EARTHQUAKE EFFECTS ON HISTORICAL MASONRY BUILDINGS IN ÜSKÜDAR

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ABSTRACT

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The purpose of this study is, identifying historical masonry structures in Üsküdar area and according to the known information about their history, revealing the damages occurred from the previous earthquakes. For this study, collected information from the libraries about the historical buildings in Üsküdar area and their history are summarized. From this library study, tables and graphs created showing these buildings damage reports after the previous earthquakes and how many times these buildings have been restorated because of these earthquakes.

In addition to this, since the library study revealed that these masonry structures have been effected from previous earthquakes, Maiden's Tower which is one of the best known historical building in Üsküdar area has been statically investigated according to the predicted earthquake scenarios.

Furthermore, Maiden's Tower, which has been damaged from the 1999 İzmit earthquake and restorated at 2001 by TURES firm, supplies a perfect example for restoration of a masonry structure. This thesis contains information about analysis of Maiden's Tower before restoration condition and after restoration condition according to the architectural surveys of the structure. In this thesis Macro-Modeling analysis of Maiden's Tower has been done by using Finite Element Methods.

All in all, this thesis with its library study proves that, previous earthquakes damaged masonry structures in Üsküdar area and these structures are in at risk. Analysis of Maiden's Tower before restoration condition showed that macro-modeling approach has given reliable results when compared to the occurred cracks at the structure after the İzmit earthquake. After restoration results showed that by restoration a masonry structure can be strengthened. This thesis also contains information about analyzing a masonry structure by using today's analyze methods and other methods for analyzing masonry structures

ÖZET

ÜSKÜDAR BÖLGESİNDEKİ TARİHİ TAŞ BİNALARDA DEPREM ETKİLERİ

Bu çalışmanın amacı, Üsküdar çevresinde bulunan tarihi nitelikteki binaların belirlenmesi ve bu binalardan elde edilebilen bilgiler ışığında bundan önce yaşanmış depremler ve diğer dış etkilerden hangi sıklıklarda etkilendiklerinin bulunmasıdır. Bu bilgiler yardımıyla bundan sonra yapılacak çalışmalara yardımcı olabilmek ve tarihi mirasın korunması için yapılan restorasyon işlerinin muhtemel deprem senaryosuna göre etkili olup olamayacağını görebilmek amacıyla, bu eserlerden tarihi açıdan en tanınmışlarından biri olan Üsküdar Kız Kulesinin restorasyon öncesi ve sonrası durumunun bilgisayar programı ile statik analizi yapılmıştır.

Bu amaçla, Üsküdar çevresindeki tarihi binaların dökümü çıkartılmış, yapılış tarihleri geçirmiş oldukları tarihsel depremler yangınlar ve diğer etkiler incelenmiş, tablolar oluşturularak grafiksel bir sonuç çıkartılmıştır.

Bu tez çalışmasında 1999 İzmit depreminde hasar gören ve 2001 yılında TURES firması tarafından restore edilen Kız Kulesi'nin, restorasyon öncesi durumu ile mevcut durumunun statik analiz sonuçları karşılaştırılmış ve mühendislik hizmeti alınarak yapılan bir restorasyon projesinin tarihi eserlerimizin diğer nesillere aktarılması bakımından yarattığı farklar incelenmiştir.

Sonuç olarak, Üsküdar bölgesinde bulunan tarihi taş yapıların geçmiş depremlerden ne kadar etkilendikleri gösterilmiş ve oluşabilecek bir depremde bu tarihi binalarının durumlarını incelemek için kullanılabilecek analiz yöntemleri gösterilmiştir. Bu yöntemlerden biri olan Maco-Modelleme yöntemi ile Kız Kulesinin restorasyon öncesi durumu ve restorasyon sonrası durumu incelenmiş ve restorasyon çalışmasının yarattığı farklar araştırılmıştır.

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LIST OF SYMBOLS/ABBREVIATIONS

Ao	Depending on the earthquake zone, design ground acceleration
A(T1)	Spectral acceleration factor
Aw	Total in plan area of earthquake resistant walls
Awi	The in plan area of earthquake resistant walls in direction ''i''
c	Cohesion
E	Young modulus
fvk_0	The cohesion
G	Quasi-permanent vertical action
g_i	Dead loads
h	Average height of the structure
I	Importance class factor of the building.
ks	Shear stiffness
m	Snow factor depending to the roof slope
n	Live load attendance factor.
Pk	Roof snow load
P_{ko}	Snow load depending to region and altitude of structure
Ra(T1)	Earthquake load reduction coefficient
rd	Design value of the normal stress
S	Total plan area of the building
S[T]	Spectrum coefficient
T1	First vibration period of the structure
q_i	Live loads
Vt	Total equivalent lateral force
W	Total weight of the structure

α	Roof slope
β	Equivalent seismic static coefficient related to the design ground acceleration.
γ	Volumetric weight
μ	Friction factor
ν	Poisson's ratio
σc	Compression strength
σt	Tension stress
τ_t	Shear strength

AR	After restoration
BR	Before restoration
DEM	Discrite Element Method
EUROCODE	European Standards
EW	Wind direction from East
FEM	Finite Element Method
FEMDE	Finite Element Method With Discontinuous Elements
KAF	North Anatolia Fault
NW	Wind direction from North
SW	Wind direction from South
TDY	Turkish Earthquake Design Code
TS	Turkish Standards
WW	Wind direction from West

1. INTRODUCTION

The recent earthquakes that occurred in Turkey have enlightened the vulnerability of masonry structures and the need to reliably assess their seismic capacity, determining an increasing interest towards research subjects aimed at the study of the mechanical behavior of masonry constructions.

Since the historical buildings are symbols of our historical heritage, their current condition and their earthquake performances are, important tasks for today's engineers. In order those structures to resist up to next generations, analyze of historical buildings are important assignments.

Analyze of historical buildings is the main scopes of this thesis. For this study, collected information from the libraries and government documents about the historical buildings in Üsküdar area and their history are summarized. Tables consisting of historical buildings, construction date, known restorations and known damages due to previous disasters are created. From these tables, graphs showing the occurred damage of these structures from previous earthquakes are created. These graphs enlighten the collapse possibility of these masonry structures in Üsküdar area from a possible earthquake.

Maiden's Tower which is the most known of these historical buildings in Üsküdar is chosen as the scope of this thesis. Maiden's Tower's before restoration condition and after the restoration condition are statically investigated in order to investigate the difference between two conditions.

Although, the Maiden's Tower is analyzed by assuming an equivalent-material approach and modeled by FEM(Finite Element Method), other available methods for evaluating historical masonry structures are mentioned.

Analyze of the Maiden's Tower is done by using SAP2000® v10.1. The analyze calculations of the Maiden's Tower are done by using the Turkish Standards for Masonry Structures and Turkish Standards for Earthquake Resistant Design. In the absence of necessary data, Eurocode 8 and Eurocode 6 are used.

For this purpose, plan of the structure is created according to the available architectural surveys. In order to stimulate the behavior of the structure, masonry walls are modeled as shells. Shell areas are divided into 1 m x 1 m smaller areas for creating a more reliable model. In the places of the wall roof connections and wall floor connections shell areas are divided into smaller elements in order to stick to the FEM.

Evaluation of analyze results are done by comparing tabled stress results with the allowable stress values which are taken from the new Turkish Code for Earthquake Resistant Design 2005.

The conditions of the Maiden's Tower before the restoration and after the restoration are compared and a conclusion of analyzes are given.

2. EARTHQUAKE AFFECTS ON MASONRY STRUCTURE IN ÜSKÜDAR

Ancient masonry structures are particularly vulnerable to dynamic actions, with a special focus on seismic action. Masonry structures in Marmara basin are particularly at risk due to the large number of ancient monuments and dwellings. Due to the ageing process as well as to the environmental factors, many cultural heritage buildings, as structures planned and constructed in the past, result to be vulnerable to dynamic loads, which may unpredictably induce a collapse of a portion or drive the whole structure to a rapid failure.

In order to figure out the previous earthquake affects on the masonry structures, this thesis focuses on the masonry structures located in Üsküdar.

2.1 Location Of Üsküdar

Üsküdar is settled between the Kadıköy and Ümraniye villages at the point where Kocaeli (Yarımada) meets with the Bosporus. The lands of Üsküdar generally composed of sloppy hills which's directions are from east to west from hills at east part and the Marmara Sea at the west part. Since 1983 Üsküdar has been a district municipality within the Istanbul Greater Metropolitan Government. Figure 2.1 and Figure 2.2 show the location of Üsküdar.

Figure 2.1 : Map of Turkey

Figure 2.2 : Map of Üsküdar

2.2 Name Of Üsküdar

There are lots of mitts and legends about the name of the Üsküdar. According to common belief first people settled at Üsküdar are the people of Kalkedonya. They had used this place as their shipyards and named this place as Chrysopolis. But when invaded by the “Iran” the sah “Iran” used this place as a safe for the taxes he collected from the Anatolian people and because of that the city called as Krizepolis which means the golden town.

Another common believe for the name of Üsküdar is told by a Byzantine historian Etyen, according to him the name came from the the king Agamemnon’s son Chryses who escaped from the Aegist and Klytaimnestra and setteled the small Asia.

Furthermore it is believed that the name came from the Roman Empire which used this place as their patrol garrison and named this garrison as Scutarion which means as frontier garrison.

The last myth about the name of the Üsküdar is told by Evliya Çelebi who stated his story according to the Ottoman transportation system. In which the incoming mails to Istanbul and outgoing mails to other Ottoman citys in Asia are delivered from Üsküdar. Eskidar is the name given to the medieval post office in “Persian” language.[1]

2.3 History of Üsküdar

The fate of Üsküdar is intertwined with that of Istanbul. Istanbul can best be seen from Üsküdar and Üsküdar from Istanbul. When we look at their historical locations, they were two separate cities. However, when one was in trouble, the other would be affected first-hand. They shared their joy and sorrow deeply. Many tribes, cultures and governments have passed through this region over the centuries. The Bosphorus Straits and Istanbul became the favorite of civilizations. The most powerful armies and nations always wanted to possess her. While Istanbul experienced all these attacks and budding civilizations, a faithful friend was always there keeping an eye on her day and night throughout all the seasons.[2]

2.3.1 Roman Empire

The first settlements on the Anatolian shore date from the migration of tribes after 1200 BC. The Thracians, Phrygians and Bithynian’s began to settle in Istanbul and on the Anatolian shore. It is agreed that in 700 BC the Megarites came to today's Kadıköy and founded Halkedon and that twenty years later the ruler of Megara founded Istanbul on behalf of Byzantium. Halkedon’s pier and shipyards were in today's Üsküdar. and this area was called Hrisopolis meaning Golden City. It is related that this name was given because the treasuries were hidden here during the Persian occupation. According to another source, this name was given because the windows of the houses shone like gold at sunset.

The emperors who wanted to take Istanbul also passed by Usküdar. The Persian King Darius, Alkibiades of Athens and Macedonian Alexander the Great were all in Üsküdar before the coming of Christ. Later under the control of Rome, an important military headquarters was established in Üsküdar, and it was called "Scutari." A similar headquarters was established in the north of Albania and the same name was given to it. Today this city is known as lshkodra and our Scutari became Üsküdar in time. It is related that the name Üsküdar comes from the Persian word "Eskudari" meaning "courier."[3]

2.3.2 Conquests

Towards the end of the 7th century and the beginning of the 8th century soldiers of the Arabic-Islamic Empire were in Üsküdar. The army of Abbasid Caliph Harun Rashit set up headquarters in Üsküdar for making a siege. In 1001 the Crusaders pillaged Üsküdar together with Istanbul. At the end of the birth pains of today's identity it was conquered by Orhan Gazi in 352 and made a part of Ottoman territory. In spite of Üsküdar's humble appearance, it carries traces from all those periods. Behind the mixed fabric of the city Üsküdar hides in her breast invaluable scattered works that are tokens of those times. For example, the historical structure called the Conqueror's Court was built before the conquest of Istanbul. Yahya Kemal wrote, "Which city has seen what she has seen?" Üsküdar is the closest witness to the conquest of Istanbul, which took place approximately 100 years after the conquest of Üsküdar. A brand new era had begun for Üsküdar.

2.3.3 Ottoman Empire

Ottoman sultans settled in Istanbul, but Üsküdar was always a part of their lives. Orchards, vegetable gardens, kiosks, summer palaces, mosques, medresses, fountains and public baths all followed one another. When people of İstanbul sought peace and quiet, they chose Üsküdar. When they died, most chose the Karacaahmet cemetery in Üsküdar as their final resting place.

The dervish lodge of the great saint Aziz Mahmut Hüdayi was established here. The trips he made from the Üsküdar pier became legends. For centuries the lodge greeted the Yahya Efendi lodge on the opposite hill, and it became an irreplaceable part of Üsküdar's identity.

Sultan Suleyman the Magnificent made a mosque just behind the pier for his daughter Mihrimah Sultan. Together with the Gülnur Valide Sultan Mosque standing opposite to it, they comprise the Üsküdar silhouette that has come down to today. Structures like the Şemsipaşa Mosque on the shore and the Atik Valide Mosque on the hill shaped the city's historical identity.

Just as he made a great impact on all of Istanbul and Ottoman urban culture, the great architect Sinan put his imprint on Üsküdar as well. Selim III had the Kavak Palace torn down and built the Selimiye Military Barracks in its place. Thus the upper silhouette that begins in Çengelköy and extends from there to Çamlıca was completed when it reached Selimiye.

The magnificent shore silhouette was completed passing by various waterfront mansions in Çengelköy to the Beylerbeyi Mosque and Palace and then extending to the Kuzguncuk Pier and, passing the Reji buildings, extending to the Üsküdar Pier, Mihrimah Sultan and Yeni Mosques, Şemsipaşa and later from the Salacak area to the Maiden's Tower.

2.4 The City of Cultures

Istanbul's multi-religious, multi-cultural structure showed itself in Üsküdar as well. The Armenians brought from Anatolia for the construction of the Mihrimah Sultan Mosque made an important contribution to Üsküdar's social fabric and culture. Together with the churches and synagogues, the cemeteries in Bağlarbaşı and Kuzguncuk, and the recent Bülbülderesi cemetery, Üsküdar's identity as the choice of those seeking peace became even more obvious.

Üsküdar’s being almost directly opposite to the Yıldız and Dolmabahçe palaces that were made in the final period of the Ottomans and those working at the palace choosing to settle in Üsküdar made a great contribution to its urban culture. Of course, the dervish lodges were one of the most important factors in Üsküdar's social life. The Özbek Lodge with its important contribution in smuggling guns and soldiers to Anatolia during the National Struggle for Independence can be mentioned among the many dervish lodges, which would be a subject for broad research.

Giving the appearance of a separate city throughout Ottoman history, Üsküdar was a post for a governor during the last period and became tied to the prefecture of Istanbul in 1876. It became a district of Istanbul in 1926 by means of the Property Organization Law. In 1931 it became a municipality. From 1984 to date Üsküdar has been a district municipality within the Istanbul Greater Metropolitan Government.[3]

2.5 Historical Places In Üsküdar

As Üsküdar ruled by different civilizations, it became a place where different cultures meet, because of this there are lots of religious building of all kind, as well as luxurious mansions and Turkish baths. [6]

The main scope of this thesis is, understanding the earthquake affects on masonry structures and saving them from collapse. In this manner, historical structures in Üsküdar area affected from previous earthquakes and being a target for a predicted earthquake, play an important role. For this purpose tables contenting construction date of the structure and previous restorations are created. From created tables, graphs showing the damaged structure ratios are achieved. Table 2.1 shows the group name and group contents. These tables created using the references [1],[2],[3],[4],[5],[6] and [7].

Table 2.1 Historical Structures in Üsküdar

#	Structure Type	# of Buildings
1	Mosques	112
2	Mansions, Pavilions	113
3	Police Stations	14
4	Medreses	9
5	Hospitals	6
6	Church	3
7	Schools	64
8	Libraries	11
9	Turkish baths	14
10	Caravanserai	2

In this thesis, from historical structures located in Üsküdar only masonry ones are considered.Table A.1. shows the considered masonry structures and their used data.

2.6 Previous Earthquake Effects in Üsküdar

Üsküdar which is in the Marmara basin has been affected from previous earthquakes occurred at the Marmara part of KAF (North Anatolia Fault) fault. Figure 2.3 shows the KAF fault in Turkey.

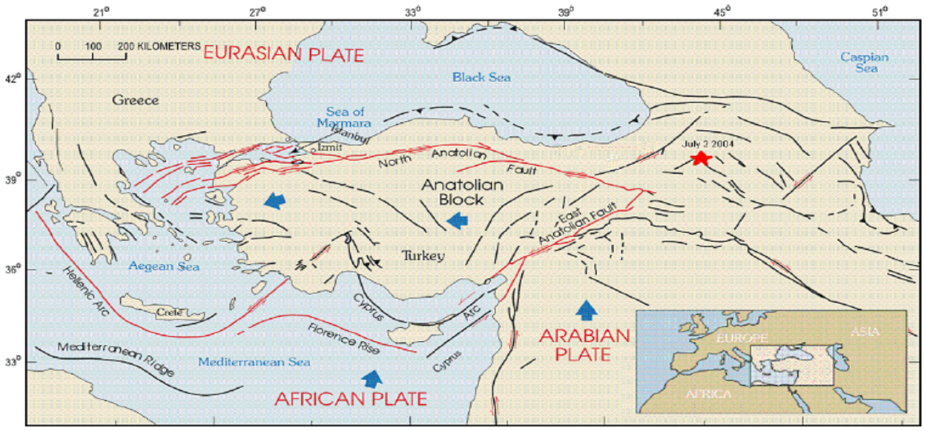

Figure 2.3 North Anatolia Fault

Table 2.2 shows the previous earthquakes affected Üsküdar and their Magnitudes.

Table 2.2 Earthquakes Affecting Üsküdar

Earthquake Date	Magnitude (M)
1489	<6
1509	7,7
1556	<6
1648	<6
1690	<6
1719	<6
1752	<6
1754	<6
1766	6,5
1790	<6
1802	<6
1855	6,1
1894	6,7

Generally, documents about the previous earthquakes occurred in Istanbul mention, cities condition after the earthquake and don't give specific details about thereupon number of buildings and which of them being damaged or collapsed. Content of those documents are rounded numbers of casualties and collapsed or damaged buildings.

Furthermore there is little information about the previous earthquake damage in Üsküdar area causing major collapse or major damage to the specific buildings, such as mosques, schools, etc.

Although, this situation creates a hard condition to understand and measure the exact results of previous earthquakes at those structures, collected information from the libraries about the masonry structures in Üsküdar shows that, masonry structures at this region directly effected from the previous earthquakes and restorated several times because of the earthquake effects.

In Ottoman reports due to the religious manners, especially mosques, which are effected after the earthquake are recorded better compared to the other masonry buildings effected from the same earthquake. From this reason, mosques give more reliable information about the earthquakes affecting the masonry structures in Üsküdar region.

In this thesis in order to understand the previous earthquakes damage at masonry structures, mosques are specially investigated. Another reason for investigating mosques is that mosques are common examples for masonry structures, other historical structures listed in table 2.1 like mansions, pavilions and schools are constructed by wood.

Although some of them used for other purposes, there are currently 112 historical mosques in Üsküdar area. Some of them having no reliable information about their construction date and previous restorations, in this thesis only 97 of them will be investigated. Figure 2.4 shows the distribution of these historical mosques according to their construction date.

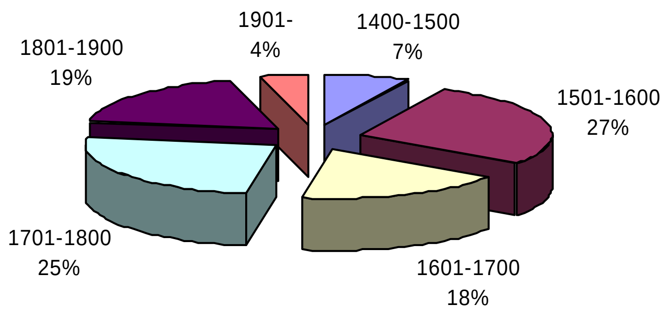

Figure 2.4 Construction date distribution of mosques

Although there are few documents focused on the damage occurred at the specific structures after the earthquake, restorations and renewals are the evidences that proves those structures effected from the occurred earthquake In the Ottoman Empire although the earthquake damages are unreliable, the funds separated from the treasury for restorations and renewals gives enough data for possessing information about their condition after the earthquake. Collected information about the Mosques in Üsküdar shows that they have been repaired several times. Figure 2.5 shows restorations date independent from the structure. Each node in the figure 2.5 shows that there has been a restoration in that date and vertical lines shows that there has been an earthquake in that date.

