DEVELOPING AN INNOVATIVE ARCHITECTURAL AND STRUCTURAL SOLUTION FOR SEISMIC STRENGTHENING OF REINFORCED CONCRETE RESIDENTIAL BUILDINGS

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ABSTRACT

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The recent earthquakes in Turkey have shown the poor seismic performance of reinforced concrete. This led to widespread utilization of several strengthening methods, each of which is convenient in different aspects. However, what is required to apply any of these methods is to evacuate the building in question since the interruptions are mostly within the building and to the structural members.

This study proposes a method for external strengthening of typical five storey reinforced concrete buildings that represent the majority of the built environment in Turkey. The method suggests addition of shear walls, which are connected to each other by means of diaphragms on two floor levels, to the existing external columns at four corners of the building. The positive effect of shear walls in seismic performance is already known; however; basically, the aim of this study is to discuss the feasibility of the proposed method in terms of architectural viewpoint since the method unavoidably covers great modifications on the architectural form of the building. Hence, the research mostly explores whether it is possible to give the reinforced concrete residential buildings, which constitute the majority of the built environment especially after 1950s due to the unhealthy urbanization period in Turkey, a common characteristic appearance by means of external structural members. As a whole, proposing an external strengthening method that provides not to evacuate the space, the study searches to obtain a typical façade resemblance by means of additional structural members.

Keywords: Seismic strengthening, Reinforced concrete buildings, Seismic design faults

ÖZ

BETONARME KONUT BINALARININ DEPREME KARSI GÜÇLENDIRILMESI IÇIN YENI BIR MIMARI VE YAPISAL ÇÖZÜM GELISTIRILMESI

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Türkiye'deki son depremler betonarme binalarin sismik dayanimindaki zayifligi ortaya çikarmistir. Bu durum, herbiri degisik açilardan elverisli olan çesitli güçlendirme metotlarinin oldukça yaygin sekilde kullanilmasina yol açmistir. Ancak, müdahalelerin çogunun binanin içinde gerçeklesmesi ve yapisal elemanlara uygulanmasi yüzünden, bu metotlardan herhangi birini uygulayabilmek için sözkonusu binanin bosaltilmasi gerekmektedir.

Bu çalisma, Türkiye'deki yapilarin büyük çogunlugunu temsil eden bes katli betonarme binalarin disaridan güçlendirilmesi için bir metot önermektedir. Metot, birbirine iki kat seviyesinde diyaframlarla baglanan perde duvarlarin, binanin dört kösesinde varolan kolonlara eklenmesini öngörmektedir. Perde duvarlarin deprem davranisina olumlu etkileri zaten bilinmektedir; ancak, çalismanin asil amaci, binanin mimari formuna kaçinilmaz olarak oldukça önemli müdahaleleri öngören metodun mimari bakis açisindan yapilabilirliginin tartisilmasidir. Bu yüzden, özellikle, Türkiye'nin 1950 den itibaren yasadigi hizli ve çarpik kentlesmenin büyük çogunlugunu olusturan betonarme konut binalarinin, disaridan eklenen yapisal elemanlarla genel bir karakteristik görünüs saglamasinin mümkün olup olmadigi üzerinde durulacaktir. Sonuç olarak, disaridan uygulandigi için mekanin bosaltilmasini gerektirmeyen bir metot öneren bu çalisma, ayni zamanda, eklenen yapisal elemanlarla tipik bir dis görünüs elde etmeyi amaçlamaktadir.

Anahtar Kelimeler: Depreme karsi güçlendirme, Betonarme, Sismik tasarim hatalari

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INTRODUCTION

1.1. Seismic History and Seismologic Characteristics of Turkey

Earthquake is one of the major problems of Turkey because of its location on the Alp-Himalayan Seismic Belt, which is one of the most active earthquake areas on the world. This seismic belt starts from the Azores in the Atlantic Ocean and stretches away into the Southeast Asia. Nearly 96% of Turkey is located on highly risky seismic zones and about 80 % of the population is exposed to high magnitude earthquakes. The seismic activity is very complex around the East-Mediterranean region. Most of the country is on the Anatolian Plate, which is located in the middle of the Eurasian, African and Arabic Plates. The African and Arabic plates travel north and forces the Anatolian plate to move west. The majority of the destructive earthquakes take place on the borders of the Anatolian Plate [1, 2].

Earthquakes are frequent activities in Turkey. They occur due to the movement of two active tectonic sections, one of which forms due to the pressure of Arabian and African Plates on the Anatolian Plate. The second tectonic section is the Anatolian fault, which consists of two plates that move horizontal to each other, on the north of Turkey till the northeast of Iran. The first of these is the plate in Russia, which moves towards the east, whereas the latter moves in the opposite direction to the former. The horizontal movement of these two plates according to each other, results as an increasing stress deposition, which leads to tectonic earthquakes [3, 4].

The North Anatolian Fault consists of several shorter fault lines and stretches over 1000 km. The width of the seismic zones varies between 100 m and 25 km. The annual average slide is about 5-8 mm. The East Anatolian Fault runs 400 km from Karliova to Iskenderun Bay. The width is between 2-3 km and the annual slide is around 6 mm. The most destructive earthquakes take place on these two fault lines. Bitlis compression zone is in a relatively silent state since the beginning of the last century. The Aegean Graben Zone is the reason for the earthquakes in West-Anatolia. The Anatolian Plate expands in the north-south direction and causes the formation of fault lines in the east-west direction [3].

Every year, there happens about more than one million earthquakes, of which human can feel only 10-20. About more than 80 % of this hazard occur on the Pacific Belt and Turkey is on the Asian Belt, which is one of the greatest seismic belts on the world.

Being very close (about 5-30 km) to the surface, the earthquakes that occur on the North Anatolian seismic belt are very dangerous. The major earthquakes that Turkey suffered in the recent decades are given in Table 1.1 [5, 6, 7]:

Table 1.1: The major earthquakes that occurred in the last decades in Turkey

Region	Date	Loss	Magnitude
Askale-Erzurum	01 March 2004	10	5.3
Bingöl	01 May 2003	176	6.4
Pülümür-Tunceli	27 January 2003	1	6.5
Sultandag	03 February 2002	41	6.5
Düzce	12 November 1999	839	7.2
Marmara	17 August 1999	17 118	7.4
Ceyhan-Misis	27 June 1998	146	5.9
Dinar	01 October 1995	94	5.9
Erzincan	13 March 1992	653	6.8
Erzurum -Kars	30 October 1983	1 155	6.8
Çaldiran	24 November 1976	3 840	7.2
Bingöl	22 May 1971	878	6.7
Gediz	28 March 1970	1 086	7.2
Varto	19 August 1966	2 394	6.9
Gerede	01 February 1944	3 959	7.2
Ladik-Tosya	26 November 1943	2 824	7.2
Erzincan	26 December 1939	32 962	7.9
Malazgirt	19 April 1903	2 626	7.0
Izmir	15 October 1883	15 000	7.0

1.2. General Overview on the Composition of Reinforced Concrete Buildings in Turkey

Turkey has experienced an increasing urbanization problem since 1920s. The urbanization rate was rather low within around 30 years after the proclamation of the Republic, than it has been in the following years afterwards. Individual efforts can be said to have satisfied the requirements for house production until 1950s, with an exception for the capital, Ankara, where the first examples of different ways of house production were seen and spread all over the country. These were the squatters and apartment buildings, which based on the contractions about the exchange of the land and the flats that were to be erected. These new ways to product residential buildings began to be seen within the years 1950-1965, and reached up to their limits in 1965-1980, in which mass housing was tried to be nationalized with the initial attempts. Today, mass housing has the largest portion among the ways to product residential buildings [8].

From 1920s, an important number of residential buildings were produced in Turkey. New construction technologies were developed. Even though the quality of the products cannot be said to be perfect, the quantity seems to be sufficient for not only in terms of main accommodation spaces, but also as weekend or summer houses, and means of investment, production, consumption, and insurance as well. Most of the residential buildings of today can be said to have been produced according to the personal needs and solutions but not according to any preliminary design of the government. The society had to satisfy the need of residential buildings since the country could not overcome the problem of rapid increase in the population. This might have been due to the simultaneous industrialization of the country, which requires a great amount of investment as well. Therefore, resources for residential buildings were highly limited. The other reason for the self-production of residential buildings can be said to have been the populist political strategies about the building lands and sites. Within these limitations, two preliminarily defined different approaches, both of which resulted as a disorganized appearance and environment, were observed. The people of low economic level mainly build squatters on national lands with difficult topographic conditions. It is inconvenient to intend to analyze these buildings since they involve no structural or aesthetic consideration.

The situation is rather different in the exchange of land and the promised flats within the apartments, which would be constructed on the site. Starting from the occupation of the sites, everything is convenient with the legal rules or constraints. The main reasons for wide spread application of this process are the requirements of rapid urbanization and a lack of rational procedure. The great profitability on lands hardened to make a single residential building for the landowner. As a result, apartments that contain a number of dwellings were built on the parcels in order to provide houses to the middle-range of the society. However, the results are generally nothing more than inharmoniously developing city forms. Later on, towards the end of 1960s, a new solution began to be seen for the construction of dwellings: mass housing. The process of mass housing can be said to have helped the improvement of the construction techniques, development of the city partially and to have affected upon the forms of the cities. However, the quality and sufficiency of its environment is still a matter of discussion [8].

As a whole, the overall appearances of the settlement zones more or less make the same sense. The buildings, which were constructed after 1960s, have constituted the main topic of many architectural, structural, and aesthetic discussions. They seem to have been built only to satisfy the main functional requirement, which is to provide a space to shelter. Even in rather different climates or regions the appearance of these buildings are nearly the same. The only means of classification might be the number of rooms in the dwellings of the apartment buildings. A great major part of the items that may be determinant to characterize a building such as dimensions, shape and configuration of the balconies, cantilevers, doors, and windows, and the ratio of openings to floor area are almost identical. The area of the parcels and the restrictions in the Town-Planning Codes may be the chief reasons of this situation. In a specific zone, the parcels are more or less identical in dimensions, and the Town-Planning Codes bring strict regulations for the construction. The distance between the building and the road, as well as the distance between two buildings are all specified in the codes. The profitability of lands is still relevant, so that every square centimeter is valuable. This leads to give importance to effective and functional use of the land rather than aesthetic values and search for variety.

As a result, all of the buildings with the maximum efficiency of the land use seem to be the work of the same design and construction team.

Beside the Town-Planning Codes, Turkish-Earthquake Code also brings some regulations. However, some regulations about structural design are mandatory in especially seismic zones. Most of the architects and structural engineers usually design residential buildings, which constitute the major part of the built environment. Nevertheless, a great major part of the architects are still unaware of the fact that their decisions are the most important factor on the seismic performance of a building. Seismic performance of a building mainly depends on its construction material and structural system, which is initially chosen by the architect and is detailed by the structural engineer in terms of feasibility, amount of reinforcement, element dimensions, and economy. Here, the importance of collaboration of the architect and the engineer can easily be understood. In the previous periods, the architect was responsible for the spatial quality of the building as well as its structural performance. In the following years, due to the developments in the construction field, the specializations of the structural engineer and architect were separated. The architect started to deal with mainly aesthetical features and spatial quality, while the structural engineer specialized on the feasibility, economy, and dimensioning of the overall geometry of the structure. However, the selection of the structural system is the work of the architect although most of the architects are still unaware of the significance of their initial design decisions.

1.3. Social Aspects and Structural Demands on Strengthening of Reinforced Concrete Buildings

Because of its highly risky location in terms of seismology, Turkey commonly suffers from high-magnitude earthquakes. These earthquakes result in very high damages and more importantly many losses of lives. Some of the buildings totally collapse, while some other has partial damages with a wide range of significance degree and still stand. Most of the damaged and collapsed structures were residential and commercial, which negatively affected the society morally and economically. The society might not be contended with owing a house and a place of work; the crucial point is to ensure the safety of these places. The only definite point, which comes out after the recent earthquakes, is that the society is very sensitive about the strength of their houses and working places due to their life insurance [9].

After the earthquakes, some buildings were demolished while some others were immediately strengthened and the rest were left as they were since they were thought not to require any strengthening. Experts from the government and from other institutions decided upon whether the buildings require strengthening due to their level of damage and existing structural behavior.

Strengthening methods may sometimes be unaesthetic due to the additions or the processes that were not preliminarily considered in the design stage. These structural interferences are strictly required in the buildings those faced with earthquake although there may not be significant damage. However, since the society become aware of the importance of the strength of their buildings, these processes may also be applied to all buildings that are located in the seismic zones. Of course, the ideal situation is that every building should have enough strength to resist a high-magnitude earthquake without any collapse. The Turkish Earthquake Code, which was revised in 1997, ensures this in terms of structural requirements of the buildings. Nevertheless, a great many portion of reinforced concrete buildings, which were constructed before the revised regulations, have serious problems in terms of resistance to earthquakes. Many settlements in Turkey have experienced a middle or high magnitude earthquake. Even if some regions are considered to be safe in terms of seismology for at least some years more, the hazard may recur in the least expected time. Most of the reinforced concrete buildings, which were built before the Turkish Earthquake Code, need strengthening in order to resist earthquakes without severe damage.

Strengthening is a rather costly and difficult process. The cost may be high due to the strengthening project, workmanship, and additional material. Moreover, the existing processes are all carried out in a wholly empty space, which means the need for another place to accommodate, which is costly and difficult for the user. This study aims to explore for an innovative method, which does not obstruct the space within. In other words, the life within the space would go on during the strengthening process as it was before.

1.4. Objectives and Scope

The recent earthquakes in Turkey have unfortunately demonstrated the poor seismic performance of reinforced concrete buildings despite the very well known capacity of the structural material. It might be misleading to relate the failures and collapses to design faults entirely, since there are many other features, some of which are out of the scope of this study, influencing the seismic performance of reinforced concrete buildings. These excluding factors can be listed as workmanship, material quality, soil conditions, or the amount of reinforcement within the structural members.

Turkey is on a highly risky seismic zone, in other words there is always the risk for reoccurrence of a high magnitude earthquake, which might lead to serious damages and collapses. The damaged buildings, according to the severity of destruction, were exposed to several strengthening processes, after the earthquake. And since the society is aware of the danger of a future earthquake and requires safety, there appears a need for strengthening even the undamaged buildings, especially the ones that were built before the revision of Turkish Earthquake Codes.

