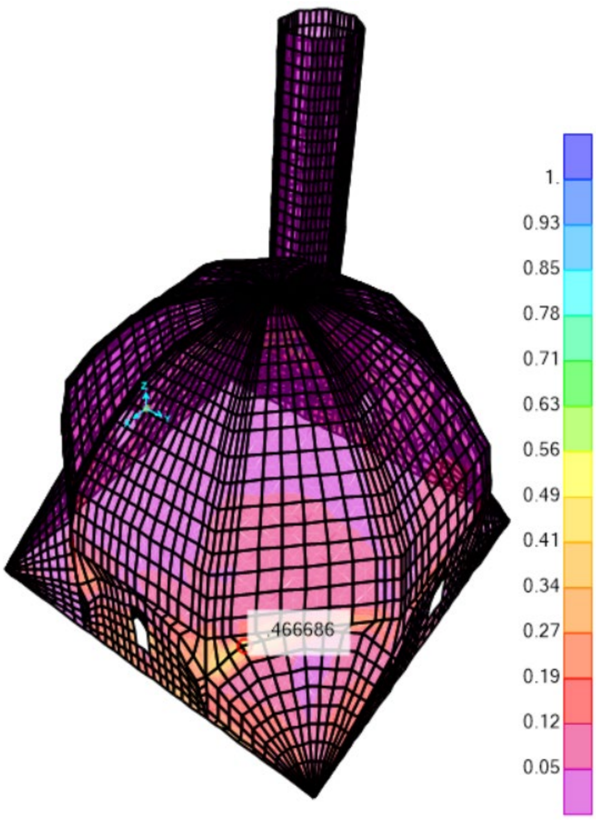


Figure 4.21. Tensile stress (absolute Smax) contours of settlement analysis on southeast squinch of the structure (kN/cm^2)

4.6. Seismicity of Helvacılar Mosque

Earthquake hazard assessments consist of two basic data groups: properties of faults that produce earthquakes and seismological properties of earthquakes caused by these faults. The first includes structural properties used to define the conditions of active faults, geographical distribution, fault activities, basic geological or geomorphological information. The second data group is a summary of earthquakes that occurred in these faults. The earthquakes that occurred before 1900 are called historical, while those that occurred later are called instrumental period earthquakes (MTA, 2005).

According to a report issued by the General Directorate of Mineral Research and Exploration (MTA, 2005), there are thirteen faults that may produce earthquakes in Izmir and its immediate vicinity (Table 4.5). These faults are divided into three categories: active faults, probable active faults, and lineaments. The activity of eight of these faults is certain. The active faults are Izmir, Tuzla, Gülbahçe, Seferihisar, Manisa, Kemalpaşa, Dağkızılca, and Gediz Graben. Faults mapped in the category of active faults may cause surface ruptures in the region and has the highest potential for producing destructive earthquakes.

As can be seen from Figure 4.22, the spot where the Helvacılar mosque is located is among the faults of Gülbahçe and Seferihisar.

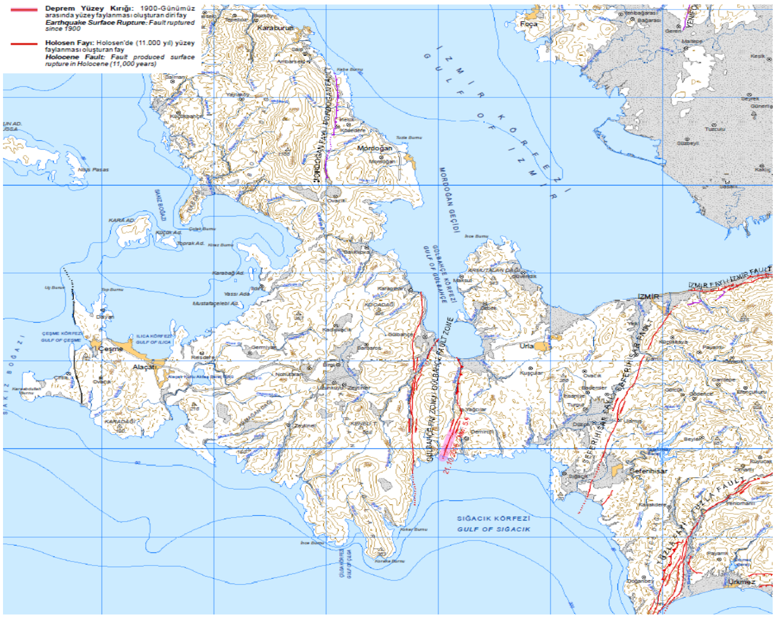


Figure 4.22. Holocene Faults around Helvacılar Mosque
(Source: http://www.mta.gov.tr)

Table 4.5. Active faults of İzmir
(Source: MTA,2005)

No	Fault Name	Activation Type	Total Length (km)	General Direction	Plane Slope and Direction	Seismicity	
						Historical	Instrumental
1	İzmir Fault	DF	35	E-W	60°N	1688	1977 (M:5.5)
2	Tuzla Fault	DF	50	N30E	E	?	1992 (M:6.0)
3	Seferihisar Fault	DF	30	N20E	E	?	2003 (M:5.6)
4	Gülbahçe Fault	DF	70	N-S	E	?	1953 (M:5.0) 1979 (M:5.7) 1994 (M:5.0)
5	Gediz Grabeni Fault (West Side)	DF	27	N70E	18°N	?	-
6	Kemalpaşa Fault	DF	24	N75E	50°N	?	-
7	Manisa Fault	DF	40	N65W	55°N	?	1994 (M:5.2)
8	Dağkızılca Fault	DF	27	N70E	E	?	1928 (M:6.5)
9	Güzelhisar Fault	ODF	25	N70W	E	?	-
10	Menemen Fault	ODF	17	N45W	E	?	-
11	Yenifoça Fault	Ç	20	N-S	-	?	-
12	Gümüldür Fault	ODF	15	N55W	50°W	?	-
13	Bornova Fault	Ç	19	N75W	E	?	-
DF: Active Fault, ODF: Probable Active Fault, Ç: Lineament							

Following the identification of the active faults of the region, defining the historical and instrumental earthquakes that have occurred in Izmir since the construction of Helvacılar Mosque is of importance in exploring the seismicity of the region where the structure is located and understanding the priority of the earthquakes that the structure has undergone. Historical earthquakes are listed in Table 4.6 and instrumental earthquakes are listed in table 4.7.

Table 4.6. Historical earthquakes (between 1600- 1900) occurred in İzmir (Source: MTA,2005)

Date	Latitude (K) Longitude (D)	Intensity (I_0)	Magnitude (M)	Description
May 20, 1654	38.50 27.10	VIII	6.4	The earthquake caused the collapse of many towers, mosques, and houses and a lot of fatalities in Izmir. Many residents left their homes and camped in the open and many European merchants took fugitives on their vessels. The area suffered a series of aftershocks every day until June 25.
June 2, 1664	38.41 27.20	VII	5.8	An earthquake that caused general panic and destroyed a number of houses.
1668	38.41 27.20	IX		The earthquake caused damage in Izmir and fires broke out. Cracks appeared on the earth. It is said that 2,000 people died.
February 14, 1680	38.40 27.20	VII	6.2	Three towns 10 miles away from Izmir were devastated. A mountain one and half hours distant from Izmir fell down onto the village of Carbon (landslide).
July 10, 1688	38.40 26.90	X	6.8	There was great destruction in Izmir. There were slips on the coast. As a result, a 30-meter wide channel opened up. It is said that 15,000 to 30,000 people died. The earthquake hit a large area and triggered a tsunami.
January 13, 1690	38.60 27.40	VII	6.4	This earthquake caused damage in Izmir and its vicinity. It caused damage along the coast; however, its impact was more severe inland.
September 1723	38.40 27.00	VIII	6.4	According to a guest visiting Izmir, the tremor two months after the earthquake destroyed 60 houses and killed people.

(Continued on next page)

Table 4.6. Continued

April 4, 1739	38.50 26.90	IX	6.8	There was great damage in In Eski Foça and Yenifoça (Phocaea). According to other reports, the damage in Izmir largely occurred in the "European Side" bordering on the sea. The number of deaths in Izmir was less than 80. The earthquake completely destroyed three-quarters of Eski Foça and the earth cracked, and bitumen spouted out of it. The part of the Delta at the mouth of the Gediz (Agria) River collapsed in the earthquake and was flooded after the earthquake. On Chios Island, many houses were destroyed, and several people died.
November 24, 1772	38.80 26.70	VIII	6.4	The earthquake and waves caused by the earthquake completely destroyed the five gates of the Foça castle and the mosque of Foça. A few houses collapsed in Lesbos (Midilli). The earthquake was felt on Chios Island; however, there was no damage.
July 3-5, 1778	38.40 26.80	IX	6.4	It took 15 seconds and ruined Izmir almost completely. In some places, the earth opened up. Two captains reported that in Urla, 18 miles away from Izmir, the earth was cracked off and opened up. Ground fissures were reported for an unnamed mountain near Ephesus. The damage spread across Seydiköy and westwards. There were more than 200 deaths in total in these earthquakes. It was the greatest after the foreshock that caused damage in Izmir on June 16. The aftershocks lasted for months, causing additional damage. Most of the aftershocks were felt more severely in the southwest of Izmir.
October 13, 1850	38.40 27.20	VIII		It was felt quite strongly in western Anatolia, Izmir, Manisa, Turgutlu, Bayındır, Ödemiş, and Tire. Cracks opened up in Kemalpaşa. Various damages occurred in the region.

(Continued on next page)

Table 4.6. Continued

November 3, 1862	38.50 27.90	X	6.9	The earthquake devastated all houses in Turgutlu and killed 280 people. There was less damage in the other six towns nearby. It was felt in Afyon Karahisar, Isparta, and in area 300 kilometers distant. Cracks appeared in houses in the aftershock that hit Afyon Karahisar on November 13. It was felt in Izmir, Aydın, Nazilli, and Denizli and on Chios Island.
February 1, 1873	37.75 27.00	IX		It was felt on Samos Island and in Izmir and Aydın.
July 29, 1880	38.60 27.10	IX	6.7	It did extensive damage in Izmir and Gediz depressions, Menemen, Bornova, and Karşıyaka. The Izmir-Turgutlu railway was broken up by cracks. The epicenter of the earthquake was around Menemen.
October 15, 1883	38.30 26.20	IX	6.8	It did widespread damage in all the villages located on the western part of Çeşme Peninsula. It did minor damage in Izmir. It is said that 15,000 people died.
November 1, 1883	38.30 26.30	VIII		A severe earthquake hit Izmir Bay and Çeşme Peninsula. Cracks opened up in the earth.

Table 4.7. Instrumental earthquakes (after 1900) occurred in İzmir (Source: MTA,2005, Türkelli et. al,1990, http://www.koeri.boun.edu.tr)

Date	**Latitude (K) Longitude (D)**	**Depth (km)**	**Magnitude (M)**	**Intensity (I_0)**	**Description**
Foça Earthquake on January 19, 1909	38.00 26.50	60	6.0	IX	The epicenter of the earthquake was amid Güzelhisar, Menemen, and Foça. 700 houses were demolished, 1000 houses were damaged, and eight people died.

(Continued on next page)

Table 4.7. Continued

Torbalı Earthquake on March 31, 1928	38.18 27.80	10	6.5	VIII	The epicenter of the earthquake was the intersection of Küçük Menderes and Izmir NS depressions in Torbalı. 2000 houses collapsed in the earthquake. It did enormous damage in the Torbalı-Tepeköy region and slight damage in Izmir, Manisa, Alaşehir, Uşak, Bayındır, Tire, and Ödemiş.
Dikili Earthquake on September 22, 1939	39.07 26.94	10	6.6	VIII IX	The epicenter of the earthquake was close to Dikili and between Dikili and Lesbos. 1,000 houses were demolished, 41 people died, 68 people were injured. Thermal springs were produced by the earthquake. Cracks opened up between Dikili and Bergama (Pergamon). The earthquake was felt in all western Anatolia.
Karaburun Earthquake July 23, 1949	38.57 26.29	10	6.6	VIII VII X	It did severe damage in the east of Karaburun-Çeşme Peninsula, between Mordoğan and the northern cape of the peninsula, the part sticking out into the sea around, Çeşme Peninsula. The waters of Çeşme hot spring increased and some rivers were cut. It did damage on Chios Island. Extremely violent movements were observed in the sea. Seven people died, 2,200 homes were demolished.

(Continued on next page)

Table 4.7. Continued

Karaburun Earthquake on May 2, 1953	38.48 26.57	40	5.0	VII VIII	The epicenter of the earthquake was the north of Karaburun Peninsula. It was strongly felt in Dikili, Urla, Menemen, Çeşme, Bergama, and Foça. It did damage in poor grounds. Approximately 300 houses were damaged.
Söke-Balat Earthquake on July 16, 1955	37.65 27.26	40	6.8	VIII	The epicenter was in the Aegean Sea. The earthquake was felt on the Aegean Islands, and in Izmir and its districts and Kuşadası and nearby settlements. The walls of many buildings cracked in Izmir and minarets of some mosques were damaged. During the earthquake, a big rumble was heard, and flooding occurred in the Gediz and Büyük Menderes rivers. During the earthquake, 300 houses collapsed, and two people died.
Menemen Earthquake on June 19, 1966	38.55 27.35	9	4.8	VI	It was strongly felt in Izmir and its surroundings. The walls of approximately 100 houses in Menemen cracked in this earthquake.
Karaburun Earthquake on April 6, 1969	38.47 26.41	16	5.9	VIII VII	The epicenter was off the coast of Karaburun. The earthquake caused damage in 443 buildings on Chios and Çeşme islands.

(Continued on next page)

Table 4.7. Continued

Izmir Earthquake on February 1, 1974	38.55 27.22	24	5.3	VII	The epicenter of the earthquake was 15 km distant from Izmir. The earthquake caused damage in many buildings. In Izmir, two people died, seven people injured, and 47 houses were severely damaged. Several damages occurred in the city center, some parts of Karşıyaka and Alsancak.
Izmir Earthquake on December 16, 1977	38.41 27.19	24	5.5	VIII	In Izmir, some houses were destroyed by this earthquake and 20 people were injured. Especially in Buca, Alsancak, Hatay, Karşıyaka, Bornova, Gültepe and Tepecik districts, some houses were damaged, walls collapsed, and cracks appeared.
Karaburun Earthquake on June 14, 1979	38.79 26.57	15	5.7	VII	The epicenter was in the Aegean Sea. In this earthquake strongly felt in Izmir and its surroundings, deep cracks opened up in the walls of some houses in the district of Alsancak. Two houses collapsed in Karaburun and one person was injured.
Doğanbey Earthquake on November 6, 1992	38.16 26.99	17	5.7	VII	The center of the earthquake was around Doğanbey. The earthquake caused serious damage in approximately 60 buildings. The earthquake was strongly felt in Izmir.

(Continued on next page)

Table 4.7. Continued

Manisa Earthquake on January 28, 1994	38.69 27.49	5	5.2	VII	60 buildings were damaged in Manisa and nearby.
Karaburun Earthquake on May 24, 1994	38.66 26.54	17	5.0	VII	10 buildings were damaged in Karaburun and nearby.
Urla Earthquake on April 10, 2003	38.26 26.83	16	5.6	VII	The epicenter of the earthquake was between Urla and Seferihisar. Cracks opened up in the walls of some houses in Urla and Seferihisar. The earthquake was severely felt in Izmir.
Seferihisar Earthquakes on October 17-21, 2005	38.14 26.60, 38.20 26.66, 38.19 26.67	16 20 10	5.7 5.9 5.9	VII	The earthquake with a magnitude of MI = 5.7 that started at 08:45 on October 17 was followed by an earthquake with a magnitude of MI = 5.9 at 12:46 on the same day and hundreds of light and very mild earthquakes occurred within this time period. The earthquakes were felt in the districts of Izmir, Manisa, Aydın, Balıkesir, and Aegean islands. Another earthquake with a magnitude of MI = 5.9 occurred at 00:40 on October 21. A total of 3500 earthquakes were recorded in the region until October 31.

In addition to the magnitude of the earthquakes, isoseismal maps are drawn to describe earthquake intensities in the impact areas of fault lines. Figure 4.23 and 4.24 show the isoseismal maps of two earthquakes in which Urla is within the impact area.

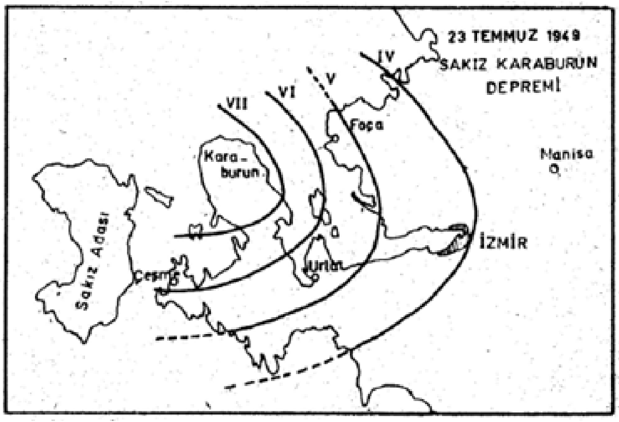


Figure 4.23. Isoseismal map of Chios Island-Karaburun earthquake (23 July 1949) (Source: Erkman,1949)

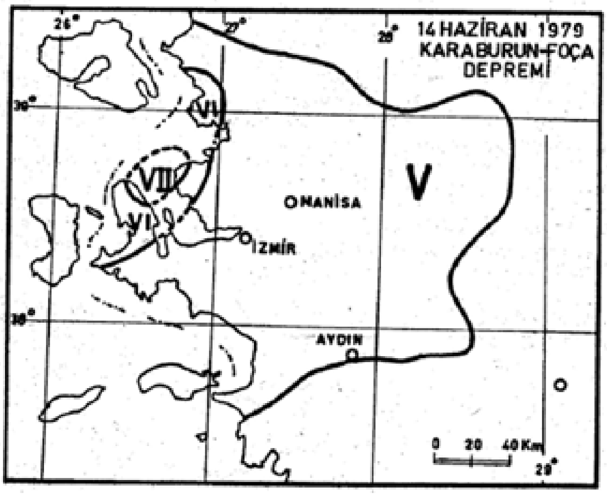


Figure 4.24. Isoseismal map of Karaburun- Foça earthquake (14 June 1979) (Source: Eyidoğan, et al.,1991)

From 1900 to 2013, 10,090 earthquakes occurred in Turkey with a magnitude greater than 4 (retrieved 25 April 2019 from http://www.koeri.boun.edu.tr/sismo/2/deprem-verileri/depremsellik-haritalari/turkiye4/). Among these earthquakes, those hit Izmir and its surroundings are given in Figure 4.25. According to the seismicity of Urla, over the last century, earthquakes of magnitude greater than 4 have frequently occurred and the regional faults have led to earthquakes of magnitude greater than 6.

The maximum magnitude of earthquakes that may occur on active faults is closely associated with the nature and length of the fault. Recurrence intervals of earthquakes on the same fault may vary according to the nature of the fault. Earthquakes on normal faults in the western Anatolia grabens region are known to recur at shorter intervals compared to strike-slip faults in the country. Tuzla fault and Gülbahçe faults in the Izmir region are defined as earthquake source zones which may cause earthquakes magnitudes greater than 6.8 (MTA,2005).

To sum up, considering the intensity of the nearby active faults and the frequency of past earthquakes, anti-earthquake safety should be of priority importance in reflecting on interventions related to the structural safety of Helvacılar Mosque.

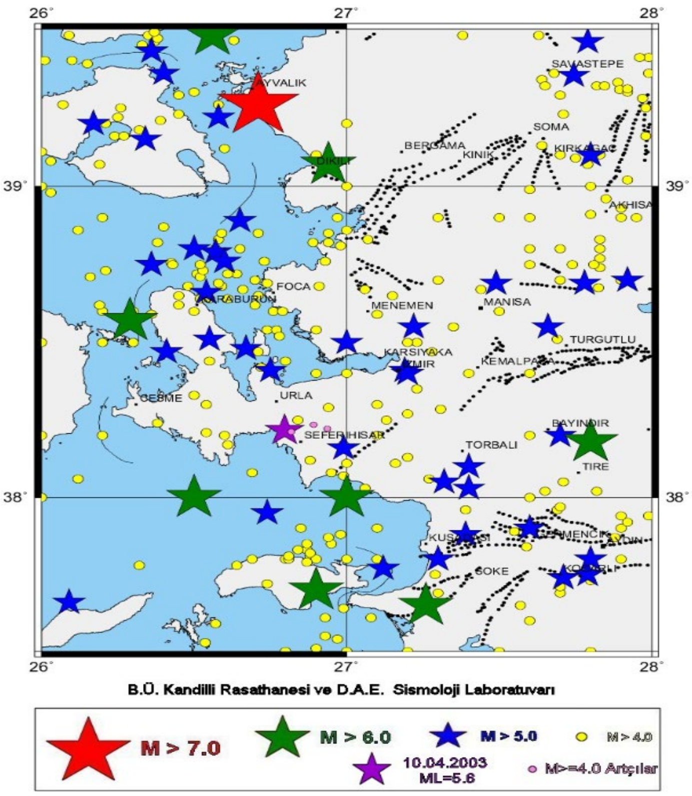


Figure 4.25. Strong earthquakes occurred in İzmir and its vicinity in 20th century (1900-2003) (Source: http://www.koeri.boun.edu.tr)

4.7. Soil Investigation and Site-Specific Coordinate Data

To understand the ground conditions of the plot on which Helvacılar Mosque is situated, the municipality of Urla was visited to obtain the soil survey of plot no. 268, which is about 200 meters distant from the building (Figure 4.26). The soil survey data of plot 268 revealed that the survey area is composed of vegetative topsoil between 0.0 and 0.50 meters and of clay and claystone between 0.50 and 3.00 meters, and there is no risk of liquefaction in the area (İlerler et al., 2015). Table 4.8 presents the static parameters prepared for the -1.00-meter level, where the foundation is thought to settle.

Figure 4.26. Location of 268 parcel

Table 4.8. Soil parameters of parcel 268 (TEC,2007)
(Source: İlerler et. al.,2015)

Bearing Capacity of Soil	1.5 kg/cm^3
Soil Group	C
Local Soil Class	Z3
Bed Coefficient	2700 t/m^3

The Seismic Hazard Map of Turkey was prepared in accordance with the current "Turkey Building Earthquake Regulation", taking into consideration the most recent seismic source parameters, seismic catalogs, and next-generation mathematical models. This new map, unlike the previous map, shows the peak ground acceleration values instead of earthquake regions, thereby abandoning the concept of "earthquake zone" (Figure 4.27).

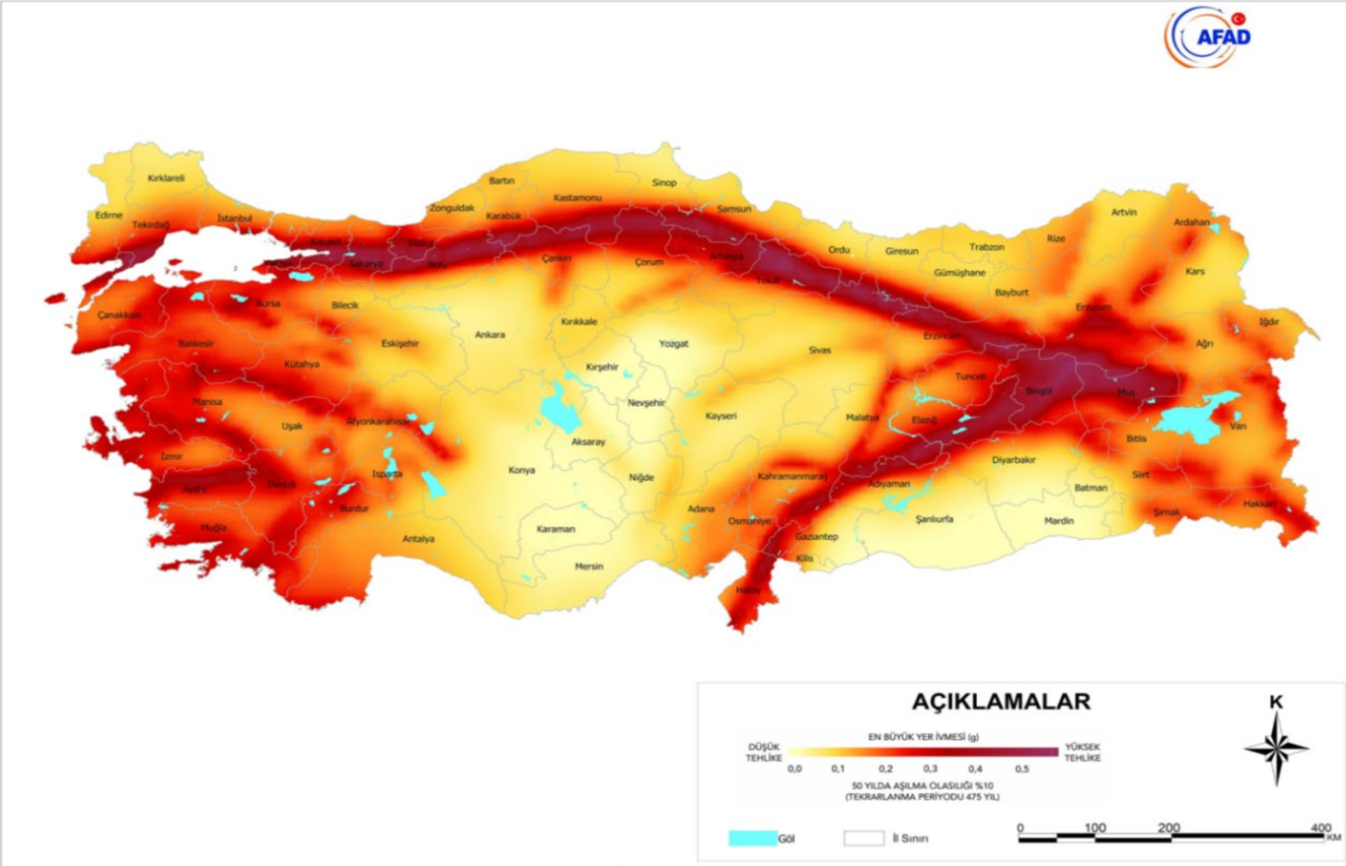


Figure 4.27. Earthquake hazard map of Turkey (DD-2)
(Source: https://deprem.afad.gov.tr)

The seismic hazard maps prepared by the Disaster and Emergency Management Authority (AFAD) are prepared for four different levels of seismic ground movements (Table 4.9).

Table 4.9. Earthquake ground motion levels (TBDY,2018)

	Information of Ground Motion Level	**Frequency**
DD-1	50 years probability of exceeding %2, repeat period 2475 years	Very rare
DD-2	50 years probability of exceeding %10, repeat period 475 years	Rare
DD-3	50 years probability of exceeding %50, repeat period 72 years	Often
DD-4	50 years probability of exceeding %68, repeat period 43 years	Service

According to the Turkey Building Earthquake Regulation (TBDY, 2018), the spectra of earthquake ground movements are defined with a 5% damping ratio in line with the coordinate-based spectral acceleration coefficients and local ground effect coefficients. To create the design spectrum defined in the regulation, non-dimensional map spectral acceleration coefficients are defined for four different levels of ground movements in line with the seismic hazard maps of Turkey:

(a) Short-term map spectral acceleration coefficient S_S

(b) Map spectral acceleration coefficient for a 1.0-second period S_1

The map spectral acceleration coefficients defined, S_S and S_1, are converted to the design spectral acceleration coefficients, S_{DS} and S_{D1}, as shown in Equation 4.3 and Equation 4.4.

$$S_{DS} = S_S \times F_s \qquad \text{Eq.4.3}$$

$$S_{D1} = S_1 \times F_1 \qquad \text{Eq.4.4}$$

F_s and F_1 show local effect classes and their values are selected from Table 4.10 and Table 4.11. (In tables, linear interpolation can be performed for interpolated values of map spectral acceleration coefficients.)

Table 4.10. Local soil impact coefficients for the short period, Fs (TBDY,2018)

Local Soil Class	$S_s \leq 0,25$	S_s=0.5	S_s=0.75	S_s=1	S_s=1.25	$S_s \geq 1,5$
ZA	0.8	0.8	0.8	0.8	0.8	0.8
ZB	0.9	0.9	0.9	0.9	0.9	0.9
ZC	1.3	1.3	1.2	1.2	1.2	1.2
ZD	1.6	1.4	1.2	1.1	1	1
ZE	2.4	1.7	1.3	1.1	0.9	0.8
ZF	Site's specific soil behavior analyses should be done					

Table 4.11. Local soil impact coefficients for 1.0 second period, F1 (TBDY,2018)

Local Soil Class	$S_1 \leq 0,1$	S_1=0.2	S_1=0.3	S_1=0.4	S_1=0.5	$S_1 \geq 0,6$
ZA	0.8	0.8	0.8	0.8	0.8	0.8
ZB	0.8	0.8	0.8	0.8	0.8	0.8
ZC	1.5	1.5	1.5	1.5	1.5	1.4
ZD	2.4	2.2	2	1.9	1.8	1.7
ZE	4.2	3.3	2.8	2.4	2.2	2
ZF	Site's specific soil behavior analyses should be done					

*The horizontal elastic design spectral accelerations S*ae (*T*), which are the ordinates of *the horizontal elastic design acceleration spectrum* for any given seismic movement level, were defined in gravitational acceleration [g] based on the natural vibration period by means of Equation 4.5, as specified in Article 2.3.4.1 of the regulation (Figure 4.28).

$$
\begin{aligned}
S_{ae}(T) &= \left(0.4 + 0.6\frac{T}{T_A}\right) S_{DS} && (0 \leq T \leq T_A) \\
S_{ae}(T) &= S_{DS} && (T_A \leq T \leq T_B) \\
S_{ae}(T) &= \frac{S_{D1}}{T} && (T_B \leq T \leq T_L) \\
S_{ae}(T) &= \frac{S_{D1} T_L}{T^2} && (T_L \leq T)
\end{aligned}
$$

Eq.4.5

Here, S_{DS} and S_{D1} represent *design spectral acceleration coefficients* and *T* represents the natural vibration period. The horizontal design spectrum *characteristic periods* T_A and T_B are defined based on S_{DS} and S_{D1} using Equation 4.6:

$$
T_A = 0.2\frac{S_{D1}}{S_{DS}} \quad ; \quad T_B = \frac{S_{D1}}{S_{DS}}
$$

Eq.4.6

The transition period to the fixed displacement zone T_L = 6 s will be taken.

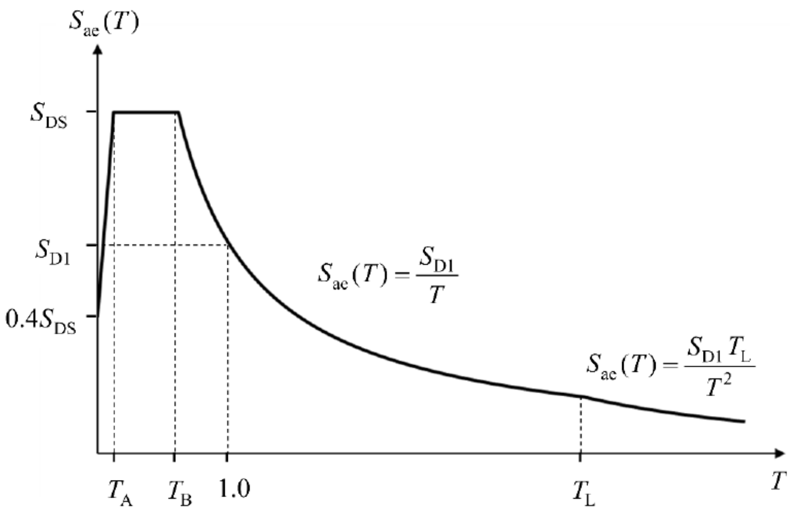


Figure 4.28. Horizontal elastic design spectrum
(Source: TBDY,2018)

According to the DD-2 earthquake, S_S = 1.113 and S_1 = 0.265 values were obtained from the web application of seismic hazard maps for the ZD local ground class for the coordinates of Helvacılar Mosque. Table 4.12 shows the inputs required for the horizontal elastic spectrum of Helvacılar Mosque. The horizontal elastic spectrum of Helvacılar Mosque was formed using these values, as seen in Figure 4.29. This spectrum will be used to spectrum analyses and selecting/scaling earthquake records for use in time history analyses.

Table 4.12. Horizantal spectrum data for Helvacılar Mosque

T:	1.19
S_s:	1.113
S_1:	0.265
Local Soil	ZD
F_s:	1.0548
F_1:	2.07
S_{DS}:	1.173992
S_{D1}:	0.54855
T_A:	0.09345
T_B:	0.467252
T_L:	6
S_{ae}(T):	0.46487

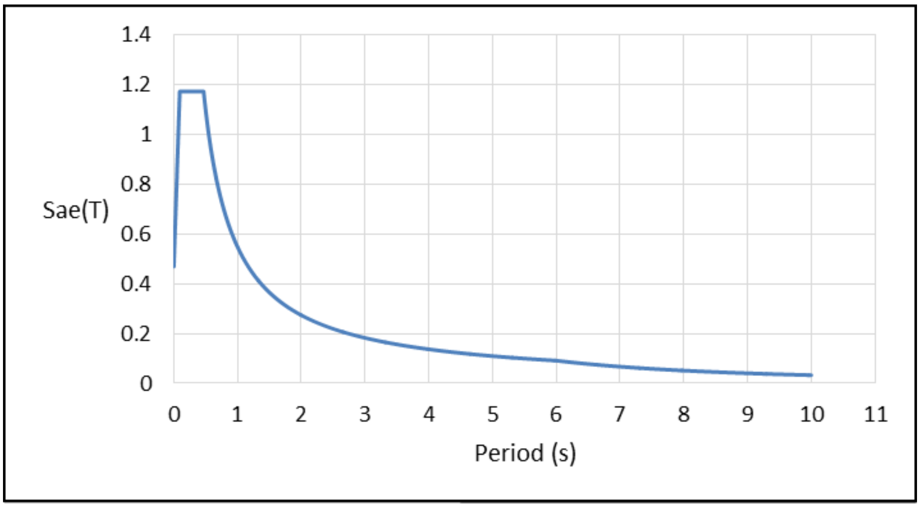
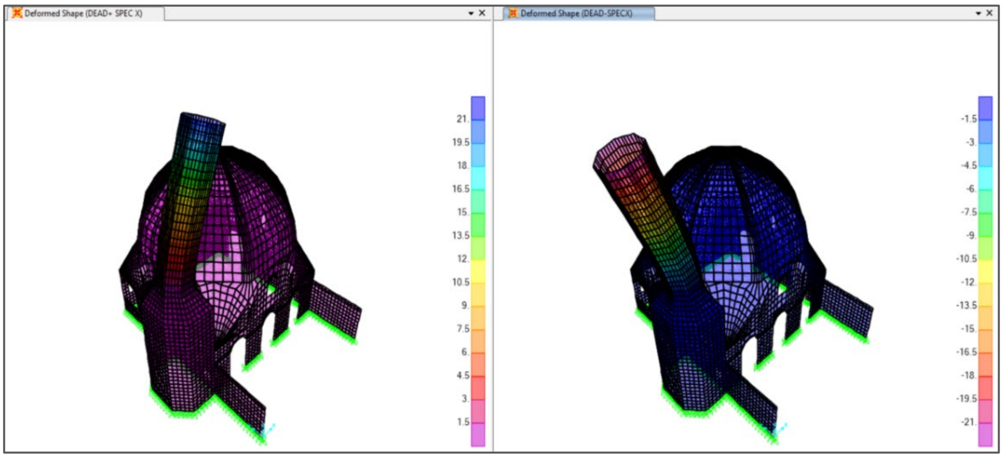


Figure 4.29. Horizontal elastic design spectrum of Helvacılar Mosque

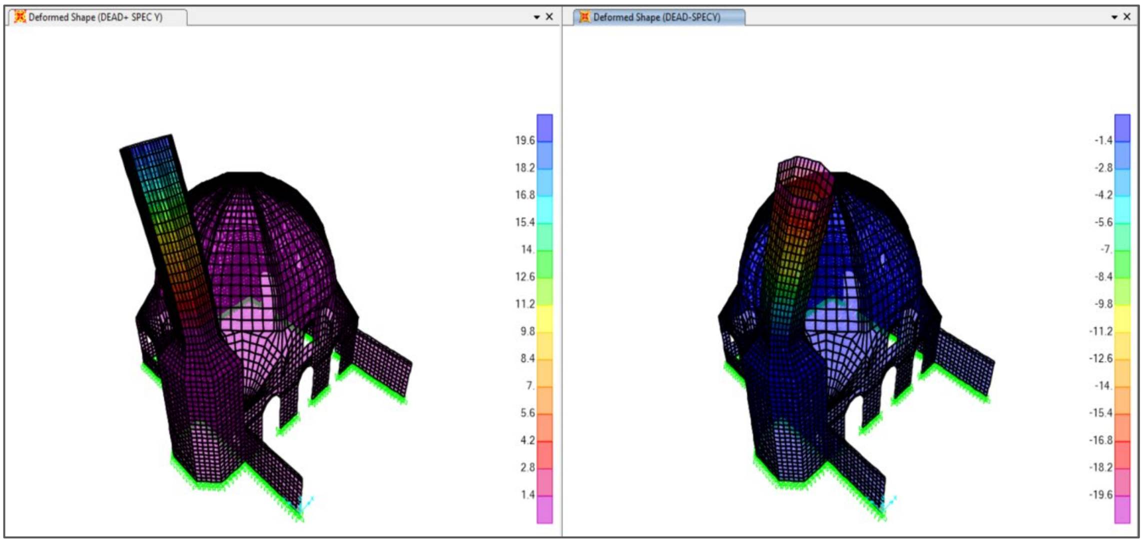
4.8. Response Spectrum Analysis

To understand the seismic behavior of Helvacılar Mosque, response spectrum analyses were carried out in both x- and y-direction with the spectrum obtained from the coordinates where the region is located. The analyses investigated parts of the structure in which displacements and in-plane and out-of-plane shear stress occurred. The mass participating ratio of the analysis is 90%. The results of the analysis showed that the displacements observed in the structure are 21 centimeters in the x-direction and 19.6 centimeters in the y-direction in the minaret. The displacement in the main mass does not exceed 1.5 centimeters in the x-direction and y-direction (Figure 4.30, Figure 4.31).



