A COMPARATIVE STUDY ON EARTHQUAKE RESISTANCE OF REINFORCED CONCRETE AND MASONRY RESIDENTIAL BUILDINGS IN SMALL-SCALE CITIES OF TURKEY

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ABSTRACT

A COMPARATIVE STUDY ON EARTHQUAKE RESISTANCE OF
REINFORCED CONCRETE AND MASONRY RESIDENTIAL BUILDINGS
IN SMALL-SCALE CITIES OF TURKEY

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Today the vast majority of urban population in Turkey is living in multi-story apartment blocks constructed of reinforced concrete due to the fact that in the late 19th century concrete and steel took the place of traditional materials such as masonry. However, it cannot be denied that masonry is still a crucial material for load bearing walls, internal walls and cladding of buildings. In addition to this masonry construction system has many advantages. From the architectural point of view, it provides flexibility in plan, spatial composition, wide variety of colours and textures and an impressive appearance for external walls. From the construction point of view, masonry system eliminates the cost of the frame because the structure is also the enclosing wall. In spite of these advantages, until recently, masonry was not considered to be a convenient material for building construction in seismic zones of Turkey. Thus, in 1950's for the residential building reinforced concrete started to be used as a construction material in every region of Turkey. This building material first became popular and was widely used but after a short while it was also used in smaller cities. Before the construction of reinforced concrete residential buildings each of these small-scale cities had their own local characteristics but after a rapid urbanization period all of these cities became similar to each other.

Therefore, in this study firstly residential building typologies in some small-scale cities (Bolu, Düzce, Çankırı, Çorum, Kastamonu, Kırıkkale) are investigated and for these cities 4-storey masonry residential buildings is proposed instead of multi-story reinforced concrete apartment blocks. Here, it is aimed to enliven the use of masonry again in these regions. To achieve this aim it is necessary to verify the fact that it is possible to construct a four-story residential building with masonry bearing walls instead of reinforced concrete beam and column skeleton system keeping the existing plan scheme in other words without changing its architectural characteristics. In order to do this, 3D models are created to compare the behaviours of the masonry building and reinforced concrete building. The behavioural investigation of the two models is performed in the finite element platform with the help of SAP 2000. Finally it is certified that this proposal is successfully efficient.

Keywords: Masonry Residential Building, Reinforced Concrete Residential Building, Small-scale Cities in Earthquake Regions of Turkey, Structural Analysis.

ÖZ

TÜRKİYE'NİN KÜÇÜK ÖLÇEKLİ ŞEHİRLERİNDEKİ BETONARME VE YIĞMA KONUT BİNALARININ DEPREME DAYANIMI ÜZERİNE KARŞILAŞTIRMALI BİR ÇALIŞMA

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Bugün Türkiye'deki kentsel nüfusun büyük kısmı yüksek katlı betonarme apartman bloklarında yaşamaktadır. Bunun nedeni, 20. yüzyılda çelik ve betonun yığma yapı malzemelerinin yerini almasıdır. Buna rağmen yığma yapı elemanlarının hala taşıyıcı duvarlarda, iç duvarlarda binaların kaplamalarında önemli bir malzeme olduğu inkar edilemez. Buna ek olarak yığma yapıların birçok avantajı bulunmaktadır. Mimari açıdan, planda esneklik, mekana ait kompozisyon, renk ve doku çeşitliliği ve dış duvarlar için etkileyici bir görünüm sağlar. İnşaat açısından, yığma sistemler bütün duvarların taşıyıcı olmasından dolayı taşıyıcı iskelet sistemin maliyetini ortadan kaldırır. Dahası, bu duvar bölücü iç duvar olarak kullanılabilir ve yangın dayanımı, sağlamlık ve ses yalıtımı sağlar. Bu avantajlara rağmen bugüne kadar, yığma yapı malzemeleri Türkiye'deki deprem bölgeleri için uygun malzeme olarak düşünülmemiştir. Böylece, 1950'lerde Türkiye'nin her bölgesinde konut blokları için yapı malzemesi olarak betonarme kullanılmaya başlanmıştır.Bu değişimin başında büyük şehirler gelmekle birlikte bir kaç yıl sonra küçük ölçekli şehirler de bu değişimin takipçisi olmuşlardır. Ancak, bu betonarme konutlarından yapımından önce kendi yerel özelliklerini taşıyan bu şehirler betonarme knout bloklarının yapımıyla birbirinin benzeri şehirler haline gelmişlerdir.

Bu sebeple bu çalışmada ilk olarak bazı küçük ölçekli şehirlerdeki (Bolu, Düzce, Çankırı, Çorum, Kastamonu, Kırıkkale) konut tipolojisi incelenmiş ve bu şehirler için yüksek katlı betonarme konutların yerine 4 katlı yığma konut yapıları önerilmiştir. Buradaki amaç bu bölgelerde yığma yapıları yeniden hayata geçirmektir. Bunu başarabilmek için, 4 katlı bir yığma yapının 4 katlı bir betonarme yapıyla mimari özelliklerinde hiçbir değişiklik yapmadan aynı performansı gösterebileceğini ispatlamak gerekmektedir. Bu nedenle, yığma ve betonarme olmak üzere iki yapının davranışlarını karşılaştırabilmek için 3 boyutlu modelleri oluşturulmuştur. Yapıların davranışsal incelemeleri için sonlu elemanlar yöntemi ve SAP 2000 bilgisayar programı kullanılmıştır. Sonuç olarak bu önerinin başarılı sonuçlar verdiği gözlemlenmiştir.

Anahtar Kelimeler: Yığma Konut Binaları, Betonarme Konut Binaları, Türkiye'nin Deprem Bölgelerindeki Küçük Ölçekli Şehirler, Yapısal Analiz.

to my family

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CHAPTER 1

INTRODUCTION

In this chapter, statement of the problem and the objectives of the study are presented, followed by an overview of its general procedure and disposition that outlines of the remaining chapters.

1.1 Statement of the Problem

In most countries of the world residential construction is at a turning point. The issues of providing housing for large numbers of people are being replaced increasingly by the concerns improving the quality of housing. In many developed countries of the world, especially in Europe (Italy, England etc.), masonry structures are widely used for the construction of residential buildings. Brick and concrete masonry blocks are much popular in these countries, due to the many advantages of masonry. Therefore, masonry is still a crucial material because of its architectural and structural characteristics. From the architectural point of view, masonry provides flexibility in plan, spatial composition, wide variety of colours and textures and an impressive appearance for external walls. From the construction point of view, masonry system eliminates the cost of the frame because the structure is also the enclosing wall. Masonry walls may also act as an interior finish surface and provide fire resistance, stability and sound insulation. Speed of erection, availability of the material, thermal and acoustic insulation other important advantages of masonry as building system.

However, today there are few studies on masonry as a construction technique for new buildings in seismic areas. Researches on the seismic behaviour of the masonry structures almost dedicated to existing buildings. These researches are generally related to assessment of seismic vulnerability of masonry buildings and strengthening techniques for these structures. Obviously, protection of masonry structures is necessary for the protection of the cultural heritage of the countries which has a long story of civilization. However, while researches major on this subject, using masonry for new construction is ignored. Therefore, masonry should be thought as a building system for the housing units in earthquake prone areas because it has so many advantages as mentioned above.

In spite of the advantages of masonry, today the vast majority of urban population in Turkey is living in multi-story reinforced concrete apartment blocks. Although masonry was a traditional building material of many regions in the country, until recently, it was not considered to be a convenient material for residential building construction. The common material for residential buildings is reinforced concrete in Turkey. The main reason of this situation is using new construction materials instead of the traditional construction materials due to the developments in technology. As a rule of the modernization period reinforced concrete started to be used and people left their traditional buildings constructed with masonry and timber. Thus brick and timber have lost their importance and they are not used as widely as they could be. In fact urbanization problem started 1920s, which was clearly observed in Ankara as its being the capital. So, the positive and the negative effects of urbanization started to be seen in Ankara. In 1950s and 1960s the effect of this urbanization process initiated to spread from Ankara to the nearest cities. Hence, the majority of the built environment consists of typical five-storey reinforced concrete buildings in the country as a result of this unhealthy urbanization period.

During this period, with the construction of reinforced concrete apartment blocks, every city started to be similar with each other. Many cities of the Anatolia started to lose their local architectural characteristics. Improper urbanization in big cities of the country could not be averted. With the onset of the domination of reinforced concrete apartments, all the cities started to resemble each other and lose their authenticity. During 1950s, the common attitude could pursue the path of strengthening and modernizing the traditional masonry building instead of investing on reinforced concrete apartments. Nevertheless, there is still hope for small scale cities. For this purpose, in this study some of these small-scale cities; Kırıkkale, Çankırı, Çorum, Düzce, Bolu and Kastamonu are investigated to have an idea for the current situation of the housing environment. While choosing the cities there are two criteria that is taken into consideration: first one is that, these cities were affected by the urbanization period firstly because they are closest cities to Ankara. Second choice of criteria is that, these cities are located in earthquake prone areas of Turkey which is an important factor that affect the residential building types. Hence, field surveys were focused on the building typologies in these cities. After the site surveys, through the visited small-scale cities (Kırıkkale, Çankırı, Çorum, Düzce, Bolu and Kastamonu), Bolu is selected for the case study.

Another important criterion for the problem definition of this thesis is seismic characteristics of Turkey. It is a well known fact that, Turkey has had a long history of large seismic actions which often occur in progressive adjacent earthquakes. Lack of seismic design in the existing buildings continues to threaten the safety of our societies and the economy. The experience gained from the last earthquakes in Turkey, have significantly enhanced researcher's understanding on earthquake design and evaluation. These earthquakes not only changed scientists thought but also changed citizens thought about the reliability of the seismic design of their residences. Throughout the course of this evolution, standards for building materials, design codes and regulations have been considerably updated. The adaptation process to the new seismic provisions was quick in cities like Bolu and Düzce in which earthquakes occur frequently. A tendency to evaluate several different types of existing built environment to decrease the deficiencies and failures has started. Among construction types, multi-storey reinforced concrete apartment buildings need special attention because of their seismic performance as observed in 1999 earthquakes of Turkey. However there is another important topic which needs special attention too. The experiences gained from recent earthquakes indicated that while many RC buildings collapsed, several buildings which have constructed with traditional materials such as masonry and timber have performed well. These earthquakes demonstrated that traditional structural systems have some practical features to resist the seismic action. The special characteristics of traditional structures may be sources of inspiration for the innovative earthquake resistant residential buildings. This aim necessitates a rational and comprehensive investigation on these buildings since the number of researches on the behaviour of traditional materials and structures are limited. However, in Turkey, there are few researches on earthquake behaviours of traditional materials and structures compared to reinforced concrete. Among traditional materials brick has high production capacity in Turkey. Together with the advantage of availability, brick masonry is an economic system which is an important factor for Turkey as a developing country. Regeneration and revival of the traditional materials for residential buildings may lead to recover the authenticity and original characteristics of the cities. In addition, using masonry units in residential buildings will increase the production of brick that can provide more employment in brick factories. What's more, with this solution, citizens who do not want to live in high reinforced concrete apartment blocks after 1999 earthquakes will prefer these masonry buildings with medium height. Also, construction time of the masonry buildings is less than the reinforced concrete buildings which is an important factor that should be taken into consideration while designing a building in an earthquake region.

As a result, brick masonry construction system insures both safety and economy instead of multi-story reinforced concrete apartment blocks. Thereby with this solution, local sources will be used, traditions in the construction systems will be regenerated, and cities will gain local architectural characteristics again. Consequently, considering all of these, this study tries to indicate the architectural potential of masonry construction in small-scale cities located on seismic zones of Turkey.

1.2 Objectives and Scope

The primary objective of this study is to assess utilization of masonry for construction of residential buildings of medium height in small-scale cities located on earthquake prone areas in Turkey instead of reinforced concrete residential buildings. In other words the hypothesis of this study is that it is possible to construct a four-story residential building with masonry bearing walls instead of reinforced concrete beam and column skeleton system keeping the existing plan scheme. Thus this hypothesis is verified with numerical simulation methods. The aim of these analyses is not to show that masonry buildings have good earthquake performance, the aim of these analyses is to show that the common four or five storey reinforced concrete apartment buildings can be constructed with masonry without any changes. Therefore, the study also aims to contribute to the general understanding and perception of the architectural characteristics of the masonry and reinforced concrete as a building material in a comparative manner.

Within the scope of this study, a comprehensive sensitivity investigation is conducted on building typologies in small-scale cities in earthquake areas of Turkey: Kırıkkale, Çankırı, Çorum, Düzce, Bolu and Kastamonu as case studies, which were affected by urbanization process in 1950s. Research in the field survey, is focused towards existing residential buildings, in terms of material, configuration, and construction characteristics. A comparative study is done which investigates the overall condition of the residential units in these cities with the effect of geographical position, seismic properties of the city, population, urbanization, climate, economic condition, building inspection and architectural practice. This comparison is done to find the optimum field of application for the masonry residential units. At the end of the comparison between the cities, Bolu is selected for the application area.

Advancement in construction techniques seems to overcome the limitations of masonry systems. To demonstrate this development and to verify the proposal computer models of two construction type (reinforced concrete and the masonry) are generated. The two models have the same plan shapes and characteristics. Structural analyses of this selected residential building from Bolu are conducted and evaluated in a comparative way. Results of the analyses show that it can be possible to construct a 4 storey reinforced concrete residential building by using masonry without any changes in architectural characteristics.

1.3 Materials and Methodology

First of all, a literature survey is conducted on the masonry building systems, and then the residential housing units in small-scale cities of Turkey are investigated. It is seen that the building types in these regions consists of multi-story reinforced concrete apartment building which do not reflect their local characteristics. Thus, the research is concentrated on the local characteristics of these regions; structural systems used in the field, masonry systems for residential construction and advantages of using brick masonry for the residential buildings in Turkey conditions. Hence, the research undertaken by the author is focused on this problem and the following materials and methods are used in this study. The materials, which are used for this study, can be listed as,

- Literature survey about the research domain conducted at libraries of Middle East Technical University, Bilkent University, Gazi University and GDDA in, the thesis library of YÖK, online library of UMI digital dissertations,
- Literature survey about residential masonry units in University of Rome "Tor Vergata".
- Photographs, which were taken by the author during both the initial visit and the detailed investigation trips to the study areas: Kırıkkale, Çankırı, Çorum, Düzce, Bolu and Kastamonu,
- Interviews with the municipalities of case studies to determine the current conditions of the residential units in the selected areas,
- Reinforced concrete apartment projects, which were taken from the municipalities of the case studies during the investigation trips,
- Interviews, which were done with the TUKDER (Tuğla Üreticileri Derneği),
- Interviews, which were done with the Autoclaved Aerated Concrete Association,
- Visits to brick fabrications in Ankara,
- Examples of masonry residential units from other countries,
- Masonry codes and standards in the world.

As a methodology, the listed steps to be considered in achieving the goal of this thesis are;

1- Study on masonry building characteristics and masonry materials;

- Literature survey: A comprehensive investigation of the existing studies on earthquake resistance design,
- Determine factors affecting the design of masonry housing units (Figure 1.1),
- Interviews with TUKDER and municipalities of case cities.

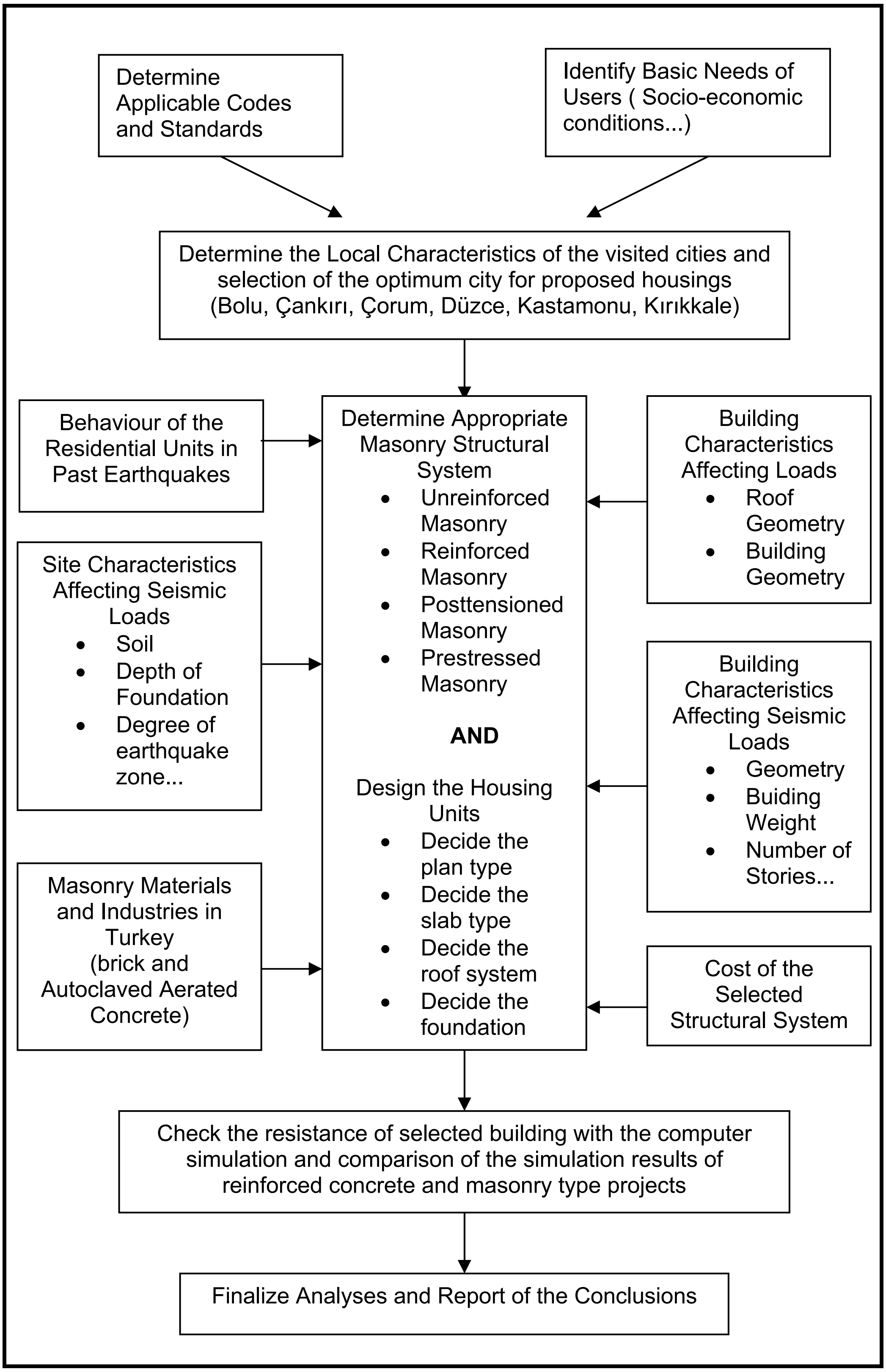

Figure 1.1 Determine Factors Affecting the Design of a Masonry Housing Unit

2- Assessment of the current condition of masonry and concrete construction industry;

- Investigation on the brick and concrete masonry unit (CMU) industry in Turkey,
- Investigation on the concrete and cement industry in Turkey,
- Comparative cost analyses between masonry and concrete.

3- Evaluation of the masonry design codes all over the world;

- Code development in USA, Europe, and Turkey,
- Deficiencies of masonry codes and standards in Turkey,
- Defining the code requirements for masonry buildings in Turkey.

4- Study on building types in small-scale cities of Turkey;

- Initial visit to the study areas: Kırıkkale, Çankırı, Çorum, Düzce, Bolu and Kastamonu,
- Research in existing building types of case studies,
- Collecting some plans of apartment blocks of these cities,
- Collecting the data about geographical position, seismic properties, population, urbanization, climate, economic condition of the city, building inspection and architectural practice,
- Photographing the existing building types.

5- Study on seismic performance of reinforced concrete and masonry buildings against earthquakes;

- Seismic performance of reinforced concrete buildings in past earthquakes
- Seismic performance of masonry buildings in past earthquakes
- Comparing the seismic performance of masonry buildings with other building technologies

6- Research in the University of Rome “Tor Vergata” in Italy about numeric simulations and masonry buildings,

7- Verification of the selected housing with numerical methods;

- Selection of a reinforced concrete residential building from Bolu,

- Drawings for masonry unit by using the same plan with the case which is selected from Bolu,
- Development of mathematical models considering all acceptable variations of suggestions and their evaluation under probable usage and loading combinations,
- Evaluation of the results of the analyses.

1.4 Disposition

General outline of this dissertation is conducted in six chapters that can be grouped into three parts as it can be seen in dissertation map (Figure 1.2). First part, Chapter I and Chapter II, include argument, objectives, and general background information about the topic. The second chapter provides explanation for the review of literature on masonry structures. This literature survey is conducted in order to demonstrate the current situation of the topic and gain information about historical development of masonry buildings. In this part of the study, materials and the types of the masonry construction have been classified and advantages of the system have been summarized. Additionally, numerous masonry building examples are provided throughout this chapter, which indicate the developments in masonry systems.

Second part of the study consists of Chapter III and Chapter IV that summarize the data collection and analysis phases. In the chapter III, current condition and the potential of the masonry building in Turkey is evaluated in terms of country economy, employment, completion time, training of specialized workers and architectural characteristics of the masonry. Then, masonry and concrete construction industries in Turkey are investigated in a comparative way. At the end of the chapter, regulations and codes of masonry in the world and the responsibility of public bodies in maintaining the standard have been discussed.

In the first part of the Chapter IV urbanization and housing typologies in Turkey, seismic performance of the residential units in recent earthquakes and seismic characteristics of masonry structures are explained. The circumstances under which such particular structures have evolved are discussed as well as the causes of failures in earthquakes of these structures. Then the site notes of initial visit to existing settlements in Kırıkkale, Çankırı, Çorum, Düzce, Bolu and Kastamonu (in order to understand the building types, types of structural systems) and local characteristics of the cases are provided including the interviews done with the municipalities (to understand their experiences and thoughts about the building types in the regions.) Furthermore, some sample projects of the housing units are obtained from the municipalities to make a comparison between the case studies. After an evaluation, Bolu is selected for the case study in order to propose masonry housing types as mentioned before. Thus, field survey was conducted again in Bolu. The properties of the housing units, the local characteristics of the regions and case studies are determined in this field survey.

Chapter V and Chapter VI constitute the third part of the study. In order to check whether our hypotheses are rational, a comparative study between concrete construction and masonry construction has been carried out with computer simulation in chapter V. This chapter discusses the verification of the proposal with finite element analyses. In the first part of the chapter information is given about the geometrical and material characteristics of the selected units. The selected units have different materials while they have the same plan organization. Then, finite element models of the units are generated and the results of the analysis evaluated in this chapter.

Finally, Chapter VI summarizes the findings and conclusions of this study and provides suggestions for future researches.

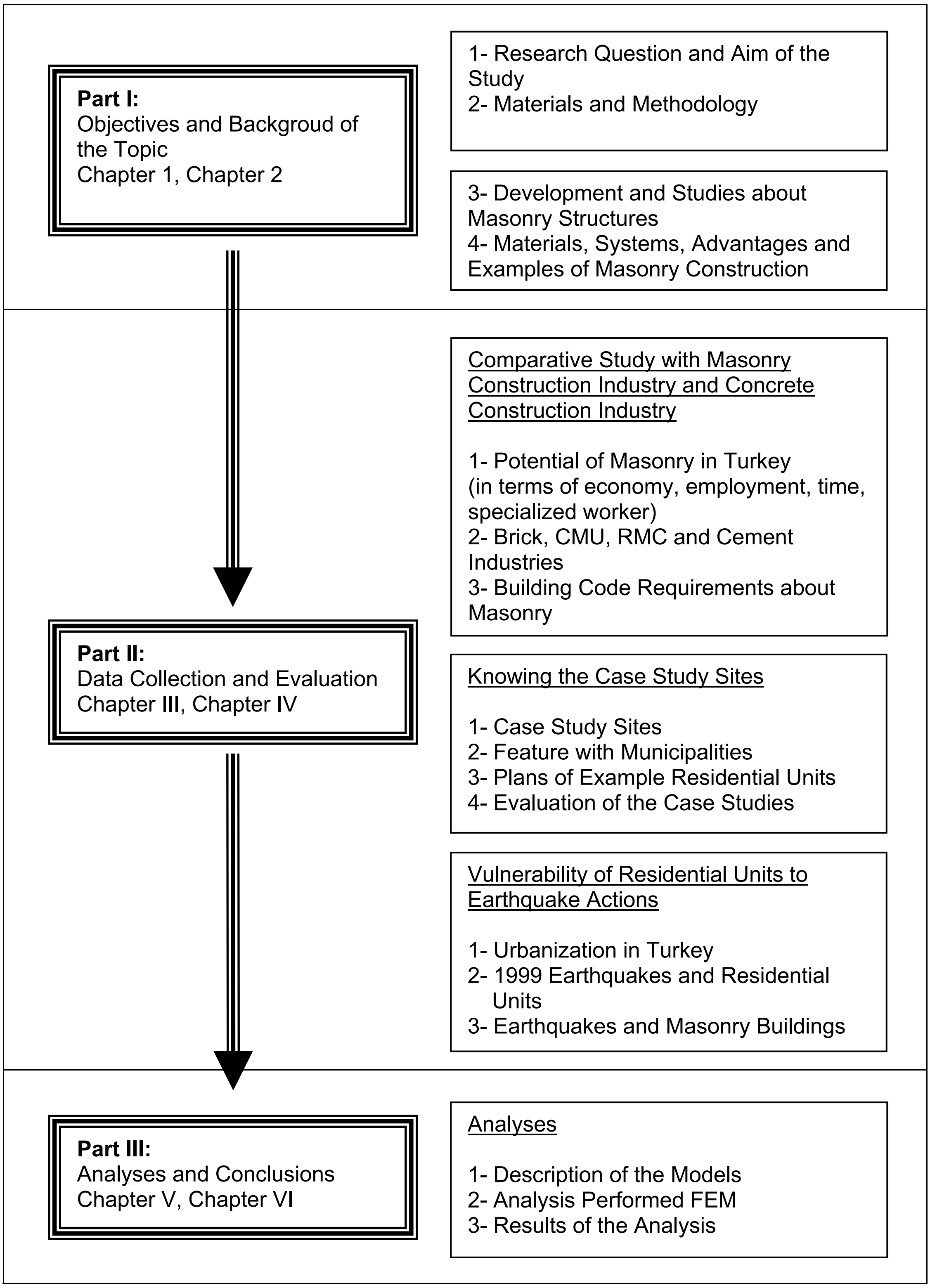

Figure 1.2 Dissertation Map

CHAPTER 2

A REVIEW OF LITERATURE ON MASONRY STRUCTURES

In this chapter is presented the literature survey on general characteristics of masonry structures including definitions, historical background of masonry and materials of masonry. Then previous studies about masonry are summarized. Furthermore, a general overview on construction of masonry buildings, which can be grouped as plain (unreinforced) masonry (solid masonry walls, hollow masonry walls, veneered walls), confined masonry, and reinforced masonry (cavity masonry walls, composite masonry walls), are included. Following a brief discussion on the potential advantages of masonry and a summary of the current state of the art with regards to this material is discussed. Finally, examples of masonry residential buildings from all over the world are examined to indicate different models of masonry housing units.

2.1 Definition of Masonry Structures

Masonry is known to be widely used construction material since the early times masonry units can be rough or cut stone, fired clay tile or bricks, or cast units of concrete. The general binder material is generally cement-lime mortar however there are ongoing studies to develop novel adhesive materials. One of the superiorities of the masonry over concrete is that it necessitates no temporary forming and bracing bringing the need for good workmanship. In order to extend the structural capabilities of masonry new reinforcing methods have been developed recently (Ambrose, 1993, p.25). Several definitions of masonry may be encountered in the literature. Some were listed by Taly as follows (Taly, 2001, pp.1.1-1.2),

- The International Building Code (IBC 2000) defines masonry as “a built-up construction or combination of building units or materials of clay, shale, concrete, glass, gypsum, stone or other approved units bonded together with or without mortar or grout or other accepted methods of joining."

- ASTM (the American Society for Testing and Materials) E 631 defines masonry as "construction usually in mortar, of natural building stone or manufactured units such as brick, concrete block, adobe, glass, block tile, manufacture stone, or gypsum block.
- The McGraw-Hill Dictionary of Scientific and technical terms defines masonry as "construction of stone or similar materials such as concrete or brick" (Taly, 2001).
- An assemblage of structural clay masonry units, concrete masonry units, stone, etc., or combination thereof, bonded with mortar or grout (Jaffle, 2003). Masonry is a highly durable form of construction because the materials used are not much affected by the elements, but the quality of the mortar and the pattern the units are laid in can strongly affect the quality of the overall masonry construction.

A common point in these different definitions is that masonry basically is a collection of individual units that might be of the same or different kind, and that have been bonded together in some way to realize wanted aim (Taly, 2001, p.1.1).

2.2 Historical Development of Masonry Buildings

It can be considered that the commencement of the masonry profession coincides with the beginning of civil engineering. Stone is the oldest and most abundant raw building material of prehistoric times which resulted in wide use as a construction material. It is known that unreinforced masonry has been used for several centuries, and also it is still in use for construction of buildings and dams. Then brick entered to human life as the man-made building material (Taly, 2001). It is the oldest manufactured building material, invented almost 10,000 years ago which has been used extensively as a result of its high strength and durability. Plain brick commenced to be used before the early Egyptians, Romans, and Greeks (Schneider and Dickey, 1994, p.5). Examples of early masonry structures can be listed as, the pyramid of Cheops in Egypt, the Great Wall of China (Figure 2.1), The

Temple of Artemis at Ephesus in Lydia, and tomb of Mausolus, King of Caria. Baked and glazed brick were firstly developed by the urban Sumerian and Babylonian cultures and they used coloured bricks in surface ornamentation.

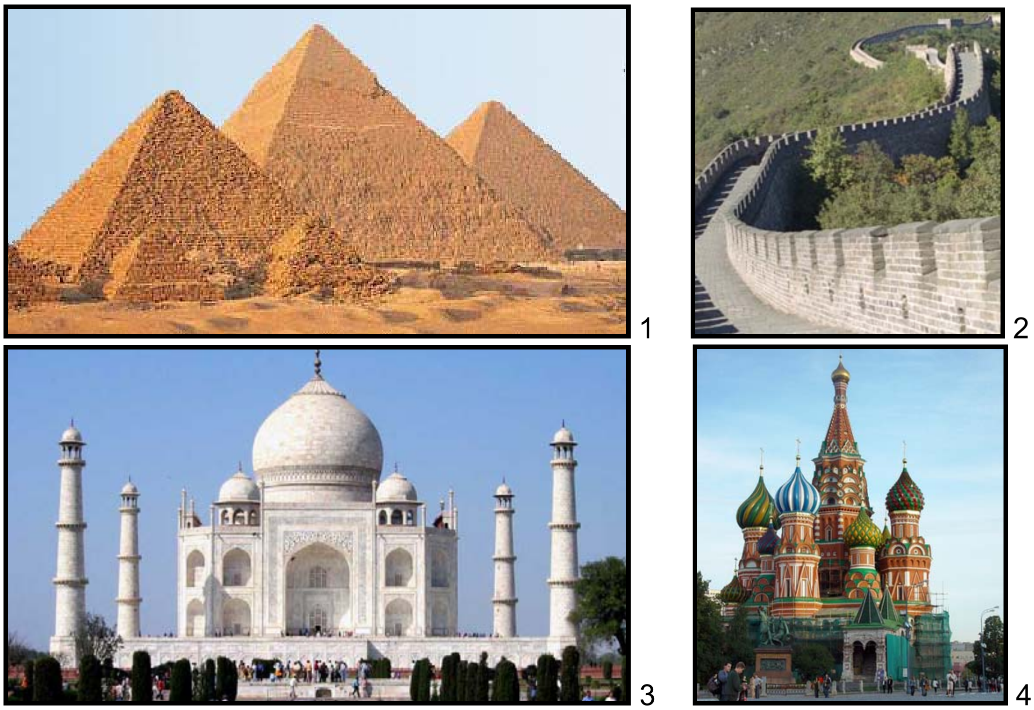

Figure 2.1 1- Egyptian Pyramids[1], 2- Great Wall of China[2], 3- Taj Mahal[3], 4- St. Basil's Cathedral in Moscow[4]

The most important innovations in masonry were arches and domed structures. They became important techniques for the architecture and engineering throughout the history. Arches were used in every civilization such as Persian, Harappan, Egyptian, Babylonian, Greek and Assyrian civilizations. In the thirteenth century arch

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[1] *Photo of Egyptian Pyramids,* <http://www.cap.nsw.edu.au/.../africa/the_pyramids.htm> Last accessed: January 5, 2008.
[2] *Photo of Great Wall Of China*, <http://www.photo.net/.../2000pcd1672/great-wall-7.tcl> Last accessed: January 5, 2008.
[3] *Taj Mahal,*<http://commons.wikimedia.org/wiki/Image:Taj_Mahal_in_March_2004.jpg > Last accessed: January 5, 2008.
[4] *St. Basil's Cathedral in Moscow*, <http://www.sacred-destinations.com/russia/moscow-st-basil-cathedral.htm> Last accessed: January 5, 2008.

was used efficiently in the domed structures of Islamic and Gothic architecture. Then, in 1889-1891 John Wellborn Root and Daniel Hudson Burnham designed the Monadnock Building in Chicago. It is the seventeen-story masonry building that stands 60 meters tall (Figure 2.2). When it was completed, the Monadnock Building was the world's largest office building. It is generally cited as the last great building in the ancient masonry architecture. According to Schneider and Dickey, such structures made it rather apparent at the turn of the century that a size limit had been reached on masonry structures using methods than currently employed (Schneider and Dickey, 1994, p. 23).

Figure 2.2 Monadnock Building, (1889-18891) Chicago, Illinois[5]

However, after this period with the Industrial Revolution masonry replaced with iron, steel and concrete construction and only used as a secondary usage as facing, infill,

[5] *The Monadnock Building,* http://www.greatbuildings.com/buildings/Monadnock_Building.html> Last accessed: January 5, 2008

and fireproofing. During this period, Antonio Gaudi is the most important architect who creates innovative solutions with masonry (Figure 2.3). He was the master of the use of masonry. However, Gaudi's designs were the exception in the world.

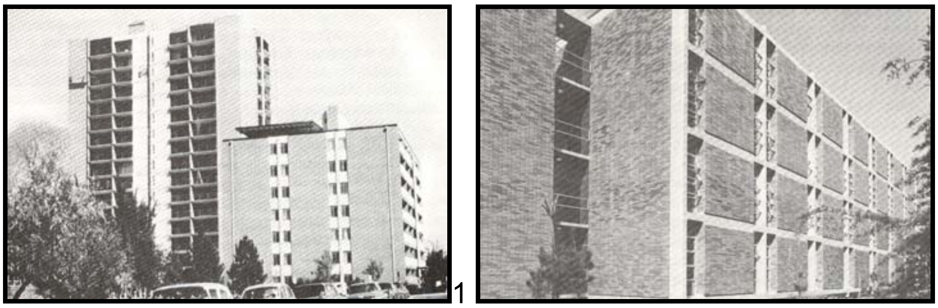
1 2 3

Figure 2.3 Examples of Gaudi's Masonry Designs[6]
(1- Casa Mila, 2- Sagrada Familia, 3- Park Guell · Montana Pelada, Spain)

During 1920's masonry structures gained importance again. For example, due to the economic recessians in India in 1920, alternative materials were utilized instead of concrete and steel system. Extensive research began into the performance of reinforced masonry walls, slabs, beams and columns. In 1923, Under-Secretary A. Brebner, Public Works Department of the Government of India, published a report that marked the true beginning of the modern development of reinforced brick masonry (Schneider and Dickey, 1994, p.7). In 1930, Indian and Japan engineers explored that reinforced masonry, if properly constructed, offered excellent resistance to seismic forces and so they turned to its use in many instances which provided more safety and less cost. Reinforced brickwork is convenient and economic in building, and the most important point is that there is always a very appreciable saving in time. These advanced techniques of design and construction are arisen in modern high-rise buildings being constructed throughout the United States. Major examples can be seen in diverse structures as the 165-ft-high 17-story

[6] *Photos of the buildings of Gaudi,* <http://www.greatbuildings.com/buildings> Last accessed: January 5, 2008

and the 9-story Park Mayfair East apartment buildings in Denver (A brick bearing-wall structural system), Colorado shown in Figure 2.4, a dormitory building (Concrete and reinforced brick bearing-wall structural system) at the U.S. Naval Base, San Diego, California shown in Figure 2.4, and the 5-story Sportsmans Lodge Hotel (Concrete block bearing-wall Structural System) in North Hollywood, California shown in Figure 2.5, among many others. This trend back to the bearing wall structure has revitalized the entire concept of load-bearing masonry walls for multi-storey buildings (Schneider and Dickey, 1994, pp.10-11).