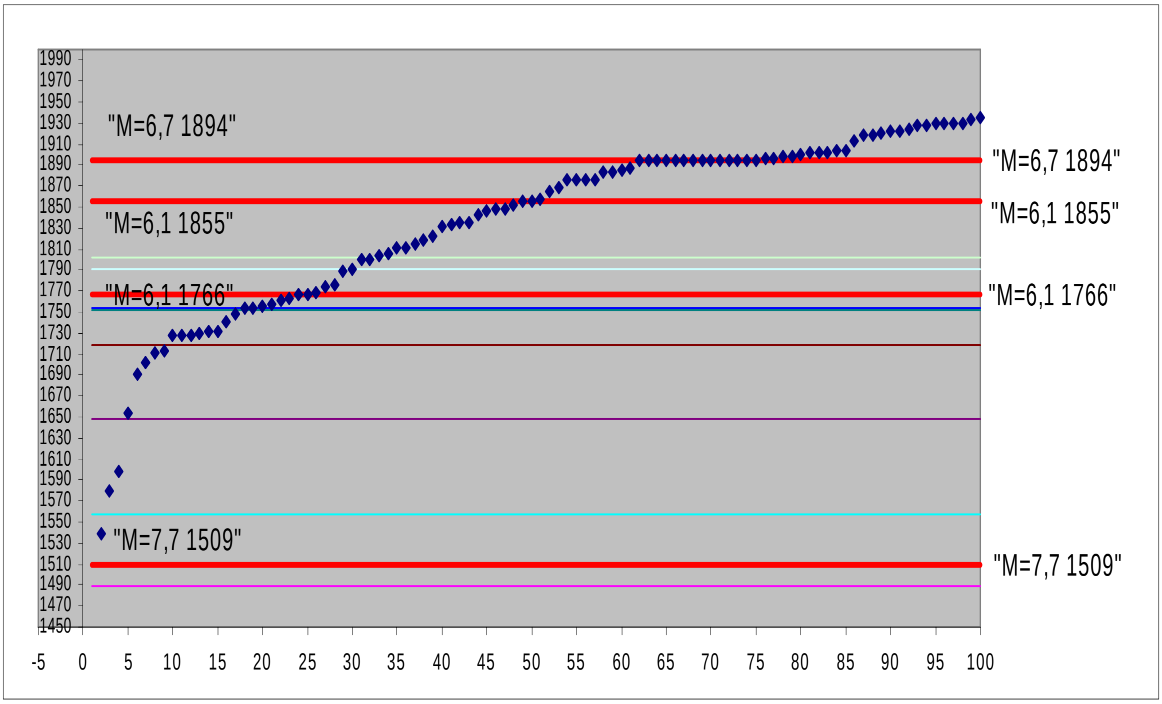

Figure 2.5 Restorations Date and Earthquake Date

In figure 2.5 it can be seen that after the earthquakes with a magnitude greater than six there is an increment for the number of restorations for that year and following years.

Figure 2.6 shows detailed information about the major earthquakes that caused damage at masonry mosques. In figure 2.6 the total number of mosques and total number which has been restorated after the earthquake are given.

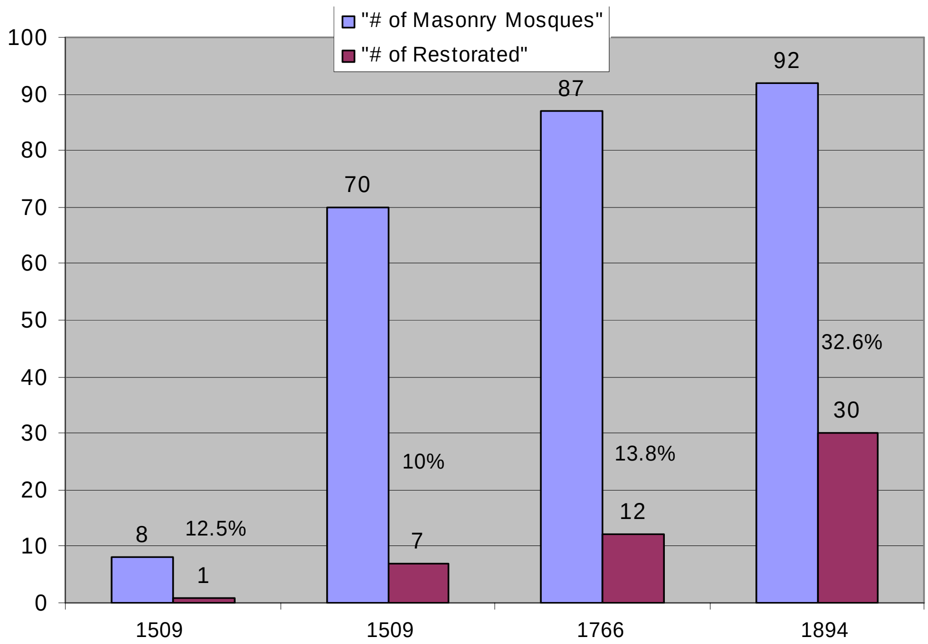

Figure 2.6 Damage ratios after major earthquakes

In Figure 2.6 it should be noted that, since the Ottoman economy was in a downfall period after the 18th century and under normal circumstances construction of a square planed two story masonry structures takes two to ten years, it is assumed to have the structure restorated in ten years. Because of this assumption, number of restorations after the earthquake includes a time period of ten years after the occurrence of the earthquake.

Data acquired from the historical documents shows that, masonry structures are at potential risk for the predicted earthquake. Although previous investigations after the İzmit 1999 earthquake revealed that greatest magnitude reached as 7.6 at 1509, from the figure 2.6 it is obviously seen that percent of the effected structures after each earthquake, with smaller magnitudes than the 1509 earthquake, is rising. This is a proof of aging factor and other factors affecting the strength of the masonry

As far as the historical data proves the risk of masonry structures in Üsküdar area, it is vital to investigate these historical masonry structures according to the predicted earthquake for Istanbul.

2.7 Scenario Earthquakes for Üsküdar

As a part of Istanbul city Seismic Micro-Division earthquake damage reduction plan, Istanbul Greater Metropolitan Government and Japan National Cooperation Agency published 4 different possible earthquake scenarios, which will affect the masonry structures in Üsküdar area as well as the rest of Marmara basin. Figure 2.3 shows the models of the predicted earthquakes. [8]

2.7.1 Model A:

Fault length is 120 km, starts from the Izmit bay and extends to the shore of Silivri. Since the seismic activity in KAF (North Anatolia Fault) moves from east to west, this model is assumed to have more possibility to happen compared to the other scenarios. It is estimated to create an earthquake with a magnitude (Mw) of 7.5.

2.7.2 Model B:

Length of this fault is 110 km. Starts from the 1912 Mürefte-Şarköy faults east edge and end at Bakırköy shores. Estimated magnitude for this fault model is 7.4.

2.7.3 Model C:

This model assumes that the full length of the KAF in Marmara Sea will broken at the same time creaking a fault length of 170 km and creating a 7.7 magnitude earthquake. According to the known historical earthquakes, highest magnitude calculated from earthquake happened in Marmara area is 7.6, thus if this scenario will come true it will create the highest magnitude value ever know for Marmara area.

There is no clue for the fault to creak at the same time and creaking 170 km but according to the historical knowledge in May of 1766 1/3 of the total length of KAF fault cracked and rest part cracked in August of 1766, in other words this scenario is a possible worst scenario.

2.7.4 Model D:

The part of KAF fault starting from İzmit Bay and continues northern side of the Marmara Sea and ends at the Bosporus shores while passing beside the Princes Islands. According to this model it is assumed that possible fault will cause an 6,9 Magnitude earthquake.

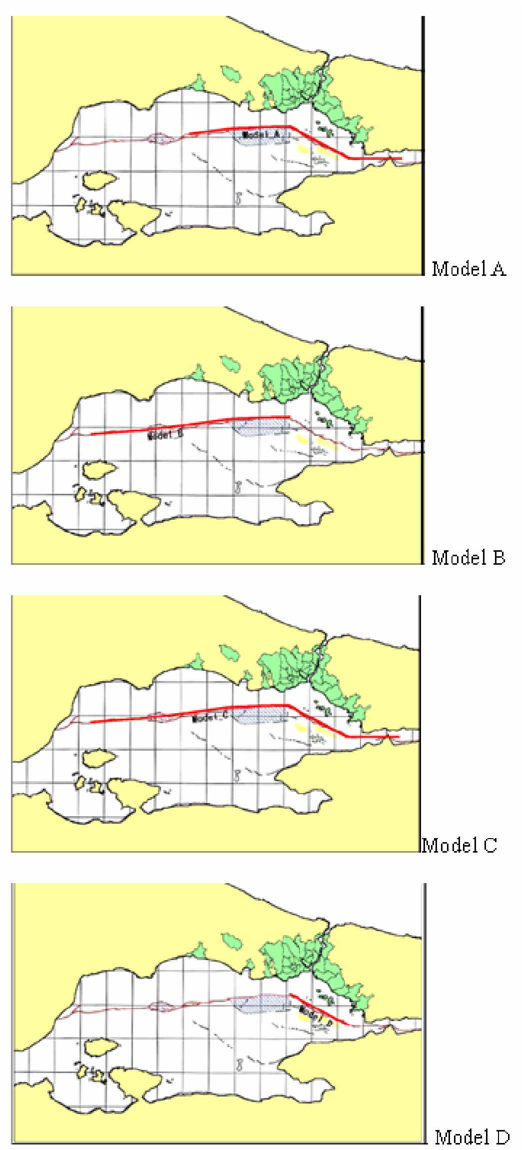

Figure 2.7: Scenario Earthquakes (İ.B.B., 2002).

Table 2.3 shows the fault models and their predicted parameters according to the Istanbul city Seismic Micro-Division earthquake damage reduction plan, Istanbul Greater Metropolitan Government and Japan National Cooperation Agency

Table 2.3: Earthquake parameters for the Scenario Models. (İ.B.B., 2002).

	Model A	Model B	Model C	Model D
Length of the fault (km)	119	108	174	37
Magnitude (Mw)	7.5	7.4	7.7	6.9

Considering the 1894 earthquake with a magnitude of 6.7 and causing damage to 32.6 percent of the masonry mosques in Üsküdar area, the scenario earthquakes with magnitudes greater than 6.9, have major potential for causing damage to the masonry structures in Üsküdar area.

All in all, this library work proves that masonry structures are affected from previous earthquakes and more over they will be affected from the prospective earthquake. This work shows the importance of analyzing the masonry structures in Üsküdar area and strengthening the structures which have potential risks.

3. ANALYZE METHODS FOR HISTORICAL STRUCTURES

Analyzing the masonry structures, located in earthquake zones are difficult tasks demanding enough labor force and enough funds. In order to decide if a structure has a potential risk for an earthquake, analyze of the structure must be done.

There are different analyze approaches deals with the vulnerability of the masonry structures, but two methods gives more reliable results.

3.1 Index Methods for Simplified Analysis

The analysis of historical masonry constructions is a complex task, namely because:

- geometry data is missing
- information about the inner core of the structural elements is also missing
- characterization of the mechanical properties of the materials used is difficult and expensive;
- large variability of mechanical properties, due to workmanship and use of natural materials;
- significant changes in the core and constitution of structural elements, associated with long construction periods;
- construction sequence is unknown;
- existing damage in the structure is unknown;
- regulations and codes are non-applicable.

Moreover, the behavior of the connections between masonry elements (walls, arches and vaults) and timber elements (roofs and floors) is usually unknown. All these factors, indicate that the quantitative results of structural analysis must be looked at with reserves, in the case of vertical loading and, even more carefully, in the case of seismic action. Therefore, more complex and accurate methods do not correspond necessarily to more reliable and better analyses.

The usage of simplified methods of analysis usually requires that the structure is regular and symmetric, that the floors act as rigid diaphragms and that the dominant collapse mode is in plane shear failure of the walls [9].

In general, these last two conditions are not verified by ancient masonry structures, meaning that simplified methods should not be understood as quantitative safety assessment but merely as a simple indicator of possible seismic performance of a building. Here, the following simplified methods of analysis and corresponding indexes are considered:

– Index 1: In-plan area ratio.

– Index 2: Area to weight ratio.

– Index 3: Base shear ratio.

These methods can be considered as an operator that manipulates the geometric values of the structural walls and produces a scalar. As the methods measure different quantities, their application to a large sample of buildings contributes to further enlightening of their application.

As stated above, a more rigorous assessment of the actual safety conditions of a building is necessary to have quantitative values and to define remedial measures, if necessary.

3.1.1 Index 1: In-plan area ratio

The simplest index to assess the safety of ancient constructions is the ratio between the area of the earthquake resistant walls in each main direction (transversal x and longitudinal y, with respect to the church nave) and the total in-plan area of the buildings. According to Eurocode 8 [10], walls should only be considered as earthquake resistant if the thickness is larger than 0.35 m, and the ratio between height and thickness is smaller than nine.

$$\gamma_{1,i} = \frac{A_{wi}}{S} \tag{2.1}$$

A_{wi} : Is the in plan area of earthquake resistant walls in direction ‘‘i’’

S : Total plan area of the building

In case of high seismicity, a minimum value of 10% is recommended for $\gamma_{1,i}$ [9]

3.1.2 Index 2: Area to weight ratio

This index provides the ratio between the in plan area of the earthquake resistant walls in each main direction (again, transversal x and longitudinal y) and the total weight of the construction.

$$\gamma_{2,i} = \frac{A_{wi}}{G} \tag{2.2}$$

$$G = A_w \times \gamma \times h \tag{2.3}$$

Awi : The in plan area of earthquake resistant walls in direction ‘‘i’’

G : Quasi-permanent vertical action

γ : Volumetric weight (kN/m^3)

h : Average height of the structure (m)

Aw : Total in plan area of earthquake resistant walls

In cases of high seismicity, a minimum value of 1.2 m^2/MN is recommended for historical masonry buildings [9]. Table 3.1 shows the recommended γ_2 values depending on the earthquake zone of the structure.

Table 3.1: Minimum Index 2 values depending on the Turkish Earthquake Zones.

Earthquake Zone	γ2,min
Zone 1	3.25
Zone 2	1.85
Zone 3	1.70
Zone 4	0.96

Recommendation for Table 3.1 is actually for Portugal’s earthquake zones which are similar to Turkish earthquake zones.[9]

3.1.3 Index 3: Base shear ratio

The base shear ratio provides a safety value with respect to the shear safety of the construction. The total base shear for seismic loading ($V_{Sd,base}$ = FE) can be estimated from an analysis with horizontal static loading equivalent to the seismic action. Equation 2.4 shows the calculation of total base shear load.

$$F_E = \beta \times G \tag{2.4}$$

β : Equivalent seismic static coefficient related to the design ground acceleration. Table3.2 shows the β values depending to the earthquake zones.

Table 3.2: β values depending on the Turkish Earthquake Zones.

Earthquake Zone	β
Zone 1	0.22
Zone 2	0.15
Zone 3	0.11
Zone 4	0.07

Recommendation for Table 11 is actual for Portugal's earthquake zones which are similar to Turkish earthquake zones.[9]

The shear strength of the structure ($V_{Rd,base}$ = F_{Rd}) can be estimated from the contribution of all earthquake resistant walls. Equation 2.5 shows the calculation of shear strength of the structure

$$F_{Rd,i} = \sum \left[A_{wi} \times \left(f_{vk0} + 0.4 r_d \right) \right] \tag{2.5}$$

f_{vk0} : The cohesion, which can be assumed equal to a low value or zero in the absence of more information

r_d: Design value of the normal stress

In the absence of design value of normal stress, assumption of r_d value calculated by using Equation 2.6 is suitable.

$$r_d = \gamma \times h \tag{2.6}$$

Equation 2.7 shows the calculation of index 3 which is advised to be larger than 1.[NOT1]

$$\gamma_{3,i} = \frac{F_{Rd,i}}{F_E} \tag{2.7}$$

3.2 Numerical Modeling Analyze

Index methods are for calculating the vulnerability of the masonry structures, in conditions where these values are larger than the boundary conditions or the structures doesn't satisfy the boundary conditions, the masonry structure should be investigated by using more specific analyze methods. In these conditions numerical modeling analyze produce more reliable and useful results.[11]

Masonry structures are made of blocks connected by mortar joints. Due to this intrinsic geometrical complexity, which is obviously reflected in the computational effort needed, it is necessary to assume a properly homogenisated material and perform the analyses through the finite element method (FEM), when the global behavior of an entire structure is investigated. On the contrary, when a single structural element is being studied, the actual distribution of blocks and joints can be accounted for. In this case, two approaches appear to be most affective: the finite element method with discontinuous elements (FEMDE) and the discrete element method (DEM).

3.2.1 Modeling with FEM

The numerical modeling of masonry structures through the FEM is a very computationally demanding task because of two different aspects: on the one hand the typological characteristics of masonry buildings do not allow us to refer to simplified static schemes, on the other hand the mechanical properties of the material lead to a widely non-linear behavior whose prediction can be very tricky. Due to the lack of reliable experimental data and the incomplete characterization of the material, renders the numerical model into uncertainty [11].

The presence of vertical and horizontal mortar joints causes the masonry to be anisotropic. Basically, two different approaches have been adopted to model such anisotropy: the 'micromodel', or 'two-material approach', and the macromodel, or 'equivalent-material approach'. In the two-material model, the discretization follows the actual geometry of both the blocks and mortar joints, adopting different constitutive models for the two components. Particular attention must be paid in the modeling of joints, since the sliding at joint level often starts up the crack propagation. Although this approach may appear very straightforward, its major disadvantage comes from the extremely large number of elements to be generated as the structure increases in size and complexity.

This renders unlikely the use of micromodels for the global analysis of entire buildings, also considering the fact that the actual distribution of blocks and joints might be impossible to detect unless invasive investigations are performed. The macromodel assumes that the masonry structure is a homogeneous continuum to be represents with a finite element mesh which does not copy the wall organism, but obeys the method's own criteria. The single element will thus have a constitutive model which must be capable of reproducing an average behavior. This assumption bypasses the physical characteristics of the problem. Nevertheless the equivalent material models have proven to be able to grasp certain aspects of the global behavior without the number of parameters and the computing effort needed in the micromodel [12].

3.2.2 Modeling with interface elements: the FEMDE

In this approach, the blocks are modeled using conventional continuum elements, linear or non-linear, while mortar joints are simulated by interface elements, the 'joint elements', and made up of two rows of superimposed nodes, with friction constitutive low [13].Figure 3.1 shows degeneration of continuum into joint elements

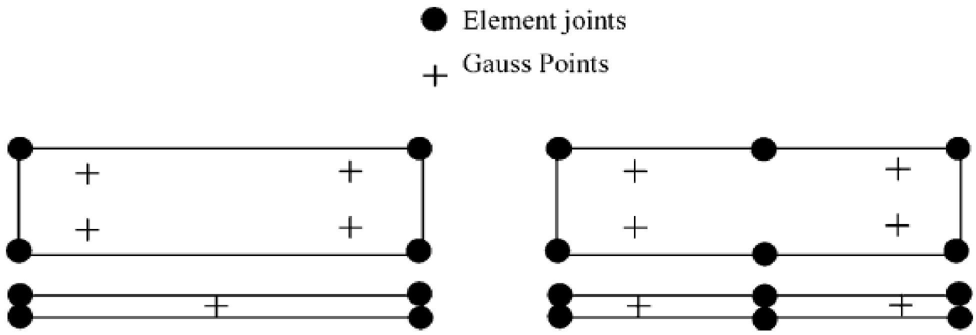

Figure 3.1: Degeneration of continuum elements into joint elements

The introduction of the joint is easy to implement in a software program, since the nodal unknowns are the same for continuum and joint elements, though for the latter the stress tensor must be expressed in terms of nodal displacements instead of deformation components. Two major concerns balance the apparent simplicity of this approach [14]:

Block mesh and joint mesh must be connected together, so that they have to be compatible, which is possible only if interface joints are identically located. This compatibility is very difficult to ensure when complex block arrangements are to be handled, like in 3D structures.

The joint element is intrinsically able to model the contact only in the small displacement field. When large motions are to be dealt, is not possible to provide easy remising in order to update existing contacts and/or to create new ones.

Typical modeling of a FEMDE mesh is shown in Figure 3.2

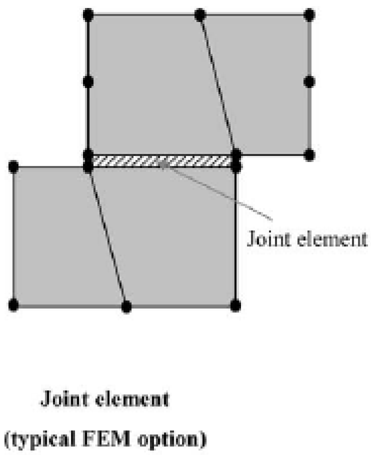

Figure 3.2: FEMDE Mesh connection detail

3.2.3 Modeling with DEM

The discrete (or distinct) element methods fall within the general classification of discontinuum analysis techniques. Originally used to model jointed and fractured rock masses, they were developed for the analysis of structures composed of particles or blocks and are especially suitable for problems in which a significant part of the deformation is accounted for by relative motion between blocks. Masonry provides a natural application for these techniques, as the deformation and failure modes of these structures are strongly dependent on the role of the joints. This approach is well suited for collapse analysis, and may thus provide support for studies of safety assessment, namely of historical stone masonry structures under earthquakes.