(a) (b)

Figure 4.30. Deformation results of response spectrum analyses, a) dead load+ response spectrum x, b) dead load- response spectrum x



(a) (b)

Figure 4.31. Deformation results of response spectrum analyses, a) dead load+ response spectrum y, b) dead load- response spectrum y

The shear stress changes in the structure are evaluated in two modes: in-plane and out-of-plane stresses.

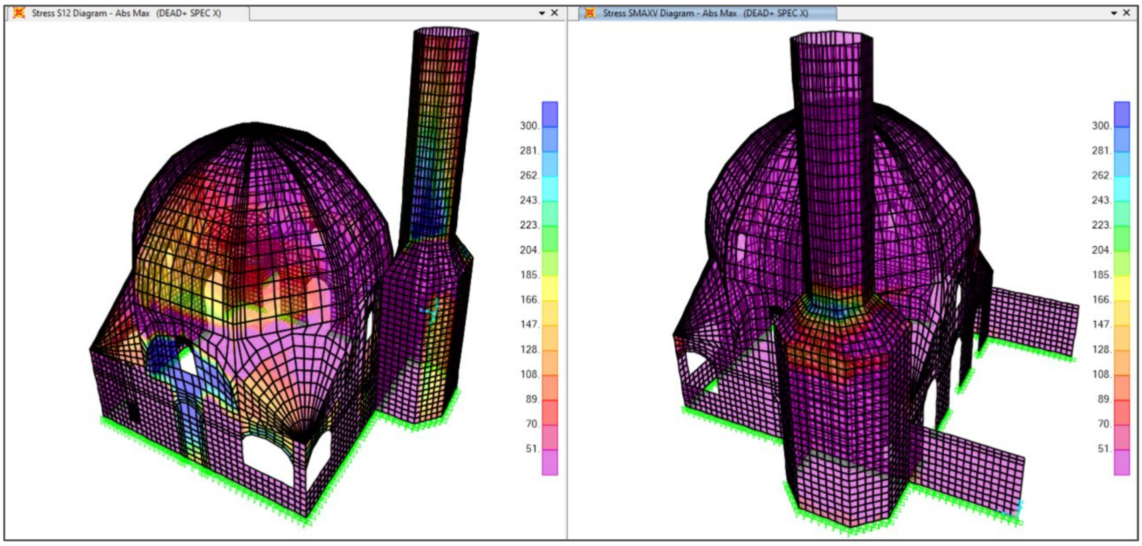
The maximum shear stress for the dead load + spectrum x load combination is observed in the connection of the minaret body and pabuc as (S12) 2120 kPa (kN/m^2) in the in-plane stresses and as (SVmax) 387.7 kPa (kN/m^2) in the out-of-plane stresses. Figure 4.32 shows the in-plane and out-of-plane stress changes for the dead load + spectrum x combination.

The maximum shear stress for the dead load - spectrum x load combination is observed in the connection of the minaret body and pabuc as (S12) 1900 kPa (kN/m^2) in the in-plane stresses and as (SVmax) 397.9 kPa (kN/m^2) in the out-of-plane stresses. Figure 4.33 shows the in-plane and out-of-plane stress changes for the dead load - spectrum x combination.

The maximum shear stress for the dead load + spectrum y load combination is observed in the connection of the minaret body and pabuc as (S12) 2448 kPa (kN/m^2) in the in-plane stresses and as (SVmax) 502.5 kPa (kN/m^2) in the out-of-plane stresses. Figure 4.34 shows the in-plane and out-of-plane stress changes for the dead load + spectrum x combination.

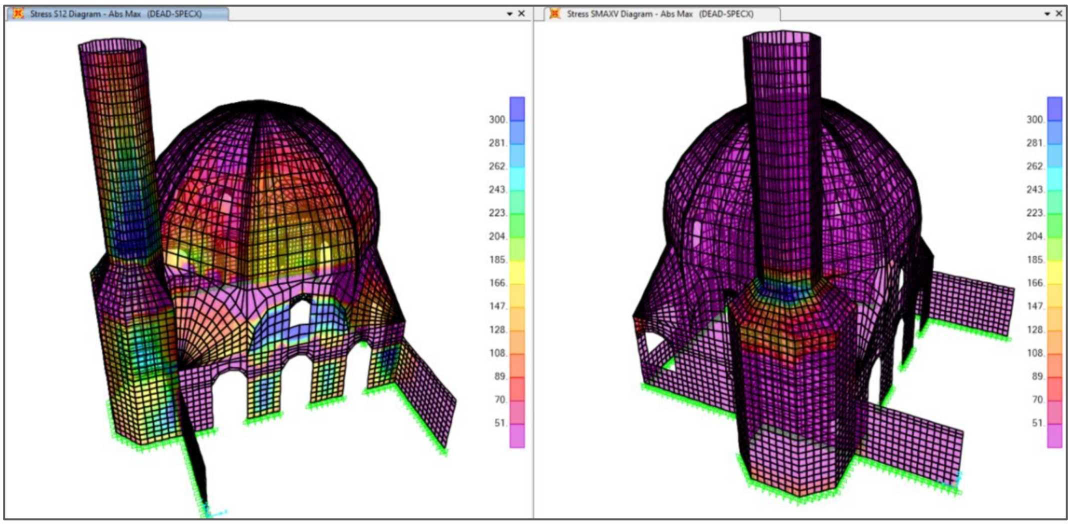
The maximum shear stress for the dead load - spectrum y load combination is observed in the connection of the minaret body and pabuc as (S12) 1585.2 kPa (kN/m^2) in the in-plane stresses and as (SVmax) 509.4 kPa (kN/m^2) in the out-of-plane stresses.

Figure 4.35 shows the in-plane and out-of-plane stress changes for the dead load - spectrum y combination.



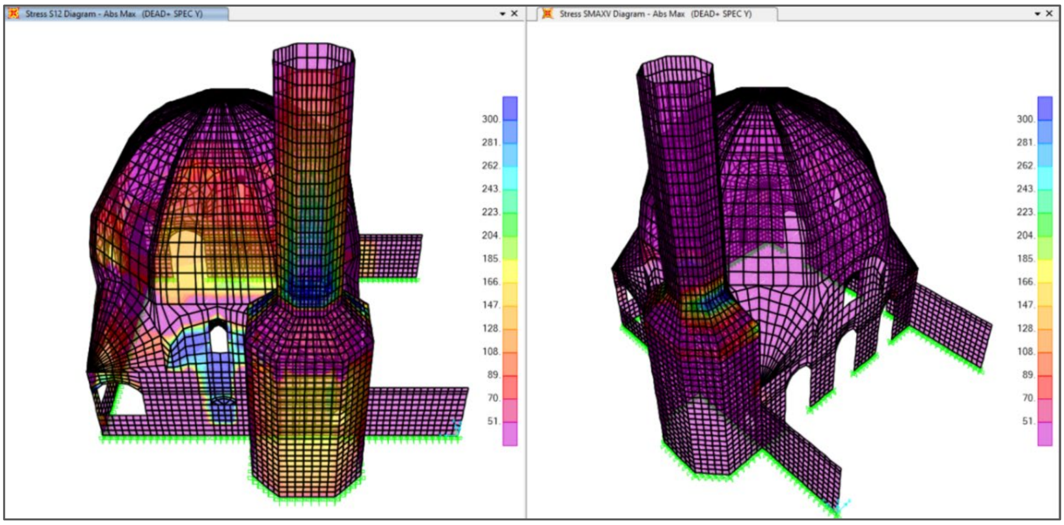
(a) (b)

Figure 4.32. Shear stress contours of response spectrum analysis (kN/cm^2) -1 (result of dead load+ spectrum x, view from east and north), a) in plane (absolute S12), b) out of plane (absolute SVmax)



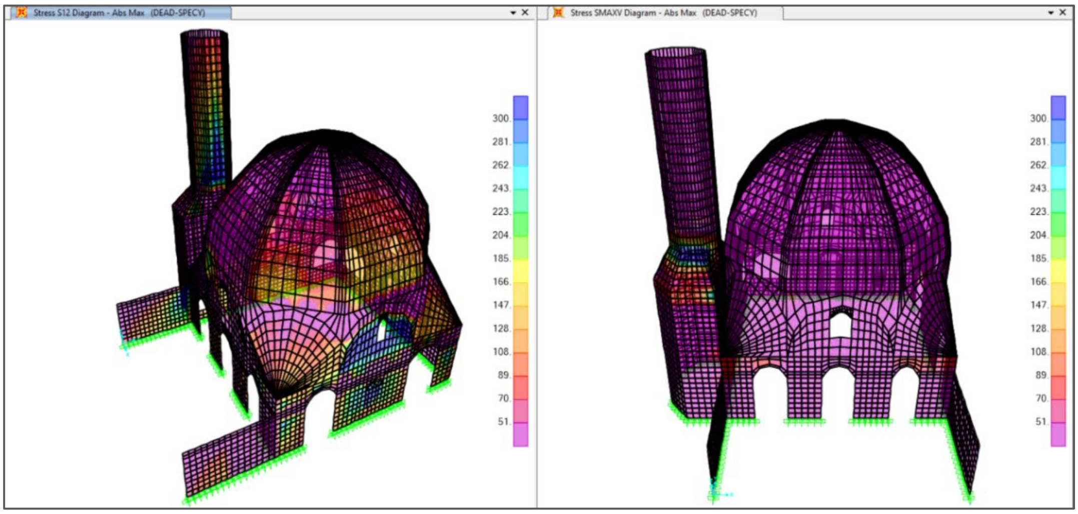
(a) (b)

Figure 4.33. Shear stress contours of response spectrum analysis (kN/cm^2)-2 (result of dead load- spectrum x, view from west and north), a) in plane (absolute S12), b) out of plane (absolute SVmax)



(a) (b)

Figure 4.34. Shear stress contours of response spectrum analysis (kN/cm^2)-3 (result of dead load+ spectrum y, view from north and west), a) in plane (absolute S12), b) out of plane (absolute SVmax)



(a) (b)

Figure 4.35. Shear stress contours of response spectrum analysis (kN/cm2)-4 (result of dead load- spectrum y, view from south and west), a) in plane (absolute S12), b) out of plane (absolute SVmax)

In these analyses performed using spectral acceleration values and different load combinations, 51 kPa (kN/m^2), the upper limit of shear stress for pitch-faced stone masonry walls, was accepted as the boundary value for walls; 92 kPa (kN/m^2), the upper limit of shear stress for lime mortar brick masonry walls, was accepted as the boundary value for the dome and the transition zone to the dome.

Given the stress changes detected in the analysis, it is apparent that the in-plane shear stresses occur in different combinations, in different directions, and in similar volumes. The most important sections for the in-plane stresses are the dome drum and the areas that mark changes in the minaret geometry. The out-of-plane shear stresses are mostly observed in the connection of the minaret body and pabuc and at the intersections where the squinches and walls. The in-plane and out-of-plane stresses are above the boundary values both in the walls and the superstructure.

4.9. Time History Analyses

As a result of rapid developments in structural analysis and computational tools, time history analysis has been widely used in seismic analysis and structural design. One of the most important problems that arise when using these methods is the provision of earthquake records that fulfill regulatory stipulations. Earthquake accelerograms can be obtained from three sources: 1) artificial records compatible with design response spectrum 2) simulated records, and 3) accelerograms recorded during earthquakes. The expansion of available strong ground motion database and the easier access to these databases thanks to advancing technology have made using and scaling real recorded accelerograms one of the latest research topics (Fahjan,2008).

In this study, time history analyses were carried out with real earthquake records. According to the “Turkey Building Earthquake Regulation” (TBDY, 2018), seismic ground movements to be used in time history analysis can be selected using simple scaling method among from the selected earthquake records. However, the amplitude of the mean spectrum of all records of the selected earthquakes (SRSS) in the period range between 0.2 Tp and 1.5 Tp must conform to the rule that the design spectrum shall not be less than the amplitude in the same period range. Therefore, amplitudes must be scaled by reference to the compliance of this range. According to the regulation, at least 11 earthquake records must be used for design.

This study performed the analyses using three earthquake records because it did not aim at design-oriented analysis but to understand the behavior of the existing structure for real earthquake accelerations. The earthquakes selected for linear time history analysis are Kocaeli (1999), Van (2005), and Imperial Valley-El Centro earthquakes (1940). The Pacific Earthquake Engineering Research Center (PEER) ground motion database and AFAD strong ground motion database of Turkey were used for earthquake records (Figure 4.36, Figure 4.37, Figure 4.38).

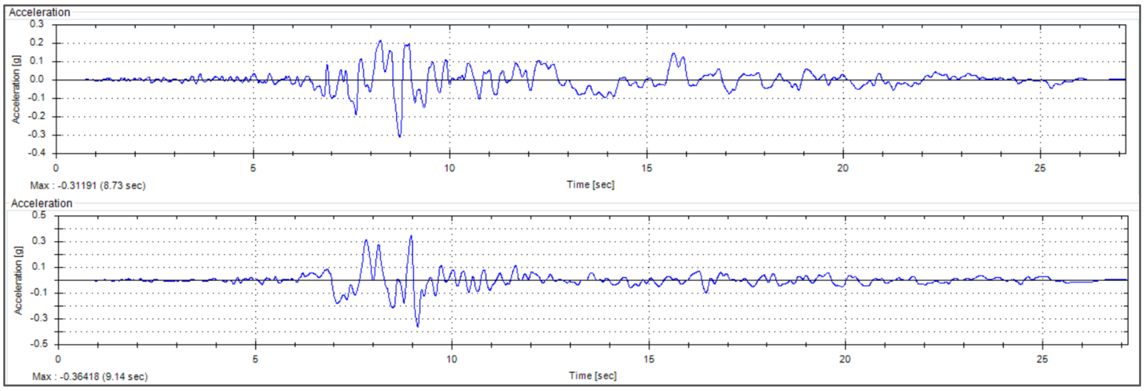


Figure 4.36. Acceleration graphics (unscaled) for two directions of Kocaeli earthquake

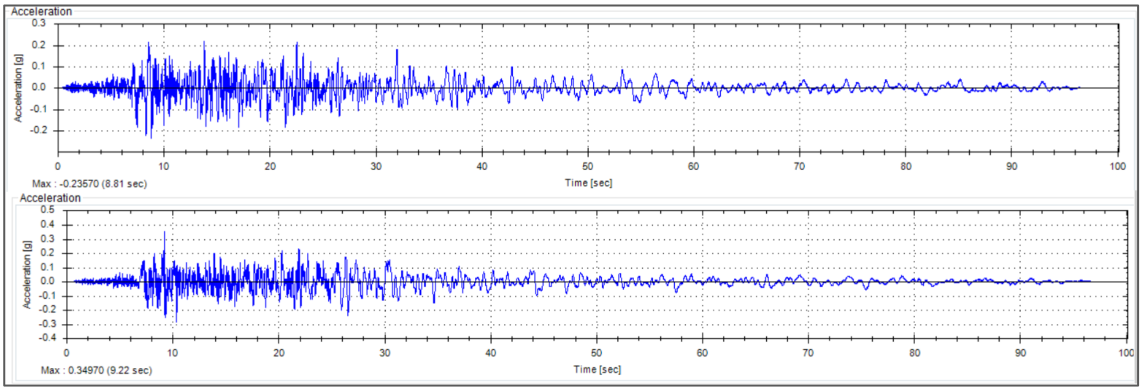


Figure 4.37. Acceleration graphics (unscaled) for two directions of Imperial Valley-El Centro earthquake

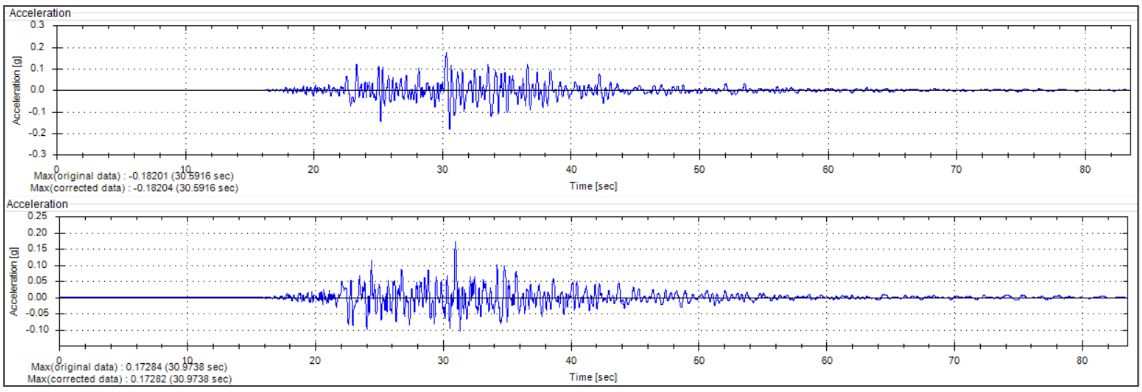


Figure 4.38. Acceleration graphics (unscaled) for two directions of Van earthquake

First, scaling was performed between the combined spectrum of two-way spectra of the earthquake records (SRSS) and the earthquake spectrum generated for Helvacılar Mosque in order to check the appropriateness of the selected earthquakes. The Kocaeli earthquake was scaled six times, the Imperial Valley earthquake was scaled seven times, and the Van earthquake was scaled five times. Thus, the condition that the amplitude of the scaled acceleration spectrum values in the period range between 0.2 Tp and 1.5 Tp shall be higher than the design spectrum was fulfilled. The correlation between the earthquake acceleration spectra and the design acceleration spectrum is shown in Figure 4.39.

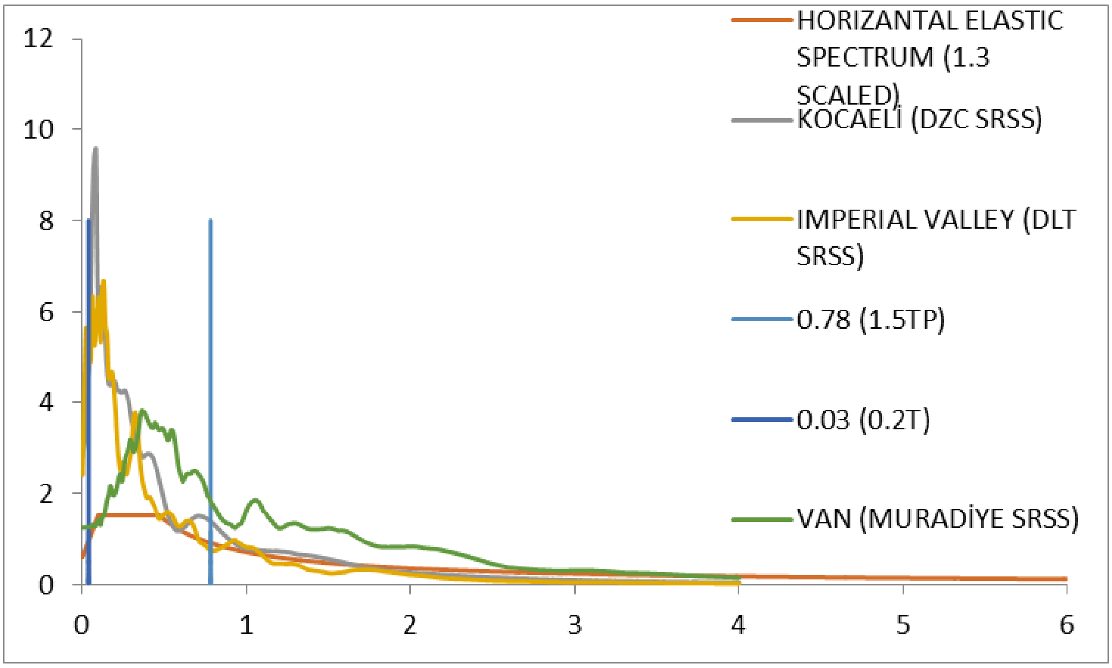


Figure 4.39. Control graphic of earthquake's acceleration spectrums and design acceleration spectrum

In the linear time history analyses, accelerograms were scaled on the software with the R coefficient of 2. The analyses were performed using both directions of the earthquake accelerograms simultaneously in accordance with TBDY (2018).

Five different points were identified using the model (Figure 4.40) for the results of the analyses performed with three real earthquakes accelerograms. During the acceleration time of three different earthquakes, the displacements in the x- and y-directions at these five points were compared.

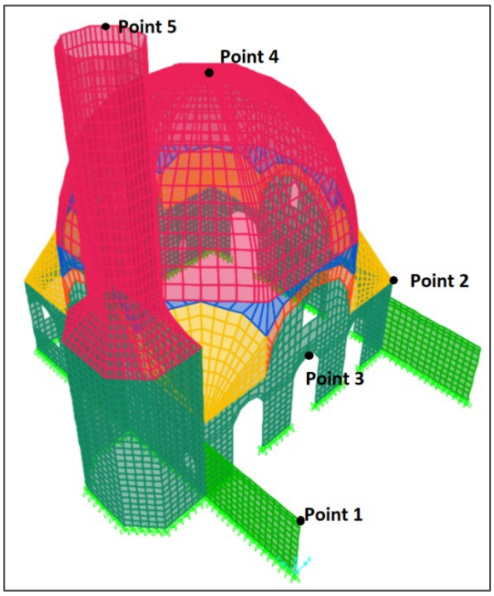


Figure 4.40. Selected points on finite element model

As is seen from the displacement graphs in Table 4.13 and Table 4.14, the maximum instantaneous displacements occur at the top of the minaret in all three earthquakes. As a result of three earthquakes, the maximum instantaneous displacement values in the dome range from 7 to 12 centimeters. In the walls and the squinch-wall intersection, the maximum displacement values ranged from 2.5 to 5 centimeters in three earthquakes.

The results of the displacement in the structure were analyzed through the analyses carried out using three different real-time earthquakes. The seismic capacity of the building during earthquakes must be increased because earthquakes with similar magnitudes to those used in the analyses might occur in the region. Strengthening the dome and minarets to decrease the displacements and making interventions by which the walls can work together in an earthquake will have a positive impact on the seismic performance of the structure.

Table 4.13. Result graphics of time history analyses-1
X direction displacements of selected points

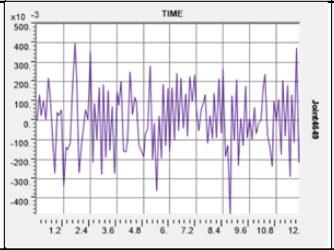
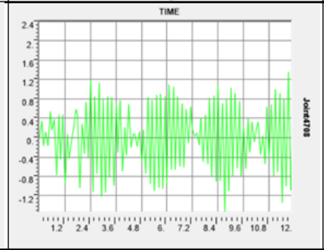
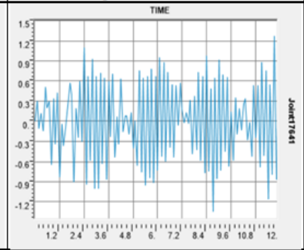
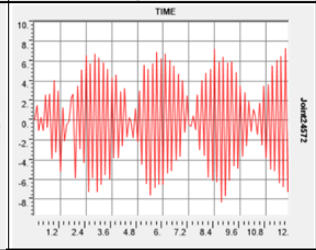
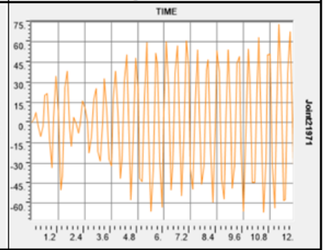
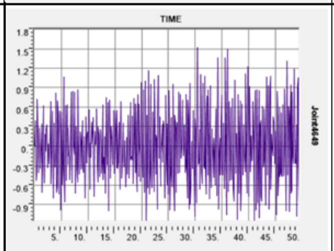
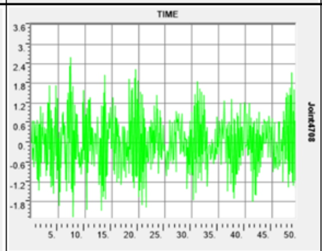
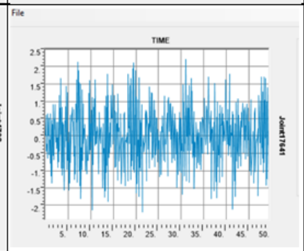
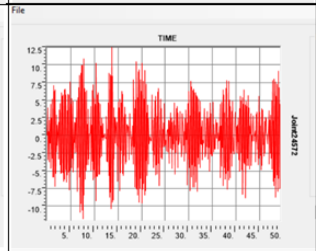
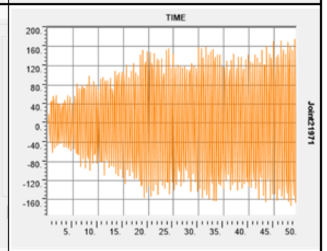
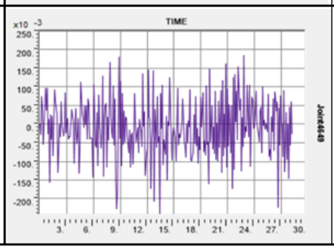
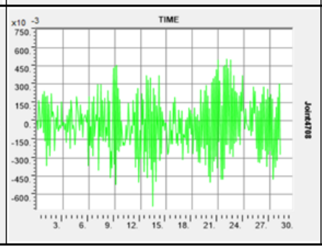
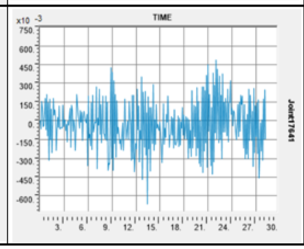
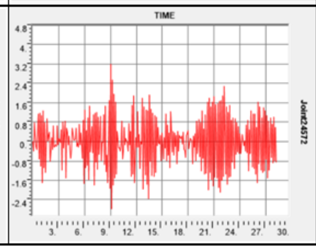
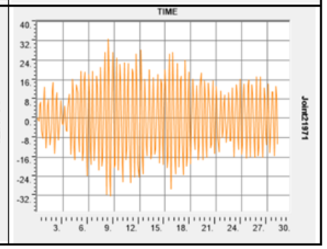
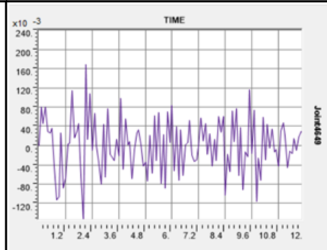
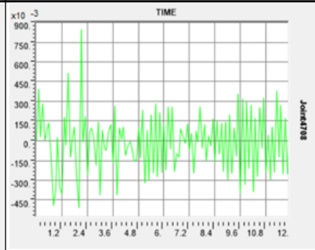
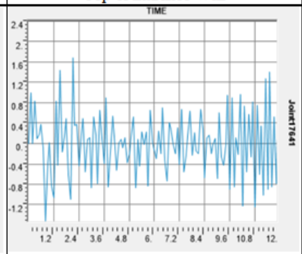
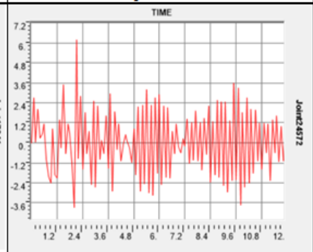
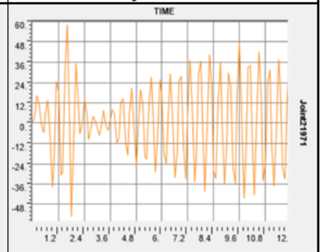
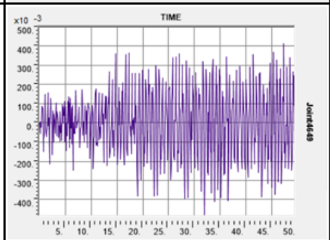
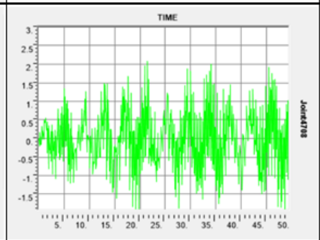
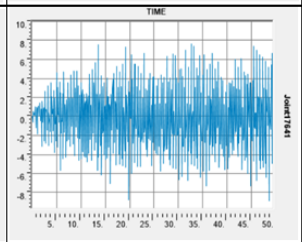
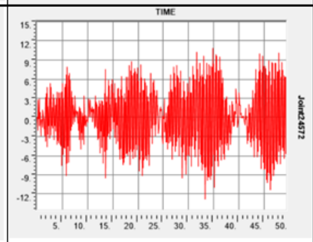
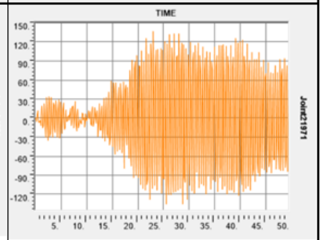
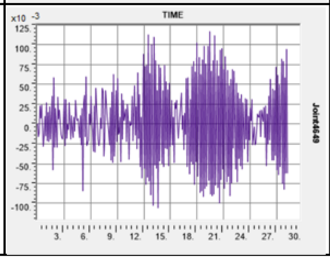
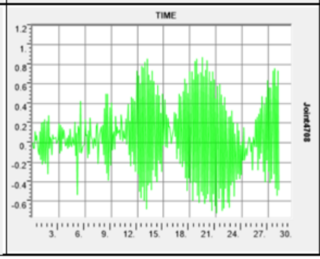
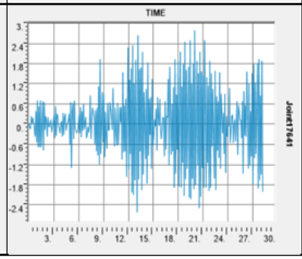
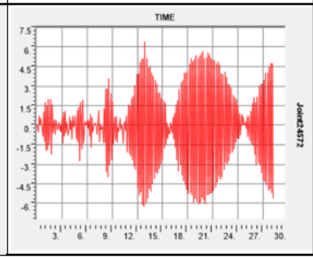
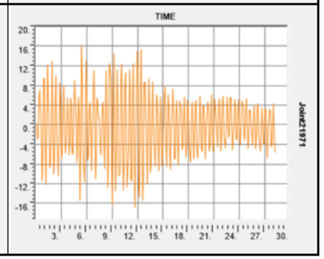
	POINT 1	POINT 2	POINT 3	POINT 4	POINT 5
Location	Top of Portico Wall	Interection of Squinch and Wall	Top of Entrance Wall	Top of Dome	Top of Minaret
KOCAELI EARTHQUAKE					
IMPERIAL VALLEY EARTHQUAKE					
VAN EARTHQUAKE					

Table 4.13. Result graphics of time history analyses-2
Y direction displacements of selected points

	POINT 1	POINT 2	POINT 3	POINT 4	POINT 5
Location	Top of Portico Wall	Interection of Squinch and Wall	Top of Entrance Wall	Top of Dome	Top of Minaret
KOCAELI EARTHQUAKE					
IMPERIAL VALLEY EARTHQUAKE					
VAN EARTHQUAKE					

CHAPTER 5

STRENGTHENING PROPOSALS WITH THE HELP OF STRUCTURAL ANALYSES BASED ON GENERAL DIRECTORATE OF FOUNDATIONS' GUIDELINE

5.1. Aim of General Directorate of Foundations' Guideline

The General Directorate of Foundations published a guideline titled "Earthquake Risk Management of Historical Structures" in 2017. This guideline is centered on the risk assessment of historical buildings against possible earthquake, risk reduction, emergency disaster response, and disaster recovery, thereby aiming to serve as a guide that offers scientific and technical definitions for all these categories.

This guideline outlines prescriptions for the pre-disaster identification of the earthquake resistance of the load-bearing structural system of historical structures, the definition of inquiries and investigations for the detailed identification of structural problems, the determination of basic principles of calculation under earthquake and vertical load, and the way of how to design and implement interventions in line with the results obtained from the previous steps and with the conservation principles.

Decisions on the restoration and strengthening of historical structures must comply with international principles and taken based on a detailed investigation of the earthquake behaviors of structures. Because each historical building clearly has its own design, construction system, materials, and different ground conditions and the damage in buildings vary for these reasons, the guideline issued by the General Directorate of Foundations adopts the principle of generating the correct approach rather than stipulating absolute rules.

5.2. Strengthening Proposals of Helvacılar Mosque

Approaches to strengthening historical structures always aim to conserve the structural safety through interventions that remain faithful to the original structure. A number of variables should also be taken into consideration in deciding on intervention strategies, such as the seismic risk of the area where the particular structure is located, current damage observed in the structure, the conditions of use of the structure, and the economic criteria of interventions.

With respect to the current situation of Helvacılar Mosque examined in this study, it is clear that the prevention of structural damage will be the most urgent intervention to ensure the survival of the structure. The main axis of interventions for Helvacılar Mosque will involve eliminating the causes of damage in the structure, repairing the damaged parts, and increasing its structural strength and rigidity by additional interventions, thereby reducing seismic demand. Accordingly, structural interventions will be discussed under nine main headings: supporting walls with buttresses, suspension of the structure, ground stabilization and ground settlement prevention, strengthening of the walls, repairs and strengthening of the dome, repairs and strengthening of the transition elements, repairs and strengthening of the arches, consolidation of the minaret and other needs.

5.2.1. Supporting Walls with Buttresses

Before the strengthening work within the structure is initiated, measures must be taken for the walls both to ensure the safety of employees and to prevent any possible out-of-plane collapse because the structure has extremely serious damages. To this end, temporary buttress systems must be installed during the strengthening of the walls. These buttresses will help transfer horizontal forces in the structural elements to the ground (Figure 5.1).

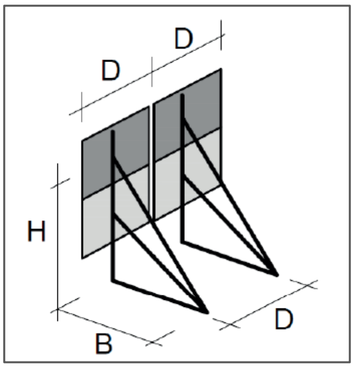
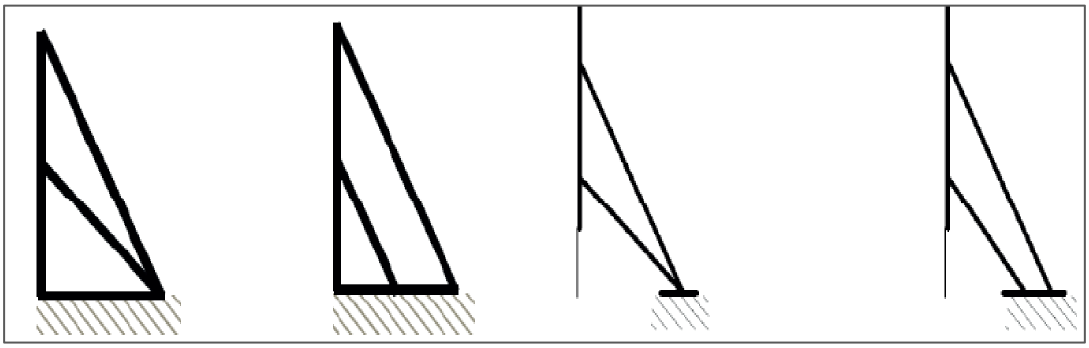


Figure 5.1. Schematic representation of buttress dimensions (H: strut height, B: strut width, D: buttress spacing)
(Source: General Directorate of Foundations' Guideline, 2017)

For the western and southern walls where settlement and damage are observed, measures must be taken against the fall with buttresses. The guideline issued by the General Directorate of Foundations divides buttress types into classic buttresses and flying buttresses (Figure 5.2).



(a) (b)

Figure 5.2. Buttress types
a) Classic buttress (with one abutment /with multiple abutment)
b) Flying buttress (with one abutment /with multiple abutment)
(Source: General Directorate of Foundations' Guideline, 2017)

Because the structure is surrounded by sloping land, classic buttresses are not suitable. Considering that the buttress pier must be at a lower level, the use of flying buttresses will be a more functional choice. Given the building height, the number of main buttress of flying buttresses also increase. UP3-type timber buttress system was chosen for the free wall height of Helvacılar Mosque (Figure 5.3).