1 2

Figure 2.4 1- Mayfair East apartment buildings in Denver, 2- Dormitory building, at the U.S. Naval Base, California (Schneider and Dickey, 1994, pp.10-11)

Figure 2.5 Sportsmans Lodge Hotel in North Hollywood, California (Schneider and Dickey, 1994, p.11)

Today, there are many ongoing researches about structural capabilities of masonry. Design of current masonry buildings is different from the historical masonry buildings in terms of earthquake and fire resistance, weather protections, etc. Consequently current researches aim to make masonry structures more economic more efficient and stronger against natural effects. Reinforced masonry has become a serious rival for reinforced concrete in a number of applications. This construction system is generally used in residential buildings. Some contemporary masonry building examples from Berlin, Germany (1997), Ludwigsburg, Germany (1998), Groningen, The Netherlands (1993), Salamanca, Spain (1998), Rungsted, Denmark (1999), Chicago, ABD (1889-1891), Cleveland, Ohio, Pittsburgh Pennsylvania Prince Georges Country, Maryland, Virginia, Pittsburgh, Pennsylvania, Jacksonville, Florida can be seen below (Taly, 2001; Ramcke, 2001).

Table 2.1 Contemporary Masonry Building Examples

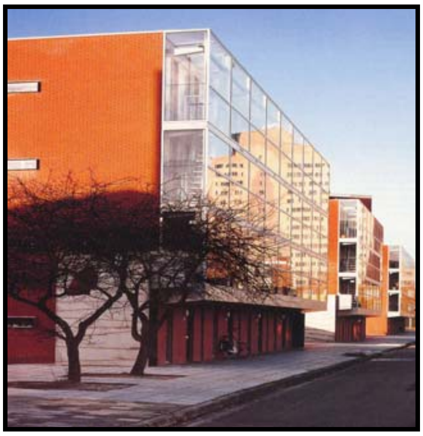
	**Housing Complex in Groningen, The Netherlands, 1993 (Ramcke, 2001, p. 272)** “The loadbearing construction consists of twin-leaf masonry walls with precast concrete floors. The external surfaces are skilfully related each other. The plan layouts are such that the houses could be divided into separate apartments on ground floor and first floor a later date.”
	**Two Apartment Blocks in Berlin, Germany, 1997 (Ramcke, 2001, p. 276)** “The simple two apartment format was developed within the scope of the guidelines for publicly assisted housebuilding. Walls of calcium silicate masonry with reinforced concrete floors and beams form the loadbearing structure. “

Table 2.1 (Continue) Contemporary Masonry Building Examples	
	**Apartment Block in Salamanca, Spain, 1998 (Ramcke, 2001, p. 342)** "The apartment block is situated in Santa marta de Tormes, a suburb of the Spanish university town of Salamanca. Four red-brick masonry storeys are supported on a rough-finish concrete plinth. "
	**Housing Complex in Ludwigsburg, Germany, 1998 (Ramcke, 2001, p. 242)** "The walls of the blocks comprise, in the main, 300 mm aerated clay brickwork covered with a coloured mineral rendering. The balconies are precast concrete units suspended in front of the façade and provided with a thermal break."
	**Housing Development in Rungsted, Denmark, 1999 (Ramcke, 2001, p.338)** "The loadbearing leaf of the external wall is enclosed by 150 mm cavity insulation, while the 115 mm outer leaf facing brickwork employs stretcher bond with flush joints. "
	**Apartment Building in Clevaland, Ohio (Taly, 2001, p. 10.5)** "The 17-story Crittenden Court apartment building in Cleveland, Ohio, is the tallest load bearing masonry building in Cleveland."

2.3 Previous Studies on Masonry Buildings

As a consequence of the developments in 19th century scientists started to study on masonry structures as one of the important topics of PhD thesis. However, there are few theses about structural masonry in architecture. Especially restoration of masonry was studied in architecture. Most of the theses about structural masonry are studied in civil engineering. Thus, this study aims to study structural masonry from the architectural point of view. For this reason in this part of the study classification of the theses about masonry is indicated in the Table 2.2.

Table 2.2 PhD Topics between 1950 and 2007 about Masonry Structures

1950's	**Physical Properties of Masonry** The physical properties of concrete masonry units were investigated in laboratories.
1960's	**Reinforced Masonry** Scientists started to study reinforced masonry such as the strength characteristics of reinforced masonry beams.
1970's	**Material Characteristics of Masonry** Strength characteristics and behaviour of concrete masonry gained importance in this period. In addition brick properties and effects of grouting on the carrying capacity were studied.
1980's	**Earthquake Resistance of the Masonry Structures** Mostly earthquake resistance of the masonry structures was evaluated in 80's. There were similar studies about seismic performance of masonry such as seismic shear strength of reinforced masonry piers, use of high-strength by-product gypsum bricks in masonry construction, modelling the deformations of masonry, studies of earthquake resistant masonry shear walls, and dynamic stability of adobe walls. Furthermore, architectural considerations in the design of earthquake resistant building started to be studied in this term.
1990's	**Seismic Resistance Control of Masonry with Experimental and Analytical Studies in Masonry** Experimental and analytical studies were conducted to determine the seismic performance of masonry walls. Development of prestressed masonry walls and reinforcing masonry walls with composite materials were studied. In addition, computational strategies started to be used for masonry.
2000's	**Strengthening Techniques for Masonry** Strengthening techniques for masonry are being developed using glass fiber reinforced polymers. Numerical analysis of structural masonry has been done. New techniques are being discovered for not only against to the earthquake but also to wind. In India some studies were done for earthquake resistant building design with bamboo-reinforced masonry. Seismic evaluation and rehabilitation of low-rise reinforced masonry buildings with flexible diaphragms is most important topic of this term.

Today various groups have members who study building behaviour during past earthquakes to learn as much as possible about structural performance of masonry subjected to seismic forces using the information to modify design criteria and building codes, making buildings safer. A considerable amount of analytical and experimental research has been carried out in the last two decades for improving the seismic safety of structural masonry. Some of these studies are summarised below.

In 1970 some researchers studied on the effects of the depth of bricks and thickness of grouting on the carrying capacity. Experiments with some changes on the thickness of the grouting showed that if the thickness of the grouting decreases the compression resistance of the wall increases.

In 1989, shaking table was often used in order to measure the compression and tension resistance of the masonry buildings by several researchers like Bayülke, Doğan and Hürata (Bayülke et. al., 1989).

In 1991 Tanrıkulu proposed numerical models for the nonlinear 3D earthquake analysis of reinforced and unreinforced masonry structures. In the study two different approaches for the nonlinear earthquake analyses are taken into consideration. The study revealed that proposed models generated by using Equivalent linear Method and nonlinear method could be used for the earthquake analyses of the masonry structures (Tanrıkulu, 1991).

In 1992 Bayülke investigated the maximum earthquake force resistance of one story masonry building and maximum horizontal forces that cause cracks (Bayülke, 1992).

In 1996, Tomazevic and Lutman studied in laboratory in order to investigate the seismic behaviour of the masonry buildings. In this study they used 32 reinforced masonry walls and carried out six different experiments with these walls. They applied earthquake loads to these walls in different ways and compared the results of the experiments and calculations (Tomazevic and Lutman, 1996, pp. 599-622).

In 1997, Sucuoğlu and Erberik conducted a study that is about the performance of masonry buildings in 1992 Erzincan earthquake in which the 8000 unreinforced masonry buildings, distributed as 6120 single storey, 1700 two-story and 180 three-storey commonly performed well with the exception of a complex of 40 two-story houses constructed with non-load bearing hollow insulation bricks. It aimed to observe the earthquake behaviour of an existing masonry building by analytical simulation of its seismic performance under an experienced earthquake. Thus, they presented a simple elastic design approach for unreinforced masonry under seismic excitations (Sucuoğlu and Erberik, 1997, pp. 319-336).

In 1997 there is another article which is written by Gambarotta and Lagomarsino, is about damage model for mortar joints. This model applied in two different approaches to the analysis of brick masonry walls resulted in a conclusion that the performance of the shear walls affected the earthquake vulnerability of masonry buildings. In their study three different approaches were used that were simply masonry assemblages, simple panels and large-scale shear walls. Then they built up finite element composite model for brick masonry walls. This article proposed a damage model for mortar joint, considering the mortar damage and decohesion in the mortar brick interface. In the second part of the study, the model generated by Gambarotta and Lagomarsino gives the chance to evaluate the effectiveness of some strengthening techniques for the masonry buildings in seismic areas (Gambarotta and Lagomarsino, 1997, pp. 423-439; Gambarotta and Lagomarsino, 1997, pp. 441-462).

Again in 1997, Tomezevic and Klemenc studied on verification of seismic resistance of confined masonry buildings that are experimentally investigated. In the study they model the confined masonry shear walls as frames and propose a rational method for seismic resistance verification of confined masonry structures (Tomezevic and Klemenc, 1997, pp. 1073-1088).

In 1998 some scientists (Saberi, 1998; Bozdoğangil, 1998; Batur, 1998) studied on similar topics such as examining earthquake behaviour of the masonry buildings located in seismic regions with experimental data. Batur studied on performance of the unreinforced masonry under lateral loads with a comparison between the different codes (TS, Eurocode 8, AIJ, ACI, BS 5628).

In 2000, Turker et.al. conducted an experiment of a masonry building project that is constructed with Pomza Bims Block with the shaking table by using. This special construction material is generally found in Isparta and environs of the town. The results of the experiments showed that shear resistance of the selected structure is similar with brick masonry (Turker et.al., 2000).

Titled evaluation of the seismic response of masonry buildings based on energy functions was conducted by Benedetti et.al. in 2001 using 12 stone and brick masonry systems subjected to 58 shaking table tests. They concentrated on energies evaluated from the responses of these structures. They also made a large number of shaking table tests on masonry buildings in 1998 to analyse the efficiency of various retrofitting techniques in improving the seismic behaviour of non-engineered masonry buildings. Comparisons of the behaviours of buildings of different types are made in these two studies. These comparisons included some hints to set up new technical interventions on existing buildings to enhance their energy dissipation and absorption capacity (Benedetti et. al., 1998, pp. 67-90; Benedetti et. al., 2001, pp.1061–1081).

In 2002 Costa aims in his study to determine physical and mechanical properties of stone masonry walls which are in the Cedros region of Faial Island, Azores, hit by the July 1998 Earthquake. After defining the wall typologies and seismic damages observed, he presented the strengthening techniques used in these structures. Results of his experimental research indicated that using steel mesh fixed in both sides of the wall and covered with 3 cm. Mortar layer increased the load bearing capacity of the wall when compared to the unreinforced wall (Costa, 2002, pp. 1361–1382).

In the same year there is another research, which is about seismic response of a new type of masonry, tie used in brick veneer walls by Memari (Memari, 2002, pp. 397–407). In this paper the forces in lateral ties in a typical brick veneer wall system are calculated during an earthquake. Brick veneer was used in medium-rise residential buildings on the enclosure wall of warehouses, commercial buildings. They presented an analytic model of the brick veneer-masonry block wall system and then compared their results to the conventional assumption. They also pointed out the potential difference between using helical tie and conventional ties. The conclusion of their study showed that helical ties could perform more satisfactorily than conventional brittle ties (Memari, 2002, pp. 397–407).

Then, in 2003 Corradi et.al. conducted a study that was a part of a large research project. This project focuses on the strengthening techniques tested on masonry structures. In this paper Corradi et.al. examine masonry buildings damaged by Umbria-Marchigiano earthquake of 1997-1998. Experimental research of this study defines the mechanical properties of these structures. In this work the walls are tested under compression, diagonal compression and shear compression. By this way the shear strength of typical masonry walls of Umbrian areas struck by the earthquake are evaluated. Moreover, this study produced a large number of data from which the mechanical characteristics of the texture were deduced (Corradi et. al., 2003, pp. 325–337).

Tezcan and Reis, in 2003, searched the earthquake calculations of the reinforced masonry structures in a detailed way. In their study theoretical method and finite element analysis with Sap 2000 were used. They compared the results of the methods and made some cost analysis to see the difference between reinforced masonry, unreinfored masonry and reinforced concrete frame (Tezcan and Reis, 2003).

Lastly in 2005 in his study Klinger investigates the behaviour of masonry buildings in the Northridge earthquake and the Tecoman-Colima earthquake (near Manzanillo, mexico, January 21, 2003). These earthquakes are discussed with emphasis on the behaviour of modern engineered masonry. He discusses the importance of structural configuration and the contrast between the generally good performances of unreinforced masonry and adobe, and the considerable improvement that seismic retrofitting makes in the performance of unreinforced masonry (Klinger, 2005, pp. 209-219).

2.4 Materials of Masonry Structures

The utilization of masonry units for construction can be traced back several thousands years. It is the building of structures from individual units laid in and bound together by mortar. It is generally a highly durable form of construction. However, the materials used, the quality of the mortar and workmanship, and the pattern the units are laid in, can highly strongly affect the durability of the overall masonry construction. Early civilizations developed primitive masonry units from a variety of readily available materials such as stones, soil deposits, and clay or mud. Stone is the first primitive masonry unit to be widely used. As technology improved, units could be shaped into more efficiently and aesthetic elements. Modern masonry construction consists of bricks, concrete masonry units, and stones bonded together by mortar. According to the type of construction, different materials are used for masonry structures. These masonry units can be listed as adobe, stone, brick, concrete blocks, clay tile blocks, architectural terracotta, and mortar. Common definitions for these masonry units can be seen below.

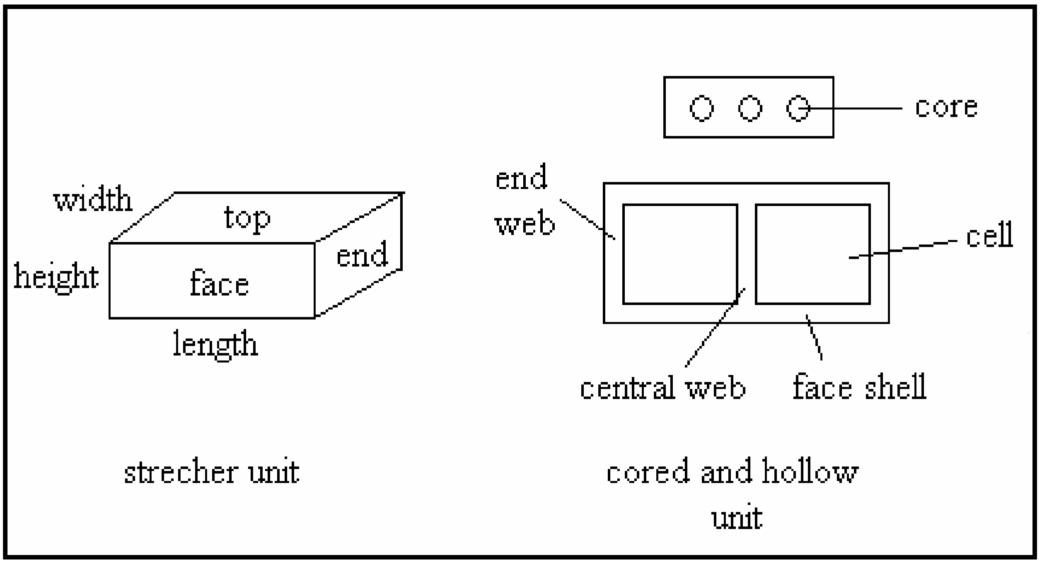


Figure 2.6 Common Definitions for Masonry Units (Taly, 2001, p. 2.3)

2.4.1 Structural Materials

- **Adobe**

From the architectural history point of view adobe was one of the oldest and crucial building materials in ancient times. Adobe was used widely in regions where forest and stones were inadequate. According to historical records it can be said that adobe was firstly used in Mesopotamia and ancient Egypt. Vigorous examples can be given as multi-storey adobe buildings in the inhabited Pueblos of Taos and Acoma in New Mexico (Schneider and Dickey, 1994, p.5). Adobe stems from clay and sand mixture with a stabilizing agent. The quality of adobe is determined by the amount of clay within the adobe. In old times, people used straw in adobe in order to reinforce these supplies. Today it is evident that cement and plaster has taken the place of straw. If adobe is compared with the other building materials it is seen that adobe is natural, healthy, and cheaper than the other materials, and also required less energy and easy to produce which, in fact, constitutes the reason why adobe is seen as way out for people having low income in under developing countries.

- **Stone**

Stone is one of the oldest materials known to man. Despite the abundance of rock, relatively few stones satisfy the requirements: strength, hardness, workability, durability, colour and grain, porosity and texture, ease of quarrying, accessibility (Smith, 1966, pp.129-130).

In construction of arch, vault and dome stone was widely used. Due to the important properties, stone has been considered as the preferred material in the construction industry prior to turn of the twentieth century. Since increasing of the height of buildings went on, it required looking more carefully at the mass of the materials that went into the basic structures. Today stone is widely used as facing equipment for buildings (with steel or concrete) that have large surfaces to be veneered. For veneering action it is used as thin slabs in these buildings (Smith, et. al., 1979, pp41-42).

- **Brick**

For appearance, durability and cost aspects brick masonry is a well-proven building material having perfect features in comparison with alternatives. In historical records, it is mentioned that brick was being used as an important material even before the Christian Era. The first arch was constructed in the ancient city of Ur by using sun-dried brick about 2000 B.C. After a short time burned brick took its place for the construction. In the erection of Great Wall of China, both sun-dried and burned brick were utilized. Furthermore in the construction of Pantheon (123 A.D.) and Colosseum (82 A.D.) roman concrete, brick and stone were used (Figure 2.7) (Smith, et. al., 1979, p.1).

Arya had classified bricks into three categories: common, facing and engineering. For general construction; there is no care for attractive appearance, common bricks; for attractive appearance on basis of colour and texture facing bricks, and for required dense and strong designation especially class A and B on the basis of strength and water absorption engineering bricks are used (Arya, 2003).

Figure 2.7 Colleseum and Pantheon (The photo archive of Er Akan, 2007)

Technological developments accelerated advanced procedures for modern brick buildings however, this acceleration has stopped. Investigations of Hendry, et.al. into brick structures demonstrated that the structural use of brick masonry has to some extent been hampered by its long history as a craft based material and some years ago its disappearance as a structural material was being predicted. Nowadays, structural brickwork is not used widely. The main reason for this fact is that design in this medium is not covered in many engineering curriculum alongside steel and concrete. However, many architects and engineers indicate that brick construction has many advantages as listed below (Hendry et. al., 1997).

- It is possible to use the same element to perform a variety of functions (provide structure, subdivision of space, thermal and acoustic insulation as well as fire and weather protection)
- As a material, it is relatively cheap but durable and produces external wall finishes of very acceptable appearance.
- Brickwork construction is flexible in terms of building layout and can be constructed without very large capital expenditure on the part of the builder (Hendry et. al., 1997, pp.1-18).
- Also bricks can be used both exterior skin and load carrying element.
- It is also environmentally friendly material. The clay and shale are harvested from the earth’s surface by a process that has minimal long-term environmental effect on the land.
- With their many hues and colours, bricks can be used to create many attractive patterns and designs for architectural treatments of wall and floor surfaces.

Brick production process is an important level for structural properties of brick. There are many similarities in manufacturing of brick and cement. The raw materials are processed and mined after this process they are mixed with additives, shaped, and then fired to produce a weather resistant product (Market Segment Specialization Program, 1998). For the manufacturing of bricks various materials such as clay, lime and sand/flint, concrete and natural stone are used. Clay bricks are produced by shaping suitable clays in the form of units. Sand facing and face textures may than be applied to the green clay. As an alternative way, the clay units may be perforated to reduce the self-weight of the unit. Afterwards, in order to obtain appropriateness for structural use the clay units are fired in kilns to a temperature in the range 900-

1500^0C. This process gives perfect fire-resistance feature to brick (Arya, 2003). Unlike metals, clays soften slowly and fuse gradually when subjected to evaluated temperatures. This softening property of clay allows it to harden into a solid and durable unit when properly fired (Amrhein, 1998).

Bayülke states that during the firing process of bricks there exist a lot of cracks and space in microscopically dimensions. These spaces affect the all of the properties of bricks. The ratio of space volume to external volume of brick is called as "porozite". In order to calculate porozite firstly dry brick is weighed and then the brick is put into water for filing the spaces with water. After this process wet brick is weighed again and the difference between two weighs is calculated and this difference is divided by specific weigh of water. But the air existing in spaces of brick can prevent the water to enter these spaces. For this reason, brick is hold in boiling water and during becoming cold process; water is expected to enter these spaces. If porozite ratio starts to be higher than 25 %, compression resistance of the brick decreases. Factors that affect the compression resistance of the brick are listed below (Bayülke, 1980).

- The porozite of brick,
- The firing degree,
- Production method,
- In hollow brick, the position, number, edge shape, loading direction and etc. of hollows.

Bricks produced in Turkey are divided into two categories.

Hand Moulded Bricks: Hand moulded bricks whose usage is limited especially in earthquake zones, is used for the construction of load bearing walls of 1-2 storey masonry buildings.

Fabricated Brick: It is produced as three types, which are shown in Figure 2.8.

Solid Brick: It is widely used for both load bearing walls and cladding.

Horizontal Hollowed Brick: It is used for partition walls.

Vertical Hollowed Brick: It is used for load bearing walls.

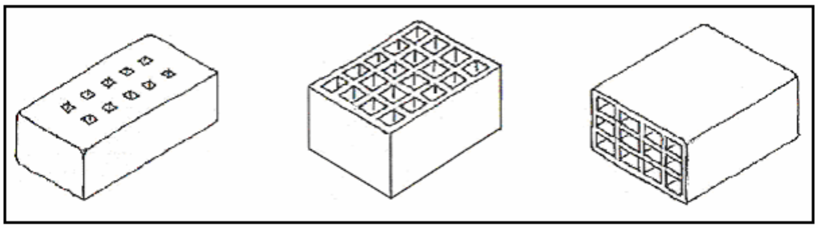


Figure 2.8 Solid Brick, Horizontal Hollowed Brick, and Vertical Hollowed Brick (Türkçü, 2004, p. 113)

- **Concrete Blocks**

For hundred of years, concrete block has constituted of the main construction material. However, concrete masonry units are new according to other building materials, such as brick or stone. In the early 1880s the first concrete blocks were commenced to use and since that time in industry it has been witnessed huge developments in the volume of units produced, in the variety of blocks available and in the quality of the products (Smith, et. al., 1979, p13). The development of Portland cement in the early 19th century changed the nature and composition of masonry mortar and eventually led to the production of concrete masonry units as an alternative to brick and stone. In United States concrete masonry units (CMU) constitute a considerable percentage of the foundation walls in homes. CMU also has a history log of use in above-grade walls in Florida, Texas, Arizona and other parts of the Southern United States.

Concrete masonry units are made from a mixture of portland cement and aggregates under controlled conditions. The units can be made to various dimensions. CMUs are typically made in forms to the desired shape and then pressure-cured in the manufacturing plant. The units are often used when masonry is to form a load-bearing wall or an interior partition between spaces within a building. They are available in wide range types, sizes, shapes, and surface textures, and they are used for a variety of purposes. Furthermore, well-recognized standards have been established covering the physical properties of block; namely, its solid content, strength, density, water absorption capacity, moisture content and linear shrinkage potential. Arya defines that blocks are available in two basic types: aerated concrete and aggregate concrete. The aerated blocks constitute of a mixture of sand, pulverized fuel ash, cement and aluminium powder. The contents of the aggregate blocks are similar to that of normal concrete. It includes chiefly of sand, coarse and fine aggregate and cement plus extenders. Density of an aerated block is lower than density of an aggregate block, so this lower density obtains superior thermal properties, lower unit weights and lower strengths. Aerated blocks are commonly more expensive than aggregate blocks (Arya, 2003).

In order to meet various requirements, concrete blocks can be produced in different shapes and sizes (Figure 2.9). The production stage for concrete blocks is similar to bricks except no kilns are involved and the raw materials are cement and special aggregates. By adding glass fibre to the mixture reinforcement of concrete blocks are increased (Bayülke, 1980). There are three basic forms of concrete blocks: **solid, cellular** and **hollow**. There are no intentional formed holes in solid blocks, but there are natural holes or cavities. Cellular blocks include one or more formed holes or cavities pass through the block. According to The U.S. Department of Housing and Urban Development Office of Policy Development and Research (1998) some benefits of CMU construction are strength, durability, fire resistance, energy conservation, variety of sizes, shapes, colours and textures. Today's multi-colored, multi-textured concrete products give designers the artistic flexibility to create strikingly beautiful single and multi-family residences, office buildings, warehouses, municipal buildings, manufacturing facilities, correctional facilities, learning institutions, hospitals and much more. The finished appearance of a concrete masonry wall can be varied with the unit size and shape, colour of units and mortar, bond pattern, and surface finish of the units.

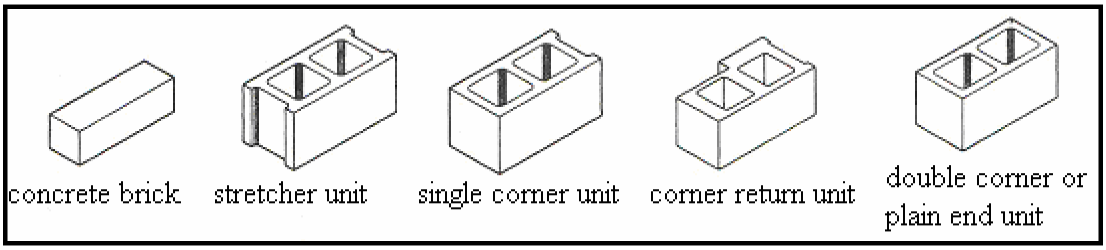


Figure 2.9 Concrete Masonry Units (Taly, 2001, p. 2.25)

- **Clay Tile Blocks**

Clay tile blocks were used widely in the past; these are hollow units similar to concrete blocks in form. Today's realized functions of concrete blocks were performed by them (Ambrose, 1993). Nearly 14 000 BC, hand-moulded clay bricks found in the lower layers of Nile deposits in Egypt, while the knowledge of preserving clay bricks by firing has been documented for circa 5000 BC. Natural stone was already quarried and cut in the same era. The urban clay structures in Yemen (Figure 2.10), for example, are distinctly different from those in Mali (Figure 2.11) even though they are subject to identical external conditions (Ramcke, 2001). Clay tile are made from the same materials and by the same manufacturing process as extruded brick. According to Smith, R.C., et.al. clay tile blocks can be divided into two general categories: hollow tile, used for the same structural proposes as brick or concrete masonry and commonly known as structural clay tile; and solid tile, which includes such products as floor tile, ceramic veneer, architectural terra cotta and ceramic mosaic (Smith, et. al., 1979, p.35). Colours, sizes and textures of clay units change according to used clay and the forming method of unit during production. Glazed brick (both clay and concrete) units, concrete brick, calcium silicate brick, and hollow clay tile in can be presented as an example for several types. According to the method used to form the brick into the desired shape, many various finishes can be formed on the exterior surface of the brick such as wire cut or sand finished. Brick units may be solid or hollow. Units categorized as solid typically contain cores for handling and to allow more uniform firing. Solid units are generally utilized for most exterior walls.

Figure 2.10 Clay Architecture in Yemen (Ramcke, 2001, p. 11)

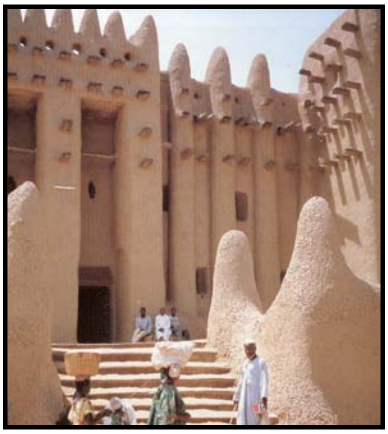


Figure 2.11 Clay Architecture in Mali (Ramcke, 2001, p. 11)

- **Terra Cotta**

Terra Cotta is a fired clay product and used for ornamental work. Meaning of terra cotta term is “baked earth” and for a long time it has been applied to describe the moulded and fired clay objects whose properties are similar to those of brick. In the aspect of architecture, terra cotta formerly was used as a load-bearing element in multi-wythe walls. In the early twentieth century, the popularity of it increased as cladding supplies, especially for structural frame buildings. Nowadays terra cotta is utilized basically as a ceramic veneer or ornamental facing tile for both exterior and interior walls (Taly, 2001).

2.4.2 Binding Materials

- **Mortar**

Beginning of mortar usage (2690 B.C.) coincides with the beginning of burned gypsum and sand mortars in Egypt. Then, in ancient Greece and Rome burned lime, volcanic tuff, and sand were used for manufacturing mortar. Modern mortar arose in conjunction with the discovery of Portland cement. The general utilization of Portland cement began in the early part of the twentieth century and led to greatly strengthened mortar either when Portland cement was used alone or in combination with lime (Taly, 2001).

Mortar includes characteristically cement, lime and sand, even though lime mortars may not include cement. Elements and proportions of mortars tend to change according to the required mortar properties. Mortars that include Portland cement and lime and also sand are most general. Before mixing the components of mortar, these elements must be examined carefully in order to obtain the actual required mixture. According to Smith, et.al., mortar is designed for a number of purposes as following (Smith, et. al., 1979, p.57);

- To join masonry units together in an integral structure (so that the masonry as a whole can resist the applied loads),
- To hold the units a specified distance apart,
- To provide compressive strength,
- To allow some movement and elasticity between units,
- To produce tight seals between units to prevent the passage of air or moisture,
- To bond metal ties and anchor bolts to the steel joint reinforcement in order to integrate them into the masonry structure,
- To provide a bed that will help accommodate variations in the size of units,
- To provide architectural effect on exposed masonry walls through various styles of mortar joints.

Hendry, et.al., states that in the process of deciding the types of mortar development of early strength, workability, water retentivity (the ability of mortar to retain water against the suction of the brick), proper development of bond with the brick, resistance to cracking and rain penetration, resistance to frost and chemical attack and immediate and long-term appearance are the factors to be taken into account (Hendry et. al., 1997, p.18).

- **Grout**

According to Smith, et.al. mortar and grout are similar products to the extent that both require a cememtatious material and aggregates for their production. However mortar and grout are not the exactly same product since they are introduced into the wall system differently, are utilized for different aims, usually requiring a different size of aggregate and quite often using a different type of cement. Grout may be thought of as a fluid concrete mix and is used to fill cores in hollow masonry or wall cavities created in the masonry to contain reinforcement or post-tensioning/prestressing wires. It should not be confused with the special grouts used to bond anchoring bolts and the like into concrete structures (Smith, et. al., 1979,p.57). Hendry, A.W., declares that the purpose of grout in masonry is to provide some additional compressive strength to the masonry, and more importantly, to connect the masonry and the reinforcement such that composite action can occur (Hendry, 1991). According to Taly grout serves many functions including the following (Taly, 2001);

- To develop bond between various masonry units to act together as one unit.
- To be used to structurally bond separate wall elements together. This is most commonly seen in reinforced construction, where grout is used to bond steel reinforcement to the masonry so the two elements act integrally in resisting loads.
- To increase the bearing area for resisting higher compressive loads.
- To increase the stiffness of the walls, and thus increase their resistance to lateral loads. Masonry cantilever walls often are grouted solidly to increase the wall's weight, thereby increasing the resistance to overturning.
- In two wythe walls, the collar joints is grouted as one of the requirements for the two wythes to act integrally.
- To help sound transmission resistance.
- To increase volume for fire resistance.

2.5 Systems of Masonry Construction

Taly claims that masonry is commonly used for the walls of buildings, foundations, and monuments. Masonry walls often are used to impart architectural beauty to buildings. This is particularly true with brick and veneer walls. Bricks and veneers have many shapes and colours and can enhance aesthetic qualities of masonry structures. The most common type of masonry construction is brick masonry that may be either solid or veneered although concrete block masonry has gained popularity in near past. Hollow-core block masonry offers various possibilities in masonry construction such as great compressive strength. Also it is generally best suited to structures with light transverse loading when the cores remain unfilled. The increase in tensile and lateral strength is provided by filling the cores with concrete and steel reinforcement (Taly, 2001). In general, masonry walls may be built from solid or hollow units. Although its being common in past decades, solid masonry units are rarely used today. Modern masonry walls are constructed from hollow masonry units, or combined hollow and solid masonry units. General terms of masonry construction system are shown in Figure 2.12. Systems of masonry construction can be divided into three groups: Plain (Unreinforced) Masonry, Confined Masonry, Reinforced Masonry.