The aim of strengthening is to make the structure capable to resist any further earthquakes without damage or collapse. A number of the existing strengthening methods are effective to some extent, whereas additional shear walls really perform a sound seismic behavior. However, all require emptying the space within the structure, since the interruptions or additions would be performed within the frame and sometimes directly on the structural members. Considering the fact that abandoning the space might be difficult especially in emergency cases, this study aims to propose a new approach for strengthening of reinforced concrete structures without obstructing the space.

The study initially covers the overall condition of the reinforced concrete buildings in Turkey with their architectural and structural characteristics. The existing situations are explored due to the limitations in construction in terms of social and economic aspects and regulations. The seismic performance of the existing reinforced concrete buildings is investigated especially in seismic zones in order to be able to determine the building types to be strengthened. The study also covers the significant need for the extra steps to be taken, the first of which is to make the architects and the engineers conscious about the structural needs and behavior of a building during their education period. After the basic considerations on architectural design related to the seismic performance of reinforced concrete buildings are given, the study demonstrates the common design faults and consequently the related types of damages. It underlines the effects of strengthening on the overall behavior of the structure and explains about the existing methods of strengthening. Afterwards, parallel to the social and structural requirements, the study covers the proposal for an exteriorly applicable method for strengthening of reinforced concrete residential buildings without obstructing the activity of life within the space. The results of structural analyses that are performed by Finite Element Method on different layouts and consequently the related considerations in strengthening are discussed in comparison with the existing strengthening methods.

The overall study is intended to include many analyses performed on different structural configurations of reinforced concrete residential buildings, which compose the majority of the built environment. The constituents of the urban settlements are explored according to structural design deficiencies and layouts of the buildings. Parallel to the outputs of the analyses, feasibility of the proposed method is evaluated in terms of not only the structural but also architectural, economic, functional and social aspects as well.

CHAPTER 2

CHARACTERISTICS OF REINFORCED CONCRETE BUILDINGS AND EARTHQUAKE RESISTANT BUILDING DESIGN CONSIDERATIONS

2.1. The Determinative Factor on the Characteristics of the Built Environment in Turkey: Urbanization

In order to be able to propose a method for strengthening of reinforced concrete residential buildings, it would be helpful to have a general overview on their characteristics with leading reasons for their formation and existing situation.

The characteristics of the built environment are basically determined during the period of the great urbanization process that Turkey has experienced mostly in the 1950s and 1960s. In general, it could be said that the unhealthy urbanization in the country has been observed due to the rapid and enormous increase in population. But, when urbanization in the areas in question is not developed according to certain regulations of predefined city plans, the result is usually decrease in the quality of service and living conditions of residences [10, 11].

Urbanization has been a great concern for most of the countries in the world for several decades. There always have been several reasons for urbanization, but what generally lead to the rapid and problematic results are the great changes in economic and social aspects all around the world. These changes, in general, lead to an uncontrolled alteration period since the rapid urbanization could not be estimated before. In other words, it could be said that the rapid and unhealthy urbanization is not something unique to Turkey and that there does not exist a way to take any precautions to prevent the formation of this process [12].

It might not be so pretentious to state that it is nearly impossible to overcome this process in an unproblematic way. Moreover, the local or the general authorities might not be able to foresee the urbanization period of the zones in question since any estimations related to this topic could not be based upon certain scientific facts. Thus, it seems normal to face with lack of urban services and misuse of authority [12].

In order to figure out the scale of the rapid increase in the population and consequently the unhealthy urbanization period in Turkey, it might be helpful to keep in mind that about 250000 residences have been built in each year after 1950s. This amount brings in minds that there must be another means of production besides the existing small-scale production methods and individual efforts rather than a systematic approach of the government. However, although it seems to be impossible, it is observed that enormous number of residences have been produced by means of only small-scale productions and individual efforts in most of the developing countries that experience modernization. Unfortunately, the methods, which are explained in the preceding parts of the study, for the production of residential buildings have not changed significantly despite the fact that some precautions are urgently necessitated to prevent the unconscious urbanization. Moreover, the lack of town planning policies has lead to the formation of a built environment that is based on only commercial profit without any notice of aesthetic, architectural and universal merit. The problems due to negative reflections of this rapid urbanization period necessitate more sensitive approaches for future. Planning and application have the utmost importance to purify the towns from the negativity of unhealthy urbanization and help them keep their original identity. Town planning should response the social and economic requirements in such a way that historic, cultural and natural values are protected [13, 14].

2.1.1. Social Aspects in Urbanization

Urbanization in the West could be said to have appeared just after the Feudal Period and become widespread after the Industrial Revolution. Due to the facts that the city is the center of economy and trade and that the large-scale industries were settled within the cities, it becomes possible to mention about the employment of the people in the rural zones in these centers and industries. By the great and sudden movement of migrants to the cities, there has appeared an urbanization problem that starts with the accommodation crisis of the workers and consolidated with bad living conditions [10, 15].

The problem of urbanization dates mostly to 1950s in Turkey. As mentioned before, there are several reasons for this rapid and great urbanization in the entire country. The main reason might be seen as the radical alteration in the rural-urban balance so that the percentage of the people living in the rural or the urban zones shifted in a very limited period. 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. One other reason for the urbanization is the facilitation of transportation, which increased both temporary and permanent migration between the rural and urban areas. 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. These people sorted the accommodation problem out by developing their own squatters and squatter zones. Thus, the difficulty that the immigrants sustain in assuming and assimilating the urban values as well as the negative configuration due to the unhealthy urbanization have prevented the modern urbanization and disturbed the identity of the towns that have been shaped for centuries. Beside these serious changes in typologies, great differences have been observed in the site and plan layouts. The alterations in living conditions, technological developments and the conditions due to life in cities for the immigrant that come from smaller-scale environments have been the basis for this change. The crucial point here is that it has become nearly impossible to differentiate between different sites of the country in terms of building typology. The villages and towns started not to reflect their own characteristics any more. This is because that the people in rather small-scale settlement zones immediately want to move into the reinforced concrete villas or apartment buildings with the idea that it is the sign of modernity. The willingness to leave the traditional houses and move into the so-called modern buildings increased the demand for the reinforced concrete buildings and accelerated their erections regardless of their quality in terms of design and construction. Nevertheless, it might still be considered to give hope to see some local characteristics inside the buildings in some regions, although the building form does not have any features of the local architecture so that it is nothing more than one that can be seen in any part of the country. In other words, some of the customs have still been lasting; however, unfortunately this is not enough to deny that there is a great rush to accept and utilize the new one [10, 12, 15, 16, 17, 18].

This difference, which is mostly seen in the rural areas and small-scale settlement zones, is experienced also in the greater towns and cities to some extent. However, the concept of "earthquake" has been effective on the residence preferences so that the housings, which are settled in the rural areas with new technologies, have been attractive for the high-income society in large-scale cities. The condition of the housings will be discussed in the following parts of the study.

2.1.2. Architecture in the Formation of the Built Environment in Turkey

Based upon the previous parts of the study, it is possible to mention that the disciplines such as sociology, architecture and planning are the necessary means to perceive the problem of residences. Among them all, architecture is the responsible discipline to create harmonious, functional and aesthetic designs that constitute the members of the built environment. However, it might not be wrong to claim that the formation of architecture has always been kept within certain limitations during the overall process despite the developments in its structure. Parallel to the developments, restrictions and the fields of application of architecture, the engineering design and application procedures has had to stay within the limits as well. Since the individual efforts, which could be said to have covered the need for residential buildings, exclude architecture due to their small-scale productivities, the architect may have not been able to apply the professional formation. In these projects, the architect has very little -even no-initiatives because the product is obvious from the very beginning. The work here is nothing more than the result of the application of some rules and regulations. The ineffectiveness of the architects could be tolerated when these rough apartment blocks spread widely in the parcel scale. There have always been light and air conditioning problems since they have been built on narrow parcels due to the most effective utilization of the land in the area in question. As a result, the residential building has become a standard unit that is obtained by multiplication of prototypes for average user profile [19].

2.1.2.1. Architecture in the Formation of the Built Environment before 20th Century

Until the 20th century there was not a great distinction between the fields of architecture and construction. In other words, the architect was the one who is responsible for both the design and the construction processes of the building. However, the design of residences was out of the formation of architecture until the end of the 19th century. The architects were dealing with the design of large-scale projects for the either the important people of the society or for the public whereas the residences were constructed according to the customs -collected since a couple of centuries- of the craftsman. In other words, it is possible to say that architects were not willing to condescend to deal with small-scale projects like residences, which could have already been built according to some customs and traditional features that have been collected by the craftsmen. To employ the architect for the design and construction of a residence required either the owner of the work should have been in the upper level of the society so that the work to be done should have been extraordinary [20].

In the second half of the 19th century, the spread of a middle-class society, the expectations of who were greater than ever, and the rapid increase in the population of the urban zones called the attention of architects to residences. Although they were refusing the customs, and consequently the residences constructed within the customs of the past, the people of the middle class society were not wealthy enough to request a residence identical to a palazzo or a pavilion. They were rather willing for both ostentation and differentiation among the others; however, the customs of the craftsman were not able to satisfy their requirements. There has been an urgent need for a new formation, which could succeed to demonstrate this differentiation. Architecture has enlarged the field of activity as the responsible discipline of this required formation towards the end of the 19th century. Alternatives to the apartment buildings, which have been built, by the craftsman and contractors were developed; however, the demand of differentiating for prestige led to degeneration in the classical approach of the discipline. In the course of time, unsuccessful examples, which were built out of the norms of scale and expression of the discipline of architecture, started to be seen [20, 21].

2.1.2.2. Architecture in the Formation of the Built Environment in Turkey in 20th Century

The Modernism Period that corresponds to the late 19th and early 20th century was the turning point for the formation of architecture so that the architects have started to be responsible for the design of residences. Since they have been dealing with the design of the extraordinary buildings such as monuments, public buildings and villas, the design of residences, which could be described to be ordinary, led to a paradox due to the fact that design contradicts to the usual. Thus, it is possible to mention that the problem of residences dates back to the beginning of 20th century. There started a search for converting the ordinary to extraordinary, whereas there also have been attempts to convert it to usual [19, 22].

The second reason that the architects have been the responsible for the design of the residences is the rapid and sudden increase in the population of the urban zones. The need for the greatest number of residences in history could not be satisfied by the craftsmen so that the problem of residence has been one of the main social problems of the late 19th and early 20th centuries. There have been attempts to design the overall settlements instead of single buildings. This has brought significant modifications and innovations to the arrangement of main street-street-building relationship and decorations of rooms, bathrooms and kitchens. These fundamental changes required a new energy, which is the formation of architecture, since they could not be done by the limited effort and capacity of the craftsmen [20, 21].

This difference in the production of residential buildings has become more obvious especially in the recent decades. Larger scale productions have started to be seen; however, the scale of the projects could not be able to solve the problem of residential buildings since the productions are so similar to those constructed without any initiative of the architect or they do not have any doubts about being built upon some standards and/or norms. Here, the crucial point becomes the boundary between the formation of architecture and the limitations such as Town Planning Codes, norms of the contractors, standards and typologies. The product is known to be an ordinary one at the end; however, the search has been to design it in the best way according to its price, profit, surface area and room number in order to compensate this routine to some extent and to give its well-known characteristics. This might be related to the Modernism period, in which the architects have started to responsible for design of residences [19, 22].

As it is well known by everyone that deals with the modernization period of Turkey, the new demand, which was determined by the movement in unusual scale after 1950s, for the residences was satisfied by means of two identical sectors. The reasons that enabled the existence and continuity of informal means of production till the second half of the 1980s are the important amount of land of the government and the multi-party system. Public lands, people who demand residences in a large scale and ready to produce them by individual efforts and the political strategies of various parties already imposed the solution itself. During the 30 years time, which is a very important period in Turkey's urbanization, the public lands -rather than being based upon a well-ruled and organized system- had been given without their rules are standardized. This was basically due to the political strategies. This informality, together with the formal ways of land distribution, and the correspondence between the formal and informal ways of producing the residences have formed the basis for the rapid urbanization period of the country [17, 23, 24].

Because of the modernism dynamics of Turkey, even the larger scale production requirements were still tried to be solved by the individual efforts. And even after 1980s, which is the period of the threshold for the demand of a widespread production of residences all through the country, this situation could not change significantly. As a result, the low-density parcels and the all the lands in the public zones have come to an end so that the mechanism could no longer run. This has been the beginning for the steps taken for the large-scale productions, in which the formation of architecture could take place with all its characteristics such as techniques, aesthetics, organization, technology, etc. since there are many alternatives for the product as opposed to the case of the production of single buildings. However, the appearances in most of the mass housings have not differed in many aspects. They could not be more than the multiplication of preliminarily defined single buildings [13].

The mass-housing program that is supposed to connect the architect with residence has also been expected to satisfy the demand of increasing the life standards of low-income society. However, insufficiency of public transportation stands as one of the major problems in moving the dense settlement zones out of the city centers for low-income group. At this point, it is possible to mention about the cooperative way of construction, which has a rather different meaning in Turkey. It means the gathering of some social groups of limited possibilities to have the chance to utilize some public credits. Cooperative construction actually implies solidarity that goes on also after the construction period is over. However, in Turkey, it covers a temporary solidarity just until the construction is over and the property is owned. The only difference from the exchange of land with the promised flats is the scale that could be huge sometimes. The scale is mostly related with the size of the blocks as well as the repetition of the same blocks rather than different searches for design and layout of the buildings within the site. The huge scale apartment blocks do not generally utilize the possibilities and advantages of design, technology and organization of the increasing scale. The scale also increases also in the people that are covered within the process. The number of people, which is about ten for the construction of a single unit, increases up to hundreds. However, architect is still excluded within the processes since everything has been the repetition of the case in the construction of the single blocks. This could be seen as a fear, which prevented to utilize all the advantages and innovations of the formation of architecture could include such as new design possibilities, new space standards and technological opportunities, against changing. The repeated new blocks have become the 3-4 times the size of the 4-5 storey apartment blocks that already have almost nothing to be defended. The means of design that could be appropriate -at least- in the buildings with 2-3 storeys become meaningless in the bulky units. The corner balconies and eaves could be given as an example for these means. Besides they become meaningless repetitions in huge units, the balconies start to threat the seismic performance of the buildings in that scale as well. Identically the insistence on using the same size of openings and eaves could be examined in this way so that the functionality of the eaves in low-rise buildings turn out to be just visual items; and the rhythm that is created by the same size of openings have no use other than a monotonous effect on the facades [13, 17, 25].