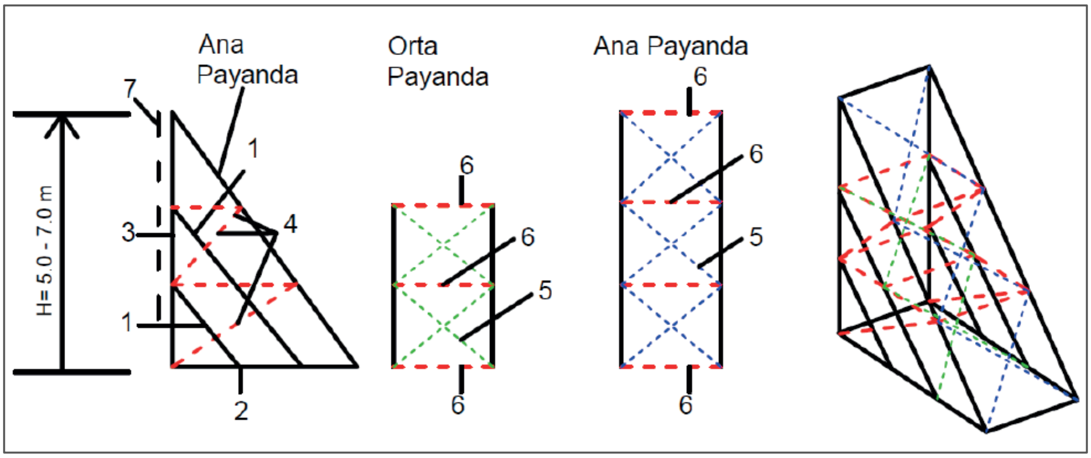


Figure 5.3. UP3 type buttress
(Source: General Directorate of Foundations' Guideline, 2017)

According to the guideline, the size of timber buttresses was decided to be 20x20 centimeters with maximum buttress width of (B) 3.5 meters and maximum buttress spacing of 1 meter because the wall thickness is more than 60 centimeters. All three rows of buttresses must have the same measurement. Vertical elements touching the wall surface must also measure 20x20 centimeters. Timber elements must be made of second-class pine wood (Figure 5.4)

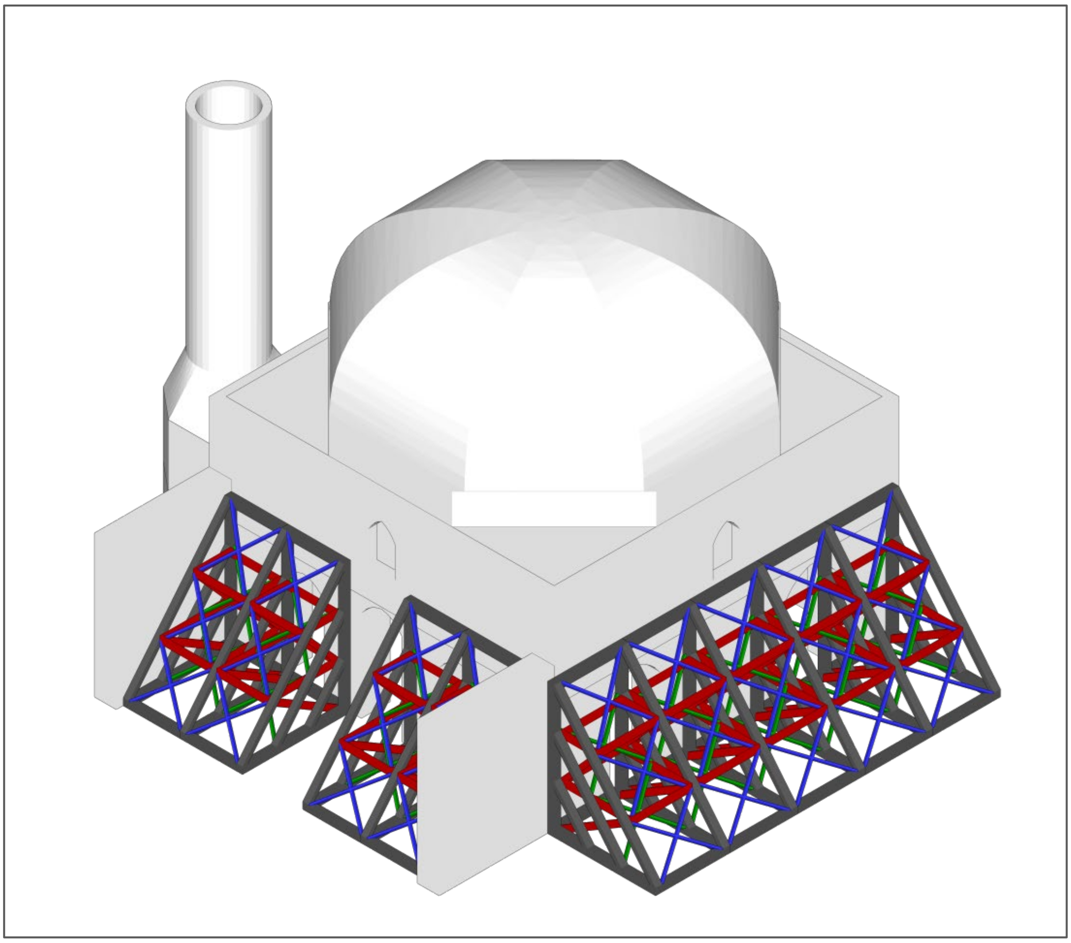


Figure 5.4. Schematic representation of buttress of Helvacılar Mosque

It must be ensured that flying buttresses have good connections at the joints and do not go down and shift from the base. Therefore,

1. Both sides of the buttress must have a bracing beam of 5x20 centimeters and they must be fastened with 3 wooden screws of φ5x100mm at each end.
2. Diagonal bracing elements that measure 5x10 centimeters must be used. These elements must be fastened with at least 2 wooden screws of φ6x100 mm at each end.

3. Longitudinal bracing elements that measure 5x10 centimeters must be used. These elements must be fastened with at least 2 wooden screws of φ6x100 mm at each end.
4. The flyers (elements resting on the walls) of flying buttresses must measure 5x20 centimeters at the minimum. The vertical center-to-center spacing between the flyer must be 1 meter at the maximum.
5. The ground connection specifications given in Figure 5.5 must be followed.

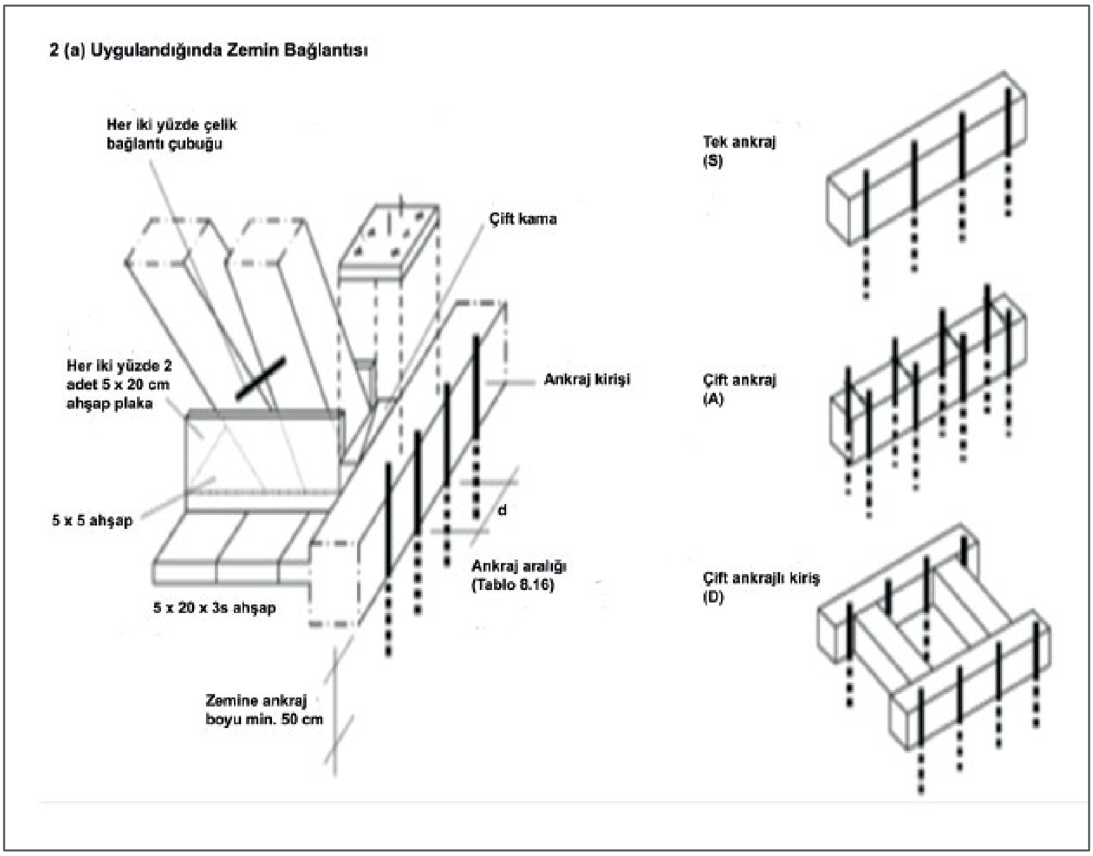


Figure 5.5. Buttress' connection details
(Source: General Directorate of Foundations' Guideline, 2017)

5.2.2. Suspension of the Structure (Scaffolding System of Superstructure)

The dome must be suspended with a scaffolding system inside the structure and the working area inside should be made safe to work. The guideline of the General Directorate of Foundations suggests suspension types for arches and vaults (Figure 5.6). These types of suspension are divided into two main groups: those that allow passage and those that do not allow passage. The bearing system of the suspension frame varies depending on the spacing between the abutments (Figure 5.7).

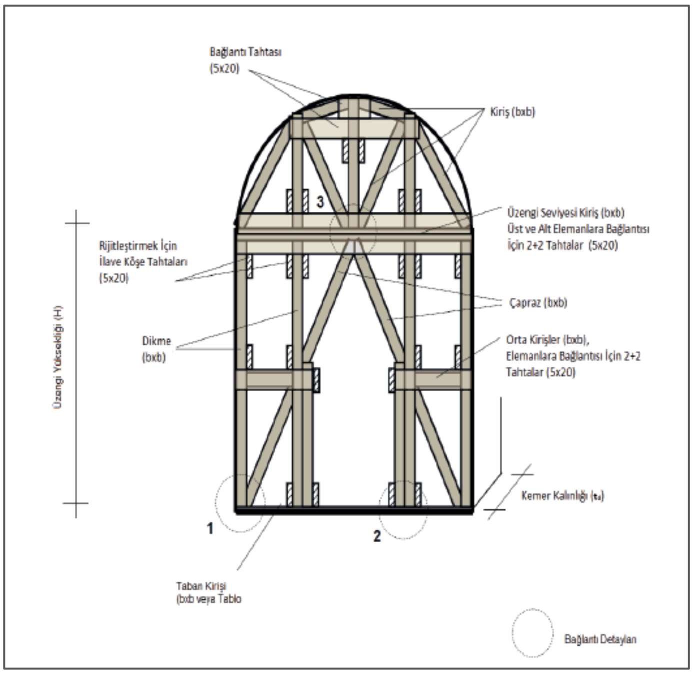


Figure 5.6. Structural elements of scaffolding systems for arch and vault (Source: General Directorate of Foundations' Guideline, 2017)

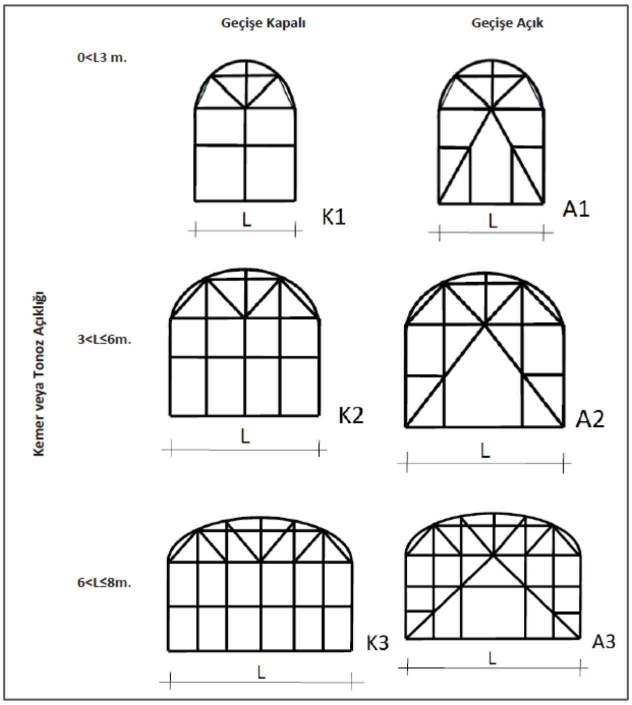


Figure 5.7. Arch and vault scaffolding types according to usage and distance of opening (Source: General Directorate of Foundations' Guideline, 2017)

Among the suspension systems defined in the guideline, the A3 type arch suspension system was adapted to the dome of the structure. In the scaffolding system constructed for the dome, three A3-type suspension structures will be used in the east-west direction. The main entrance gate will be taken as a reference as the central axis and the passage hall will be on this axis. Three parallel suspension systems will be connected to the beams on the spring line (Figure 5.8).

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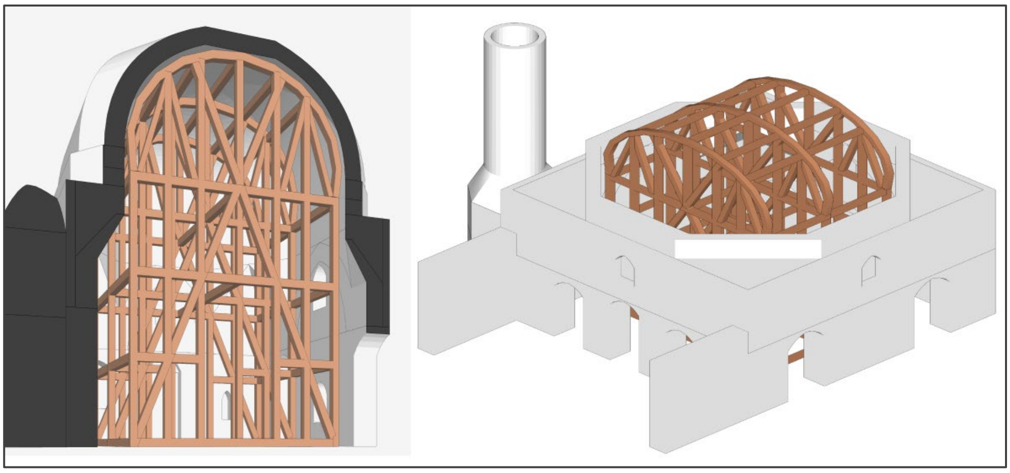

Figure 5.8. Schematic representation of scaffolding system

Pillars, beams, and wooden cross-section bracing components used in the suspension system must measure 20 x20 centimeters at the minimum. The connection specifications in Figure 5.9 must also be followed.

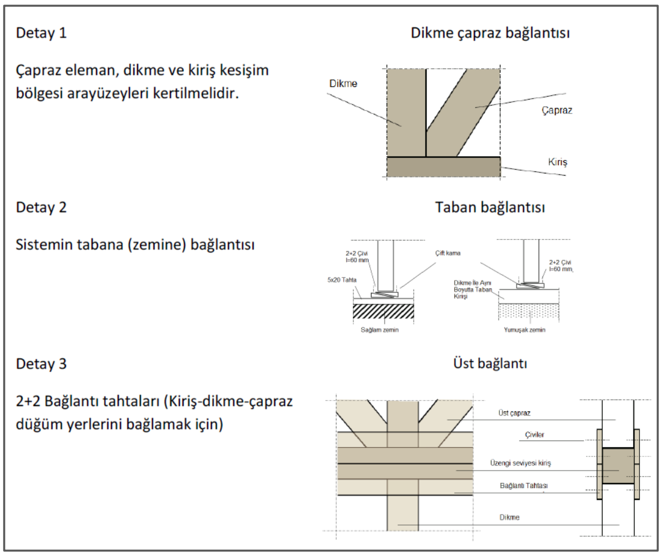

Figure 5.9. Connection details for timber-frame scaffolding system of superstructure (Source: General Directorate of Foundations' Guideline, 2017)

5.2.3. Soil Stabilization and Settlement Prevention

In line with the measured drawings, manual measures, and the finite element analysis, one of the main causes of damage to the southern wall of the structure is the problem of ground settlement.

Ground settlement may be due to changes in groundwater levels or excavations in the area. Ground settlement leads to material crushing, shear cracks along the wall plane, and balance distortion resulting in rotation and destruction. Settlement causes arch abutments to move. If the depth of the arch stones is enough, the three joints that stem from this movement in the arch help adapt to this movement. The movement of abutments as a result of ground settlement produced cracks in dome and vault parallel to abutments. The disappearance of the abutment thrust leads to the collapse of the arch, vault or dome. (General Director of Foundations' Guideline, 2017, p.102).

In light of this information, the actions to stabilize the soil and prevent settlement are listed below.

1. It is not possible to understand the cause of settlement with the information obtained from the overlying structure. To discover the status of the below-grade soil, groundwater level, soil bearing capacity, and mechanical parameters, a comprehensive soil survey must first be carried out in the field.
2. For the prayer hall and portico walls, trial pits must be dug in parallel to the wall plane to extend the foundation level. Thanks to these trial pits, both the measures of the foundation must be learned, and the below-grade settlement should be identified with exact values along the wall planes. In the process of digging trial pits, excavation should not be simultaneously carried out in multiple wall areas.
3. For places that are unreachable through trial pits, ground-penetrating radar (GPR) must be used to check whether there are voids or cracks.
4. If there is a problem with the soil bearing capacity according to the results from the soil survey, foundations must be extended to increase their bearing capacity. The foundation extension must be equal on both sides of the wall and the newly built sections must operate together with the existing foundation.
5. Ground improvement should be carried out by injecting mortar/chemical material at the below-grade level. Because injection methods do not produce a vibration on the ground, they do not have a negative impact on the structure.

During the intervention, the injection pressure must be controlled, and care must be taken to avoid the leaning of walls due to pressure. The injection method is used for the problem of bearing capacity. If there is a risk of liquefaction on the ground, jet grouting must be used through a detailed geotechnical project to prevent liquefaction and to strengthen the bearing capacity. Ground improvement should be carried out by measuring until the below-grade level is the same under each wall. After the improvement, it must be ensured that the foundation of the building rests on solid ground.

6. If there is groundwater on the ground, it is necessary to reduce the groundwater level in a controlled manner and prevent water from damaging the foundation. For this reason, if necessary, gravel and sand drains can be constructed into the ground. However, different forms of settlement in the upper structure should not be allowed due to irregular water drainage in such applications.

Prevention of settlement must be the first intervention to make in the structure. After appropriate ground conditions are ensured, other strengthening procedures must proceed from the ground to the top cover.

5.2.4. Wall Strengthening

1. For the repair and strengthening of the walls, window openings must be surrounded by temporary scaffolding systems. According to the guideline, the in-plane rigidity of the walls can be increased by filling the door and window openings with wooden support elements and local collapse can be prevented due to damage in elements such as lintel.

   Therefore, all window spaces will be supported by wooden elements of 20 x 20 centimeters as seen in Figure 5.10. Because the wall thickness is 80 centimeters, two support systems must be installed for the inner and outer borders of each window opening (Figure 5.11).

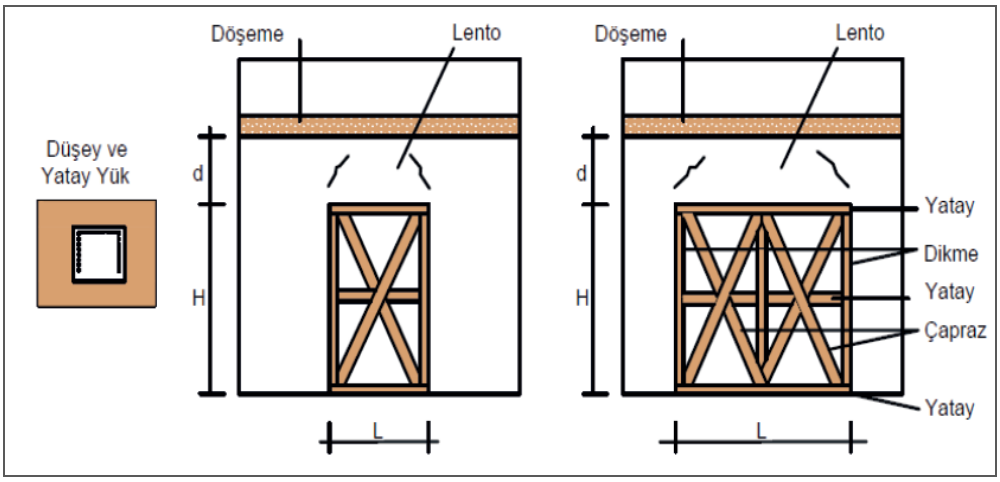

Figure 5.10. Scaffolding system of window openings
(Source: General Directorate of Foundations' Guideline, 2017)

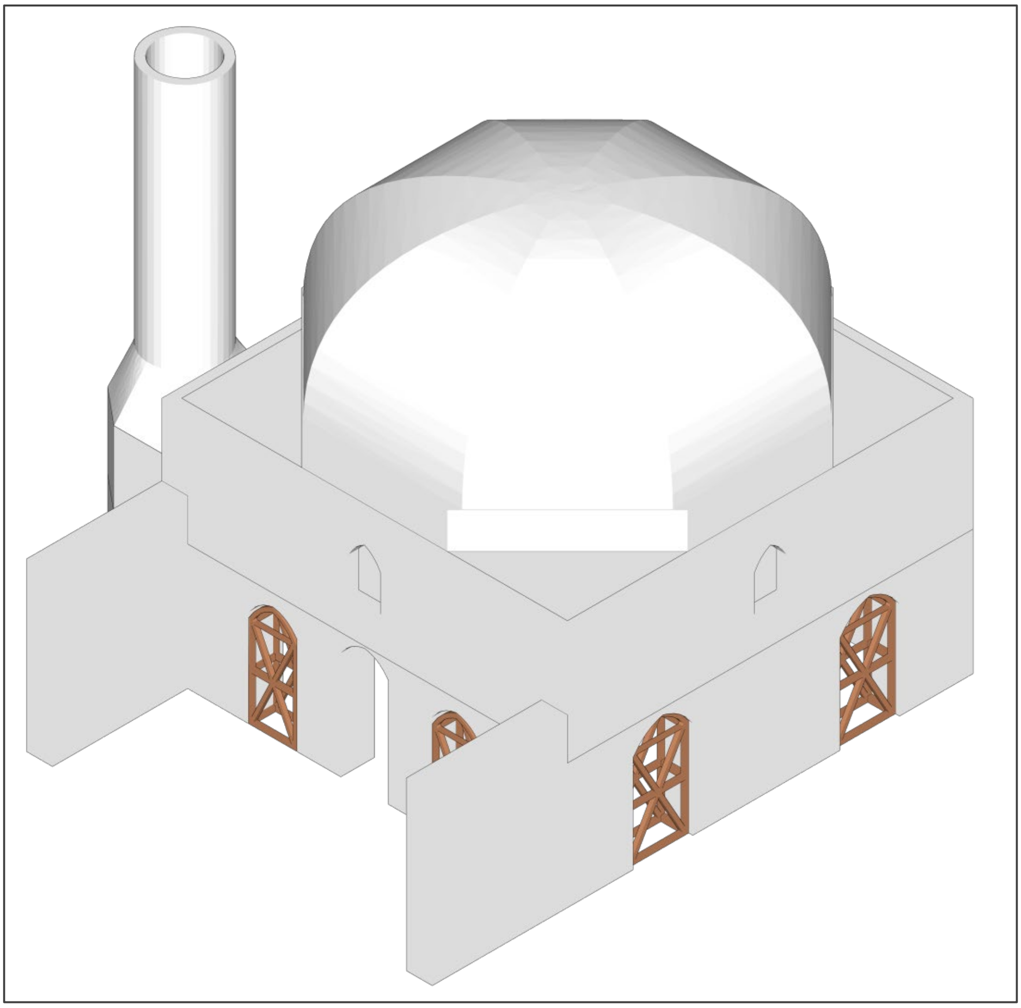

Figure 5.11. Schematic representation of scaffolding system of window openings

2. According to the guideline, lintel has been used in masonry structures since ancient times in order to protect the integrity of the wall, increase its stability in the out-of-the-plane direction, and ensure that the walls work together. The deterioration and decay of wooden lintels in historical masonry structures over time may lead to some damage to walls. In such cases, although using the same type of material to place new lintels in the masonry wall is a troublesome solution, it results in a noticeable improvement in the behavior of the wall. After the lintel is renewed, it must be fixed to the wall with anchors (thin stainless rod). Then, the gap between the timber lintel and the lintel bed must be filled with mortar if possible and mortar injection should be made with appropriate materials to ensure that the lintel and the wall operate together.

   For this reason, a new lintel system must be established using timber lintels of 30 x 20 centimeters that are anchored at the corners in the four walls of the prayer hall at the level of lintels inside the wall by reference to lintel spaces in the walls (Figure 5.12).

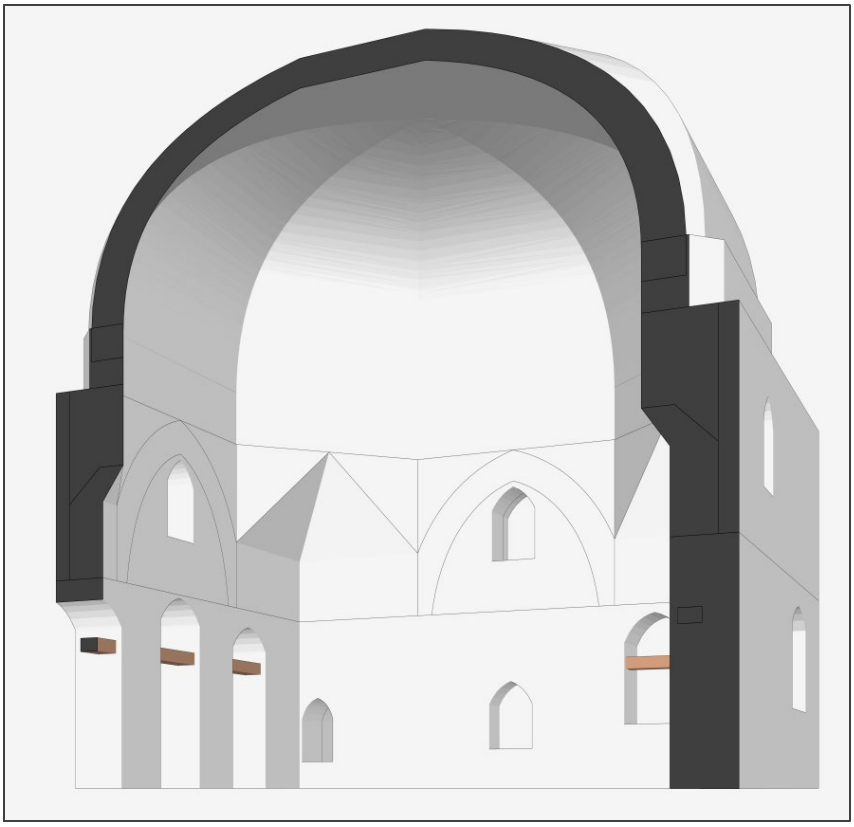

Figure 5.12. Schematic representation of new lintel system in walls

3. The damaged southern wall must be rebuilt to have a load transfer from the load-bearing system. The window openings in the southern wall and the top and bottom fillings of the windows will not be completed.

   Careful attention must be devoted to the visual resemblance of wall pointing with the original pointing, the preparation of the mortar material in the same content as the original material, the similarity of stones with the originals in size and shape, and the maintenance of the traditional construction technique in binding.

4. The repair of capillary cracks must be done using lime mortar injection material.

   According to the guideline, the method is used to restore the integrity of the stone masonry walls with empty joints due to irregular and external effects and of the hollow masonry walls with porous filling material in the inside. The mechanical properties of the wall can be improved by injecting high- binding mortar compatible with the original materials into hollow walls under proper pressure.

   <u>What to do before the application:</u>

   • The original material characteristics of the historical building must be identified.

   • The width of the cracks in the structure to be repaired must be measured to determine the fineness of the materials used in the production of injection materials.

   • Injection materials suitable for the original material properties must be produced.

   • Physical properties of injection materials such as fluidity, volume stability, and penetration, as well as the mechanical, chemical, mineralogical and durability properties of newly produced materials must be examined, and their suitability should be investigated.

   • The gap distribution of the historical structure to be restored must be determined.

   • The holes to be opened in the elements must be decided depending on the gap distribution and the masonry element must be wetted depending on the water absorption capacity of the original material.

• During the application, the material injection must be started from the bottom hole; when the material pours out of the holes in the upper row, the injection must proceed to the upper holes.

<u>The application;</u>

The material injection is done with the help of plastic tubes placed in the holes opened. During the application, care is taken to keep the injection pressure constant (approximately 1 bar). The injection process starts in the lower parts of the wall, and the gaps are closed to be cleaned later in order to prevent leakage from cracks throughout the application.

(a) (b) (c) (d)

Figure 5.13. Injection application a) drilling holes in the wall, b) cleaning the holes with air, c) wetting application, d) injection application (Source: General Directorate of Foundations' Guideline, 2017)

<u>After the application:</u>

Pre- and post-application ultrasound measurement can be one of the appropriate methods for evaluating the performance of the injection application. Whether the intervention has caused any damage to the historical structure must be monitored at regular intervals.

5. To reduce the wall free height in the southern facade, a T-section reinforced concrete retaining wall will be built along the length of the wall. The retaining wall must have a minimum thickness of 30 centimeters and a minimum height of 200 centimeters. One footing of the retaining wall must sit at the bottom level of the foundation under the southern wall of the structure. The other exposed footing must be given soil filling not less than 150 centimeters.
6. The surviving wall sections of the portico do not pose structural risks; the details of the top cover are unknown. For this reason, the necessary injection applications in these walls must be carried out using the methods presented in

Figure 5.13. Capping must be installed using lime-based waterproof material in the uppermost level of the walls (Figure 5.14).

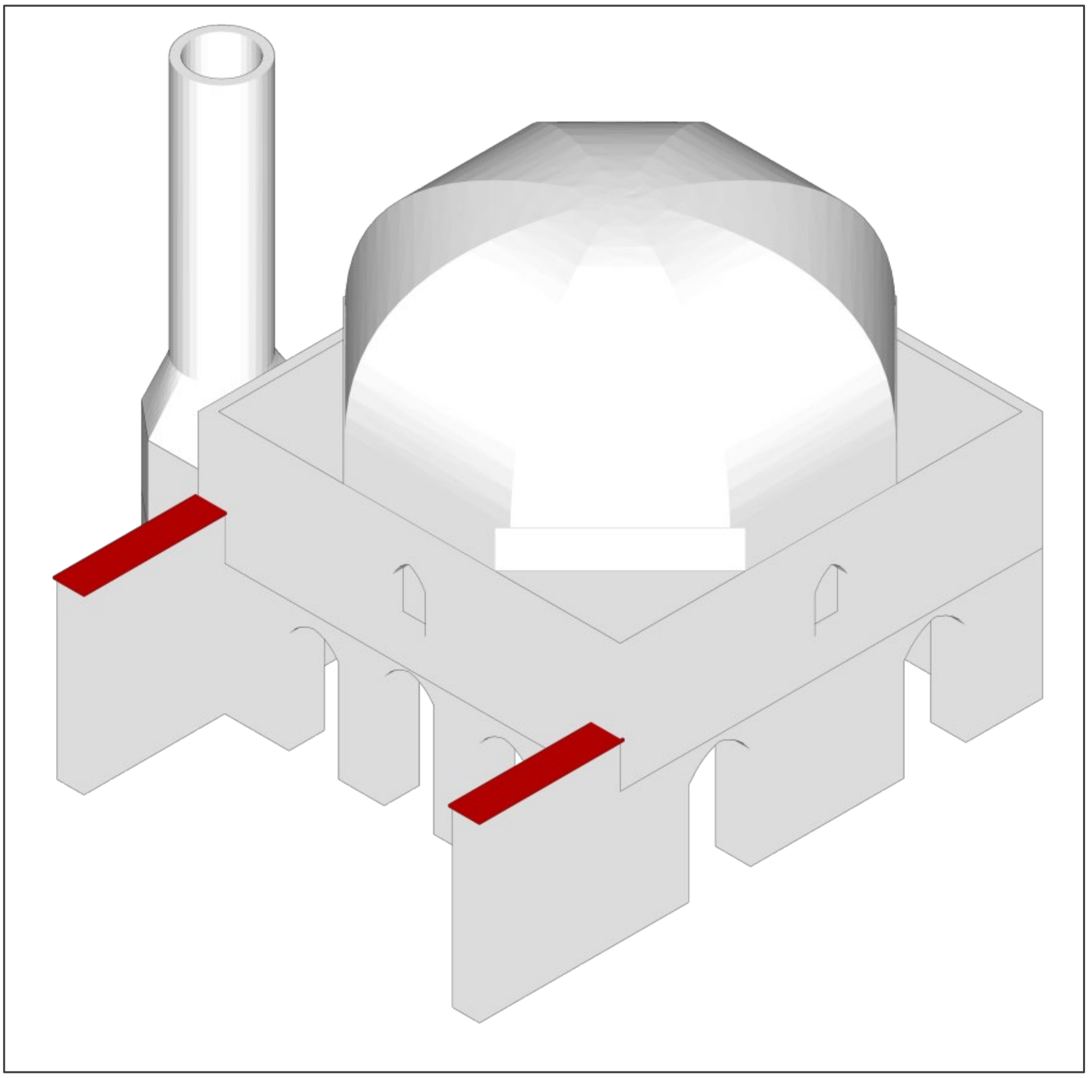

Figure 5.14. Schematic representation of capping on top of portico walls

5.2.5. Arch Repair and Strengthening

1. Due to the damage in the southern wall, the eastern abutment of the southern wall and the above-abutment section of the arch are not present. This section must be reconstructed.
2. The keystone section of the southern arch suffers a wide crack due to damage. This section must also be reconstructed.
3. Joint repairs must be made in all four arches of the structure.

5.2.6. Transition Zone Repair and Strengthening

1. The pendentive section around the southeast squinch must be rebuilt in keeping with its original form.
2. Cracks that have developed in the central intersection lines of all squinch must be filled with lime mortar injection (Figure 5.13). The cracks must be stitched with metal clamps along the crack line.
3. Joint repairs in the squinches and pendentives must be made using lime-based materials.
4. Steel tie rods used in the intersection of the walls and squinches for the wall reinforcement must also be used for the outside of the structure to reinforce the four facades (Figure 5.15, Figure 5.16).

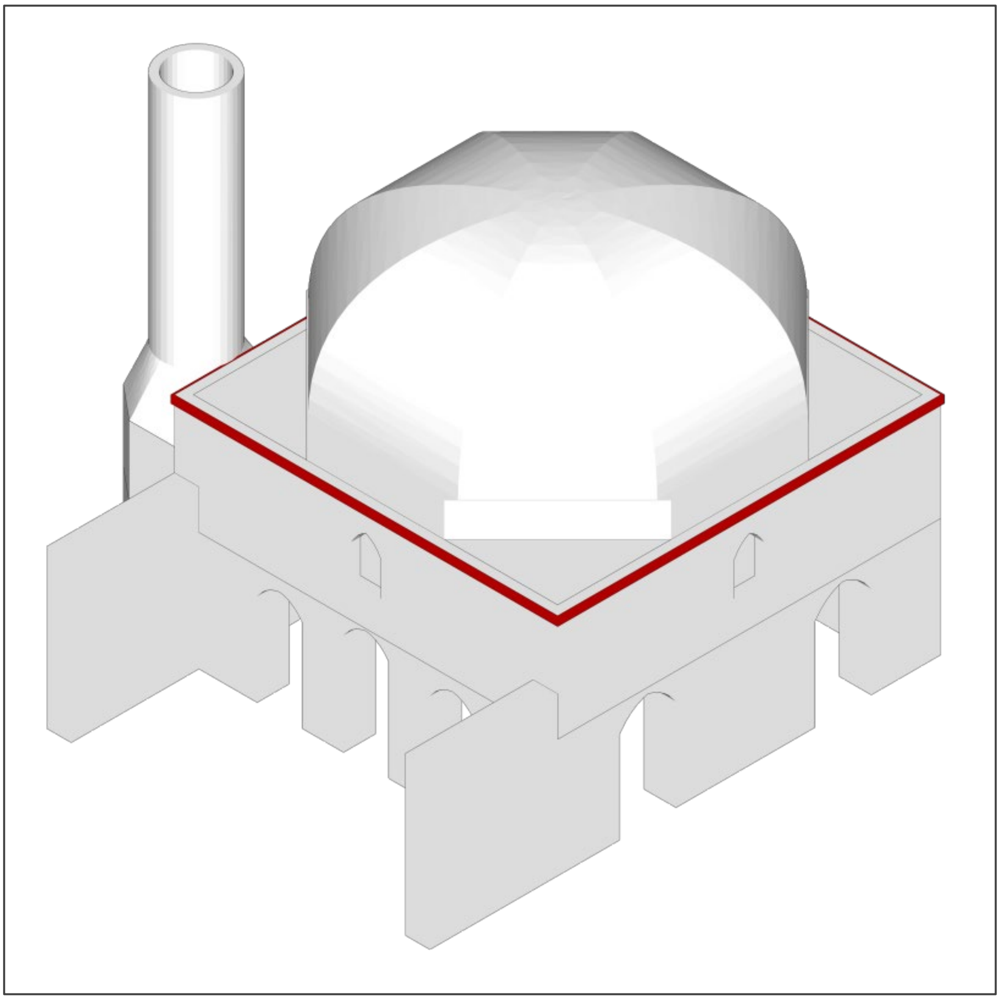

Figure 5.15. Schematic representation of location of tie rods

Figure 5.16. Steel tie bar application on the tomb of Çifte Minareli Madrasah in Erzurum

5.2.7. Dome Repair and Strengthening

1. To ensure the structural integrity of the dome, brick courses in the cracks in the southern side must be partly removed and reconstructed. Because the width of the cracks decreases when moving upwards through the dome drum, the cracks must be filled with mortar injection as shown in Figure 5.13. After this application, the crack line must be fastened with metal clamps in the injection area.
2. Framing must be made using UPN 240 type steel elements in the stone frame that currently partly encloses the dome. The stone frame that was originally covering the extrados of the dome drum must be rebuilt (Figure 5.17).
3. Joint repairs must be made in the entire.
4. The humidity problem in the northwest side of the dome must be solved. The dome must be insulated.