Two main features of the discrete element method (DEM) led to its use for the analysis of masonry structures by means of UDEC - Universal Distinct Element Code. One is the allowance for large displacements and rotations between blocks, including their complete detachment. Other, is the automatic detection of new contacts as the calculation progresses. The block material may be assumed rigid or deformable.

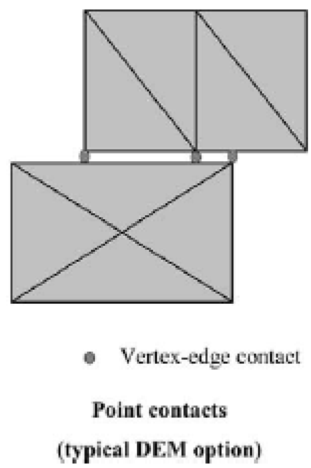

Figure 3.3: FEMDE Mesh connection detail

In discrete element models, the representation of the interface between blocks relies on sets of point contacts. Adjacent blocks can touch along a common edge segment or at discrete points where a corner meets an edge or another corner. At each contact, the mechanical interaction between blocks is represented by a force, resolved into a normal (Fn) and a shear (Fs) component. Contact displacements are defined as the relative displacement between two blocks at the contact point. In the elastic range, contact forces and displacements are related through the contact stiffness parameters (normal and shear).

The necessary parameters to define the contacts mechanical behavior are the normal stiffness (kn), shear stiffness (ks), friction angle (μ), cohesion (c) and tensile strength (σt).

The selection of a solution algorithm for the discrete element method must take into account the fact that the geometry of the system, as well as the number and type of contacts between the discrete bodies, may change during the analysis. In the discrete element method the structural analysis, both static and dynamic, is based on explicit algorithms.

Among the most important capabilities of DEM (and UDEC) that make it very suitable for masonry structures could be mentioned: the ability to simulate progressive failure associated with crack propagation; the capability of simulating large displacements/rotations between blocks; the fact that contact points are updated automatically as block motion occurs and the fact that the problem of interlocking is overcome by automatically rounding the corners.[15]

4. ANALYSIS OF MAIDEN’S TOWER

4.1 About the Maiden’s Tower

The Maiden's Tower is a tower located on a stone pile, 200 m distant from the Asian coast, at the intersection point of Asia and Europe. It is one of the unique structures throughout the world, between two continents. Figure 4.1 shows the satellite picture of Maiden’s Tower located in Üsküdar.

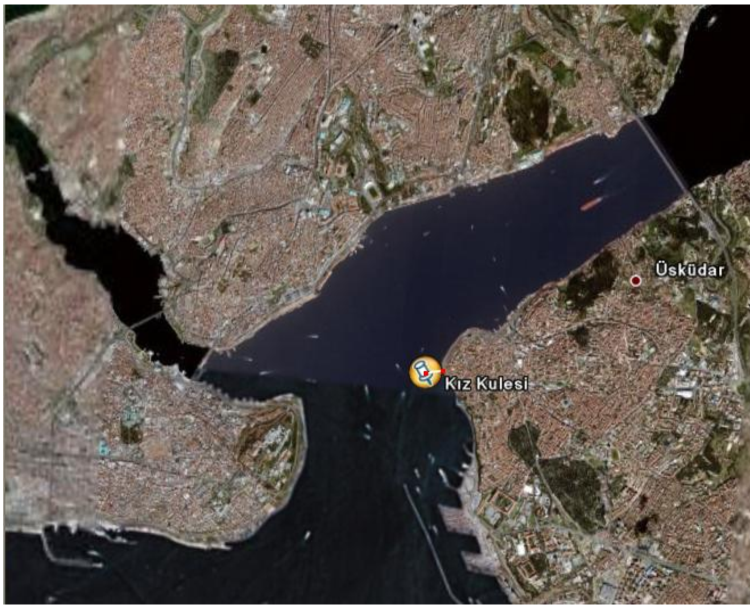

Figure 4.1 Location of Maiden’s Tower

This tower, which dates back to 2500 years ago, had a history identical to Istanbul’s history, being an eyewitness to whatever the city has encountered. Its history started in the antiquity, and it existed throughout the Greek times to Byzantine Empire, and from Ottoman Empire until the present.[19]

This island, which first hosted a burial chamber during the Greek Era, was used as a customs area with the additional building constructed during the Byzantium Era. It had assumed several functions from a show platform to a defense castle, from an exile area to a quarantine island. Its main duty was being a lighthouse, and through the centuries it has guided people during daytime, and the boats passing by during nighttime, with its ever-winking light.

This tower, remembered with stories throughout centuries, opened its doors to public 2500 years later, after the restoration carried out by Hamoğlu Holding and TURES.

4.2 Legends About the Maiden's Tower

As the Maiden's Tower was remote and inaccessible, people did not have much information about what was lived in it, and they sufficed with telling interesting stories about the inside, and imagining. The first story about the Maiden's Tower was a love story told by Ovidius. This story, relating to the sad love of Hero and Leandros, begins with Hero leaving the tower. Hero is one of the holy women of Aphrodite, and love is banned for her. She leaves the tower years later to attend a ceremony to be held at the Aphrodite temple, and there she meets Leandros. These two youngsters in love with each other, bless their love with Leandros visiting the tower at nights. The Maiden's Tower witnesses the devotion and the forbidden love of these two young people every night. On a stormy night when Leandros was swimming to the tower, the love light that Hero burnt was put out. Leandros losing his way in the darkness is buried in the waters of the Bosporus. Hero, seeing that her lover dies, lets herself in the arms of the waters as well. Other than this story on lovers that cannot meet, there is a snake story, similar to the Cleopatra's end. According to a prophecy, a king is to lose her beloved daughter at the age of eighteen, with a snakebite. Therefore, the king has this tower in the middle of the sea repaired, and places his daughter here. Proving that the fate cannot be escaped, a snake emerging from a grape basket sent to the tower, empties its poison to the princess. The king has an iron vault prepared for his daughter and places it above the gate of Hagia Sophia. [20]

The last story is from the Ottoman times. It is the story about Battal Gazi raiding the Maiden Tower with his soldiers and taking away the hidden treasures and the daughter of Üsküdar Tekfur (Governor). Battal Gazi took the daughter of the tekfur and the treasury, and rode away from Üsküdar, on his horse. The expression "Atı alan Üsküdar'ı geçti" (He who took the horse is already past Üsküdar) is a reflection of this story. Another aspect of this story coming to the present is about the name of this tower. In reference also to the princesses in other legends, Turks named this tower Kız-Kulesi (the maiden's tower). The tower, which was called as Arkla (small castle) in the Antiquity and Damialis (calf), was also famous with the name Tour Leandros. Currently it is "Kızkulesi" (the Maiden's Tower), and known with this name.

4.3 History of the Maiden’s Tower

The architectural structure of the Maiden's Tower (Kız Kulesi) dates back to 341 BC. This cape, which was an extension of the Bosphorous straits at the time (there are rumours that it was a peninsula before) used to be called "vus". At this date, after being a mausoleum built on marble columns for the wife of Commander Chares, a chain was pulled from its location at Sarayburnu to the island where the tower was located, in 410 BC, to make it a customs area controlling the entries and exits of the Bosphorous strait. At 1110 AD, the first apparent structure (tower) was built by the Emperor Manuel Comnenos. Figure 4.4 shows the Maiden’s Tower at Byzantium Empire times.

Figure 4.2 Maiden’s Tower Before 1453

This structure, which was built as a defense tower, was named Arcla, meaning "Small Tower". Although there is no clear information about this structure, it is believed to be close to its current dimensions. The tower, which was used for defense purposes during the conquest of İstanbul, was used for very different purposes after 1453. During the Ottoman period, it was used rather as a show platform, than a defense team and the Mehteran team cited the *nevbet* (a national anthem) accompanied by the canons placed on the island. [20]

The structure, which was damaged during the earthquake of 1509, was rebuilt later. Furthermore, it acted as a lighthouse with the lights that were added. The structure that was built then included a tower and a castle, and a cistern was built in it.

Figure 4.3 Maiden's Tower before 18th Century

The tower that burnt down with the fire from the light, in 1719, was repaired again in 1725 by Nevşehirli Damat İbrahim Paşa who is the Head Architect of the city. The tower section was changed a little, and a glass chalet was added to the top, and a lead dome was placed on it, and the building was built with wood. It was converted into a quarantine hospital in order for the cholera epidemic not to spread to the city in 1830.

Figure 4.4 Maiden's Tower at 19th Century

It was started to be used as a defence castle again with the decline of the Ottoman Empire, and it is equipped with canons. The epigraph bearing the signature of Sultan Mahmut the Second was placed on the marble above the gate, with the handwriting of the famous calligrapher Rakim. In 1857, a light is added again, and in 1920, an automatic system is introduced as the light of the lighthouse.

Figure 4.5 Maiden's Tower at 20th Century

It is thought of transferring this building to private sector as of 1992, and several institutions such as the İstanbul Metropolitan Municipality, Üsküdar Municipality, Chamber of Architects, Turing, Ulusoy Group of Companies, etc. develop various projects.[21]

4.4 Analysis Method

Most of the existing historical monumental structures are, at least in Europe, made of masonry, using either stone or brick blocks. These unreinforced blocky masonry structures can not be considered a continuum, but rather an assemblage of compact stone or brick elements linked by means of mortar joints. Seismic events have often caused massive damage or the destruction of such structures with great cultural significance.

Examples can be found in past earthquakes, which affected most of this type of constructions of the ancient Turkish, Greek and Roman civilizations. In recent events, earthquakes have also caused great damage and destruction of religious temples and other monumental buildings.

Unlike today’s structures where the seismic vulnerability can be inferred by means of existing codes and analysis methodologies, the assessment of the seismic behavior of old masonry structures lacks scientific background.

The evaluation of the seismic vulnerability of such structures, as is the case for the other types of structures, depends on reliable numerical simulation of their seismic response. Numerical modeling of the seismic behavior of masonry structures represents a very complex problem due to the constitutive characteristics of the structural material and its highly physical and geometrical non-linear behavior when subjected to strong ground motion. Whatever method is used to analyze this type of structures, it must account for the fundamental importance of the discontinuities, and such an unreinforced masonry structure will display a mechanical behavior essentially different from a continuum.

Masonry structures can not be correctly studied by conventional methods of structural mechanics like the ones that are used to analyze today's structures. Being composed of two very different materials, i.e. the masonry units and a joining material such as mortar, masonry exhibits a heterogeneous structure and it is a discontinuous system. Its blocky nature governs the deformation and failure mechanisms.[18]

Practical analysis of unreinforced masonry (URM) buildings for design and/or assessment purposes is typically carried out using static analysis involving planar at two - dimensional (2D) models, and isotropic homogeneous linear elastic behavior is assumed.

However, currently available analytical tools for URM also include finite element (FEM) models based on isotropic–orthotropic homogeneous nonlinear material, or even heterogeneous nonlinear material assumptions. Furthermore, discrete element formulations are available, focusing on the nonlinear behavior of joints between masonry units

As explained above DEM and FEMDE are valid and more accurate analysis methods compared to other methods, but due to the complexity of the modeled structure and lack of necessary site experimental data, such as detailed material properties, brick dimensions and brick age, in this thesis, Maiden’s Tower is analyzed by assuming the structure to behave isotropic homogeneous linear elastic. The analyze method of equivalent-material approach is used to analyze Maiden’s Tower.

A three-dimensional model of the Maiden's Tower was implemented using SAP2000® and the fundamental frequencies and the corresponding mode shapes of the structure, based on its assumed physical and mechanical properties, were determined.

In the preliminary phase, it is assumed that all the materials of the structure have the following characteristics:

- they are homogeneous and isotropic;
- they behave linear elastic
- the geometry of the structure is idealized considering the structure to be made of shell elements

4.5 Geometry of Maiden's Tower

Geometry of Maiden's Tower before restoration surveys are shown in Figure 4.6, Figure4.7 and Figure 4.8. After restoration surveys are shown in Figure 4.9, Figure 4.10 and Figure 4.11 These surveys are acquired from Tasarım Group.[22]

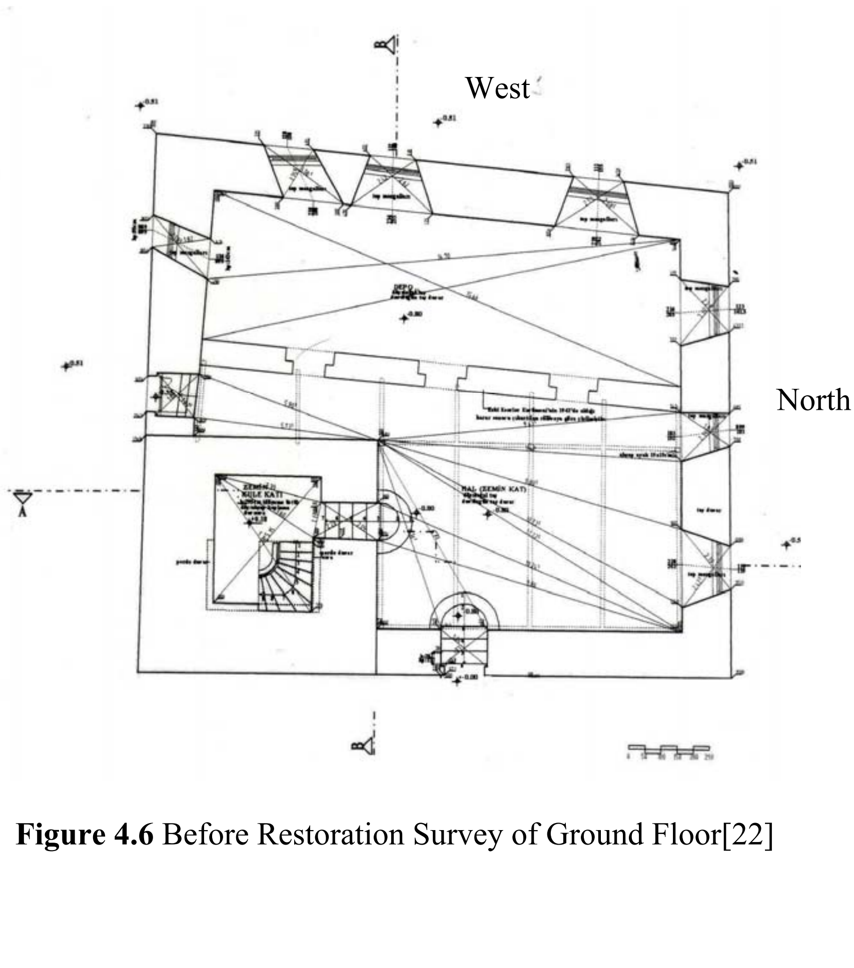

Figure 4.6 Before Restoration Survey of Ground Floor[22]

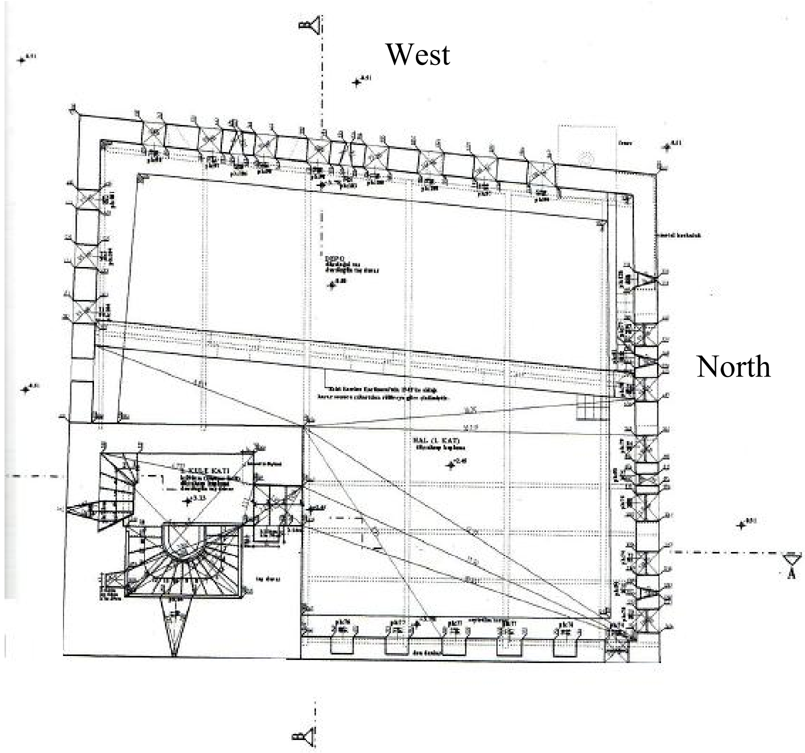

Figure 4.7 Before Restoration Survey of First Floor[22]

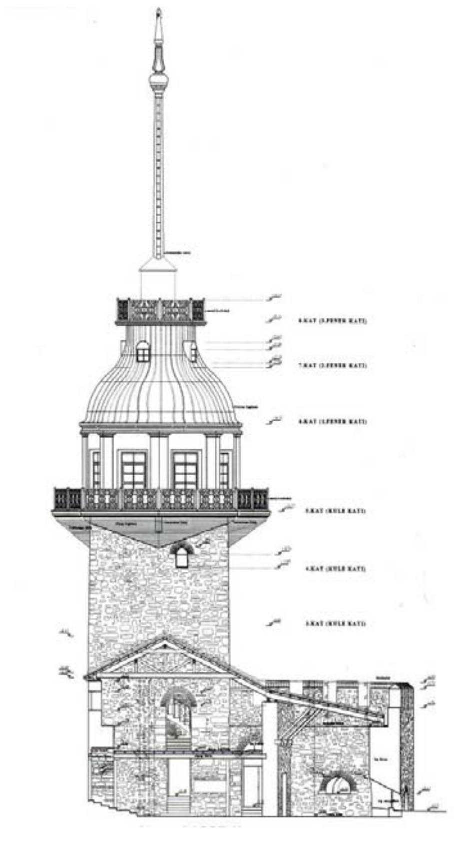

Figure 4.8 B-B Section View of Before Restoration Condition[22]

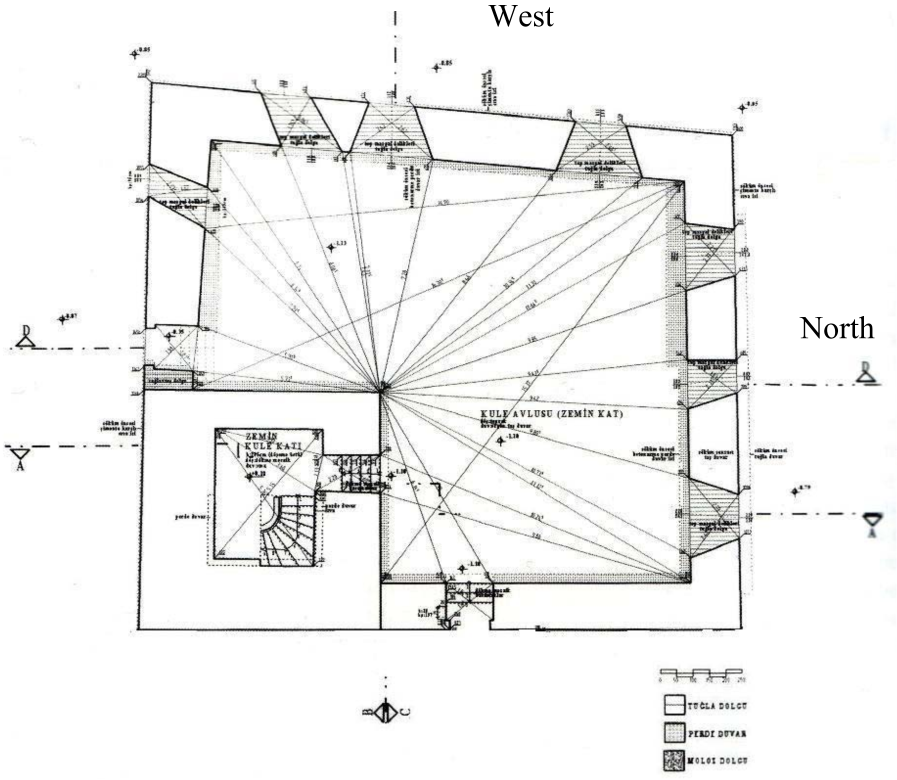

Figure 4.9 After Restoration Survey of Ground Floor[22]