On the other hand, there also seen some extensive mass housing plans, which start with the projects that address the high income society due to their high qualities, of the private sector are seen to be the forerunners of the developments in this aspect. However, these attempts would probably remain within a very small scale when compared to the rest of the other ways of producing the residences.

In general, it could be said that the differentiating characteristic of the 20th century residences from those of the previous periods is that they are mass productions, which is based upon repetitions. However, the basic problem that this repetition should be created by means of a design technique with the potential of variation and differentiation is seen to remain. Rather than erecting the same units, the residences should be created by multiplying the identical units that should differ from each other as well. The 20th century residence architecture should be based upon this permutation technique that enables flexibility [25].

2.1.3. Role of Town Planning Codes in the General Characteristics of the Members of the Built Environment

Other than the process, which could be said to be normal, the unharmonious silhouette of almost all the urban settlement zones in the country could be related to many reasons one and most important of which is the unconsciously settled Town Planning Codes, as mentioned before. The architects are usually seen as the chief responsible of this unhealthy development. This could be relevant to some extent; however, it should be kept in mind that the contribution of architecture might not be more than color and texture of the elevations of the buildings when the Town Planning Codes offer the identical parcels and regulations for every residence that is planned to be erected. Also, it is possible to observe many unauthorized buildings, which were built out of the regulations of these codes. Besides, the profitability of the parcels is also still relevant, which results as that the architecture is nothing more than a means for the maximum and the most efficient way for land utilization [17, 26, 27].

In this study it is aimed to explore the feasibility of the proposed method to the reinforced concrete buildings in Turkey and discuss the architectural and structural aspects of the method related to its application with all advantages and disadvantages. Hence, it becomes necessary to have a detailed study on the existing structural and architectural situation of the buildings. As a result of the rapid urbanization period especially after 1950, the reinforced concrete buildings in Turkey unfortunately do not display a very brilliant appearance. They seem to be almost identical in each region. In other words they were constructed without any considerations related to climatic conditions, traditional features, etc. that differ regionally. The reasons of this situation were discussed in the previous sections of the study in detail. Besides the great and sudden rush to greater settlement zones due to several reasons, the Town Planning Codes prepare the basis for this condition. Moreover, the misunderstanding of the concept of modernity speeds the construction and utilization of the unconsciously designed reinforced concrete buildings up.

At this point, it would be helpful to have a general overview of the appearance of the urban settlement zones in Turkey. In the urban settlement zones in general, it is possible to observe the parcels of almost the same dimensions. Turning into a standard rather than framing, this strict limitation in the parcels could be seen as the reason that the formation of architecture is excluded in small-scale productions. The Town Planning Codes also define the boundaries, and consequently the form of the buildings, since the main concern is to obtain the maximum space within the limited parcel. The variations are only of about secondary preferences such as façade material, color, etc. Thus, for the formation of architecture, it becomes impossible to take place in such a physical environment. The alternative solutions and space arrangements that the architecture could offer are not required under these circumstances. The built environment is characterized by the Town Planning Codes and the customs of the contractors.

The effects of these boundary conditions are seen also in the mass housings, which are claimed as projects of larger-scale. The mass housings appeared in such a way that each of the constituents is aligned –again- according to the limitations of the Town Planning Codes. The buildings, the locations of which are defined according to the limitations between the main road and among each other according to the codes, are put together to create uniformity so that the material and color are seen to be the only means of differentiation.

2.2. Characteristics of Reinforced Concrete Residential Buildings in Turkey

In order to determine and identify the characteristics of the reinforced concrete buildings in Turkey, some explorations were carried out. These explorations were preformed in order to categorize the buildings according to structural features that could be the determinative factors for the feasibility of the proposed method.

In Turkey, independent from the size and scale of the cities, the built environment more or less displays the same characteristics. According to the explorations carried out in Afyon, Eskisehir and Ankara as the representatives of the small, medium and large-scale cities, it is possible to figure out the characteristics as follows.

Figure 2.1: General view from the city center of Afyon

There observed a strict distinction between the commercial and residential zones in all of the cases. However, especially in the city centers, the buildings are utilized both for commercial and residential purposes. In these zones, the buildings are generally attached to each other with identical heights (Figure 2.1,

Figure 2.2 and Figure 2.3). Moreover, the ground floors in these buildings are generally used as shops and offices; in other words they don't have the inner partition walls. This situation creates the effect of soft storey in case of an earthquake.

Figure 2.2: General view from the city center of Eskisehir

Figure 2.3: General view from the city center of Eskisehir

The upper floors in these buildings are used as either offices or residences. These buildings contain projections only in one direction since they already are constructed to cover every available square meter and they are attached to each other. The pattern slightly changes away from the city centers. Here, as seen in the Figure 2.4-Figure 2.6, the buildings don't have the soft storey effect since all the floors serve as residences. However, these buildings sustain danger due to the different utilization of the shelters as stores or garage in the basement floor. Moreover, the projections on either one or two sides of the buildings threat the buildings in terms of seismic performance.

Figure 2.4: General view from side streets of Afyon

Figure 2.5: General view from side streets of Eskisehir

Figure 2.6: General view from side streets of Eskisehir

The investigation in Ankara was performed in more details so that the buildings are categorized according to their form, layout and sizes. The reason to perform a more detailed study in Ankara is that it is the city that experienced the urbanization process since the very early years of the Turkish Republic. Ankara is among the cities that experienced the period in a better way since the very beginning. It clearly demonstrates the products of the urbanization period in both the previous and the recent years. Considering the fact that urbanization reached the greatest increase by the 1950s and 1960s, the Barbaros district, in which the Tunali Hilmi Street takes place, could be claimed as one of the best examples. The masonry buildings in this district were not taken into consideration since the masonry buildings are out of the scope of the study.

According to the site surveys that were carried out in this district shows that the appearance of these buildings, in general, are more regular than those in any other zone of the city. The buildings are either single or attached to each other; however, except the main street, which is Tunali Hilmi Street, it is not possible to see adjacent buildings in series. Generally two, very rarely three buildings constitute the examples of the attached layout in this district. Moreover, the attached buildings are in harmony with each other so that the number and the level of the storeys are alike. Most of the buildings are single, which are located in gardens with a considerable amount of green area. The buildings in this district are generally 3-5 storeys.

The explorations that were carried out in Sincan give more different results than those performed in Barbaros district. The majority of this district has been built-up in the recent years. As seen in the Figure 2.7, the situation is similar to the general layout described above in commercial zones in Afyon and Eskisehir; however, what was observed in the more residential parts is that the buildings are plainer so that they even do not have the projections. What lies beneath this might be that most of the buildings are the cooperative works so that cost comes out to be the most determinant factor. In other words, it could be said that there has been a search for the simplest, which is the cheapest as well, solution to provide accommodation for especially the low-income group. There observed no search even on the color and texture of buildings, either.

Figure 2.7: General view from the main street in Sincan

The buildings in this district are also seen to be of medium-height of 4-5 storeys. In the more commercial zones the profitability of the land is still relevant so that the attached layout is seen widespread. This means there hasn't been a change in the built-up areas since the last decades. On the contrary, the buildings explored in the more residential zones, are seen as pairs, which are generally attached on one side (Figure 2.8).

Figure 2.8: Typical building of attached layout from the side streets in Sincan

Under these circumstances, it is possible to categorize the reinforced concrete buildings under three headings according to their layout in the parcels:

1. Single buildings: Buildings of this type are similar to each other in terms of layout, scale and architectural and structural aspects. In general, they display similar characteristics in all around Turkey. The only difference might be the number of stories, but even that might be the same for the buildings around the same location. The ratio of the area of the openings to that of the floor, as well as the size of the projections and the balconies are seen to be the same in all the buildings due to the regulations of the Town Planning Codes and the intend to use the area in the most effective way in terms of land utilization. However, it is for sure that utilization of the openings of a three-story building does not create the same design effect when it is used with the same dimensions on the twenty-story building. This ignorance or fear of creating new design approaches instead of using the usual one without any change or modification was discussed in detail in the previous sections of the study.

   Buildings of this type stand alone in a part of land and generally have small gardens, which are usually left due to the restrictions related to the ratio of the building to the site. The first floor projects out in one or two directions. This might be done by means of balconies as well. They are usually five storey buildings, which is a very common figure in Turkey. This group might be classified in itself according to some other architectural and structural aspects. The staircase might either be at the center or on one side of the building. They usually have two flats on each floor, however these can rise up to four flats depending on the size of the building. The flats are usually of two or three bedroom type with a kitchen, a bathroom and a living room. The layout is usually typical. The kitchen and the living room are the closest sections to the entrance whereas the rest of the rooms are usually along a corridor. Two balconies, one of which is for the living room and the other is for the kitchen, are common for these type of flats. Usually the flat on the last floor is duplex with the one at the roof level. In other words, these buildings have a terrace flat as well.

2. Attached buildings on one side: These buildings are constructed on the sites where the Town Planning Codes allow the utilization of the land until the very end at one side. There are a few centimeters left between the two buildings however, this layout usually creates problems in case of an earthquake because of the pounding effect. The adjacent buildings sustain more danger due to pounding if the floor levels are not identical. There are some examples that the adjacent buildings are designed similarly in terms of appearance such as color and texture; however, there are also some examples that two buildings do not have anything in common. This difference starts with the level difference, which is more important since it is related with safety, and continues with the decorative issues at the end. The result is, in this case, two buildings that seem to be together but have nothing in common in appearance. The plan layout, however, does not differ much as it is explained above in the single buildings. Moreover, the other features such as the projections and location of the staircases are almost the same as they are in the single buildings.

3. Attached buildings on both sides: These buildings are generally located at the city centers due to the aim of effective utilization of the land. It is hard to mention about the space left and used as a garden in the layout of these buildings. The ground floors of the buildings are usually used as shops whereas the rest may be either the offices or the residences. They are usually identical in terms of number of floors; however, the difference

between the floor levels creates problems more than it does in the buildings that are attached only on one side. Because the pounding effect would be on both sides when the building is attached on two sides.

The layout of a building within the parcel is one of the most important factors that act upon its seismic performance due to pounding effect. Although it seems to be a feature related to architectural design, it has strong influences on structural behavior. Among those listed above, there are many other characteristics that affect this performance such as floor discontinuities, irregularity and discontinuity of structural members, projections, soft storeys, etc. The analyses related to the feasibility of the proposed method will be performed on both single and attached layouts with seismic design defects, which might result from architectural considerations, in order to observe the effects of the additional structural members on different configurations.

2.3. Earthquake Resistant Building Design Considerations in Reinforced Concrete Buildings

The very fundamental for the architects to understand is how earthquake-induced forces are translated into the building and how these forces are resisted. Occurrence of any rupture in a fault zone produces a multitude of vibrations or seismic waves that spring in all directions. The effects of this ground shaking might have severe effects on a building depending on the amplitude, velocity, acceleration, displacement, duration, and magnitude of the earthquake as well as the mass, stiffness, damping, and strength of the structure. Causing the ground and the building to shake in a very complex manner, these motions are translated into dynamic loads, which introduce the structure at the foundations. Followed by a transmission to the vertical supports and into the foundations, the horizontal earthquake loads are assumed to be initially distributed throughout the building by means of floor and roof systems. Essentially, the vertical supporting system must be capable of resisting the dynamic loads at the ground and roof levels without excessive distortion and/or failure [28, 29].

Past earthquake records are useful means in determining the levels of seismic loads for codes. However, it is impossible to obtain an entire description of a future earthquake in a specific area. As a major principle of earthquake resistant building design, the structure is expected to have no or only insignificant nonstructural damages in a minor frequent earthquake whereas it might suffer repairable structural damage in occasion of a moderate earthquake. And since the basic concern is the safety of human life, the building should be designed so as not to collapse, even if it is severely damaged in a high intensity earthquake. Because of economical considerations, the building is -without losing its capacity- allowed to undergo inelastic rather than elastic deformations during high magnitude earthquakes. By means of plastic hinges that are to be formed on the desired regions, the structure is guaranteed to sustain severe damages without collapse because of excessive amount of energy dissipation. Being flexural, moment failures also spend a great amount of energy and do not cause a sudden collapse. However, it is the brittle failure that must be prevented basically, which develops due to stiffness degradation and strength reduction as a consequence of high shear stresses. Diagonal cracks must be prevented by sufficient amount of transverse steel reinforcement about connections.

Experiences related to the past earthquakes in Turkey have indicated that two main reasons for the failure of reinforced concrete buildings are inconvenient system selection and insufficient dimensioning and detailing. Moreover, soil conditions and constructions of poor quality might be the significant explanations of damages and collapses (Figure 2.9).

The defeats in system selection and detailing arise from the lack of knowledge about seismic behavior and performance. Inconvenient system selection has been the reason of severe damages and collapses. There are some basic considerations in the design of structural system related to its seismic performance. The system is required to be as symmetrical as possible and should have a constant rigidity through the entire height. Structural members should be arranged and located in a continuous manner so as to avoid structural irregularities. Dimensioning and detailing of structural members are seriously effective on the seismic performance of the building. Excessive sway and deformation must be essentially restrained in order to keep away from failure since they might lead to stability problems and additional bending moments especially in slender structural members.

Figure 2.9: Failures of reinforced concrete structures [30]

The other importance of dimensioning and detailing is seen on the decisions related to the occurrence of plastic hinges. The basic principle of reinforcement detailing should be providing enough ductility and resistance. Ductility, which is usually measured by the amount of deformation that occurs between first yield and ultimate load with small losses in load carrying capacity, is defined as the ability to accommodate relatively large deformations without failure. The structure's behavior is of utmost importance in the arrangement of plastic hinges, which are required to take place at the ends of beams rather than those of the columns in order to obtain a ductile failure [31].