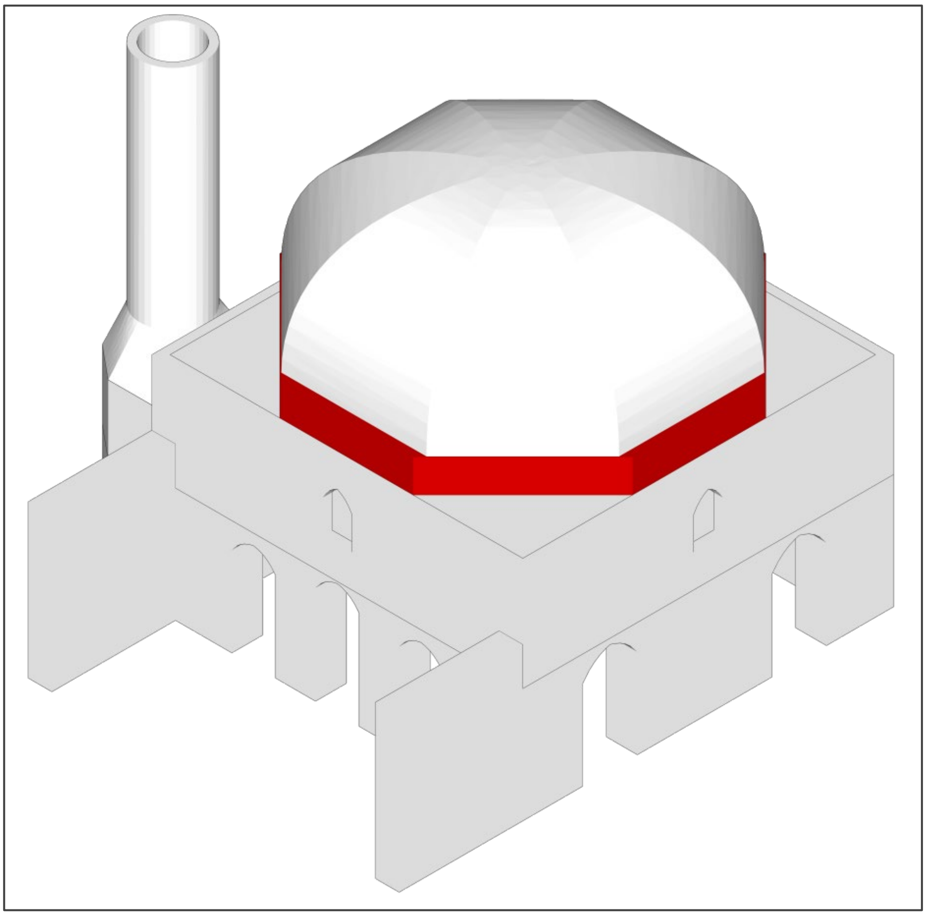

Figure 5.17. Schematic representation of location of dome's stone frame

5.2.8. Consolidation of the Minaret

Interventions do not vary widely due to the geometry of the minaret. The damage in the minaret is in its body. For this reason, the currently damaged part of the minaret body up to the uppermost level must be rebuilt of brick and mortar in keeping with its original form. The body must also be braced by steel tie from its connection with the minaret base up to the uppermost level. The maximum brace distance must not greater than 50 centimeters. Capping must be installed using lime-based waterproof material in the uppermost level of the minaret to prevent water leakage into the minaret (Figure 5.18).

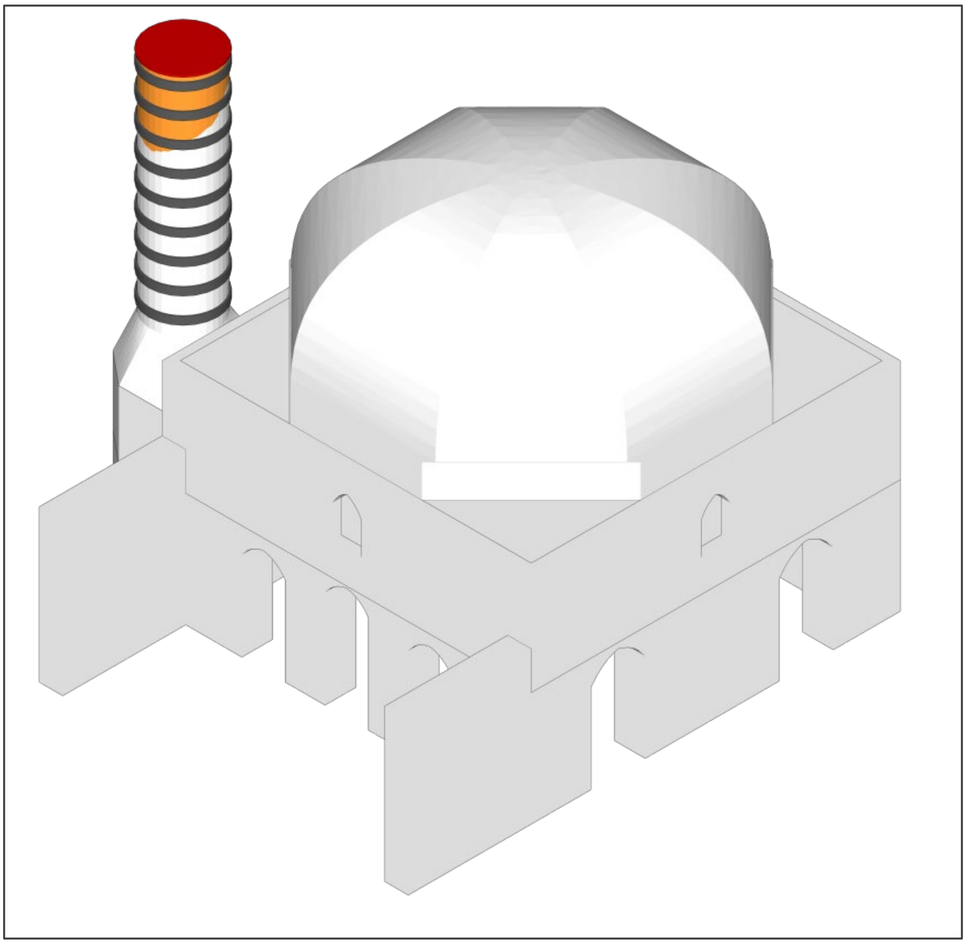

Figure 5.18. Schematic representation of minaret consolidation

5.2.9. Other Needs

These proposals are not structural strengthening proposals. However, if these proposals are not implemented, the resulting problems may cause structural problems in the long term. These proposals, which can be described as preventive measures, are listed under three items:

1. Weeds around the structure need to be cleared. Weeds that spread around the structure have negative effects that will reduce the strength of the walls.
2. The ground elevation around the structure walls needs to be corrected. Thereby, the structure will be liberated from the negative effects of the soil filling loads on the walls.
3. A drainage system must be installed around the structure. In this way, the impact of groundwater and environmental water on the structure will be eliminated and water-related strength losses in the load-bearing system will be prevented.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

This thesis investigated the architectural and structural characteristics of Helvacılar Mosque in Urla that has survived since the 15^{th} century and developed conservation proposals. The results of the study are listed below.

1. The mosque is a prominent structure in terms of understanding the single-domed mosque architecture and construction techniques of the period of the Aydın Dynasty although it is today derelict and seriously damaged.
2. In comparison with six similar-dated mosques and masjids within the borders of the same district, Helvacılar Mosque is similar to them in the architectural elements, space dimensions, structural system features, materials used, and construction technique.
3. The location of the mosque is not convenient for transportation. Because it has been deserted for a long time, it is surrounded by trees and plants. Environmental factors negatively affect the structure.
4. The current damages of the structure have been similar since 1985 but have grown more severe. While there were brick motifs decorations under the top balcony of the minaret in 1985, there are not today. In the structure observed under this study during 2017-2019, the body damage of the damaged minaret, which was open to external factors, has increased. The damaged southern facade has been the same since 1985. However, the eastern squinch of this facade survived until 1995 but is today demolished. The three cracks in the dome are larger than they were in 1985. This information clearly indicates that the damage mechanism of the structure is ongoing.
5. The structural analysis of historical buildings is complex and based on acceptance due to limitations to the detailed knowledge of material properties and load-bearing system. Therefore, this study used the finite element method in the analyses to gain deeper insight into the behavior of the bearing system. In these analyses, the stresses in the structure and their relationship with the material strengths were investigated under different load types. These

engineering analyses also aimed to reveal the reasons for the potential damage and investigated the parts of the structure and the type of needs which the interventions required for structural strength would target.

6. The linear self-weight analysis revealed increases in stresses in areas with structural geometry changes; however, the tensile stresses in the structure did not exceed the material strengths.
7. The dynamic characteristics of the structure were investigated using modal analysis for the identification of vibration frequencies and modes. The first two modes were found to form in both directions of the minaret. The main modes of the building are third, fourth, and fifth modes. The building moves in the east-west direction in the third mode and in the north-south direction in the fourth mode. The torsion movement was found to be active in the fifth mode.
8. The analysis of the settlement scenario designed after the settlements were identified in the structure investigated whether the settlement was one of the main causes the damage in the southern side, which is the most damaged part of the structure. Due to the effect of vertical displacements on the structure in the settlement scenario, the limits of the tensile stress on the southern facade and the southeastern squinch were found to be greater than the strength limits.
9. Urla and its surroundings have frequently been shaken by earthquakes of varying magnitudes throughout history and confronted with devastating damage. The location of the structure is amid the active Gülbahçe and Urla faults which extend parallel to each other and remains in the impact areas of these faults. Helvacılar Mosque has been shaken by many earthquakes that hit the region with a magnitude greater than 4 since the 15th century. For this reason, the safety of the structure against earthquakes is a matter of priority.
10. The coordinate-based horizontal design spectrum created for earthquake ground movement level 2 in line with the Turkey Building Earthquake Regulation (2018) and the seismic hazard maps prepared by the Disaster and Emergency Management Authority (AFAD) was created for the coordinates of Helvacılar Mosque. Response spectrum analyses which provide clues about the earthquake behavior of the structure were carried out using the spectrum. The results of the analysis showed that shear stresses were much higher than the cutoff values. In-plane shear stresses are found more in the dome drum and the intersection of the minaret with the pabuc. Out-of-plane shear stresses are found

in the geometry changes in the minaret and the intersection of the squinches with the walls. These areas need additional safeguard measures during the strengthening process.

11. This study carried out linear time history analyses based on the Kocaeli, Imperial Valley and Van earthquakes to understand the behavior of the structure during the earthquake. Instantaneous displacements that occurred at different points of the structure were investigated through the effects of three different earthquakes. The largest displacement is seen in the uppermost levels of the minaret and at the top of the dome.
12. The guideline issued by the General Directorate of Foundations in 2017 was used for the repair and strengthening of the structure, in which the causes of damages were investigated using a set of engineering analysis. The load-bearing system mechanism of the structure, which is today in a poor condition, has been repaired in line with strengthening proposals developed according to this guideline and strengthening proposals have been offered to increase seismic capacity.
13. The safety measures and reinforcements detailed for the structure should be carried out, but the structure should not be completed except in structurally non-compulsory cases.

Recommendations for future studies are listed below.

1. Experiments on the material mechanical properties of Helvacılar Mosque were not carried out. To define the material properties of the structure, the destructive and non-destructive testing methods must be used and the mechanical properties of the structure must be identified.
2. The engineering analysis performed in the study is linear analysis. An earthquake analysis should be performed in the structure in a non-linear fashion using non-linear material mechanical parameters and non-linear permanent damage mechanisms should be investigated.
3. The General Directorate of Foundations as the title holder should implement the interventions which are required for the survival of the structure and explained along with their justifications within this study. Helvacılar Mosque, which has been abandoned for many years, should be securely passed down to the future.

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APPENDIX A

MEASURED DRAWINGS

Figure A.1. Measured Drawings

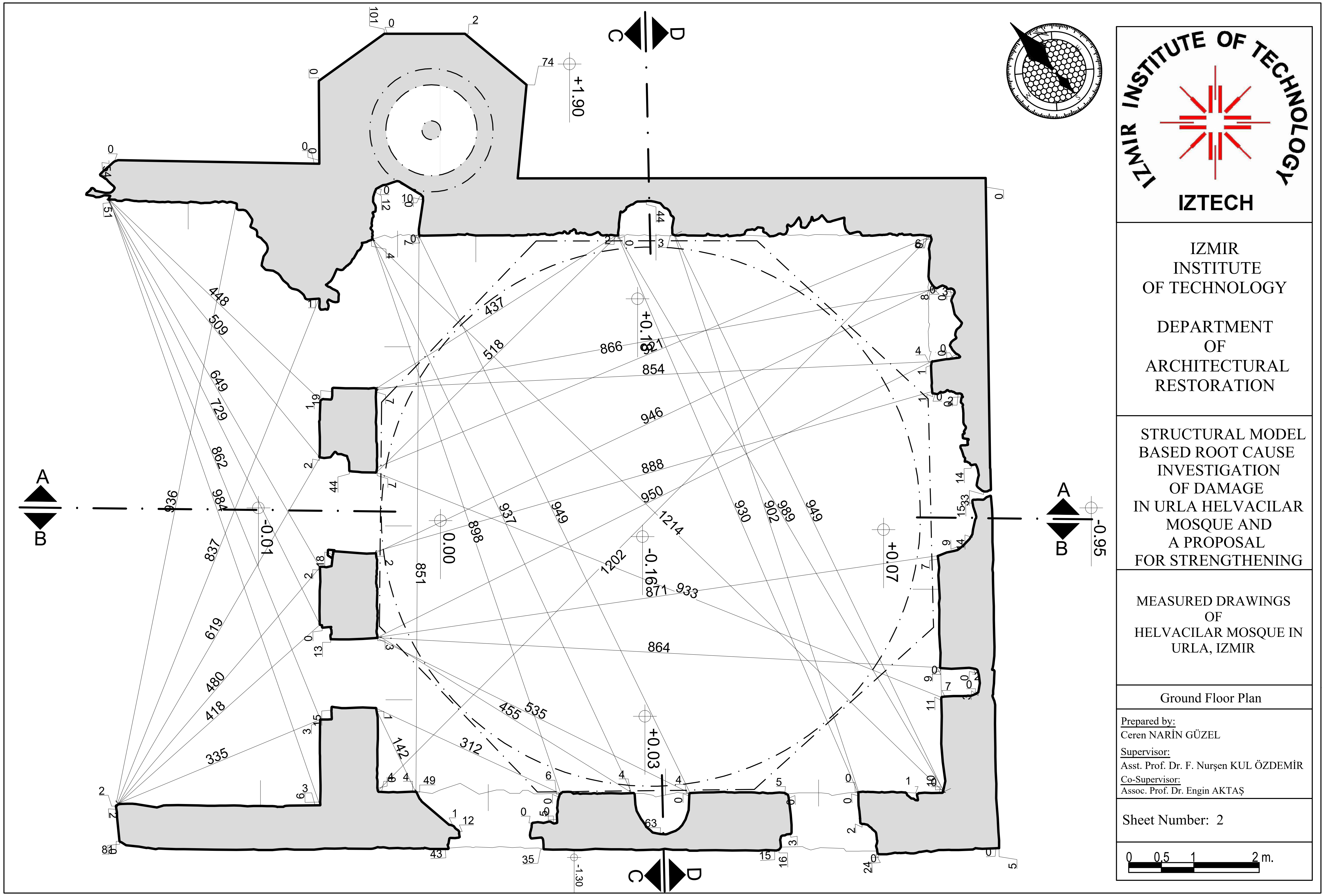


Figure A.2. Measured Drawings

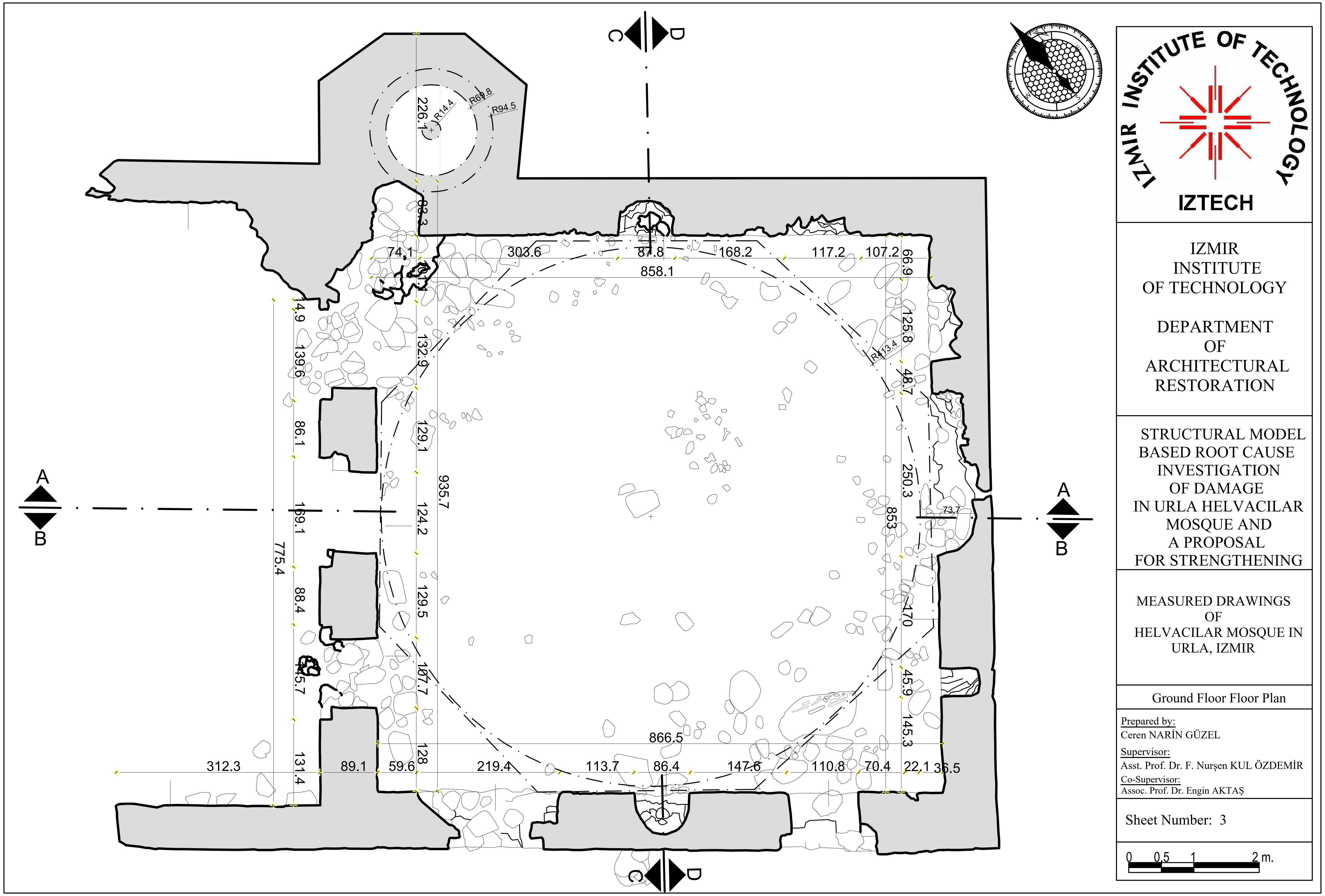
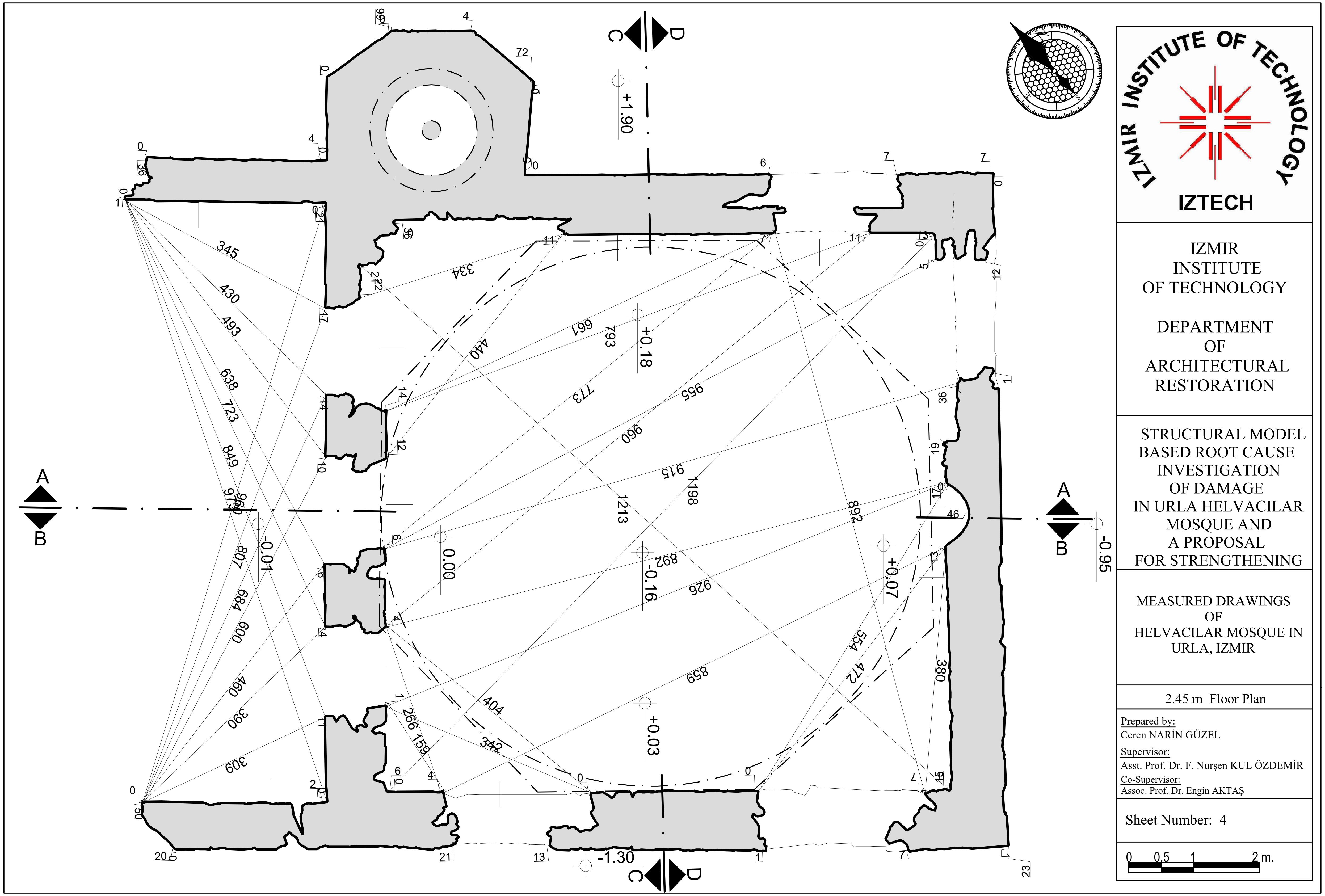


Figure A.3. Measured Drawings



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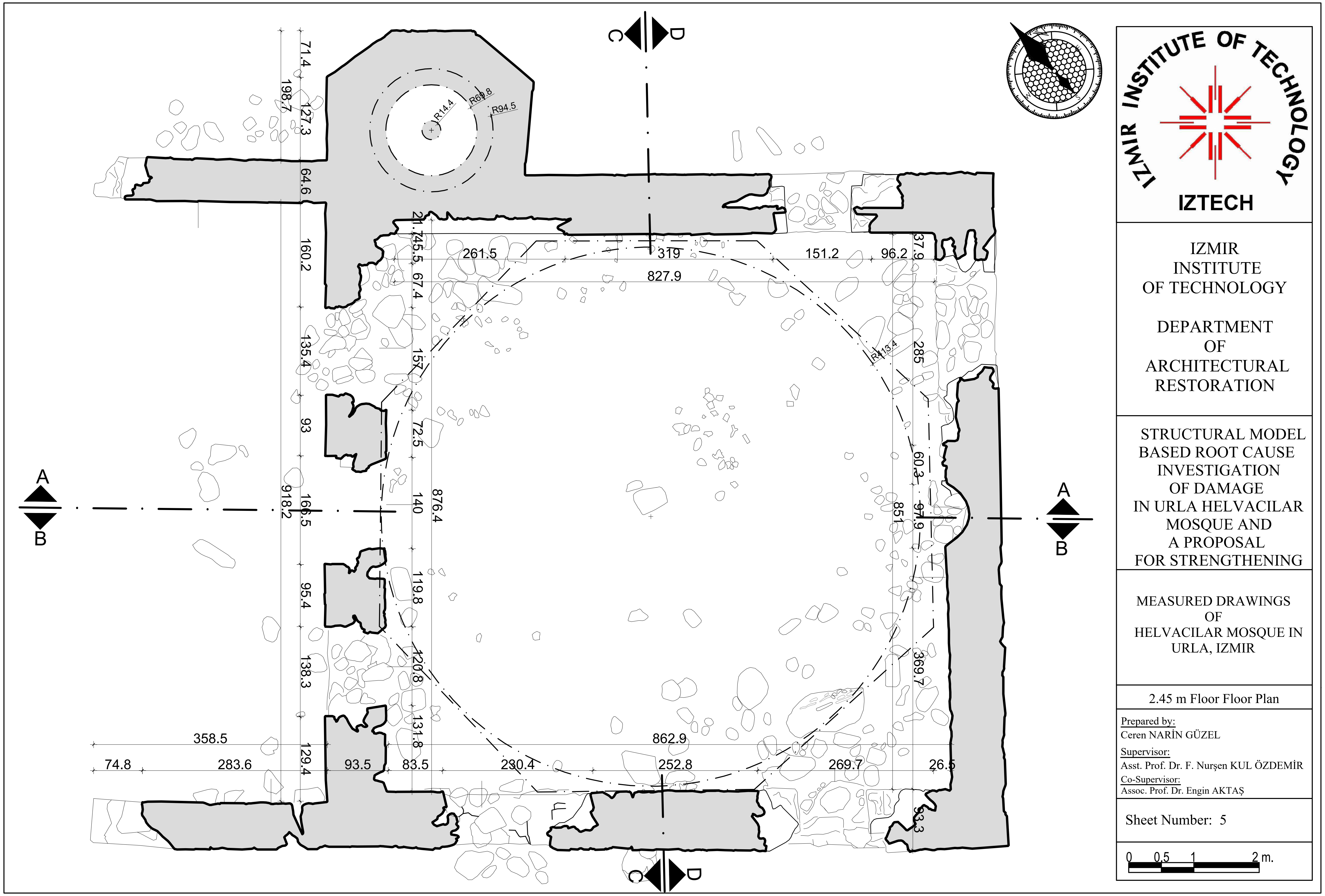
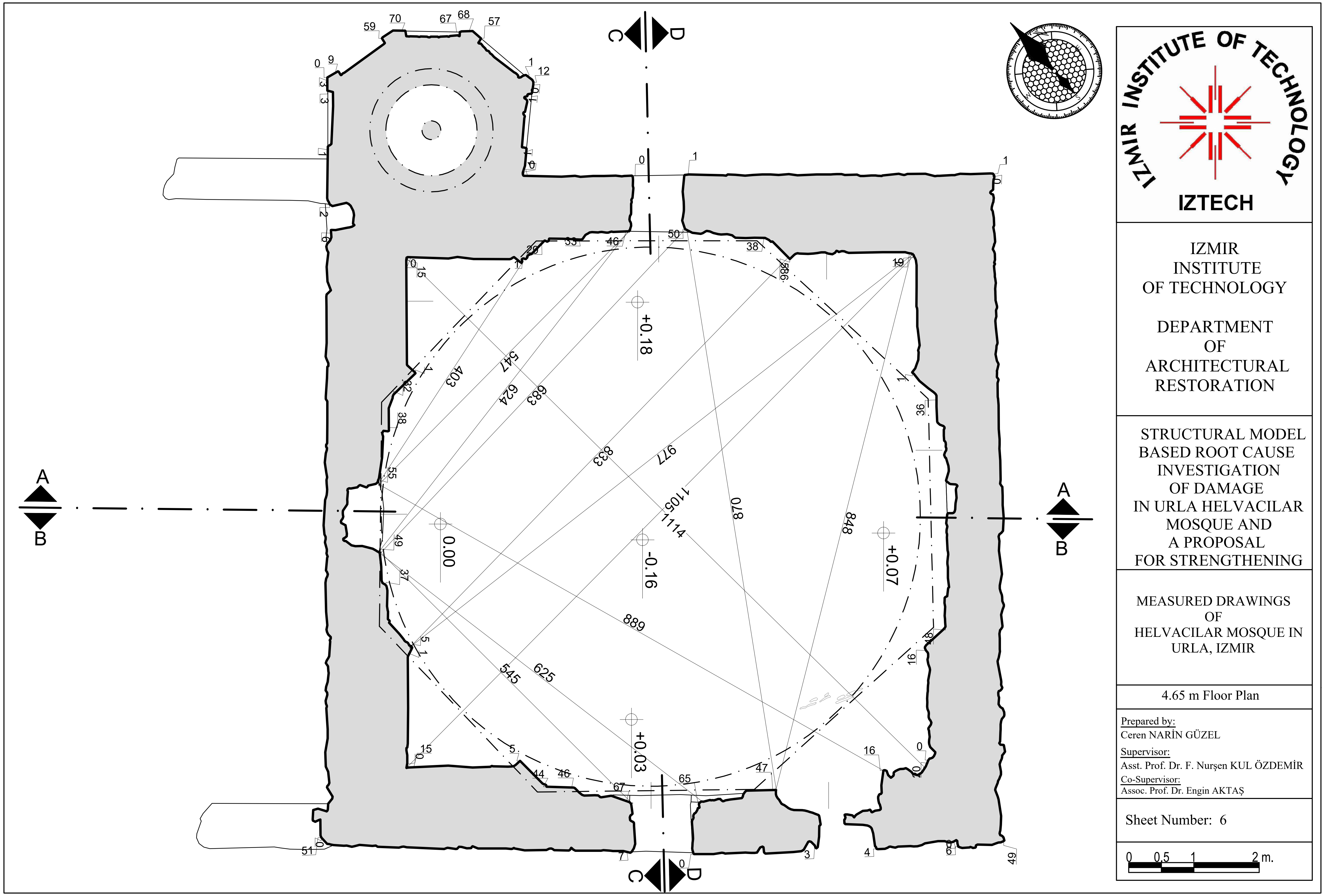


Figure A.5. Measured Drawings



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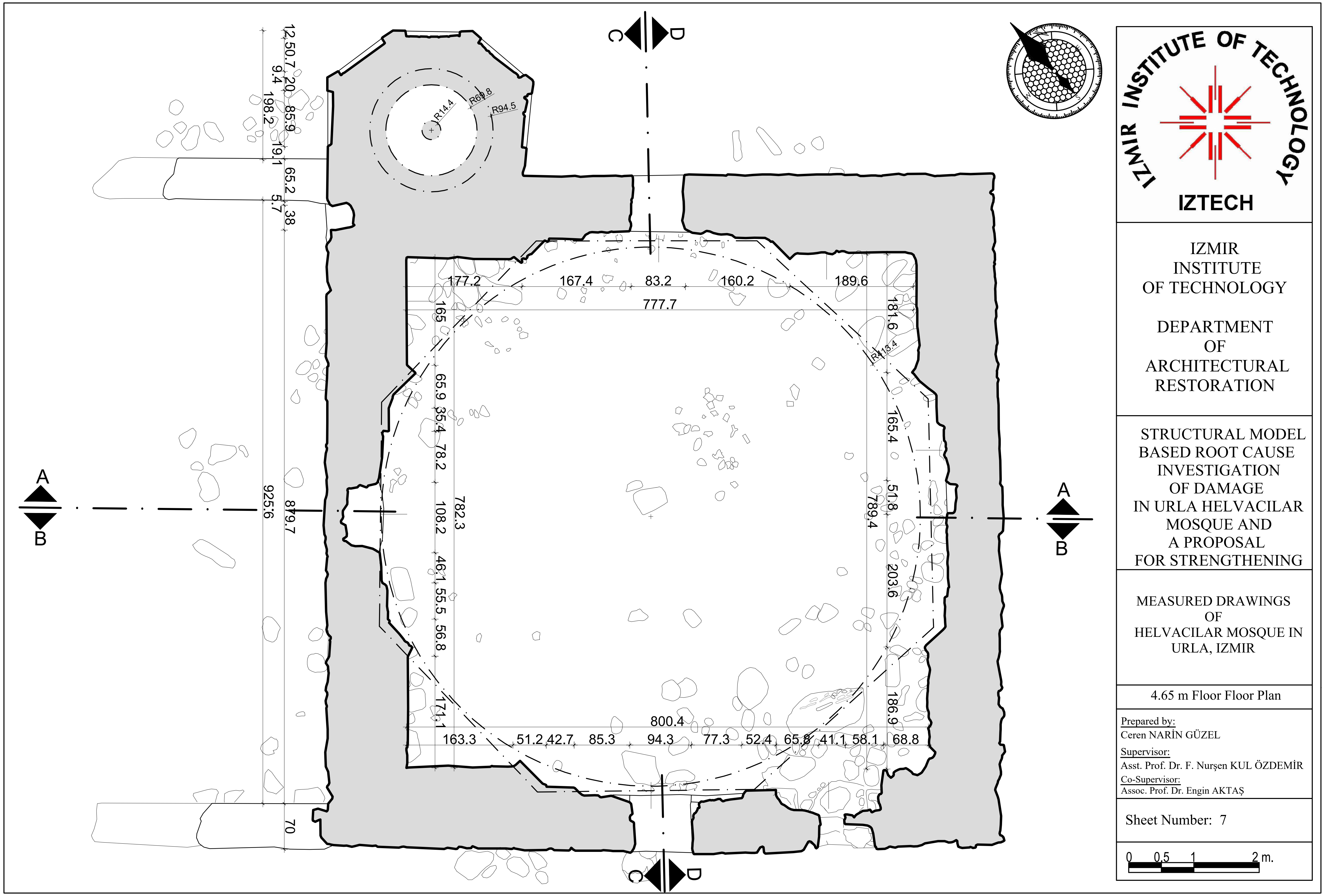
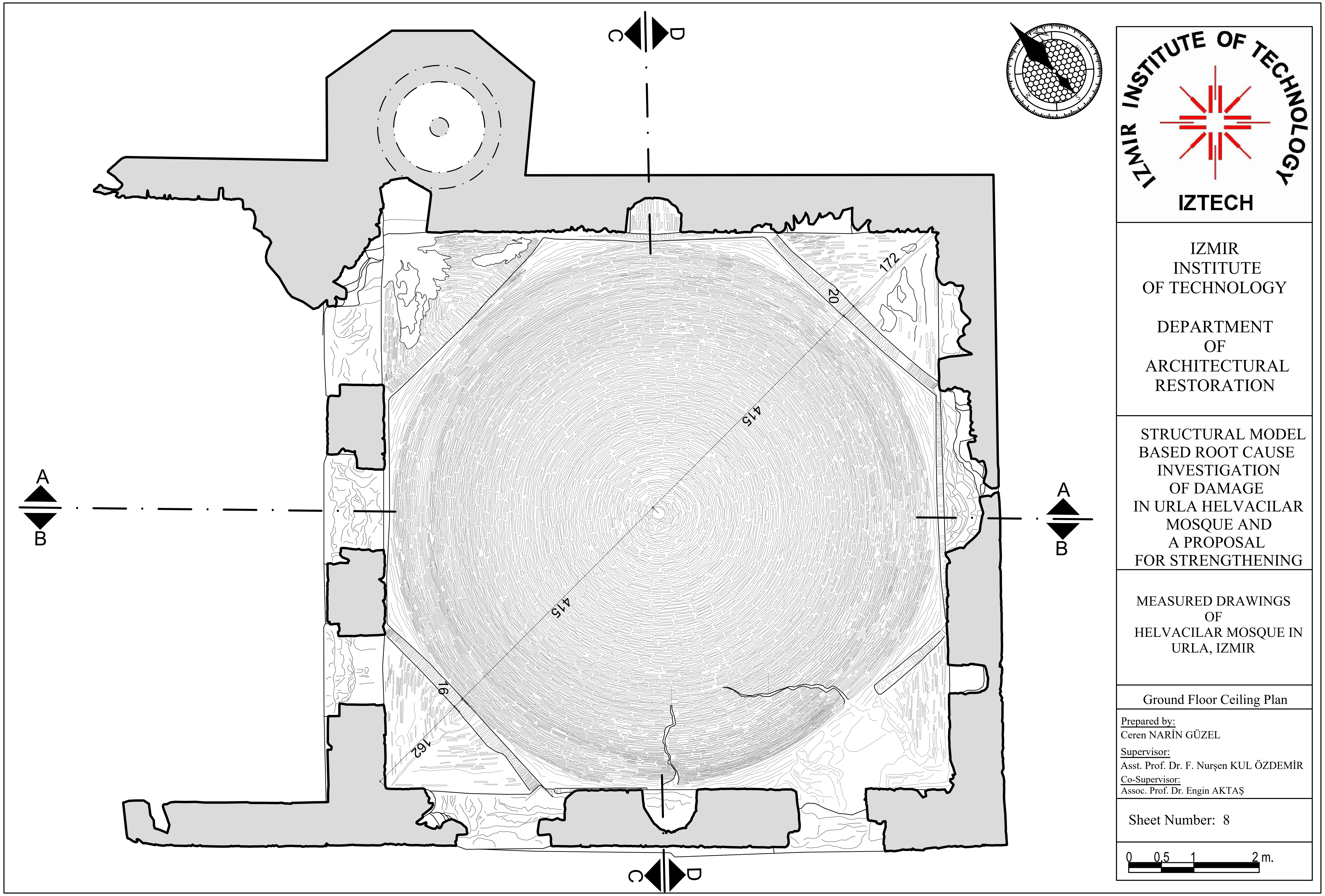