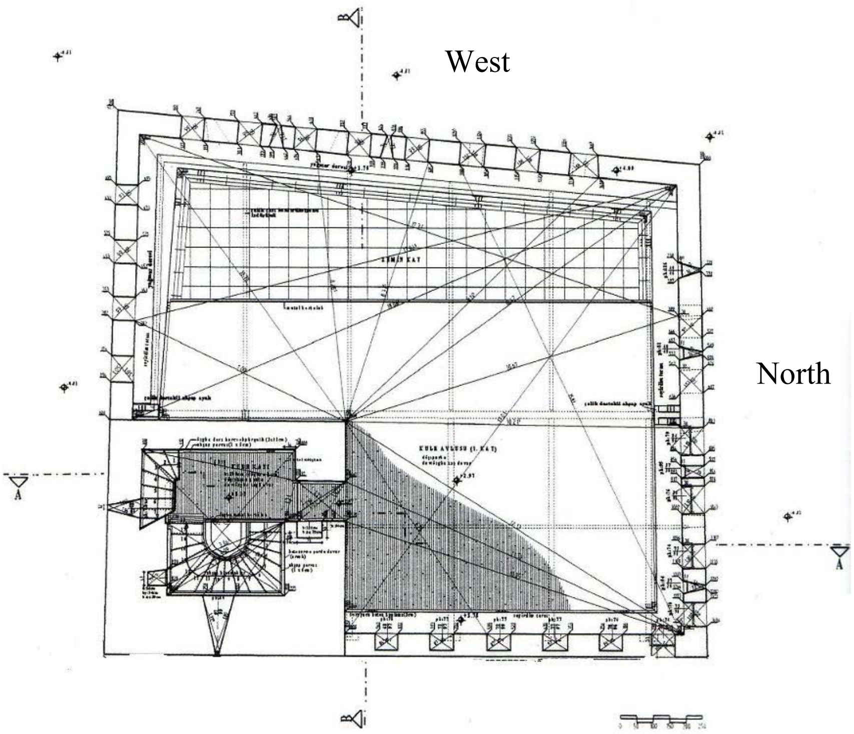

Figure 4.10 After Restoration Survey of First Floor[22]

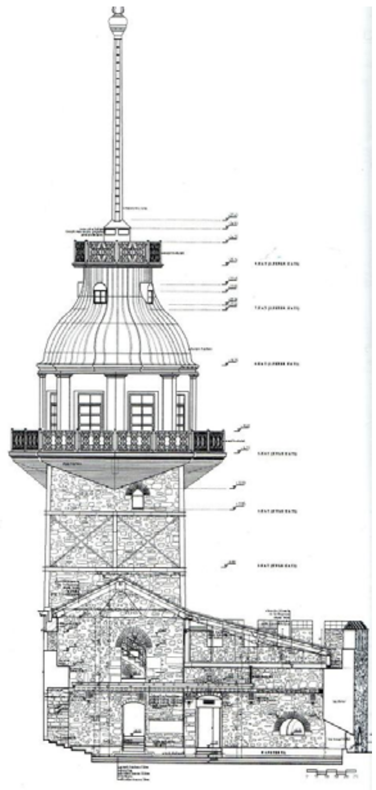

Figure 4.11 B-B Section View of After Restoration Condition[22]

The positions of openings and the variation of the thickness of the tower with respect to that quoted have been carefully recorded. Surveys served as a basis for the mesh generation needed for further FEM analysis.

As it can be noted from the before and after restoration surveys, the main differences between the two conditions are steel bracings at the tower and repealing of the masonry walls carrying the first floor slab.

4.6 Material Properties of Maiden's Tower

The Tower had lots of major and minor restorations since its construction date but all the restorations including the 1943 restoration, restoraters used the tuff masonry to replace the cracked stones. Figure 4.12 shows the chronological wall analysis of Maiden's Tower.

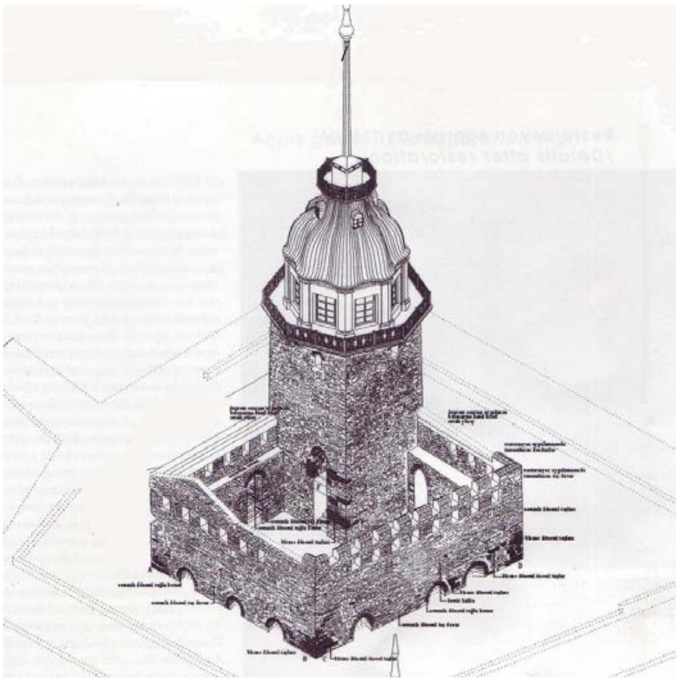

Figure 4.12 Chronological wall analysis[22]

The materials used in the previous restoration process differ from Byzantium era tuff masonry stones, Ottoman era tuff masonry stones and Ottoman era giant bricks.

Although in 2001 the tower has been restorated by TURES firm, due to their uncooperative attitude, site experimental data about the Maiden's Tower are unavailable in order to use in this thesis.

In this thesis since there is not enough information about the material properties of masonry stones nor the giant bricks, assumption of tuff masonry stone material properties are taken from the similar restorations.[24]. Young modulus (E), tangential elasticity modulus (G), Poisson's ratio (ν), weight per unit volume (γ), compression strength (σ_c) and tension stress (σ_t) are given below.

G	:	518 MPa
ν	:	0.071
γ	:	17 kN/m^3
σ_c	:	2.0 MPa
σ_t	:	0.165 Mpa

4.7 Modeling of Maiden's Tower

Due to the considerable irregularities of the Maiden's Tower, a simplified arrangement of the plan has been set up for the structural analysis of the structure. From this "design" plan, quite more regular than the actual one, the single macro-elements which constitute the structural system of Maiden's Tower can be identified.

4.8 Load Calculations for Maiden's Tower

Maiden's Tower which was constructed as a castle with a tower and later on castle covered by wooden roof, have several different load groups acting on the structure. The load values acting on the structure are calculating by using the relevant Turkish Codes.

4.8.1 Roof Loads

According to the TSE498, roof load values depending on the roof top height and roof angle are calculated. The table 4.1 shows the 2 different roofs and dome values which will be used in calculating the roof loads.

Table 4.1. Roof types in the structure

Name	Roof Angle (^{o})	Roof Top Height (m)
Roof A	40.50	8.31
Roof B	10.66	5
Dome	62	26.25

It should be noted that although the dome section has a sinusoid form, in order to simplify analyze of the structure, it's assumed to have a roof angle of 62^o.

4.8.1.1 Roof Dead Loads

Roof covering material is 2.5x20 cm x cm wood and above it ottoman type roof tile.

Dead load = 1.20 kN /m^2 (TSE 498) (covering material and tile included)

4.8.1.2 Roof Snow Load

Maiden's Tower which is located in Üsküdar / Istanbul is Region 2 according to the TSE 498. Since the tower is at sea level, snow load (P_{ko}) taken from the TSE498 roof load table as 0.75 kN/m^2.Equation 4.1 and equation 4.2 shows the calculation method for snow loads.

$$P_k = m \times P_{ko} \tag{4.1}$$

$$m = 1 - \frac{\alpha - 30^0}{40^0} \tag{4.2}$$

P_{ko} : Snow load depending to region and altitude of structure (kN/m^2)

m : Snow factor depending to the roof slope

P_k : Roof snow load (kN/m^2)

α : Roof slope (^{0})

Table 4.2 Shows the snow loads acting to the roofs

Table 4.2 Snow Loads

Name	Roof Snow Load (P_k)
Roof A	0.56
Roof B	0.75
Dome	0.15

4.8.1.3 Roof Wind Load

Wind load is calculated by using TSE498[25] wind load table depending to structure height. Table 4.3 shows the suction force (q) which is used to calculate wind force at the structure.

Table 4.3 Wind Force Depending on the top height of the structure

Structure top height (m)	Wind Speed (km/h)	Suction Force (kN/m^2)
0 – 8	100.8	0.5
9 – 20	129.6	0.8
21 – 100	151.2	1.1
>100	165.6	1.3

Affective roof wind load values used in the analyze of the structure is given at Table 4.4

Table 4.4 Wind Loads at Roofs

Roof Type	Wind Acting Side (kN/m^2)	Other Side (kN/m^2)
Dome	0.73	0.55
A	0.31	0.44
B	-0.082	0.20

4.8.2 Wind Loads at Walls

Maiden's Tower is a complicated structure with different wall heights. In order to create a reliable model of the structure, walls are classified in to several groups. Table 4.5 shows the walls grouped and their corresponding wind load.

Table 4.5 Wind Loads at Walls

Location of the wall	**Height (h) (m)**	**Wind Velocity (km/h)**	**Suction Force (q) (kN/m^2)**	**Wind Affecting Side (0.8xq)**	**Other Side (0.4xq)**
Castle walls	6.03	100	0.5	0.4	0.2
Tower walls (0.00~8.00)	8	100	0.5	0.4	0.2
Tower walls (8.00~20.00)	12	130	0.8	0.64	0.32
Tower walls (20.00~26.25)	12	151	1.1	0.88	0.44

Because the structure is not symmetrical wind loads affecting to both walls and the roof are entered to the SAP2000 model from 4 different wind directions.

NW : Wind direction from North

SW : Wind direction from South

EW : Wind direction from East

WW : Wind direction from West

4.8.3 Live Load

Although Maiden's tower is designed as castle and used as military base ,it is currently used as a restaurant. Since the restoration process is for creating a structure which will be used as a restaurant. Live loads for the floors are taken as 5 kN/m2. [25]

4.8.4 Earthquake Load

Earthquake load calculations of the Maiden's Tower are calculated by using TDY2005. The main scope of the TDY2005 Sketch Section 10 is, design of buildings unreinforced, confined and reinforced masonry in seismic regions.

In this thesis in order to evaluate Maiden's Tower by using TDY2005, it is assumed that masonry units have sufficient robustness in order to avoid local brittle failure.

In Turkish Standards for earthquake resistant design 2005 edition, methodology and coefficients are given;

- Masonry structures will be analyzed by using "Equivalent Lateral Force Method"
- In order to simplify the analyze of masonry structures, spectrum factor $S(T_1)$ which is necessary for calculating earthquake loads will be taken as 2.0
- Earthquake load reduction factor ($Ra(T_1)$) will be taken as 2.0 is take[26]

4.8.4.1 Equivalent Lateral Force Method:

In this method it's assumed that the earthquake load affecting to the structure, is entered to the model of the structure as the vertical loads acting at the floor levels.[26] Figure 4.14 shows the horizontal earthquake loads acting to a structure.

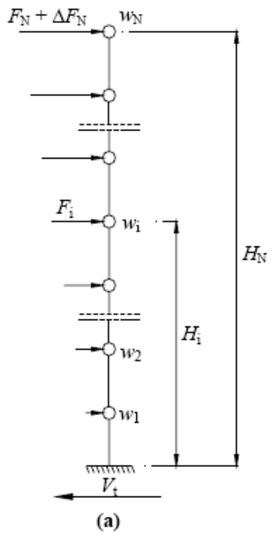

Figure 4.14 Earthquake Load Distributions [25]

In this thesis it is assumed that the vertical loads act to the structure at floor levels where ever a wall is connecting to a floor and at top heights of the walls where ever there is no floor connection to the wall.

The top height level is chosen as the location for acting for the vertical earthquake load because of the belt course added to the structure at the 1943 restoration.

$$Vt = \frac{Wi \times A(T_1)}{Ra(T_1)} > 0{,}10 \times A_o \times W \times I \tag{4.3}$$

$$A(T_1) = A_o \times I \times S(T_1) \tag{4.4}$$

$$V_t = \Delta F_N + \sum_{i=1}^{N} F_i \tag{4.5}$$

$$\Delta F_N = 0.07 \times T_1 \times V_t \tag{4.6}$$

$$W_i = \sum_{i=1}^{N} w_i \tag{4.7}$$

$$w_i = g_i + n \times q_i \tag{4.8}$$

A_o : Depending on the earthquake zone, design ground acceleration. The value of Ao is taken from the table 4.6 considering the Maiden's Tower constructed in Üsküdar which is in earthquake zone one.

Table 4.6: Design Ground Acceleration Coefficient (A_o)

Earthquake Zone	A_o
1	0.40

I : Importance class factor of the building. The value of I is taken from table 4.7. Since the building is used as a museum I is taken as 1.4.

Tablo 4.7: Importance Class Factor (I)

Structure Usage Type	**Importance Class Factor (I)**
2. Buildings where people stay long and at high densities and buildings which are used to stock expensive materials a) Schools, education centers, dorms, military bases, prisons, etc. b) Museum	**1.4**

S : Spectrum coefficient

T1 : First vibration period of the structure

W : Total weight of the structure

$Ra(T_1)$: Earthquake load reduction coefficient

$A(T_1)$: Spectral acceleration factor

gi : Dead loads

n : Live load attendance factor.

According to the TDY2005 live loads acting to a structure must be taken in to account considering the earthquake loads.Table 4.8 shows the live load attendance factor depending on the usage of the structure.

Table 4.8: Live load attendance factor (n)

Usage of the Building	**n**
Schools, sport facilities, theater, concert halls, restaurant, stores, etc	0.60

qi : Live loads

V_t : Total equivalent lateral force

$$A(T_1) = A_o \times I \times S(T_1)$$

$$A(T_1) = 0.40 \times 1.4 \times 2.0 = 1.12$$

$$Vt = Wi \times \frac{A(T_1)}{Ra(T_1)}$$

$$\frac{A(T_1)}{Ra(T_1)} = \frac{1.12}{2.0} = 0.56$$

Earthquake load acting to the structure is, 56 percent of total weight of the structure.

4.9 Evaluation of Analyze Results

4.9.1 General Rules For Evaluating the Results

Gravity loads, earthquake loads and wind loads causing nominal stone wall stress should be lower than the allowable stone materials sliding stress and compressive stress values.(TDY2005)

4.9.1.1 Stone Wall Compressive Stress Values

The TDY2005 specifies the compressive stress value depending on the wall material and mortar type in Table 3.1

Table 4.9: Allowable compressive stress value

Wall Material Average Compressive Strength (MPa)	**Mortar Type Used in the construction of walls (MPa)**				
	A (15)	**B (11)**	**C (5)**	**D (2)**	**E (0.5)**
25	1.8	1.4	1.2	1.0	0.8
16	1.4	1.2	1.0	0.8	0.7
11	1.0	0.9	0.8	0.7	0.6
7	0.8	0.7	0.7	0.6	0.5
5	0.6	0.5	0.5	0.4	0.4

Since there is no available result of materials average compressive strength nor the mortar type used in Maiden's tower. The material properties are assumed to have the tuff masonry material properties.

σ_c = Compression strength = 2.0 MPa

Depending on the slenderness ratio of the wall, chosen allowable compressive stress value will be multiplied by a coefficient. Table 4.10 shows the coefficient changing due to the slenderness ratio.

Table 4.10: Reduction coefficient

h/t	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**
Reduction coefficient	1.0	0.95	0.89	0.84	0.78	0.73	0.67	0.62	0.56	0.51

The Maiden's Tower has 2 different wall thicknesses depending on the place of the wall and the height of the wall. Table 4.11 shows the wall locations, height and thickness of the walls. Corresponding reduction factors are calculated according to the Table 4.10

Table 4.11: Reduction Factors for Maiden's Tower

Location of the wall	**Height (h) (m)**	**Thickness (t) (m)**	**h / t**	**Reduction Factor**	**Material Compressive Strength (σ_c) (MPa)**	**Affective Compression Strength (σ_c) (MPa)**
Castle walls first floor	3.78	1.5	2.52	1	2.0	2.0
Castle walls second floor	2.25	0.75	3	1	2.0	2.0
Tower walls (0.00~8.89)	8.89	1.5	5.92	1	2.0	2.0
Tower walls (8.89~19.25)	10.36	0.75	13.8	0.79	2.0	1.58

4.9.1.2 Stone Wall Shear Stress Values

The shear stress values calculated from the earthquake load and other horizontal load should be smaller than the wall sliding strength which is calculated by Equation 3.7

$$\tau = \tau_0 + \mu \times \sigma \qquad (3.7)$$

μ : Friction factor = 0.5

The Maiden's Tower has 2 different wall thicknesses depending on the place of the wall and the height of the wall. Table 4.12 shows the wall locations and corresponding affective shear strength values.

Table 4.12 Affective shear Strength

Location of the wall	**Affective Compression Strength (σ_c) (Mpa)**	**Friction Factor (μ)**	**Shear Strength (τ_0) (MPa)**	**Affective Shear Strength (τ) (MPa)**
Castle walls first floor	1.7	0.5	0.165	1.015
Castle walls second floor	1.7	0.5	0.165	1.015
Tower walls (0.00~8.89)	1.7	0.5	0.165	1.015
Tower walls (8.89~19.25)	1.34	0.5	0.165	0.835

4.10 Analyze Results for Before Restoration Condition

Weight of the structure is the most important factor calculating the earthquake effects at a structure. In order to avoid local modes occurring from the roof sections and flag pole which are light weighted compared to the rest of the structure, the modal analyze of the analyze of Maiden's Tower excludes these elements. The model of Maiden's Tower consists of 1923 shell areas and 42 wood beams which are carrying the wood floor. Figure 4.15 shows the model created from the surveys acquired for before restoration condition.

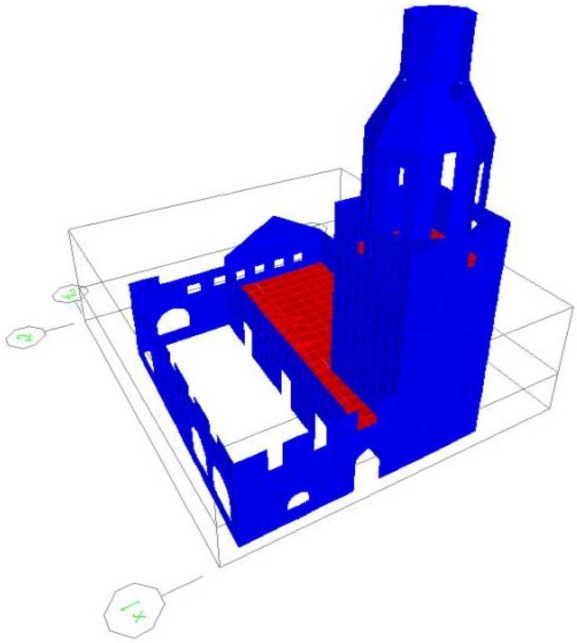

Figure 4.15 SAP2000® Model of Maiden's Tower Before Restoration

For the sake of analyze results to be reliable, the modal static load participation ratios must be lager than the 90 per cent of the total weight of the structure[26]. Table4.13 shows the modeled Maiden's Tower modal load participations and effective periods of the structure.

Table 4.13 Modal Load Participations and Effective Periods

TYPE	Name	Static	Effective Period
ACC	UX	99.7917	0.326923
ACC	UY	99.8763	0.338052
ACC	UZ	96.2035	0.169908
ACC	RX	99.2796	0.343882
ACC	RY	99.2600	0.334184
ACC	RZ	99.6757	0.306037

The advantage of analyzing Maiden's Tower is that, the structure had affected from the Izmit 1999 earthquake which had a magnitude of 7.4. Although the center of this earthquake was 60 km away from the Maiden's Tower, some major cracks as shown in figure 4.16 occurred.