Due to the fact that concrete is brittle and reinforcing steel is ductile, a brittle failure unavoidably happens if the concrete crushes before the steel yields. In seismic zones, it is a must to prevent sudden shear failures to obtain ductility. Shear failures might be prevented by means of stirrups according to the results of the capacity design. The critical sections where the plastic hinges are to occur and the ends of the columns must be confined by stirrups. The axial loads of the columns should be kept within the capacity limits.

2.3.1. Importance of Architectural Education on Earthquake Resistant Building Design

There is a very common tendency in our society to relate everything about earthquake with the field of engineering. This is mainly because of the fact that most of the research material interconnected to this topic belongs to the engineers. Architects feel themselves distant to the topic since all the research materials, publications, and related science works about this topic covers sets of equations and technical explanations. Thus, they prefer to deal with the aesthetic considerations, appearance, and details instead of structural requirements of the buildings. The utmost importance given to the art and aesthetics in the education period facilitates this tendency and hardens to perceive the importance of the initial steps of design in terms of structural behavior of any building. The education should cover to enable the student of architecture to understand the behavior and importance of seismic performance of the buildings. Architects should graduate by realizing the significance and responsibility of being the head of the design team.

The architectural design issues initially cover the decisions upon the form, shape, architectural elements, and structural system of the building. Related scientific works and observations, which were carried on just after the earthquakes, point out the importance of the form, shape, and structural system of the building on its seismic performance. The consciousness of this importance can only be imposed to the architects during their education. The students of architecture have to be educated about the behavior of structures in order to be able to select a convenient structural system for the building. They must know what should and should not be done in an earthquake resistant building design and should collaborate with the engineer in every step of the design process, instead of considering the drawbacks as sets to their creativity. Especially the buildings to be built in seismic zones should be designed considering principally the safety of human life. It should be well perceived that not only the structural system but also the irregularities in plan and in elevation lead to deficiencies in the seismic performance of the building.

2.3.2. Common Seismic Design Faults and Types of Seismic Damages in Architectural Design of Reinforced Concrete Buildings

After the past earthquakes, it is observed that in a certain area, with almost identical soil characteristics and distance to the seismic belt, some of the buildings collapsed while the rest has some structural damage in a varying range and characteristics. The observations that were carried out after the hazard enabled to indicate the reason of structural damages and collapses in very similarly designed reinforced concrete buildings. Based on these observations and research outputs, it is possible to say that some architectural design faults might result in structural damages and even in collapses. The reasons for structural damage and collapse in terms of architectural design can be listed as:

- Undesirable geometric configuration
- Inadequate lateral stiffness
- Flaws in detailing [32].

Undesirable Geometric Configuration: These configurations might be seen due to many cases, one of which is the interruption of the continuity of the frame. The configuration is again defective if the beams do not connect to all the columns throughout the building, or if the columns support the beams in an exaggerated eccentric way. Movement of the columns from the axis of the frame or the intersection of the beams with each other without any vertical support creates the same effect.

Inadequate Lateral Stiffness: The tall building sways under the action of transverse lateral forces, which are perpendicular to the longitudinal axis of the structure. Elimination of partition walls results in soft storey effect, the columns of which display the concentration of inelastic occurrence at the upper parts because of significant reduce in stiffness. Another case that is developed due to inadequate lateral stiffness is hammering of adjacent buildings at separation points.

Flaws in Detailing: One of the most common cases of this defect is seen as the formation of short columns by improper use of partition walls. The joints should be in the form of strong column-weak beam connections and reinforcements should be detailed properly for adequate strength and ductility. Column longitudinal steel must be confined by tie reinforcement so as to overcome the problem of buckling under the column compression load (Figures 2.10 and 2.11).

Figure 2.10: Buckling due to insufficient reinforcement

Figure 2.11: Buckling due to insufficient reinforcement

2.3.2.1. Design Faults in Plan

Seismic design faults in plan may be investigated under some certain categories such as:

- Torsion eccentricity
- Floor discontinuities
- Projections in plan
- Non-parallel axis, irregularity, dislocation, and discontinuity of columns, beams, slabs and shear walls [4, 33, 34, 35].

Torsion eccentricity occurs as a result of the distance between the center of gravity and the center of rigidity. The lateral earthquake forces would create a torsion moment, which would lead to additional shear forces in the columns, around the center of rigidity proportional to the eccentricity. The center of rigidity should be changed by means of some modifications on the cross sections and the locations of structural elements (Figures 2.12 and 2.13) [34].

Figure 2.12: Torsion failure

Floor discontinuities, which might occur because of drastic changes in slab rigidity or large openings in slabs, lead to critical and unpredictable changes in the distribution of lateral loads to columns and shear walls. Consequently the dynamic behavior of the building is negatively affected and irregular lateral displacements with additional shear stresses on the columns come into existence.

Figure 2.13: Torsion failure

Projection in plan is a very common feature of a great major part of reinforced concrete structures and residential dwellings mostly due to the intent for the effective use of the area. However, large projections cause additional stresses and torsion eccentricities on the structure. The most critical shear forces and moments occur in the intersection line of the projection and the main body [36].

Configuration and alignment of structural elements is one of the most important aspects in earthquake resistant architectural design (Figures 2.14-2.16). There are some critical points about the configuration of beams, columns, shear walls, and slabs. The main axes of the structural members should be parallel to the lateral earthquake forces in order to avoid the occurrence of additional moments and shear stresses. The beams must continue throughout the whole frame so as not to handle the distribution of the lateral forces to the vertical structural elements to a rather thin floor slab. Furthermore, irregular spans and altering beam cross-sections harden to estimate the lateral stiffness of the system and critical stresses of the structural elements. It is strictly recommended to support the beam connections by means of vertical structural elements in order to avoid a large point load on the connection point creating critical moments, which might lead to large deflections and cracks. At least, these connections should not be placed near the support in order to avoid critical torsion moments. Leading to torsion and decrease in the resistance to lateral forces, another important fault is the creation of frames with broken axis, which would make to handle the structural analysis in two dimensions and realistically predict the forces applied on the system impossible [37].

Figure 2.14: Failures due to irregularities of structural members

As the means to transmit the lateral forces to vertical elements, the slabs should have complete in-plane rigidity. Over-stretched one-way slabs are troublesome in terms of large deformations under lateral loads and contraction cracks due to the difficulties in insertion of reinforcements in the long direction.

Figure 2.15: Failures due to irregularities of structural members

Figure 2.16: Failures due to irregularities of structural members

The very commonly used slab type in residential buildings in Turkey is the block-joist slab, which usually result as shallow main beams. Leading to the destruction of the bond between the floor blocks and the joists, shallow beams are open to large deflections under lateral forces. Necessarily of the same height of the main beam, the direction of the joists should be parallel to the longer side of the slab.

As those of beams and frames, broken axis of the columns is also dangerous due to the creation of additional moments. Besides, to make a system that has beams and frames with broken axis resistant to earthquake, large and uneconomical element cross-sections are needed. However, on a regular plan, the building has high lateral rigidity due to the uniformly alignment of columns according to an axial system. One other important aspect is the connection of beams and columns, which is desired to have minimum eccentricity especially in the cases where beams with varying cross-sections meet. Additional torsion moments would lead to failure unless the connection is effectively reinforced [37].

Increasing the lateral rigidity of the structure as well as reducing the excessive displacements, shear walls are the most effective means of creating earthquake resistant buildings. However, concentration of shear walls on one side of the building leads to excessive torsion eccentricities and uneven displacements on the structure. They would be effective provided that they are placed symmetrically and in such a way to keep the center of gravity and rigidity as close as possible. Besides, they are required to be organized according to an axial system just as the case in the configuration of the columns. They should be perpendicular to the building façades in the critical lateral force direction, which is parallel to the shorter side of the building [31].

2.3.2.2. Design Faults in Elevation

The very commonly seen seismic design faults in elevation are as follows:

- Weak storey irregularity
- Soft storey irregularity
- Discontinuity of vertical structural elements
- Irregular motion of building blocks
- The pounding effect
- Irregular distribution of masses
- Creation of short columns
- Irregularities in foundations
- Creation of weak column-strong beam connections [4, 33, 34, 35]

Weak storey irregularity occurs due to the discontinuity of vertical elements through the entire height of the building. If the ratio of effective shear area in a floor to the effective shear area of the upper floor is between 0.8 and 0.6 there is a weak storey irregularity in the structure [38].

Soft storey irregularity is similar to the weak storey irregularity. Instead of the shear strength, the relative displacements of the floors are critical. Soft storey is commonly seen in the ground floors of residential buildings in Turkey, which are used as stores, shops, or garages (Figures 2.17 and 2.18). This irregularity mainly occurs due to rather high columns in the ground floor, discontinuity of the shear walls in the ground floor, and omission of partition walls, which partially increase the lateral rigidity of upper floors [34, 39].

Figure 2.17: Soft-story effect

Discontinuity of the vertical structural elements is seen by the elimination of some columns and shear walls due to spatial, functional, or aesthetical concerns. The beam or column underneath the omitted column or shear wall, respectively, would be subjected to excessive moments and shear stresses and require uneconomical cross-sections.

Since the seismic behavior is dependent on the mass of the building, irregular motion of individual building blocks, which create its own loads of inertia, lead to critical torsions and shear stresses at the intersection areas during earthquake. Seismic performance can be obtained by dividing the building into structurally independent sections in order to avoid additional torsion moments and shear forces.

Figure 2.18: Soft-story effect

The Town-Planning Codes permit to build structures wall-to-wall adjacent to each other. If there is not enough space between the buildings, this adjacency might lead to destructions of structural elements due to the collision of one building into the next, since each building makes displacements according to its own natural period [34]. The most dangerous pounding type is the one between the buildings with different floor levels, since the crushing of floor slabs of one building with the columns or shear walls of the adjacent building would result in the crushing of the columns due to the much less rigidity when compared to those of slabs (Figure 2.19). According to the Turkish Earthquake Code minimum 30 mm space is required between buildings up to 6 m. From 6 m high buildings and on, the distance is to be increased 10 mm for every raise of 3 m [37].

Irregular distribution of masses might form due to some additions such as heavy machinery and water tanks although the structure may seem to be regular in terms of configuration and alignment of structural members. Setbacks and cantilever projections are the other reasons for the creation of irregular mass distribution, which create different torsion irregularities and lateral rigidity from the floors below and above, especially if they are not on the central axis of the building [37].

Figure 2.19: The pounding effect

Another very common seismic design fault is the formation of short column, which leads to an increase on the lateral rigidity of the element and, consequently, the stresses that it attracts to itself. Short column effect is seen due to the occurrence of low partition walls, which are not isolated from the structural member by means of earthquake joints. Partition walls might have a vital effect on the seismic performance of the building either negatively or positively so that they might decrease the ductility of the structure and might cause additional torsion and shear stresses on structural elements, or they might act as shear walls and might prevent a probable collapse.

Figure 2.20: Short-column effect [40]

Figure 2.21: Short-column effect [40]

Short column formation is observed due to any decrease in the height of the columns in a certain storey when compared to those of the other storey (Figure 2.20). Low mechanical floors, irregular beam depths in a frame, strip windows, or foundations on inclined topography may cause short columns [41]. In order to avoid any probable short column formation, it is necessary to construct the foundations on the same level if possible. All the footings should be connected to each other with beams to prevent individual displacements. Due to the fact that irregular foundations cause additional torsions and excessive displacements in the structure, a failure in the foundations may cause the total collapse of a building having a strong superstructure since the earthquake energy is transferred to the structure by means of foundations [31] (Figure 2.21).

The last of the most common design faults in elevation is observed as the strong beam-weak column connections. However, the primary consideration in an earthquake resistant building design, which is to prevent total or partial collapse of the structure in order to save human life, can be achieved provided that maximum energy is absorbed by means of ductile deformations in column-beam connections and lateral stability is protected. In the case of more rigid beams compared to columns, ductile deformations, which would lead to excessive displacements, occur at the top and bottom ends of the columns. The result is the loss of lateral stability, which would lead to a collapse in the ground floor and unavoidably, the destruction of the other floors (Figure 2.22). On the contrary, if the columns were more rigid than the beams, ductile deformations would occur at the ends of the beams, which already can absorb a considerable amount of earthquake energy by ductile deformations without an important loss in the load carrying capacity. It is the beam-column connection to fail before the collapse of the ground floor.

Figure 2.22: Strong beam-weak column effect

CHAPTER 3

METHODS OF STRENGTHENING AND ITS EFFECTS ON REINFORCED CONCRETE BUILDINGS IN TERMS OF SEISMIC BEHAVIOR

3.1. Repair / Strengthening / Retrofitting / Rehabilitation of Reinforced Concrete Buildings

Before going into the details of the existing methods that are used to increase the seismic capacity of reinforced concrete buildings, it might be necessary to have an overview on the technical terminology. *Repair* is the process that is carried out to provide a damaged structure or a structural member a predefined safety level. *Strengthening* is the process that is carried out to provide a damaged or undamaged structure or a structural member to a predefined safety level. The former of these terms is generally used to provide a damaged structure its original safety level whereas the latter aims to offer the structure extra strength and resistance to whether damaged or undamaged structures. Contrasting to routine maintenance or repair, the term *retrofitting* means the strengthening of a structure in advance to minimize damage due to a possible earthquake [42, 43].

Including all the concepts of *repair, retrofitting* and *strengthening* that lead to reduce earthquake vulnerability, the term *rehabilitation* is used as a general term that covers all the physical upgrading on a structure or its structural members in terms of structural performance [44]. In this study, since the aim is to propose a method to give extra resistance to existing structures, the term “strengthening” is used as a general term.

There exist many ways of strengthening; however the crucial point is to decide upon the most convenient one for the circumstance. The first step for the determination of the strengthening method is to assess the existing structural condition, in other words, the structural reliability of the building. When the case is a post-disaster investigation, identification of the structural damage on each building just after the hazard is the starting point of the process. However, the lack of a universally accepted systematic procedure to assess the post-earthquake damages or structural soundness of a building leads that the judgment upon the degree of the damage and the most convenient strengthening method are depend mostly on the basis of local conditions and engineering criteria.