Figure A.7. Measured Drawings



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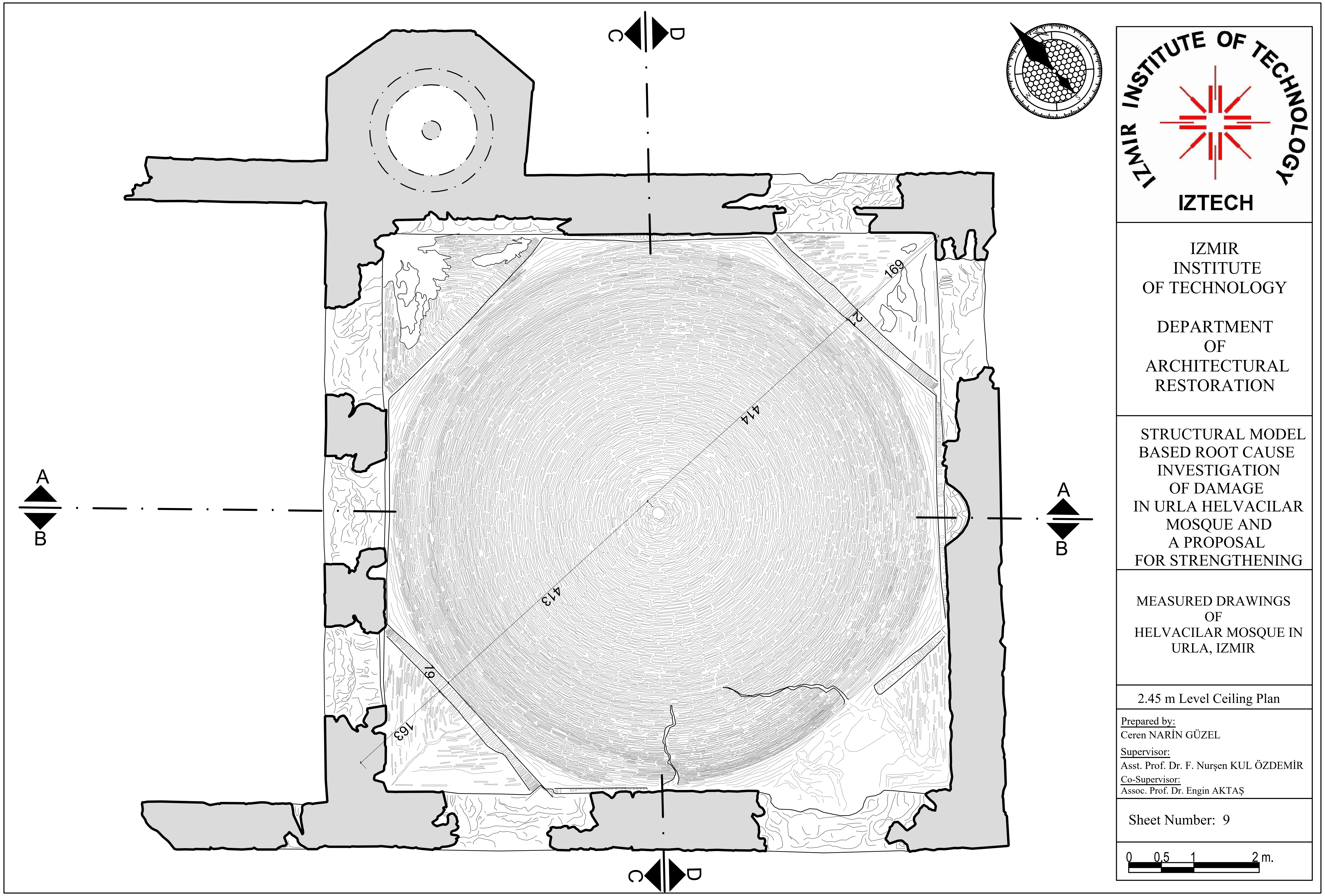


Figure A.9. Measured Drawings

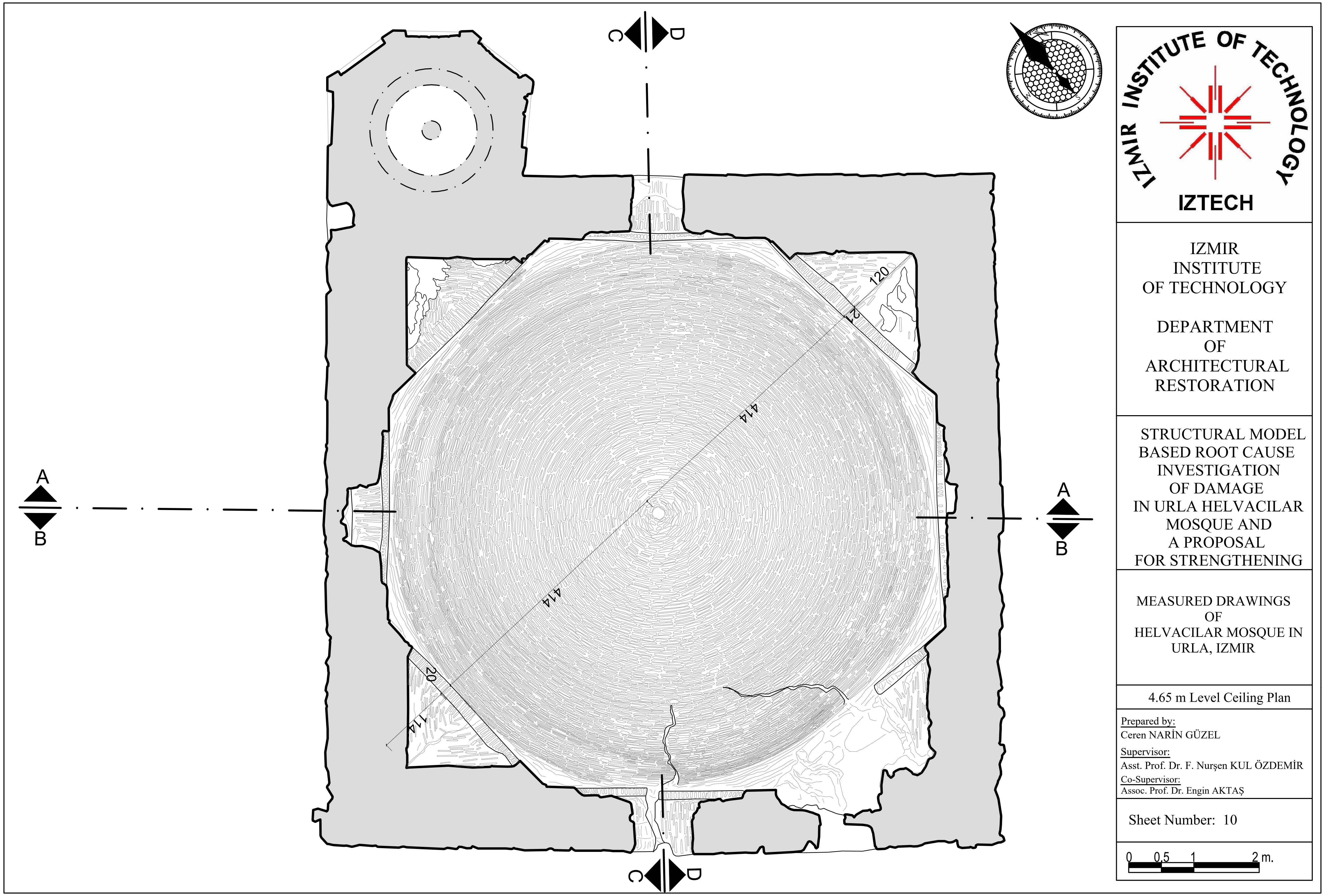


Figure A.10. Measured Drawings

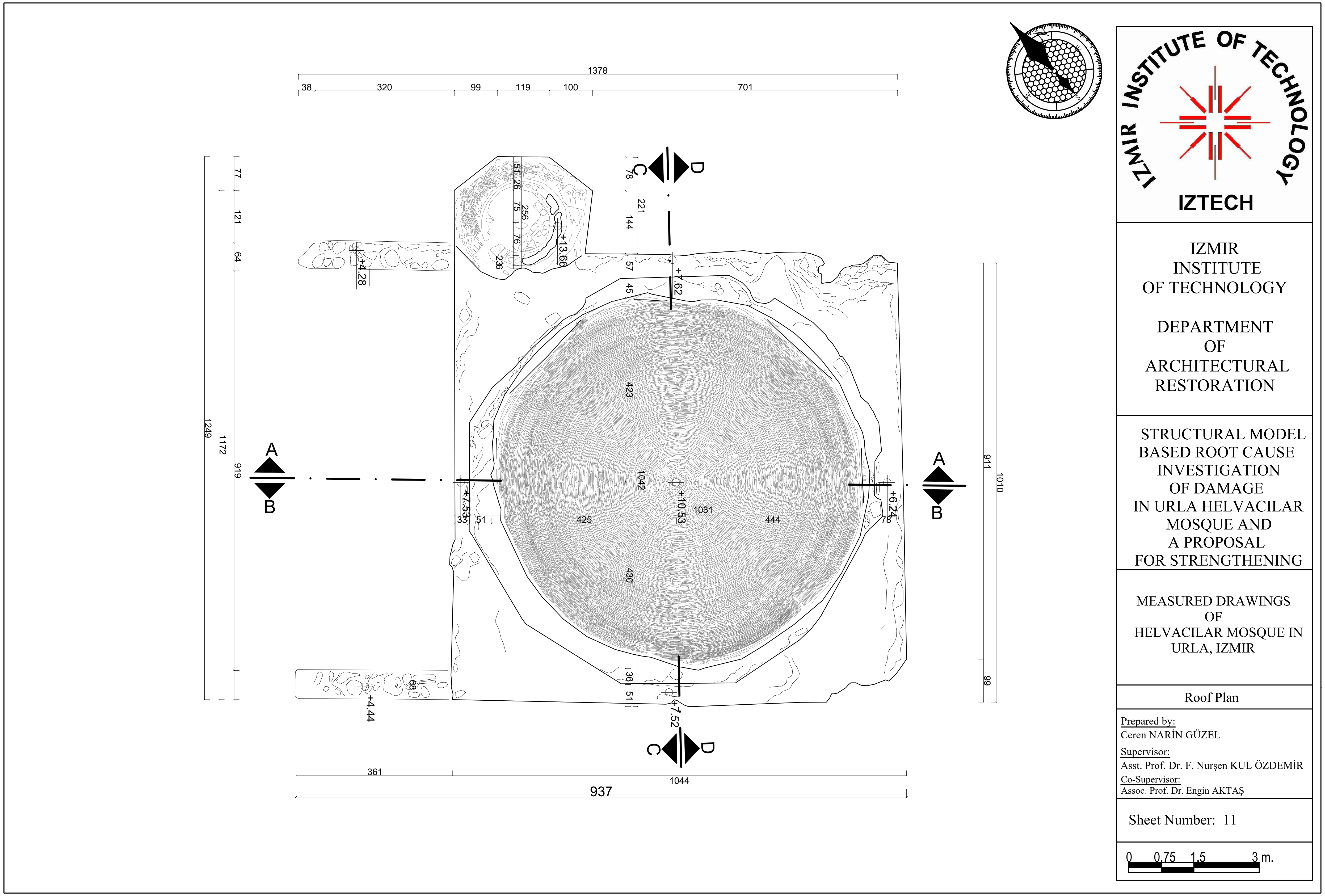
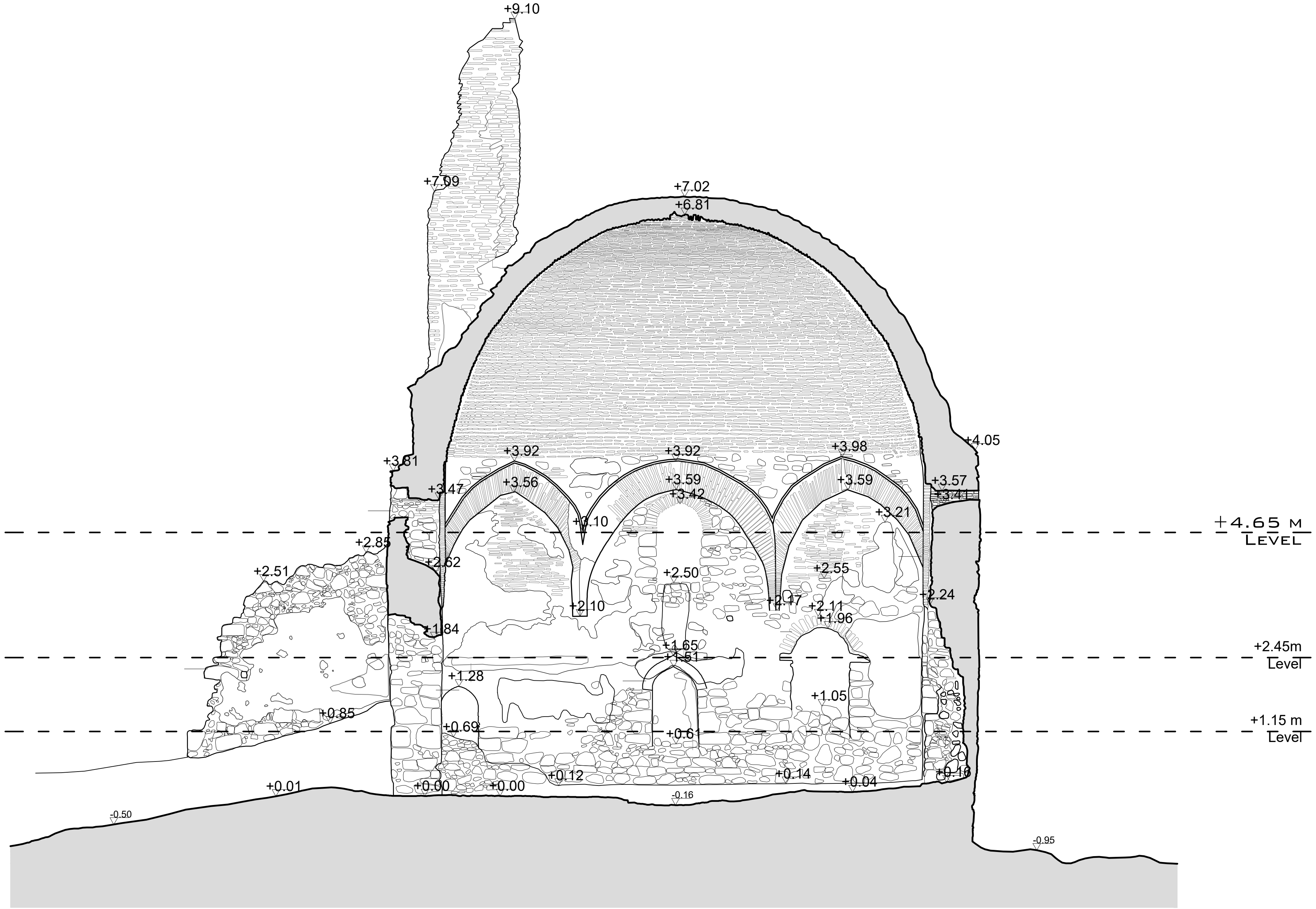


Figure A.11. Measured Drawings



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MEASURED DRAWINGS OF HELVACILAR MOSQUE IN URLA, IZMIR

AA Section

Prepared by:
Ceren NARİN GÜZEL

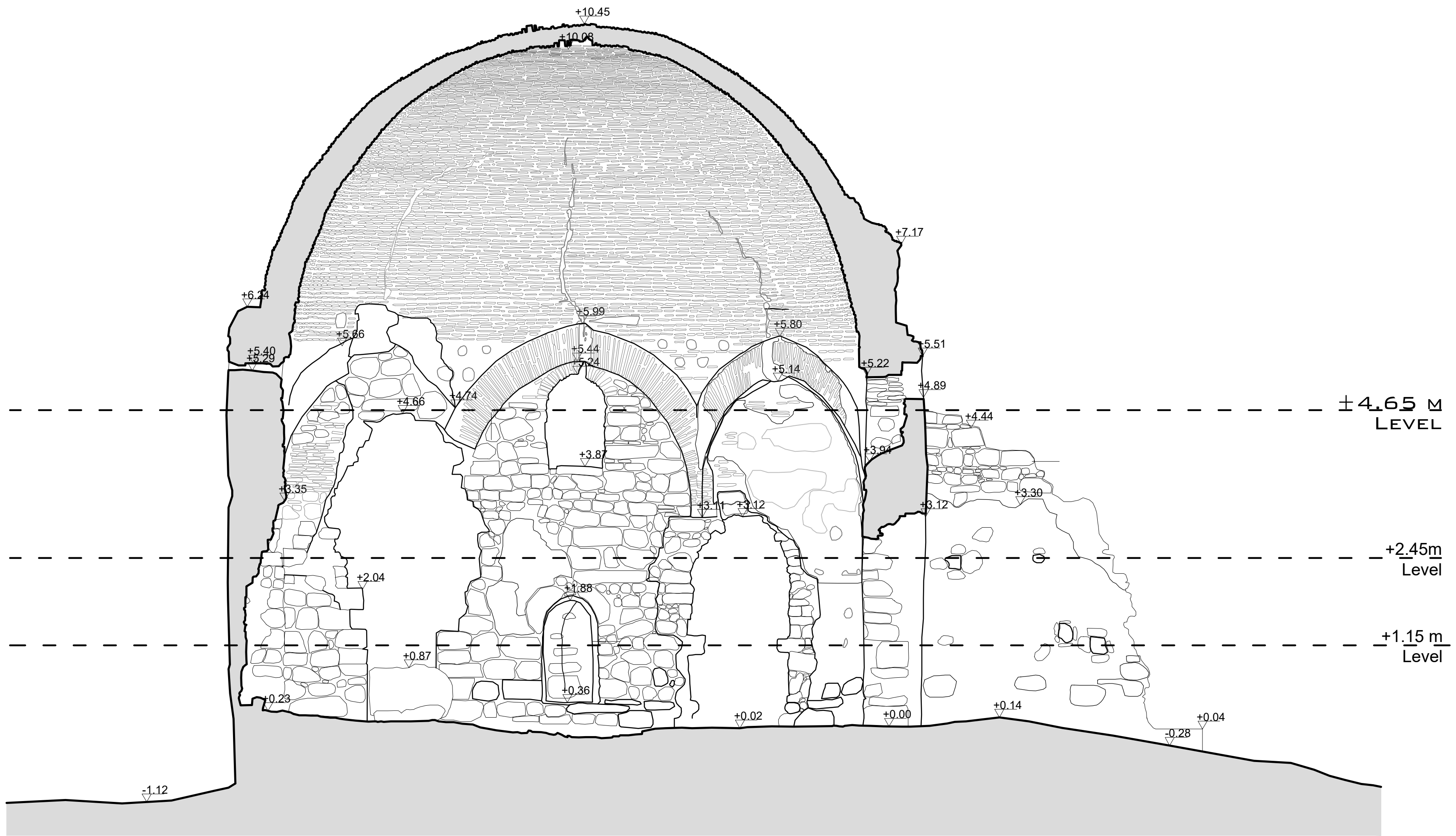
Supervisor:
Asst. Prof. Dr. F. Nurşen KUL ÖZDEMİR

Co-Supervisor:
Assoc. Prof. Dr. Engin AKTAŞ

Sheet Number: 12

0 0.75 1.5 3 m.

Figure A.12. Measured Drawings



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MOSQUE AND
A PROPOSAL
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URLA, IZMIR

BB Section

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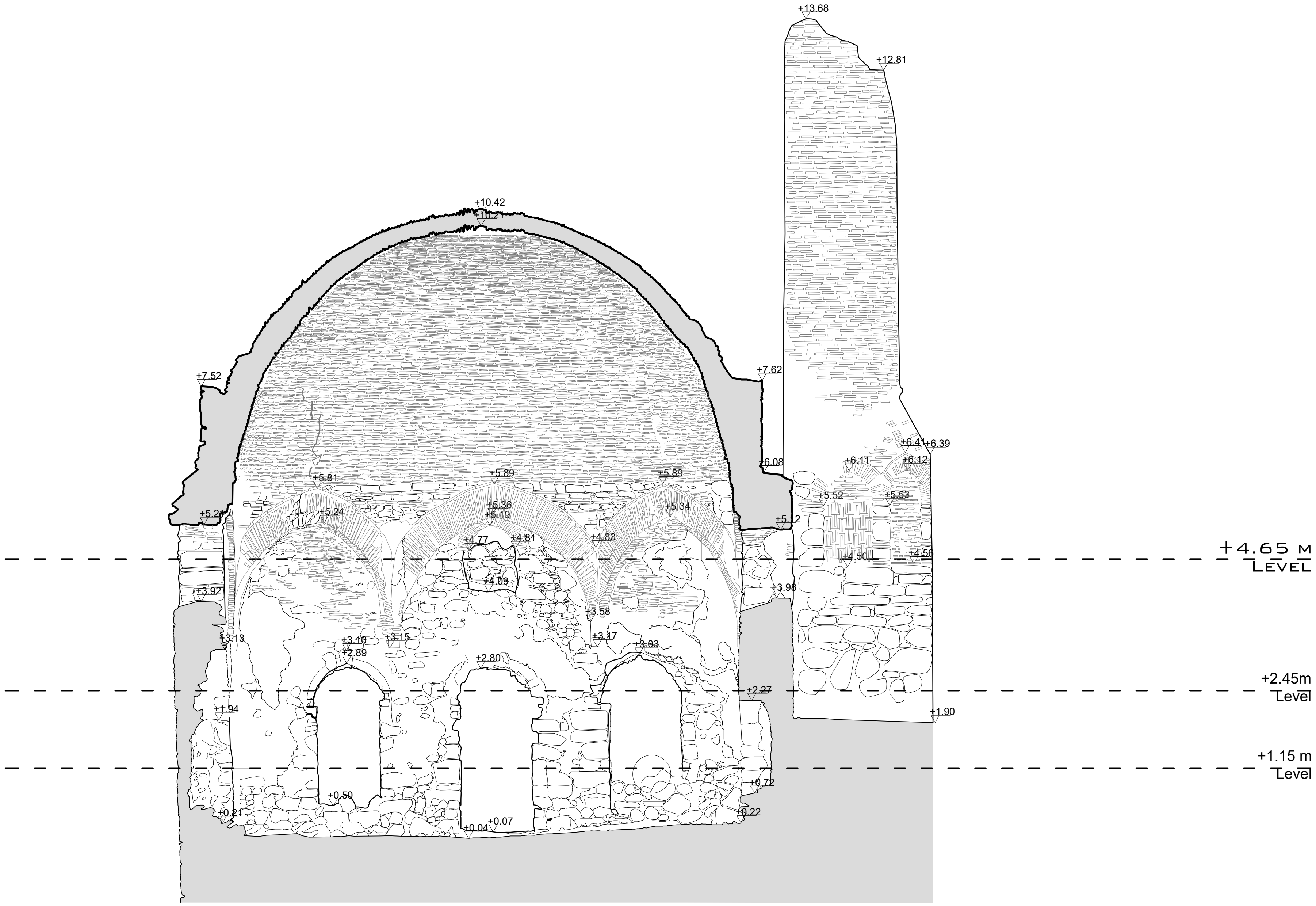
Sheet Number: 13

0 0.75 1.5 3 m.

Figure A.13. Measured Drawings



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CC Section

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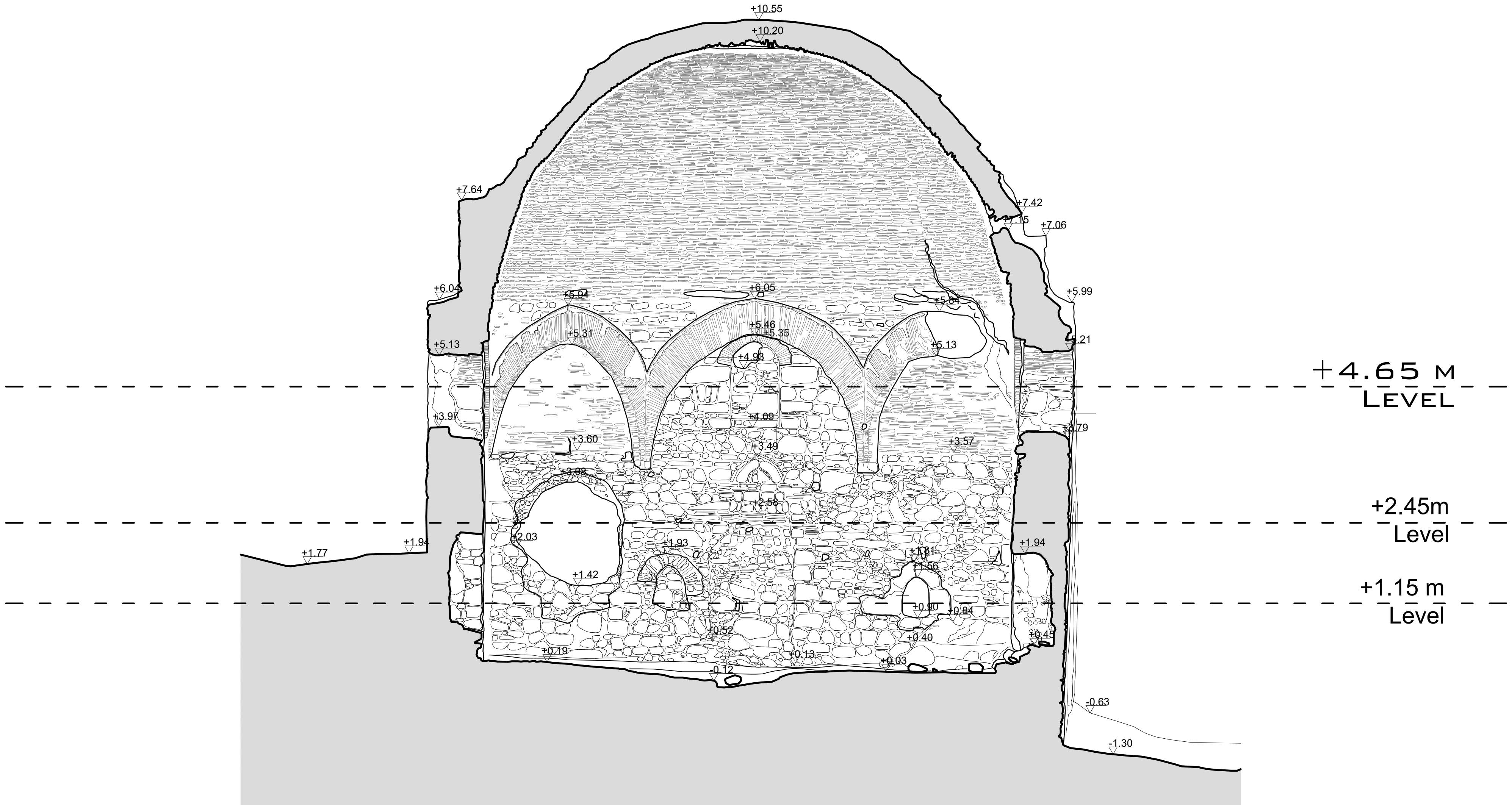
Sheet Number: 14

0 0.75 1.5 3 m.

Figure A.14. Measured Drawings



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DD Section

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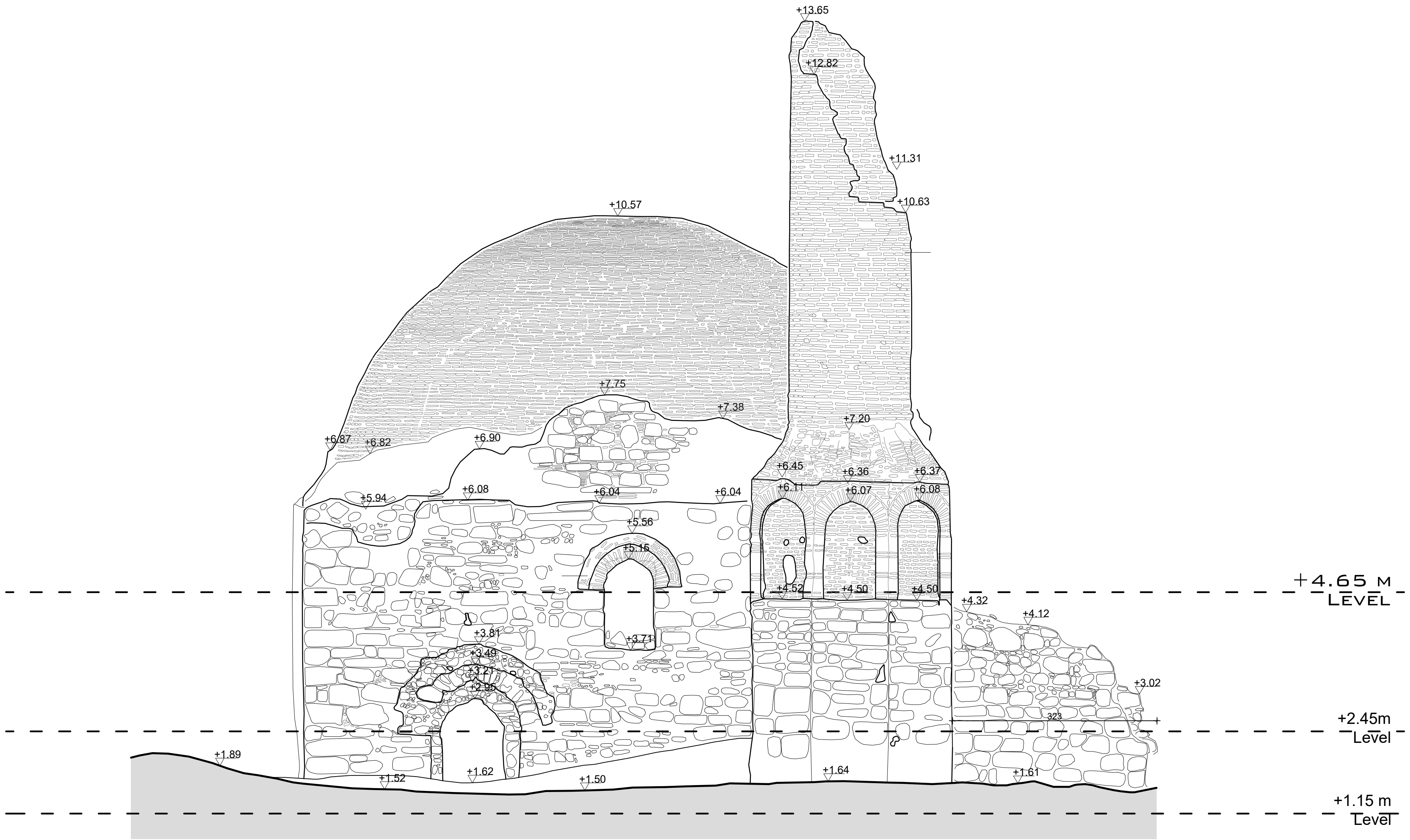
Sheet Number: 15

0 0.75 1.5 3 m.

Figure A.15. Measured Drawings



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MEASURED DRAWINGS OF HELVACILAR MOSQUE IN URLA, IZMIR

North Façade

Prepared by:
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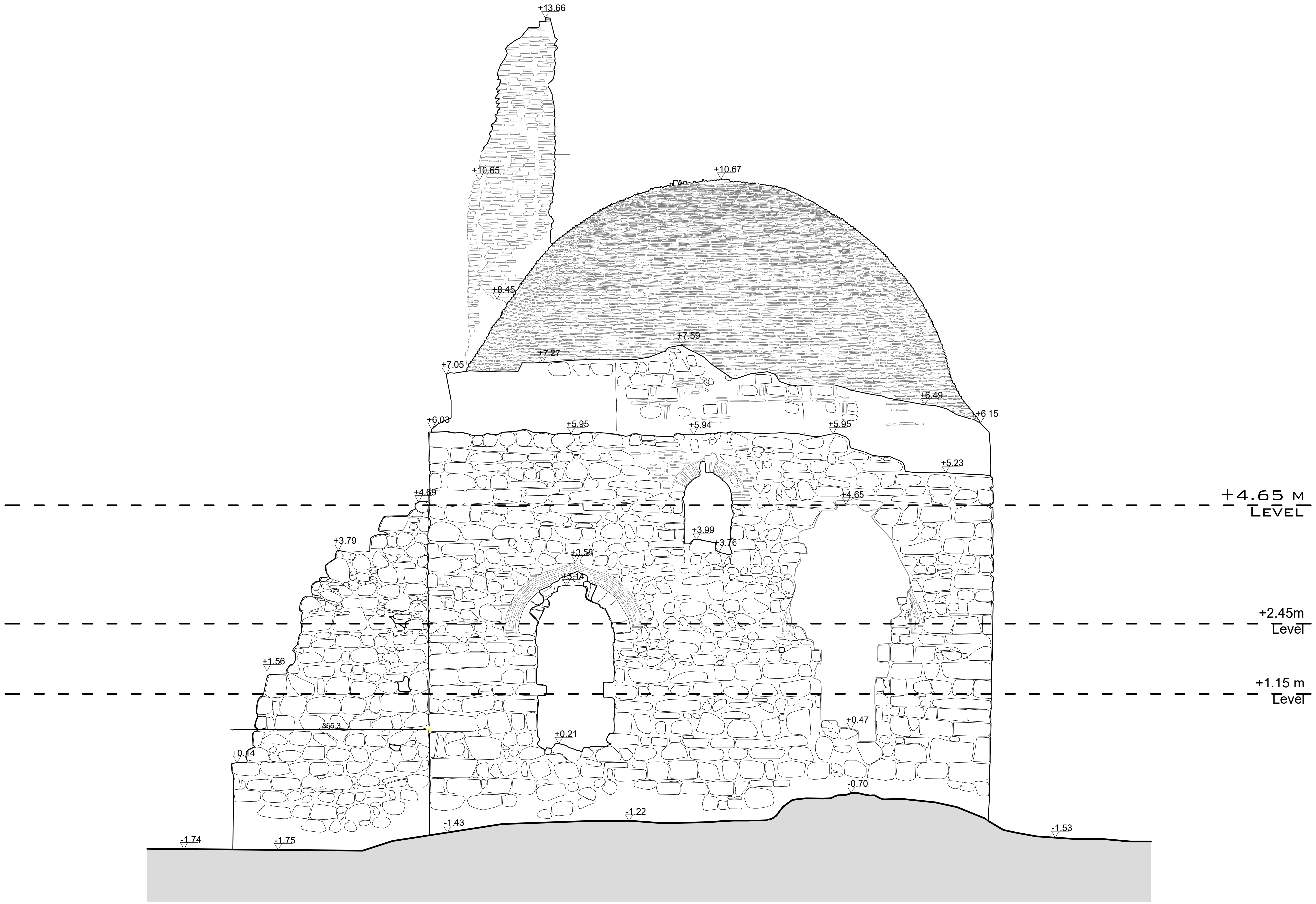
Co-Supervisor:
Assoc. Prof. Dr. Engin AKTAŞ

Sheet Number: 16

0 0.75 1.5 3 m.