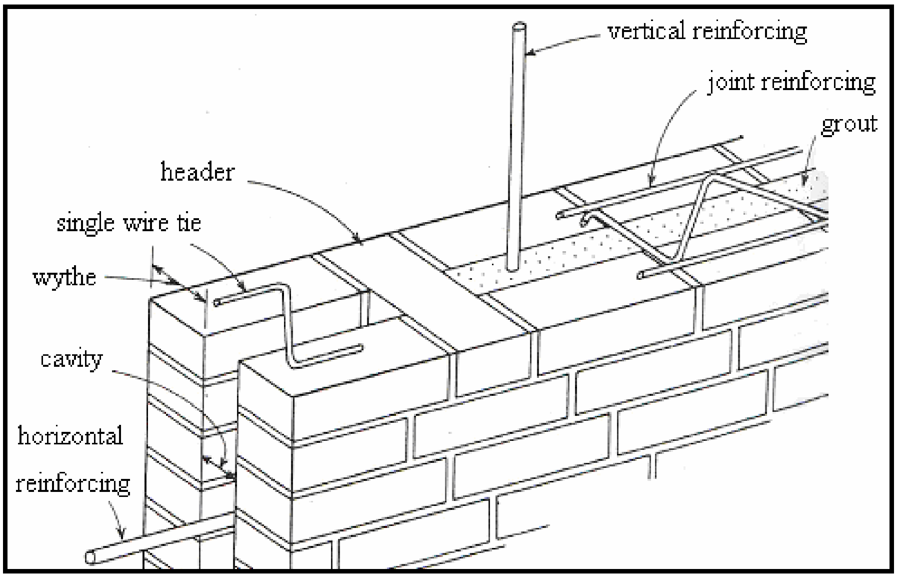


Figure 2.12 General Terms of Masonry Construction System
(Ambrose, 1993, p. 354)

2.5.1 Plain (Unreinforced) Masonry

Plain (unreinforced) masonry structures are constructed without strengthening horizontal or vertical confining elements; therefore it is called “unreinforced”. For this reason, the effects of earthquakes on unreinforced masonry bearing wall buildings can be severe. Wall types in plain masonry can be summarized in three groups which are;

- Solid masonry walls (single wythe and multiple wythe solid masonry)
- Hollow masonry walls
- Veneered walls (non-loadbearing walls)

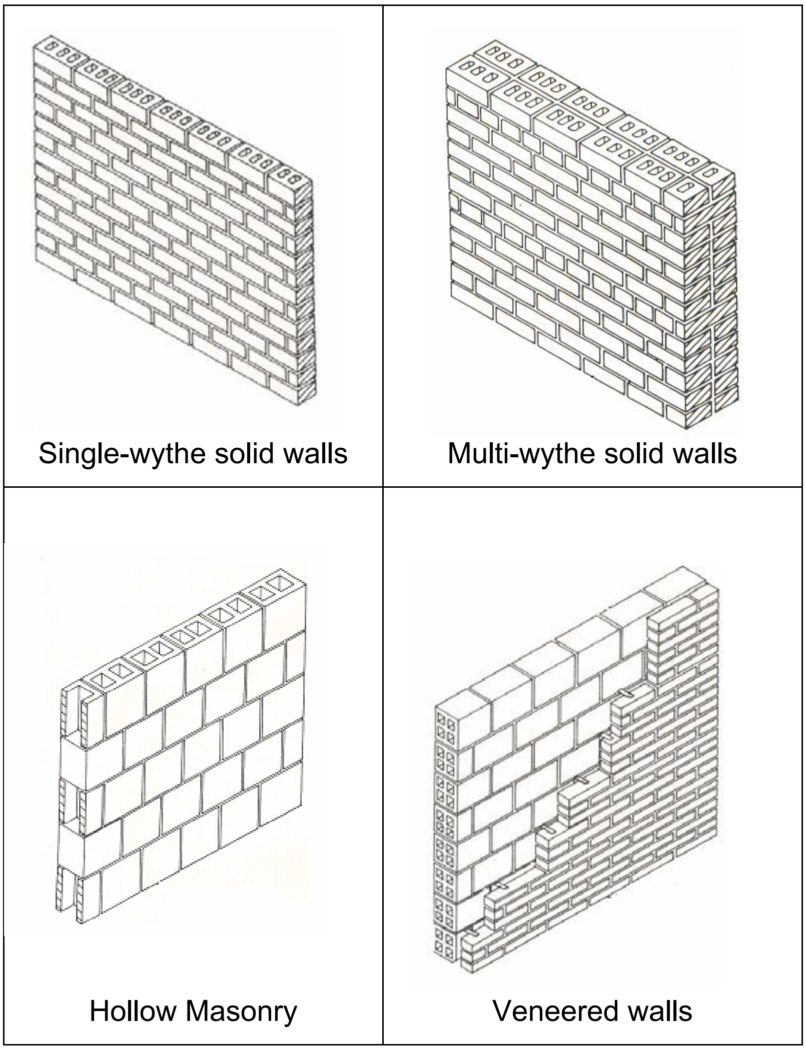


Figure 2.13 Unreinforced Masonry Wall Types (Smith, et. al., 1979, pp. 178-179)

2.5.1.1 Solid Masonry Walls

Solid walls are consisted of two wythes of brickwork or stonework with the space in between filled with rubble or concrete before the development of modern masonry. In modern masonry construction practice, solid walls are constructed with two or more closely spaced wythes. They are built up of solid units laid up in mortar. Such walls may be either single or multiple wythe. Single-wythe, solid masonry walls generally used as partitions in a non-load-bearing capacity, although 150 mm single-wythe walls are also used in a load-bearing capacity in residential construction. Multiple-wythe, solid walls are used extensively in load-bearing construction for firewalls and in reinforced brick masonry. The facing wythe and backup wythe or wythes are bonded together by masonry headers or by metal ties, and in many cases, the facing wythe may be decorative in nature (Smith, et. al., 1979, p.177).

2.5.1.2 Hollow Masonry Walls

Hollow brick masonry is a natural development in brick masonry construction. Several reasons led to the production of hollow brick as the need for units that can be more easily reinforced and grouted, and more economically constructed with large size brick. More stringent structural requirements for buildings in high wind and seismic regions have required masonry units that can be grouted and reinforced. These requirements cannot be achieved as easily with solid masonry units. Typical applications of hollow brick include commercial, retail and residential buildings, hotels, schools, noise barrier walls and retaining walls. Hollow brick are generally larger than solid brick and are produced in a variety of sizes (BIA Technical Notes, 2008).

These walls are built with hollow masonry units that may be brick, concrete masonry or structural tile. Hollow units are those whose net area is less than 75 percent of the gross area. As in the case of solid units, all horizontal and vertical edges are embedded in mortar. Depending on the type of unit and the particular circumstances, hollow walls may be used in either load-bearing or non-load-bearing capacities (Smith, et. al., 1979, p.77).

2.5.1.3 Masonry Veneered Walls

A veneered wall consists of a brick, stone, tile or concrete masonry facing over a backup wall of wood, concrete, concrete masonry, common brick or structural tile. A veneer is defined as a non-structural facing of brick, concrete, stone, tile, metal, plastic or any other material attached to a backing for the purpose of ornamentation, protection, or insulation. This veneer is tied but not bonded to the backup wall. The metal ties used are flexible to allow for differential movement (Smith, et. al., 1979). Veneer walls are characterized by non-structural cladding, which enhances the aesthetic qualities of the wall. Veneered wall construction types can be seen in Figure 2.14.

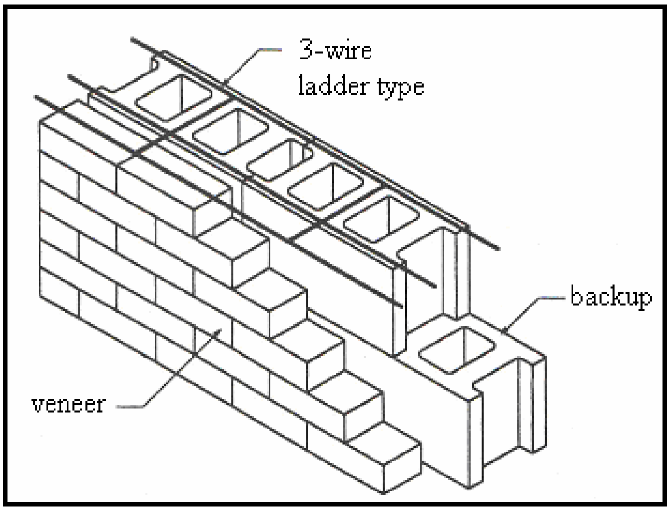


Figure 2.14 Veneered Walls (Taly, 2001, p. 6.14)

According to technical notes of The Brick Industry the exterior wythe of a brick veneer wall transfers out-of plane loads to the backing and is not subject to limitations of the allowable stress values. No axial loads are applied to the veneer wythe. Out-of plane lateral loads are transferred by metal ties to the backing which is designed for the full load. Shear stresses generated by the veneer's weight are ignored (BIA Technical Notes, 2008).

2.5.2 Confined Masonry Walls

In this masonry construction system, structural walls are surrounded by reinforced concrete on all four sides. In order to provide structural integrity, vertical confining elements are located at all corners and recesses of the building, and at all joints and wall intersections. Surrounding bond beams and tie columns used in confined masonry provides seismic resistance to the structure. These confining elements have the same characteristics with horizontal bond beam and vertical grouted cells in the reinforced masonry structures. Especially they are located above and below the critical points such as openings and corners. Generally horizontal reinforced concrete elements are located on the bottom and the top of the building.

2.5.3 Reinforced Masonry Walls

Brick masonry is one of the oldest forms of building construction, and reinforcement has been used to strengthen masonry since 1813. In unreinforced masonry structures, the lateral stability is provided by gravity. Since masonry is weak in tension, no tension can be allowed to develop at the base of the structure. To accomplish this, unreinforced masonry structures have to be sufficiently massive so that the resultant of all forces acting on the structure does not fall outside the middle third of the base. This requirement imposes an economic limit on the height masonry structures can be built. Furthermore slender structures proved incapable of withstanding lateral loads induced by earthquakes as demonstrated by damages during the seismic events in many countries throughout the world, such as India, China, Iran, Mexico, the former U.S.S.R. and Turkey. Extensive damage and collapse of masonry structures during these earthquakes strongly indicated the need for a better-engineered construction (Taly, 2001). In the modern sense reinforced brick masonry in the United States is a relatively new type of construction, with specific design procedures and construction methods. These have been developed from experimental investigations beginning in the 1920's and with the experience of the performance of thousands of reinforced masonry buildings. These structures demonstrate the practicality and economy of the construction, and their performance confirms the soundness of the design principles (BIA Technical Notes, 2008).

Smith, Honkala, and Andres explain the reinforcement as below (Smith, et. al., 1979, p.181),

> *"When buildings are more than three stories in height and are located in seismic zones or in any situation where greater resistance is required to applied loads and stresses, added strength should be provided for the walls by introducing reinforcement into them."*

Reinforced masonry walls are walls in which the interior space or spaces are filled with grout and reinforcing steel. This may involve a single-wythe concrete masonry wall with some or all of the cells filled or a cavity wall with the space between two wythes filled with a reinforced grout. Reinforced masonry acts in a very similar way to reinforced concrete, due to the flexibility added when reinforcing is introduced. Reinforcing systems of masonry can be listed as follows:

- Reinforced Masonry: While, masonry walls are constructed, horizontal and vertical steel reinforcing bars are placed in some of the cores, and grout is poured in to fill the voids.

- Pre-stressed Masonry: In this system for the construction of the masonry buildings pre-stressed reinforcing bars are used. Building codes of foreign countries include this construction type and rules for these structures. However in Turkey, pre-stressed masonry is not used and included in the earthquake code of Turkey. Pre-stressing masonry prevents brittle tensile failure modes of masonry walls.

- Post-tensioned Masonry: Post-tensioning offers desired level of axial load and performance. This system also increases the durability of masonry.

However, there are no examples of post-tensioned and pre-stressed masonry in Turkey.

Reinforced masonry has increased the resistance to forces that produce tensile and shear stresses, allowing better use of brick masonry's inherent compressive strength. The two materials complement each other, resulting in an excellent structural material. The principles of reinforced brick masonry design are the same as those commonly accepted for reinforced concrete. In Figure 2.15 steel reinforcing rods are placed both vertically and horizontally in the hollow voids and grout is placed around the roads, filling the voids. The result is in effect similar to creation of two way rigid frame of concrete inside a wall.

For reinforced, single-wythe walls, the vertical reinforcement is usually set before the units are placed, since otherwise it is difficult to tie to the foundation steel. Special care must be taken with the partially grouted wall to make sure that the cross-joints on either side of the cavity to be grouted are well bedded with mortar. The cross-sectional area of the space into which the reinforcement is placed should not be less than 50x75 mm as adequate bonding will not occur in a smaller space (Smith, et. al., 1979, p.185).

Figure 2.15 Reinforced Masonry Wall Construction (Bachmann, 2003, pp.34-35)

2.5.3.1 Cavity Walls

Cavity walls, which are common in Europe, were first built in the United States as early as 1850. However this type of construction gained official acceptance by any building code or construction agency in the U.S. after 1937. During and after this period use of cavity walls in this country has increased rapidly. To determine cavity wall properties and performance, extensive testing and research of existing cavity wall construction has been used. Cavity walls are often regarded as the first masonry wall system. Brick masonry cavity walls have been selected mostly for structural frames and bearing walls, especially for use in commercial construction. These wall types are utilized for their superior in-service performance resulting from such properties as excellent moisture penetration resistance, thermal capabilities, sound transmission resistance and fire resistance. The early use of cavity walls was limited primarily to exterior load-bearing walls, one and two-stories in height. In the 1940's, the advantages of cavity walls started to be recognized by designers and used as curtain and panel walls in structural frame buildings. Today, masonry cavity walls are widely used masonry system in Europe and in the United States in all types of buildings. As it is mentioned before, the primary reasons for their popularity are: excellent rain penetration resistance, fire resistance, thermal capabilities and sound transmission resistance (BIA Technical Notes, 2008).

Cavity walls consisting of two wythes of masonry, are separated by an air space of 50 to 75 mm. For structural strength they joined together by horizontal metal ties. The outside or face wythe and the backup wythe can be of similar materials or the face wythe may be of brick or facing tile while the backup wythe can be concrete masonry or structural tile. The exterior wythe of a brick masonry cavity wall may be of solid or hollow brick. The interior wythe can be solid brick, hollow brick, structural clay tile or hollow or solid concrete masonry units. (Smith, et. al., 1979, p.177).

Design, material selection, detailing and construction are the four important parameters in all qualities of brick masonry cavity walls. Proper design does not compensate for inadequate material selection or detailing. On the other hand, superior design, material selection, or detailing does not compensate for poor construction practices. The use of high quality materials in the construction of brick masonry cavity walls is of prime importance. The selection of materials is even more critical now that masonry design standards and model codes put greater emphasis on material properties for design requirements (BIA Technical Notes, 2008).

2.5.3.2 Composite Masonry Walls

Smith describes composite walls as a multible-wythe wall made of solid or hollow units, in which the material in one wythe is dissimilar to that in the other. Composite walls are normally used as exterior walls and usually consist of a brick, stone or tile face bonded to a concrete masonry or structural tile backup. The tie is made between the two by masonry headers or noncorrosive metal ties (Smith, 1966).

Taly also states that in composite walls, the wythes are assumed to act as a single unit in resisting loads. A masonry wall in which two or more wythes are bonded to act as a structural unit often is referred to as a bonded wall. A composite wall is simply a multiwythe wall in which at least one of the wythes is different from the other wyhte or wythes with respect to type or grade of masonry unit or mortar. Composite masonry walls may consist of brick-to-brick, block-to-block, or brick-to-block wythes, having the collar joint filled with mortar or grout, and the wythes connected by metal ties. The joint may be reinforced horizontally or vertically, or the reinforcement may be placed in either the brick or block wythe. Alternatively, the two wythes may be connected by headers (Taly, 2001).

2.6 Advantages of Masonry Structures

Masonry has been commonly used for the walls of buildings, retaining walls and monuments. It has a wide application area. In addition to the wide application areas of masonry building, it has a number of advantages that can be summarized as below.

- **Wideness of Application:** Application areas of masonry can be listed as; exterior loadbearing walls, interior loadbearing and nonloadbearing walls, fire walls,party walls, curtain walls, partitions, panel walls, solar screens, piers, plasters, columns, bond beams, lintels, and sills, chimneys and fireplaces, retaining walls, slope protection, ornamental garden walls, highway sound barriers, backing for screens, backing for brick, stone, stucco, and exterior insulation and finishing systems, veneer and non-structural facing for steel, wood, concrete, or masonry, fire protection for steel structural members, fire safe enclosures of stairwells, elevator shafts, storage vaults, catch basins, manholes, valve vaults, paving for walkways and landscaping (Taly, 2001)

- **Sound Insulation, Fire Protection, Weather Protection, Thermal Insulation:** It is a single element can fulfill several functions including structure, fire protection, thermal and sound insulation, weather protection and sub-division of space.

- **Aesthetics for Architecture:** From the architectural point of view, masonry offers advantages in terms of great flexibility of plan form, spatial composition and appearance of external walls for which materials are available in a wide variety of colours and textures.

- **Resistance/Combination with other Materials:** The combination of masonry and reinforcing is very compatible. The masonry brings to the system a high degree of compressive resistance, weathering, durability, fire protection, and stability. Its stiffness and mass distribution minimize flexural and shear deflections, and its composite heterogeneous nature tends to maximize the damping response to dynamic vibratory forces. This modern concept of engineered reinforced masonry thus makes it possible for owners to continue to derive the benefits of economic construction (Schneider and Dickey, 1994, pp.497-517).

- **Cost:** Masonry construction is an economic system when the construction technique and the performance of the system considered. Basically, the load bearing masonry system eliminates the cost of the frame because the structure is also the enclosing wall. This particular wall may also act as an interior finish surface, provide a fire resistive structure, is infiltration free, provides a large amount of mass for maintaining temperature, stability and is resistant to sound transmission.

- **Maintenance/Durability:** When used in its natural form, masonry provides lasting beauty that requires considerably less maintenance than other building materials. It also holds its colour, which never needs to be repainted, and it will not rot or decay.

- **Environmentally Friendly/Availability:** Masonry products play a large role in ecologically responsible building methods and are recognized by government programs as a contributor to green building status.

- **Construction Time:** In masonry system, construction process can begin immediately and continue without delay. Masonry construction avoids waiting for fabrication and the problems associated with the accumulation of fabrication tolerances. Also construction process does not usually require the same amount of temporary forming and bracing as it does for a structure of poured concrete.

CHAPTER 3

ASSESSMENT OF THE CURRENT CONDITION OF MASONRY BUILDINGS IN TURKEY: A COMPARATIVE STUDY BETWEEN MASONRY CONSTRUCTION INDUSTRY AND CONCRETE CONSTRUCTION INDUSTRY

3.1 Re-Evaluating the Potential of Masonry in Turkey Conditions

It is a very-well known fact that masonry is a common construction technique around the world. It is generally used for the construction of low-rise residential buildings due to the limitations in the capacity of the materials. On the other hand, this technique is favored due to many advantages it provides. It is economic when used for construction of low-rise buildings, constitutes of user-friendly materials, requires less technology and skill, and is easy to be constructed. Moreover, from the architectural point of view, it provides a strong characteristic with the built environment.

In Turkey, it is hard, even impossible to claim that the built environment has a specific characteristic in each region. The reason for this unprincipled appearance is the rapid and unhealthy urbanization period that the country has been experiencing since the second half of the 20th century. This painful period is one of the major problems of Turkey. The other problem is seen as the earthquakes, the problems of which could easily be said to go in parallel with the quality of urbanization. Because of unconscious attempts to produce buildings in a very short period, the quality of buildings has never been assessed in either structural or architectural viewpoint. The results have always been devastations after earthquakes that the country has been suffering especially in the last decade.

The urgent need for residential units explains the reason for abandoning masonry in a very short time although the construction technique has a strong background in

Turkey. However, in might not be reasonable to reject masonry regarding the fact that Turkey has a rich potential in terms of its materials and construction. In Turkey, especially in cities with more than 500000 populations, it is unavoidable that high-rise buildings are required. However, in medium-scale and small-scale cities, where the buildings are about 5-8 storeys in height, utilization of masonry should be revised. Reinforced concrete and steel might seem to replace masonry thoroughly since they are the materials of the last century. On the other hand, it is a fact that an important portion of reinforced concrete buildings either collapsed or was severely damaged in the recent earthquakes despite the very well known capacity of the construction material. Moreover, the reliability of buildings becomes susceptible with the introduction of every earthquake code. In other words, every building built before the last revision of earthquake codes should be considered as vulnerable to earthquakes. However, this should not mean to demolish all the buildings and to rebuild them up. After performing careful inspections and necessary calculations, most of these buildings could be reinforced. This would consume less energy, time and money. Strengthening might also address to post disaster precautions, which also cover rehabilitation of the damaged buildings.

Afore mentioned, masonry is a well-proven building material possessing excellent properties in terms of appearance, durability, and cost in comparison with alternatives. In the first half of the present century brick construction displaced by steel and reinforced concrete framed structures. Then, masonry gained importance again in some countries. Over the past 20 years has led to the improvement and refinement of the various structural codes. Besides the technological advances a wealth of research information exists on a variety of topics related to the diverse aspects of masonry design and construction. As a result, the structural design of masonry buildings is approaching a level similar to that applying to steel and concrete. As mentioned before, in this research it is intended to demonstrate the advantages of masonry construction system especially for developing countries in terms of social, economic and environmental aspects. Thus, it could be possible to revitalize of the masonry construction techniques with the architectural characteristics. In summary, masonry is an appropriate construction technique for Turkey due to four crucial advantages; contribution to the country economy, providing employment, requiring less time for completion (speed of erection), training of specialized worker which are reported here to reveal the potential of the masonry in Turkey.

3.1.1 Contribution to the Country Economy

In economic development in every country, the construction sector plays a significant role by providing the development and expansion of economic activities in the country. The construction industry has strong influences on the country economy. In Turkey, following food and textile sector, construction industry is the third important sector having the major employment source. Over the past two decades, especially after the 1999 earthquakes the Turkish residential construction sector has increased with a rising population and a rapid urbanization rate. The two major earthquakes in the country over the last 10 years have also increased the demand for the services of the industry both in terms of quantity and quality. It is expected that demand for this industry will continue to grow. However, this demand requires a powerful economic structure creating some problems in the case of Turkey which is a developing country and needs economic solutions for construction technology. Advances in construction technology have led many organizations to seek new solutions to decrease the cost and completion time of construction. Masonry construction technique which is one of these solutions has the advantage of low cost. As mentioned before, masonry construction is more economic compared to other systems. Hence, if Turkey starts to use masonry construction system instead of reinforced concrete in the construction of low-rise residential buildings, country economy will be affected from this situation positively. Due to the fact that masonry construction cost is nearly half of the concrete construction cost as it can be seen in the next part of the study.

Thus it can be said that with its many advantages masonry construction systems has also positive effect on economy. One of the most important factors that make masonry economic is using waste material in the production process of the bricks. Waste materials have a potential for use in the manufacture of masonry units and products. Using waste materials in the manufacturing process of the masonry units decrease the cost of production. This also reaps benefits in responding to environmental concerns by preventing to consume the physical and natural resources of the environment. Another important point that affects economy is that masonry construction does not need expensive formwork while concrete structures can not be constructed without formwork. Additionally to deliver and pour the concrete at higher level in multi-storey construction requires a special consideration. For this purpose concrete construction needs heavy machinery and special equipment that increase the cost of construction significantly. On the other hand, these expensive requirements are not required in masonry construction which is a positive effect for the country economy.

3.1.2 New Employment Opportunity

In developing countries, employment is a very important problem. Although industry and services grew rapidly after 1950, these sectors did not create enough jobs to meet the demand in Turkey. In the early 1990s, Turkey suffered from serious structural unemployment, although the country continued to lack skilled workers and managers. Job creation has been relatively slow in Turkey as shown in Table 3.1. Brick and block industry of Turkey has very important place in the country economy and 300.000 workmen are working in brick factories. Construction industry constitutes significant part of the employment. Admittedly, economy and employment go parallel to each other. Thus, in this situation, using masonry construction systems for residential units can have a positive effect on the economy and employment since with the increase in housing units, the production of brick and block will increase, too. As a consequence, there will be need for new companies to produce brick and block masonry units which may also provide employment for many unemployed people in Turkey. Using masonry as a solution of a design problem requires the masonry industry from suppliers, structural engineers, and contractors to rethink their approach to design and construction and to see the many opportunities that structural masonry offers clients, users, and the general public (Curtin, 2006).

Table 3.1 Employment by Sector, 1980 and 2004 (millions)
(Türk Yapı Sektörü Raporu, 2005)

Employment	1980	2004
Employment, total (15 years and over)	15.7	21.7
Employment in agriculture	8.4	7.4
Employment in industry	2.3	4.0
Employment in construction	0.9	1.0
Employment in services	4.1	9.4

3.1.3 Completion Time

The completion time is a very important factor that affects construction sector in terms of financial income and employment. As an earthquake country, Turkey suffered from many devastating earthquakes in the past. Therefore, the demand for new housing units increased since homeless people needed new permanent settlements immediately. Masonry construction takes less time than the other construction systems, which is an essential feature when the construction sector in Turkey is considered. For each level of concrete construction the structure must have the formwork applied. After the reinforcement added and concrete poured and cured the formwork can be taken down. However, masonry construction systems do not need formwork, due to the fact that each masonry unit has its own form and strength, they can easily be stacked one on top of the other. Thus, contrary to concrete, masonry systems save in overall construction times by eliminating the need for expensive formwork.

3.1.4 Training of Specialized Worker

Admittedly, masonry has a very long tradition of building, by craftsmen, without engineering supervision of the kind applied to reinforced concrete construction. One of the most important differences between masonry construction and concrete construction is the need of skilled workers. While masonry construction require specialized worker, there is no need for this personnel in a building that construct with ready mixed concrete. It is important for engineers and architects designing and constructing in masonry to have an appreciation of the workmanship factors, which are significant in developing a specified strength. Like most developing countries, Turkey lacks an adequate number of trained and skilled personnel. There is the need of knowledge base of information including but not limited to material properties and performance, design procedures, construction details, construction procedures, and maintenance requirements. There are not enough courses which are on structural masonry construction in the universities and vocational schools of Turkey. Especially vocational high schools are important for training people who provide the connections between architects, engineers and workers. To fill this gap, vocational high schools should gain importance in Turkey. By this way, training of specialized worker can be provided with the renovation of the vocational high school.

There are two important teams in building construction: designers and construction operatives. Some of the graduates should be able to produce designs for masonry structures and some of them should be able to construct masonry structures. Shortage of the availability of skilled workers restricts the number of new masonry houses. To have high performance with masonry improvements in construction practices are required. Furthermore, the durability and employability of a building depends on the quality of design and construction. Along with an awareness of construction details the detailed design should be learnt in practice. For this purpose suitably educated and experienced designers and construction operatives are required. Thus, for the education of specialized worker, the vocational high schools require much broader curriculum than the ones in the current. Educational process (in the design, calculations, construction) should be questioned by way of different thoughts and definitions related to interdisciplinary approach and relationship between civil engineering, architecture and skilled workers (graduated from vocational schools should be reviewed from point of view of possible contributions for qualified education). A new interdisciplinary program could be built up in the vocational high schools to achieve this aim. Giving importance to these schools provide new skilled employees. Thus the people who graduate from these vocational high schools could easily find work in the construction sector. For this purpose, in the European Union Accordance Process, MEB has prepared a project named as SVET (Strengthening the Vocational Education and Training System in Turkey/Mesleki Eğitim ve Öğretim Sisteminin Güçlendirilmesi Projesi-MEGEP). Thus, Turkey signed an agreement with the European Union on 4 July 2000 (SVET, 2000). Then, project team started to work on 30 September 2002 for five years period. Draft occupational standards including many different branch of business are prepared with the contribution of organizations, universities and institutions.

In the construction process another crucial factor is the workmanship that affects the building quality. Thus, education of the construction workers is as important as education of the architects and engineers. All people working in construction sector should understand each other very well to construct an absolute building. In this context, recent days that we stand as a candidate to the European Union, there are many items which are needed reorganization as explained below.

Firstly, it is considered to be very important that Turkish workers should have certificate of their proficiency to work in the foreign countries. In Turkey, there are some studies to master this difficulty such as; a construction site; TES (Turkish Education Site) was established with the cooperation of İNTES and YOL-İŞ and it was opened on 25 November 2004. According to interview with INTES (Türkiye İnşaat Sanayicileri İşveren Sendikası), there are different kinds of courses in this site including education of first aid, ceramic, plasterboard, floor tile, granite, whitewash, installation, heavy construction equipment, aerated concrete, industrial pipe, insulation, iron, scaffolding and form-working. Since 2006 totally 3182 workers (Table 3.2) has been attended these construction site education. In addition to the Turkish workers many workers attend the courses from Turkic Republics (INTES, 2007).

As seen in the table, there should be many education branches, to have qualified workers in every areas of the construction. Nevertheless, it can be said that for the first step this education site achieved a good job. However, to fill the gap in workers education it is necessary to establish additional education sites to TES. Every new education site will raise the number of educated and certificated workers. Besides all of these, there should be also mutual interaction between these education sites and vocational high schools. This interaction provides the connection between theoretical knowledge and practice which is an important problem in Turkish Construction industry.

Table 3.2 Number of Workers who took certificates from TES (INTES, 2007)

Education Type (Year 2006)	Number of Workers	Duration (Hour)
First Aid Education	358	240
Ceramic Education	45	96
Plasterboard Education	156	144
Whitewash Education	259	360
Floor Tile Education	60	150
Granite Education	92	150
Installation Education	120	32
Heavy Construction Equipment	118	200
Industrial Pipe Education	85	850
Aerated Concrete Education	38	80
Total	**1331**	**2302**
Education Type (Year 2007)	**Number of Workers**	**Duration (Hour)**
First Aid Education	30	48
Whitewash Education	224	176
Plasterboard Education	75	96
Installation Education	273	144
Aerated Concrete Education	88	80
Insulation Education	132	264
Industrial Pipe Education	554	5540
Iron and Scaffolding Education	31	40
Heavy Construction Equipment	444	840
Total	**1851**	**7228**

Second important item that should be taken into consideration is trade proficiency in construction sector. It appeared necessity that must be provided appropriately in the European Union Accordance Process of the Turkey. For this purpose Trade Proficiency Institution was established on 7 October 2006 with law no 5544. Today, many studies are being done for this object in Turkey.

In summary, after all, for the proper completion of any building, skilled labour is the fundamental need. Inexperienced labour can result undesirable defects in construction. Thus, to fill the specialized worker gap the construction training courses with practices in sites should be improved with in the connection with vocational high schools.

3.1.5 Revival of Traditional Construction Technologies

Cities and towns are characterized by the types and design of buildings constructed with local materials for each space. Climate, availability of the materials, and environment determine both the housing types of the regions and architectural style. However, developing technology and current fashion have influenced these local characteristics of the regions negatively. As mentioned in the first chapter, after 50's building environment in Turkey started to lose its local identification. While constructing new RC apartment blocks with the sign of modernity, general characteristics of the regions are not taken into consideration. This insensitive approach brought about similar built environment in all of the country even in different climatic and physical geography. This reinforced concrete block production leaded to the standardization of building elements. As a result these apartments caused breakdown of traditional structural characteristics in cities of Anatolia.

Vernacular buildings in Anatolia typically were designed and constructed by residents of the regions who utilized traditional building techniques. Thus in every region there were different local knowledge, social capital, builds relations with communities and local builder. Masonry and timber were the main materials of these structures. Plan shapes, structural characteristics and interrelationship between proportion, scale, height, depth and width constitute the architectural characteristics of these buildings. Traditional buildings had specific features depending on the regional characteristics. For this reason after earthquakes in 1999, it was seen that traditional constructions had a good performance. Thus, it is important to find out which local technologies perform better and could be used in reconstruction.

As an objective of this dissertation using masonry in residential building construction can revive the vernacular architecture of Turkey that is the most significant consequence in defining the unique characteristics of a place. The advantages of masonry which are summarized in Chapter II make it an attractive choice for residential construction. To gain different architectural characteristics in different regions of the country again, this aim should be evaluated. Respectful to local values and traditions, masonry could be used in residential construction easily with the development in the construction technology. Besides bringing high added value to country economy, masonry construction for the residential buildings is important to regenerate the traditions with the awareness of social responsibility and with awareness of environment.

3.2 Masonry Construction Materials in Turkey

Although it has been replaced by framed structures, which are generally of reinforced concrete and steel, masonry construction system has come back on the scene in the recent decades due to many advantages it provides, such as availability, ease in construction, appearance, textural warmth, and etc. Modern masonry construction consists of bricks, concrete masonry units, and stones; all are bonded to each other by means of mortar. Today, the design of masonry construction system is based upon structural analysis methods of the 20th century, as in the case contemporary structural materials (Sinha, 2002, p.9-10). Among the above mentioned masonry constructions, it is stone masonry that was used more common in the first half of the 20th century, while those constructed of bricks and concrete blocks has become more popular in the recent decades.

Today, load bearing masonry systems are used especially for construction of low-rise housing units in many countries. In modern masonry construction, a major evaluation took place with the introduction of steel reinforcement. Masonry systems can be classified into three groups: plain masonry, confined masonry and reinforced masonry. Plain masonry structure is the ordinary type of masonry systems that has been in use for many years. These structures have problems especially in earthquake prone areas because of the poor tensile strength of mortar joints. To strengthen this weakness, reinforced masonry is used in seismic zones. Reinforced masonry is required by code in areas of recurring hurricane, winds or earthquake activity where major damage to buildings is highly probable. Today, there are a great many types of blocks and bricks used in residential and commercial construction. In addition, prefabricated masonry panels are being used to reduce the amount of on-site construction.

In Turkey, adobe, brick and concrete blocks are mostly used materials for masonry construction. The architectural history literature depicts that adobe is one of the oldest and crucial building materials in antiquity. It was widely used in regions where timber and stone were inadequate or unavailable in terms of natural resources. The quality of adobe is determined by the amount of clay contained. In old times, straw was used for reinforcing the adobe. Today it is evident that cement and plaster has replaced the straw. When compared to the other building materials, it is seen that adobe is natural, healthy, and cheaper. It also requires less energy and is easy to produce. Because of these characteristics, adobe is seen as a way out for people of low income in Turkey, where an important portion of the residential units were produced by individual efforts rather than by the supervision of the government during the rapid urbanization period. This could also be related to the fact that adobe is a well-known constructional material that even today it is possible to see many examples of adobe housing units in the villages of Turkey. Furthermore, depending on soil types and climatic conditions, adobe construction can achieve both strength and durability. One of the major defects of adobe as a constructional material lies in its inability to show adequate resistance to earthquake forces (Wasti and Gülkan, 1980).

The second material used in masonry constructions is brick. In Turkey brick is standardized for dimensional and technical properties according to tst EN 771-1 (Specification for Masonry Units) and TS 704-TS 705 (Solid Bricks and Vertically Perforated Bricks). Bricks produced in Turkey are divided into six categories such as; hand moulded brick, fabricated brick, press brick, hollow brick, iso-brick, and fired brick.

Concrete masonry unit is the contemporary alternative for masonry construction systems. Concrete block is made from a mixture of Portland cement and aggregates. The units are often used when masonry is to form a load-bearing wall or an interior partition between spaces. They are produced in the desired shapes and then cured under pressure in the manufacturing plant. They are available in wide range of types, sizes, shapes, and surface textures, and are used for a variety of purposes. Since the material has come on the scene in the 19th century, it is treated as a contemporary material. Not only the standards have been established for its physical properties such as solid content, strength, density, water absorption capacity, moisture content and linear shrinkage potential, but also production techniques were improved to provide the blocks with greater strength, lighter weight (Beall, 2000, pp. 296-303).

3.3 Masonry Construction Industry in Turkey

The Industrialization Period, which started in the late 18th century, gave rise to many developments throughout the world. Industrialization drew attentions of many developed/developing countries due to many advantages provided such as decreasing unemployment, helping with utilization of natural sources, providing the country to gain foreign exchange, and decreasing dependency on foreign countries. An appropriate management to utilize the natural resources and to assess the potentials of the country is the most important means to make the maximum use of industrialization in economy. The production of necessary items for the economy of the country should be re-evaluated and the capacity of the potentials should be pushed beyond the limits. Insufficient branches should be developed in order to decrease dependency on the foreign countries. Besides, the natural resources and potentials of the country should be highlighted.

Industrial activities have gained more importance in the economy of Turkey especially in the recent years. Among the several developing industrial branches, there are two important sectors in Turkey: masonry construction industry and concrete construction industry. Masonry construction industry includes the production of brick and concrete block. Brick is the first material of the construction history in the world and it has been used in many different areas of the construction process. With the development of the technology brick also gained new properties and dimensions in the time. Having natural and cheap raw material made the brick an indispensable material in the construction technology.

The most important parts of the concrete construction industry are the ready mixed concrete (RMC) production and the cement production. Cement production is not environment-friendly that is different from brick industry. There are also many other differences between two construction technologies. Consequently, to make a comparison between concrete and masonry construction industry, brick & concrete block production and cement & RMC production of Turkey are investigated in this part of the study.