While assessing the safety of the building, it is very important to determine the effect of the repair and strengthening processes on the rigidity of the members and center of rigidity of the building. Provided that it does not create torsion eccentricity, the center of rigidity should not be changed. On the other hand, it should be modified so as to minimize the danger due to torsion eccentricity. Estimating the rigidity of the buildings with composite structural systems due to repair and strengthening is impossible without a good knowledge of structural behavior [42].

3.2. Determinants on Selection of Strengthening Method

There exist several ways of repair and strengthening methods, each of which might be effective in several aspects. The selection of the most convenient method depends mostly on the information related to the existing situation, which should be based on economic conditions, available geological and structural information, and the performed analyses that cover the damage level of the building.

There are many parameters that act upon the selection of the most convenient repair or strengthening method. The importance of these parameters depends on the circumstances. Feasibility of the proposed methods includes various aspects such as time, cost, availability of the building materials, design, and construction techniques and technology. A strengthening or repair method chosen for one building may not be that convenient for another. Or, a method that is proper for strengthening of a single building may not be practical when the question is a post disaster strengthening that covers more than one building. The possibility of evacuating the houses during the repair or strengthening process is another determinant. It is necessary to provide another place for accommodation of the residents of the buildings to be strengthened during the process.

If there is a post-disaster investigation, the case should initially cover the determination of existing structural capacity of the buildings. The buildings, which should be demolished, which require strengthening and which do not, should be identified clearly in order to specify the content of the process. Moreover, the type of the damage should be identified in order to form a basis for the strengthening method. One of the most commonly observed damage type is that the structural frame of the building suffers due to the enormous energy that could not be dissipated within the building. The building could also sustain danger due to the foundation settlements, which lead to a serious decrease in the strength of the load bearing system, as well. Identification of the damage type and level would be helpful to specify the application points of the repair or strengthening method. Some buildings might be given the desired strength, rigidity and ductility by means of strengthening only its structural members, whereas the others require improvement of the overall structural system. In both cases, the process should be very carefully organized in order to facilitate the application.

3.2.1. Structural Assessment of Existing Buildings

The very initial step of the strengthening processes is the exploration of the structure on site. Besides the identification of the dimensions of the members and the reinforcements, the existing cracks and deformations, which are the most reliable data, are indicated. In a structural analysis that would be performed to indicate the structural reliability of the building, knowledge of structural behavior is very important in order to determine the effects of cracks and deformations on rigidity and strength [42, 43, 45].

After the explorations on the building site are completed, it is necessary to decide upon the structural reliability of the building. If the proposed strengthening process covers more than one building such as those handled just after an earthquake, the post-disaster investigation of the area in question covers the decisions upon the severity of the damage in order to identify the buildings, which need to be demolished and which require strengthening. The further examinations need more systematic approaches that categorize the damage besides the required level and type of strengthening and repair processes. The basis for these decisions should be the three primary concern of earthquake resistant building design: strength, ductility, and rigidity. These principles should be provided in the modified building by means of any repair or strengthening process [42, 43].

For a more detailed assessment of the existing structural performance of the buildings, the entire available document, such as the architectural and structural drawings and as built plans as well as design calculations, soil test data and all relevant information, should be collected. The second step includes the examination of the dimensions and details of the structural members of the building in the aspects of quality and quantity by means of universally accepted methods. Moreover, cracks and deformations as the most reliable data should be checked out and categorized. The last step before the application of the strengthening or repair process on the site is the selection of an analytical method for the evaluation of the existing structural capacity of the building.

3.2.2. Principles of Seismic Strengthening

The effects of earthquake to the building are rather different than those of gravity loads. Earthquake is a dynamic event and the effects of earthquake are dependent upon the characteristics of ground motions as well as the dynamic features of the building such as rigidity, period, and damping ratio. Rigidity, which determines the dynamic characteristics of the building, is dependent on the moment of inertia of structural members as well as the load-deformation relationship. Actual estimation of the rigidity of members that are of nonlinear elastic materials such as reinforced concrete is quite difficult and requires a good knowledge of material behavior [34, 35, 42].

The aim of strengthening is to enable a structure to resist probable future earthquakes. If this structure had been destroyed in a previous earthquake, it should be given enough strength to resist the further earthquakes of the same or higher magnitude without any damage or failure. The probability of a future earthquake within the lifespan of a building requires strengthening the building so that it becomes more resistant than it has ever been. One of the basic assumptions in earthquake resistant building design is that the building would not be able to stay within the elastic limits in a high magnitude earthquake so that plastic hinges would develop in the required regions due to the yielding of steel. The important point here is that the building should not collapse. It is unavoidable that the building would be damaged; however it should be repairable. The building could stand in a high magnitude earthquake by dissipating sufficient energy. Energy dissipation would be the greatest at the points where the plastic hinges occur. As mentioned before, the examination and assessment of the structure is one of the most important parameters that determine the strengthening method and level. Excessive deformations and cracks are the indications of problems in the resistance and load bearing mechanism of the structure. Accordingly, the primary principles and precautions for strengthening can be listed as follows [40, 47]:

22. To keep the mass of the structure constant: Cracks in a structural member are the indications of excessive amount of load acting on the element. Since a structure attracts loads in an earthquake proportional to its mass, any reduce in its mass would lead to decrease in the dynamic loads.
23. To increase ductility of the structure: Ductility is the ability of a structure to dissipate energy. Reinforced concrete structures spend energy by plastic hinges that occur on the beam-column connections. Although strengthening methods provide extra rigidity and enlarge the load bearing capacity of the structure or the member, they do not propose any increase in ductility. Moreover, the more rigid is the element, the less ductile it is.
24. To increase the load bearing capacity of the structure: The lateral load bearing capacity of a structure should be increased for a sound seismic performance. Damages on a structure because of an earthquake indicate insufficient resistance to lateral loads and mean that it would be less resistant to any probable future earthquake. Moreover, although the vertical loads are constant, the damage reduces the reliability of the structure against vertical loads as well. Increasing the load bearing capacity of a structure is obtained by inserting new structural members and/or by enlarging the cross-sections of the present ones.
25. To rehabilitate the dynamic characteristics of the structure: Increasing the loads on a structure provides prolongation of its period; however, this requires enlarging the load bearing capacity of the structure since it would attract more

seismic loads. Rigidity and period of a structure are inversely proportional to each other. Inserting additional structural members to the structure would increase both the rigidity and load bearing capacity of the structure.

26. To decrease torsion eccentricity: Torsion eccentricity occurs as a result of the distance between the center of gravity and the center of rigidity. Considering their probable torsion effect, the additional elements should be placed in a manner that would not create eccentricity.
27. To place additional load bearing members: If a structure suffers from lack of resistance to lateral loads, either the load bearing capacities of present members should be increased or additional members should be inserted. However, the process needs strict control and quality in material and workmanship.

3.3. Repair or Strengthening of Structural Members

Provided that it has sufficient lateral rigidity, a damaged building could be repaired or strengthened by means of some processes that would be carried upon some of its structural members. However, when the process is related to the repair or strengthening of the beams, it should be kept in mind that enlarging the bending moment capacity of the beam would lead to an increase in the shear forces acting upon the member in question. Safety level after the repair or strengthening processes according to shear forces should be controlled. No matter the case is related to either the beams or the columns, the details in the design and preciseness in the construction are of utmost importance in a repair/strengthening process [42].

The reinforcement is of great importance on the behavior of beams under bending. Any beam reaches to ultimate strength capacity by the crushing of the concrete in compression zone. The yielding of the reinforcement in advance provides the beam a ductile behavior [2, 42, 48].

The collapse of a beam due to shear rather than bending leads to a brittle failure. In the cases where shear is of more importance than bending, the shear cracks are seen in a 45-degree to the axis of the beam since the principal tensile stresses occur inclined. While designing a beam, the shear capacity should be greater than that of bending in order to prevent shear failure. This would be obtained by providing enough shear reinforcement. The well-detailed closely-spaced stirrups would increase not only the shear capacity, but also the ductility after yielding in bending [2, 42, 48, 49].

Strengthening processes can be classified according to their point of application and intent. There are several strengthening methods applied on various parts of the frame. Increasing the bending moment capacity and resistance to shear forces as well as attaching steel plates are the different methods, which are used to strengthen a beam. Jacketing, adding shear walls to the sides, and wrapping up by a steel lattice are the common ways to strengthen a column. Modifications on some parts of the frame so as to obtain the powerful effect of shear walls by increasing the thickness of the existing shear walls, filling with prefabricated panels, bracing by steel diagonal members, placing reinforced/unreinforced masonry walls and in-situ cast shear walls are the other means to increase the seismic performance of a frame [46].

Adding extra tensile reinforcement and increasing moment arm are the ways to improving the bending moment capacity of a beam. For this, the depth of the beam should be increased by the additional concrete, which has to be reinforced against tension. At this point, the problem is to bond the present concrete with the new and to anchor the additional tension reinforcements to concrete. V and Z type reinforcements are welded to both the existing and additional reinforcing bars in order to provide connection among them (Figure 3.1 and Figure 3.2). Beside increasing the depth of the beam and connecting the existing and new longitudinal reinforcing bars, it is necessary to increase the length of the ties as well since they have positive effects on the behavior of the member. The other detail is the anchorage of the additional longitudinal reinforcing bars to the structure either by welding or bolting to the beam or the column underneath. The ways to anchor the longitudinal reinforcements are shown in the Figure 3.3 [46].

To increase the capacity of a beam against shear forces requires enlarging the cross-section of the beam and placing extra ties. Inclined cracks near the supports are the indications of lack of shear resistance. So as to prevent any probable increase in number and extent of the cracks and to supply enough capacity against shear forces that reach to the ultimate value near the supports, additional stirrups should be tied to the beam and should be gripped at the top (Figure 3.4). [2, 46, 50]

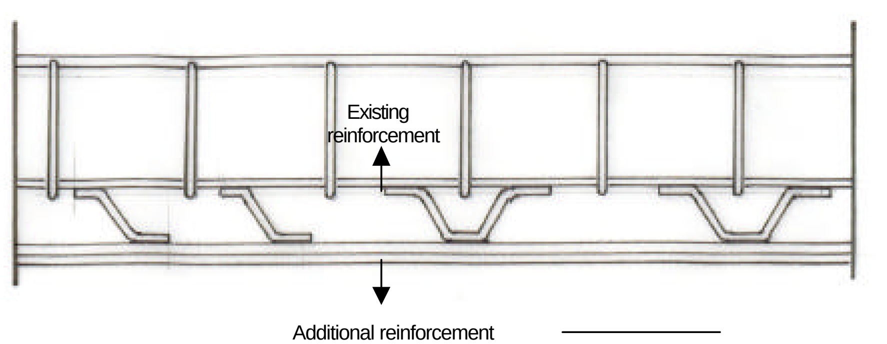


Figure 3.1: Connection of existing and new reinforcements by means of V and Z reinforcing bars [46]

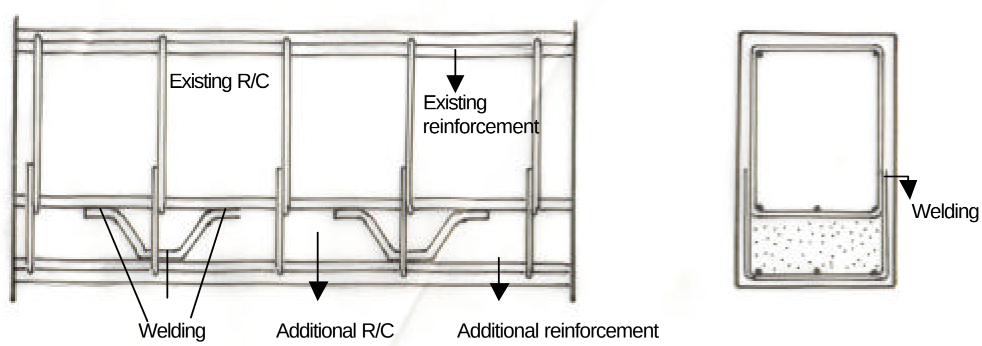


Figure 3.2: Connection of additional stirrups by welding in increasing the depth of the beam [46]

With the purpose of increasing the bending moment capacity and shear force resistance, steel plates might be bolted or fixed by epoxy adhesive to the underneath or side surfaces of the beam, respectively. If steel plates are attached not only to the side surfaces but also to the surface beneath with the aim of increasing the capacity to both bending moment and shear forces, they might be connected to each other by means of welding (Figure 3.5). The crucial point is to obtain smooth surfaces both at the beam and the plate. The plate and the surface should have extra holes if epoxy resin is to be injected besides bolting.

External or internal stirrups should be introduced to counteract shear cracks in beams. The use of prestressed tie-rods to strengthen beams is common but is not suitable for cyclic or reversed loading [43].

Figure 3.3: Anchorage types for longitudinal reinforcements in beam strengthening [46]

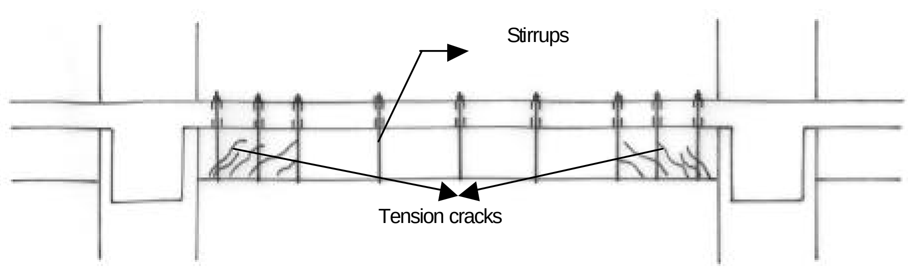


Figure 3.4: Strengthening of beams by means of stirrups [46]

Columns reach the ultimate strength by the crushing of concrete in the compression zone. Ductility in the columns is related to the amount of axial loading. There are two ways to increase the ductility of a column. One is to increase the cross sectional dimensions of the column whereas the other is to provide confinement by stirrups. On the other hand, by the crushing of the concrete, the vertical reinforcement buckles since it has to take all the compression forces. Confinement by means of closely spaced stirrups would prevent buckling. The crushing of columns due to excessive earthquake loads would be prevented by well-detailed and sufficient stirrups [42, 47, 51].