Figure A.16. Measured Drawings



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OF DAMAGE
IN URLA HELVACILAR
MOSQUE AND
A PROPOSAL
FOR STRENGTHENING

MEASURED DRAWINGS
OF
HELVACILAR MOSQUE IN
URLA, IZMIR

South Façade

Prepared by:
Ceren NARİN GÜZEL

Supervisor:
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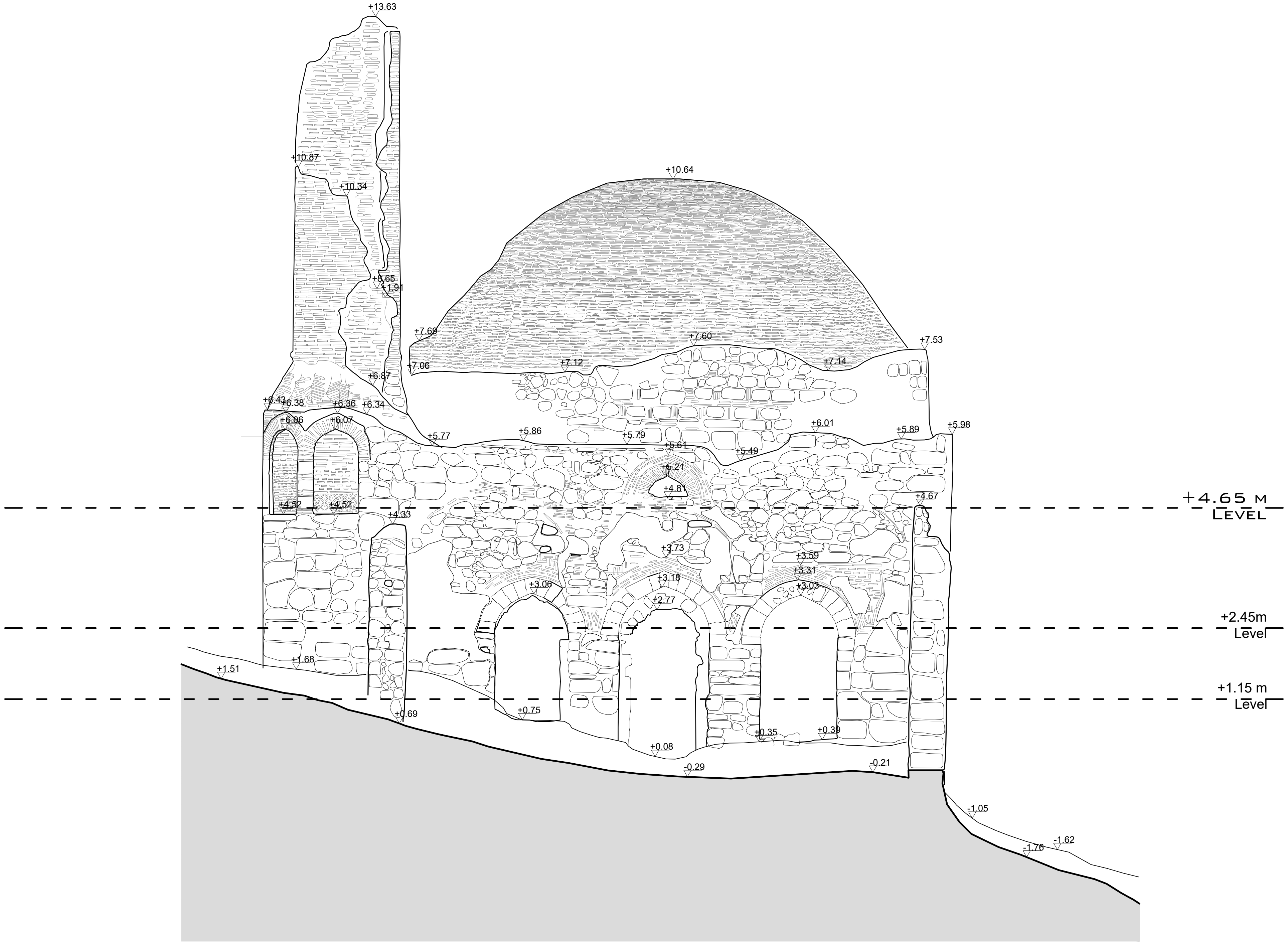
Co-Supervisor:
Assoc. Prof. Dr. Engin AKTAŞ

Sheet Number: 17

0 0.75 1.5 3 m.

Figure A.17. Measured Drawings



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MEASURED DRAWINGS OF HELVACILAR MOSQUE IN URLA, IZMIR

West Façade

Prepared by:
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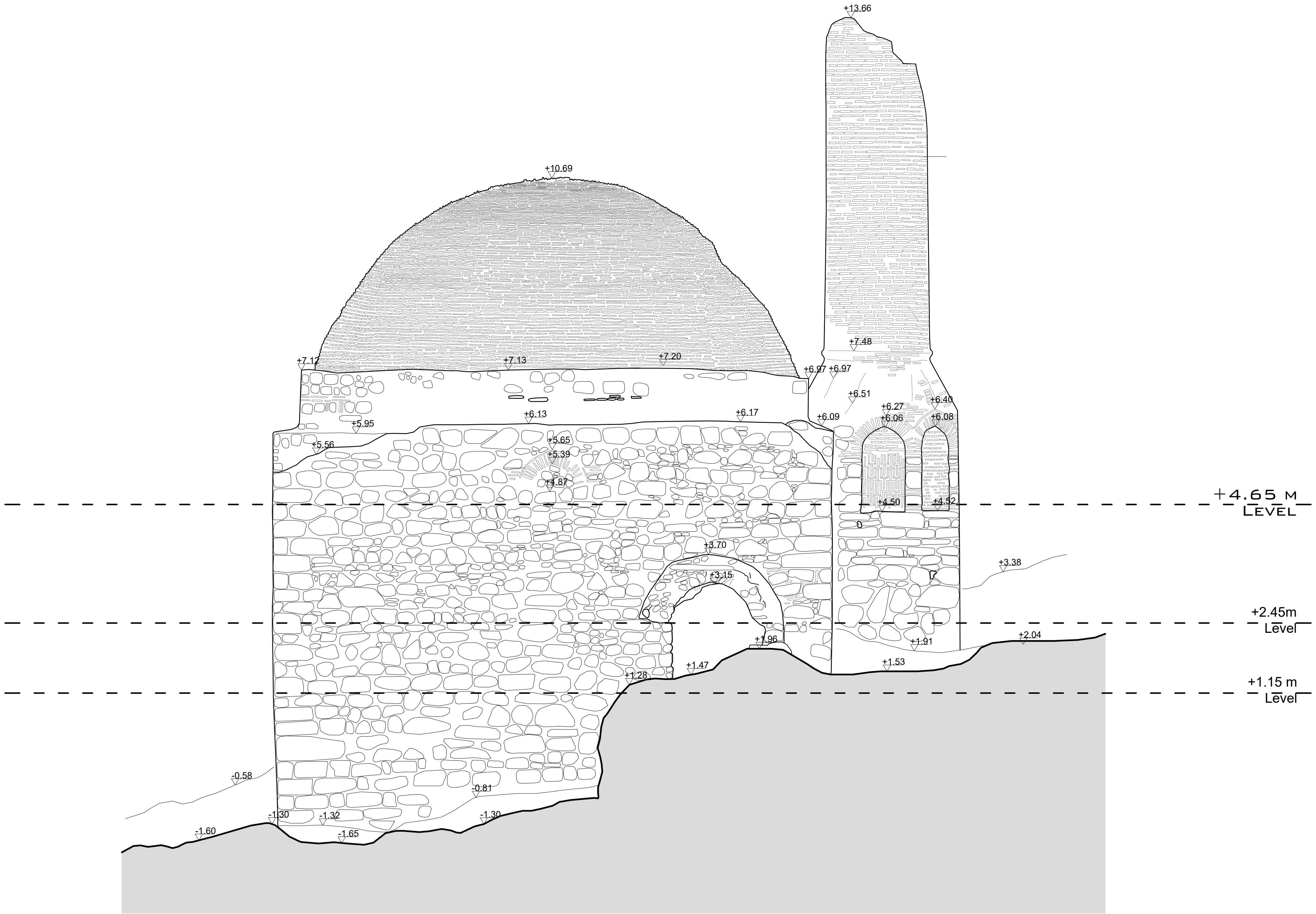
Co-Supervisor:
Assoc. Prof. Dr. Engin AKTAŞ

Sheet Number: 18

0 0.75 1.5 3 m.

Figure A.18. Measured Drawings



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East Façade

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Sheet Number: 19

0 0.75 1.5 3 m.

Figure A.19. Measured Drawings

APPENDIX B

SPATIAL AND ARCHITECTURAL ELEMENTS

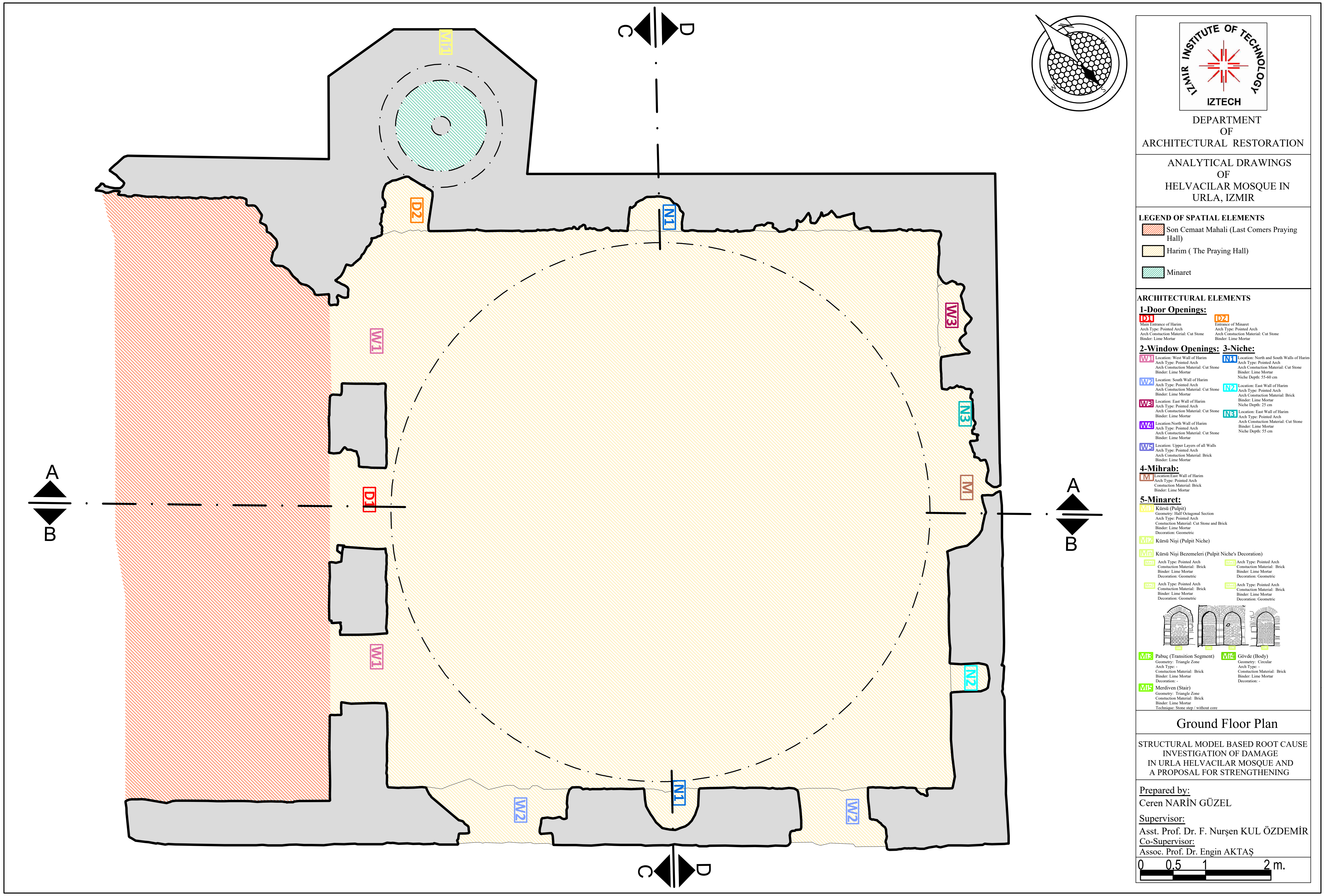


Figure B.1. Spatial and Architectural Elements

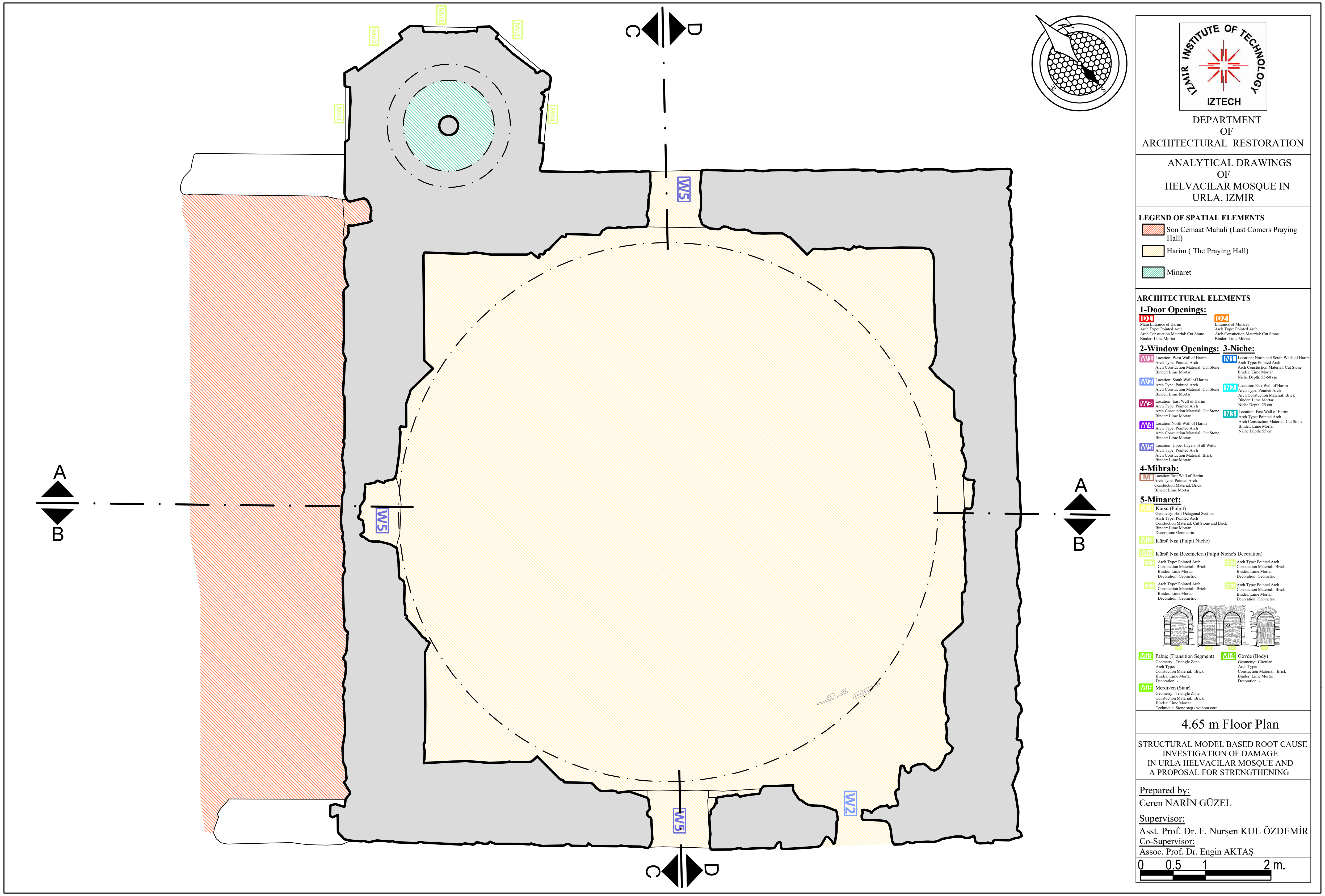


Figure B.2. Spatial and Architectural Elements

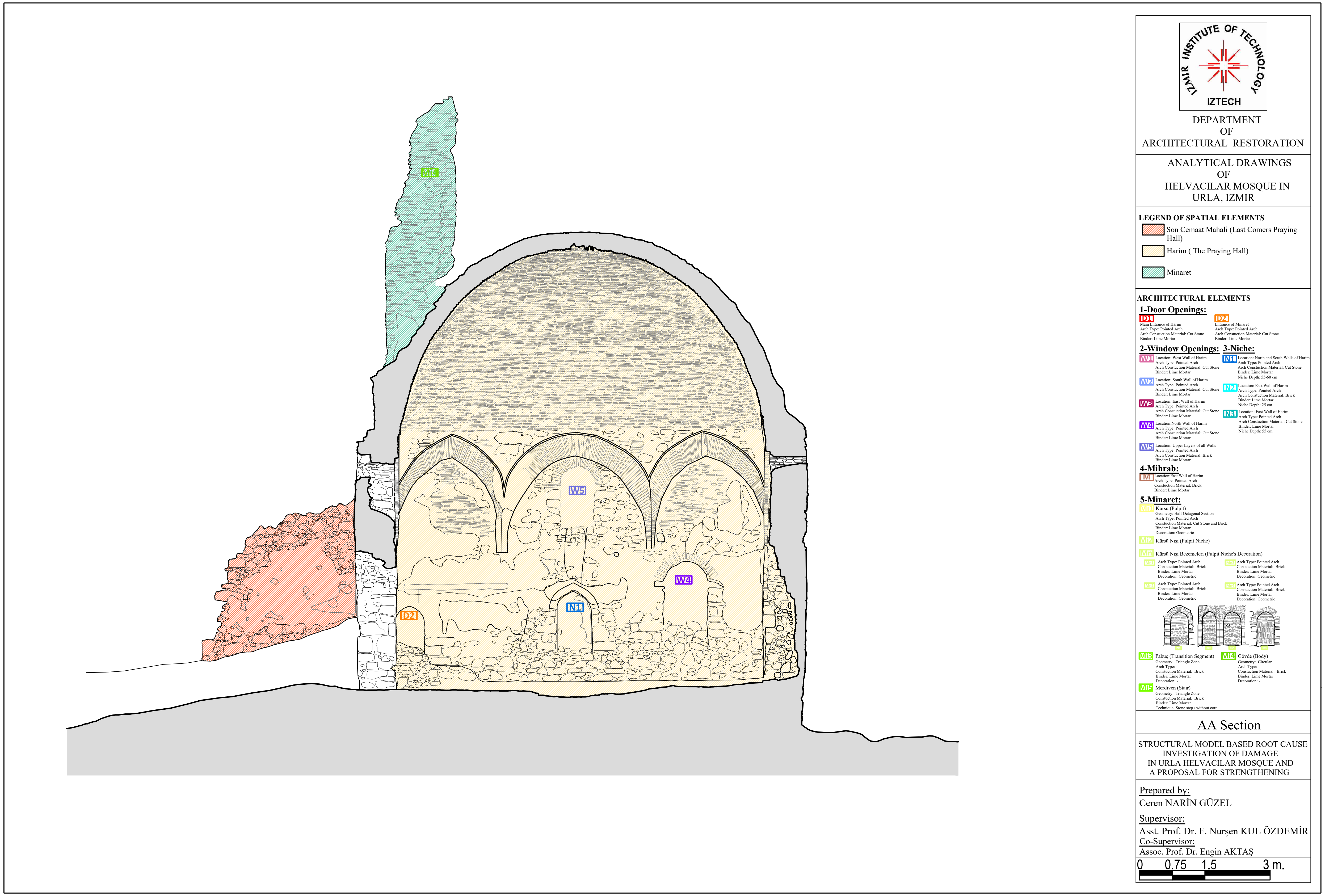
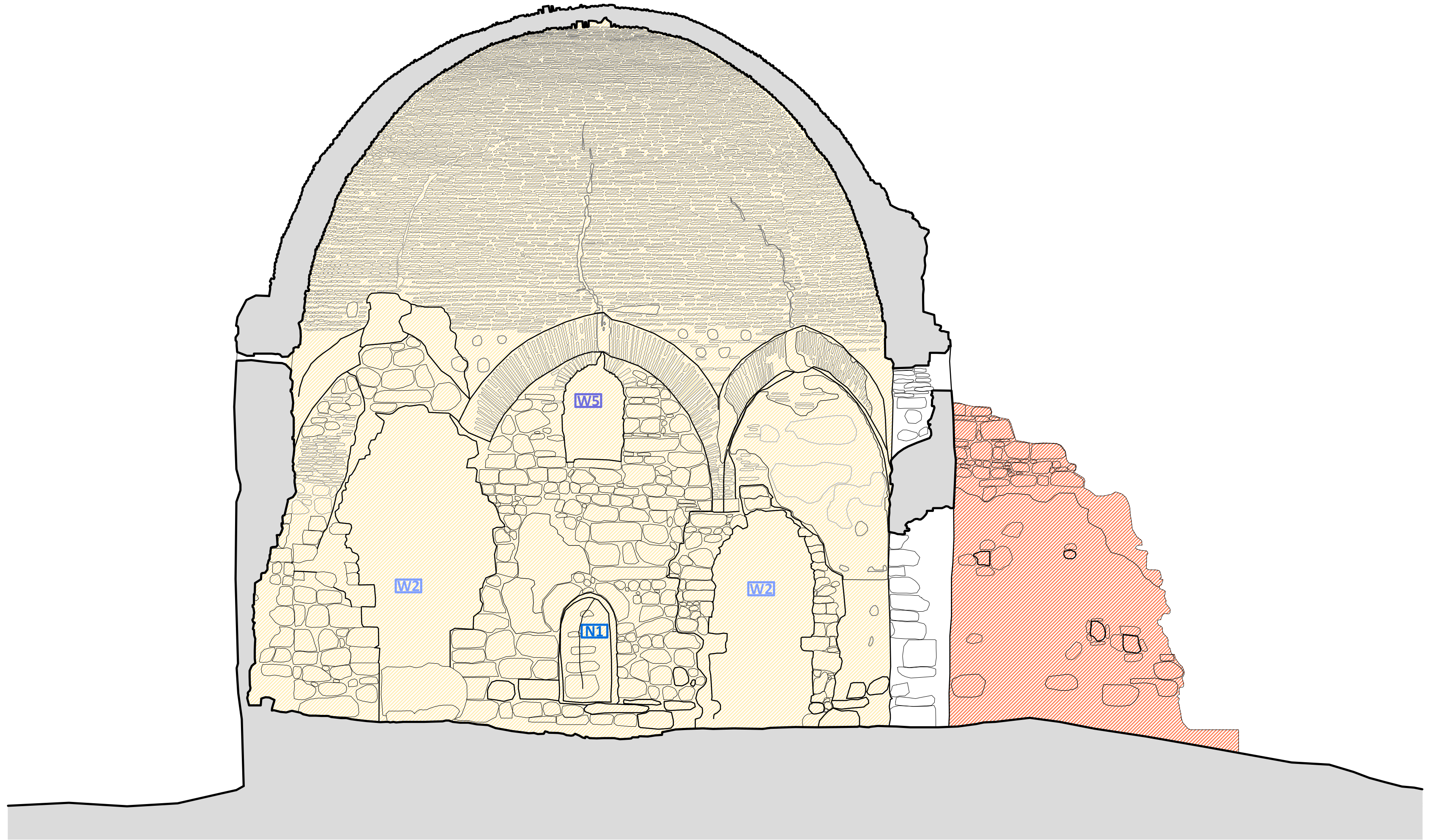


Figure B.3. Spatial and Architectural Elements



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LEGEND OF SPATIAL ELEMENTS

- Son Cemaat Mahali (Last Comers Praying Hall)
- Harim (The Praying Hall)
- Minaret

ARCHITECTURAL ELEMENTS

1-Door Openings:

D1
Main Entrance of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

D2
Entrance of Minaret
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

2-Window Openings:

W1 Location: West Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W2 Location: South Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W3 Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W4 Location:North Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W5 Location: Upper Layers of all Walls
Arch Type: Pointed Arch
Arch Constuction Material: Brick
Binder: Lime Mortar

3-Niche:

N1 Location: North and South Walls of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar
Niche Depth: 55-60 cm

N2 Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Brick
Binder: Lime Mortar
Niche Depth: 25 cm

N3 Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar
Niche Depth: 55 cm

4-Mihrab:

M Location:East Wall of Harim
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar

5-Minaret:

Mi1 Kürsü (Pulpit)
Geometry: Half Octagonal Section
Arch Type: Pointed Arch
Constuction Material: Cut Stone and Brick
Binder: Lime Mortar
Decoration: Geometric

Mi2 Kürsü Nişi (Pulpit Niche)

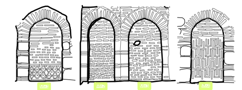
Mn Kürsü Nişi Bezemeleri (Pulpit Niche's Decoration)

Mn1 Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn3 Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn2 Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn4 Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric



Mi3 Pabuç (Transition Segment)
Geometry: Triangle Zone
Arch Type: -
Constuction Material: Brick
Binder: Lime Mortar
Decoration: -

Mi4 Gövde (Body)
Geometry: Circular
Arch Type: -
Constuction Material: Brick
Binder: Lime Mortar
Decoration: -

Mi5 Merdiven (Stair)
Geometry: Triangle Zone
Constuction Material: Brick
Binder: Lime Mortar
Technique: Stone step / without core

BB Section

STRUCTURAL MODEL BASED ROOT CAUSE
INVESTIGATION OF DAMAGE
IN URLA HELVACILAR MOSQUE AND
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Prepared by:
Ceren NARİN GÜZEL

Supervisor:
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Co-Supervisor:
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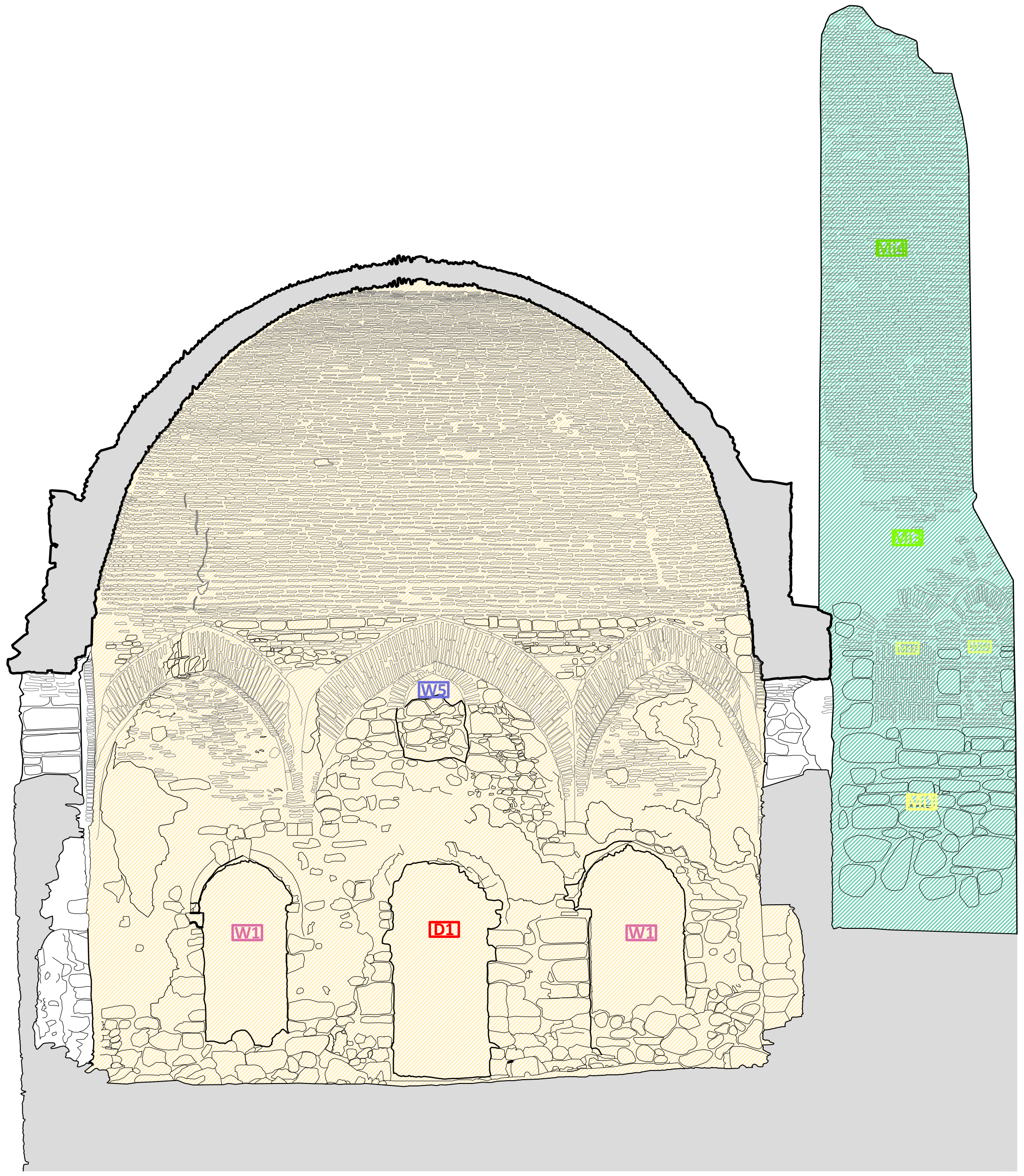
0 0,75 1,5 3 m.

Figure B.4. Spatial and Architectural Elements



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- Harim (The Praying Hall)
- Minaret

ARCHITECTURAL ELEMENTS

1-Door Openings:

D1
Main Entrance of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

D2
Entrance of Minaret
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

2-Window Openings:

W1
Location: West Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W2
Location: South Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W3
Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W4
Location:North Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W5
Location: Upper Layers of all Walls
Arch Type: Pointed Arch
Arch Constuction Material: Brick
Binder: Lime Mortar

3-Niche:

N1
Location: North and South Walls of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar
Niche Depth: 55-60 cm

N2
Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Brick
Binder: Lime Mortar
Niche Depth: 25 cm

N3
Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar
Niche Depth: 55 cm

4-Mihrab:

M
Location:East Wall of Harim
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar

5-Minaret:

Mi1 Kürsü (Pulpit)
Geometry: Half Octagonal Section
Arch Type: Pointed Arch
Constuction Material: Cut Stone and Brick
Binder: Lime Mortar
Decoration: Geometric

Mi2 Kürsü Nişi (Pulpit Niche)

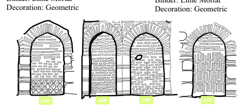
Mn Kürsü Nişi Bezemeleri (Pulpit Niche's Decoration)

Mn1
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn3
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn2
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn4
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric



Mi3 Pabuç (Transition Segment)
Geometry: Triangle Zone
Arch Type: -
Constuction Material: Brick
Binder: Lime Mortar
Decoration: -

Mi4 Gövde (Body)
Geometry: Circular
Arch Type: -
Constuction Material: Brick
Binder: Lime Mortar
Decoration: -

Mi5 Merdiven (Stair)
Geometry: Triangle Zone
Constuction Material: Brick
Binder: Lime Mortar
Technique: Stone step / without core

CC Section

STRUCTURAL MODEL BASED ROOT CAUSE
INVESTIGATION OF DAMAGE
IN URLA HELVACILAR MOSQUE AND
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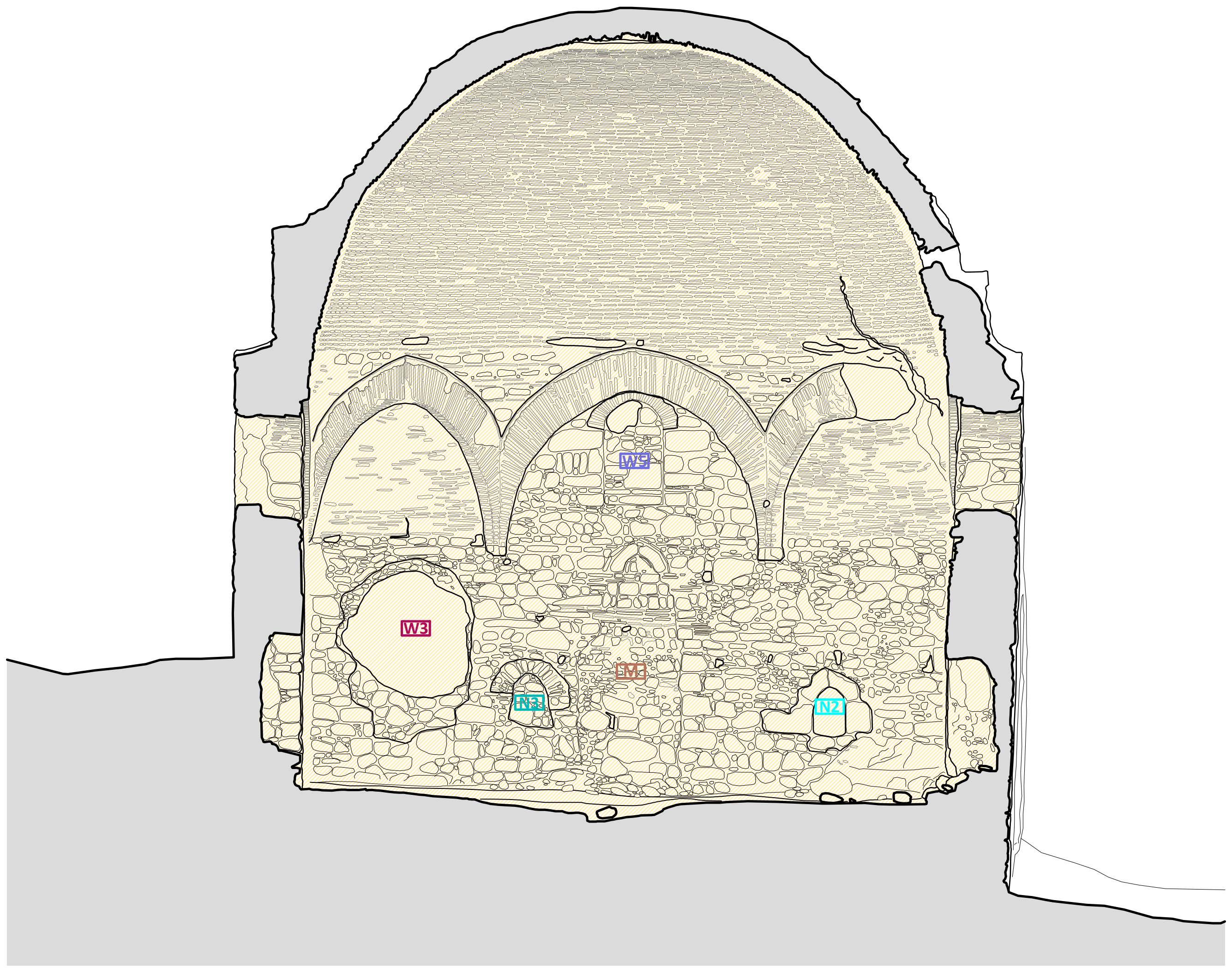
0 0.75 1.5 3 m.

Figure B.5. Spatial and Architectural Elements



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Entrance of Minaret
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
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2-Window Openings:

W1 Location: West Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W2 Location: South Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W3 Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W4 Location:North Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W5 Location: Upper Layers of all Walls
Arch Type: Pointed Arch
Arch Constuction Material: Brick
Binder: Lime Mortar

3-Niche:

N1 Location: North and South Walls of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar
Niche Depth: 55-60 cm

N2 Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Brick
Binder: Lime Mortar
Niche Depth: 25 cm

N3 Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar
Niche Depth: 55 cm

4-Mihrab:

M Location:East Wall of Harim
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar

5-Minaret:

Mi1 Kürsü (Pulpit)
Geometry: Half Octagonal Section
Arch Type: Pointed Arch
Constuction Material: Cut Stone and Brick
Binder: Lime Mortar
Decoration: Geometric

Mi2 Kürsü Nişi (Pulpit Niche)

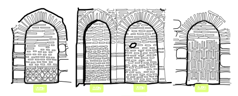
Mn Kürsü Nişi Bezemeleri (Pulpit Niche's Decoration)

Mn1 Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn2 Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn3 Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn4 Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric



Mi3 Pabuç (Transition Segment)
Geometry: Triangle Zone
Arch Type: -
Constuction Material: Brick
Binder: Lime Mortar
Decoration: -

Mi4 Gövde (Body)
Geometry: Circular
Arch Type: -
Constuction Material: Brick
Binder: Lime Mortar
Decoration: -

Mi5 Merdiven (Stair)
Geometry: Triangle Zone
Constuction Material: Brick
Binder: Lime Mortar
Technique: Stone step / without core

DD Section

STRUCTURAL MODEL BASED ROOT CAUSE INVESTIGATION OF DAMAGE IN URLA HELVACILAR MOSQUE AND A PROPOSAL FOR STRENGTHENING

Prepared by:
Ceren NARİN GÜZEL

Supervisor:
Asst. Prof. Dr. F. Nurşen KUL ÖZDEMİR

Co-Supervisor:
Assoc. Prof. Dr. Engin AKTAŞ

0 0,75 1,5 3 m.