3.3.1 Brick and Brick Industry in Turkey

In this part of the study, an analysis of Turkish brick industry is undertaken. Brick production has shown a sharp increase in the recent years despite the negative effects of devastating earthquakes on the construction market. It is encouraging to see that Turkish brick industry puts a great effort to keep up with the latest technologies and to improve product quality. The manufacturers pay great effort to satisfy the requirements of modern construction with over 80 different brick types and formats (Harder, 2004). Furthermore, raw materials of brick can easily be found in Turkey, which is a significant factor for the economy of the country.

The first codes for the tile and brick was produced and used by Romans. Then Romans and British improved the production of brick and tile with different characteristics. In the 13 century Holland, Germany, France and Italy started to produce brick and improved the production technology of it until 19 century. In the half of this century machines started to be used in the production process of brick. In the Seljuq Empire period brick and stoned was used together effectively in the building construction in Anatolia. Then in ottoman period, codes and standards for brick and tile were developed and used (Görçiz, 2000).

The first attempts to establish tile and clay factories started in the late 1930s, but took effect in almost ten years time. Due to the strict relationship between clay and construction industry, the number of tile and clay factories has shown a sharp increase after 1950s in parallel to urbanization period. In 1955, the number of tile and clay factories was recorded to be 78 with 8136 employees (CCI and TOBB, 1958, p. 19). Especially in the 1980s, which is the beginning of the construction boom with the introduction of mass housings, significant growth rates were observed in clay and tile industry afterwards. The number of factories is seen to be 358 in 2001 (Şahin, 2001, p.25), while this number is stated as 498 according to the information directed from TUKDER (Association of Brick and Tile Makers) in 2006 and report of T.R. Prime Ministry State Planning Organization (SPO). More than 300000 people are employed in these factories, which points out an important work opportunity for the unemployed (TUKDER, 2006; DPT: 2530.ÖİK:546.2000, 2000).

Figure 3.1 and Table 3.4 give the number of brick factories in seven geographical regions of Turkey. According to the report of SPO, more than 20 % of the factories are located in the western part of the country while almost 30 % take place in the central region (Şahin, 2001, p.25; DPT: 2530.ÖİK:546.2000, 2000).

There might be several reasons for this uneven distribution of the factories, one and the probably the most important of which could be seen as the local availability of the raw material. On the other hand, it is a well-known fact that the western region is much more developed than the rest of the country, which points out the correspondence between construction and clay industry. According to Şahin (Şahin, 2001, p.26) the other reasons could be listed as the climatic conditions, which are a dependant factor on the production of clays and tiles, ease of transportation, distance from industrial zones, and the rate of urbanization. The western and central parts of Turkey step forward when all these considerations are in question. The eastern and south-eastern regions are undoubtedly far behind in these aspects.

Parallel to the establishment of production units, a sharp increase has been observed in the quantity of bricks as well. In 1955, 101.999.670 units of brick were produced in 78 factories (Şahin, 2001, p.23). This number is seen to be 5.250.000.000 units in 2004 (Harder, 2004) and 7.353.100.000 units in 2006 (DPT: 2530.ÖİK:546.2000). Based on the report of SPO, Table 3.3 gives the importation and exportation of bricks and tiles in Turkey.

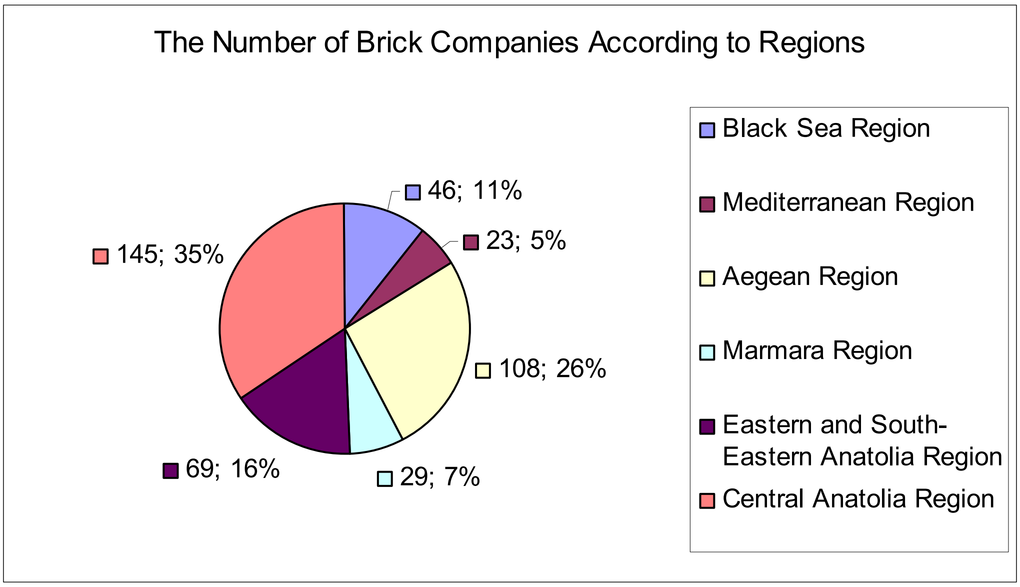


Figure 3.1 Brick Company Distributions According to Regions

Table 3.3 Importation of Brick and Tile in Turkey

(DPT: 2530.ÖİK:546.2000, 2000, p.15)

Importation	**1995**	**1996**	**1997**	**1998**	**1999**
Brick (Tone)	14	3	67	219	265
Tile (Tone)	100	28	2	5	6
Brick (USD)	69.288	108.026	36.076	125.643	213.227
Tile (USD)	704.722	35.671	32.790	25.949	7.807
Exportation	**1995**	**1996**	**1997**	**1998**	**1999**
Brick (Tone)	4240	7031	522	489	409
Tile (Tone)	6901	230	782	1483	1.128
Brick (USD)	254.009	685.251	486.500	460.248	294.847
Tile (USD)	590.572	642.948	521.466	624.214	721.773

Table 3.4 List of Brick Companies According to Regions

(DPT: 2530.ÖİK:546.2000, 2000, p.4)

MARMARA BÖLGESİ	
İstanbul	4
Tekirdağ	20
Edirne	1
İzmit	7
Çanakkale	2
Keşan	3
Bursa	1
Gönen	1
Biga	1
Orhangazi	1
İnegöl	1
Bandırma	1
Balıkesir	2
KARADENİZ BÖLGESİ	
Düzce	1
Kavak	7
Trabzon	1
Boyabat	31
Bartın	4
Tosya	11
Çaycuma	1
Bafra	1
Çankırı	3
AKDENİZ BÖLGESİ	
Antakya	4
Adana	5
Mersin	6
Antalya	3
Burdur	12
İskenderun	2

İÇ ANADOLU BÖLGESİ	
Bilecik	2
Afyon	23
Ankara	16
Polatlı	5
Çorum	38
Osmancık	14
Eskişehir	6
Kütahya	9
Konya	13
Aksaray	2
Yozgat	15
Avanos	8
Amasya	6
Kırıkkale	1
Kırşehir	1
EGE BÖLGESİ	
İzmir	8
Turgutlu	50
Salihli	31
Akhisar	1
Aydın	6
Ortaklar	6
Denizli	1
Uşak/Banaz	2
Muğla	3

DOĞU VE G.DOĞU ANADOLU	
G.Antep/Islahiye	2
Mardin	2
Batman	6
Urfa	1
Diyarbakır	11
Bingöl	1
Erbaa	22
Turhal	8
Erzincan	3
Elazığ	6
K.Maraş	5
Malatya	2
Tunceli	1
Sivas	3
Iğdır	1
Erzurum	1
Adıyaman	1
Ağrı	1
Van	1
Generek	1
Bayburt	1
Cizre	1
Siirt	1
Zile	1
Niksar	2
Şırnak	1

Similar to USA and EU countries, the production process of brick consists of preparing raw material, moulding, drying, and firing steps in Turkey. Although the phases seem to be similar, there observed differences in context and application. In countries with stronger economies and industries, huge machines are used for increasing the capacity in the phase of preparing raw material. Tunnel kilns are used instead of Hoffmann kilns, which are widely used in Turkey. The Hoffmann kiln is a multichamber kiln in which the bricks remain stationary and the fire moves. The principles of it can be seen in Figure 3.2. Tunnel kilns are the complement of Hoffmann kilns in that the fire is stationary and the bricks move through the kilns as stacks on a continuous train of cars (Figure 3.3). Transportation of the products between each process phase is realized by automation without manual manipulation. Computer dominates to all of the production steps. It could easily be understood that developed countries deal with not only decreasing the cost but also increasing the quality. The above-mentioned issues are the proofs of this concern.

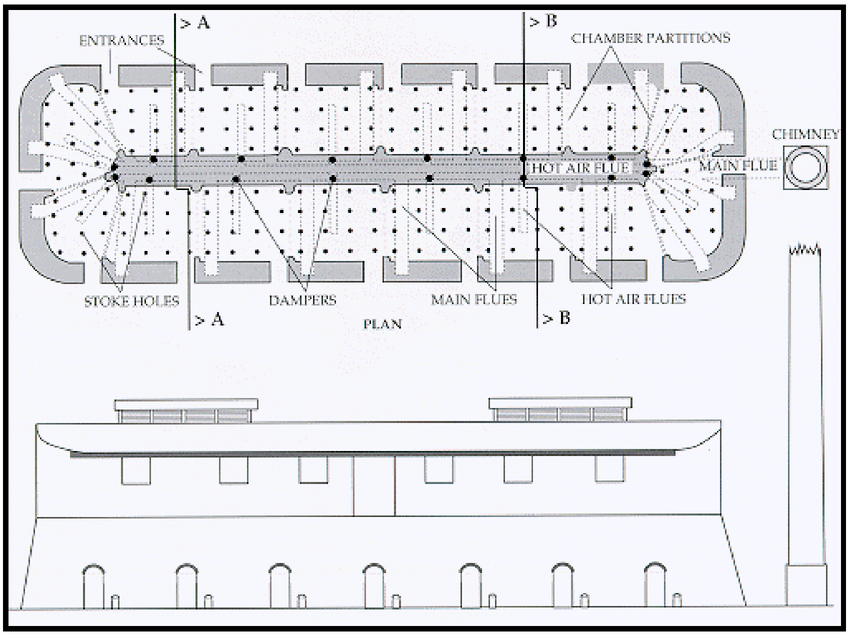


Figure 3.2 A modern 16 chamber Hoffmann Kiln[7]

[7] *Principles of the Hoffman Kiln,* <http://sleekfreak.ath.cx:81/3wdev/GATE_DL/BUILDING/HK.HTM> Last accessed: November 12, 2007

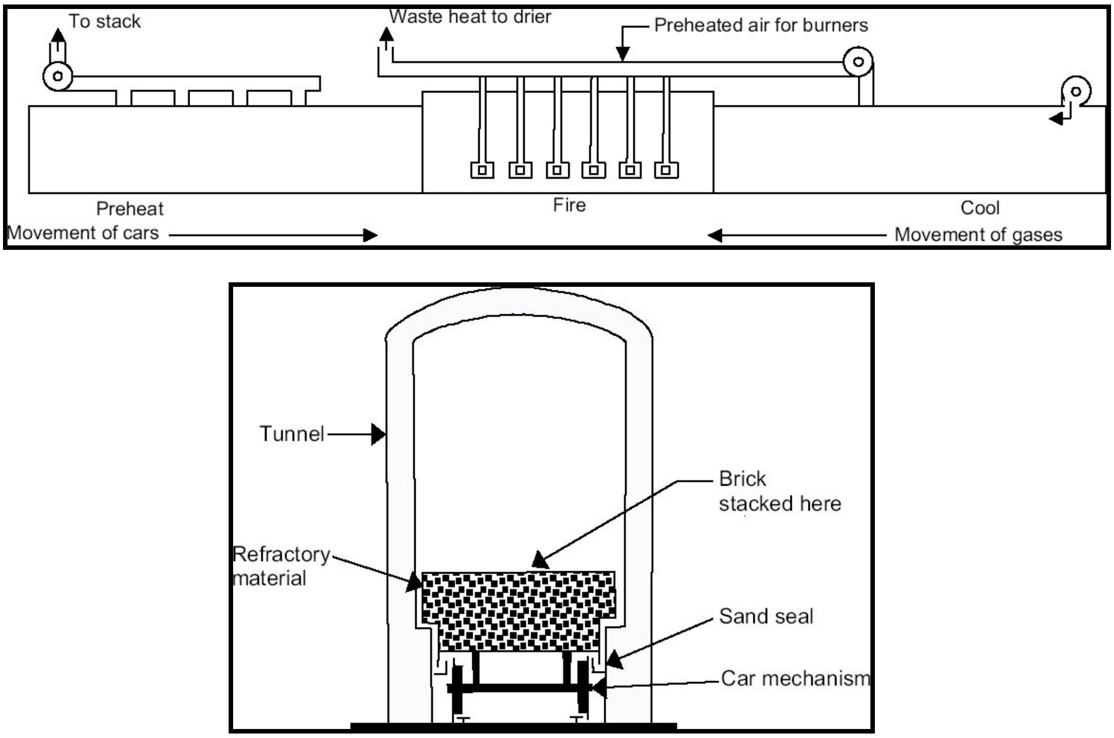


Figure 3.3 Principles of the Tunnel Kiln (Laefer, et. al., 2004, p.269)

3.3.2 CMUs and Autoclaved Aerated Concrete Industry in Turkey

Autoclaved Aerated Concrete (AAC) is a light-weight, strong, economic and environment-friendly building material that offers significant savings not only in transportation, but also in the amounts of binder and steel reinforcement consumed. It is owing to these basic attributes that it finds widespread use in a broad range of applications, from residential and tourism facilities, to industrial, commercial, civic and recreational ones, particularly in zones of seismic hazard. In the Turkish building sector report it is stated that the first application of autoclaved aerated concrete (AAC) in Turkey was Istanbul Hilton Hotel in 1950’s (Türk Yapı Sektörü Raporu, Gazbeton, 2005). Firstly in Pendik-Istanbul, Ytong Factory started to product autoclaved aerated concrete in 1963. Today, in Turkey there are eight AAC factories that continue the production. These companies are in Tekirdağ, Antalya, Gaziantep, Istanbul, Kırıkkale, and Izmir. According to the report, the total capacity of these factories for AAC is around 2 million m^3 in a year. Examples of the autoclaved aerated concrete masonry blocks are illustrated in Figure 3.4. and also, the company distributions according to regions can be seen in Figure 3.5. Annual exportation value of AAC is 250 tones.

Plain-End Blocks	Tongue-and-Groove Blocks	U Blocks
		

Figure 3.4 Examples of the Autoclaved Aerated Concrete Masonry Blocks[8]

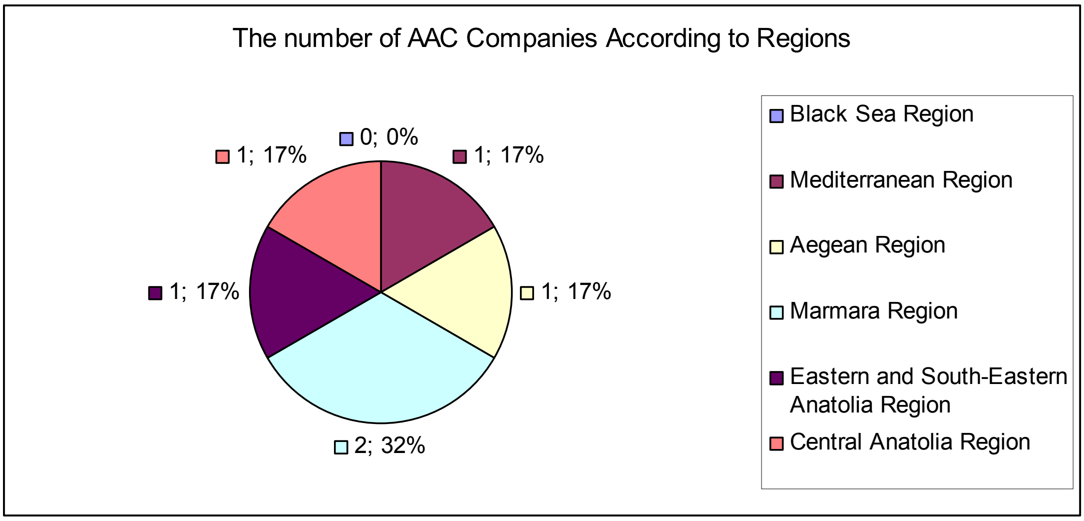


Figure 3.5 AAC Company Distributions According to Regions (Türk Yapı Sektörü Raporu, Gazbeton, 2005)

[8] *Autoclaved Aerated Concrete Masonry Blocks*, Türkiye Gazbeton Üreticileri Birliği, <http://www.tgub.org.tr > Last accessed: September 15, 2007

3.4 Concrete Construction Industries in Turkey

3.4.1 Ready Mixed Concrete Industry in Turkey

Concrete has been the most common building material in Turkey for many years as it is a well known fact that Turkey is located on high seismic zone where earthquakes happen with certain frequency. Thus, the quality of the concrete is so crucial for building safety in an earthquake. Although concrete is a widespread material in Turkey for construction there are many quality problems that were apparently seen in 1999 earthquakes. As an earthquake country Turkey have still not had expected standards of concrete. Especially in residential buildings, concrete is not used correctly due to the deficiencies in placing, curing, and formwork. According to earthquake code of Turkey, minimum BS 20 type concrete should be used in the construction of the buildings which are located in the first and second degree earthquake zones of the country. This kind of concrete can be produced in only an organized ready mixed concrete factory. Experiences gained from the past earthquakes in Turkey displayed that in the construction of many buildings poor quality concrete was used and not comply with standards. Unconscious use of concrete in the buildings caused heavy damaged and loss of life. In spite of this hard facts, in some buildings poor quality concrete produced by primitive methods are still used although their use caused heavy damage, loss of life and monetary. The underlying aim of this study is to increase the use of masonry in the buildings as a confidential construction method.

Ready mixed concrete was first used in Germany in 1903 and after few years it started to be use in USA. It became more widespread towards the end of the 80's. Raw materials of the concrete are cement, water, aggregate (sand, broken stone, crushed stone), chemical and mineral additions. Ready Mixed Concrete Organization of Turkey was founded in 1988. According to the records of the association for 2005 there are 277 companies, 568 foundations, 11007 personnel and 46.300.000 m^3 concrete production. The number of ready mixed concrete companies according to region can be seen in Figure 3.6 and Table 3.5 (Türkiye Hazır Beton Birliği, 2007).

Table 3.5 List of Ready Mixed Concrete Companies According to Regions

MARMARA BÖLGESİ	
İstanbul	47
Tekirdağ	5
Edirne	1
İzmit	14
Bursa	11
Sakarya	5
Bilecik	1
Yalova	4
KARADENİZ BÖLGESİ	
Düzce	3
Samsun	3
Trabzon	1
Rize	1
Zonguldak	2
Bartın	1
Bolu	2
Sinop	1

İÇ ANADOLU BÖLGESİ	
Niğde	1
Karaman	2
Ankara	14
Kırşehir	1
Kırıkkale	1
Nevşehir	2
Kayseri	2
Eskişehir	2
Kütahya	2
Konya	6
EGE BÖLGESİ	
İzmir	23
Balıkesir	7
Manisa	5
Muğla	4
Aydın	7
Denizli	5

DOĞU VE G.DOĞU ANADOLU	
G.Antep	1
Şanlı Urfa	1
Diyarbakır	1
K.Maraş	2
Malatya	2
Erzurum	1
AKDENİZ BÖLGESİ	
Hatay	3
Adana	4
Mersin	4
Antalya	14
Isparta	1

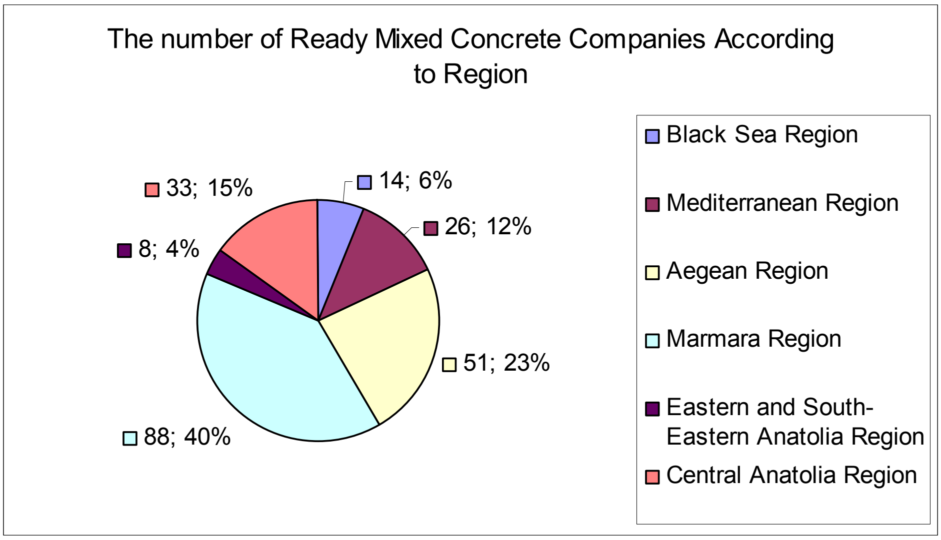


Figure 3.6 The Number of RMC Companies According to Region

3.4.2 Cement Industry in Turkey

Cement is used nearly every type of construction mostly in concrete as a raw material. However cement is one of the most important air pollution contributors. For this reason, many countries are setting the strategy for the response of the cement industry to sustainable development. Recently, air pollution has started to be a serious problem for all of the world countries. Cement production consumes high energy and has dust emission potential. Thus, in the production process of cement many precautions should be taken not to damage the environment.

The most commonly produced cement type is Portland cement which is derived from a combination of calcium (usually in the form of limestone), silica, alumina, iron oxide, and small amounts of gypsum and other minerals, such as iron ore or sand. Portland cement concrete is used in a wide variety of construction applications including residential buildings, commercial buildings, public buildings etc. In Turkey, in the late 1980s and early 1990s demand for cement increased due to the increase of need for additional housing units. Until 1970, Turkey imported most of its cement but since 1970s it has been produced cement and started to export especially to the Middle East. However, in 2006 (according to the records of TÇMB) cement demand increased in Turkey. Hence, the proportion of the cement exportation decreased for the first time in many years to fill the need of cement in the country[9]. Today, there are a total number of 49 cement plants operating in Turkey (Table 3.6 and Figure 3.7) presently with 16 grinding-packaging (G-P) plants with a total production of 29,148,000 tons/year of clinker and 37,488,000 tons/year of cement (Canpolat, et. al., 2002, pp. 235-252). In these cement plants there are 8638 people including managers, engineers, technicians, and workmen are working. Due to the fact that cement is one of the most important raw materials in concrete for the effect of resistance, it should be produced according the rules defined in TS EN 197-1.

[9] *TÇMBülten Ocak-Şubat 2007*, <http://www.tcma.org.tr> Last accessed: September 15, 2007

Table 3.6 Cement Companies According to Regions

MARMARA BÖLGESİ		İÇ ANADOLU BÖLGESİ		DOĞU VE G.DOĞU ANADOLU	
İstanbul	2	Niğde	1	Elazığ	1
Çanakkale	1	Sivas	1	Kars	1
Bursa	1	Ankara	4	Erzurum	1
Edirne	1	Yozgat	1	Uye olmayan	1
Kocaeli	3	Konya	1	**KARADENİZ BÖLGESİ**	
Kırklareli	1	Kayseri	1	Zonguldak	1
Balıkesir	1	Eskişehir	1	Samsun	2
AKDENİZ BÖLGESİ		Afyon	1	Çorum	1
Hatay	1	Nevşehir	1	Bartın	1
Adana	1	Uye olmayan	2	Bolu	1
Mersin	1	**EGE BÖLGESİ**		Ordu	1
Isparta	1	İzmir	3	Trabzon	1
Uye olmayan	3	Denizli	1	Uye olmayan	2
		Aydın	1		

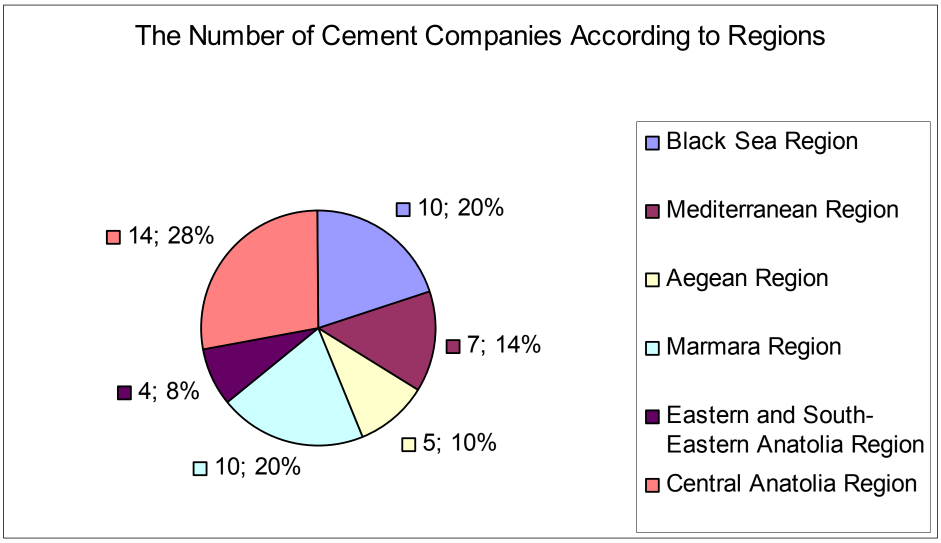


Figure 3.7 The number of Cement Companies According to Region

3.5 Comparative Study between RC Construction and Masonry Construction with a Cost Analysis

Selecting the structural system of a building depends on some criteria such as economy, functionality, time and aesthetics as well as the location. As a result of the comparisons in this chapter, it seems to be more feasible and economic to built three-storey masonry residential buildings rather than reinforced concrete. The first of these reasons is in masonry system; construction process can begin immediately and continue without delay. Masonry construction avoids waiting for fabrication and the problems associated with the accumulation of fabrication tolerances. Furthermore, Turkey has an important potential for the production of the brick. This potential also provides employment opportunities for many people. To summarize some important numerical values about reinforced concrete and masonry industry Table 3.7 is formed.

The second important reason is that masonry is a more economic system than the others. This is an important factor in Turkey's conditions as mentioned previous sections. Therefore, in this part of the study, cost analyses are performed on two different structural materials: masonry and reinforced concrete. According to observations from case studies a typical small-scale three-storey apartment building is designed. Then, firstly it is assumed that the building is constructed with reinforced concrete as seen in Figure 3.8. According to this assumption cost analysis of this building was done with the 2007 unit prices that are derived from The Ministry of Public Works and Settlement[10]. For the cost analysis, quantity of concrete, wrought shuttering, supporting scaffold, steel, brick and formwork is calculated with the help of a civil engineer. Secondly, the same building is designed with masonry (Figure 3.9). Similar cost analysis of the reinforced concrete apartment building is conducted for masonry building. The results of these cost analyses indicates that the cost of the masonry building system is nearly half of the cost of the reinforced concrete building system as seen in the Table 3.8 and Table 3.9.

[10] *Unit Prices of the Ministry of Public Works and Settlement,* Last accessed: November 14, 2007 from, http://www.birimfiyat.com/

Table 3.7 Comparison between brick masonry industry and concrete industry (Türk Yapı Sektörü Raporu, 2005, pp. 70, 77, 100, 102)

	Masonry Buildings		Reinforced Concrete Buildings	
	Brick Industry (unit)	Autoclaved Aerated Concrete (AAC) Industry (m^3)	Ready Mixed Concrete (RMC) Industry (m^3)	Cement Industry (tone)
Quantity of Production	5 280 000 000 (unit)	1 417 000 000 (m^3)	31 590 886 (m^3)	38 795 797 tone
Quantity of Capacity	6 600 000 000 (unit)	2 230 000 000 (m^3)	90 000 000 (m^3)	65 900 000 tone
Percentage of Capacity Usage	%80	%63.5	%35.1	% 58.9
Importation	18 196 (unit)	-	-	13 365 (m^3)
Exportation	25 525 000 (unit)	250 000 (m^3)	-	8 206 317 (m^3)
Number of Factory	490	8	409 RMC Firms 718 production units	39 integrated foundation 17 grind-packaging foundation
Number of Employees	40000-50000	1000	7049	8398
Cost of the construction	27214.43 YTL		42974.54 YTL	

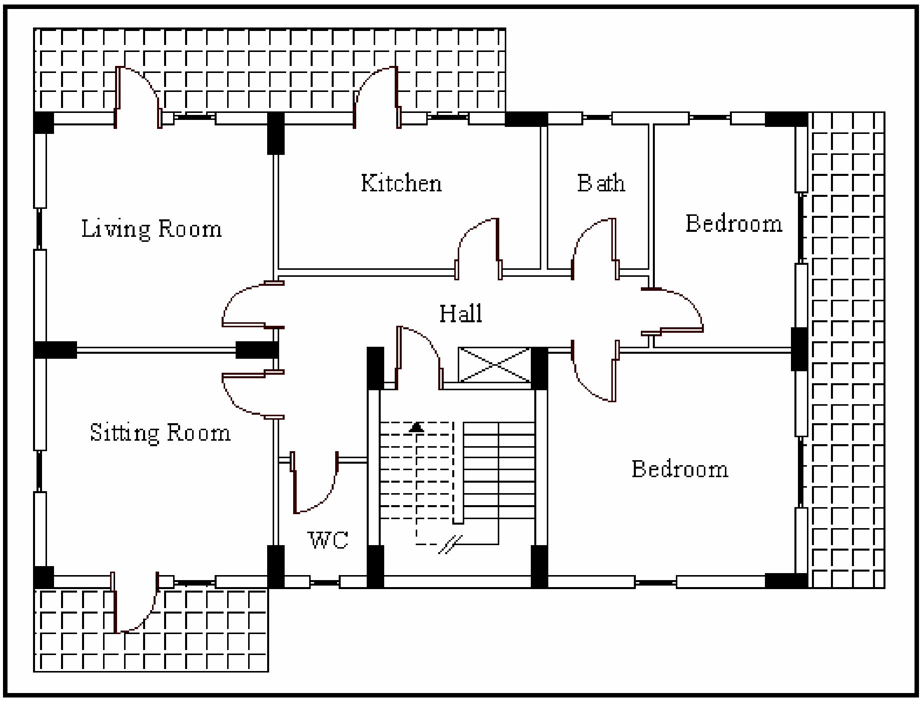


Figure 3.8 Reinforced Concrete Type Project (Designed by Er Akan)

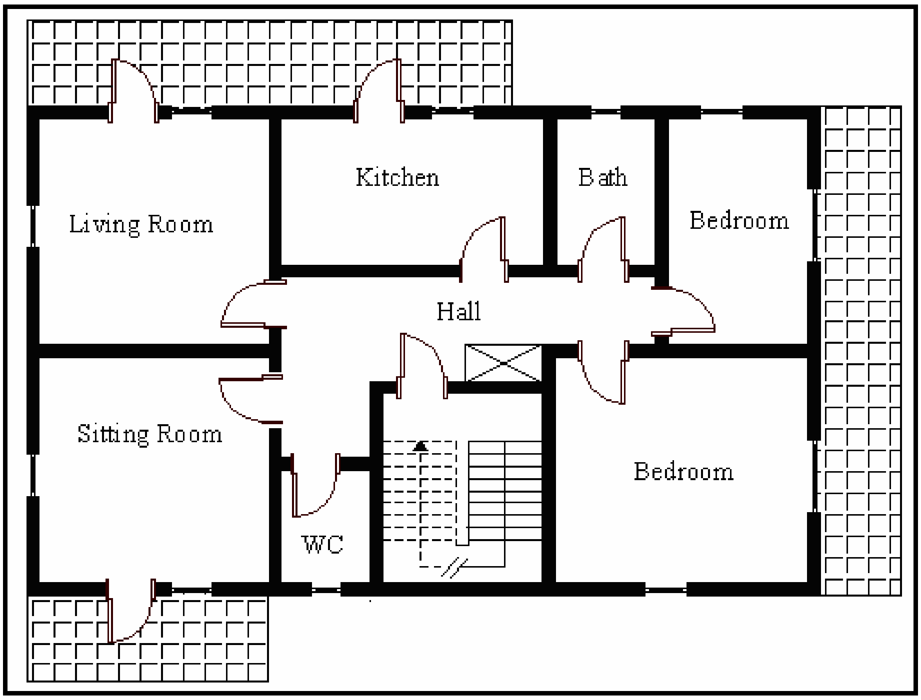


Figure 3.9 Masonry Type Project (Designed by Er Akan)

Table 3.8 The Cost Analysis of the Reinforced Concrete Type Project

*** Cost of Floors for Reinforced Concrete Construction**				
B.F. Poz No.	**Manufacture**	**Quantity (m^3, ton, m^2)**	**Unit Price (YTL)**	**Total (YTL)**
16.059/A	1. Concrete C25	64.608 m^3	98.79	6382.62
21.013	2. Wrought Shuttering (rendeli kalıp)	403.8 m^2	16.58	6695.00
21.054	3. Supporting Scaffold (kalıp iskelesi)	600 m^3	2.34	1404.00
23.014	4. Steel (ø8-12)	5.82 ton	1,451.56	8448.08
23.015	5. Steel (ø14-28)	2.14 ton	1,373.75	2939.83
16.059/6	6. Casting concrete with concrete pump	64.608 m^3	2.89	186.72
18.071	7. Brick Wall	32.793 m^3	93.84	3077.30
18.071/1	8. 1/2 Constructing Brick Wall	149.685 m^2	10.86	1625.58
				Total:30759.13 YTL
***Cost of Foundation for Reinforced Concrete Construction**				
B.F. Poz No.	**Manufacture**	**Quantity (m3, ton, m2)**	**Unit Price (YTL)**	**Total (YTL)**
16.059/A	2. Concrete for Foundation C25	54.06 m^3	98.79	5340.59
	3. Leveling Concrete	16.38 m^3	98.79	1618.18
23.014	4. Steel for Foundation (ø 8-12)	2.29 ton	1,451.56	3324.07
	5. Formwork for Foundation	130 m^2	13.30	1729.00
16.059/6	6. Casting concrete with concrete pump	70.44 m^3	2.89	203.57
				Total: 12215.41 YTL
				Total Construction:42974.54 YTL

Table 3.9 The Cost Analysis of the Masonry Type Project

* Cost of Floors for Masonry Construction				
B.F. Poz No.	**Manufacture**	**Quantity (m^3, ton, m^2)**	**Unit Price (YTL)**	**Total (YTL)**
16.059	1. Concrete C25	6.404 m^3	98.79	632.65
21.013	2. Wrought Shuttering (rendeli kalıp)	64.04 m^2	16.58	1061.78
21.054	3. Supporting Scaffold (kalıp iskelesi)	600 m^3	2.34	1404.00
23.014	4. Steel (ø 8-12)	3.66 ton	1,451.56	5312.71
23.015	5. Steel (ø14-28)	1.78 ton	1,373.75	2445.28
16.059	6. Casting concrete with concrete pump	6.404 m^3	2.89	18.51
18.081	7. Bearing wall (Brick)	90.06 m^3	113.94	10261.44
				Total: 21136.36 YTL
***Cost of Foundation for Masonry Construction**				
B.F. Poz No.	**Manufacture**	**Quantity (m^3, ton, m^2)**	**Unit Price (YTL)**	**Total (YTL)**
	1. Foundation Excavations	290 m^3		
16.059	2. Concrete for Foundation C25	12.808 m^3	98.79	1265.30
	3. Leveling Concrete	16.38 m^3	98.79	1618.18
23.014	4. Steel for Foundation (ø8-12)	0.237 ton	1,451.56	344.02
23.015	5. Steel for Foundation (ø14-28)	0.774 ton	1,373.75	1063.28
	5. Formwork for Foundation	128.04 m^2	13.30	1702.93
16.059	6. Casting concrete with concrete pump	29.188 m^3	2.89	84.35
				Total: 6078.07 YTL
				Total Construction: 27214.43 YTL

3.6 Masonry Code Developments and Requirements in Turkey

It is a very well known fact that buildings were constructed by trial and error method before the structural design, structural analysis, earthquake resistant building design, and dynamic analysis concepts were developed. In time past experiences started to form the basis of structural design. The masterpieces of architectural heritage are the best proofs for the relevance of experience (Er Akan and Toker, 2006).