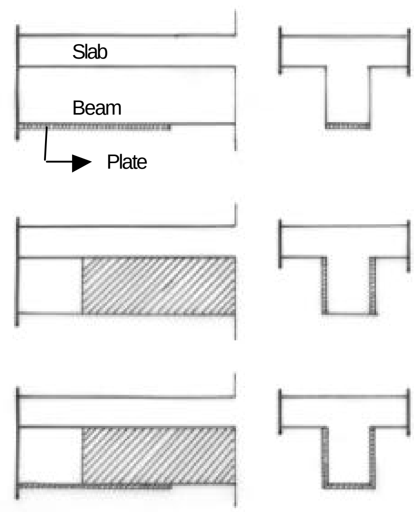


Figure 3.5: Attachment of steel plates to increase a)bending moment, b)shear force, c)bending moment and shear force [46]

Strengthening of columns means increasing their capacity against axial forces, bending moments, and shear forces. As mentioned before, enlarging the cross-section of the column, inserting extra sections with reinforcement to its sides, or wrapping the column by means of a steel lattice, could be used to perform this process [46]

Enlargement of the total cross-section of a column is known as jacketing while the expansion of column only in one direction is the process of inserting wings (Figure 3.6). The principle of jacketing process is to increase the capacity to vertical loads. However, to bond the existing and additional concrete and to anchor the existing and additional longitudinal reinforcement is of great significance, since the loads should be transferred from the existing section to the additional part. The thickness of the additional parts would be either 50 mm or 100 mm. In most cases 50 mm thick jacketing provides a significant raise in the vertical load bearing capacity, since it leads to a great increase in cross sectional area as percentages. The connections should be rigid in 50 mm thickness, whereas they should be elastic in 100 mm thick jacketing. Figure 3.7 shows the elastic and rigid connections by means of reinforcing bars and plates. Combination of existing and additional concrete and longitudinal reinforcements could be obtained by means of S, L, Z and V reinforcing bars. [2, 46, 50]

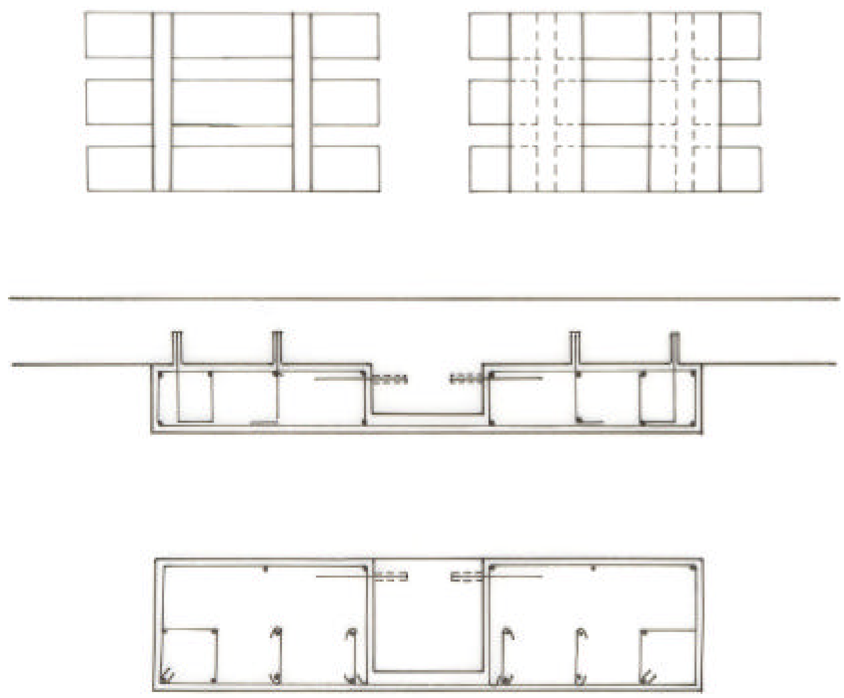


Figure 3.6: Strengthening of columns by inserting wings [46]

Enveloping the column by a steel lattice does not provide an effective increase in the moment capacity and axial force resistance. However, this method might be practical due to ease in providing a nearby support, which prevents collapse.

3.4. Repair or Strengthening of the Overall Structural System

Repair or strengthening of individual members may not be practical or economic if the structure is suffering from insufficient lateral rigidity and the ends of the members are not reinforced by means of stirrups. Here, the most convenient method, rather than applying repair or strengthening processes to an excessive number of structural members, is to develop new structural members to take the earthquake forces by improving the rigidity of the overall system. Improvement of the whole system is required in some cases such that there exist a great number of structural members to be strengthened or repaired, or the structure does not have the required rigidity, or there exist some system weaknesses like soft storey, short column, etc. Improving the overall system does not require any repair or strengthening of the individual structural members, except the columns with excessive damage [2, 42, 50].

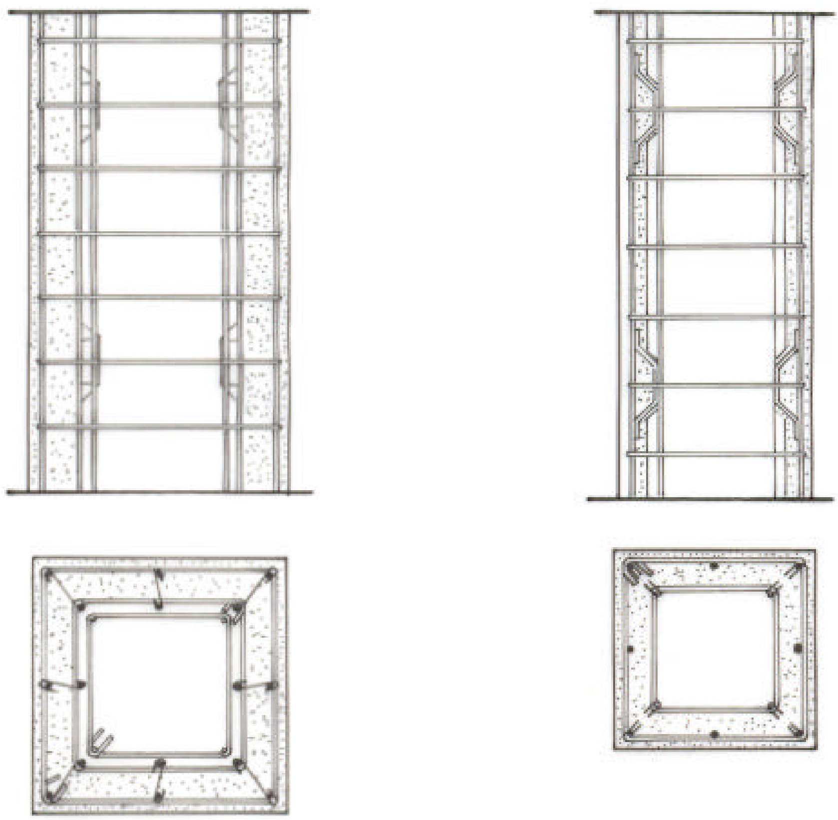


Figure 3.7: a)Elastic b)Rigid connection of additional reinforcements to existing reinforcements [46]

The fundamental in improving the overall system is to strengthen some part of the structural frame and make it more rigid than it has ever been. One method used for strengthening of the overall system is to add shear walls in the manner of inserting wings to the sides of the existing columns. The horizontal reinforcement of the shear wall and the column are welded to each other so as to obtain unity in between. The thickness of the additional parts should be identical with that of the column in order to provide a total surround by means of stirrups and longitudinal reinforcement as shown in the Figure 3.6 above. Thus, the system would act as shear walls with high strength and ductility. Figure 3.8 shows system improvement by increasing the thickness of the existing shear walls whereas Figure 3.9 displays different ways of system improvement that could be applied for columns and frames [42, 46].

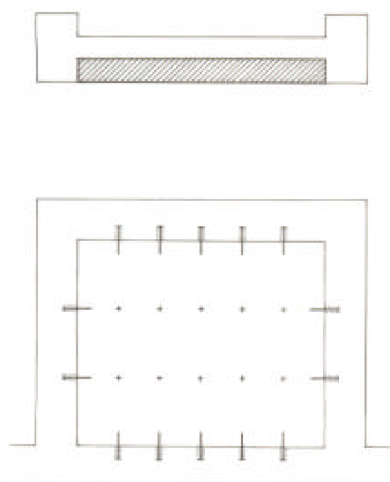


Figure 3.8: System improvement by thickening of shear walls [46]

Another method that is used for system imporvement is to place steel bracings and infill walls within some structural members as well as shown in the Figure 3.10. In Turkey, steel bracings are very rarely used since most of the buildings suffer from low lateral rigidity, which could not be increased by steel diagonals. The infill walls could be of prefabricated panels or in-situ cast plain concrete or reinforced concrete. Prefabricated panels might be more advantageous in some cases, such as the existence of many identical spans to be filled. Although their lateral-load resistance is not as high as that of a shear wall, the prefabricated panels provide more ductility. The plates should be welded to each other and to the beams and columns as shown in the Figure 3.11. Also in the application of in-situ cast concrete, the infill element and the frame elements should be effectively connected to each other in order to provide the behavior of a shear wall. This could be obtained by providing that the vertical reinforcements pass through the holes within the beams and the horizontal reinforcements are anchored to the columns. Not only the reinforcements but also the shear walls must be continuous through the entire height of the building. The columns at the ends of the shear walls must be jacketed because of extra forces, which develop due to the additional bending moment that the shear wall would attract. If the longitudinal reinforcements of the columns are not effectively surrounded by stirrups, the shear walls could not reach their ultimate capacity because of torsion. Or, it is possible to leave joints, which might create the effect of tie beams, between the column and the shear wall [42, 46].

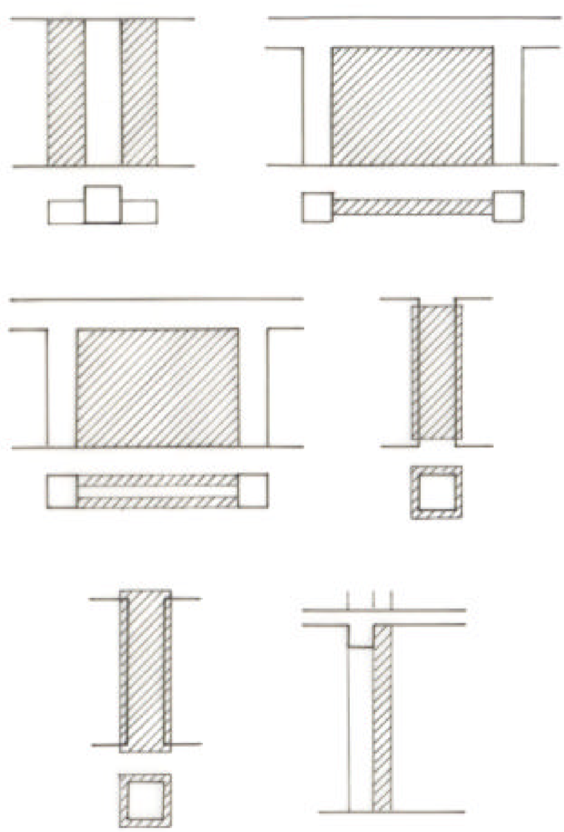


Figure 3.9: Different ways for strengthening of columns and frames [46]

Providing only a little increase in the load bearing capacity, nonstructural masonry walls do not provide ductility. They might be considered as a preparation stage for further infill with reinforced masonry walls, which would be performed by placing reinforcing bars in vertical and horizontal directions among the blocks on both sides of a partition wall. Connected to each other by S shaped reinforcing bars, mesh wire, which should be placed on both sides of the wall, could also be used in strengthening of existing brick walls. If reinforcing bars are preferred instead of mesh wire, the continuity should be provided. Just as in the case of application of cast in place shear walls, the vertical reinforcements should pass through the holes within the beams and the horizontal reinforcements should be anchored to the columns.

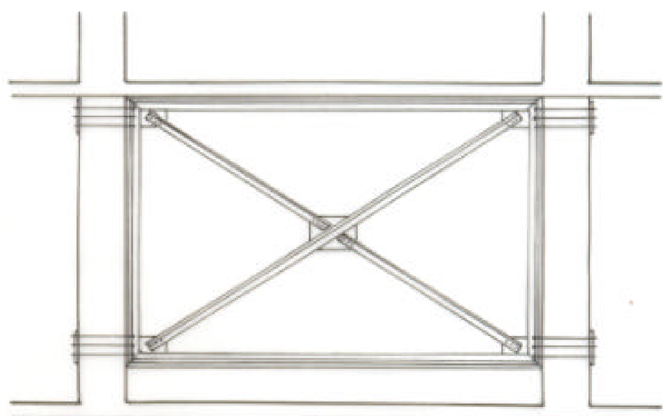


Figure 3.10: Placing diagonal steel bracings within the frame [46]

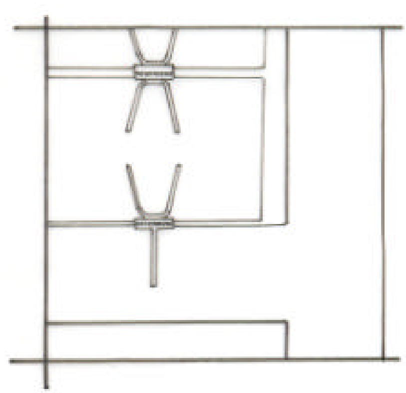


Figure 3.11: Connection of prefabricated panels to columns and beams [46]

Another way of strengthening is to increase the thickness of the existing thin shear walls by an additional shear wall in such a way that they would have a sound seismic performance. In repair or strengthening of reinforced concrete buildings by infill walls, the main concern is to constitute shear walls effective enough to resist the earthquake forces in both directions. Thus, the lateral rigidity would be increased to the desired level. Since the shear walls take the earthquake forces, the structural frames are assumed to resist only the vertical loads. In other words, the structural frame of the building does not require any repair/strengthening. Only the highly damaged structural members are repaired by jacketing [42].