Figure B.6. Spatial and Architectural Elements

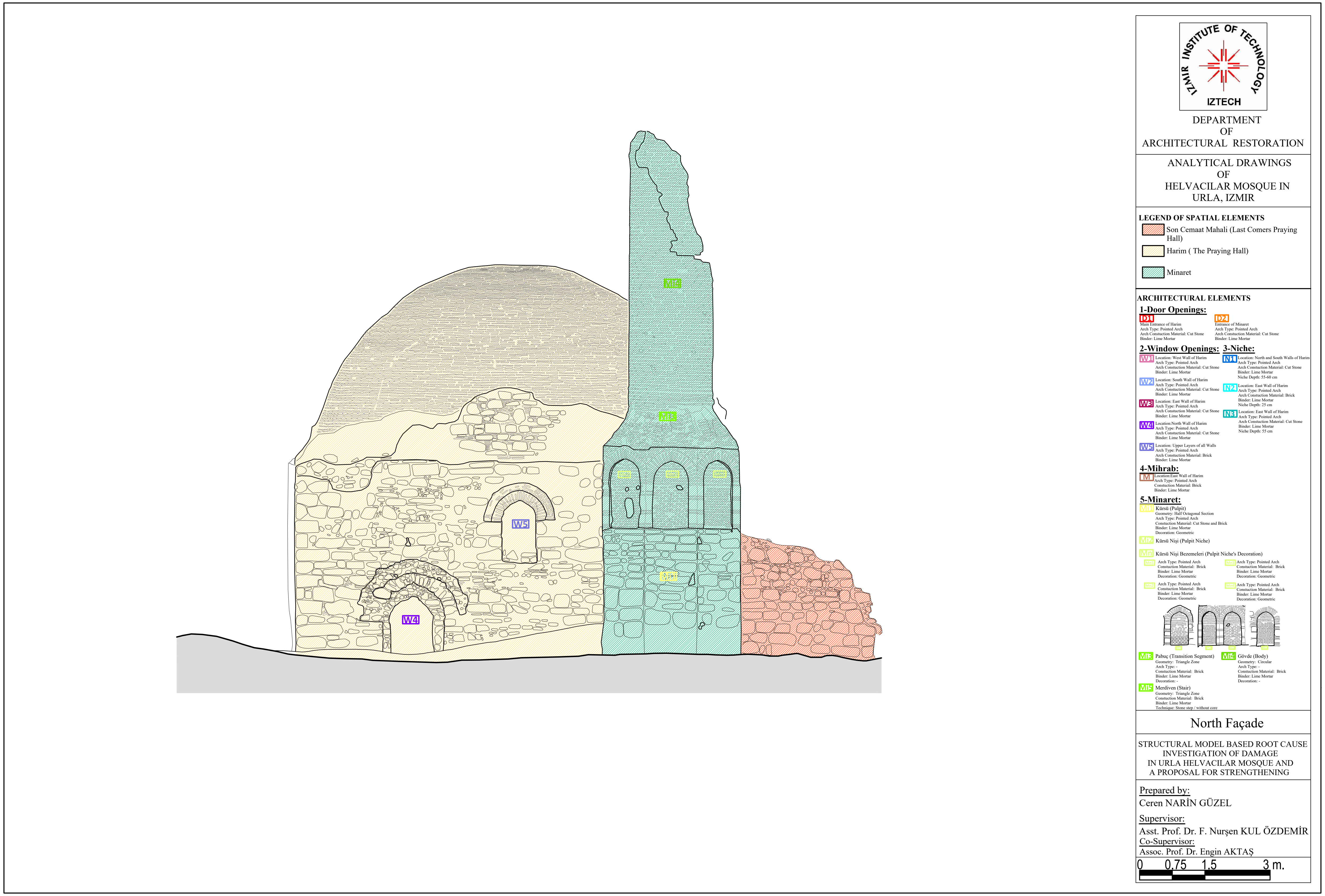
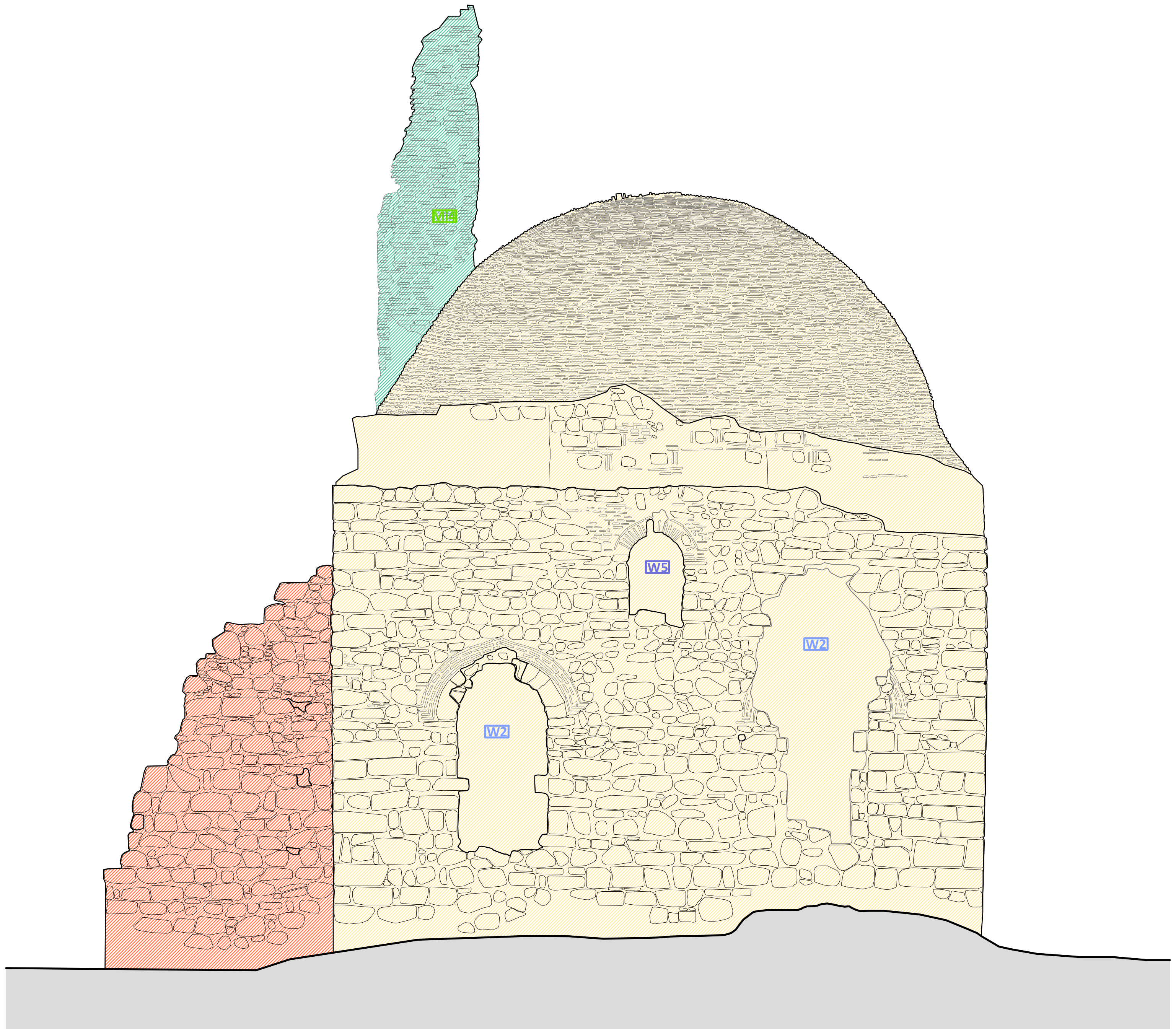


Figure B.7. Spatial and Architectural Elements



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URLA, IZMIR

LEGEND OF SPATIAL ELEMENTS

- Son Cemaat Mahali (Last Comers Praying Hall)
- Harim (The Praying Hall)
- Minaret

ARCHITECTURAL ELEMENTS

1-Door Openings:

D1
Main Entrance of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

D2
Entrance of Minaret
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

2-Window Openings:

W1
Location: West Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W2
Location: South Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W3
Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W4
Location:North Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W5
Location: Upper Layers of all Walls
Arch Type: Pointed Arch
Arch Constuction Material: Brick
Binder: Lime Mortar

3-Niche:

N1
Location: North and South Walls of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar
Niche Depth: 55-60 cm

N2
Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Brick
Binder: Lime Mortar
Niche Depth: 25 cm

N3
Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar
Niche Depth: 55 cm

4-Mihrab:

M
Location:East Wall of Harim
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar

5-Minaret:

Mi1 Kürsü (Pulpit)
Geometry: Half Octagonal Section
Arch Type: Pointed Arch
Constuction Material: Cut Stone and Brick
Binder: Lime Mortar
Decoration: Geometric

Mi2 Kürsü Nişi (Pulpit Niche)

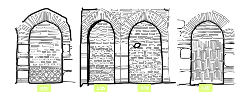
Mn Kürsü Nişi Bezemeleri (Pulpit Niche's Decoration)

Mn1
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn2
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn3
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn4
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric



Mi3 Pabuç (Transition Segment)
Geometry: Triangle Zone
Arch Type: -
Constuction Material: Brick
Binder: Lime Mortar
Decoration: -

Mi4 Gövde (Body)
Geometry: Circular
Arch Type: -
Constuction Material: Brick
Binder: Lime Mortar
Decoration: -

Mi5 Merdiven (Stair)
Geometry: Triangle Zone
Constuction Material: Brick
Binder: Lime Mortar
Technique: Stone step / without core

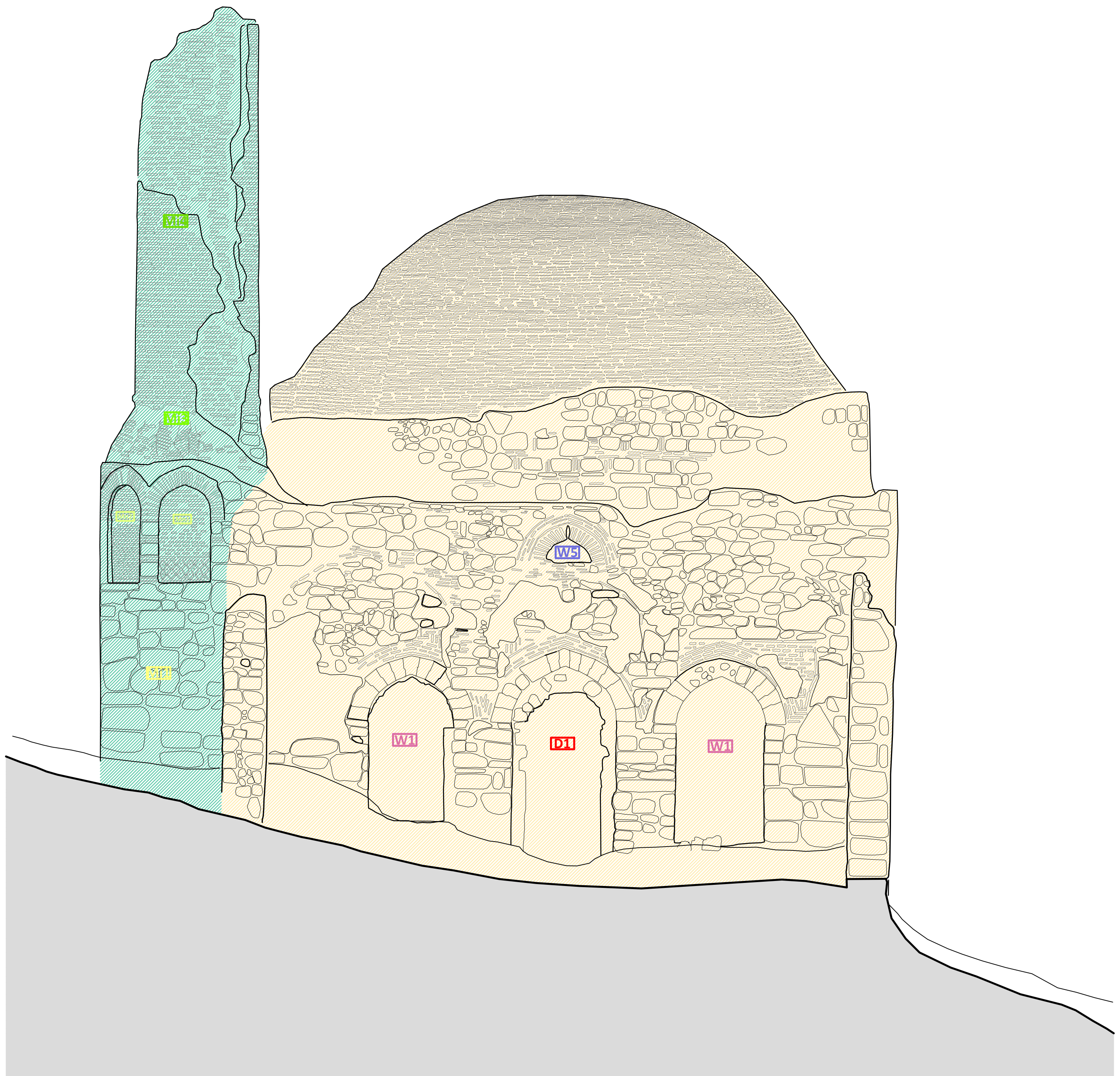
South Façade

STRUCTURAL MODEL BASED ROOT CAUSE
INVESTIGATION OF DAMAGE
IN URLA HELVACILAR MOSQUE AND
A PROPOSAL FOR STRENGTHENING

Prepared by:
Ceren NARİN GÜZEL
Supervisor:
Asst. Prof. Dr. F. Nurşen KUL ÖZDEMİR
Co-Supervisor:
Assoc. Prof. Dr. Engin AKTAŞ

0 0.75 1.5 3 m.

Figure B.8. Spatial and Architectural Elements



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LEGEND OF SPATIAL ELEMENTS

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- Minaret

ARCHITECTURAL ELEMENTS

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Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

D2
Entrance of Minaret
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

2-Window Openings:

W1 Location: West Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W2 Location: South Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W3 Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W4 Location:North Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W5 Location: Upper Layers of all Walls
Arch Type: Pointed Arch
Arch Constuction Material: Brick
Binder: Lime Mortar

3-Niche:

N1 Location: North and South Walls of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar
Niche Depth: 55-60 cm

N2 Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Brick
Binder: Lime Mortar
Niche Depth: 25 cm

N3 Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar
Niche Depth: 55 cm

4-Mihrab:

M Location:East Wall of Harim
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar

5-Minaret:

Mi1 Kürsü (Pulpit)
Geometry: Half Octagonal Section
Arch Type: Pointed Arch
Constuction Material: Cut Stone and Brick
Binder: Lime Mortar
Decoration: Geometric

Mi2 Kürsü Nişi (Pulpit Niche)

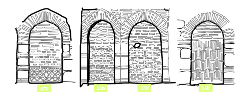
Mn Kürsü Nişi Bezemeleri (Pulpit Niche's Decoration)

Mn1 Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn3 Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn2 Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn4 Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric



Mi3 Pabuç (Transition Segment)
Geometry: Triangle Zone
Arch Type: -
Constuction Material: Brick
Binder: Lime Mortar
Decoration: -

Mi4 Gövde (Body)
Geometry: Circular
Arch Type: -
Constuction Material: Brick
Binder: Lime Mortar
Decoration: -

Mi5 Merdiven (Stair)
Geometry: Triangle Zone
Constuction Material: Brick
Binder: Lime Mortar
Technique: Stone step / without core

West Façade

STRUCTURAL MODEL BASED ROOT CAUSE INVESTIGATION OF DAMAGE IN URLA HELVACILAR MOSQUE AND A PROPOSAL FOR STRENGTHENING

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Ceren NARİN GÜZEL

Supervisor:
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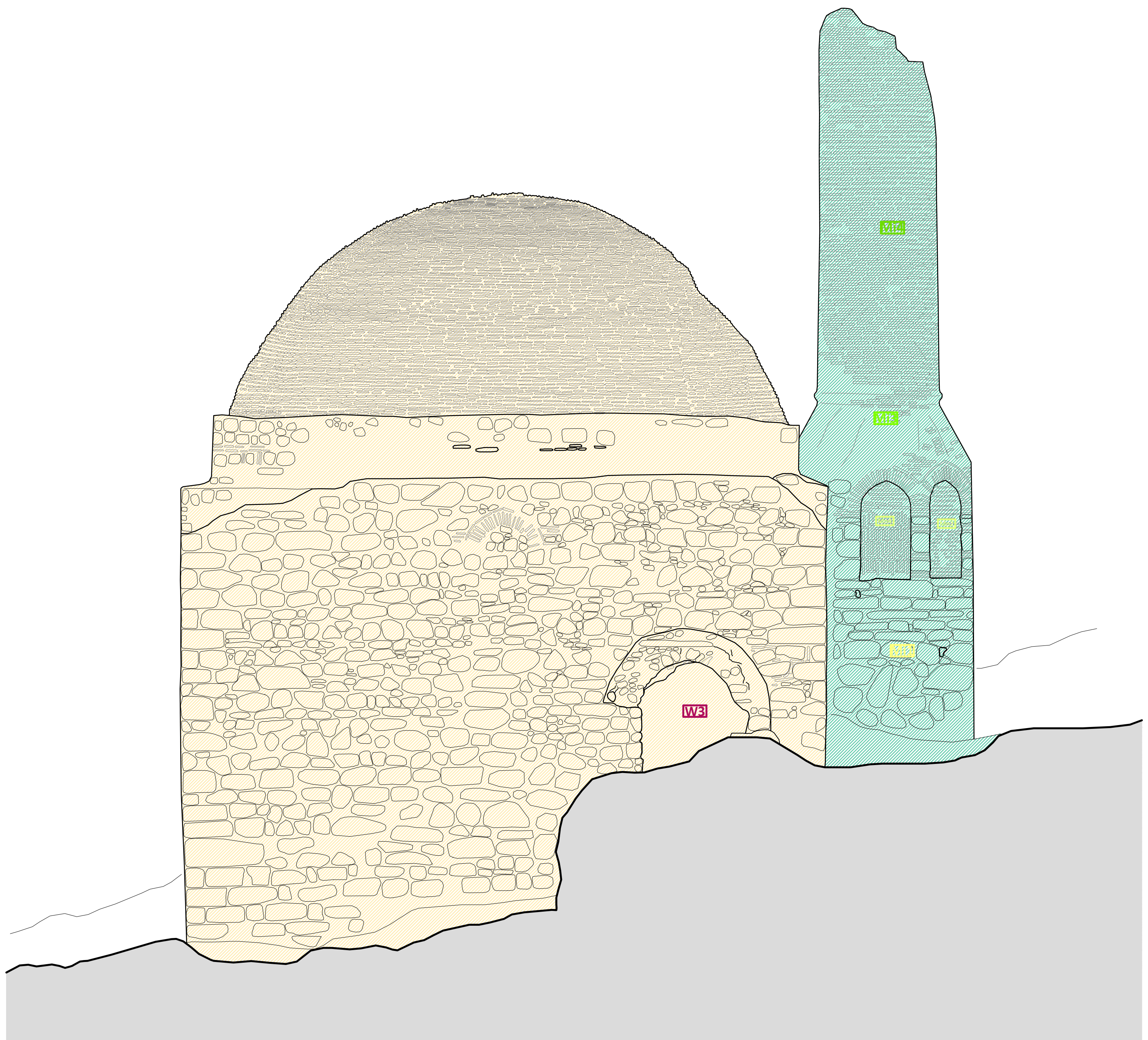
0 0,75 1,5 3 m.

Figure B.9. Spatial and Architectural Elements



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- Minaret

ARCHITECTURAL ELEMENTS

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Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

D2
Entrance of Minaret
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

2-Window Openings:

W1
Location: West Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W2
Location: South Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W3
Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W4
Location:North Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar

W5
Location: Upper Layers of all Walls
Arch Type: Pointed Arch
Arch Constuction Material: Brick
Binder: Lime Mortar

3-Niche:

N1
Location: North and South Walls of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar
Niche Depth: 55-60 cm

N2
Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Brick
Binder: Lime Mortar
Niche Depth: 25 cm

N3
Location: East Wall of Harim
Arch Type: Pointed Arch
Arch Constuction Material: Cut Stone
Binder: Lime Mortar
Niche Depth: 55 cm

4-Mihrab:

M
Location:East Wall of Harim
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar

5-Minaret:

Mi1
Kürsü (Pulpit)
Geometry: Half Octagonal Section
Arch Type: Pointed Arch
Constuction Material: Cut Stone and Brick
Binder: Lime Mortar
Decoration: Geometric

Mi2
Kürsü Nişi (Pulpit Niche)

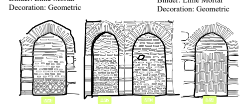
Mn
Kürsü Nişi Bezemeleri (Pulpit Niche's Decoration)

Mn1
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn2
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn3
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric

Mn4
Arch Type: Pointed Arch
Constuction Material: Brick
Binder: Lime Mortar
Decoration: Geometric



Mi3
Pabuç (Transition Segment)
Geometry: Triangle Zone
Arch Type: -
Constuction Material: Brick
Binder: Lime Mortar
Decoration: -

Mi4
Gövde (Body)
Geometry: Circular
Arch Type: -
Constuction Material: Brick
Binder: Lime Mortar
Decoration: -

Mi5
Merdiven (Stair)
Geometry: Triangle Zone
Constuction Material: Brick
Binder: Lime Mortar
Technique: Stone step / without core

East Façade

STRUCTURAL MODEL BASED ROOT CAUSE INVESTIGATION OF DAMAGE IN URLA HELVACILAR MOSQUE AND A PROPOSAL FOR STRENGTHENING

Prepared by:
Ceren NARİN GÜZEL

Supervisor:
Asst. Prof. Dr. F. Nurşen KUL ÖZDEMİR
Co-Supervisor:
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0 0.75 1.5 3 m.

Figure B.10. Spatial and Architectural Elements

APPENDIX C

CONSTRUCTION TECHNIQUE AND MATERIAL USAGE

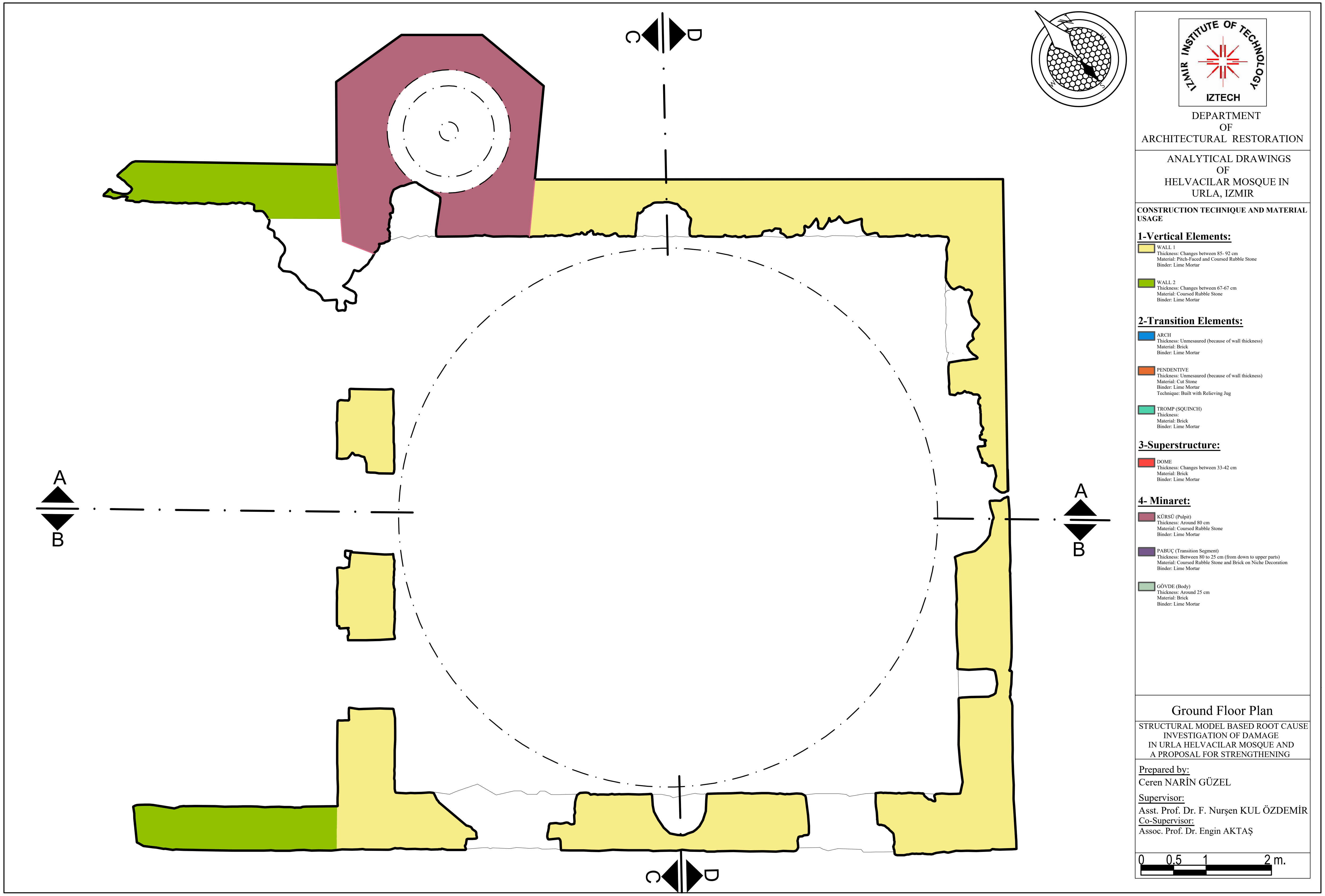


Figure C.1. Construction Technique and Material Usage

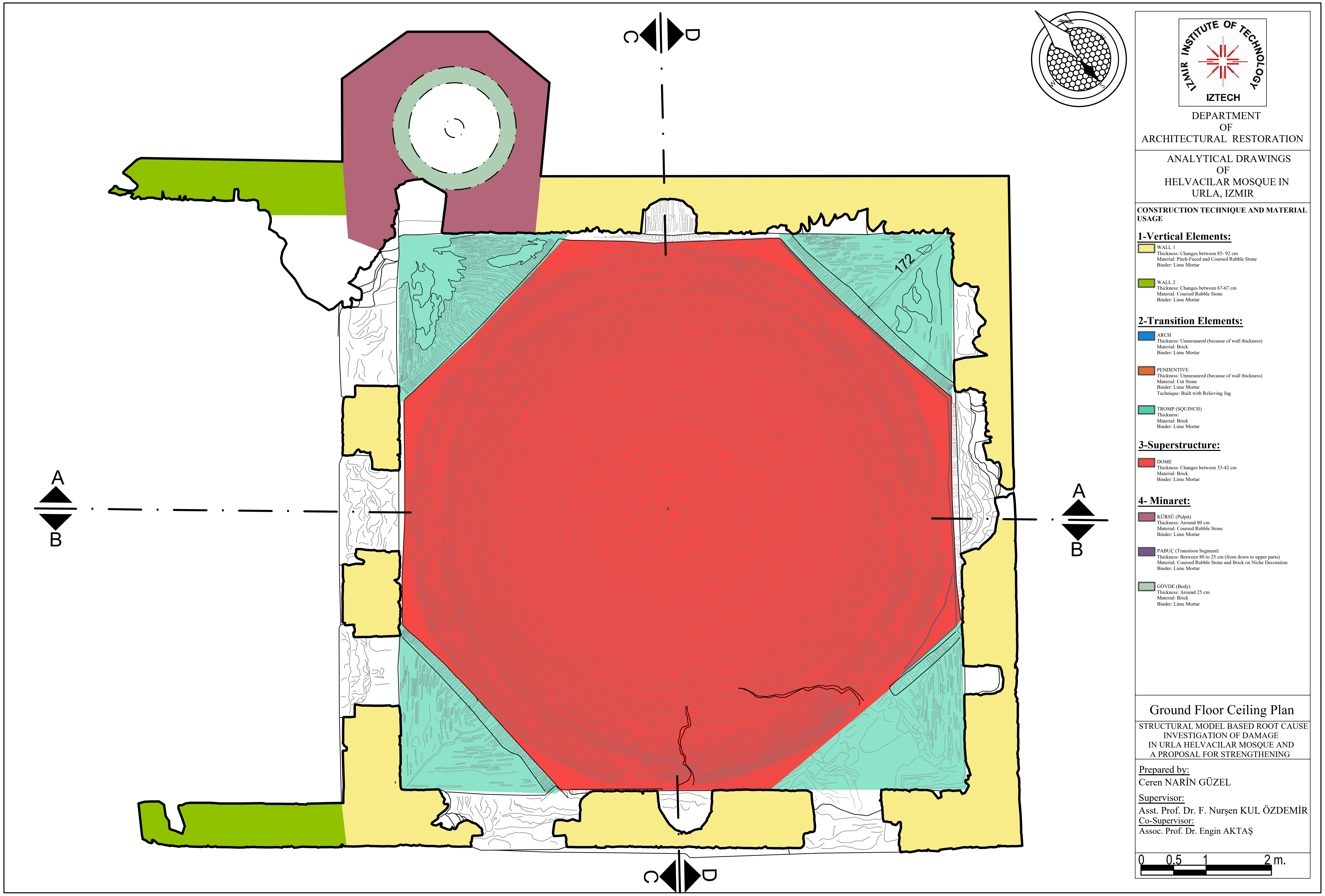


Figure C.2. Construction Technique and Material Usage

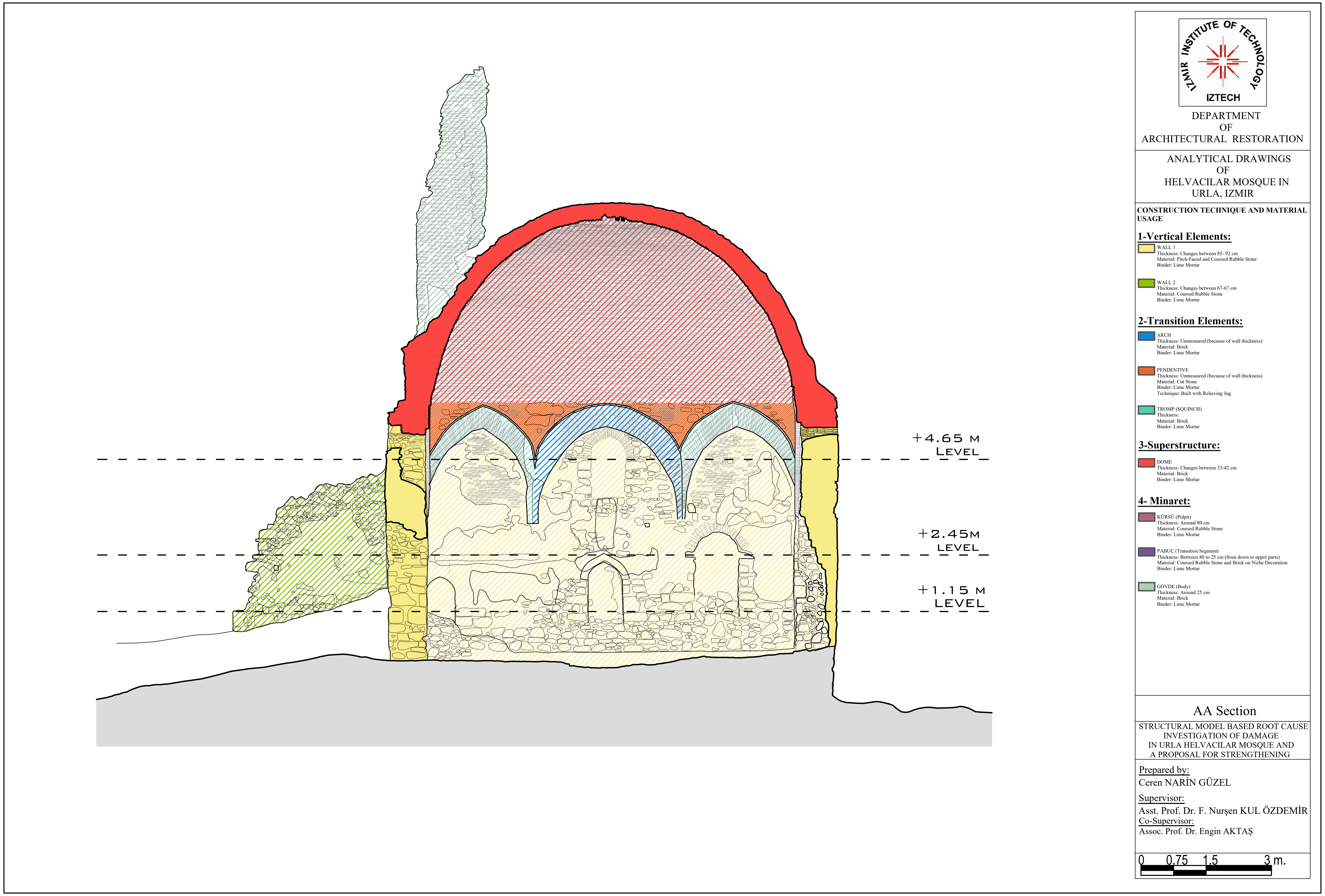
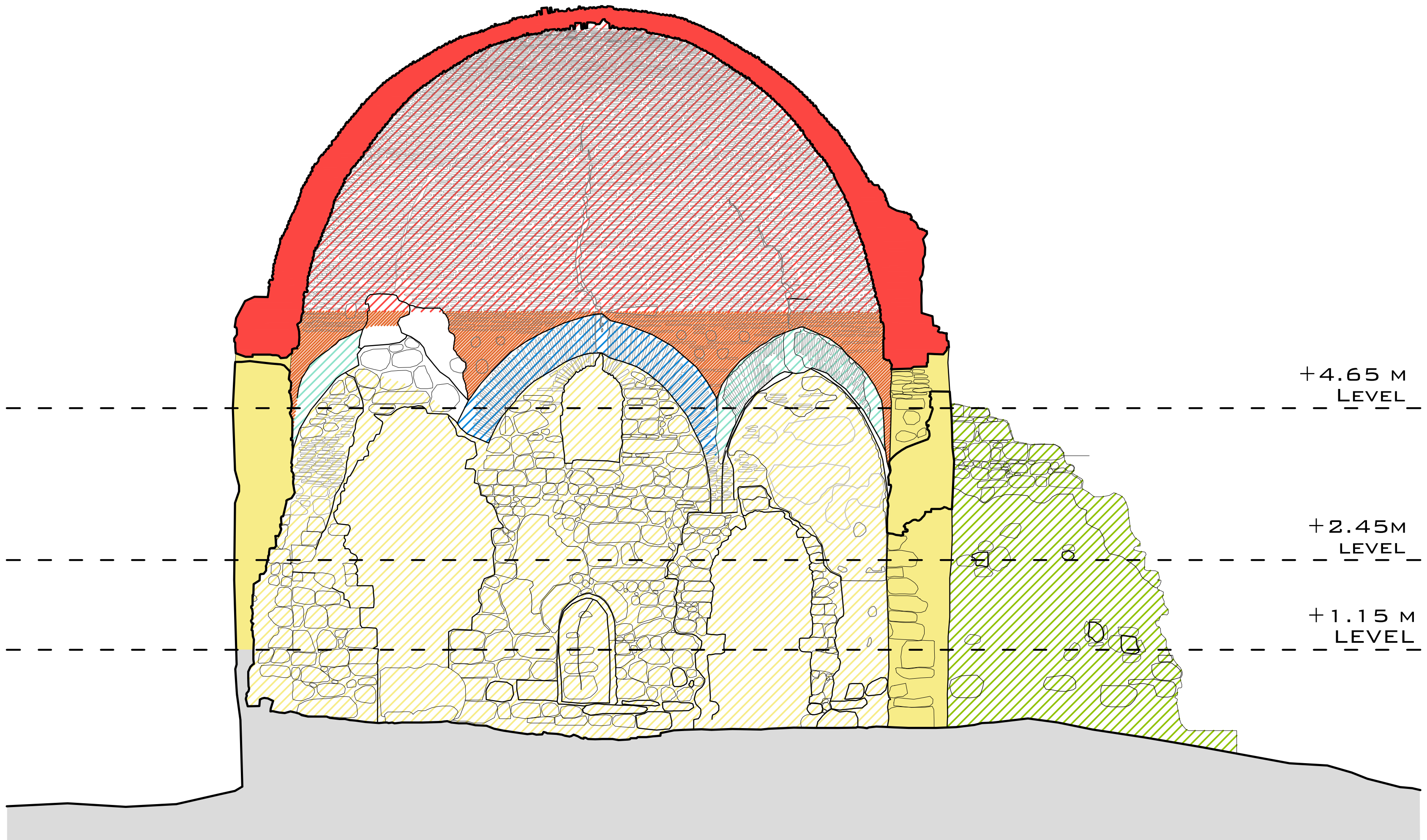


Figure C.3. Construction Technique and Material Usage



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URLA, IZMIR

CONSTRUCTION TECHNIQUE AND MATERIAL USAGE

1-Vertical Elements:

WALL 1
Thickness: Changes between 85- 92 cm
Material: Pitch-Faced and Coursed Rubble Stone
Binder: Lime Mortar

WALL 2
Thickness: Changes between 67-67 cm
Material: Coursed Rubble Stone
Binder: Lime Mortar

2-Transition Elements:

ARCH
Thickness: Unmesaured (because of wall thickness)
Material: Brick
Binder: Lime Mortar

PENDENTIVE
Thickness: Unmesaured (because of wall thickness)
Material: Cut Stone
Binder: Lime Mortar
Technique: Built with Relieving Jug

TROMP (SQUINCH)
Thickness:
Material: Brick
Binder: Lime Mortar

3-Superstructure:

DOME
Thickness: Changes between 33-42 cm
Material: Brick
Binder: Lime Mortar

4- Minaret:

KÜRSÜ (Pulpit)
Thickness: Around 80 cm
Material: Coursed Rubble Stone
Binder: Lime Mortar

PABUÇ (Transition Segment)
Thickness: Between 80 to 25 cm (from down to upper parts)
Material: Coursed Rubble Stone and Brick on Niche Decoration
Binder: Lime Mortar

GÖVDE (Body)
Thickness: Around 25 cm
Material: Brick
Binder: Lime Mortar

BB Section

STRUCTURAL MODEL BASED ROOT CAUSE INVESTIGATION OF DAMAGE IN URLA HELVACILAR MOSQUE AND A PROPOSAL FOR STRENGTHENING

Prepared by:
Ceren NARİN GÜZEL

Supervisor:
Asst. Prof. Dr. F. Nurşen KUL ÖZDEMİR

Co-Supervisor:
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0 0.75 1.5 3 m.