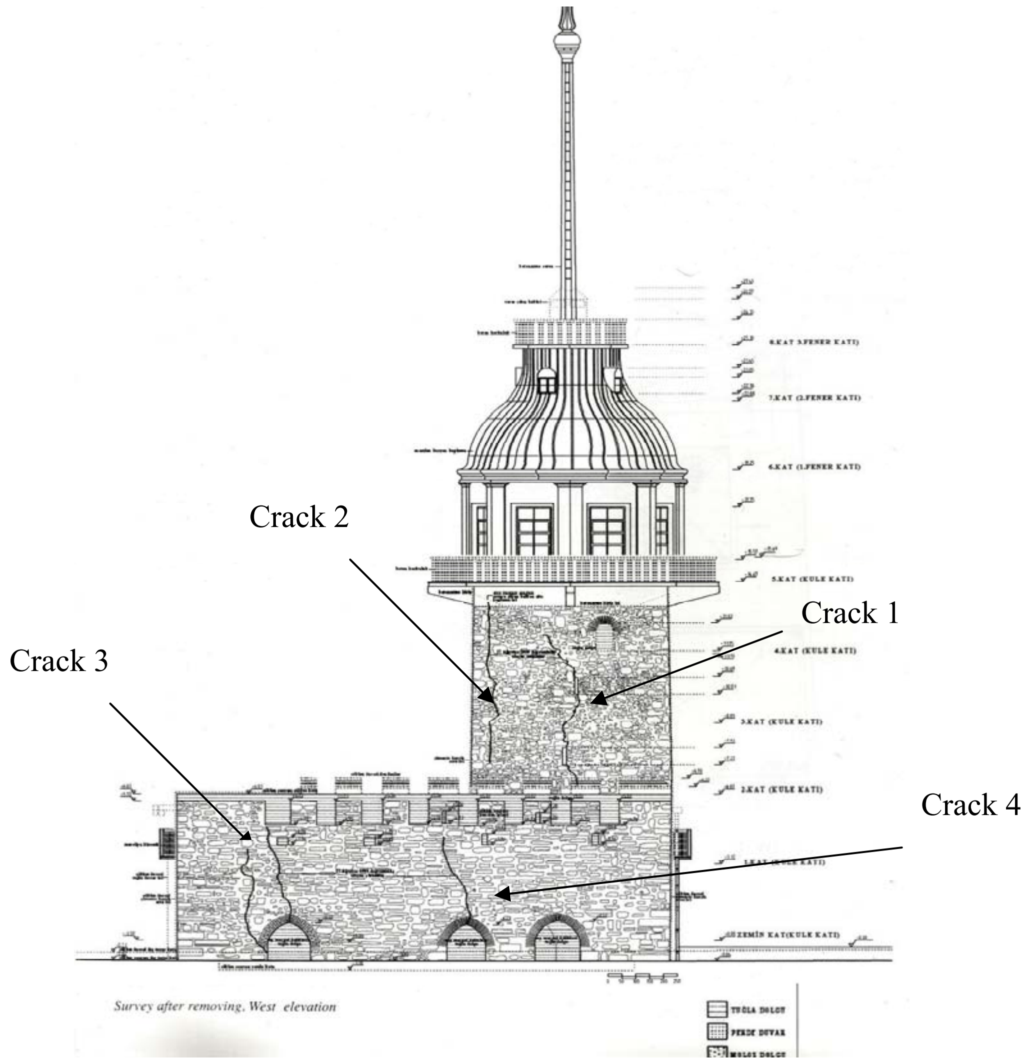

Figure 4.16 Cracks after the 1999 İzmit Earthquake [22]

Since the earthquake forces effected to the structure from East-West direction and South-North direction figure 4.17, figure 4.18, figure 4.19 and figure 4.20 shows the stress values occurred at the structure from South-North direction earthquake forces.

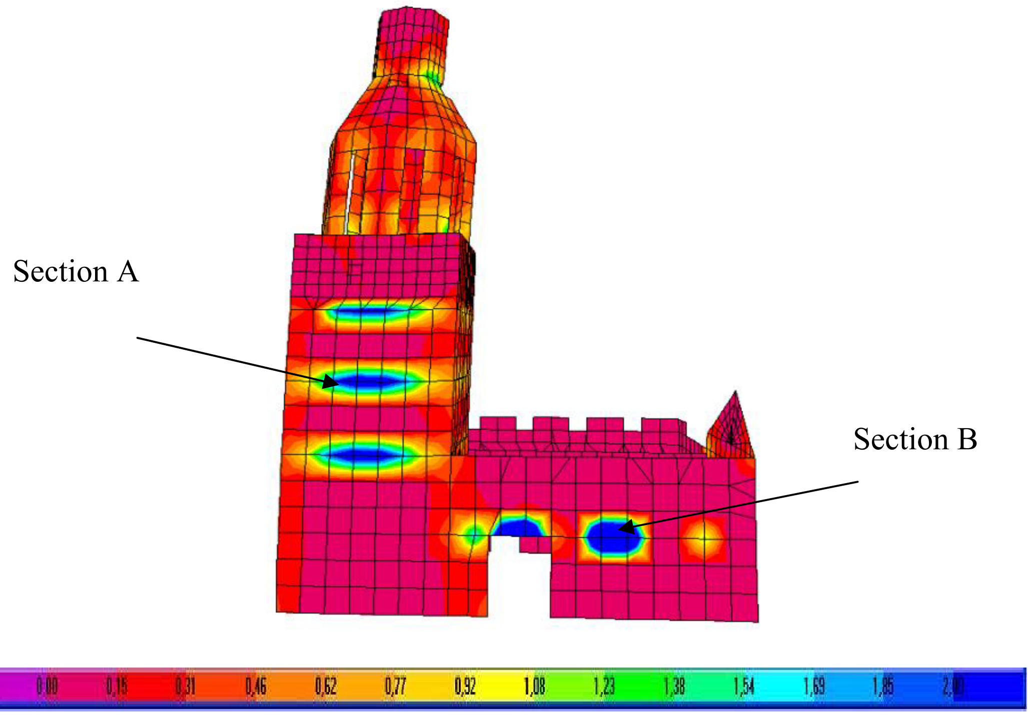

Figure 4.17 BR South-North Direction Earthquake Force, East Side Stress Results

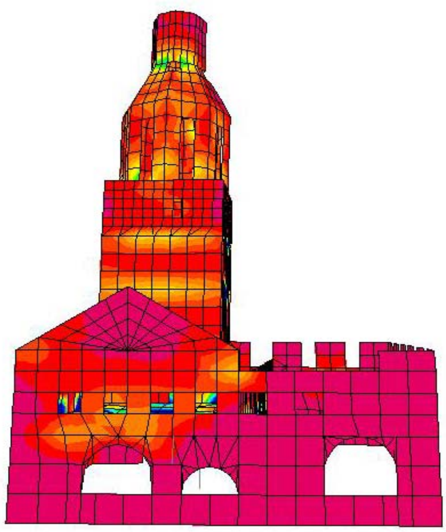

Figure 4.18 BR South-North Direction Earthquake Force, North Side Stress Results

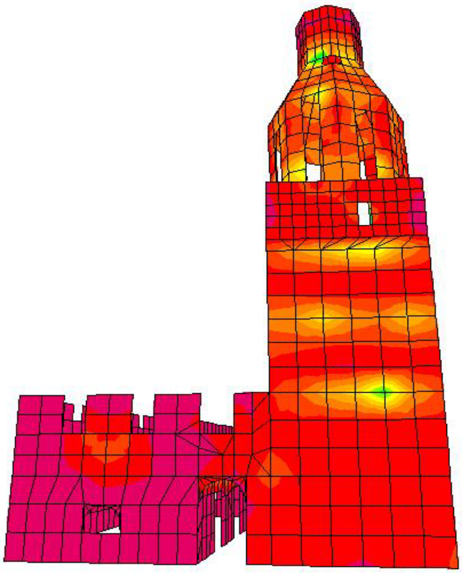

Figure 4.19 BR South-North Direction Earthquake Force, South Side Stress Results

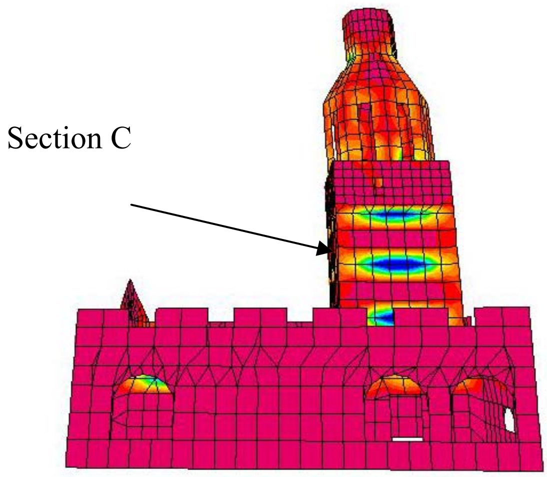

Figure 4.20 BR South-North Direction Earthquake Force, West Side Stress Results

Stress values occurred from the South-North direction earthquake forces and dead loads at Section A, Section B and Section C are larger than the allowable stress values. Table 4.14 shows the stress values and their allowable limits.

Table 4.14 Stress Values at Overstressed Sections

Section Name	Max. Stress Value (MPa)	Allowable Stress (MPa)
Section A	2.51	2.0
Section B	3.02	2.0
Section C	2.45	2.0

Figure 4.21, figure 4.22, figure 4.23 and figure 4.24 shows the stress values occurred from East-West direction earthquake forces.

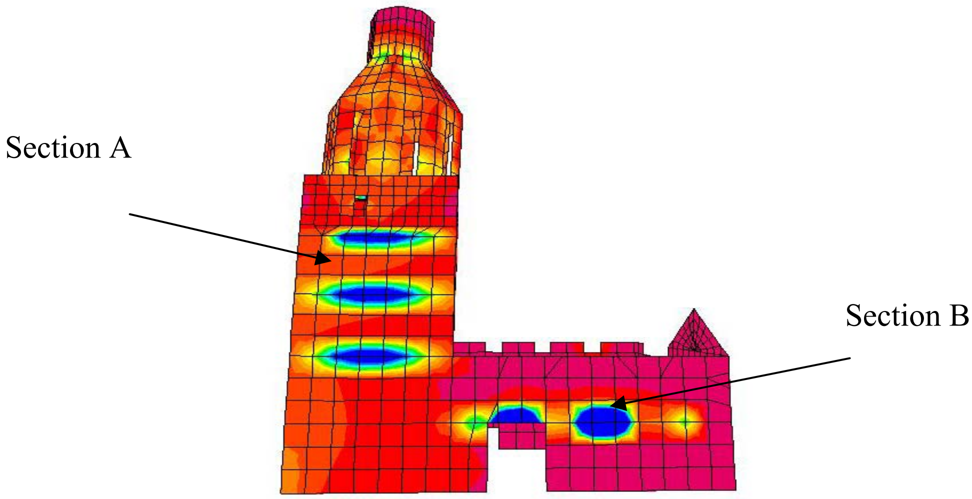

Figure 4.21 BR East-West Direction Earthquake Force, East Side Stress Results

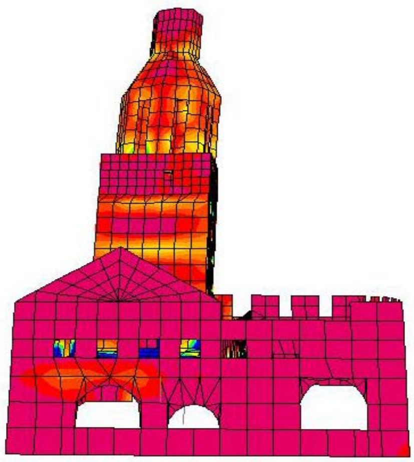

Figure 4.22 BR East-West Direction Earthquake Force, North Side Stress Results

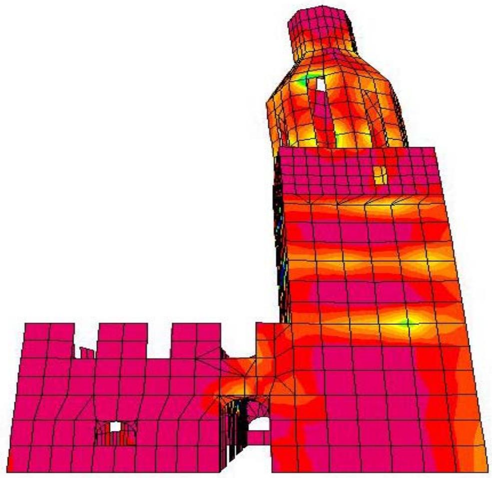

Figure 4.23 BR East-West Direction Earthquake Force, South Side Stress Results

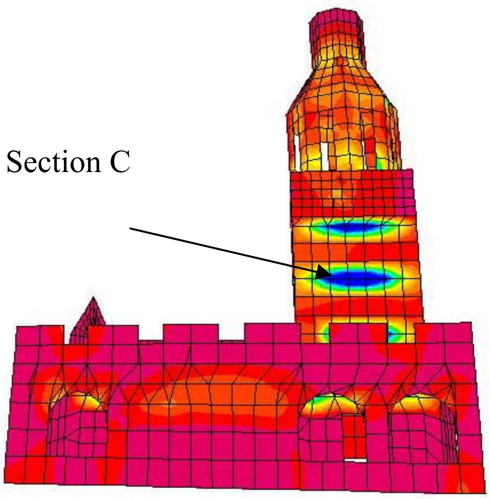

Figure 4.24 BR East-West Direction Earthquake Force, West Side Stress Results

Stress values occurred from the East-West direction earthquake forces and dead loads at Section A, Section B and Section C are larger than the allowable stress values. Table 4.15 shows the stress values and their allowable limits.

Table 4.15 Stress Values at Overstressed Sections

Section Name	Max. Stress Value (MPa)	Allowable Stress (MPa)
Section A	2.70	2.0
Section B	3.02	2.0
Section C	2.82	2.0

As shown in table 4.14 and table 4.15 the earthquake forces occuring from both East-West direction and South-North direction caused the sections A,B and C to be overstressed. This overstressing at Section A and C are the main reasons for the crack one and crack two which are shown in figure 4.16. The over stress in section B is the result of wooden beams carrying the first floor slab.

Although the stress values for West section castle walls are below the allowable stress values, the displacements occurred in the West section castle walls by earthquake forces affecting from East to West direction are the main reasons for cracks occurring after the 1999 earthquake. The reasons of these cracks are hidden in the geometry of Maiden's Tower. Since the West Section walls are not connected to the first floor slab they act like a free wall with a height of six meters. This free wall action causes the displacements as shown in figure 4.25 and figure 4.26.

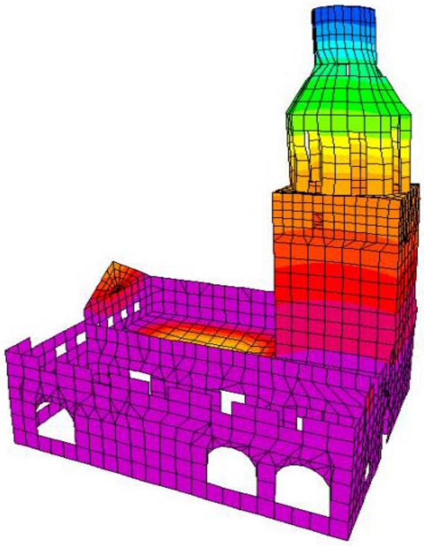

Figure 4.25 BR South-North Direction Earthquake Force, West Side Displacements

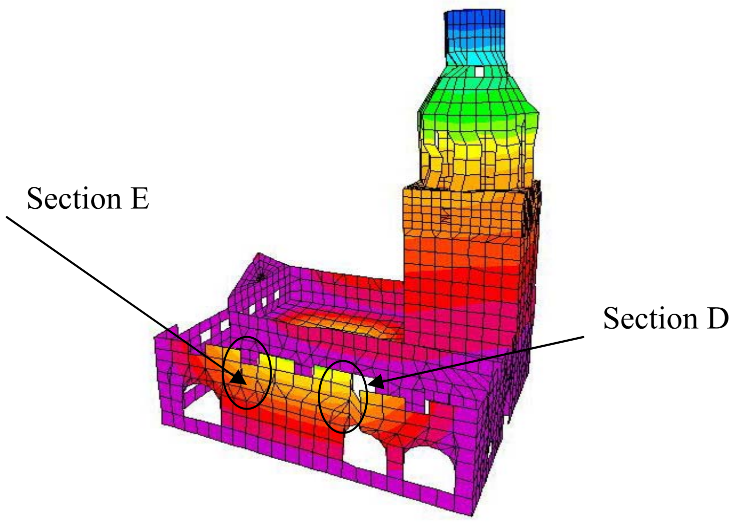

Figure 4.26 BR East-West Direction Earthquake Force, West Side Displacements

The displacements at West Side walls reach their highest values at section E and section D. Table 4.16 shows the displacements at section E and section D

Table 4.16 Displacements for BR

Section Name	Direction	Displacement (mm)
Section D	U1	1.79
	U2	34.87
	U3	0.265
Section E	U1	1.60
	U2	29.88
	U3	0.21

For a masonry stone wall connected by mortars, relative displacement between the adjacent masonry stones has a major importance. The main reason creating cracks three and four is not only the displacement values reaching 3.5 cm also the adjacent masonry stones only reaching 1.25 cm causes a sudden difference between the two adjacent masonry stone displacements. These sudden differences are the main reason for crack three and crack four.

As a conclusion, analyze of the before restoration condition showed that, although the material properties are not more than assumptions and the model is created by using equivalent macro elements method, the analyze results concur with the cracks occurred after the Izmit 1999 earthquake.

This analyzes shows the importance of restoration and strengthening the Maiden's Tower. It is obvious that when one of the scenario earthquakes occurs, without the restoration process, the structure will collapse.

4.11 Analyze Results for After Restoration Condition

Analyze results for before restoration condition showed that the structure has a potential risk for an earthquake. Although restoraters for masonry structures are generally architects since Maiden's Tower severely damaged from the Izmit earthquake, forced them for considering special engineering help.

As in this thesis, engineers reached the same results for potential failure areas and made major changes at the geometry of the structure.

First of all since the tower section A and section C are overstressed at horizontal earthquake loads. They had attached steel bracing frames to the tower section. Modification one as shown in figure 4.26 shows the steel bracing frames.

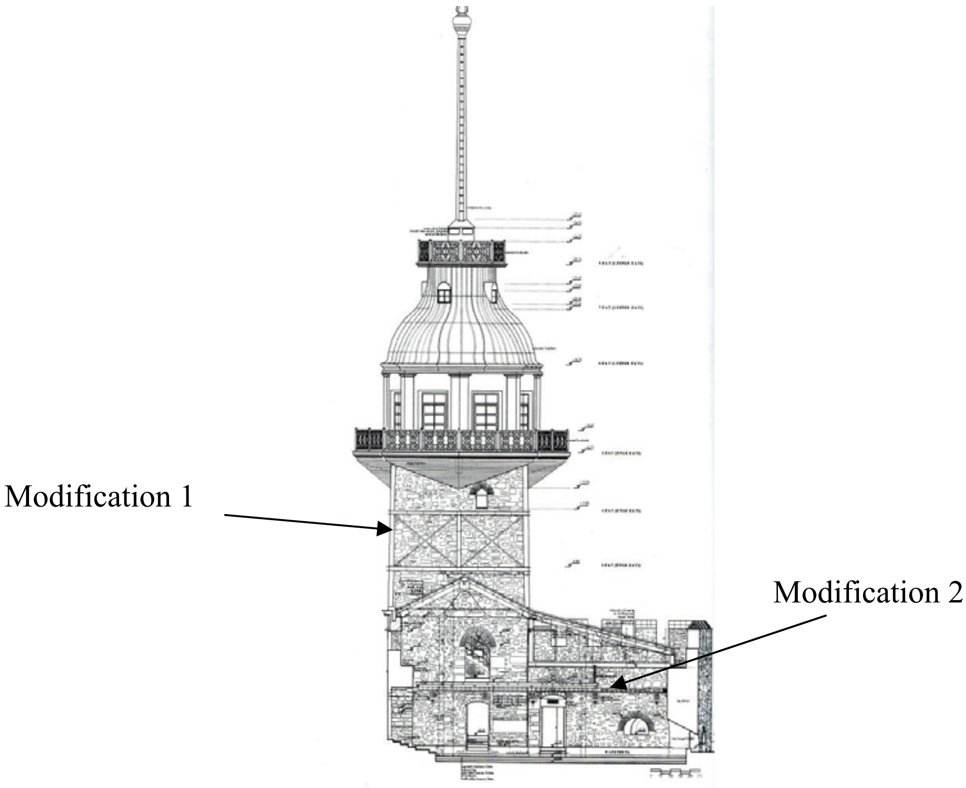

Figure 4.27 Modifications for Maiden's Tower[22]

Secondly in order to avoid the displacements at the West side walls, modification two as shown in figure 4.27, the engineers changed the first floor slap which was ending at inside walls as shown in figure 4.28 and connected West side walls to East side walls by steel beams as shown in figure 4.29.