3.4.1. Application of Overall System Improvement

In the application of the processes in order to improve the overall structural system, the initial step is to demolish the partition walls among the spans to be filled with new structural members. The foundations of the buildings should be examined by both investigation and excavation. The quality of the concrete is also among the items to be explored in order to determine its strength. Afterwards, according to the construction details, holes, which should be cleaned and filled with epoxy, are drilled for the anchorage bars to the columns and the beams. The anchorage bars are placed accordingly to the holes and are let dry.

The ongoing steps are to prepare the reinforcement of the new wall together with the footings and the anchorage bars, to cast the concrete for the footings and to construct the formwork for the new walls. Meanwhile, it should not be forgotten to drill larger holes of about 200-250 mm within the slabs to pour the concrete. After the reinforcements of the walls are placed, concrete is cast within the formwork. Here, a plank could be used at the top to make casting of the concrete easier [43].

The sequence of this process could be followed at different stages in the upper floors. When the construction of the new shear wall is just completed at the ground floor level, there could be the preparation for the formworks at the first floor, and for the reinforcements and anchorages at the second floor.

While the case is jacketing or enlarging the cross-sectional dimensions of the columns, the initial step is to remove the plaster and concrete on the columns and expose the existing reinforcement. The reinforcing bars are welded to the existing reinforcement of the columns. Afterwards, an outer cage surrounding the column is to be formed by means of longitudinal and shear reinforcement. There should be holes nearby the beam column connections on the slabs to pour the concrete. The last steps are to construct the formwork in place and pour the concrete through the holes.

3.4.2. Principles in System Improvement

Infill walls are the most frequently used strengthening members in Turkey due to the insufficient seismic performance of almost all structural members in the buildings and lack of lateral rigidity. However there are some criteria to be taken into consideration while using the infill walls [42].

- The ratio of the total area of the cross sectional dimensions of the shear walls in each direction –provided that the areas are of the shear walls strong in the direction in question- to the total area of all the floors should not be less than 0.0025. Moreover, the ratio of the total area of the cross sectional dimensions of the shear walls to that of the floor area should not be less than 0.01.
- The shear walls should be arranged as symmetrical as possible.
- The reinforcements in the shear walls should be in both the vertical and the horizontal direction and should satisfy the requirements of Turkish Earthquake Codes in amount.
- The proposed shear walls should be connected to the holes within the structural members of the frame by means of tie bars, which are clamped by epoxy.
- The length of the embedded tie bars to the structural frame members should be minimum 10, preferably 15 times the diameter. The diameter of the holes should be 5 mm greater than that of the tie bars. The tie bars should be of deformed type reinforcing bars and should be inserted into the shear wall with a length of 35 times the diameter.
- The total area of the cross sectional dimensions of the tie bars within the shear walls should not be less than that of the shear wall reinforcement in

that direction. Under this circumstance, the commonly used tie bars are those with 20 mm diameter spaced at 500 mm.

- The shear walls should be constructed on footings. If there exist a continuous footing underneath the shear walls, they should be attached to the footings by means of tie bars, which are clamped by epoxy. The depth of the hole in the footing should be at least 20 times the diameter of the bars. The total area of the cross sectional dimensions of the tie bars that connect the shear walls to the footings should be at least twice the area of the cross sectional dimensions of the vertical reinforcement. The foundation tie bars should go into the shear walls as 35 times the diameter.

The crucial point in placing shear walls is the serious increase in the mass, and consequently, the lateral force that is taken by the structure. So as to increase the rigidity and especially ductility of a structure without enormous raise in the mass, it is possible to perform strengthening process by inserting steel frames or diagonal steel braces within the spans. This method does not require closing the door and window openings within the span and could be constructed in a rather short time to prevent a sudden collapse. On the other hand the process is rather costly and less effective in terms of load bearing capacity when compared to the application of shear walls; moreover, load transfer between steel and concrete creates some problems. The frame or the braces should be connected to the columns by bolts or welding. Bolt connections, which are more effective than welding, might be on the outer surfaces of the column or might be done by passing the bolts through the holes within the column.

3.4.3. Construction Problems

Repair or strengthening of structures is a rather difficult work than a new construction of the same building type. This is due to the fact that any strengthening process covers many details and parameters that may not be taken into consideration at the design stage while the building is constructed. Additionally, it is clear that any modification on an already constructed building requires more skill and experience than to build up a new structure.

While the excavations for the construction of the foundations of the new structural elements are carried out, there may be unexpected situations due to soil conditions. There should not be any leakage of the water during construction. If there is, the water should be pumped out at least temporarily before casting of concrete till the first hardening could be provided.

Also some problems could be faced while arranging the location of the new structural elements. Some partition walls may have to be dismantled. In Turkey, thick stone masonry walls are frequently used at the basement level so that they could be almost monolithically integrated to the existing skeletal frame of the buildings. The demolition of these walls could be dangerous in case of any sudden settlement or collapse. When these walls are to be removed, the floors should be supported temporarily.

The eccentricity of the existing structural members also makes it more difficult to align all the newly constructed structural members. While improving the overall system, all the newly constructed elements are considered to be cast without eccentricity within the frame. However, since the workmanship and construction details are generally problematic in the buildings that require strengthening in Turkey, the irregularities, especially in the elevation, create serious problems in the alignment of the new structural members. In order to provide the vertical continuity, some elements may have to be cast thicker than they are proposed. The existing beams of the structure should fit into the newly cast frame.

Another problem could be faced during the drilling of the holes to the existing members. Especially in the beams, where the longitudinal reinforcements are very close to each other and to the column surfaces, drilling machines may not work if they come across these reinforcements. To overcome this problem, the reinforcements within the concrete could be bent so that they would not obstruct the way of the holes. Or, special drilling machines, which could drill larger holes, could be used; however, this process is disadvantageous in some aspects, the first of which is the leakage of the epoxy before hardening due to the enormous width of the holes. Additionally, more than required epoxy would be consumed by the application of this method.

Also during the welding of the connecting bars to the columns, some problems may be faced related to probable disorder in the alignment of the new longitudinal reinforcements if the existing reinforcements are not properly placed at the corners. Moreover, if the building is damaged due to an earthquake the alignment of the existing longitudinal bars might differ between the top and bottom of the same column. The type of the connecting bars might be changed in order to obtain a leveled alignment of the new reinforcing bars.

The problems listed above are mostly related to constructional problems and are generally overcome. However, the strengthening process may sometimes require serious modifications on the architectural form and function of the structure. For instance, the improvement of the structural system require the infilling of some spans or enlargement of the cross-sectional dimensions of the structural members. This may require changing the positioning and sizes of the openings. In other words, the original architectural plans as well as design of the sanitary system should be revised due to the structural requirements of the building [43].

CHAPTER 4

A PROPOSAL FOR THE STRENGTHENING OF REINFORCED CONCRETE BUILDINGS IN SEISMIC ZONES

4.1. Description of the Models and Analyses Phases

It was previously mentioned that the aim of this study is to propose a new approach for strengthening of reinforced concrete structures. The existing strengthening methods are based upon the rehabilitation of the seismic performance of the buildings. They propose either some modifications on the existing structural members of the buildings or addition of new structural members on appropriate parts of the structure. In this study, the proposed method suggests the addition of shear walls and diaphragms to the structure in order to increase the seismic capacity of the building. Shear walls, which are known as the very effective means to increase the seismic capacity of a building, are proposed to be added on the exterior sides of the corner columns with 250x1800 mm dimensions. Afterwards, the method suggests diaphragms with 900 mm width around the structure in order to obtain continuity between the shear walls.

The feasibility of the proposed method is initially explored by means of finite element analyses by SAP2000 computer programme [52, 53, 54, 55, 56]. The analyses are performed on different structural configurations reflecting the present situation of an important part of the reinforced concrete buildings erected during the great urbanization period of the country. In this part of the study, the analyses are performed on two different layouts of residential buildings. The first part of the analyses were performed on the model of a single building whereas the second group covered the analyses on three adjacent buildings, the first member of which is the one selected as the model of the single building. In order to get the behavior of reinforced concrete residential buildings, all the members of the models are selected so that they have some seismic defects and structural irregularities since these faults are common in the majority of reinforced concrete residential buildings in Turkey. These models reflect the behavior of buildings that have undesirable geometric configurations and inadequate lateral stiffness as well.

As mentioned above, the first group of the analyses was performed on the models of a single building. These analyses in this group were carried out in three steps in order to show the effects of the additional structural members on the seismic performance of the selected building typologies. Initially, the models were analyzed so that the only structural members are those that the building already includes itself. In the proceeding section, shear walls and, for the last step, diaphragms were added around the models. The purpose behind performing the analyses under three different structural configurations is to explore the effect of additional structural members on structural behavior.

The model, which was selected as the representation of a typical residential building is rectangular in plan with 14x12 meter dimensions in X and Y directions, respectively. The model reflects the structures with structural irregularities since it includes some beam interferences that are not supported by columns. The columns and the beams are 250x500 mm in dimension. The thickness of the slabs is 120 mm.

For the second part of the analysis process, 250 mm x 1800 mm shear walls are added to the building to the four corner columns. Later on, diaphragms of 200 mm thickness and 900 mm width at two floor levels are placed between the shear walls as connecting members. In structural viewpoint, the reason why the diaphragms are used at two floor levels is to obtain the behavior of a sound frame. Figure 4.1 shows the models of these three structural configurations.

The behaviors of all the selected models were observed by means of response spectrum analyses so as to test the seismic performances of all configurations in terms of mode shapes, maximum displacements and distributions of shear forces and bending moments.

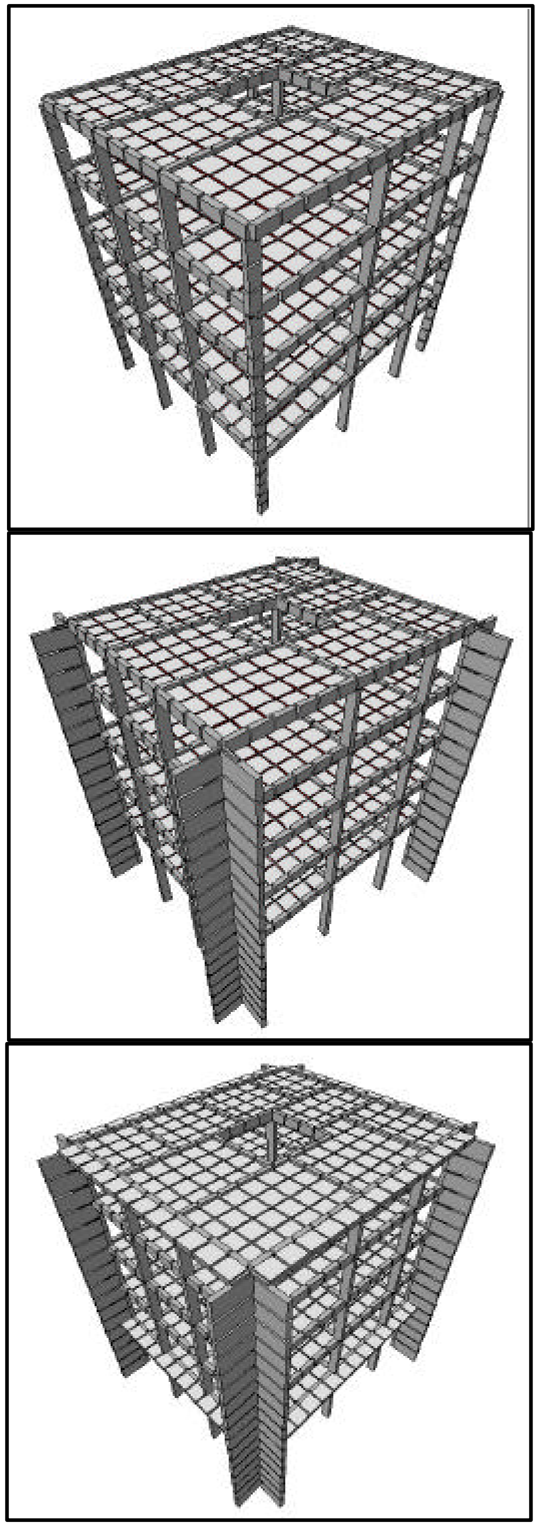


Figure 4.1: The undeformed shapes of the three configurations of single building model

The analyses that constitute the second group were performed on a model of three adjacent five-storey reinforced concrete residential building frame, which is very common in the general urban layout of Turkey. The first constituent of the adjacent arrangement is the model developed for the analyses of the single layout. The reason for using the same model for single and attached layout is to have the chance to compare the results in terms of mode shapes, deflections, and distribution of forces on the same members. This is thought to give a clear idea about the positive and negative effects of the additional structural members. Figure 4.2 shows the models developed for adjacent buildings.

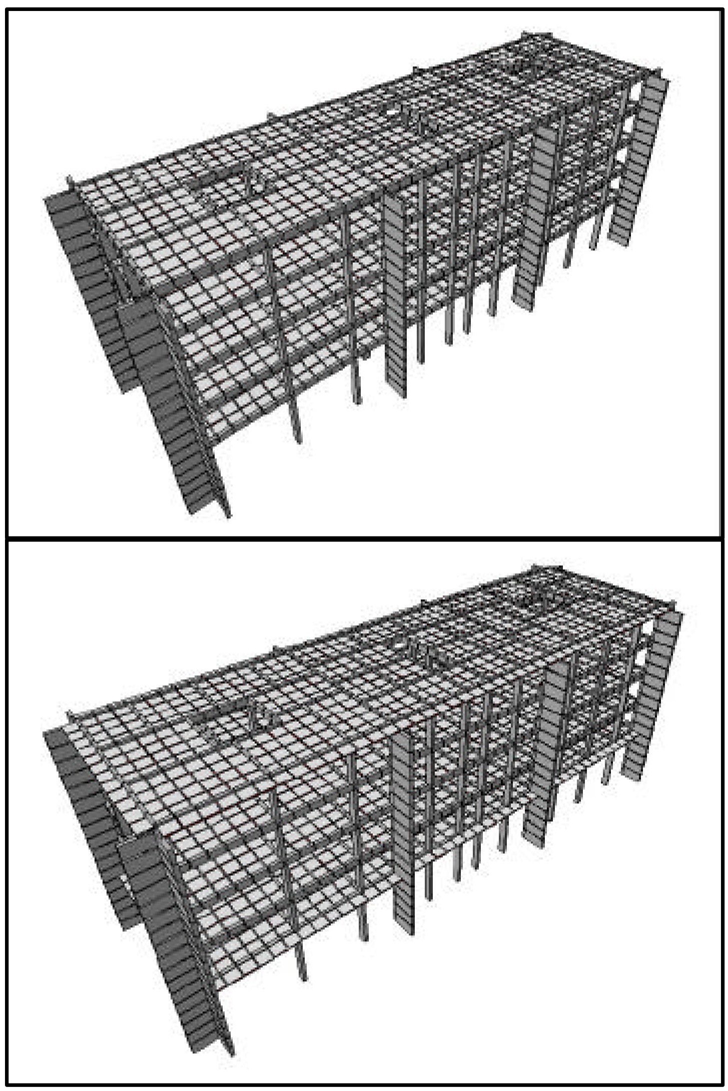


Figure 4.2: The undeformed shapes of the adjacent building models

In general, the analyses were performed almost in the same manner that they were done for the single building model. The only difference is that the models were not analyzed in their original forms since the first member was already analyzed to give an opinion about the behavior of the types without strengthening. The analytical studies of this group started with the analyses performed on the models with shear walls. They were placed at the corners and at the connection points of buildings with each other. For the last part of the analyses two continuous diaphragms, which are connected to the beams and the exterior shear walls at 1st and 5th floors are added to the building models. The time periods, deformations and distribution of shear forces and bending moments are studied by means of a response spectrum analysis.