Figure C.4. Construction Technique and Material Usage

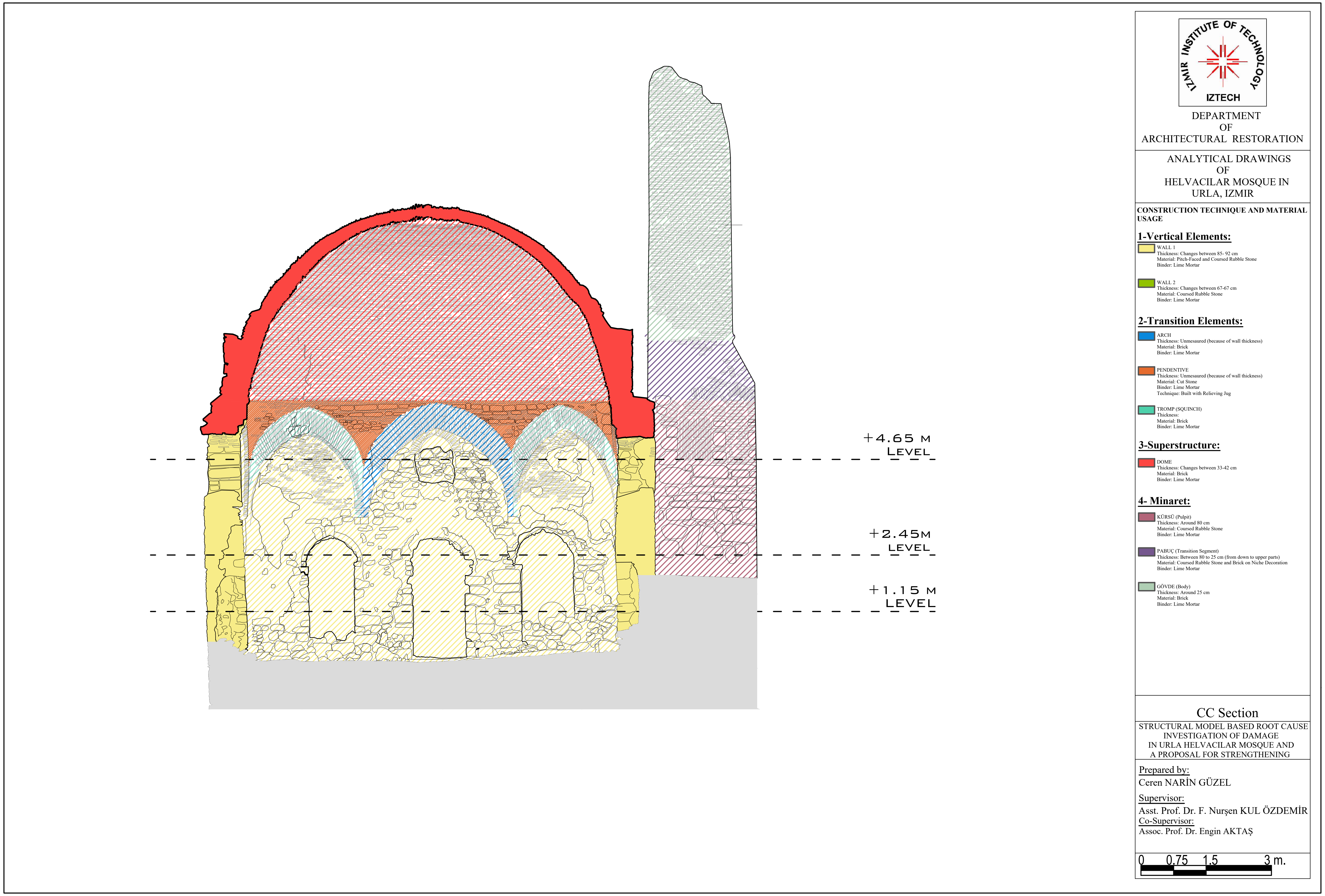
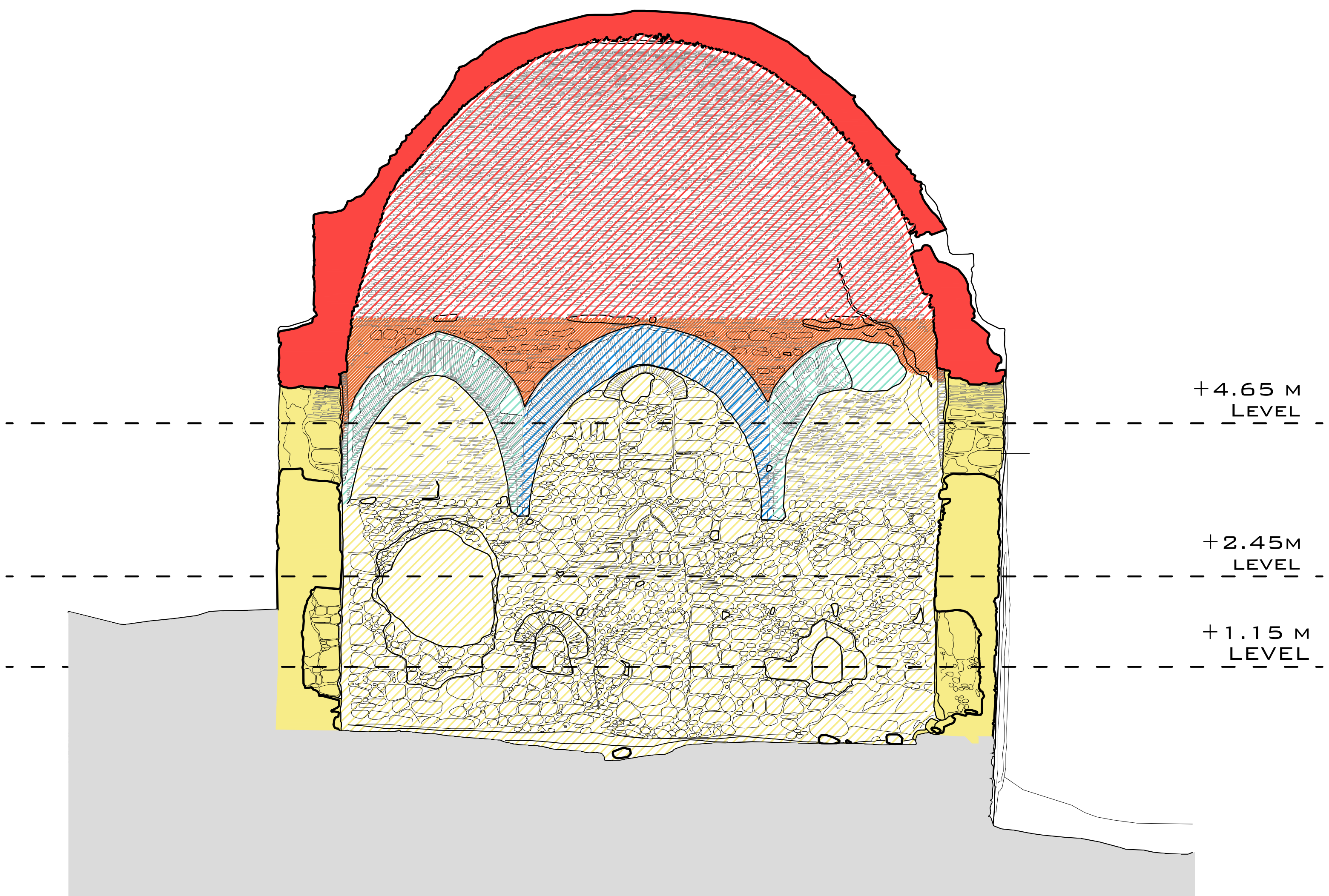


Figure C.5. Construction Technique and Material Usage



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CONSTRUCTION TECHNIQUE AND MATERIAL USAGE

1-Vertical Elements:

WALL 1
Thickness: Changes between 85- 92 cm
Material: Pitch-Faced and Coursed Rubble Stone
Binder: Lime Mortar

WALL 2
Thickness: Changes between 67-67 cm
Material: Coursed Rubble Stone
Binder: Lime Mortar

2-Transition Elements:

ARCH
Thickness: Unmesaured (because of wall thickness)
Material: Brick
Binder: Lime Mortar

PENDENTIVE
Thickness: Unmesaured (because of wall thickness)
Material: Cut Stone
Binder: Lime Mortar
Technique: Built with Relieving Jug

TROMP (SQUINCH)
Thickness:
Material: Brick
Binder: Lime Mortar

3-Superstructure:

DOME
Thickness: Changes between 33-42 cm
Material: Brick
Binder: Lime Mortar

4- Minaret:

KÜRSÜ (Pulpit)
Thickness: Around 80 cm
Material: Coursed Rubble Stone
Binder: Lime Mortar

PABUÇ (Transition Segment)
Thickness: Between 80 to 25 cm (from down to upper parts)
Material: Coursed Rubble Stone and Brick on Niche Decoration
Binder: Lime Mortar

GÖVDE (Body)
Thickness: Around 25 cm
Material: Brick
Binder: Lime Mortar

DD Section

STRUCTURAL MODEL BASED ROOT CAUSE INVESTIGATION OF DAMAGE IN URLA HELVACILAR MOSQUE AND A PROPOSAL FOR STRENGTHENING

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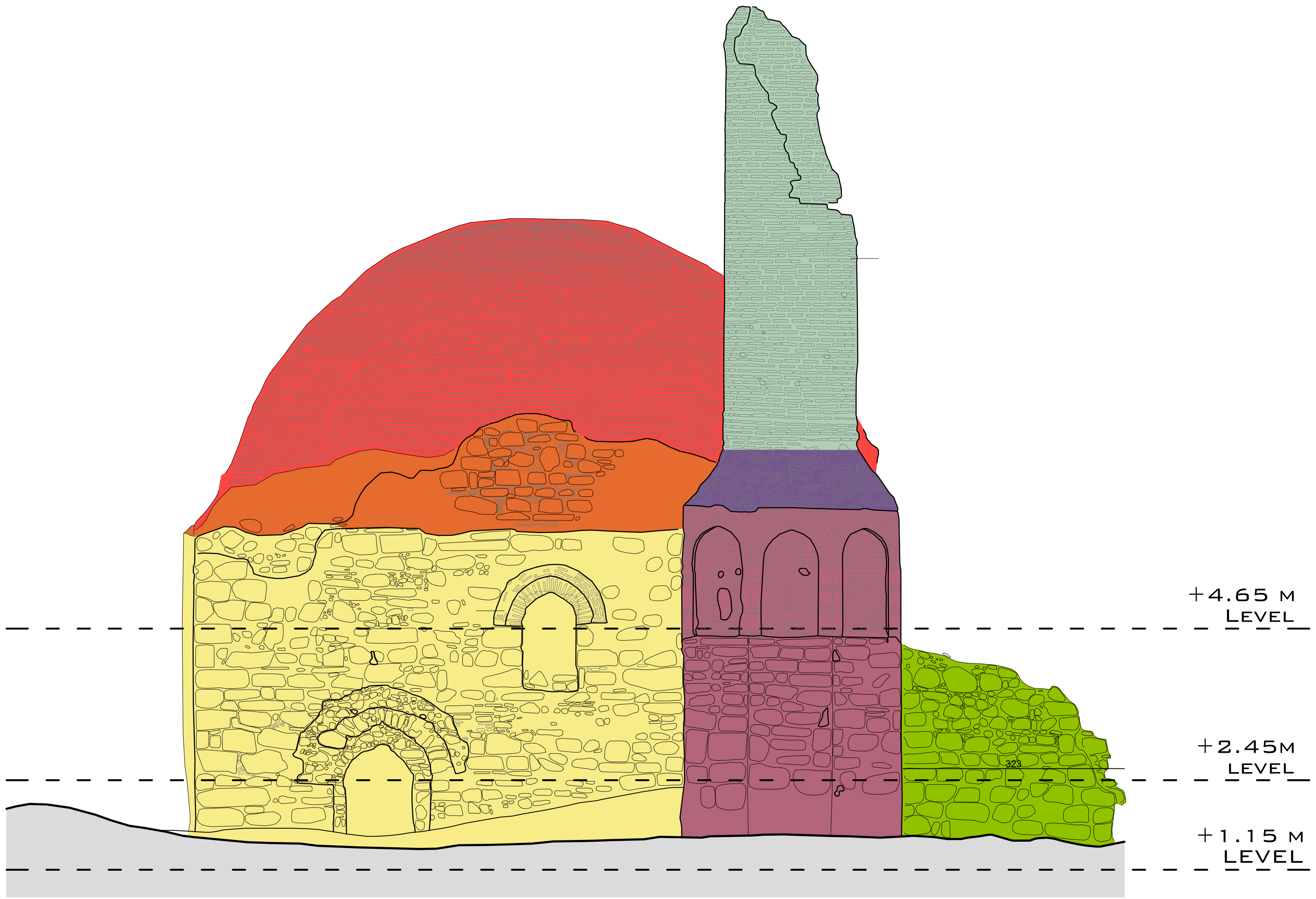
0 0.75 1.5 3 m.

Figure C.6. Construction Technique and Material Usage



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1-Vertical Elements:

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Material: Pitch-Faced and Coursed Rubble Stone
Binder: Lime Mortar

WALL 2
Thickness: Changes between 67-67 cm
Material: Coursed Rubble Stone
Binder: Lime Mortar

2-Transition Elements:

ARCH
Thickness: Unmesaured (because of wall thickness)
Material: Brick
Binder: Lime Mortar

PENDENTIVE
Thickness: Unmesaured (because of wall thickness)
Material: Cut Stone
Binder: Lime Mortar
Technique: Built with Relieving Jug

TROMP (SQUINCH)
Thickness:
Material: Brick
Binder: Lime Mortar

3-Superstructure:

DOME
Thickness: Changes between 33-42 cm
Material: Brick
Binder: Lime Mortar

4- Minaret:

KÜRSÜ (Pulpit)
Thickness: Around 80 cm
Material: Coursed Rubble Stone
Binder: Lime Mortar

PABUÇ (Transition Segment)
Thickness: Between 80 to 25 cm (from down to upper parts)
Material: Coursed Rubble Stone and Brick on Niche Decoration
Binder: Lime Mortar

GÖVDE (Body)
Thickness: Around 25 cm
Material: Brick
Binder: Lime Mortar

North Facade

STRUCTURAL MODEL BASED ROOT CAUSE INVESTIGATION OF DAMAGE IN URLA HELVACILAR MOSQUE AND A PROPOSAL FOR STRENGTHENING

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Co-Supervisor:
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0 0.75 1.5 3 m.

Figure C.7. Construction Technique and Material Usage

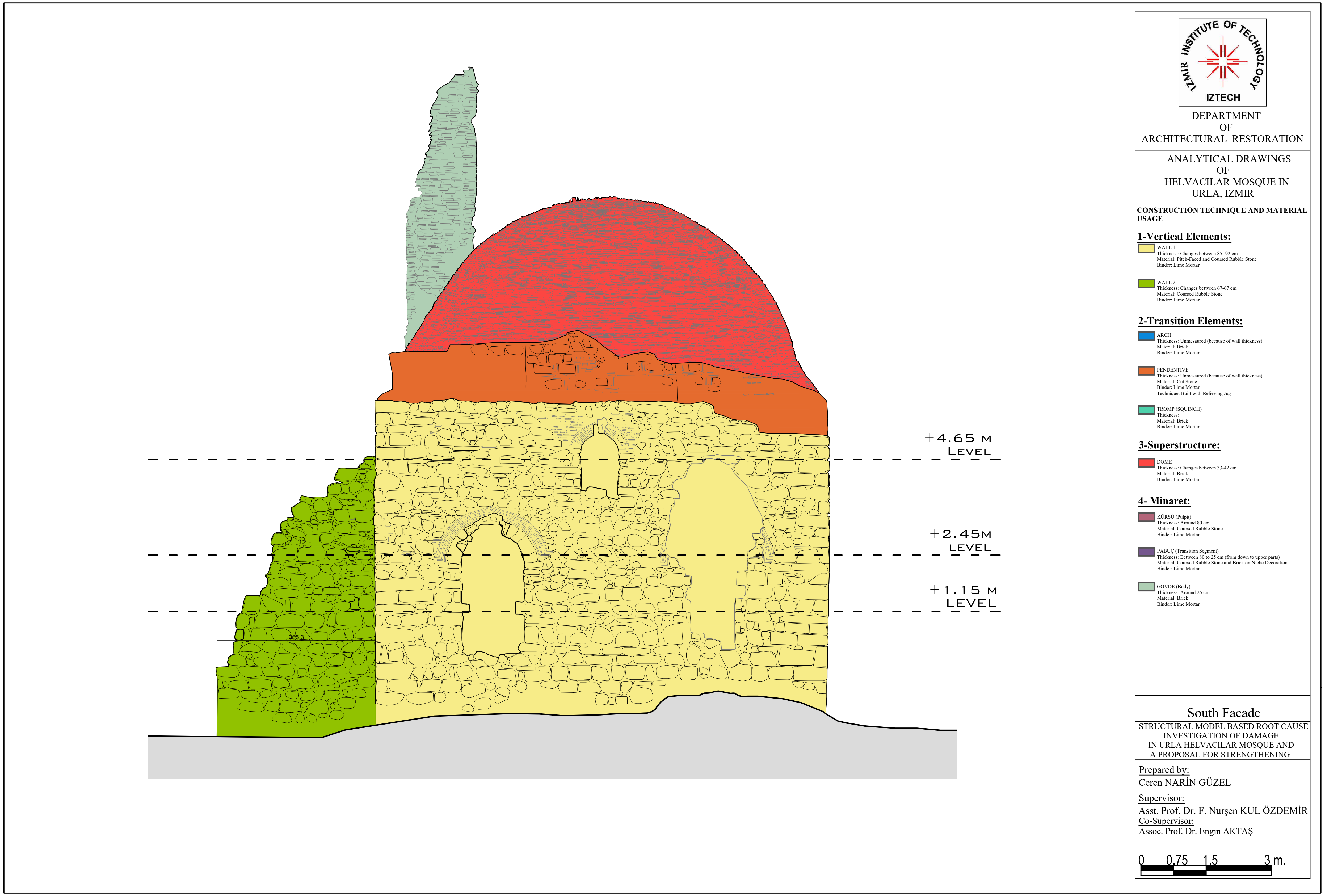
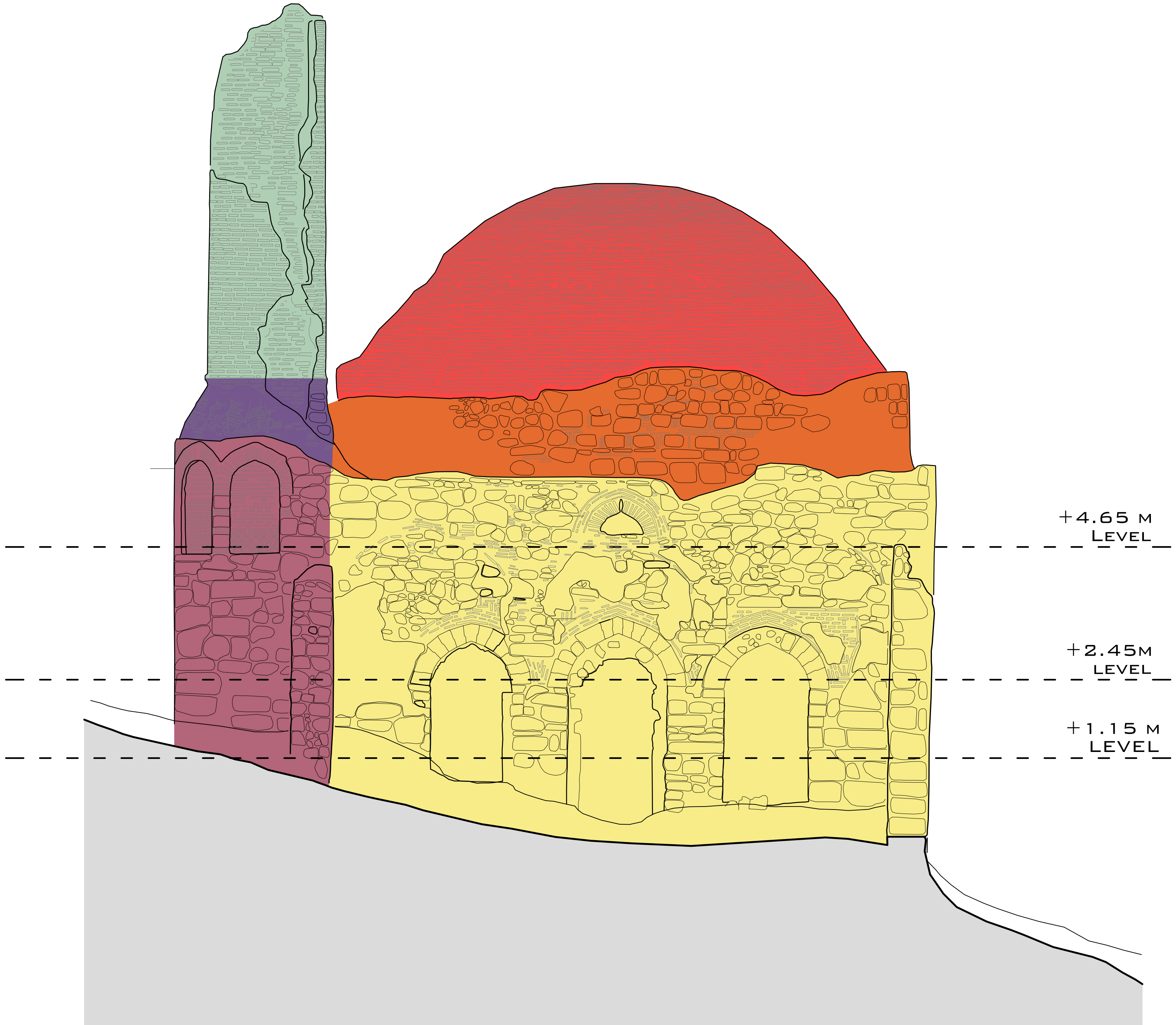


Figure C.8. Construction Technique and Material Usage



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Binder: Lime Mortar

WALL 2
Thickness: Changes between 67-67 cm
Material: Coursed Rubble Stone
Binder: Lime Mortar

2-Transition Elements:

ARCH
Thickness: Unmesaured (because of wall thickness)
Material: Brick
Binder: Lime Mortar

PENDENTIVE
Thickness: Unmesaured (because of wall thickness)
Material: Cut Stone
Binder: Lime Mortar
Technique: Built with Relieving Jug

TROMP (SQUINCH)
Thickness:
Material: Brick
Binder: Lime Mortar

3-Superstructure:

DOME
Thickness: Changes between 33-42 cm
Material: Brick
Binder: Lime Mortar

4- Minaret:

KÜRSÜ (Pulpit)
Thickness: Around 80 cm
Material: Coursed Rubble Stone
Binder: Lime Mortar

PABUÇ (Transition Segment)
Thickness: Between 80 to 25 cm (from down to upper parts)
Material: Coursed Rubble Stone and Brick on Niche Decoration
Binder: Lime Mortar

GÖVDE (Body)
Thickness: Around 25 cm
Material: Brick
Binder: Lime Mortar

West Facade

STRUCTURAL MODEL BASED ROOT CAUSE INVESTIGATION OF DAMAGE IN URLA HELVACILAR MOSQUE AND A PROPOSAL FOR STRENGTHENING

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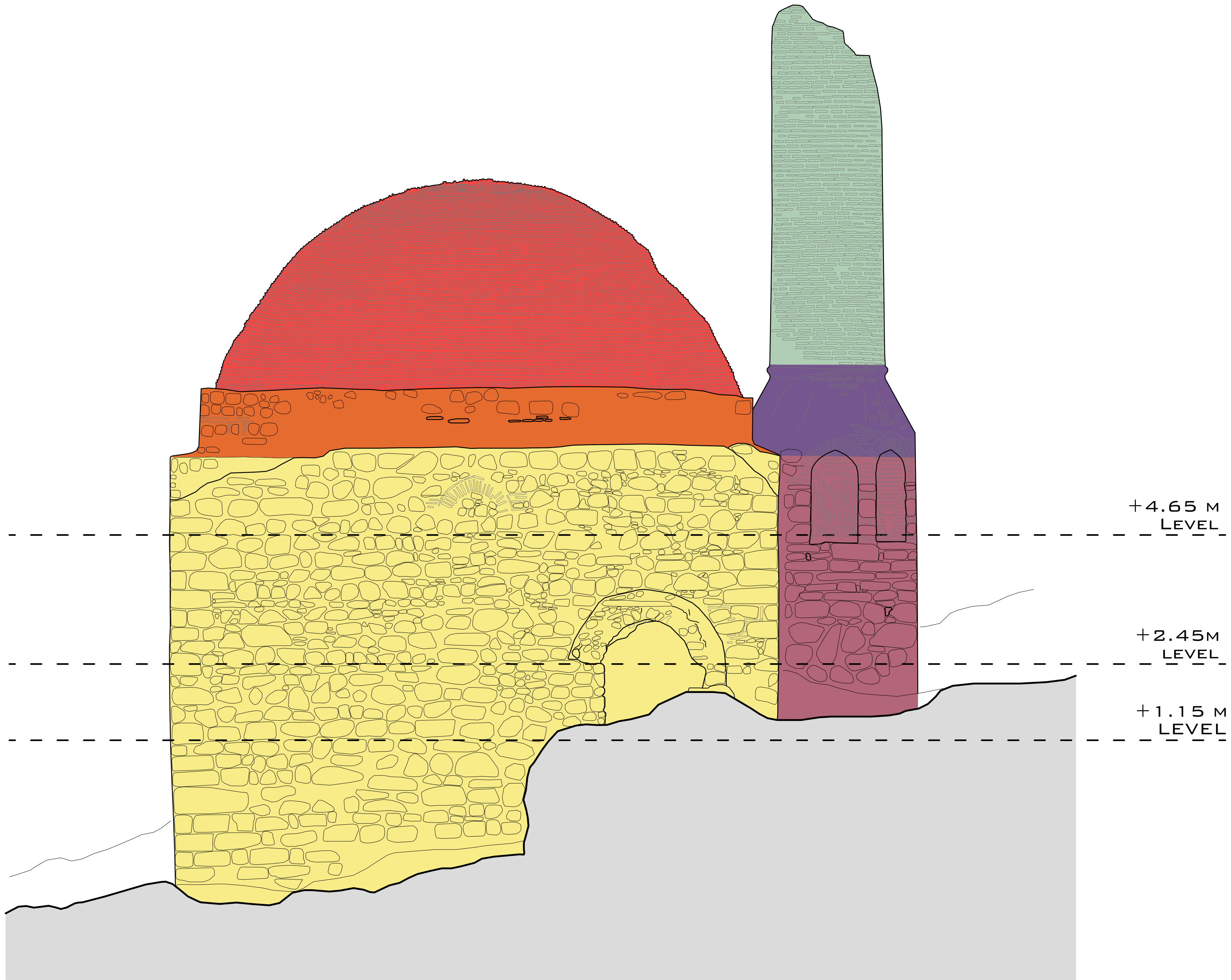
0 0.75 1.5 3 m.

Figure C.9. Construction Technique and Material Usage



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Binder: Lime Mortar

WALL 2
Thickness: Changes between 67-67 cm
Material: Coursed Rubble Stone
Binder: Lime Mortar

2-Transition Elements:

ARCH
Thickness: Unmesaured (because of wall thickness)
Material: Brick
Binder: Lime Mortar

PENDENTIVE
Thickness: Unmesaured (because of wall thickness)
Material: Cut Stone
Binder: Lime Mortar
Technique: Built with Relieving Jug

TROMP (SQUINCH)
Thickness:
Material: Brick
Binder: Lime Mortar

3-Superstructure:

DOME
Thickness: Changes between 33-42 cm
Material: Brick
Binder: Lime Mortar

4- Minaret:

KÜRSÜ (Pulpit)
Thickness: Around 80 cm
Material: Coursed Rubble Stone
Binder: Lime Mortar

PABUÇ (Transition Segment)
Thickness: Between 80 to 25 cm (from down to upper parts)
Material: Coursed Rubble Stone and Brick on Niche Decoration
Binder: Lime Mortar

GÖVDE (Body)
Thickness: Around 25 cm
Material: Brick
Binder: Lime Mortar

East Facade

STRUCTURAL MODEL BASED ROOT CAUSE INVESTIGATION OF DAMAGE IN URLA HELVACILAR MOSQUE AND A PROPOSAL FOR STRENGTHENING

Prepared by:
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0 0.75 1.5 3 m.

Figure C.10. Construction Technique and Material Usage

APPENDIX D

STRUCTURAL FAILURE

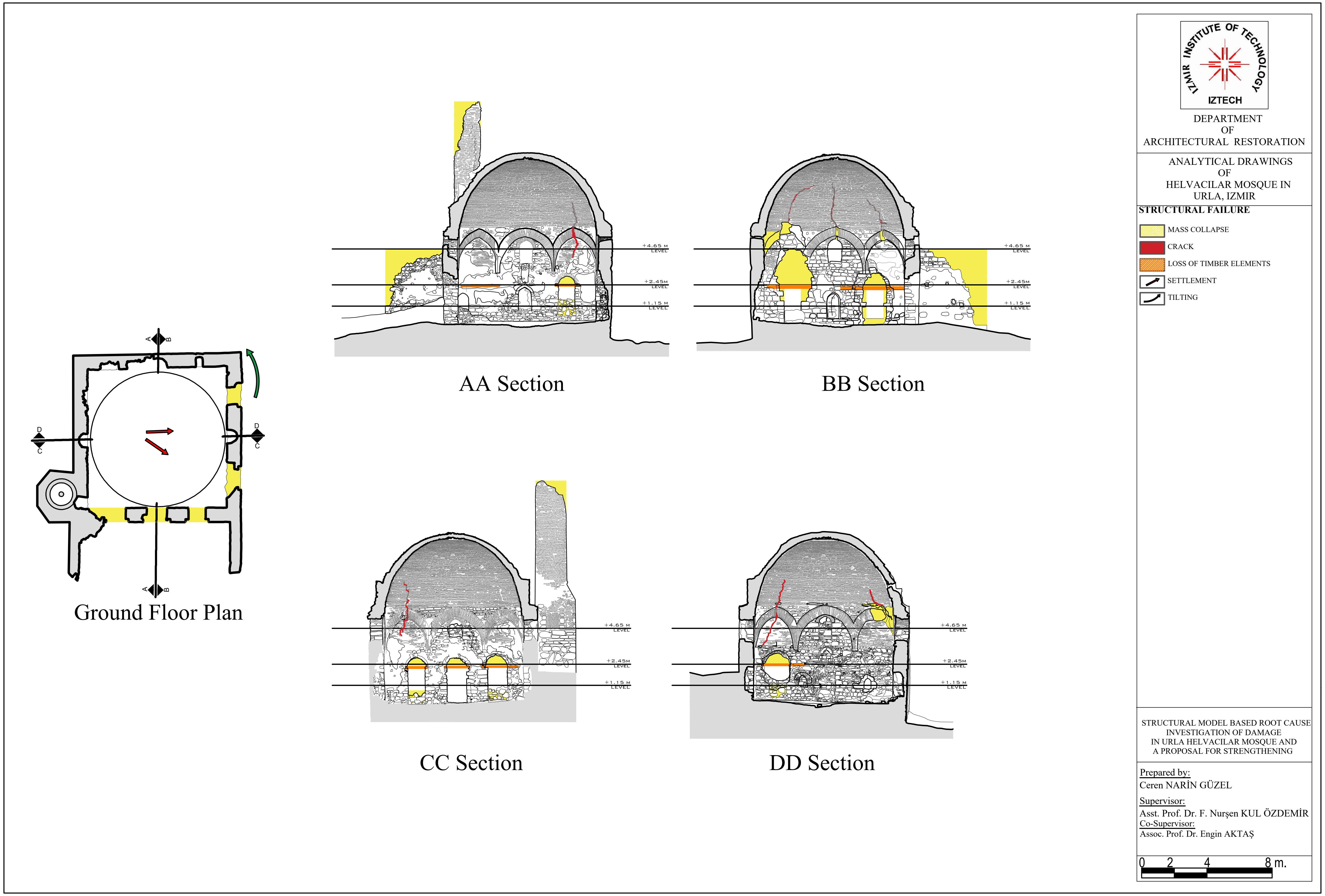
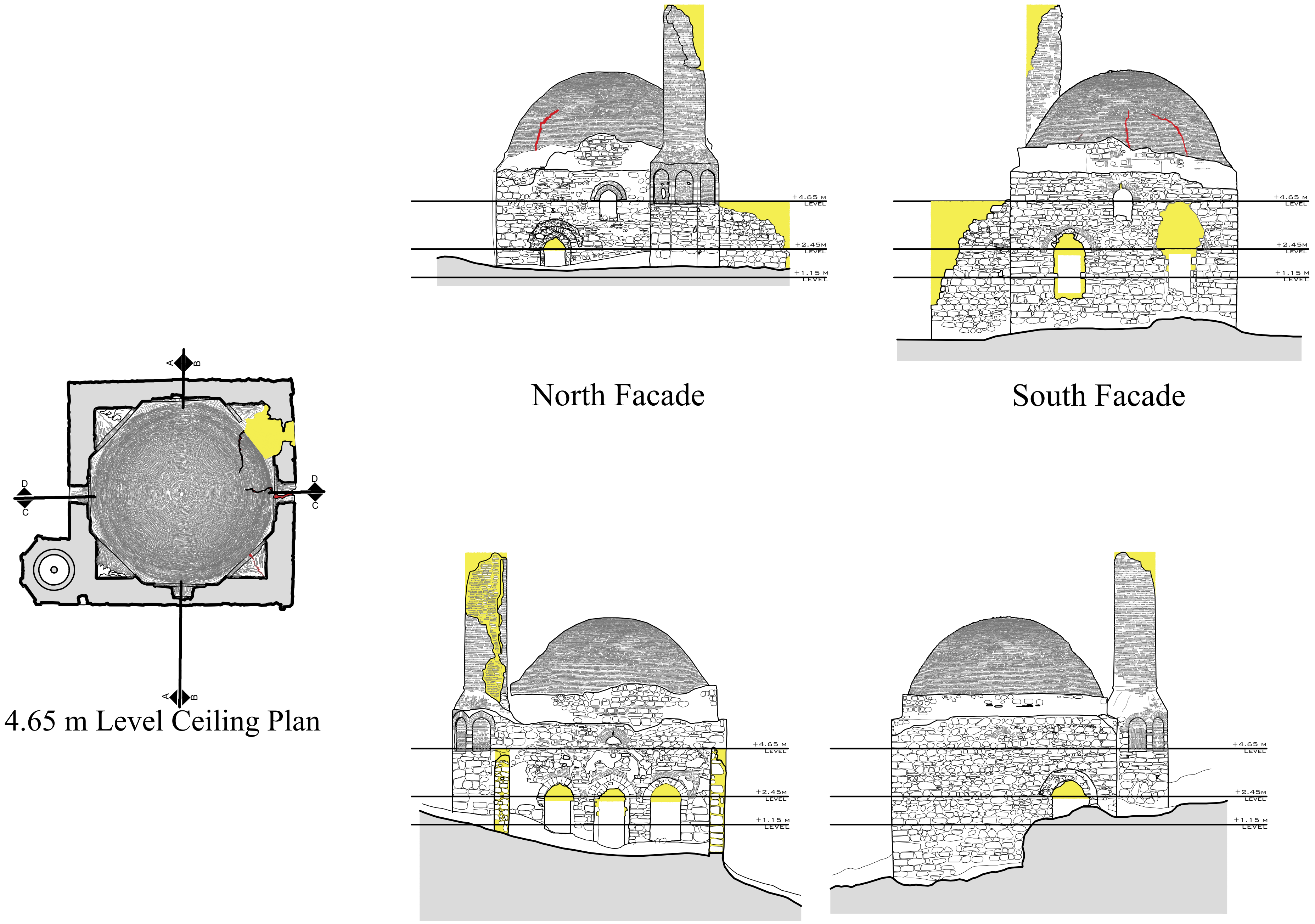


Figure D.1. Structural Failure



IZMIR INSTITUTE OF TECHNOLOGY
IZTECH

DEPARTMENT
OF
ARCHITECTURAL RESTORATION

ANALYTICAL DRAWINGS
OF
HELVACILAR MOSQUE IN
URLA, IZMIR

STRUCTURAL FAILURE

- MASS COLLAPSE
- CRACK
- LOSS OF TIMBER ELEMENTS
- SETTLEMENT
- TILTING

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0 2 4 8 m.

Figure D.2. Structural Failure