The union of science and experience is the most appropriate means to constitute or develop the codes to decrease devastation due to hazards. The main target of the codes is to prevent loss of lives, where the second is to minimize economic costs. Earthquake resistant building design principals require a building to stand with minor hazards in low-magnitude earthquakes, to sustain damage only within the nonstructural members in medium-magnitude earthquakes, and not to collapse in high-magnitude earthquakes (Er Akan and Toker, 2006). As known that Turkey is located on a high seismic region. However, to stop disasters from happening is impossible but to stop demolishing of the buildings is possible with adequate building and planning codes and regulations.

In the world, many seismic codes pay attention to structural elements especially for engineers. The contribution of architects to earthquake resistant design principles is not taken into consideration in these codes. However, for a good initial conceptual design for earthquake zones responsibility of the architects is needed as well as engineers. For instance Earthquake Code of Turkey deals with details of construction without the plan forms to be adopted. However, architectural aspects of earthquake resistant building design are as crucial as structural design of the buildings. Thus architects play also key role in seismic resistant design. For this reason there should be close relationship between the two professions: architects and engineers while designing the seismic codes.

Masonry is generally used for components subjected to compressive loadings such as walls, columns; that have to bear in vertical direction, arches, vaults, domes that span across spaces and rooms. Therefore the most effective use of masonry construction is seen in load bearing structures. There were no engineering methods for designing masonry buildings until 1950s. However, after 1950s theoretical and experimental research started to be conducted, on various aspects of masonry. Standardization of the basic requirements and design concepts for the different types of construction has been identified, which need to be considered in design. Developing clear and concise code language is a significant factor that affects the understanding of design professionals with little or no experience in masonry design and construction. Simplification of design procedures helps to reduce the depth of knowledge needed by the young and unexperienced designers and to assure more effective use of building materials. First provisional masonry standard was introduced in 1943 in Switzerland. In 1966 In the United States engineered masonry building code was published. Since this period many standards and codes for masonry structures have been improved which can be listed as below.

- US Masonry Design Provision
- International Building Code 2000
- New Zealand Standard 1990
- BS EN 1996 Eurocode 6 Design of Masonry Structures
- BS EN 1998 Eurocode 8 Design of Structures for Earthquake Resistance
- Indian Standard (Code of Practice for Structural Use of Unreinforced Masonry) IS: 1905-1987
- ACI 530-02/ASCE 5-02/TMS 402-02, (2002), Building Code Requirements for Masonry Structures, Masonry Standards Joint Committee, USA.
- ACI 530-99/ASCE 5-99/TMS 402-99, (1999)
- BS 5628: Part1, (1978), Code of Practice for Structural use of Masonry
- NFPA, (2002), NFPA Building Construction and Safety Code.
- TS 2510, TS 705
- Earthquake Code of Turkey, 2007.

In Turkey, the past earthquakes are among the most useful means of experience to perceive the deficiencies in the seismic performance of structures. Regarding the impact of the great Erzincan Earthquake occurred in 1939, the first code of Turkey was published in 1940. Table 3.10 shows the close dates between a major earthquake and a consequent revision.

Table 3.10 The close dates between a Major Earthquake and a Consequent Revision[11]

Year	Place of Occurrence	Magnitude	Loss of Life
1939	Erzincan	7.9	32962
1940	First seismic code published.		
1944	Bolu-Gerede	7.2	3959
1944-1949	**Seismic code revised.**		
1953	Yenice, Gonen	7.4	265
1953	**Seismic code revised.**		
1957	Fethiye	7.1	67
1962	**Seismic code revised.**		
1966	Varto	6.9	2394
1968	**Seismic code revised.**		
1970	Gediz	7.2	1086
1975	Lice	6.9	2385
1975	**Seismic code revised.**		
1976	Caldiran, Muradiye	7.2	3840
1977	**TS 2510 “Rules of Calculations and Constructions for the masonry walls” was started to use.**		
1992	Erzincan	6.8	653
1995	Dinar	6.3	94
1997	**Seismic code revised.**		
1998	Ceyhan, Adana	5.9	-
1998	**Seismic code revised.**		
1999	Kocaeli	7.4	17408
1999	Duzce, Kaynasli Izmit	7.2	845
2002	Sultandagi, Cay	6.3	42
2003	Bingöl	6.1	184
2005	Seferihisar-Izmir	5.9	-
2005	Hakkari	5.4	3
2006	**Seismic code revised.**		

[11] *Ministry of Public Works and Settlement Government of Republic of Turkey,* Earthquake Research Center, <http://sismo.deprem.gov.tr/VERITABANI/hasar.php > July 10, 2006

In recent earthquakes many masonry houses in rural areas and in small cities damaged heavily but it should be kept in mind that most of these buildings were not provided with any structural analysis or calculations. Although widespread use of masonry in Turkey, it is not taken into consideration from a technical point of view. Determining rules for masonry buildings firstly published in the earthquake code of 1975 then in 1977 TS 2510 “Rules of Calculations and Constructions for the Masonry Walls” came into effect. Today, in Turkey masonry construction rules still are in an additional chapter of the earthquake code, namely, there is not a specific masonry design code. However, past earthquakes brought out that there should be specific codes for masonry construction in Turkey including both architectural and structural necessities. Differently from Eurocode 6, rules for masonry buildings in Turkish design codes are primitive and do not include calculations of the mechanical properties of masonry walls. Thus the earthquake code of Turkey provides little support to the designer for the masonry buildings as compared with other European countries. Since, it does not include different types of masonry systems while the codes of other countries propose additional types such as reinforced masonry, confined masonry etc. Turkish earthquake code includes only unreinforced masonry buildings design rules. Reinforced masonry construction systems are not used in Turkey; hence the rules of this construction type are not included in the earthquake code. Masonry is reinforced with only reinforced concrete horizontal and vertical ties according to this code.

In the design of masonry structures, there are three main important titles that should be taken into consideration especially for the earthquake prone areas. These can be listed as;

- Plan layout: Plan layout is an important factor that affects the seismic performance of any kind of building. However regularity in plan is more important in masonry buildings than the others. Symmetry and regularity in plan makes the structure stronger than the one which has different shapes. Irregular plans twist as it shakes during an earthquake, thus in the irregular plan shaped buildings more damage is occur. According to Turkish Earthquake Code, load bearing walls of masonry buildings should be located symmetrical or nearly symmetrical in plan. Furthermore reinforced concrete vertical bond beams shall be constructed along the full storey and also unsupported length of walls shall not be more than 16 m (Figure 3.10).

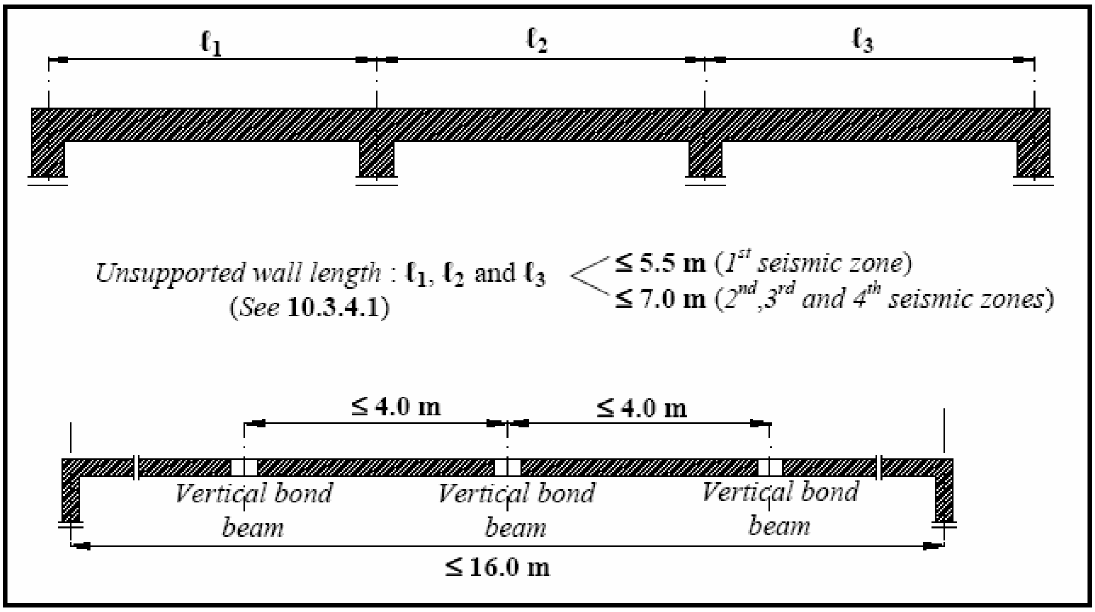


Figure 3.10 Unsupported Lengths of the Walls
(Specification for Structures to be Built in Earthquake Areas, 2007, p. 92)

- Number of Storey*:* One of the most important structural parameter in the masonry buildings is the number of stories, results of which was seen in the past earthquakes. In the first degree earthquake region, the permitted number of stories is 2, whereas this number is 3 in seismic zones II and III and it is 4 in seismic zone IV. Adobe buildings are allowed only with a single story in all seismic zones.

- Openings in Load-bearing Walls: Plan length of the load-bearing wall segment between the corner of a building and the nearest window or door opening to the corner shall not be less than 1.5 m in the first and second seismic zones and 1.0 m in the third and fourth seismic zone (Figure 3.11).

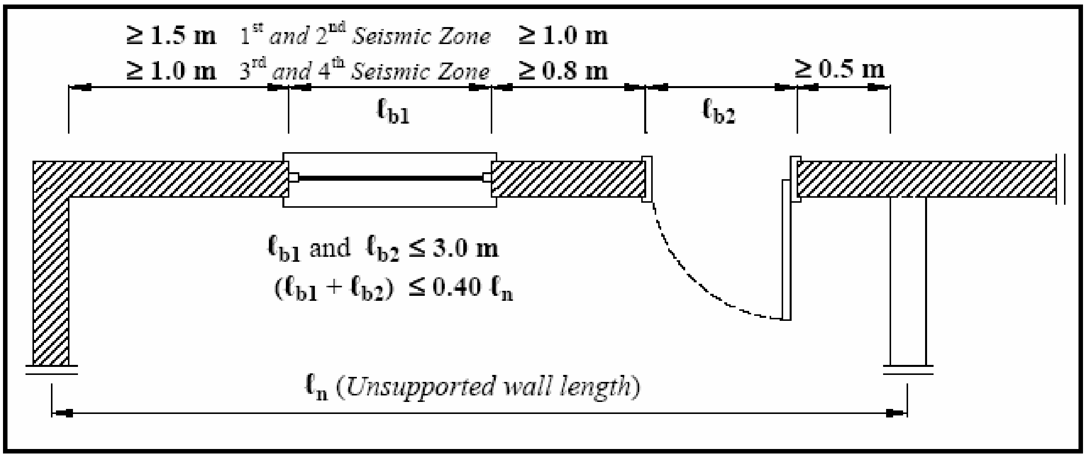


Figure 3.11 Openings in Load-bearing Walls
(Specification for Structures to be Built in Earthquake Areas, 2007, p. 92)

- Wall Material: Construction materials of masonry walls in the Turkish Earthquake code are natural stone, solid brick, brick with vertical holes and solid concrete blocks. Some materials can not be used in the construction load-bearing walls of masonry buildings such as brick units with horizontal holes and concrete blocks with holes. As it is stated in the previous chapter of the study, adobe construction has a widespread use especially in the rural areas of Turkey. However past earthquakes indicated that these buildings have poor earthquake performance. Cellular concrete which is the second material of masonry buildings in urban areas of Turkey, should not be used in the load-bearing walls of masonry buildings that are constructed in the earthquake prone areas since it has low strength.

There are also other rules in the earthquake code of Turkey for the design of masonry buildings. Table 3.11 compares these rules with Eurocode 6 and Eurocode 8. With this table, it is tried to demonstrate the differences between the codes.

Table 3.11 Comparison of the Eurocode 6-Eurocode 8 and Earthquake Code of Turkey-TS ENV 1996

<table>
<tr><td colspan="2"></td><td colspan="3">Eurocode 6 and Eurocode 8</td><td colspan="6">Earthquake Code of Turkey and TS ENV 1996</td></tr>
<tr><td rowspan="5">Max. number of Storey</td><td></td><td>Unreinforced</td><td>Reinforced</td><td>Confined</td><td colspan="6"></td></tr>
<tr><td>1. Degree earthquake Zone</td><td>1</td><td>3</td><td>2</td><td colspan="6">2</td></tr>
<tr><td>2. Degree earthquake Zone</td><td>2</td><td>4</td><td>3</td><td colspan="6">3</td></tr>
<tr><td>3. Degree earthquake Zone</td><td>3</td><td>5</td><td>4</td><td colspan="6">3</td></tr>
<tr><td>4. Degree earthquake Zone</td><td>3</td><td>5</td><td>4</td><td colspan="6">4</td></tr>
<tr><td colspan="2" rowspan="2">Height of the storey</td><td>Unreinforced</td><td>Reinforced</td><td>Confined</td><td colspan="4">Brick and Concrete Masonry</td><td colspan="2">Adobe Masonry</td></tr>
<tr><td>Max. 3,15 m</td><td>Max. 3,60 m</td><td>Max. 3,60 m</td><td colspan="4">Max. 3 m</td><td colspan="2">Max. 2.70 m</td></tr>
<tr><td colspan="2" rowspan="2">Thickness of the load-bearing walls</td><td>Unreinforced</td><td>Reinforced</td><td>Confined</td><td>Natural Stone</td><td colspan="3">Concrete</td><td colspan="2">Brick and AAC</td></tr>
<tr><td>Min 350 mm</td><td>Min 240 mm</td><td>Min 240 mm</td><td>Min. 500 mm</td><td colspan="3">Min. 250 mm</td><td colspan="2">Min. 30 cm</td></tr>
<tr><td colspan="2" rowspan="2">Max length of the wall that is not supported by another walls</td><td colspan="3" rowspan="2">Max. 7.20 m</td><td colspan="3">1. Degree earthquake Zone</td><td colspan="3">1., 2., 3., Degree earthquake Zone</td></tr>
<tr><td colspan="3">Max. 5.5 m</td><td colspan="3">Max. 7.5 m</td></tr>
<tr><td colspan="2">Max length of the wall that is supported by another walls</td><td colspan="3">-</td><td colspan="6">Max. 16 m</td></tr>
<tr><td colspan="2">Proportion of the openings in the load bearing walls</td><td colspan="3" rowspan="3">-</td><td colspan="2">From the corner of the building</td><td colspan="3">Between the openings</td><td>From the partition wall</td></tr>
<tr><td colspan="2">1. and 2. Degree earthquake Zone</td><td colspan="2">Min. 1.5 m</td><td colspan="3">Min. 1 m</td><td>Min. 0.5 m</td></tr>
<tr><td colspan="2">3. and 4. Degree earthquake Zone</td><td colspan="2">Min. 1 m</td><td colspan="3">Min. 0.8 m</td><td>Min. 0,5 m</td></tr>
</table>

Table 3.11 (Continued) Comparison of the Eurocode 6-Eurocode 8 and Earthquake Code of Turkey-TS ENV 1996 (BS EN 1996 Eurocode 6, 2007; BS EN 1998 Eurocode 8, 2005; Specification for Structures to be Built in Earthquake Areas, 2007, TS ENV 1996, 2005)

	Eurocode 6 and Eurocode 8	Earthquake Code of Turkey and TS ENV 1996
Classification of the masonry structure types	-Unreinforced -Reinforced -Confined -Prestressed	Unreinforced Confined
Wall types	-Load bearing wall -Single-leaf wall -Cavity wall -Double-leaf wall -Grouted cavity wall -Faced wall -Shell bedded wall -Veneer wall -Shear wall -Stiffening wall -Non-load bearing wall	-not applicable
Types of Masonry Units	- Clay units - Calcium silicate units - Aggregate concrete units - Autoclaved aerated concrete units - Manufactured stone units - Dimensioned natural stone units	- Düşey delikli Blok Tuğla - Dolu blok Tuğla - Harman Tuğlası - Stone units - Autoclaved aerated concrete units - Beton Briket - Adobe units
Strength of Masonry Unit	Min. 4.0 N/mm^2 normal to the bed face Min. 2.0 N/mm^2 parallel to the bed face	-

CHAPTER 4

CHARACTERISTICS OF RC RESIDENTIAL BUILDINGS OF TURKEY IN COMPARISON WITH MASONRY BUILDINGS: EXAMPLES FROM EARTHQUAKE PRONE AREAS

4.1 An Overview of Urbanization and Housing Typologies in Turkey

With effect from the very early years after the proclamation of Turkish Republic, traditional housing units started to change in Turkey. These houses are in a way the reflections of the way of life of Turkish people. They used to be of generally two or three storeys, which was suitable for accommodating two or three generations of the same family. There was a sofa, generally used as the living room that also served as a passage to all the rooms around. One other characteristic of the traditional Turkish houses is the garden that it is located or the court, depending on the climatic conditions of the region. Since the buildings are of two or three storeys, the construction was masonry in general, the material of which is brick, stone or adobe. However, there started to be great changes especially after the 1950s, when Turkey faced with a new problem: rapid urbanization. These changes were obvious almost in every characteristic of residential buildings such as dimensions, location on the construction area, plan configuration and structural system.

There are several reasons for these serious changes, some of which could be listed as alterations in social and economic conditions, technological developments, lack of town planning policies and great increase in population. The enormous increase in population gave the start for unhealthy urbanization in 1950s. Another important effect is the radical alteration in the rural-urban balance, which is a result of sudden movement of migrants from towns to cities. This is mostly due to the deprivation of opportunities for health, education and cultural facilities that the rural areas generally suffer. It is unavoidable that the urban areas become attractive in these aspects and in parallel, the developments in technology that eased the agricultural facilities, which was one of the main ways of life in rural areas, led to the migration of many people to urban areas for employment. This was the beginning of the alert for accommodation problems. After 1950s, around 250000 residences have been built in each year. This is the evidence of the great increase in population and the unhealthy urbanization. Other than this very rapid formation, the restrictions due to Town Planning and Turkish Earthquake Codes might seem to be the causes of unhealthy development of the built environment. Because of these rules and regulations architects has had to stay within the limits and as a result, every product become to be evident from the very beginning. In other words, there started to be only standard works to do for architects, since they do not have the opportunity to apply their professional formation (Toker, 2004; Bilgin, 2002a; Bilgin 2002b). As a result of these limitations residential buildings have become standard units in Turkey as seen in Figure 4.1.

Until 1950s in Turkey, self-building was the principal form of housing provision. With the rapid rise in land prices under the effects of high rates of urbanization, pressures to raise development rights of land had increased. The legislation had to be changed to allow ownership of flats in apartments by different people. This cleared legal problems against marketing of housing produced by emerging speculative builders in the form of multi-storey apartments. The cooperatives building low-storey houses or villas before 1950s tended to produce apartment dwellings in 1960s (Türel, 1988; Türel, 1993). In 1965 flat ownership was legalized. With this regulation built-and-sell (yap-sat) strategy came forth as a major housing mechanism, which have exploited the urban land through endless implementation of the apartment block, up to present (TOKİ, 2006).

In all visited cities during this study, it is seen that the building typologies are very similar to each other. These residential buildings have no specific characteristics which reflect regional, climatic, geographical etc. features. The plans turned out to be the western “three rooms and a living room”, which is nothing more than the arrangement of rooms along a corridor. Plans are generally based on a strict symmetry to achieve to distribute equal amount of space. To ease the equal distribution, commonly rectangular plan is used in apartment blocks. This also brought the adjacent apartment blocks replacing the separate housing units that are far away from satisfying the traditional living habits. Another important change in this aspect is the sudden shift to concrete as a construction material from traditional materials such as adobe, brick and wood. Most of domestic buildings, turned out to be in the earthquake area, had the constructive system in the form of reinforced concrete frame with brick wall filling. The height of those buildings varied within the range 2-8-storey as a rule.

Figure 4.1 Typical reinforced Concrete Apartment Buildings From
a-Bolu, b-Kastamonu, c-Çankırı, d-Çorum (*The photo archive of Er Akan,*, 2006)

With a population of over 70 million and a rapid urbanization and population growth of 1.4 million people per year, Turkey continue to experience high demand for new housing units. According to the report of Housing Development Administration of Turkey, residential construction constitutes 58% of Turkey's construction industry. Turkey sum up to 11,600,000 units which of these, 4.9 million are located in rural areas not served by municipalities, and the rest with in municipal boundaries. In urban areas 30% of all buildings are the reinforced concrete frame type, 48% are brick masonry or timber framed, and 22% are adobe or rubble masonry. In rural areas 82% of the housing stock is masonry of some form, while 18% are timber frame or reinforced concrete. Stone or adobe masonry constituted 90% of the former group, and totalled 3.5 million units, with 32% older than 50 years of age. These can be seen in Table 4.1 (Erdik and Aydınoğlu, 2002).

Table 4.1 Housing Typologies in Turkey

Material	Structural System	Building Classification
1. Wood	Timber Frame (Bağdadi, Hımış)	Timber Frame with Unreinforced Masonry Infill
2. Masonry	Unreinforced Masonry	Rubble Stone with Heavy Earthen Roof
		Adobe Block Masonry
		Cut Stone Masonry
		Solid Brick Masonry
		Hollow Concrete Block Masonry
	Reinforced Masonry	Hollow Concrete Block/Clay Brick
3. Reinforced Concrete	Reinforced Concrete Frame	RC Frame with Unreinforced Masonry Infill
		Dual RC Frame and RC Shear Wall System
4. Steel	Steel Frame	Unbraced Steel Frame with Unreinforced Masonry Infill

Even though the new materials like reinforced concrete and steel are being used mostly in construction, masonry buildings have still importance especially in rural areas of Turkey. In certain parts of the country plain masonry buildings constitute most of the residential buildings as well as different kinds of masonry buildings changing with available materials, technical knowledge, traditional practices and workmanship. Stone and adobe are the oldest materials used in masonry buildings in Turkey for several years. The buildings that were constructed with these materials generally have regular structural layouts. Afore mentioned in previous sections after 60's concrete started to be used as a common construction material in Turkey. Until today, it has been considered that apartment blocks are symbols of the modern urban life in Turkey. This opinion caused to change the traditional residential building types of the cities. Most of the traditional housing units were demolished to built reinforced concrete apartment blocks. This exchange of the building types can be read from the pictures of small-scale cities. There are many traditional buildings that are closely pressed between new reinforced concrete blocks (Figure 4.2).

However this situation has started to be changed in some cities of Turkey because of two reasons. The first one is the increase in the demand of high-income groups in Turkey to low-storey housing. The latter one is the safety considerations in the structural systems. Especially after 1999 earthquakes, because of safety considerations, the low-storey housing became the dominant preference of the society in earthquake prone areas. In disaster areas many people moved from their apartments to the two or three-storey independent dwellings. As a consequence of these preferences of resident community after devastating earthquakes, architects and engineers started to think an alternative solution for residential construction that are based on traditional techniques instead of multi-storey reinforced concrete apartment buildings.

Figure 4.2 Exchange of building types in small-scale cities
(The photo archive of Er Akan, 2006)

4.2 Seismic Performance of Residential Buildings in Recent Earthquakes

Turkey has had a long history of large earthquakes that often occur in progressive adjacent earthquakes due to its location on the Alp-Himalayan Seismic Belt. Furthermore most of the land is on the Anatolian plate, which is located in the middle of the Eurasian, African and Arabic Plates as seen in Figure 4.3. After the 1939 Erzincan earthquake, 17 August 1999 Kocaeli and 12 November 1999 Düzce earthquakes are the largest natural disasters of the 20th century in Turkey. These earthquakes caused extensive damage in the region which is the industrial center of Turkey, the economic life in the area and in the housing stock most of which are reinforced concrete apartments.

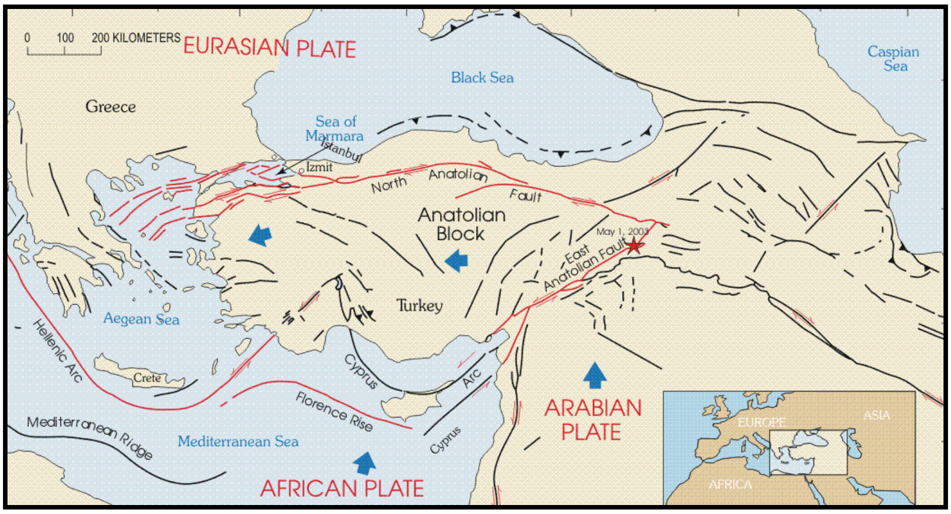


Figure 4.3 Seismic Plates around Turkey[12]

Structural framing of damaged buildings were generally irregular, detailing was poor, and shear walls were not employed even in buildings taller than five stories. However, the amount of damage was less in properly designed buildings. An

[12] *Seismic Plates around Turkey,* <http://neic.usgs.gov/neis/eq_depot/2003/eq_030501/neic_tgac_anaflt.gif> Last accessed: September 16, 2007

important correlation exists between the number of stories and the amount of damage in buildings. The most critical buildings against seismic hazard are 5 to 8 story reinforced concrete buildings (Sucuoğlu, 2000). Beyond all other considerations, the true tragedy of 1999 earthquakes is that 17,000 people were killed by the collapse of their homes.

M.Erdik et.al. state that in contradiction to other earthquakes in developing countries, most of the people affected in urban earthquakes in Turkey were the upper middle class living in multi-story residential apartment blocks that compromise on the quality of construction (Erdik and Aydınoğlu, 2002). Taking into consideration examples like the above and those mentioned in the literature and in the study of M.Erdik et.al., high vulnerability can be especially criticized for the following:

- The building construction system in Turkey has been leading to poor construction.
- The chronic high rate of inflation associated with high real interest rates are the main obstacle to the development of the mortgage market, large-scale housing development schemes and to the industrialization of housing construction.
- The high rate of industrialization and urbanization creates the ever-present need for inexpensive housing.
- Even the total number of housing units being built was beyond the capability of municipalities to regulate and supervise.
- Much of demand has been met by construction of five to six-storey reinforced concrete buildings by local builders with inadequate engineering, faulty construction practices and often without inspection by local municipalities.
- Sectors and institutions have no integration and planning.

Also, Özmen and Ünay explain the reasons behind the poor seismic performance of the buildings with a general classification as follows (Özmen and Unay, 2007, pp. 1406 – 1416):

- The universal lack of knowledge in the sciences related with earthquake engineering.
- The indifference of the public and some members of the engineering and architecture community towards the earthquake threat.
- The ignorance of geological and geo-technical conditions in the choice of location for urban settlements in countries with fast and undisciplined city growth.
- The structural defects in masonry buildings due to the general lack of understanding of this structural system and poor construction quality.
- The structural defects in reinforced concrete buildings, which are built on every scale and everywhere from the remote villages to large urban settlements.

Accordingly, lessons learned from the past devastating earthquakes indicated various types of architectural design faults such as undesirable geometric configuration, inadequate lateral stiffness, and flaws in detailing. Especially, regularity in plan is one of the most important points in the seismic design. Regular plans have always better earthquake performance than the irregular plans. For example if the columns are organized according to an axial system and distributed evenly for every earthquake direction, the building has high lateral rigidity; therefore, the displacements are limited (Tuna, 2000, pp. 133-135). In summary, there are many structural and architectural problems in the residential housing units located in earthquake prone areas. Thus, there is a lot to be done in all respects to construct earthquake resistant buildings in Turkey. Initially, as an earthquake country Turkey should have clear understanding of the earthquake risk and the need earthquake preparedness, also should revise building codes and regulations. After all, the process of the building construction consists of several people such as the architects and engineers, the owners, the builders, the inspectors, the materials suppliers, even the teachers in the local schools. In consequence, there should be an excellent team work between these people to have an earthquake resistant building.

The second significant topic is the lessons learned from earthquake resistance of traditional dwellings in Turkey. Until the 1999 earthquakes, communities thought that modern materials are better than the traditional materials against earthquakes. Thus, the adaptation of reinforced concrete was rapid. After the good earthquake behaviour of the traditional buildings in 1999 caused to change this idea. Public opinion backs to traditional materials. At the end of this period citizens and the engineers started to think innovative construction systems with traditional materials as an alternative solution to reinforced concrete apartment blocks. As recent earthquakes demonstrated that traditional Turkish construction have creative approaches to earthquake actions. While little was left standing from reinforced concrete buildings, numerous traditional buildings were still standing. Hence, understanding both positive and negative attributes of traditional construction practices could be supportive for the design of earthquake resistant buildings. Designers should borrow from the past for present construction by taking into consideration local methodologies of the regions. Lastly, in order to figure out previous earthquake effects on the residential buildings Figure 4.4 can be seen.

Figure 4.4 Heavy Damages of 1999 Earthquakes in Turkey
(Bachmann, 2003, pp.15,20,31,45,66)

Figure 4.4 (Continue) Heavy Damages of 1999 Earthquakes in Turkey
(Bachmann, 2003, pp. 15, 67)

4.3 Seismic Characteristics of Masonry Buildings

In recent years scientist in the world renewed interest in masonry made this material the object of extensive research to understand its behaviour, define its mechanical properties and to improve its safety and seismic performance. Therefore masonry is thought not only an architectural material but also true structural material. As it is well known fact that, masonry has a high compression resistance while its tensile resistance is low. In consequence, apart from non-structural applications masonry is used primarily as a construction material for vertical members subjected to gravity loads. Minor lateral loads and deformations may be resisted by the weight of the masonry walls. However, under larger lateral loads and deformations it exhibits poor cracking behaviour and low strength.

Under these circumstances, it would be beneficial to assess the earthquake resistance of masonry buildings. It is a well-known fact that materials of masonry construction are strong in compression. However, during an earthquake, the forces to be resisted are not only compressive forces. There are shear forces and bending moments as well. The maximum load is seen to be on the top of the structure; nevertheless, since the forces would be summed from top to the bottom, it could easily be understood that the maximum shear force would be at the bottom level. Under these circumstances, it is clear that the amount of shear forces to be resisted by a building is also dependent on the height of the building. The higher the building, the more are the shear forces. This case clearly demonstrates why masonry is allowed only for the construction of low-rise buildings.

Masonry structures could be regarded as monolithic boxes, which constitute of shear walls in two orthogonal directions. These walls are to be connected to each other by means of floors acting as diaphragms in between. The walls and diaphragms constitute the very basic elements that resist the vertical gravity loads and horizontal seismic loads. Arranged uniformly in both directions, the walls should be sufficient in number and strength to obtain a structurally sound behaviour. The length to thickness and height to thickness ratios should be decreased since the walls are the most vulnerable elements during earthquakes and tend to topple down in the weak direction. Precise interlocking of the courses as well as horizontal bands and floors that act as rigid diaphragms would be helpful (Tomazeviç, 1997, pp. 88-95; NICEE, 2004).

The introduction of reinforced concrete slabs, which act as rigid diaphragms, changed the limits of masonry construction in a positive way beyond its limits. Lack of resistance to bending and shear as well as insufficient ductility and energy dissipation capacity, however, limited the utilization of the system despite several advantages offered.

In the second half of the 20th century, masonry construction started to come back on the scene; but with constructional and structural design principles, which are applied for contemporary systems. This enabled to construct high-rise masonry structures with reduced wall thickness (Hendry, 2002, pp. 291–300). Klingner, states that reinforced masonry structures, designed according to the provisions sustained little damage while plain masonry structures on the other hand, were severely damaged or even collapsed (Klingner, 2004). For instance, in Northridge earthquake many reinforced masonry buildings exhibited good performance as seen in Figure 4.5. On the contrary, steel structures are known to behave better in earthquakes. This brings out question whether the properties of steel could be passed over to masonry structures or not. If masonry is reinforced by means of steel, then it might be possible to overcome the problems about resisting shear forces and bending moments.

1

2

Figure 4.5 1-Six-storey senior citizens' residence, undamaged,2-Undamaged 17-storey Hotel (Northridge earthquake) (Klingner, 2006, pp. 4-5)

It is possible to handle utilization of steel as the means for reinforcing masonry structures in two aspects. The first of these is the construction of new buildings in earthquake prone areas regarding the codes and regulations. The buildings could be constructed of masonry that is reinforced by means of steel in the load bearing members. Masonry can be reinforced both horizontally and vertically (Figure 4.6) as mentioned in the Chapter II.

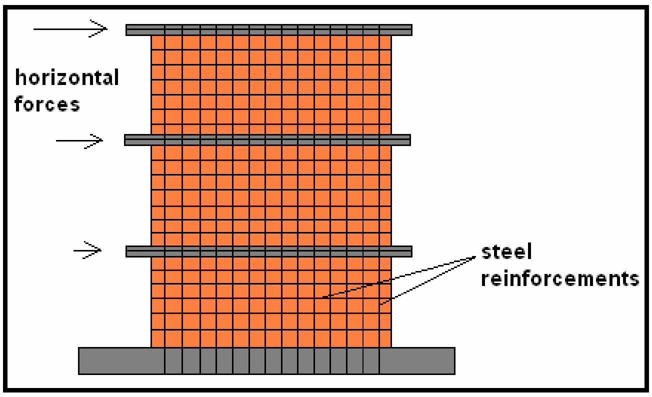


Figure 4.6 Reinforced both Horizontally and Vertically

The hollow core concrete blocks enable reinforcement through the wall. The blocks might be laid with or without mortar. The vertical reinforcement not only helps the structure to sustain bending instead of rocking but also prevents collapse in the weak direction. Furthermore, the steel ratio is dependent on yielding due to tension (Casabonne, 2000, NICEE, 2004). Despite the wide spread application throughout the world, the concept of "reinforced masonry" is somehow unfamiliar to Turkish construction industry. There are several reasons for limited use of reinforced masonry construction. The first and probably the most important of these reasons is the lack of information about seismic performance of reinforced masonry structures. As long as the advantages that the system provides remain unknown, it would not be possible to see serious attempts on the topic.

4.4 Residential Building Environment of the Small-Scale Cities in Turkey

The vast majority of Turkey's urban population today is living in multi-story apartment blocks constructed of reinforced concrete. According to statistics on urban housing compiled by State Statistical Institute (DIE), in the three largest cities (İstanbul, Ankara, İzmir) over 50% of the buildings in existence today are of reinforced concrete frame construction, and over 75% of these are of more than three stories. So, 80% of urban households live in these mid-rise apartment blocks. Mid-rise reinforced concrete residencies are more heavily dominate buildings in recent years (Erdik and Aydınoğlu, 2002).