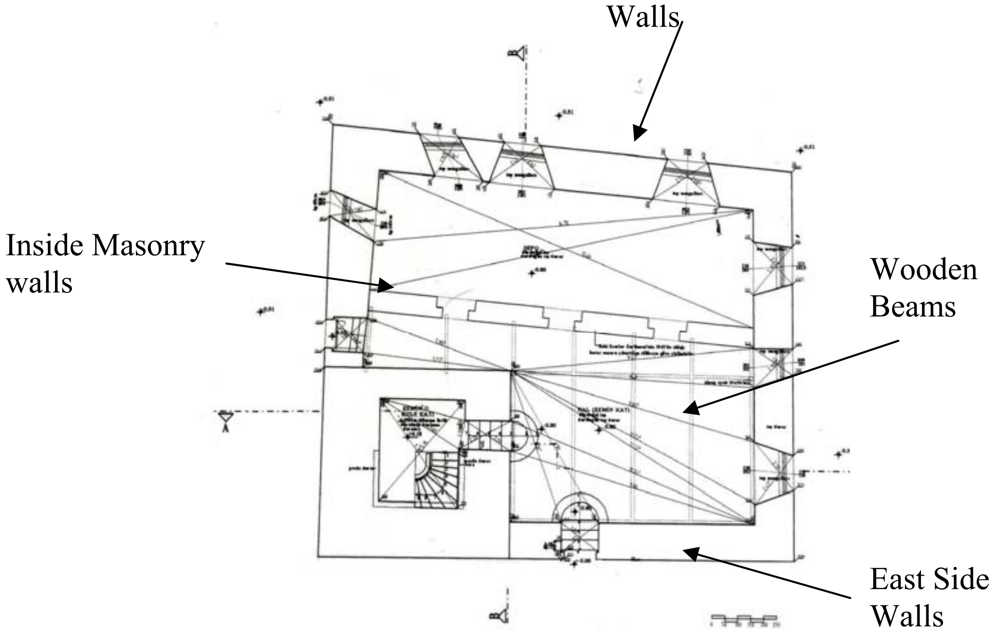

Figure 4.28 first floors survey before modifications[22]

As it can be seen from the figure 4.29 instead of wooden beams ending at the inside walls, steel beams ends at the West side walls

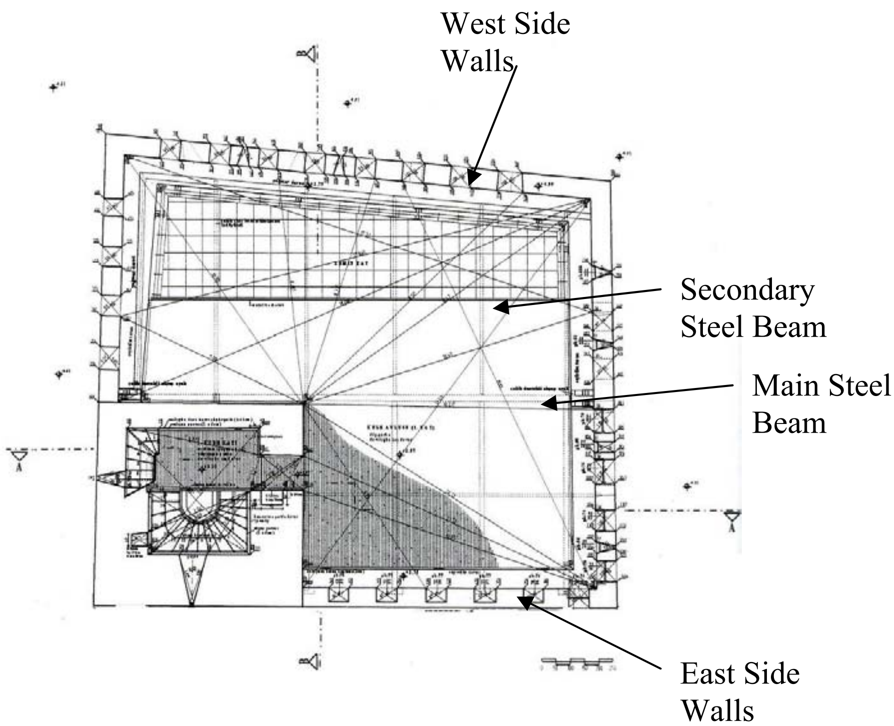

Figure 4.29 First floors survey after modifications[22]

The SAP2000 model of the structure created considering the modifications according to the Maiden's Tower after restoration surveys is shown in figure 4.30. This model like the before restoration condition, excludes the roof sections and flag pole. This model consists of 1661 shell areas and 65 steel frames. Since this thesis deals with the masonry parts of the structure and their earthquake performance, in order to establish these steel sections robustness and avoid their local failures before the masonry parts, these sections are assumed to be W18x35.

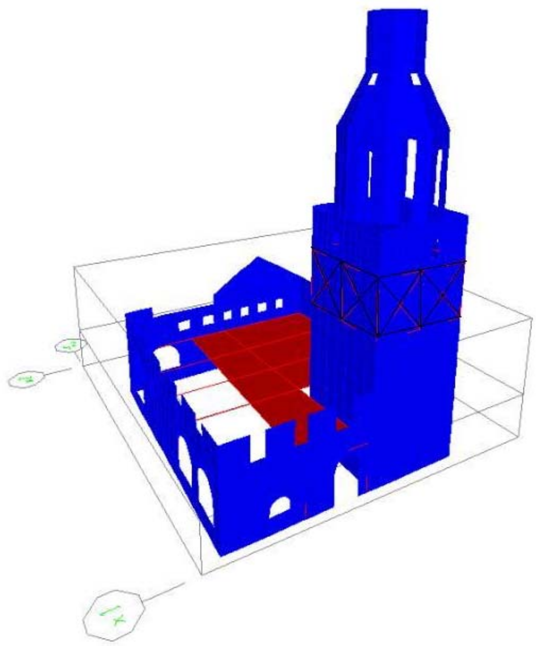

Figure 4.30 SAP2000® Model of Maiden's Tower After Restoration

For the sake of analyze results to be reliable, the modal static load participation ratios must be lager than the 90 per cent of the total weight of the structure.(TDY2005) Table4.17 shows the modeled Maiden's Tower modal load participations and effective periods of the structure.

Table 4.17 Modal Load Participations and Effective Periods of AR

TYPE	Name	Static	Effective Period
ACC	UX	99.8706	0.317774
ACC	UY	99.8965	0.338847
ACC	UZ	96.1166	0.451837
ACC	RX	99.6353	0.409867
ACC	RY	99.5494	0.403380
ACC	RZ	99.7976	0.292940

Since the earthquake forces effected to the structure from East-West direction and South-North direction figure 4.31, figure 4.32, figure 4.33 and figure 4.34 shows the stress values occurred at the structure from South-North direction earthquake forces.

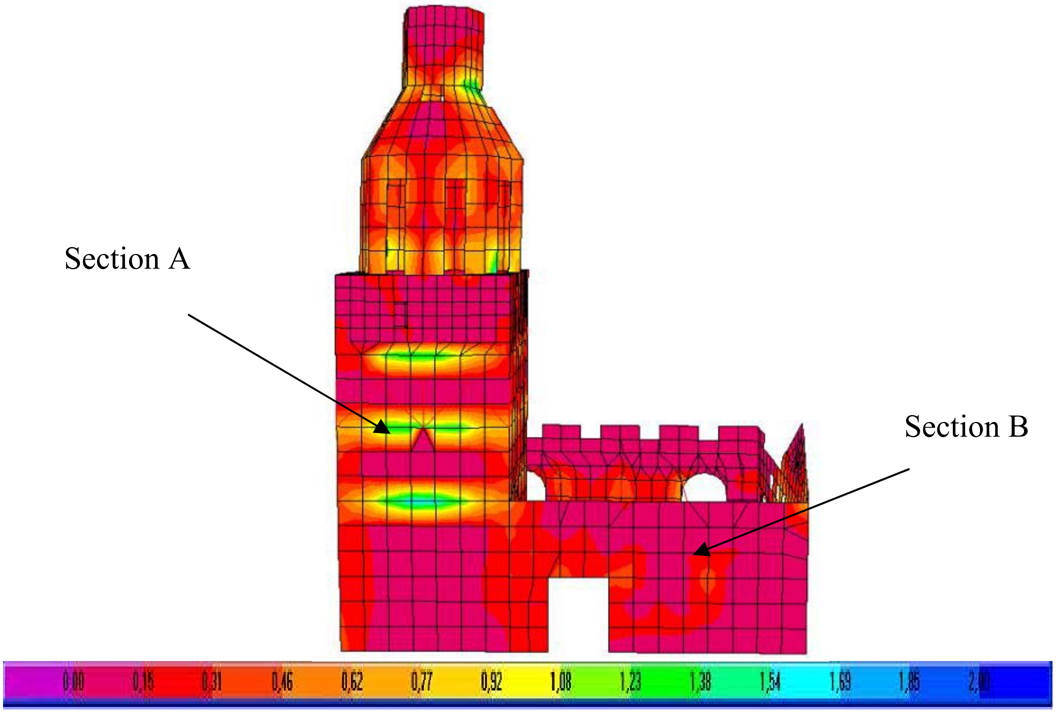

Figure 4.31 AR South-North Direction Earthquake Force, East Side Stress Results

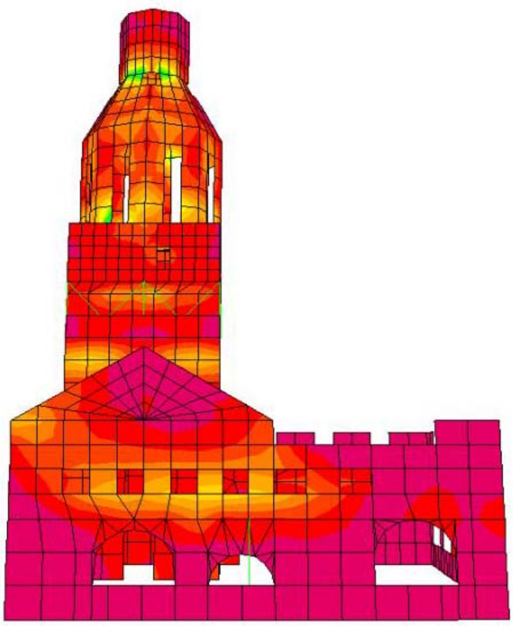

Figure 4.32 AR South-North Direction Earthquake Force, North Side Stress Results

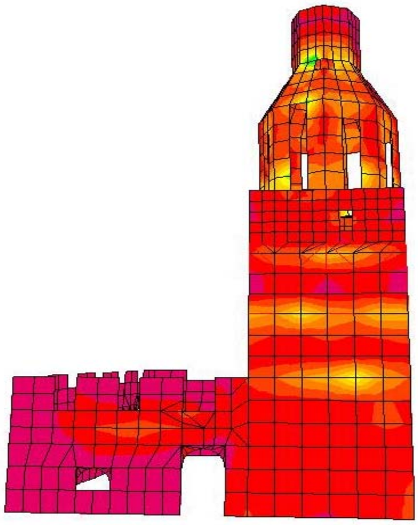

Figure 4.33 AR South-North Direction Earthquake Force, South Side Stress Results

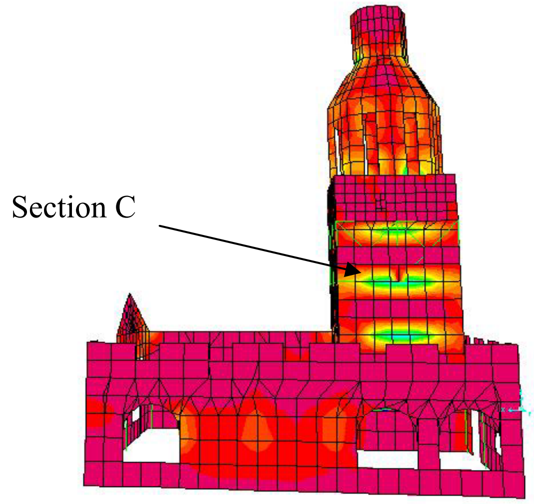

Figure 4.34 AR South-North Direction Earthquake Force, West Side Stress Results

The aim of restoration process is strengthening the structure so it is important to reduce the previous stress values occurred in the overstressed section.Table 4.18 shows the before restoration condition stress values compared with the after restoration occurred from South-North direction earthquake force and allowable stress values.

Table 4.18 Stress Values at Overstressed Sections for AR

Section Name	BR Max. Stress Value (MPa)	AR Max. Stress Value (MPa)	Allowable Stress (MPa)
Section A	2.51	1,65	2.0
Section B	3.02	0,40	2.0
Section C	2.45	1,63	2.0

Figure 4.35, figure 4.36, figure 4.37 and figure 4.38 shows the stress values occurred from East-West direction earthquake forces.

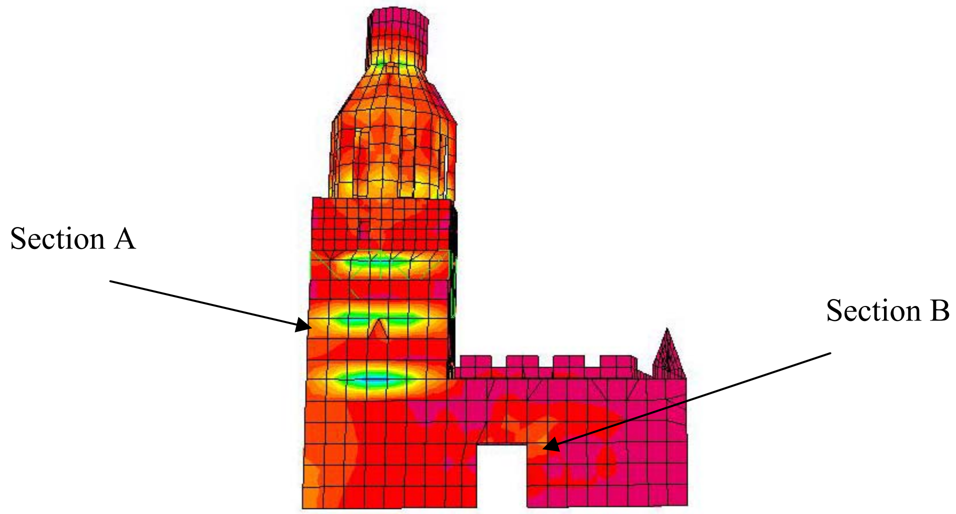

Figure 4.35 AR East-West Direction Earthquake Force, East Side Stress Results

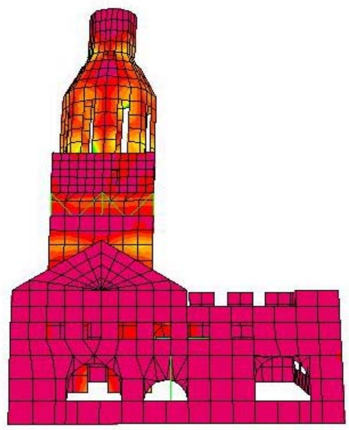

Figure 4.36 AR East-West Direction Earthquake Force, North Side Stress Results

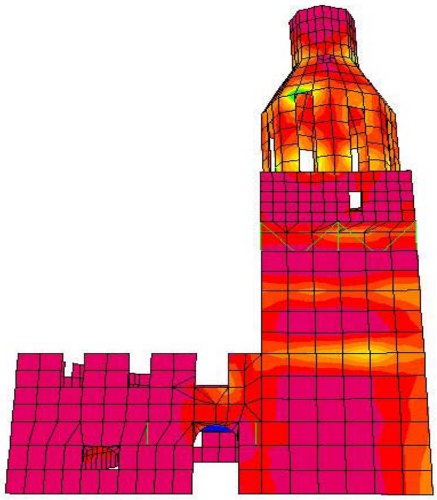

Figure 4.37 AR East-West Direction Earthquake Force, South Side Stress Results

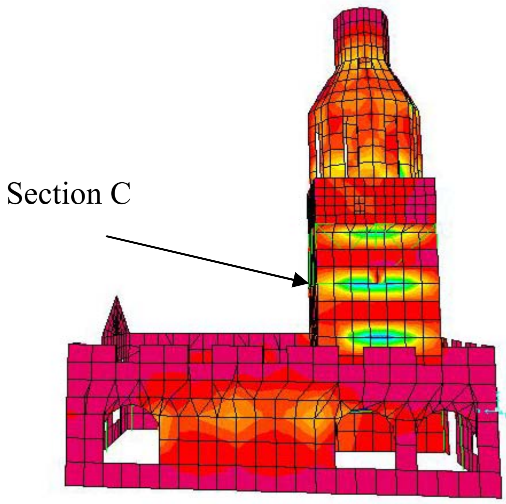

Figure 4.38 AR East-West Direction Earthquake Force, West Side Stress Results

The aim of restoration process is strengthening the structure so it is important to reduce the previous stress values occurred in the overstressed section. Table 4.19 shows the before restoration condition stress values compared with the after restoration occurred from East-West direction earthquake force and allowable stress values.

Table 4.19 Stress Values at Overstressed Sections

Section Name	BR Max. Stress Value (MPa)	AR Max. Stress Value (MPa)	Allowable Stress (MPa)
Section A	2.70	1.36	2.0
Section B	3.02	0.45	2.0
Section C	2.82	1.91	2.0

Crack A and crack C are results of horizontal earthquake forces and after restoration results showed that steel bracings decreased the stress values considerably to boundary limits.

Crack C was the result of the wooden beams carrying the wooden floor and after restoration results showed that modified geometry of the floor slab improved the structure and decreased the stress values occurred in section B.

Although the stress values for West section castle walls are below the allowable stress values, the displacements occurred in the West section castle walls by earthquake forces affecting from East to West direction are the main reasons for cracks occurring after the 1999 earthquake. Since the reasons of these cracks are hidden in the geometry of Maiden’s Tower, the restoraters changed the geometry of the first floor and connected the West side walls to East side walls by steel beams. The figure 4.39 shows the displacements occurred after the restorated condition.

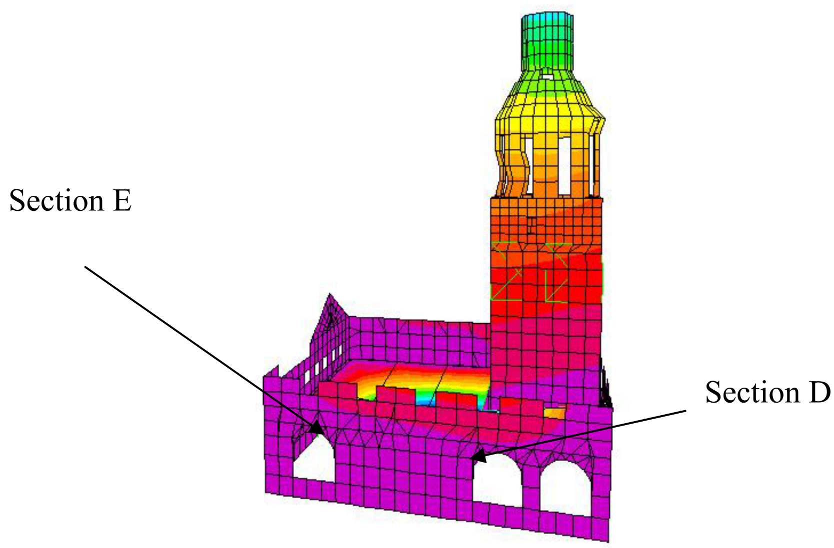

Figure 4.39 Displacements for AR condition

The before condition analyze results proved that cracks occurred at crack 3 and crack 4 at figure 4.16 are the results of the high displacement values. The purpose of changing the floor geometry was connecting the East side walls to West side walls. This major change caused the West side walls to leave its free wall action and act as a part of the structure. In order to compare the analyze results for before condition and after condition, displacements at section D and section E are given in table 4.20.

Table 4.20 Displacements for AR

	BR Condition		AR Condition	
Section Name	Direction	Displacement (mm)	Direction	Displacement (mm)
Section D	U1	1.79	U1	0.7
	U2	34.87	U2	10.01
	U3	0.265	U3	0.33
Section E	U1	1.60	U1	0.29
	U2	29.88	U2	8.16
	U3	0.21	U3	0.32

As shown in table 4.20 horizontal displacements for both section D and section E are decreased by using the steel beams. Since these beams are used for carrying the floor slab, the vertical displacements for section D and section E have increased. These increments can be inconsiderable due to behavior of masonry walls. The masonry walls are considered to be at risk for the horizontal displacements, vertical displacements are considered to be absorbed by the masonry elements compression stress values.

5. CONCLUSION

Masonry structures having lots of unknowns due to their material properties and insufficient site experiments, this thesis with its library work proofs that masonry structures in Üsküdar area have been affected from previous earthquakes. Considering their age and other factors affecting them since their construction date, it is obvious that these masonry structures will be affected from the predicted earthquake.

In my opinion, considering their potential risks, masonry structures in Üsküdar area can be investigated by using the Index methods. But even for Index Method's, enough labor force and funds should be supplied. Although in some cases like Maiden's Tower, Index Method's can not be used because of the geometrical considerations, Macro Modeling analyze can be used as it is used to analyze Maiden's Tower.

Although only available data about Maiden's Tower was surveys of the structure, before restoration analyze results correspond with the cracks occurred during the 1999 Izmit earthquake. This parallelism with damages after the İzmit earthquake is a proof, showing the effectiveness of Macro Modeling.

Furthermore, after restoration results showed that by restoration, the stress values occurring from the earthquake action decreases considerably. Restoration process saved a historical monument, not only by reducing the stress values at tower section and decreasing displacements at west side walls but also creating a great place for public.