As mentioned before alteration in living conditions and technological developments seek to move people into reinforced apartment building with the idea that is the sign of modernity. Because of these reasons towns and villages does not reflect their own characteristics. In urban areas most of framed buildings had either trade occupancy or offices on the ground floor as seen in Figure 4.7 (Kırıkkale and Düzce). Residential, offices and commercial facilities take place in the same building. The height of the ground floor reached 4-5 metres and essentially exceeded the height of the upper dwelling storeys. The filling of the frame within the ground floor either was not provided or was of much less stiffness than that one of the above storeys. To provide accommodations to their all children and also to provide annuity, people build multi-storey apartment buildings in their parcels. These apartment buildings are frequently irregular with many offsets and setbacks with inadequate engineering. In order to depict the effects of these limitations and the results of unconscious attempts, the building typologies of some small-scale cities in earthquake prone areas, such as Bolu, Çankırı, Çorum, Düzce, Kastamonu and Kırıkkale, are investigated in this study (Figure 4.8).

Figure 4.7 Trade Occupancy or Offices on the Ground Floor
(The photo archive of Er Akan, 2006)

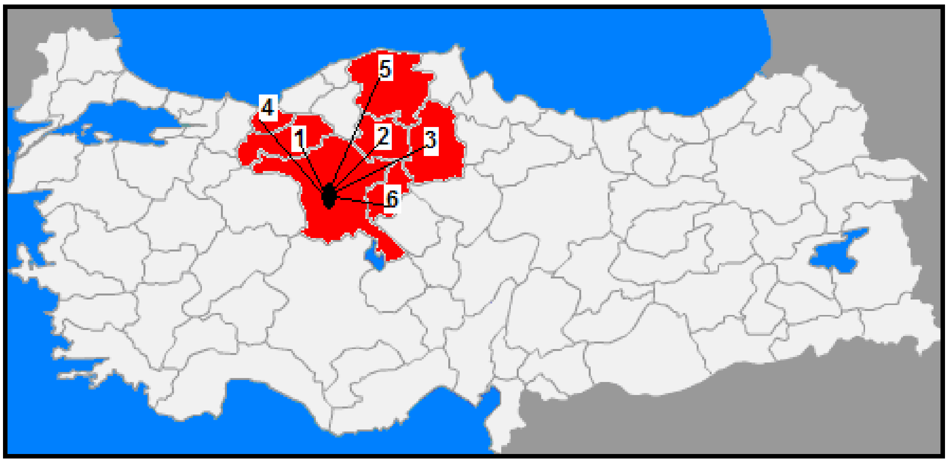


Figure 4.8 1-Bolu, 2- Çankırı, 3- Çorum, 4- Düzce, 5- Kastamonu, 6- Kırıkkale[13]

[13] *Map of Turkey*, <http://www.die.gov.tr> Last accessed: September 14, 2005

Strictly related to the fact that they are located close to the capital Ankara, these cities were affected by urbanization at the ultimate level. Therefore, the case in Ankara, the negative and positive effects of urbanization process are visible in the characteristics of the built environment. The field survey reveals that although these cities are located in earthquake region, the residential building stock is mainly composed of multi-storey reinforced concrete apartment buildings. The safety of reinforced concrete apartment blocks is still in question since the recent earthquakes showed their poor performances. The weight of these buildings led to the death of about 80,000 people in the earthquakes that happened in Turkey over the last century. In fact, low-rise buildings that are constructed of lightweight materials are more effective to keep away people from the devastating effects of earthquakes. Nevertheless, since rather than the safety of buildings the monetary benefit is of utmost importance, construction of multi-storey reinforced concrete buildings are still going on. The restrictions of Town Planning Codes and Turkish Earthquake Codes also contribute to this standardization. As a result, the built environment almost in every settlement zone depicts the same characteristics around the country. The buildings do not reflect any features of the local architecture, which were dominant once. During the field trip the plan and elevation of apartment building types are derived from the municipalities of the cities. Also a number of photographs were taken to explain the building types in these cities.

4.4.1 Building Types in Bolu

This zone takes part in Western Black Sea region with 8.294 km² area. Bolu has nine counties with the centrum: Dörtdivan, Mengen, Mudurnu, Gerede, Göynük, Kıbrıscık, Seben, Yeniçağa. This city is located in the first-degree earthquake zone according to the seismic risk map of Turkey (Figure 4.9). In this city centrum and urban development places completely rest on alluvial soil. The material, which constitutes ground, is congested in northern part of the city and loose in southern part of the city and underground water layer is very closed to the surface of the ground. There occurred a lot of earthquakes with moderately damaged and without causing damage. However, in 1944 and 1999 earthquake, there existed heavy damages in a lot of buildings[14].

The North Anatolian fault passes through the town of Gerede which was destroyed by 1944 Bolu-Gerede earthquake. In the second half of 1999, two devastating earthquakes shook the Marmara and Bolu regions of Turkey, the industrial heartland of the country to the east of Istanbul. Therefore, in order not to be affected from an active fault passing through Ilıcalar that is located in the southern part of the city and to escape from the loose ground¸ widening of the city into the southern part should be prevented. Building types is generally five-storey apartment buildings. However, the permanent housing units which built after 1999 earthquakes are three-storey. A selection of the examples of is given in Figure 4.10. Elevation and plan type of a reinforced concrete apartment building are seen in Figure 4.11 and Figure 4.12.

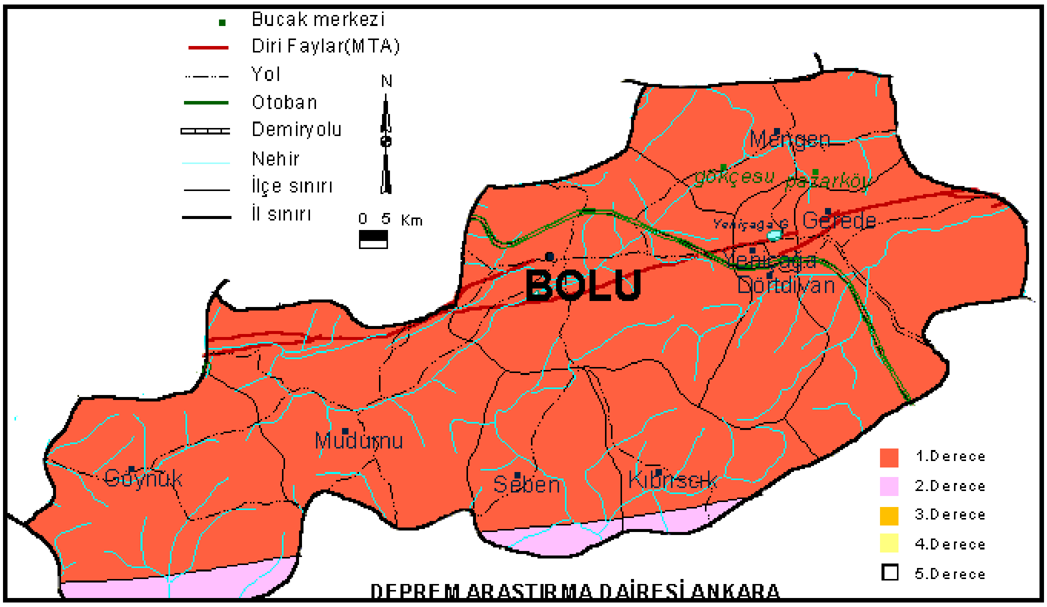


Figure 4.9 Seismic Risk Map of Bolu[15]

[14] *Governorship of Bolu*, <http://www.bolu.gov.tr > Last accessed: September 14, 2005
[15] *Deprem Araştırma Dairesi,* <http://www.deprem.gov.tr/linkhart.htm> Last accessed: October 14, 2005

Figure 4.10 Building Types of Bolu (The photo archive of Er Akan, 2006)

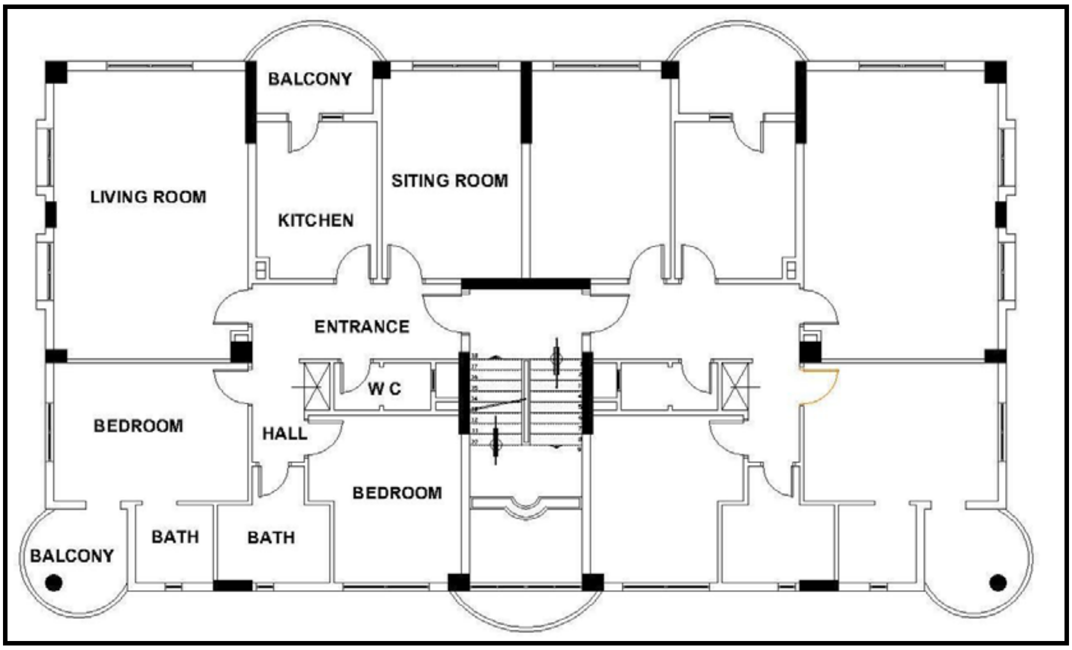


Figure 4.11 Plan of an Apartment Block in Bolu
(constructed after 1999 earthquakes)

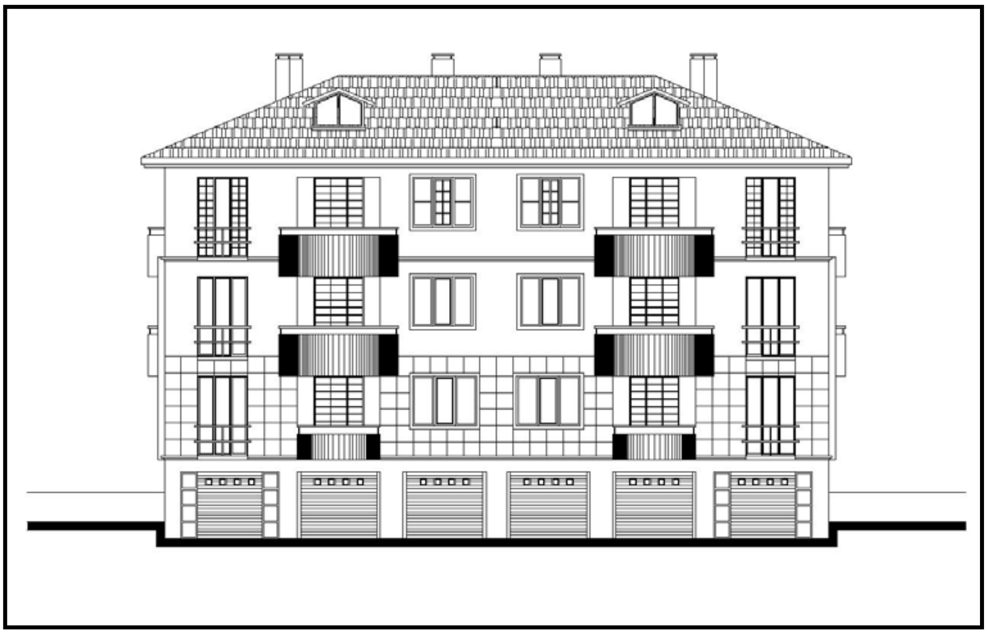


Figure 4.12 Façade of an Apartment Block in Bolu
(constructed after 1999 earthquakes)

4.4.2 Building Types in Çankırı

Çankırı is located in between Kızılırmak and western black sea basins in middle Anatolia. The neighbouring cities are Bolu in west, in northwest Karabük, Kastamonu in north, Çorum in east and Ankara and Kırıkkale in south. The altitude from the sea level is 723m and it has 7388 km² area[16]. This city is also located in the first-degree earthquake zone according to the seismic risk map of Turkey as seen in Figure 4.13. The area is generally mountainous and characterized by valleys. Also, North Anatolian Fault zone cuts across the area in its central parts. Therefore, a moderate size (M=6.0) earthquake occurred on June 6, 2000 in Orta–Çankırı and many buildings were damaged in this earthquake. Photographs that were taken during field trip can be seen in Figure 3.14. Also, elevation and plan type of a reinforced concrete apartment building are given in Figure 4.15 and 4.16. Housing units are mostly reinforced concrete multi-storey apartment buildings as in the case of other case studies. They do not reflect the local characteristics of Çankırı. The total increase in population was reported as 8,09 %. This increase caused unhealthy urbanization as in the case of the other cities. Residential, offices and commercial facilities are seen in ground floor.

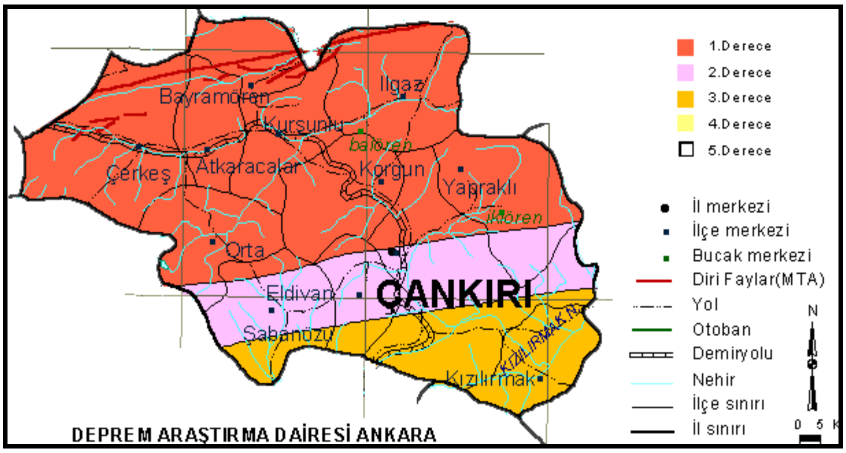


Figure 4.13 Seismic Risk Map of Çankırı[17]

[16] *Governorship of Çankırı,* <http://www.cankiri.gov.tr> Last accessed: September 14, 2005
[17] *Deprem Araştırma Dairesi,* <http://www.deprem.gov.tr/linkhart.htm> Last accessed: October 14, 2005

Figure 4.14 Building Types of Çankırı (The photo archive of Er Akan, 2006)

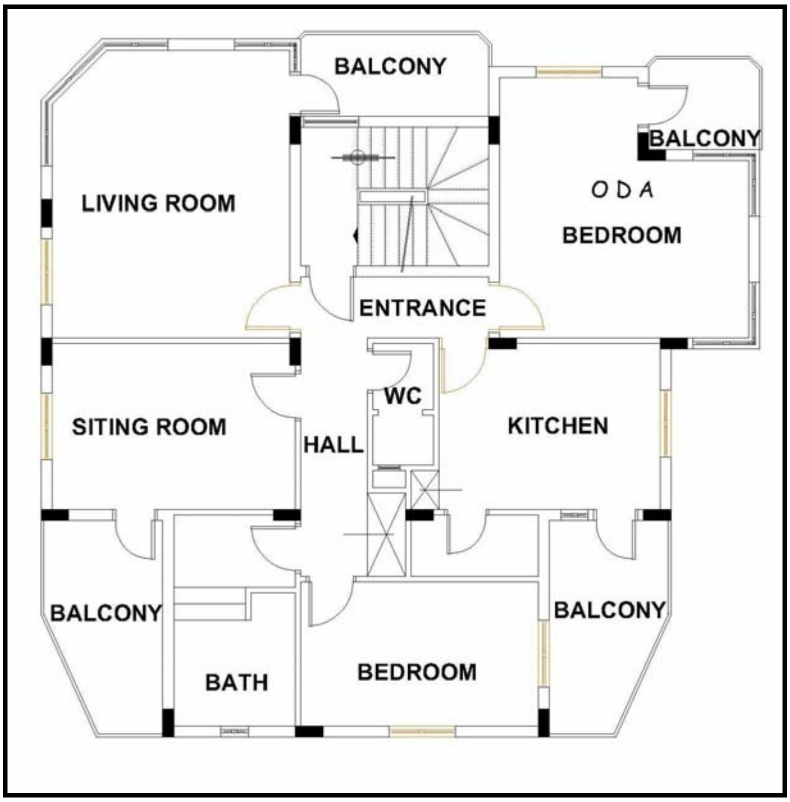


Figure 4.15 Plan of an Apartment Block in Çankırı (constructed in 1957)

Figure 4.16 Façade of an Apartment Block in Çankırı (constructed in 1957)

4.4.3 Building Types in Çorum

Çorum is located in the Central Anatolian Region, which had been suitable for settlements throughout history. Çorum is also on the main route connecting the Karadeniz Region with the rest of Turkey. The neighbouring cities are Çankırı in west, in southwest Kırıkkale, Samsun in northeast, Sinop in north, Çorum in east and Yozgat in south. The height from the sea level is 801m. Çorum is located on the North Anatolian Fault (NAF) line, which is in the Alp-Himalayan Seismic Belt. NAF is passes from the point that is located 20 km away from the center of the city[18]. It is one of the big cities with its industry and 12 820 km² land area. Urbanization period gained acceleration after 1950s. Beginning from these years various sections of industry have been developed in Çorum. The two important industry sections in the city are brick and tile industry. Development and demand in the housing industry caused to develop the brick industry in the city. Today there are more than 40 brick and tile factories in Çorum. Housing stock in the city is composed of 5-7-storey reinforced concrete apartment buildings (Figure 4.18), in spite of the fact that it is in earthquake region. There is also some masonry housing units whose elevation and plan type are seen in Figure 4.19-4.20.

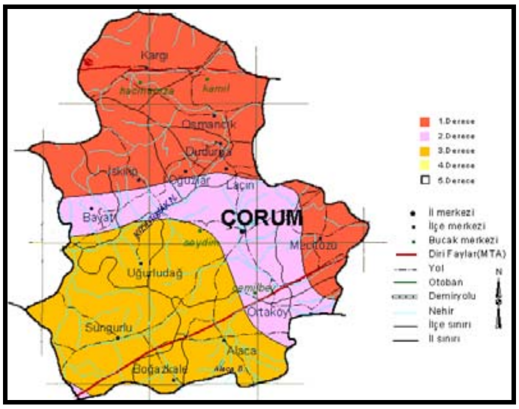


Figure 4.17 Earthquake Map of Çorum[19]

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[18] *Governorship of Çorum*, <http://www.corum.bel.tr/bpi.asp?caid=459&cid=853> Last accessed: September 14, 2005

[19] *Deprem Araştırma Dairesi,* <http://www.deprem.gov.tr/linkhart.htm> Last accessed: October 14, 2005

Figure 4.18 Building Types of Çorum (The photo archive of Er Akan, 2006)

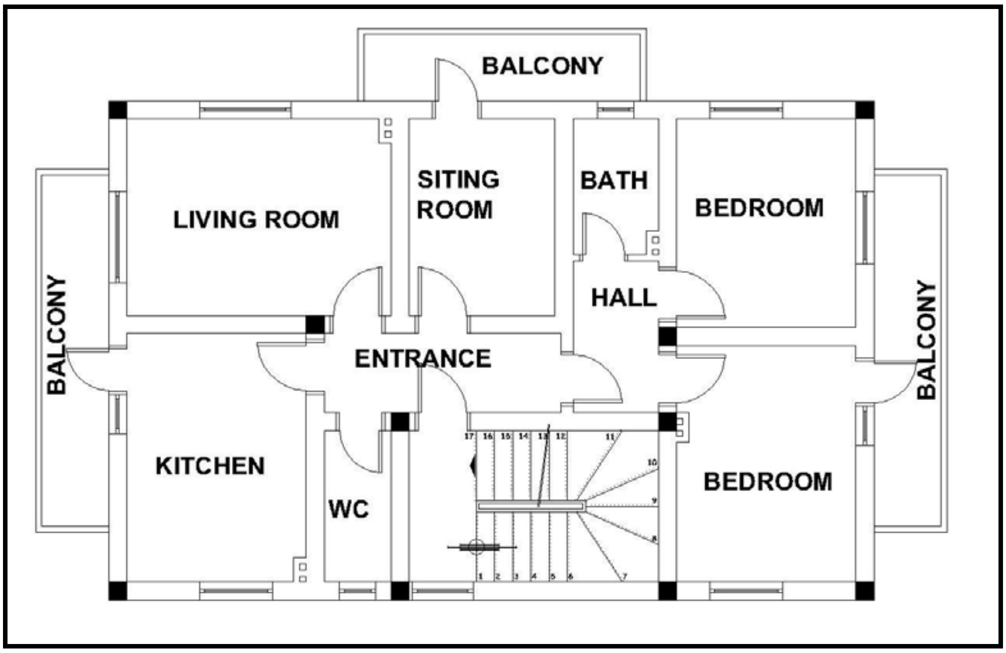

Figure 4.19 Plan of an Apartment Block in Çorum (constructed in 1958)

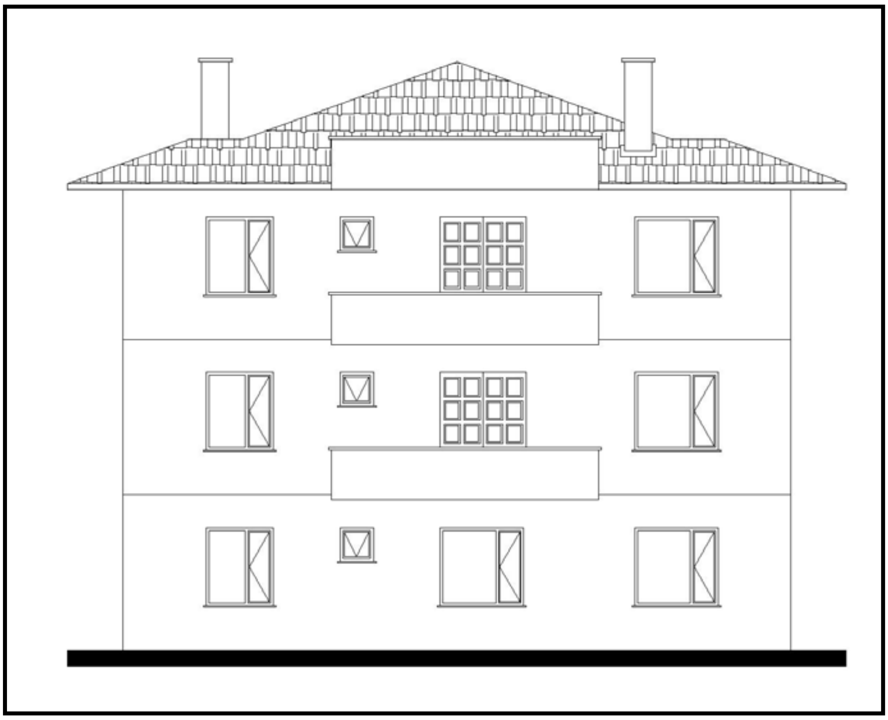

Figure 4.20 Façade of an Apartment Block in Çorum (constructed in 1958)

4.4.4 Building Types in Düzce

It is located in West Black Sea region which is in an active earthquake zone (Figure 4.21). Bolu, Sakarya and Zonguldak are the neighbouring cities of Düzce. The aititude from the sea level is 160 m and the city has 1065 km^2 area. Until 1967 the buildings were traditional timber framed buildings with two-storey. In 1970s multi-storey apartment buildings started to be constructed under the effect of urbanization. Therefore, the abandonment of traditional building techniques has disappeared rapidly. In 1980s cooperative apartment houses began to be appearing in Düzce. Both the number of buildings and stories of the buildings were increased during this period. The number of stories in Duzce was in the range of two to seven; however three to five stories were more common among residential buildings around the city center until 1999 earthquakes (Figure 4.23). A destructive earthquake of magnitude 7.2 occurred in Düzce on November 12, 1999 and caused demolitions in these buildings with many loss of life. Düzce was an excellent laboratory in order to observe the effects of the building regulations and construction techniques on the earthquake performance of the buildings. Thus some additional requirements and limitations were added to the earthquake code of Turkey. One of these limitations is that the limitation on the numbers of the storey to two-storey in building code of 2001.

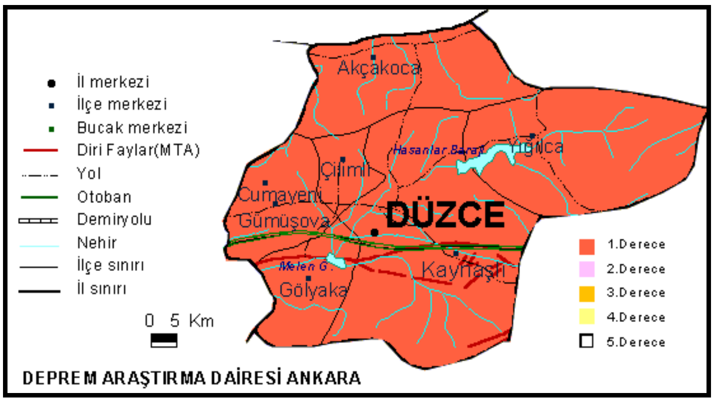

Figure 4.21 Earthquake Map of Düzce[20]

[20] *Deprem Araştırma Dairesi,* <http://www.deprem.gov.tr/linkhart.htm> Last accessed: October 14, 2005

However, if the soil characteristics are good, the number of storey could be increased. In addition to the limitation in the number of storey another limitation was prepared for the column and shear wall dimensions. In Figure 4.22 an example of apartment plan is provided that was designed according to these limitations. After 1999 earthquakes, nearly 10000 new permanent settlements were built for homeless people. Moreover, TOKİ continues to construct new settlements, there are 3000 new housing blocks under construction because there is still need for new housing units[21]. Although the city is located on a high seismic zone the proportion of emigration is significantly high. Thus construction of apartments, new roads and infrastructure has increasingly been continuing. These constructions carry on without any feasibility studies on the needs of people and local characteristics of the city. After 1999 earthquakes mass housing projects are constructed by using reinforced concrete as a building material. There is no remainder of the traditional construction techniques.

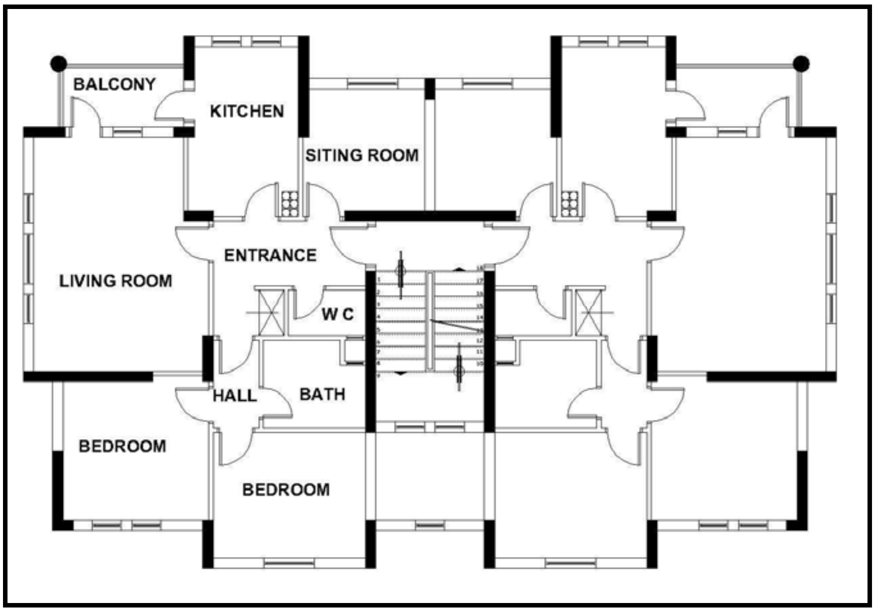

Figure 4.22 Plan of an Apartment Block in Düzce
(constructed after 1999 earthquake)

[21] *Governorship of Düzce*, <http://www.duzce.gov.tr/> Last accessed: September 14, 2005

Figure 4.23 Building Types in Düzce (The photo archive of Er Akan, 2006)

4.4.5 Building Types in Kastamonu

Kastamonu, which is placed in Western Black Sea Region, has boundaries with Sinop, Bartin, Karabük, Çankırı, and Çorum. The altitude from the sea level of the centrum is 780m and it has 13.108 km^2 areas.[22] The half of the city is in first-degree earthquake zone (Figure 4.24). Kastamonu is placed on slopes that rise with a sharp inclination after flat areas in two sides of the brook in the city. Roads that are placed in slopes of hills and provide transportation go towards the hills as parallel to the inclination. Buildings, which are placed as parallel to the lines of inclination, have wide base areas owing to the arrangements in the land. However buildings erected on the ways that intersect lines of inclination perpendicularly, have less base areas and these buildings attached to each other. Number of buildings decrease near the castle, because of the increasing inclination. One third of a year the weather is almost rainy. Because of amount of rain, which cannot be neglected, shapes of the roofs on buildings in Kastamonu have been affected directly. However, for monetary benefit, by demolishing traditional buildings new reinforced concrete buildings were erected which can bee seen in Figure 4.25.

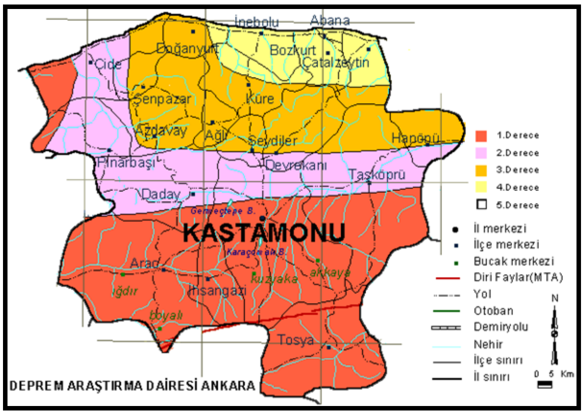

Figure 4.24 Earthquake Map of Kastamonu[23]

[22] *Governorship of Kastamonu,* <http://www.kastamonu.gov.tr> Last accessed: September 14, 2005

[23] *Deprem Araştırma Dairesi,* <http://www.deprem.gov.tr/linkhart.htm> Last accessed: October 14, 2005

Figure 4.25 Building Types of Kastamonu (The photo archive of Er Akan, 2006)

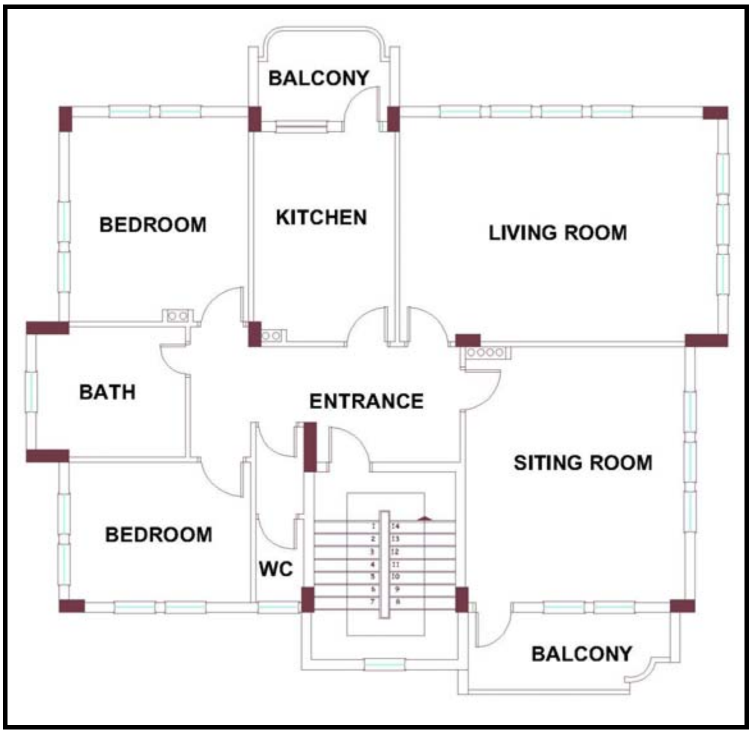

Figure 4.26 Plan of an Apartment Block in Kastamonu (constructed in 1956)

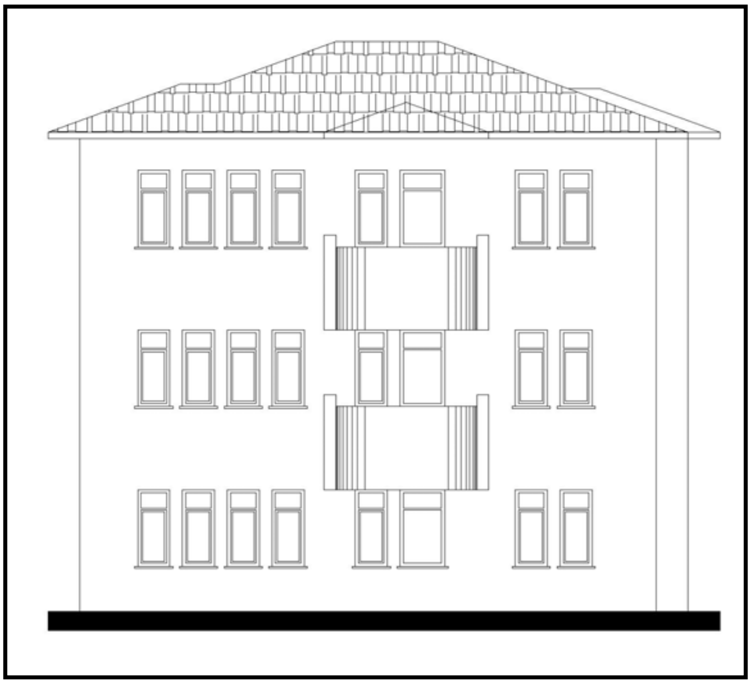

Figure 4.27 Façade of an Apartment Block in Kastamonu (constructed in 1956)

4.4.6 Building Types in Kırıkkale

Kırıkkale is placed in Middle Kızılırmak that takes part in Anatolia. This city is encircled with Çorum, Yozgat, Kırşehir, Ankara, Çankırı. It is mostly in first-degree earthquake zone (Figure 4.28). After foundation of Mechanical and Chemical Industry Corporation factories the first regular settlement began with MKE houses. However, settlement of personal buildings did not develop regularly. After 1960, regular urbanization and settlement started firstly in the city centre. Besides, after 1985 reinforced concrete apartment buildings were erected in regions of housing estates. The houses placed in districts, small towns and villages are generally adobe with one storey and reinforced concrete. Recently, in districts construction of reinforced concrete residences have been started. This city is in the scope of the Emergency Action Plan and so in the city with six-administration building application type project 1014 unit building are being constructed by Housing Development Administration of Turkey[24]. Maximum number of storey is ten in Kırıkkale although most of the city is located in the first earthquake region. Photographs of building types that were taken during field survey are seen in Figure 4.29 and also a plan example from the residential buildings is illustrated in Figure 4.30 -4.31.