As a conclusion, the historical masonry structures in Üsküdar area are at in risk but with enough labor force if they are investigated by using index methods and restorated by using one of the numerical analyze methods, they can be saved from being collapsed or damaged from earthquakes.

APPENDIX A: MASONRY BUILDINGS IN ÜSKÜDAR

This appendix contains information about historical masonry structures located in Üsküdar area. Name of the building, location, construction date, previous restorations and material type of the structure is given in table A1.

Table A.1. Historical masonry structures in Üsküdar

Name	Type	Location	Con. Date	Restorations	Material
ABDURRAHMAN AĞA CAMİİ (PAŞALİMANI CAMİİ)	Mosque	Paşa Limanı	1766-67	1832(Sultan 2. Mahmut)	Tuff Masonry
AĞA CAMİİ (MALATYALI İSMAİL AĞA CAMİİ)	Mosque	Ağahamamı Manin Street	1635	1902 (sultan 2. Abdülhamit) 1974	Hewn Stone
AHMEDİYE CAMİİ	Mosque	Gündoğumu Street	1721	1883	Tuff Masonry
AHMET ÇELEBİ CAMİİ	Mosque	Açıktürbe Street	1567	1767(Burn in 1763 Fire) 1790(Burn in 1789 Fire) 1895(Damaged in 1894 EQ)	Tuff Masonry
ALTUNİZADE CAMİİ	Mosque	Küçük Çamlıca Street	1865	No Restoration Information	Tuff Masonry
ARAKİYECİ HACI MEHMET AĞA MESCİDİ (KAPIAĞASI MESCİDİ)	Mosque	Toptaşı Street	1543 (before)	1757 Sadrazam Mehmet Paşa	Hewn Stone
AŞÇIBAŞI CAMİİ	Mosque	İnadiye Camii Street	1585	1711 (Pulpit edit) 1943 (Collapsed) 1989 Remaked	Tuff Masonry
ATPAZARI OSMAN EFENDİ MESCİDİ	Mosque	Toptaşı Street	1720	1984 (Remaked)	Tuff Masonry
AYAZMA CAMİİ	Mosque	Ressam Ali Rıza Bey Street	1760	No Restoration Information	Tuff Masonry
AZİZ MAHMUD HÜDAYİ EFENDİ TEKKESİ CAMİİ	Mosque	Aziz Mahmut Street	1594	1849 (Burned) 1855 (remaked) by Sultan Abdülmecit	Hewn Stone
BAKİ EFENDİ CAMİİ(ABDÜLBAKİ EFENDİ CAMİİ)	Mosque	Sultantepe/ Servilik Street	1644	1875 (repaired)	Tuff Masonry
BALABAN TEKKESİ MESCİDİ	Mosque	Doğancılar Street	1630	1945 (collapsed) 1946 (repaired) 1975 (restorated)	Tuff Masonry
BALİ ÇAVUŞ MESCİDİ(TUNUSBAĞ MESCİDİ)	Mosque	Tunusbağ Street	1591-1592	1598 (restorated)	Tuff Masonry
BANDIRMALI TEKKESİ MESCİDİ(İNADİYE TEKKESİ MESCİDİ)	Mosque	Gündoğumu Street	1732	1732 (restorated) 1775-1756 (restorated) 1895 (repaired)	Tuff Masonry
BODRUMİ ÖMER EFENDİ CAMİİ	Mosque	Küçük Çamlıca/ Bulgurlu Town	1891-1892	1975 (collapsed) 1989 (restorated)	Tuff Masonry
BULGURLU KÖYÜ CAMİİ	Mosque	Bulgurlu Town	1451-1481 (Fatih Sultan Mehmet)	1852 (restorated) 1876 (restorated by Abdülhamid)	Tuff Masonry

BULGURLU MESCİDİ	Mosque	Çavuşdere Street	1679(Sadrazam Ragıp Paşa)	1756-1763 (restorated by Sadrazam Ragıp Paşa) 1852 (Burned)	Tuff Masonry
BURHANİYE CAMİİ(II.ABDÜLHAMİD CAMİİ)	Mosque	Halitağa Street	1794	1876 (restorated) 1902 (restorated again)	Tuff Masonry
CAFER EFENDİ CAMİİ	Mosque	Unknown	1551	No Restoration Information	Tuff Masonry
CEHVER AĞA CAMİİ(ÜMRANİYE CAMİİ)	Mosque	Alemdar Street	1897	1876 (restorated) 1962 (upgraded)	Tuff Masonry
ÇAKIRCBAŞI HASAN CAMİİ(DOĞANCILAR CAMİİ)	Mosque	Doğancılar Street	1548 (built by Mimar Sinan)	1580(damaged) 1702 (a fountain built) 1857 (restorated)	Tuff Masonry
ÇİÇEKCİ CAMİİ	Mosque	Tunusbağ Street	1801	1835 (restorated)	Tuff Masonry
ÇİLEHANE MESCİDİ(MUSALLA MESCİDİ)	Mosque	Çicek Street	1616	1690 (restorated)	Tuff Masonry
ÇİNGENE FIRINI CAMİİ(KARAKADI CAMİİ)	Mosque	Üsküdar/Selamsız	1590	1988 (restorated)	Tuff Masonry
ÇİNİLİ CAMİİ	Mosque	Çin Çin Hamam Street	1640 (by the mother of IV.Murat)	1890-93 (repaired) 1900 (repaired) 1964 (damaged by a thunder but	Tuff Masonry
DARÜ'Ş-ŞİFA MESCİDİ	Mosque	Toptaşı Street	1583	1834-35 (repaired by II.Mahmut)	Tuff Masonry
DEBBAĞLAR CAMİİ(TABAKLAR CAMİİ veya KONYALI	Mosque	Tabaklar Camii Street	1587	1803 (repaired) 1973 (repaired)	Tuff Masonry
DEMİRCİ MESCİDİ	Mosque	probably in the Demirciler Çarşısı	1502	No Restoration Information	Tuff Masonry
DIVITÇIZADE ŞEYH AHMET TALİB EFENDİ CAMİİ(SULTAN	Mosque	Gündoğumu Street	1675?	nearly 1745? (damaged) 1748 (remaked by I.Mahmut 1918 (burned	Tuff Masonry
DURBALİ CAMİİ	Mosque	Durbali Street	1454-1460	in 1930's (damaged very badly)	Tuff Masonry
EVLİYE HOCA CAMİİ	Mosque	Evliya Hoca Street	1828	1885 (repaired) 1925 (collapsed)	Tuff Masonry
FAİK BEY CAMİİ	Mosque	Faikbey Mescidi Street	Unknown	1907 (repaired) 1975 (restorated)	Tuff Masonry
FAİK PAŞA CAMİİ	Mosque	Tekin Street	?1882-1892?	1956-57 (remaked) 1992 (burned)	Tuff Masonry
FATİH SULTAN MEHMET CAMİİ	Mosque	Salacak	nearly 1453	1732 (turned into a mosque) 1753 (remaked) 1811 (repaired by Sultan	Tuff Masonry
FATMA HATUN MESCİDİ	Mosque	Hatmi Street	Unknown	1762 (remaked) 1887 (remaked) 1965 (repaired by people)	Tuff Masonry
FENAYİ TEKKESİ MESCİDİ	Mosque	Boy Beyi Street	1714	1766 (damaged by a thunder but restorated) 1864 (repaired)	Tuff Masonry
MİHRİMAH SULTAN CAMİİ(İSKELE CAMİİ)	Mosque	İskele Street	1547-48	1728 Sultan III.Ahmet(restorated) 1970 (restorated)	Tuff Masonry

MİRAHUR CAMİİ(İMRAHOR CAMİİ)	Mosque	İmrahor Street	1597	1898 (repaired)	Tuff Masonry
MİRZADE CAMİİ(ŞEYHÜLİSLAM veya NUR CAMİİ)	Mosque	Sultantepe/ Servilik Street	1730-31	1899 (restorated)	Tuff Masonry
MİSKİNLER TEKKESİ MESCİDİ(DEDELER MESCİDİ)	Mosque	İbrahim Ağa Street	1810	1811 (11 house added and restorated) 1923 (restorated)	Tuff Masonry
NALÇACI HALİL TEKKESİ	Mosque	Balcılar Street	1595	1946 (collapsed)	Tuff Masonry
NAMAZGAH CAMİİ (CAVİT AĞA CAMİİ)	Mosque	Alemdağ Street	1906	1960 (restorated)	Tuff Masonry
NASUHİ MEHMET EFENDİ TEKKESİ CAMİİ	Mosque	Tunusbağ Street	1684	1776 (repaired) 1849 (restorated) 1904(collapsed) [illegible]	Tuff Masonry
NUHKUYUSU CAMİİ(CEVRİ USTA CAMİİ)	Mosque	Toptaşı Street	1813	1819 (restorated) 1918 (burned)	Tuff Masonry
PAZARBAŞI MESCİDİ	Mosque	Kabzımal Street	1607	1896 (restorated) 1942 (collapsed) 1980 (remaked)	Tuff Masonry
RUH MEHMET PAŞA CAMİİ	Mosque	Şemsi Paşa Street	1471	1894 (damaged by earthquake)	Tuff Masonry
SALACAK CAMİİ(TEŞRİTAFA CAMİİ)	Mosque	Salacak	1761	1930 (collapsed)	Tuff Masonry
SALİH EFENDİ CAMİİ	Mosque	Çavuşdere Town	1817	1890 (collapsed)	Tuff Masonry
SARIGAZİ KÖYÜ CAMİİ	Mosque	Sarıgazi Town	1455	1768 (restorated) 1789 (restorated)	Tuff Masonry
SELAMİ ALİ EFENDİ CAMİİ(KURUÇEŞME CAMİİ)	Mosque	Bağlarbaşı	1965	No Restoration Information	Tuff Masonry
SELAMİ ALİ EFENDİ TEKKESİ CAMİİ	Mosque	Selamsız	1677	1921 (collapsed by fire)	Tuff Masonry
SELİMİYE CAMİİ	Mosque	Selimiye	1801-1805	1823 (damaged)	Tuff Masonry
SELMAN AĞA CAMİİ	Mosque	Hakimiyet-i Milliye Camii	1840	No Restoration Information	Tuff Masonry
SERÇE HATUN CAMİİ	Mosque	Bülbüldere	Unknown	1940 (collapsed)	Tuff Masonry
SİNAN PAŞA CAMİİ	Mosque	Halk Dersanesi Street	1592	1974-75 (repaired by people)	Tuff Masonry
SOLAK SİNAN CAMİİ	Mosque	Selami Ali Street	1728-1729	1883 (restorated) 1994 (restorated)	Tuff Masonry
ŞEHİTLİK CAMİİ	Mosque	Karacaahmet Cemetery	1917	1984 (restorated)	Tuff Masonry
ŞEHİT SÜLEYMAN PAŞA CAMİİ	Mosque	Viransaray Street	1677	1894 (collapsed by earthquake) 1957-58 (repaired by people)	Tuff Masonry

ŞEMSİ PAŞA CAMİİ	Mosque	Şemsi Paşa Street	1580	1895 (repaired because of damage of earthquake)	Tuff Masonry
ŞEREFABAD CAMİİ(ADLİYE CAMİİ)	Mosque	Şemsi Paşa Central	1760	1815 (restorated) 1842 (restorated) 1894 (damaged by earthquake)	Tuff Masonry
ŞÜCA'BAĞI CAMİİ	Mosque	Bülbüldere Cemetery	1738	1740 (built an addition) 1991 (restorated)	Tuff Masonry
TAKKECİ MESCİDİ(ARAKİYECİ MESCİDİ)	Mosque	Körbakkal Street	1537	1835 (restorated)	Tuff Masonry
TAŞÇILAR CAMİİ(MEHMET AĞA CAMİİ)	Mosque	near Karacaahmet Türbesi	1545	No Restoration Information	Tuff Masonry
TAVAŞİ HASAN AĞA CAMİİ	Mosque	Gündoğumu Street	1587	1892 (restorated)	Tuff Masonry
TAZICILAR OCAĞI MESCİDİ	Mosque	Çeşme-i Kebir Street	1822	No Restoration Information	Tuff Masonry
TEMBEL HACI MEHMET EFENDİ CAMİİ(ATLAMATASI	Mosque	Selamsız Street	1710	1896 (burned) 1937 (a school built in its ground)	Tuff Masonry
VALİDE ATİK CAMİİ (TOPTAŞI CAMİİ)	Mosque	Üsküdar Hill	1571-1583	1892(restorated)	Tuff Masonry
YENİ ÇEŞME CAMİİ	Mosque	Ahmediye Square	1587	1965 (collapsed)	Tuff Masonry
YENİ VALİDE CAMİİ	Mosque	Hakimiyet-i Milliye Camii	1708	1940 (restorated) 1976 (restorated)	Tuff Masonry
FERİDUN PAŞA CAMİİ (FERİDİYE CAMİİ)	Mosque	Koşuyolu	1912	No Restoration Information	Tuff Masonry
FETHİ AHMET PAŞA CAMİİ (KARACAAHMET CAMİİ)	Mosque	next to Karacaahmet Türbesi	1795	No Restoration Information	Tuff Masonry
FEVZİYE CAMİİ (BÜLBÜLDERESİ CAMİİ)	Mosque	Bağlarbaşı	1882-83	1913 (collapsed9	Tuff Masonry
GEREDELİ MESCİDİ	Mosque	Uncular Street	1598	1930(restorated) 1936-37 (damaged) 1939(collapsed)	Tuff Masonry
GÜLFEM HATUN CAMİİ	Mosque	Gültem Street	1539-40	1539(restorated)	Tuff Masonry
HACI HESNA HATUN CAMİİ	Mosque	Sultantepe	1793	1957(restorated)	Tuff Masonry
HARAP MESCİD	Mosque	next to kavak iskelesi	1639	1654 (restorated)	Tuff Masonry
HAYRETTİN ÇAVUŞ CAMİİ	Mosque	Beygirciler Street	1730	1846 (burned) 1945 (collapsed)	Tuff Masonry
HÜSREV AĞA CAMİİ (ESKİ HAMAM CAMİİ)	Mosque	in front of Eski Hamam	1728	1901 (repaired)	Tuff Masonry
İBRAHİM AĞA ÇAYIRI CAMİİ	Mosque	İbrahim Ağa Street	1580	1753 (restorated) 1939 (repaired)	Tuff Masonry

İHSANİYE CAMİİ	Mosque	Dr.Sıtkı Özterenderci Street	1824	No Restoration Information	Tuff Masonry
İHSANİYE MESCİDİ	Mosque	Küçük İhsaniye	1755-1756	1890-91 (restorated) 1940 (restorated and re-opened)	Tuff Masonry
İRANLILAR CAMİİ	Mosque	near Seyyid Ahmet River	1837	1903 (restorated) 1923 (built again by İran) 1933 (built again)	Tuff Masonry
KAPTAN PAŞA CAMİİ	Mosque	Kaptan Paşa Street	1499	1727 (restorated) 1890 (burned)	Tuff Masonry
KARA DAVUT PAŞA CAMİİ	Mosque	Hakimiyet-i Milliye Street	1817	1868 (restorated) 1892 (restorated)	Tuff Masonry
KAVAK İSKELESİ MESCİDİ	Mosque	Next to Sinan Paşa camii	1610	1855 (burned in war) 1895 (repaired)	Tuff Masonry
KAVAK SARAYI MESCİDİ	Mosque	next to Selimiye Barracks	1614	1805 (restorated)	Tuff Masonry
KAVSARA MUSTAFA EFENDİ CAMİİ	Mosque	Çavuşdere	1655	1713 (restorated) 1930 (collapsed)	Tuff Masonry
KAYMAKÇI TEKKESİ MESCİDİ	Mosque	Dönme Dolap Street	1540	1800 (restorated)	Tuff Masonry
KAZASKER CAMİİ (DİVİTÇİLER CAMİİ9	Mosque	near Zeynep Kemal	1729	1927 (burned an never remaked)	Tuff Masonry
KAZGANCI MESCİDİ	Mosque	Unknown	Unknown	collapsed before 1768	Tuff Masonry
KISIKLI CAMİİ	Mosque	Kısıklı Square	1881	1927 (restorated)	Tuff Masonry
KURBAĞI NASUH CAMİİ	Mosque	Tabaklar Square	1728-29	1945 (roof repaired) 1973-74 (restorated)	Tuff Masonry
KÜÇÜK ÇAMLICA MEDRESESİ CAMİİ	Mosque	Küçük Çamlıça Hill	1654	1800 (restorated)	Tuff Masonry
MEHMET TAHİR EFENDİ CAMİİ	Mosque	near Harem İskelesi Camii	1827-28	No Restoration Information	Tuff Masonry
MEVLEVİHANE MESCİDİ	Mosque	İmrahor	1787	1975 (restorated)	Tuff Masonry
AHMEDİYE CAMİİ MEKTEBİ	Schools	Gündoğdu Street in Ahmediye Külliyesi	1720-21	No Restoration Information	Tuff Masonry
AHMEDİYE MEKTEBİ	Schools	Ahmediye Street	1721	1865 (burned) 1872 (repaired)	Hewn Stone
ALİ AĞA SIBYAN MEKTEBİ	Schools	in the Doğancılar Camii	1702	1925 (collapsed)	Hewn Stone
ALTUNİZADE İSMAİL ZÜHDÜ PAŞA MEKTEBİ	Schools	Altunizade	1865-66	1925 (collapsed)	Hewn Stone
ALTUNİZADE RÜŞDİYE MEKTEBİ	Schools	near Altunizade Camii	1901-02	No Restoration Information	Hewn Stone

ATİK VALİDE MÜLKİYE RÜŞDİYESİ (ÜSKÜDAR MÜLKİYESİ)	Schools	Barbaros	1874	No Restoration Information	Hewn Stone
ATİK VALİDE SULTAN SİBYAN MEKTEBİ	Schools	Kartalbaba Street	1583	1928 (closed)	Hewn Stone
ATLAMATAŞI MÜLKİYE RÜŞDİYESİ	Schools	Selamsız Street	1874	1930 (restorated) 1935 (collapsed)	Hewn Stone
AYAZMA SINYAN MEKTEBİ	Schools	in the Ayazma Camii	1758-61	1915 (turned into school) 1975 (restorated)	Hewn Stone
AYŞE HATUN SIBYAN MEKTEBİ	Schools	Alemdağ Street	Unknown	1930-35 (collapsed)	Hewn Stone
AZİZ MAHMUR HÜDAYİ EFENDİ MEKTEBİ	Schools	Aziz Mahmut Efendi Street	1594-95	1850 (burned)	Hewn Stone
BAYTAR MEKTEBİ	Schools	next to Selimiye Barracks	1894	No Restoration Information	Hewn Stone
CEVHER AĞA MEKTEBİ	Schools	in the Ümraniye Camii	1897-98	No Restoration Information	Hewn Stone
CEVRİ USTA SIBYAN MEKTEBİ	Schools	Nuhkuyusu Street	Unknown	1810 (restorated) !966 (closed)	Hewn Stone
ÇAKIRCIBAŞI HASAN PAŞA MEKTEBİ	Schools	near Doğanlar Camii	built by Mimar Sinan 1588	1788 (rebuilt)	Hewn Stone
ÇAVUŞBAŞI MEKTEBİ	Schools	Pazarbaşı	1704	1881 (repaired) 1935 (collapsed) 1991 (restorated) 1994	Hewn Stone
ÇİNİLİ CAMİİ SIBYAN MEKTEBİ	Schools	Çavuşderesi Street	1640	1964 (restorated)	Hewn Stone
DEBBAĞLAR MEKTEBİ	Schools	Büyük Selim Paşa Street	1728-29	1950 (collapsed)	Hewn Stone
DEFTERDAR MEKTEBİ (MEHMET TAHİR EFENDİ MEKTEBİ)	Schools	Selimiye İskele Street	1826-1827	1925 (damaged heavily) 1953 (collapsed)	Hewn Stone
ESMA SULTAN MEKTEBİ	Schools	Tunusbağ Street	1925-30 (existing)	No Restoration Information	Hewn Stone
EVLİYA HOCA MEKTEBİ	Schools	at the right side of Evliya Hoca Camii	Unknown	collapsed before XX.century	Hewn Stone
FATMA HANIM MEKTEBİ	Schools	at the Küçük Çamlıca Hill	1893-94	till 1925 is being used as a school	Hewn Stone
FETTAH EFENDİ MEKTEBİ	Schools	Bülbüldere Street	Unknown	in 1924 it was just a ground	Hewn Stone
FEVZİYE MEKTEBİ	Schools	Bülbüldere	1882	1925 (is in very bad conditions) 1925-30 (collapsed)	Hewn Stone
FISTIKLI MEKTEBİ (HATİCE SULTAN MEKTEBİ)	Schools	Sinan Paşa	1757-1774	1935(collapsed)	Hewn Stone
GEREDELİ MEKTEBİ	Schools	Uncular Street	Unknown	1924 (collapsed)	Hewn Stone