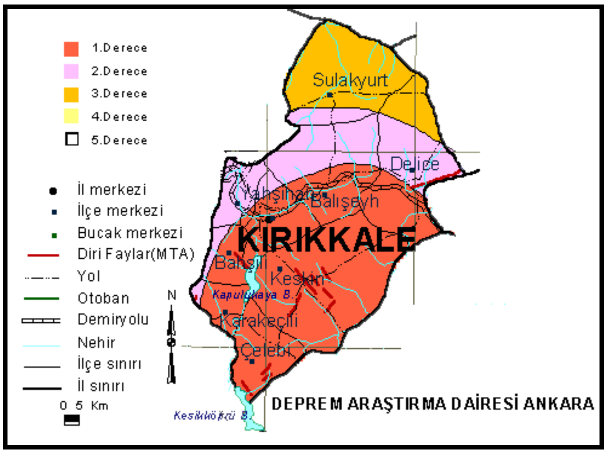

Figure 4.28 Seismic Risk Map of Kırıkkale[25]

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[24] *Governorship of Kırıkkale*, <http://www.kirikkale.gov.tr/ilplanlama.htm> Last accessed: September 14, 2005

[25] *Deprem Araştırma Dairesi,* <http://www.deprem.gov.tr/linkhart.htm> Last accessed: October 14, 2005

Figure 4.29 Building Types of Kırıkkale (The photo archive of Er Akan, 2006)

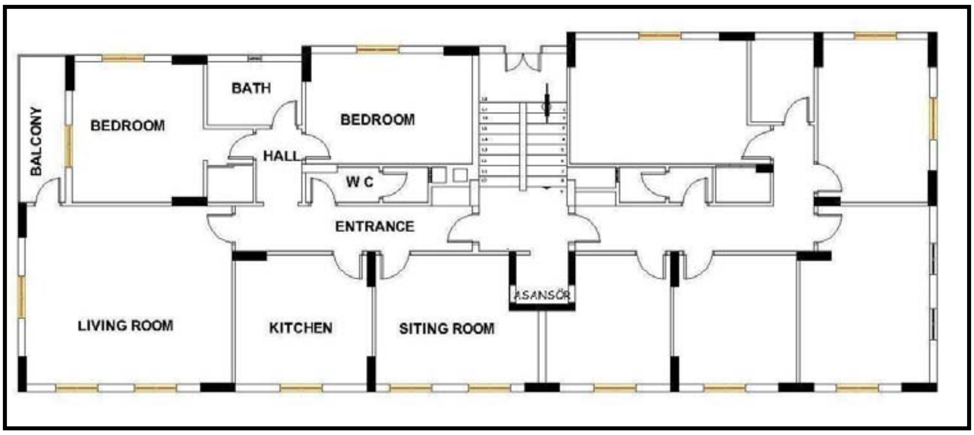


Figure 4.30 Plan of an Apartment Block in Kırıkkale (constructed in 1960)

Figure 4.31 Façade of an Apartment Block in Kırıkkale (constructed in 1960)

4.5 Evaluation of the Investigated Cities

As seen in the case studies most of the housing unit is composed of multi-storey reinforced concrete residences. Observations show that these units have been built only to satisfy the main functional requirement; they do not have regional characteristics even in rather different climates and regions. There is no difference between the building in Bolu and the building in Kastamonu or Çorum. Although these case studies are located in first-degree earthquake region, there is no distinction between these buildings and a building that is not located in an earthquake region. The main reasons for these situations are the area of the parcels, Town-Planning Codes, and Turkish Earthquake Code. Shape and configuration of balconies, cantilevers, the ratio of openings to floor area, the distance between two buildings, and the distance between the road and building are all specified in building codes. However, it is possible to construct different buildings which reflect the local characteristics of the region. In the visited cities it is ignored and people continues to construct typical reinforced concrete apartment blocks in every cities which have different characteristics.

Consequently, to make a comparison every data of the visited cities is collected in tables (Table 4.2 and Table 4.3). In these tables data about population, earthquake region, climate, and number of factories of construction sector are included. Furthermore, according to information gained from Turkish Statistical Institute the numbers of residential buildings in different structural systems are shown in the Table 4.3.

Finally, after the evaluation of the visited cities Bolu is selected for the proposal of this thesis. The availability of the access for the database for Bolu constituted the main reason for its selection for detailed information. Apart from that, there constructed several buildings after the earthquakes with a clear understanding of the earthquake phenomenon mostly due to its being sensitive to environmental and urban development issues.

Table 4.2 Comparison of the visited Cities

	BOLU	ÇANKIRI	ÇORUM	DÜZCE	KASTAMONU	KIRIKKALE
Area	8194.45 km^2	7565.74 km^2	12 786.70 km^2	2566.10 km^2	13 346.88 km^2	4519.90 km^2
Population (1990 and 2000)	1990: 262 919 2000: 270 654 2007: 270 417	1990: 249 344 2000: 269 579 2007: 174 012	1990: 608 660 2000: 597 065 2007: 549 828	1990: 273 679 2000: 314 266 2007: 323 328	1990: 423 206 2000: 376 725 2007: 360 366	1990: 350 360 2000: 383 508 2007: 280 234
Density= Population/ Area	33	23	43	126	27	62
Earthquake Zone	1	1	2	1	1	2
Past Earthquakes	1944/Gerede M=7.2, 3959 dead 1944/Mudurnu M=5.6, 30 dead 1957/Abant M=7.1, 52 dead 2000 M=5.1	1902 M=5.6, 4 dead 2000 M=6.1, 2 dead	1942 M=5.9, 25 dead 1996 M=5.4, 6 injured	1944 M=5.4 1999 (Kocaeli) M=7.4, 270 dead 1999 (Düzce) M=7.5, 763 dead	-	-
Number of Brick Factory	-	2	35	1	-	-
Number of CMU Factory	-	-	-	-	-	1
Number of RMC Factory	2	-	-	2	-	1
Number of Cement Factory	1	-	1	-	-	-
Number of Yapı Denetim	2	-	-	7	-	-

Table 4.3 (Continued) Comparison of the visited Cities (Turkish Statistical Institute, Building Census, 2000)

			BOLU	ÇANKIRI	ÇORUM	DÜZCE	KASTAMONU	KIRIKKALE
Number of Residential Buildings According to Structural Systems	1- Frame Construction	Steel	4	-	-	3	-	29
		Reinforced Concrete Block	23	5	75	33	46	121
		Hollow Concrete Block	199	103	442	225	561	157
		Brick	7734	4227	5720	9956	13753	9284
		Wood	2490	294	74	187	2131	21
		Stone	22	426	65	4	76	13
		Sun Dried Brick	235	3296	4626	203	5381	94
		Other	52	8	22	20	161	25
		Total	**10 759**	**8359**	**11 024**	**10 631**	**22 109**	**9744**
	2- Masonry Building	Brick	2607	3235	26033	1894	1706	16 462
		Hollow Concrete Block	332	197	890	245	428	4361
		Wood	1734	986	2818	1177	1961	674
		Stone	82	447	191	31	284	2006
		Sun Dried Brick	92	1552	7898	57	324	6646
		Other	56	39	496	64	48	625
		Total	**4903**	**6456**	**38326**	**3468**	**4751**	**30774**
	3	Prefabricated	341	26	-	286	-	19
	Total Residential Units		**16 003**	**14 841**	**49 350**	**14 385**	**26 860**	**40 537**

4.6 Detailed Information about the Characteristics of the Selected Region: Bolu

Geographical Position: Bolu is in West Blacksea Region and surrounded by Zonguldak in North, Karabük in north east, Çankırı in east, Ankara in south, Bilecik and Eskişehir in south west, Düzce and Sakarya in west. In addition, Bolu is near the highway that connects İstanbul to Ankara and passes through the Bolu plain. The urbanization of the city has been developed in the region of D-100 highway periphery. Therefore, in the aspects of the urbanization, the city has been divided into two main regions as north and south.

Seismic Properties of the City: Bolu is in the active earthquake zone. North Anatolian fault line that comes from Karlıova and Erzincan and enters into Bolu region is very active as tectonic. The geologic characteristic of the city that formed by the existence of North Anatolian Fault, makes Bolu first degree risky earthquake region. The effects of Gölcük earthquake occurred in 17 August 1999 as 7.5 strength was observed in İstanbul and Bolu. The second destructive earthquake centered as Düzce-Beyköy in 12 November 1999 and magnitude of 7.2 affected mostly Düzce and Bolu. Bolu like the other cities in the earthquake zones was affected seriously because of the unplanned urbanization, usage of landing and mistakes in the application of public improvements.

Economic and Demographic Condition of the City: Bolu located between two metropolises like Ankara and İstanbul has important transportation and position advantages for social and economic developments. However the economy of the city is based on agriculture and trade. In 1999, by the application of 584 numbered law about "Foundation of one city and two districts" Düzce became city and a lot of districts, county, villages were joined to Düzce. So, in this city there occurred a lot of important demographic, social and economic improvements[26].

Population: According to result of the General Population Census in 2000, the total population of Bolu is 270.654. The ratio of this population to total Turkey population

[26] Interview with the Governorship of Bolu, June 14, 2007.

is 3.8 over one thousand. According to Turkey general population extent, the population of Düzce is ranked as 62. The central district of Düzce is the most crowded one with 135.009 people. In addition, the population density of Bolu central district' (ratio of the population to 1km^2) is higher than the average of Turkey. The population growth rate has been always under Turkey's general rate. Today according to the results of 2007 population cencus, the population of Bolu is 270.417[27].

Urbanization: The reasons for the increasing deviation of the Turkey's population are listed as follows: Decreasing need for man power in agriculture because of technology, not enough income for a family in farming, much sharing in farming land, fluctuations in product prices, natural disasters and etc. Since there are no satisfactory conditions in rural areas, the population in the villages of Bolu migrates to the cities as in the other rural areas of Turkey. The most important unsatisfactory condition is the restricted economic and cultural opportunities in the rural areas of Turkey.

Housing Industry: Since the foundation of Republic of Turkey in 1923, in the different time periods the different sides of housing problem has gained importance. In this context, from 1923 to 1950 population and urbanization growth showed slow progress as a result of which there was no housing problem. As mentioned in previous chapters, after 1950 the urbanization rate commenced to rise. For this reason application of housing and institutional housings could not be enough for housing needs according to the urbanization rate. Later than 1965, the build and sell system and slum house production began to accelerate in 1970 mass housing aroused but this housing type could not be institutional and cooperatives became the most important housing constructor[28].

In 1980s, there were evolutions not only in the urbanization, but also in the public life. In this period for Bolu, it was tried out to overcome that residual urbanization and housing problem from previous periods and the problems arise with the new period. After 80's housing constructors started to instruct multiple storey buildings

[27,29] Interview with the Governorship of Bolu, June 14, 2007

instead of user's own constructions like shanty. Moreover, in residentially-zoned areas of the cities there occurred similar construction applications and effort of the cooperatives increased. Because of the population growth in the center of Bolu, need for housing increased day by day in 1985-2000. The housing potential of the city is not enough for the growing population so the prices for sale and hiring are always going up in the city. Unplanned urbanization, wrong land using and mistakes in the application of residentially-zone development with the earthquake caused loss of property and life. In addition, the damage ratios are 53% in public buildings, 46% in private buildings and also 2000 people were out of work[29]. After Düzce-Kaynaşlı Earthquake in 1999 construction sector stopped and entered a crisis. During this recession period in construction sector, there were an intensive study on the rearrangement of the regulations and so the building permit was not given for any kind of building. On the other hand constructions was going on for rehabilitation and strengthening of the damaged buildings.

After 2005 construction sector gained an acceleration and started to produce new housing units especially mass housing. Until 2005, according to story limitation rules, buildings should have maximum three-story. However, in the beginning of 2005, Municipality of Bolu decided to increase the number of story from 3 to 5 providing the rules of earthquake code in the construction process. They aimed to raise construction sector again with this new alteration in the story limitation rules[30].

Increase in the demand for housing after 2005, seeks Municipality to prepare new built up areas. However, after devastating earthquakes in 1998, thought of people about the apartment height changed. People do not want to live in the high-rise apartment buildings due to the psychological effect of the earthquakes who were living in the high-rise apartment buildings before earthquakes[31].

[29] Information from the Ministry of Public Works and Settlements, <http://www.bayindirlik.gov.tr> Last accessed: November 17, 2007

[30] Interview with the Governorship of Bolu, Last accessed: June 14, 2007.

CHAPTER 5

VERIFICATION OF THE SELECTED HOUSING'S SAFETY WITH NUMERICAL SIMULATION METHOD

The use of masonry for new building constructions seems to be ignored based on the literature survey in the previous chapters although its inherit properties and advantages as a construction material like earthquake resistance, economy, opportunities for new employment etc. The design procedure considers the earthquake zone, soil, and site geology characteristics, the occupancy of the building, the structural system, the height of the building and the configuration of the structure both vertically and horizontally. Among these selection of the structural system is one of the most important parameters which is, in fact, highly dependent on the geographical location of the building, local characteristics of the site, potential of the selected structural system and country conditions.

The main purpose of this study is not to demonstrate that masonry buildings have better performance than reinforced concrete buildings against earthquake forces but to show that it is possible to construct a four-story residential building with masonry bearing walls instead of reinforced concrete beam and column skeleton system keeping the existing plan scheme in other words without changing its architectural characteristics.

The advantages of this proposal explained in the Chapter 3. In summary, if masonry is used for residential buildings there are many advantages such as low cost, speed of erection, new employment, and training of specialized worker etc. This proposal is not for the apartment blocks located on the main streets with commercial units in their ground floor but it is only for the four or five-storey classical apartment units in the cross streets.

In consequence, it is tried to indicate using masonry as a material for the main bearing system of residential units without compromising from building safety. For this purpose a typical reinforced concrete apartment building from Bolu is selected. Two distinctive models (by using reinforced concrete and brick masonry) are generated with this four-story residential building's plan scheme. While creating the models nothing is changed in the architectural design decision of the selected residential building from Bolu. Then, the finite element models of these buildings are generated with Sap 2000 version 10 commercial structural analysis software. The aim of these analyses is to verify the proposal with numerical simulations. Then, the results of the analyses are compared in terms of modal displacements and internal forces due to gravity and earthquake forces. The comparison of the results revealed that the hypothesis of this study is verified.

5.1 Geometric and Material Characteristics of the Selected Building

As a case study, a 4-storey residential building with a regular geometrical shape is selected considering the fact that it is a classical model used in reinforced concrete residential buildings in the visited cities. Two distinctive numerical models are generated using the original dimensions of the architectural drawings. The buildings will be abbreviated as follows in the succeeding parts of the study: reinforced concrete apartment model (RCA) and brick masonry apartment model (BMA) respectively.

Both models have rectangular plan configurations with 12 m x 22 m as seen in Figure 5.1. and Figure 5.2. The height of both structures from foundation level to the top is 14.5 m. Reinforced concrete slabs with 150 mm thickness are used in both RCA and BMA.

Initially for the RCA, in order to obtain the accurate structural behaviour, 3-D model is prepared according to actual cross-sections of all elements of framed systems. There are four different column sections in the RCA which are 25 x 100 cm, 250 mm × 2000 mm, 500 mm × 500 mm and 400 mm × 600 mm (Figure 5.2). These columns are modelled with frame elements, while floors of the structure modelled with shell elements. With the same geometry and architectural characteristics the second model BMA is established. It has brick masonry walls with 300 mm thickness instead of reinforced concrete frame system (Figure 5.2).

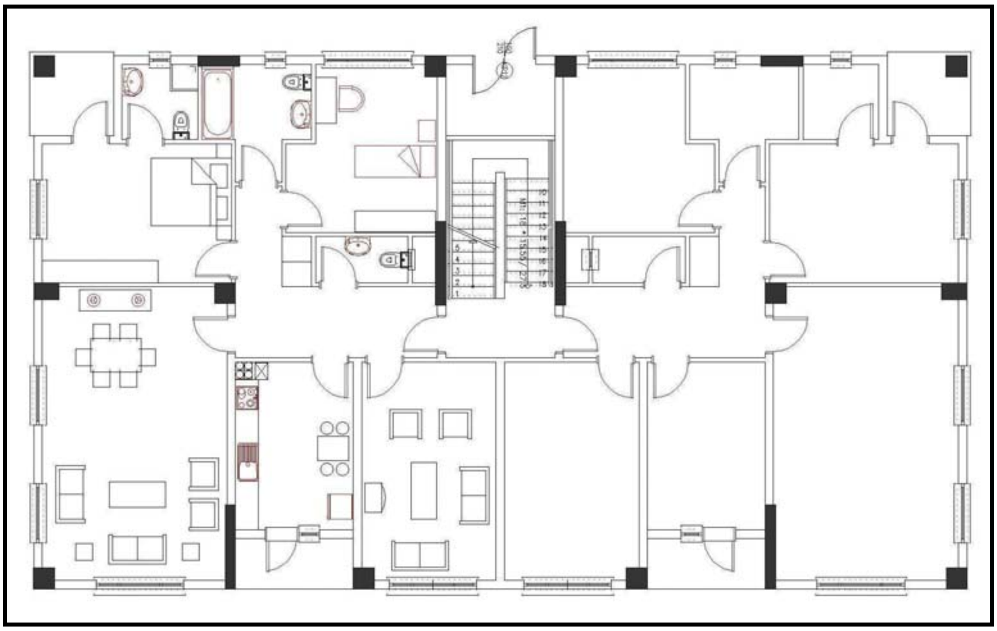


Figure 5.1 Reinforced Concrete Apartment Model (RCA)

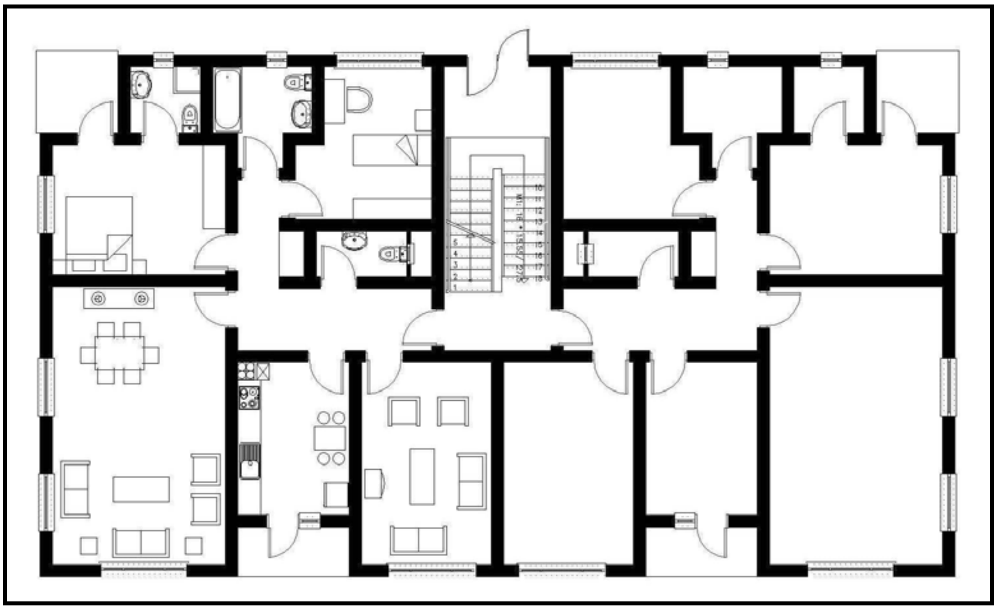


Figure 5.2 Brick Masonry Apartment Model (BMA)

5.2 Finite Element Analysis of the Selected Housing Units

5.2.1 Description of the Finite Element Method

The development of computers and new numerical methods made the analysis of structures easier. Finite Element Analysis (FEA) is an analytical engineering tool which is developed in the 1950's, is used for the evaluation systems and structures. Theoretically the finite element method can be utilized to find approximate solutions to any kind of engineering problems with many complex variables. Recently the method has continually developed and many engineers use FEA for the analysis of the complex structures which have different geometries, materials, and loading conditions. To calculate stress points, deflections, movement of loads and forces, and other basic physical behaviours this method uses integral calculus, very large matrix arrays and mesh diagrams. Then, it compares the results with acceptable defined limits.

Finite element method is based on representation of the structure as a finite number of lines and two or three-dimensional minor classes called as finite elements. The connection points of the elements are called nodes. The intention beyond this is to convert the problem with infinite number of degrees of freedom to one with a finite number. The stresses and displacements are calculated for each finite element and these results are transferred to the whole structure (Toker, 2000, Unay 1997). In other words, the analysis is done by modeling the structure into thousands of small pieces (finite elements). Breaking the entire structure into such small pieces or "elements" is called discretization. Accuracy of the analysis depends on the number of elements used in the model.

Because of the amount of calculations required, even for simple elements, this method is limited to computer applications. Even so, with large complex elements idealized into small numerous finite elements, computation time can be significant. Thus, typically, results for more complex structures require more computing power for this method (Tüken, 2004).

5.2.2 Description of the Finite Element Model of the Selected Building

In order to verify the validity of the proposed method, models are tested by the finite element analysis with Sap 2000 structural analysis software (Sap 2000, 2000). Computer models are generated, according to actual geometry and cross-sectional sizes of structural elements.

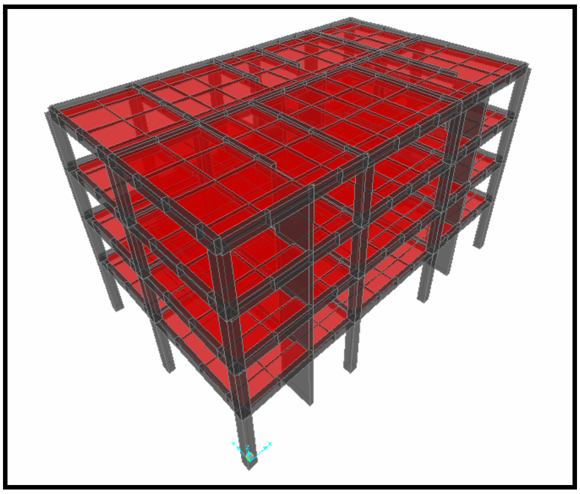


Figure 5.3 Finite Element Model of RCA

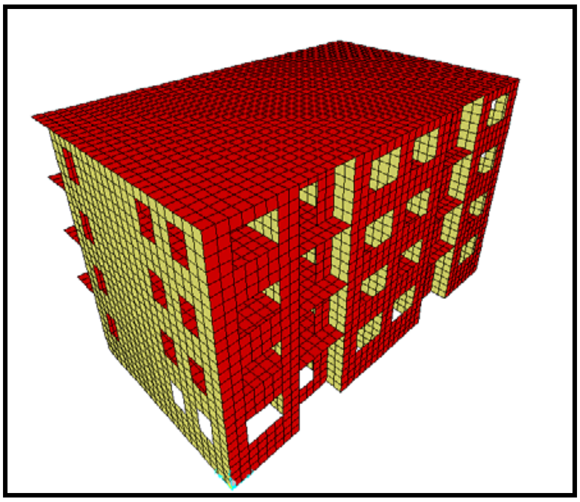


Figure 5.4 Finite Element Model of BMA

Table 5.1 Values Used in the Computer Analyses

Property of walls	For BMA Model	For RCA Model
Material	Brick	Reinforced concrete
Thickness (cm)	30	20
Modulus of Elasticity, E (KN/m^2)	3500000	28500000
Shear Modulus (KN/m^2)	1458333.3 brick walls 11875000 RC slabs	11875000
Weight per unit volume (kN/m^3)	15 (for brick walls)	25 (for columns)
Weight per unit volume (kN/m^3)	100 (for slabs)	70 (for slabs)
Mass per unit Volume	1.5291 (15/9.81) (brick walls)	7.1356 (70/9.81) (slabs)
Mass per unit Volume	10.1937 (100/9.81) (RC slabs)	2.5484 (25/9.81) (columns & beams)
Poisson's Ratio	0.2	0.2
Column Sections (mm)	-	250/2000 250/1000 500/500 400/600
Beam Sections (mm)	-	250/600
Property of slabs	**Masonry**	**Concrete**
Material	Reinforced concrete	Reinforced concrete
Thickness (mm)	150	150
General Characteristics	**Masonry**	**Concrete**
Number of Storey	4	4
Total Height (m)	14.5	14.5
Building Type	residential	residential
Project Parameters of the Buildings	**Masonry**	**Concrete**
Project of the building	Not Exist	Exist
Earthquake Zone	1	1
Soil Class	2	2

The first model is the reinforced concrete apartment model (RCA) consists of 408 frame elements, 360 shell elements and 477 joints. Figure 5.3 presents the 3D view of the RCA model. On the other hand, another model is created by using brick masonry walls instead of reinforced concrete frame system (Figure 5.4). This BMA model is composed of 12400 shell elements 11913 joints. Table 5.1 gives the values used during the computer analyses.

In both RCA and BMA models similar load patterns are applied. Three different loads are used in these cases. The first one (L1), is the total load which is the sum of the dead load and live load. The second load (L2) is the earthquake load in the x direction. The third one (L3) is the earthquake load in the y direction. To evaluate the results of the analyses there are two different load combinations are defined. These are G+EQx (dead load+live load+earthquake load in the x direction) and G+EQy (dead load+live load+earthquake load in the y direction).

5.2.3 Methodology for the Comparison of the Analysis Results between BMA Model and RCA Model

As a methodology for the analyses, the results are compared with each other in terms of modal periods, displacements, moments and stresses. This comparison is made in order to demonstrate if the selected reinforced concrete apartment unit can be constructed by using masonry or not. For this aim, selected comparison parameters are modal periods, displacements and internal forces (moments, axial forces and stresses) which are defined below.

Modal Periods: First parameter is modal periods which also effects the displacement occurs in the structure. In fact, a real structure has nearly infinite number of modes. However, all of the modes are not concerned in practice. As Atımtay states, natural period is related with the mass, lateral rigidity and the energy absorption of a structure. These properties are determined by the geometric configuration in other words it is mostly related architectural decisions (Atımtay, 2001, pp. 207-209). While the number of modes increases, the modal deformed shapes become more complicated which is due to different deformation combinations of the nodes. For an ordinary building the number of modes considered is generally 3 or 4. Thus, in this study three modes of the models are observed. For this modal verification, the modal deformed shapes for SAP2000 are compared. When Tables 5.2 and 5.3 are investigated, it can be observed that the first three modes are deformations in the strong and weak direction and also torsion effect. One of the expected behavior of this kind of a masonry structure (BMA) is low modal periods. The results verify this expectation. Also the calculated modal periods of BMA lower than modal periods of RCA.

Displacements: The displacement is a significant value for the evaluation of the behaviour of a structure. Because it helps to indicate how the geometry of the elements and the original location of joints changes under that specific loading. There are some limitations for the values of displacements that are defined not only according to structural concerns but also according to serviceability conditions. When the values obtained for the displacements exceed the limit value; a failure is expected not necessarily because of the structural insufficiencies but also functional inadequacies. Displacement is a parameter to understand the physical problems that are encountered in the structure. Thus, displacements occured under earthquake forces are compared in BMA and RCA models in order to have an opinion about the structural differences between two model.

Moments, Axial Forces and Stresses: The last parameters which are used in this study are internal forces; moments and axial forces and stresses. There are also limitations for the internal forces as in the displacements. At the end of the analyses it should be checked that if the internal forces are within the limits or if there is any failure possibility through the structure. Thus in this study, the elements which are carrying the loads are analysed and checked under earthquake forces. Here, the aim is to observe the ratio of the present behavior to the expected capacity of that element in the structure and understand how much of structure’s capacity is used with these geometry and dimensions. So, moment and axial forces occured in the columns of RCA model compared with the M-N grafics drawn by Response 2000 (Response 2000, 2000) which defines the limit values of these columns. For the BMA model largest stresses (compression and tension values) are compared with the allowable stress that is defined in the earthquake code of Turkey.

5.2.4 Analysis Performed with Finite Element Model

The analyses of the two models are carried out according to load combinations as mentioned before. The results of the analyses are commented with the help of the mode shapes, stresses and internal forces according to graphical outputs of Sap 2000 as shown in Table 5.2 to Table 5.7. According to modal analyses, time periods are T1= 0.220 sec, T2= 0.200 sec, T3= 0.173 sec respectively in BMA model whereas these values are T1= 0.702 sec, T2= 0.466 sec, T3= 0.443 sec in RCA model.

For the BMA model, displacements are measured as Δ_x= 12.4 mm in EQx loading, Δ_y= 11.9 mm in EQy loading as shown in Table 5.4. For the RCA model the displacements are measured as Δ_x= 142.2 mm in EQx loading, Δ_x= 639 mm in EQy loading. Results show that displacements observed in the RCA model higher than the displacements in the BMA model. Then, for the BMA model, determined stresses are compared with the allowable stress value which is written in the earthquake code of Turkey. Allowable stress value for the brick in the code is 0.8 Mpa (800 KN). This value is increased three times to make a comparison. It is taken as f_{em}= 0.8 × 3 = 2.4 Mpa.(2400 KN)

According to load combinations, G+EQx and G+EQy, S22 (stresses in vertical direction) and S12 (shear stress) stress distributions of the BMA model are given in the following Tables. In Table 5.4 and Table 5.5 compression and tension distributions in the BMA model are seen. Location of the maximum compression and tension areas are shown on the diagrams (Table 5.6 and Table 5.7). Maximum compression and tension values in BMA model are in the safe side according to limitation of the earthquake code. Moment (M) and Axial Force (N) diagrams are generated by the Response 2000 software by defining the capacity of the columns to control safety of the RCA model (Response 2000, 2001). There are four different column sections in the RCA model as seen in the Table 5.1. M-N interaction diagrams which are constituted for each of them, compared to the actual M and N values obtained from the analyses in the SAP 2000. The results of comparison indicated that all actual moments and axial forces in the columns are not in the safe side.

Table 5.2 Mode Shapes of BMA Model

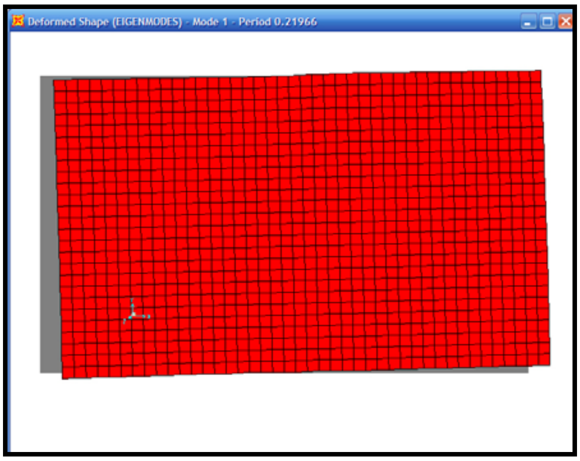
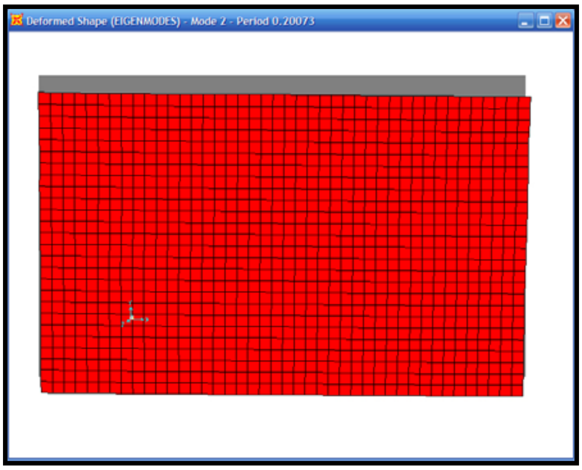
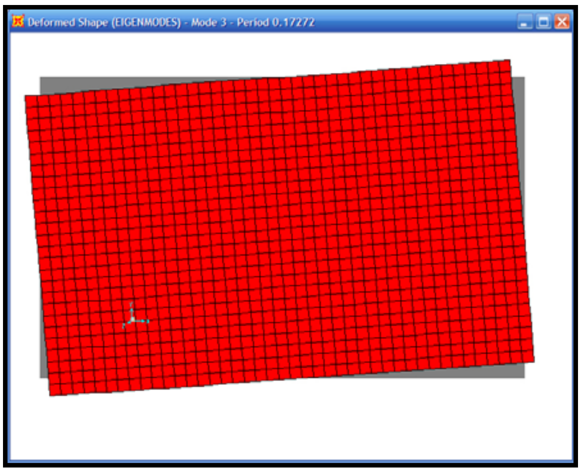
Mode 1 T= 0.21966 sec	
Mode 2 T= 0.20073 sec	
Mode 3 T= 0.17272 sec	

Table 5.3 Mode Shapes of RCA Model

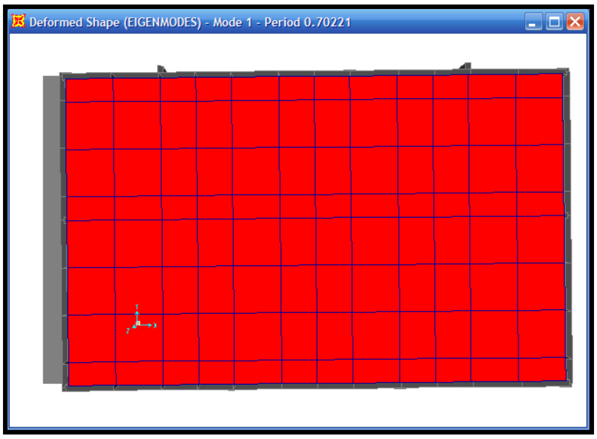
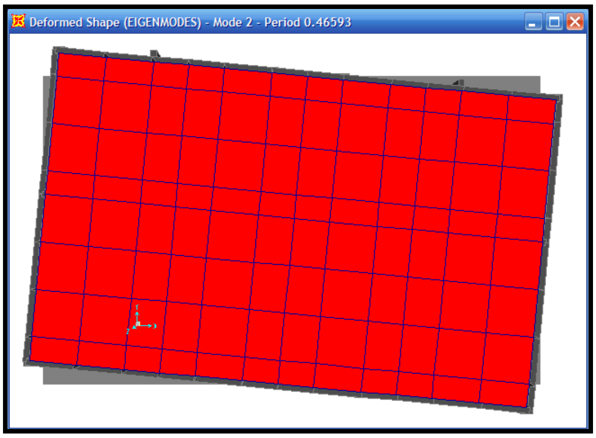
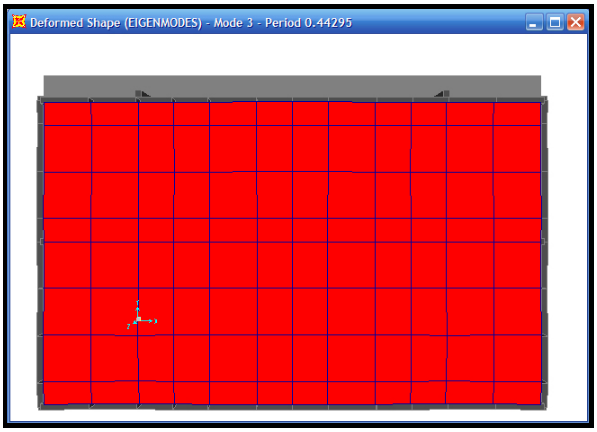
Mode 1 T= 0.70221 sec	
Mode 2 T= 0.46593 sec	
Mode 3 T= 0.44295 sec	