GÜLFEM HATUN MEKTEBİ	Schools	Hakimiyeti Milliye Street	1561 1562 designed by Mimar Sinan	1940 (collapsed)	Hewn Stone
GÜLFEM HATUN KIZ RÜŞDİYESİ	Schools	Pazarbaşı Street	1877	No Restoration Information	Hewn Stone
HACI AHMET PAŞA MEKTEBİ	Schools	Doğancılar Square	1585 by Mimar Sinan	No Restoration Information	Hewn Stone
HACI BEDEL MEKTEBİ	Schools	Beygirciler Street	1728-29	1875(opened as a school) 1940 (sold)	Hewn Stone
HACI FAİK EFENDİ MEKTEBİ	Schools	Durbalı Street	Unknown	1762-63 (repaired)	Hewn Stone
HAS ODABAŞI AHMET AĞA MEKTEBİ	Schools	Tunusbağ	1643	in 1940 it was almost collapsed	Hewn Stone
KALINOĞLU AHMET AĞA MEKTEBİ	Schools	nexto Hüsrev Ağa Camii	1783	No Restoration Information	Hewn Stone
KARAKOL MEKTEBİ (İSMAİL AĞA MEKTEBİ)	Schools	Selami Ali Efendi Street	1610	althoug it needs a repair in 1925-30 it is collapsed in 1935	Hewn Stone
MAHMUT CAVUŞ MEKTEBİ (TAŞ MEKTEBİ)	Schools	Aşçıbaşı Mektbi Street	1706	1742 (repaired)	Hewn Stone
MALATYALI İSMAİL AĞA DAR'ÜL KÜFRASI	Schools	Ağahamamı	1617	1902 (collapsed while it is being repaired)	Hewn Stone
MEHMET AĞA MEKTEBİ (BULGURLU MESCİT MEKTEBİ)	Schools	İnkilap	1890	1998(repaired)	Hewn Stone
MEHMET AĞA MEKTEBİ	Schools	Hacı Mutlu Street	1764	collapsed before 1920	Hewn Stone
MEHMET AĞA KEMER ALTI SIBYAN MEKTEBİ	Schools	Valide-i Atik Çeşmeşi Street	1589-90	collapsed before 1975	Hewn Stone
MEKTEB-İ TIBBİYE-İ ŞAHANE(HAYDARPAŞA LİSESİ)	Schools	Tıbbiye Street	1876-1909	No Restoration Information	Hewn Stone
MİHRİMAH SULTAN SIBYAN MEKTEBİ	Schools	Yenidünya Street	1548	1968(turned into child library)	Hewn Stone
MUMCUZADE MEKTEBİ (MUMCUBAŞI MEKTEBİ)	Schools	Hacı Hesna Hatun	1600?	1900 (no longer exist)	Hewn Stone
MÜHENDİSHANE-İ BERRİ-İ HÜMAYUN	Schools	near Ayazma Camii	1734	1799 (reopened in Sütlüce)	Hewn Stone
NAKKAŞTEPE İLKOKULU	Schools	Nakkaştepe Street	1914	closed during the building of Bosphorus Bridge 1991(restorated)	Hewn Stone
NEVFİDAN HATUN MEKTEBİ	Schools	Bülbülderesi Street	Unknown	1924 (repaired)	Hewn Stone
NURBANU SULTAN DARÜ'L - KURBASI	Schools	Çinli Camii Street	1583	No Restoration Information	Hewn Stone
RODOSİ AHMET AĞA MEKTEBİ	Schools	near Fethi Ahmet Paşa Camii	1790-95	1940 (collapsed)	Hewn Stone

RÜSTEM PAŞA SIBYAN MEKTEBİ	Schools	İmrahor	1598-99 probably built by Mimar Sinan	1897 (repaired)	Hewn Stone
RUH MEHMET PAŞA MEKTEBİ	Schools	Eşref Saat Street	1471-72	No Restoration Information	Hewn Stone
SELİM AĞA SIBYAN MEKTEBİ	Schools	Selamsız Street	1782	1937(collapsed and built Taş Mektep)	Hewn Stone
SELİMİYE SIBYAN MEKTEBİ	Schools	selimiye camii avlusunda	1805	1915(it became a karakol)	Hewn Stone
SOLAK SİNAN SIBYAN MEKTEBİ	Schools	Solak Sinan Camii Tophaneli Street	1548	1930 (collapsed)	Hewn Stone
SOLAK SİNAN MEKTEBİ	Schools	Medrese Street	1548	1930(sold)	Hewn Stone
SULTAN III.SELİM NĞMĞNE MEKTEBİ	Schools	Neyzanbaşı Halil Can Street	1931	1940 (burned) 1949 (restorated)	Hewn Stone
SÜLEYMAN AĞA MEKTEBİ	Schools	Bulgurlu Street	1755-56	1872 (restorated)	Hewn Stone
SÜLEYMAN PAŞA SIBYAN MEKTEBİ	Schools	Viransaray Street	1687	1935 (collapsed)	Hewn Stone
TÜRK AHMET PAŞA MEKTEBİ	Schools	Hakimiyeti Milliye Street	1704-1705	Burned 1834-35 (no longer exist)	Hewn Stone
ÜSKÜDAR AMERİKAN KIZ KOLEJİ	Schools	between Selamsız and Bağlarbaşı	1871	1905 (burned)	Hewn Stone
SAURP HAÇ ERMENİ KİLİSESİ	Churchs	Görümce Street	1676	1797,1831 (restorated) 1880 (Major Restoration)	Tuff Masonry
SURP KARABET ERMENİ KİLİSESİ	Churchs	Allami Street	1617	1727,1844(Major Restoration) 1887 (burned) 1888 Rebuilt	Tuff Masonry
İLYA PROFİTİ RUM ORTODOKS KİLİSESİ	Churchs	Selamsız Street	1804	1831,1945 Restorated 1987 Sold to private Sector	Hewn Stone
AHMEDİYE MEDRESESİ	Medreses	Ahmediye Sterrt	1721	1965 Closed due to its condition	Hewn Stone
ÇİNİLİ MEDRESESİ	Medreses	Çinili Street	1640	1970	Hewn Stone
GÜLFEM HATUN MEDRESESİ	Medreses	Hakimiye Milliye Street	1562	1766 Collapsed at Earthquake	Hewn Stone
HACI KADIN MEDRESESİ	Medreses	KocamustafaPaşa Street	1527	1552	Hewn Stone
MİHRİMAH SULTAN MEDRESESİ	Medreses	Mihrimah Sultan Street	1547 (mimar Sinan)	No Restoration Information	Hewn Stone
RUM MEHMET PAŞA MEDRESESİ	Medreses	Medrese Street	1471	1642,1777	Hewn Stone
ŞEMSİ PAŞA MEDRESESİ	Medreses	Şemsi Paşa Street	1580 (mimarsininan)	1894 Damaged from Earthquake	Hewn Stone

ŞEYHÜLİSLAM MİNKARİZÂDE YAHYA EFENDİ MEDRESESİ	Medreses	Ahmet Çelebi Street	1665	1855 damaged at earthquake, 1955 restorated	Hewn Stone
VALİDE-İ ATİK MEDRESESİ	Medreses	Kartalbaba Street	1583	No Restoration Information	Hewn Stone
HAYDARPAŞA ASKERÎ HASTAHANESİ	Hospitals	Haydarpaşa	1520	1802 collapsed 1845 Major Restoration 1935,1956 Restorated	Tuff Masonry
VALİDE-İ ATİK DARÜ'Ş-ŞİFASI (BİMARHANESİ)	Hospitals	Toptaşı Street	1583	1876,1909	Hewn stone and Wood
VÂLİDE-İ ATİK TABHANESİ	Hospitals	Toptaşı Street	1875	No Restoration Information	Tuff Masonry
KÖSEM SULTAN KERVANSARAYI	Kervansarai	Çavuşdere Caddesi	1640	No Restoration Information	Tuff Masonry
MİHRİMAH SULTAN KERVANSARAYI	Kervansarai	Mihrimah Sultan Street	1547	No Restoration Information	kesme taş
VALİDEYİ ATİK KERVANSARAYI	Kervansarai	Bağlarbaşı	1583	No Restoration Information	Tuff Masonry
ARAPZÂDE KARAKOLU	Police Stations	İcadiye Street	1839	1970 Collapsed	Hewn Stone
ÇİNİLİ KARAKOLU	Police Stations	Nuhkuyusu Street	1883	1927 Restorated, 1980 Collapsed	Hewn Stone
AĞA HAMAMI	Turkish Baths	Gündoğumu cad.	1610	1798(water flood)	Hewn stone and Wood
ALTUNİZADE İSMAİL PAŞA HAMAMI	Turkish Baths	Koşuyolu	1865	1915(collapesed due to lack of maintance)	Solid masonry
AYAZMA HAMAMI	Turkish Baths	Ayazma	1584 (Mimar Sinan)	1760-1974-1914(collepsd)	Solid masonry
BULGURLU KÖYÜ HAMAMI (AZİZ MAHMUD HÜDÂI~Î EF6NDİ	Turkish Baths	Bulgurlu	1618	still using	Solid masonry
CİNCİ HÜSEYİN EFENDİ HAMAMI	Turkish Baths	İnadiye	1645	1755	Solid masonry
ÇARŞI HAMAMI (BÜYÜK HAMAM - YEŞİL DİREKLİ HAMAM)	Turkish Baths	Hakimiyet_i Milliyet Cad.	1583 (Mimar Sinan)	1940-1962	Hewn Stone
ÇİNİLİ HAMAM	Turkish Baths	Çavuşdere Cad.	1642	1923(damage at fire) 1963(restoreted)	Hewn Stone
DAĞ HAMAMI	Turkish Baths	Yüksel Sk.	1840	1921(damage at fire)	Hewn Stone
DOĞANCILAR HAMAMI	Turkish Baths	Doğancılar	1585	1798 (damaged at fire) 1918 (damaged at fire)	Wood
ESKİ HAMAM	Turkish Baths	Doğancılar	1472	1734 (restorated) 1885 (restorated)	Wood
HÜSEYİN PAŞA HAMAMI	Turkish Baths		1540	Unknown information	Hewn Stone

İCADİYE DAĞ HAMAMI	Turkish Baths	Kuzguncuk	1854	1905 (restorated)	Solid masonry
İSKELE HAMAMI	Turkish Baths	Selman Ağa Sokak	1547	1766 (restorated)	Wood
SELAMİ ALİ EFENDİ HAMAMI	Turkish Baths	Selamsız Semti	1677	Used as a home today	kesme taş
SELİMİYE HAMAMI	Turkish Baths	Selimiye	1805	No Restoration Information	Solid masonry
SİNAN PAŞA HAMAMI	Turkish Baths	Salacak	1593	1918 (burned at fire)	Solid masonry
VALİDEYİ ATİK HAMAMI (TOPTAŞ HAMAMI)	Turkish Baths	Üsküdar askeri lisesi yanı	1583	1985 (restorated)	Solid masonry
SELİMİYE MILITARY BASE	Military Bse	Kavak İskele Street	1793	1800,1807 Restorated	Tuff Masonry

APPENDIX B: SAP2000 TABLES

Table B.1. Modal participating mass ratios for After Restoration Condition (AR)

Output Case	Mode Num	Period	UX	UY	UZ	ΣUX	ΣUY	ΣUZ
Text	Unitless	Sec	Unitless	Unitless	Unitless	Unitless	Unitless	Unitless
MODAL	1	0,37544	0,08502	0,28374	0,00000	0,09	0,28	0,00
MODAL	2	0,34527	0,23207	0,08878	0,00001	0,32	0,36	0,00
MODAL	3	0,29943	0,00019	0,05203	0,00000	0,32	0,42	0,00
MODAL	4	0,25258	0,00002	0,00013	0,05760	0,32	0,42	0,06
MODAL	5	0,22471	0,00009	0,00000	0,00003	0,32	0,42	0,06
MODAL	6	0,21485	0,01543	0,00054	0,00000	0,34	0,42	0,06
MODAL	7	0,18142	0,00400	0,24969	0,00028	0,34	0,67	0,06
MODAL	8	0,17079	0,00001	0,00007	0,08817	0,34	0,67	0,15
MODAL	9	0,16996	0,00000	0,00000	0,00007	0,34	0,67	0,15
MODAL	10	0,16651	0,00005	0,00002	0,01883	0,34	0,67	0,16
MODAL	11	0,16016	0,18566	0,00552	0,00003	0,53	0,68	0,17
MODAL	12	0,14543	0,00103	0,00675	0,00312	0,53	0,68	0,17
MODAL	13	0,14021	0,00106	0,00001	0,00060	0,53	0,68	0,17
MODAL	14	0,13920	0,00031	0,00005	0,00529	0,53	0,68	0,17
MODAL	15	0,13366	0,00003	0,04609	0,00071	0,53	0,73	0,17
MODAL	16	0,12875	0,00004	0,00015	0,00029	0,53	0,73	0,18
MODAL	17	0,11630	0,00001	0,00053	0,00002	0,53	0,74	0,18
MODAL	18	0,10912	0,01431	0,01098	0,00001	0,55	0,75	0,18
MODAL	19	0,10760	0,00978	0,06094	0,00020	0,56	0,81	0,18
MODAL	20	0,10530	0,00132	0,00314	0,00007	0,56	0,81	0,18
MODAL	21	0,10476	0,00013	0,00000	0,00000	0,56	0,81	0,18
MODAL	22	0,10132	0,00136	0,00029	0,00013	0,56	0,81	0,18
MODAL	23	0,09972	0,10722	0,00185	0,00105	0,66	0,81	0,18
MODAL	24	0,09419	0,00561	0,00267	0,00000	0,67	0,82	0,18
MODAL	25	0,08867	0,00084	0,00007	0,12793	0,67	0,82	0,30
MODAL	26	0,08799	0,00028	0,00000	0,46320	0,67	0,82	0,78
MODAL	27	0,08726	0,00136	0,01647	0,00053	0,67	0,83	0,78
MODAL	28	0,08616	0,00001	0,00001	0,00022	0,67	0,83	0,78
MODAL	29	0,08537	0,00068	0,00001	0,00043	0,67	0,83	0,78
MODAL	30	0,08315	0,00020	0,00012	0,00191	0,67	0,83	0,78
MODAL	31	0,08300	0,00054	0,00000	0,00001	0,67	0,83	0,78
MODAL	32	0,08259	0,00028	0,00075	0,00232	0,67	0,83	0,78
MODAL	33	0,08244	0,00130	0,00062	0,00010	0,67	0,83	0,78
MODAL	34	0,08236	0,03574	0,00607	0,00006	0,72	0,84	0,78
MODAL	35	0,08190	0,00042	0,00002	0,00003	0,72	0,84	0,78
MODAL	36	0,08079	0,00001	0,00095	0,00003	0,72	0,84	0,78
MODAL	37	0,08057	0,00224	0,00848	0,00000	0,72	0,85	0,78
MODAL	38	0,07967	0,00292	0,03383	0,00021	0,72	0,89	0,78
MODAL	39	0,07855	0,01657	0,00011	0,00001	0,73	0,89	0,78
MODAL	40	0,07825	0,00334	0,00747	0,00011	0,74	0,89	0,78
MODAL	41	0,07691	0,08514	0,00962	0,00043	0,82	0,90	0,78
MODAL	42	0,07479	0,00006	0,00624	0,00049	0,82	0,91	0,78
MODAL	43	0,07437	0,00002	0,00080	0,00063	0,82	0,91	0,78
MODAL	44	0,07322	0,00054	0,00026	0,00002	0,82	0,91	0,78

MODAL	45	0,07205	0,00005	0,00047	0,00040	0,82	0,91	0,78
MODAL	46	0,07092	0,00003	0,00024	0,00021	0,82	0,91	0,78
MODAL	47	0,06901	0,00000	0,00172	0,00907	0,82	0,91	0,78
MODAL	48	0,06761	0,00202	0,00002	0,00006	0,82	0,91	0,78
MODAL	49	0,06505	0,00541	0,00493	0,00000	0,84	0,91	0,78
MODAL	50	0,06322	0,00084	0,00003	0,00000	0,84	0,91	0,78
MODAL	51	0,06296	0,06759	0,00022	0,00000	0,91	0,91	0,78
MODAL	52	0,06228	0,00030	0,00066	0,00009	0,91	0,91	0,78
MODAL	53	0,06197	0,00087	0,00002	0,00000	0,91	0,91	0,78
MODAL	54	0,06190	0,01536	0,00035	0,00000	0,92	0,91	0,78
MODAL	55	0,06061	0,00132	0,00005	0,00058	0,92	0,91	0,80
MODAL	56	0,05829	0,00022	0,00001	0,00620	0,92	0,91	0,80
MODAL	57	0,05803	0,00004	0,00377	0,00242	0,92	0,92	0,80
MODAL	58	0,05779	0,00030	0,00143	0,00007	0,92	0,92	0,80
MODAL	59	0,05688	0,00003	0,00063	0,00097	0,92	0,92	0,80
MODAL	60	0,05673	0,00011	0,00003	0,00061	0,92	0,92	0,80
MODAL	61	0,05671	0,00035	0,00027	0,00119	0,92	0,92	0,80
MODAL	62	0,05653	0,00218	0,00297	0,00029	0,92	0,92	0,80
MODAL	63	0,05544	0,00033	0,01218	0,00058	0,92	0,93	0,80
MODAL	64	0,05529	0,00005	0,02646	0,00103	0,93	0,96	0,80
MODAL	65	0,05368	0,00309	0,00060	0,09230	0,93	0,96	0,89
MODAL	66	0,05323	0,00321	0,00003	0,03593	0,93	0,96	0,93
MODAL	67	0,05247	0,00131	0,00150	0,00211	0,93	0,96	0,94
MODAL	68	0,05211	0,00156	0,00446	0,00843	0,93	0,96	0,94
MODAL	69	0,05122	0,00066	0,00003	0,00093	0,93	0,96	0,94
MODAL	70	0,05071	0,00083	0,00189	0,00002	0,93	0,96	0,94
MODAL	71	0,04999	0,00018	0,00044	0,00072	0,93	0,96	0,94
MODAL	72	0,04982	0,00023	0,00162	0,00001	0,93	0,98	0,94
MODAL	73	0,04940	0,00161	0,00009	0,00027	0,94	0,98	0,94
MODAL	74	0,04908	0,00218	0,00002	0,00014	0,94	0,98	0,94
MODAL	75	0,04857	0,02005	0,00019	0,00005	0,96	0,98	0,94
MODAL	76	0,04819	0,00421	0,00013	0,00002	0,96	0,98	0,94
MODAL	77	0,04777	0,00014	0,00003	0,00286	0,96	0,98	0,94
MODAL	78	0,04737	0,00730	0,00877	0,00002	0,97	0,98	0,94
MODAL	79	0,04730	0,00027	0,00281	0,00002	0,97	0,99	0,94
MODAL	80	0,04682	0,00168	0,00776	0,00003	0,97	0,99	0,94
MODAL	81	0,04579	0,00000	0,00303	0,00000	0,97	1,00	0,94
MODAL	82	0,04577	0,00016	0,00009	0,00020	0,97	1,00	0,94
MODAL	83	0,04548	0,00001	0,00507	0,00009	0,97	1,00	0,94
MODAL	84	0,04504	0,00338	0,00047	0,00001	0,97	1,00	0,94
MODAL	85	0,04499	0,00001	0,00001	0,00001	0,97	1,00	0,94
MODAL	86	0,04450	0,00048	0,00003	0,00167	0,97	1,00	0,94
MODAL	87	0,04448	0,00092	0,00018	0,00014	0,97	1,00	0,94
MODAL	88	0,04432	0,01229	0,00059	0,00034	0,99	1,00	0,94
MODAL	89	0,04410	0,00076	0,00003	0,00089	0,99	1,00	0,96
MODAL	90	0,04397	0,00006	0,00009	0,00097	0,99	1,00	0,96
MODAL	91	0,04378	0,00000	0,00015	0,00099	0,99	1,00	0,96
MODAL	92	0,04359	0,00286	0,00027	0,00002	0,99	1,00	0,96
MODAL	93	0,04340	0,00001	0,00000	0,00400	0,99	1,00	0,96
MODAL	94	0,04324	0,00156	0,00001	0,00013	1,00	1,00	0,96
MODAL	95	0,04306	0,00003	0,00022	0,00102	1,00	1,00	0,96

MODAL	96	0,04300	0,00024	0,00001	0,00627	1,00	1,00	0,96
MODAL	97	0,04272	0,00000	0,00003	0,00160	1,00	1,00	0,96
MODAL	98	0,04242	0,00001	0,00020	0,00000	1,00	1,00	0,96
MODAL	99	0,04175	0,00000	0,00008	0,00038	1,00	1,00	0,96
MODAL	100	0,04173	0,00001	0,00004	0,00005	1,00	1,00	0,96

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