Table 5.4 Displacements under EQx and S12-S22 Diagrams under G+EQx in BMA Model

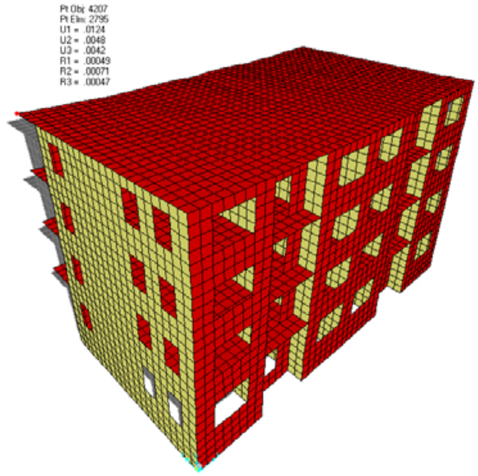
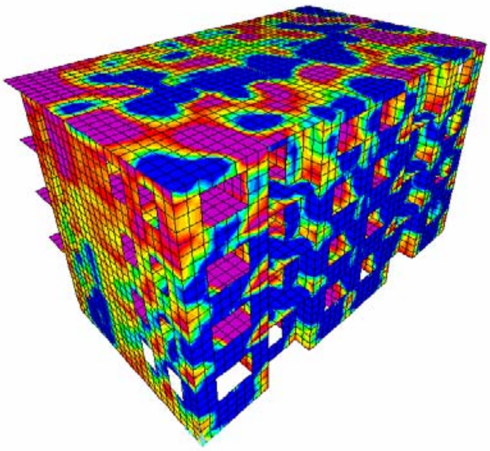
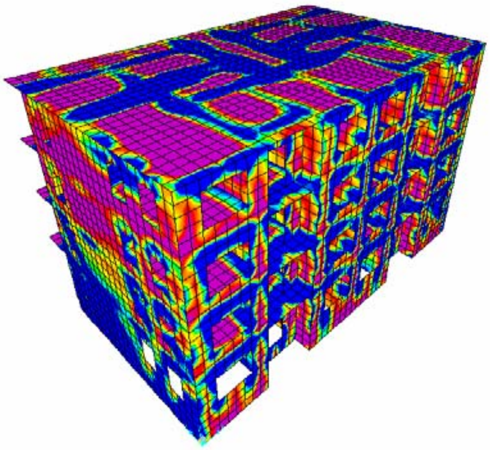
<table>
<tr>
<td>Deformed Shape under EQx
U1= 12.4 mm
U2= 4.8 mm
U3= 4.2 mm
R1=0.00049 rad
R2=0.00071 rad
R3=0.00047 rad</td>
<td>
</td>
</tr>
<tr>
<td>S12 (In- plane shear stress) Diagram under G+ EQx</td>
<td></td>
</tr>
<tr>
<td>S22 (In- plane direct stress) Diagram under G+ EQx</td>
<td></td>
</tr>
</table>

Table 5.5 Displacements under EQy and S12-S22 Diagrams under G+EQy in BMA Model

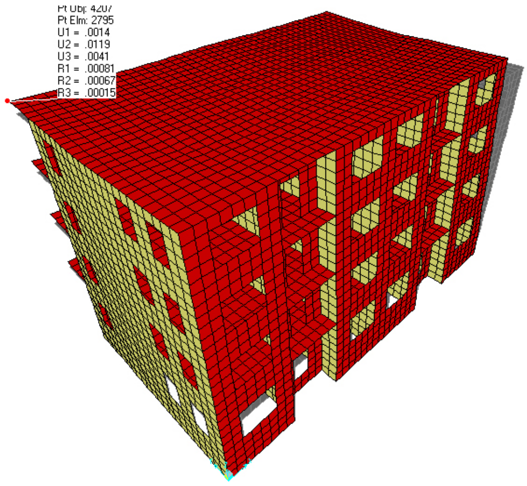
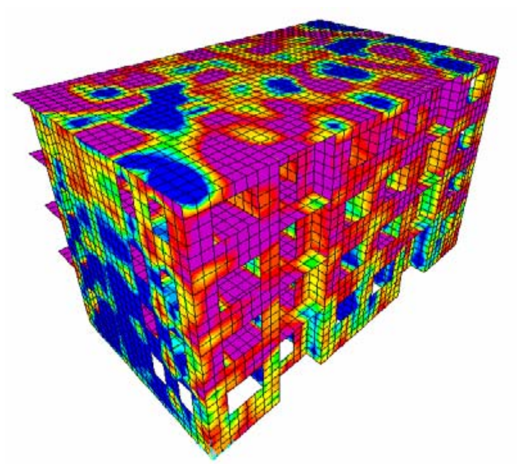
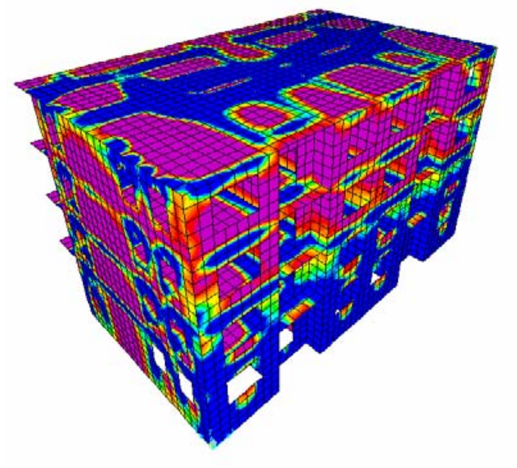
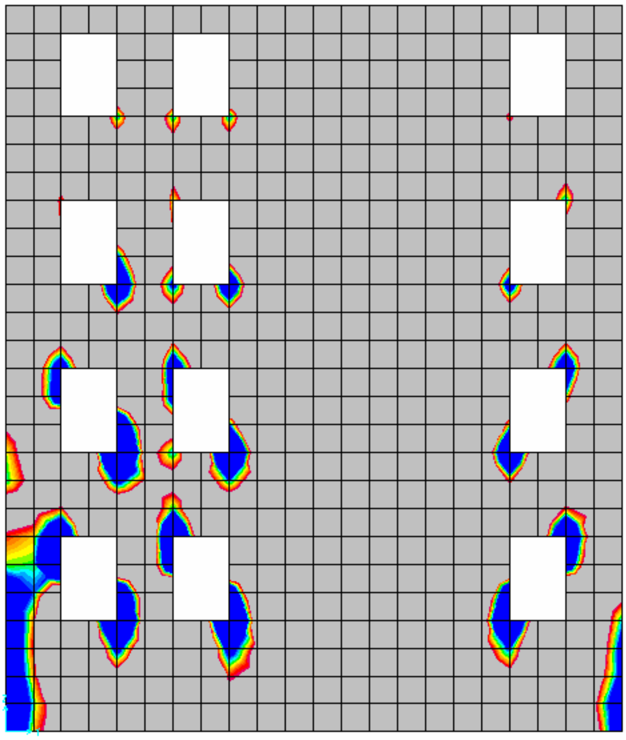
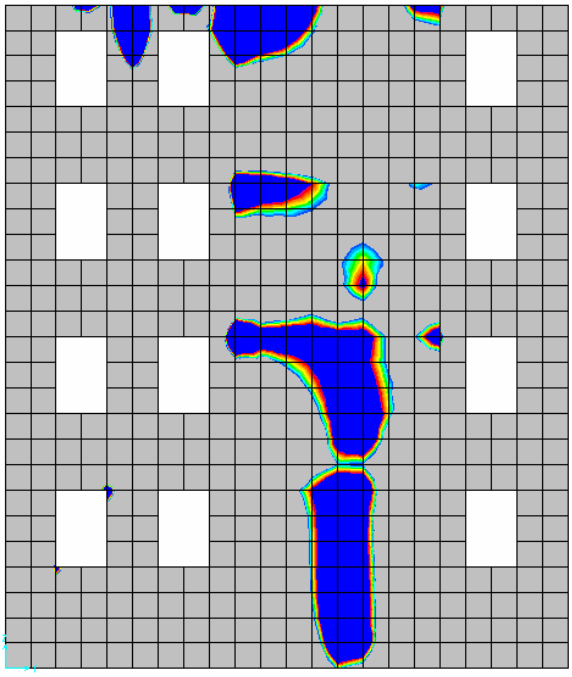
Deformed Shape under EQy U1= 1.4 mm U2= 11.9 mm U3= 4.1 mm R1=0.00081 rad R2=0.00067 rad R3=0.00015 rad	
S12 (In- plane shear stress) diagram under G+ EQy	
S22 (In- plane direct stress) diagram under G+ EQy	

Table 5.6 Max. Compression and Tension Areas under G+EQy

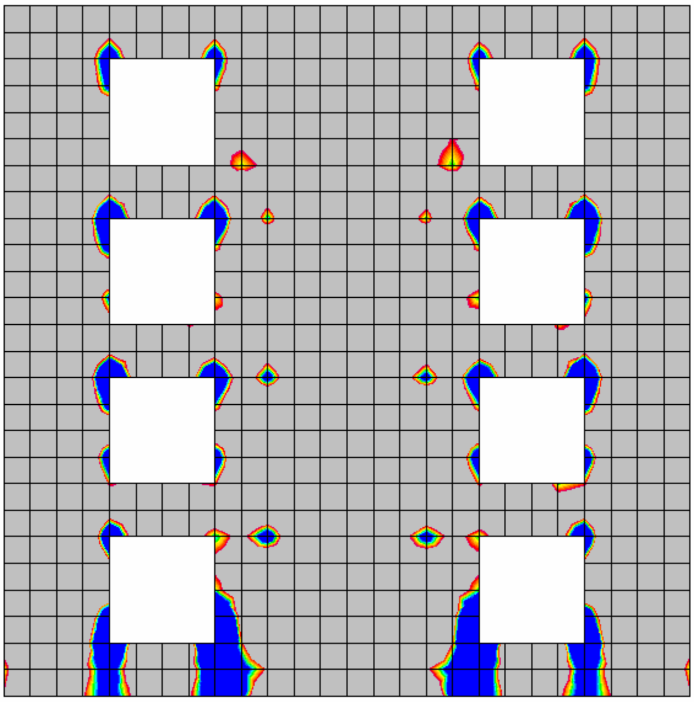


Tension areas in Wall 1 under G+EQy according to S22 Diagram

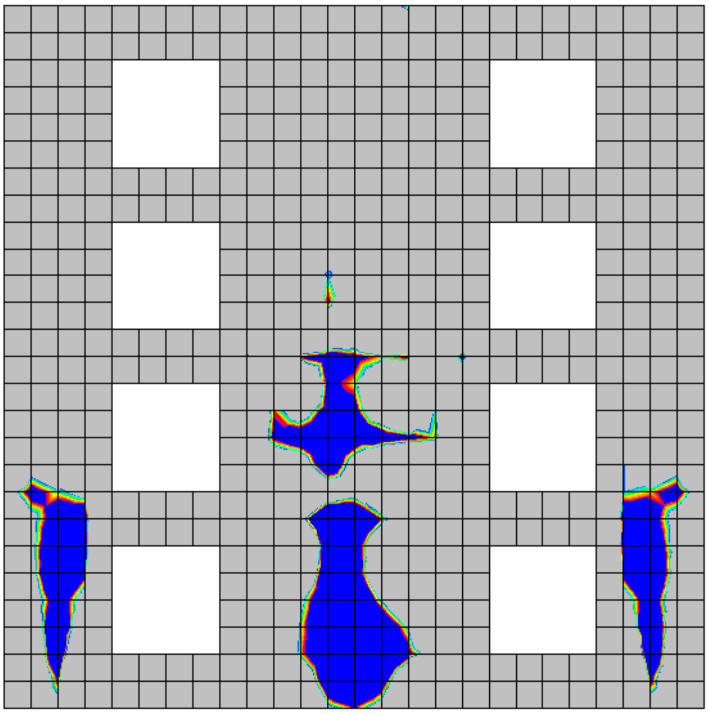


Compression areas in Wall 1 under G+EQy according to S22 Diagram

Table 5.7 Max. Compression and Tension Areas under G+EQx



Tension areas in the Wall 6 under G+EQx According to S22 Diagram



Compression areas in the Wall 6 under G+EQx According to S22 Diagram

Table 5.8 Displacements under EQx and S12-S22 Diagrams under G+EQx in RCA Model

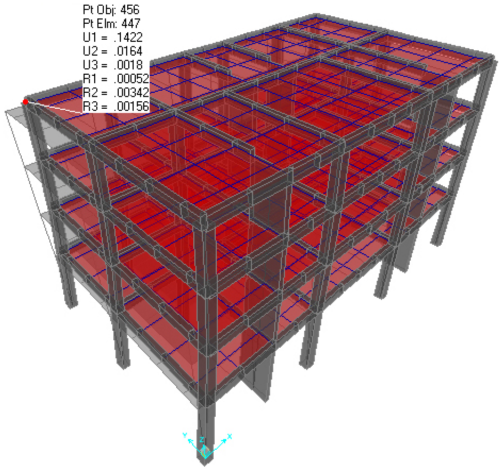
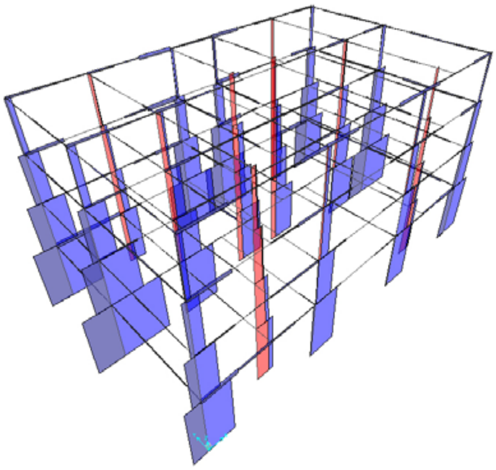
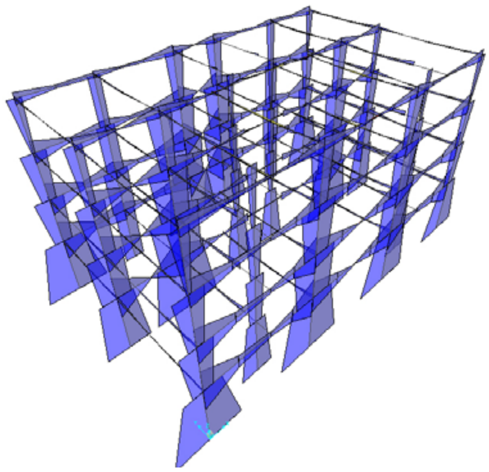
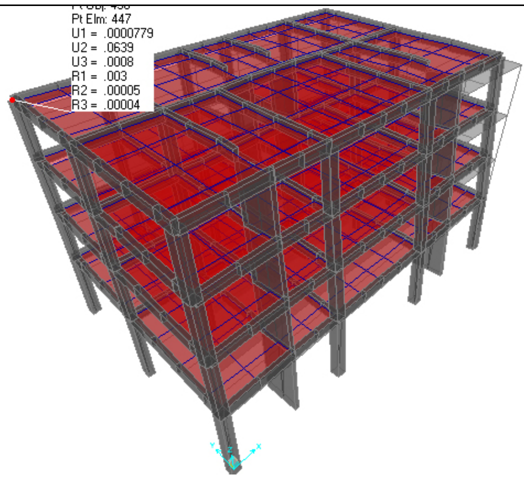
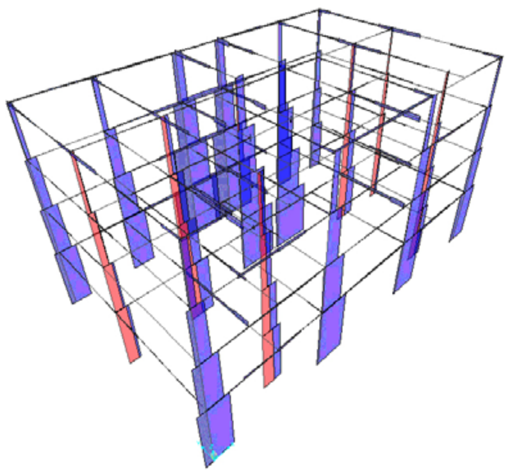
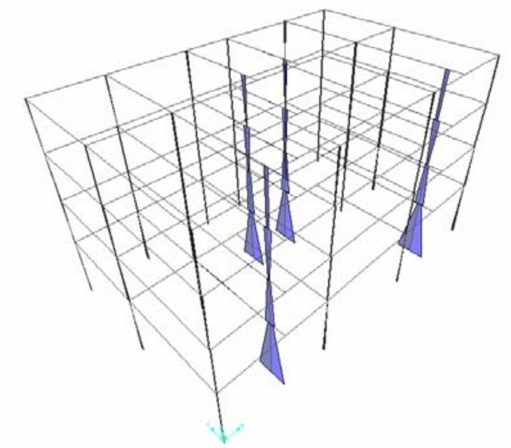
Deformed Shape under EQX U1= 142.2 mm U2= 164 mm U3= 1.8 mm R1=0.00052 rad R2=0.00342 rad R3=0.00156 rad	
Max Axial Force in the columns -1755.477 KN In the Column 500mm × 500 mm	
Max Moment in the Columns 10358.5526 KN.m In the Column 250 mm × 2000 mm	

Table 5.9 Displacements under EQy and S12-S22 Diagrams under G+EQy in BMA Model

Deformed Shape under EQY U1= 0.0779 mm U2= 639 mm U3= 0.8 mm R1=0.003 rad R2=0.00005 rad R3=0.00004 rad	
Max Axial Force in the columns -2776.500 KN In the Column 250 × 2000	
Max Moment in the Column 10358.5280 KN.m In the Column 250 × 2000	

5.3 Discussion of the Results

At the end of the analyses the conclusive comments are drawn as follows:

Firstly, the finite element model is tested by considering the mode shapes. The modal deformed shapes are obtained for the first 3 modes by using SAP 2000 software. As seen from the related tables (Table 5.2 and Table5.3) periods observed in the BMA model is lower than the periods of RCA model. Also it can be possible to see the comparison in the Table 5.10. Thus, verification of the proposal with modal periods is performed.

After the verification of the model with modal periods, displacements under the lateral loading (under EQx and EQy) are investigated. As understood from the difference between modal periods of BMA and RCA models, displacements in the BMA modal is again lower than displacements in the BMA modal (Table 5.10). Because if the modal periods decrease displacements decrease too with a direct proportion. Hence, second verification is performed by using the results of displacements.

Table 5.10 Comparison of the Modal Periods and Displacements

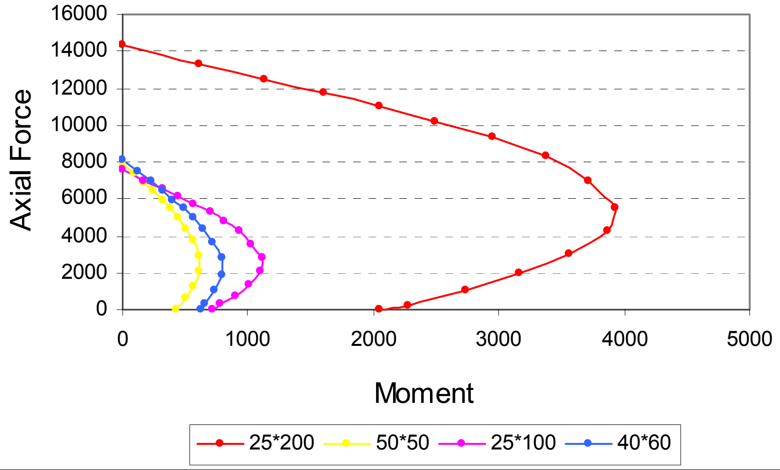
Parameters	Masonry	Reinforced Concrete
Mode 1	T= 0.21966 sec	T= 0.70221 sec
Mode 2	T= 0.2007 sec	T= 0.46593 sec
Mode 3	T= 0.17272 sec	T= 0.44295 sec
Displacements Under G	U1= 0.01184 mm U2= 0.2 mm U3= 2.5 mm	U1=0.00001265 U2=0.0004 U3=0.0024
Displacements Under G+EQX	U1= 12.4 mm U2= 4.8 mm U3= 4.2 mm	U1= 142.2 mm U2= 168 mm U3= 2.2 mm
Displacements Under G+EQY	U1= 0.8 mm U2= 14 mm U3= 3.6 mm	U1= 0.09056 mm U2= 643 mm U3= 1.2 mm

Thirdly, the capacities of the columns in RCA model are determined with the help of the Response 2000 computer program. M-N interaction diagrams of which define the capacity of the columns is obtained with this program. Then, according the results of the analyses done with Sap 2000, moment and axial forces in the columns under the lateral loadings are determined and compared with the M-N interaction diagrams. Results of comparison show that maximum moments and axial forces observed in all columns higher than the maximum moments and axial forces that the columns can withstand. The M and N values are over the columns' capacities (Table 5.11).

Finally, the capacity of the brick walls in BMA modal is determined. As mentioned before, the allowable stress value in the earthquake code of Turkey is 0.8 MPa (800 KN). This value is increased three times as f_{em}= 0.8 × 3 = 2.4 MPa. (2400 KN) and compared with the occurred stresses in the walls. As seen in the Table 5.12 observed compression values in all walls are under the limit defined in the earthquake code. Thus with this result, the third verification for the proposal is performed.

Consequently, it can be said that a four storey classical reinforced apartment unit can be constructed by using masonry systems instead of reinforced concrete without any changes in the architectural configuration of the building.

Table 5.11 M-N Diagram and Internal Forces in the Columns of the RCA Model



Column Sections (mm)	500 × 500	400 × 600	250 × 1000	250 × 2000
M3 (kN.m)	2450.776 -2450.772	1499.5049 -1499.5014	858.9034 -858.9072	1160.426 -1160.4284
M2 (kN.m)	849.204 -824.2121	702.9384 -718.4709	1538.8406 -1597.1862	10358.5526 -10390.1912
P (kN)	1514.854 -2583.583	1729.077 -3151.389	60.614 -1578.675	192.185 -2776.572
T (kN)	17.1872 -17.1872	13.6177 -13.6176	8.7229 -8.7229	18.2151 -18.215

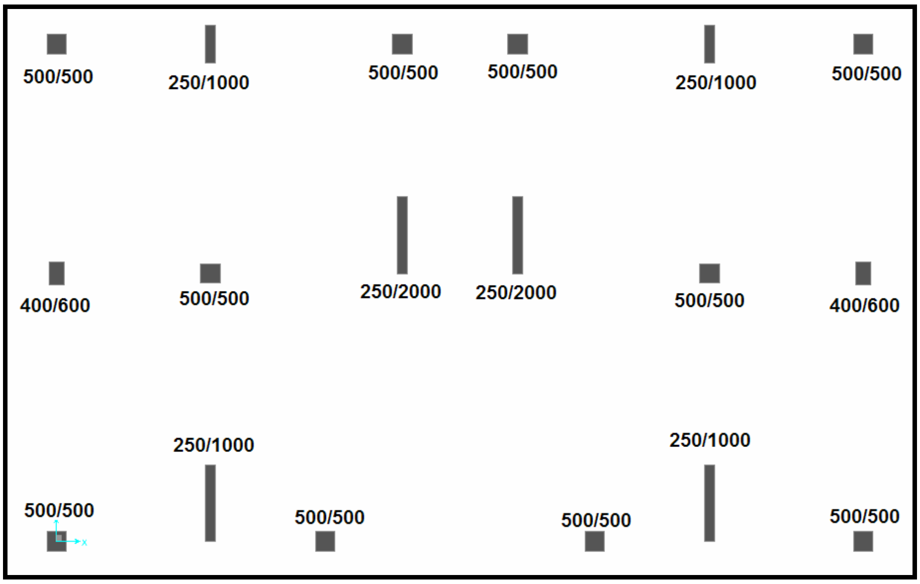


Figure 5.5 Column Sections in the RCA Model

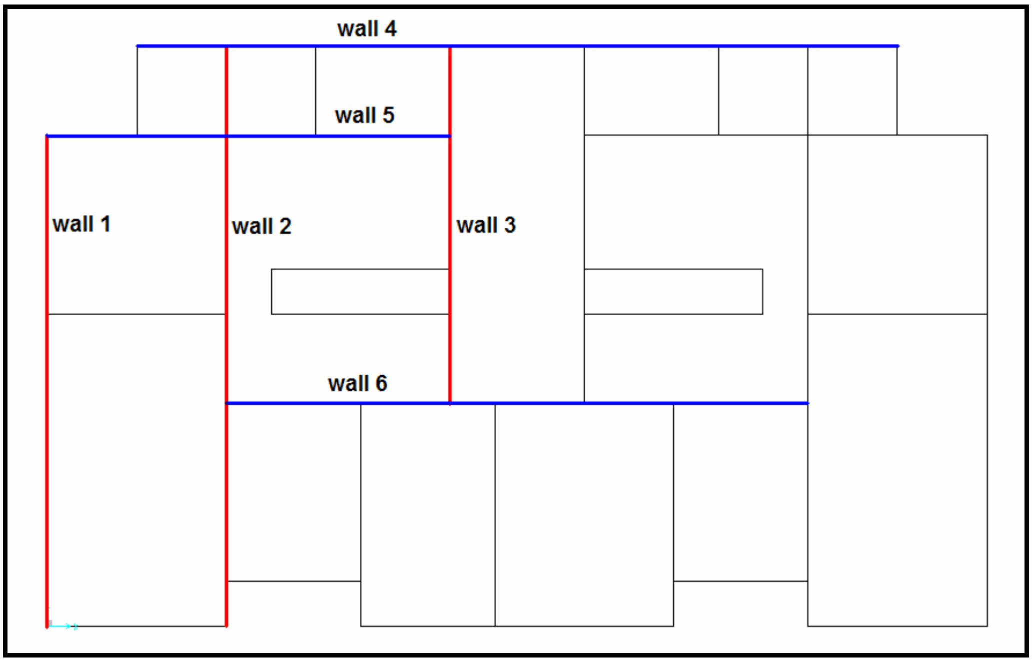


Figure 5.6 Critical Walls in the BMA Model

Table 5.12 Compression and Tension Values in the Critical Walls of the BMA Model According to S22 Diagrams

Brick Walls		Under G + EQX kN/m^2	Under G + EQY kN/m^2
Wall 1	Compression	-616.8702	-453.5958
	Tension	1924.1564	2137.8877
Wall 2	Compression	-571.7892	-617.4399
	Tension	2088.8588	1887.1563
Wall 3	Compression	-334.6284	-466.8790
	Tension	1817.3668	1768.2821
Wall 4	Compression	-212.7229	-71.8243
	Tension	2243.6638	1939.4317
Wall 5	Compression	-370.5247	-409.3414
	Tension	1604.6404	1297.4747
Wall 6	Compression	-558.7612	-530.1447
	Tension	1646.1648	1785.1366

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 General

As it is stated all through this thesis, the recent earthquakes in Turkey brought up the questions about seismic performance of buildings since an important portion of buildings collapsed where the rest were damaged either slightly or severely. Turkey is located on the highly active Eurasian Geological Plate where three main fault line pass through the territory as North Anatolian Fault (NAF), East Anatolian Fault (EAF), and Western Turkey Graben Complex resulting in several high magnitude earthquake throughout the history.

The researches carried out just after the earthquakes depicted that the most important reason for the collapse or severe damage of is inadequate or unconscious structural design. The most critical hazard was observed in the buildings of medium height, which are 5-8-storey. Therefore, there should be new building solutions for earthquake prone areas, which almost correspond to the entire country. Besides structural safety, one other concern should be the characterization of the built environment, which should be the reflections of environmental, geographical, social, economic and cultural values. Under these circumstances, masonry buildings step forward with their strong background in the traditional heritage of Turkey.

Afore mentioned, there is an important market and sector for the materials of masonry construction. Among all, brick and autoclaved aerated concrete blocks step forward as the most important units. Masonry has a very important background in Turkey although the aerated concrete block is a newly introduced material to construction industry. Masonry structures of stone or brick were the most important means for construction before the country fell into the chaos of urbanization. When urbanization came into light with all of its problems, these materials were abandoned, and a sudden shift from traditional materials to reinforced concrete and steel was observed. Reinforced concrete and steel might be seen as the reasons for abandoning masonry. The tendency to use reinforced concrete and steel structures in Turkey could be seen usual in some aspects. In the first place, reinforced concrete and steel structures offer multi-storey buildings, which would satisfy the urgent requirement for residential building that arose because of increasing population. Besides, the earthquake codes has been revised several times since the 1940s, which means a more detailed and experienced approach to the design of reinforced concrete structures. The common belief that masonry is not capable material to resist earthquake drew all the attentions to reinforced concrete and steel. Masonry, consequently, remained as a means for ornament, cladding and furniture. The variety of bricks is an evident for this type of utilization.

It is an undeniable fact that the brick and autoclaved concrete block industry has shown a sharp increase in the recent years in Turkey. On the other hand, it is still susceptible whether the market has satisfied the demand that arose because of urbanization period or not. Production of masonry units is expected to run in parallel with the amount and speed of construction throughout the country. But, the general appearance of the built environment, which is characterized by reinforced concrete and steel, brings the questions about the sufficiency of production. Lack of knowledge about the potential of masonry structures also affected the application negatively. This ignorance is also relevant for structural analysis and design considerations and detailing, which are among the most important determinants on seismic performance of buildings. The leading actors of the Turkish construction industry are not competent and experienced on the techniques and design aspects of masonry structures. The attention is directed towards reinforced concrete structures in particular, probably due to familiarization with the so-called “modern” materials in the recent decades.

It is unfortunate that the potential of neither the natural resources nor the production industry are effectively utilized in Turkey despite the fact that the availability of the raw material is one of the most important criteria to assess the potential of the material. The western and central regions of Turkey are rich in this aspect. The presence of the raw material would be beneficial for the economy of the country in many aspects. The own resources of the country could be utilized and the industry could be among the most important means to provide work opportunity for the unemployed, which is another serious problem in the economic concerns of the country.

Today, it might not be so pretentious to claim that the relevant earthquake codes for reinforced concrete structures work properly in terms of structural design in Turkey. Nevertheless, construction details still remain in question. In other words the reinforced concrete buildings that comply with the requirements of the codes might not sustain damage or collapse if the construction detailing is properly done. Provided that the attention for the design of reinforced concrete buildings is paid to the design of masonry structures, the seismic performance would depend on construction details, just as the case of reinforced concrete structures.

Now, in order to evoke masonry once again, verification of the advantages of masonry (as it is stated in the previous chapters: being an economic solution, providing new employments, having similar earthquake performance with reinforced concrete etc.) is required. This method might be the most appropriate way for both freshening the traditions and keeping pace with the innovations of the age. As a result, this study can be the first step of proposing the most suitable construction material(s) and system(s) for small-scale cities in the earthquake prone areas in Turkey.

6.2 Conclusions

As mentioned in the previous chapters, this study aims to indicate the potential of the masonry in Turkey. For this objective some comparative studies between reinforced concrete and masonry are conducted during the study. These comparisons include the construction materials and industries of reinforced concrete and masonry. Results of these comparisons show that Turkey has an important potential for the production of brick. In this context, distinctions of masonry building systems for Turkey condition are emphasized. Contribution to the country economy, new employment opportunities, completion time of construction, revival of traditional construction are underlined as advantages of masonry. To show the difference between construction costs of brick masonry and reinforced concrete, a cost analysis is conducted by using typical plan of a three storey apartment block. Results of the cost analysis indicate that the brick masonry construction cost is nearly half of the reinforced concrete construction cost. This economic advantage makes masonry an important system for Turkey construction sector. In summary, brick has many advantages as a construction material that can be listed as: Raw material of brick can be easily found in Turkey and it can be produced only with domestic capital. It is a long-lasting material which is not easily affected from the environmental effects. It has not additives; it is a natural and healthy material. Brick is also environmental friendly material because waste materials are used again for production. Labour intensive production of brick provides employment opportunities for many people.

This thesis also aims to show that it is possible to use masonry instead of reinforced concrete in the construction of 4-5 storey residential buildings in small-scale cities of Turkey. To verify this proposal a typical 4-storey reinforced concrete residential building is selected from Bolu. Then, two distinctive numerical models (by using reinforced concrete and masonry) are generated using the original dimensions of the architectural drawings. The finite element method which is the most powerful and suitable tool for the analysis of structures, is used for the analyses of these two models and SAP 2000 computer program is used for doing the analyses.

For the evaluation of the validity of the proposal the two models are compared under two different load combinations (G+EQx and G+EQy) in terms of structural behaviors. In the comparison the following parameters are taken into account:

- Modal periods and deformed shapes
- Displacement values
- Internal Forces (Moment and Axial Forces) of the RCA model
- Overall stress distribution of BMA model

According to these parameters, the major observations and corresponding conclusions drawn from the analyses results are summarized as follows:

- Modal periods and deformed shapes: Results of the modal analyses demonstrate that periods observed in the BMA model lower than the periods of RCA model. The difference is in order of 0.48255 s. The modal period is an important parameter as it is one of dynamic properties of structures and the response of the structure to a dynamic load can be controlled with modal periods. Accordingly, BMA model have better response under loading than RCA model. This is the first step that is performed for the verification of the proposal. Thus the modal periods and deformed shapes of the analyses confirmed the proposal.

- Displacement values: In the second step, displacements in x, y and z direction at the location of maximum deformation of the models measured. In the gravity analysis, the displacements for BMA and RCA model are U1= 0.01184 mm, U2= 0.2 mm, U3= 2.5 mm, U1=0.00001265, U2=0.0004, U3=0.0024 respectively. In the case of analyses of load combinations (G+EQx and G+EQy) there is a larger difference between displacements of BMA and RCA model. Displacements under G+EQx are (for BMA) U1= 12.4 mm, U2= 4.8 mm, U3= 4.2 mm and (for RCA) U1= 142.2 mm, U2= 168 mm, U3= 2.2 mm. Under G+EQy displacements are (for BMA) U1= 0.8 mm, U2= 14 mm, U3= 3.6 mm and (for RCA) U1= 0.09056 mm, U2= 643 mm, U3= 1.2 mm. Therefore, as it can be seen from the values, the results showed that, displacements (under G+EQx and G+EQy) in the BMA model are lower than the displacements in the RCA model.

- Internal Forces (Moment and Axial Forces) of the RCA model: In the third step columns capacities in the RCA model are investigated with the help of Response 2000 and SAP 2000 computer programs. Moment and axial force values occurred in the columns obtained from the analyses in the SAP 2000. Then values are controlled with the M-N interaction diagram which is drawn with Response 2000. The results of the comparison indicate that moment and axial forces occurred in the columns are higher than their capacities.

- Overall stress distribution of BMA model: In the fourth step, stress distributions, S12 (In- plane shear stress) and S22 (In- plane direct stress), in the BMA model is investigated. Maximum stress values occur around the openings unsurprisingly. However, the numeric values of these stresses reveals that maximum stress values are smaller than the allowable stress value (f_{em}= 0.8 × 3 = 2.4 Mpa) which is stated in the earthquake code of Turkey.

The analyses results show that the method applied for the constructing of the 4 storey residential building in Bolu is proved to be effective in reflecting the better structural behavior than the reinforced concrete apartment model. In other words, all parameters used in the comparison confirmed the proposal.

6.3 Recommendations for Future Studies

This dissertation has presented and discussed selected issues pertaining to structural characteristics and seismic assessments of masonry and reinforced concrete residential buildings. During the study the necessity of introducing potential of masonry in Turkey conditions is emphasized. A large part of the discussion has been dedicated to the applicability and the efficiency of using masonry in the construction of 4-storey residential buildings in Bolu. Its contribution to the country economy, new employment areas, local architectural characteristics of the small-scale cities, completion time of the constructions and training specialized worker are also covered within the scope of the study.

Future studies can be focused on design approaches and design rules for masonry. Codes and regulations for masonry are not studied in a detailed way in this dissertation, however, during the study it was seen that studies about the codes for masonry are not sufficient in Turkey. Therefore codes and regulations for masonry structures including, construction materials, systems (such as reinforced masonry), detailing, etc. can be studied. It is hoped that this thesis will stimulate researchers and code makers to pay attention to the relevance of masonry as a structural material for residential buildings.

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PUBLICATIONS

Conference Papers

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