4.2. Interpretation of the Analyses Results

In order to understand the effects of shear walls and the diaphragms in terms of seismic behavior, the results were interpreted in a comparative manner. Initially, all of the five models were compared to each other in terms of time periods as shown in the set of figures from 4.3 to 4.7. The reason for comparing the time periods of the single building model with those of the adjacent layout is that the model of the single building is the first member of the adjacent layout; so that the time period of this model without strengthening was already obtained by the analyses that were performed in the first group. If the models of the attached layout were analyzed with their original structural configuration –without strengthening- each of the three buildings would have their own time periods independently since they were not connected to each other by shear walls and diaphragms. This approach would display the effects of additional structural members on time periods of even the adjacent layout where all of the three buildings should act together in case of an earthquake.

In order to identify the results more clearly, five columns were selected in the single building model as plotted in the Figure 4.8. These columns are named as C-1, C-2, C-3, C-4 and C-5 in the rest of the interpretations. This approach is thought to provide handling a meaningful evaluation of the values of time periods, deformations, shear forces and bending moments in a comparative manner.

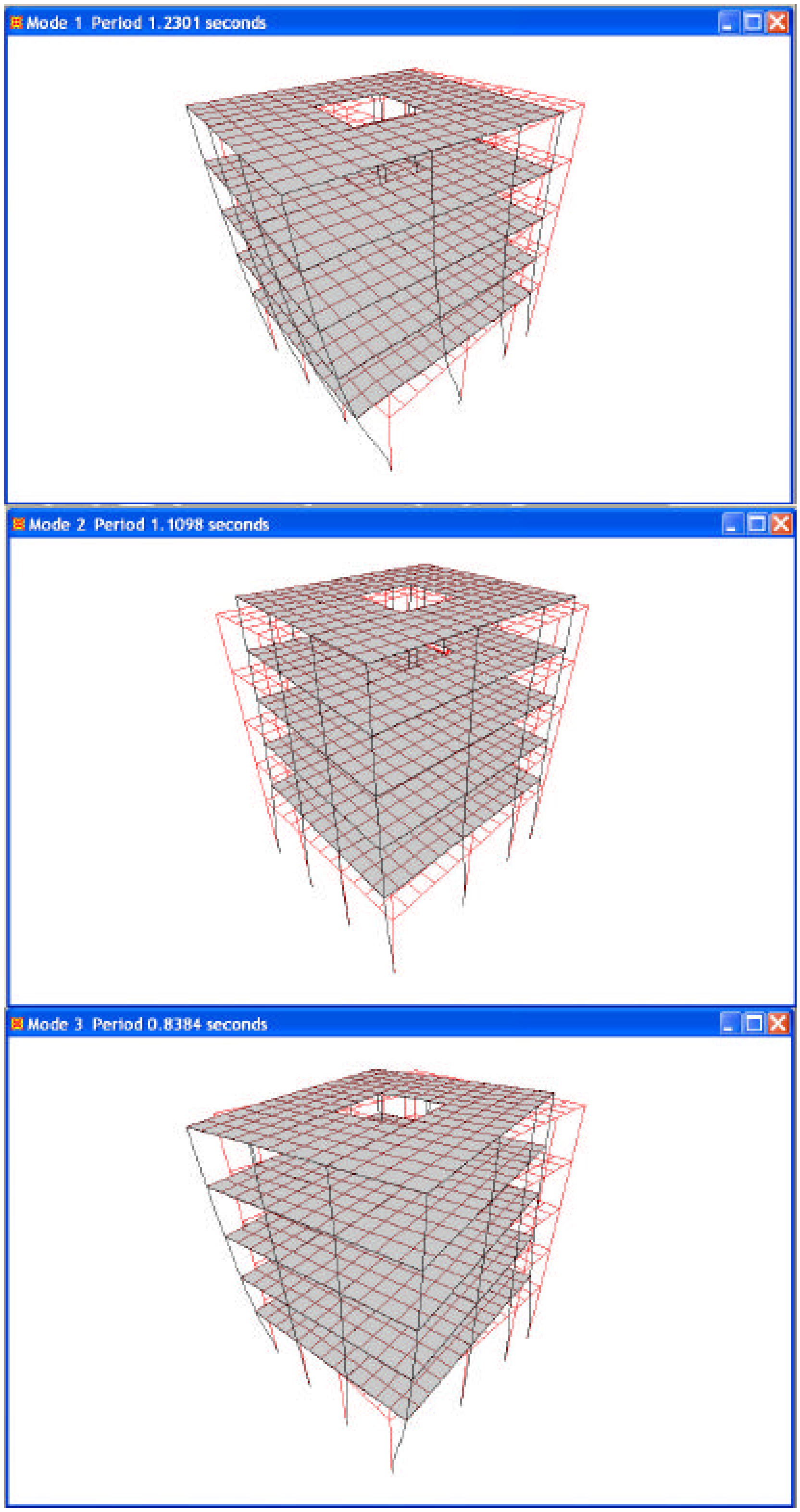


Figure 4.3: The mode shapes of the single building model without strengthening

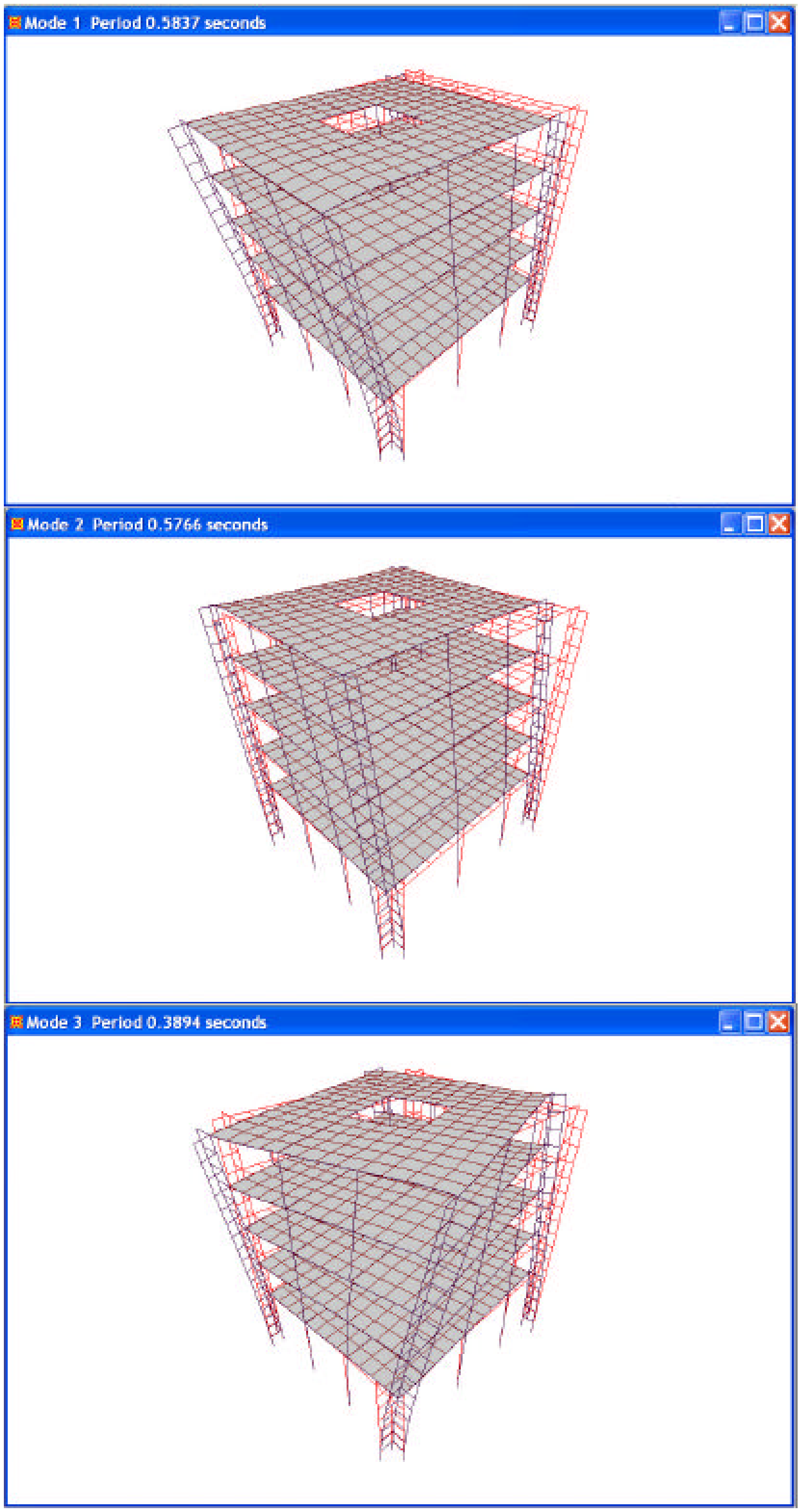


Figure 4.4: The mode shapes of the single building model with shear walls

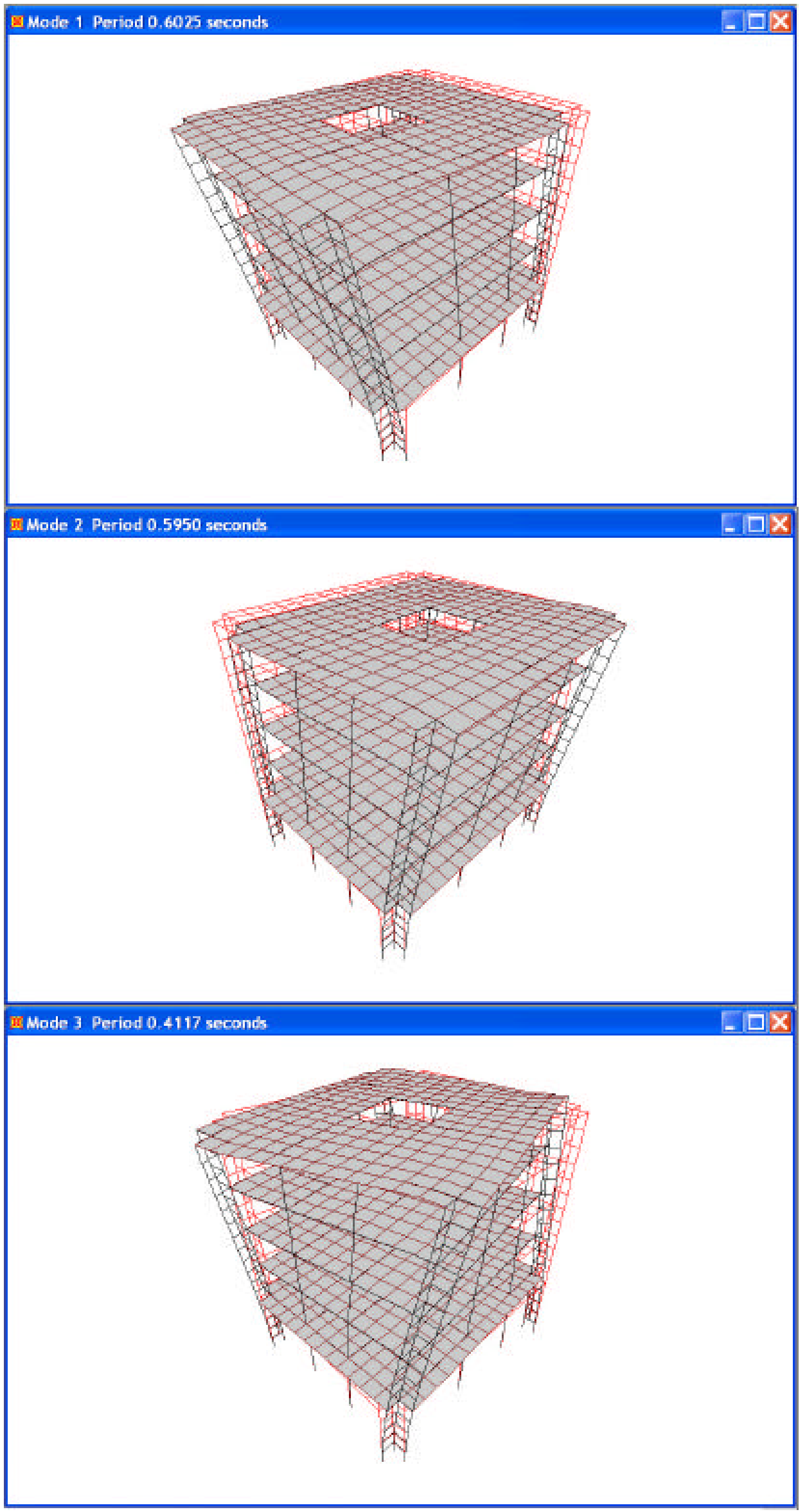


Figure 4.5: The mode shapes of the single building model with shear walls and diaphragms

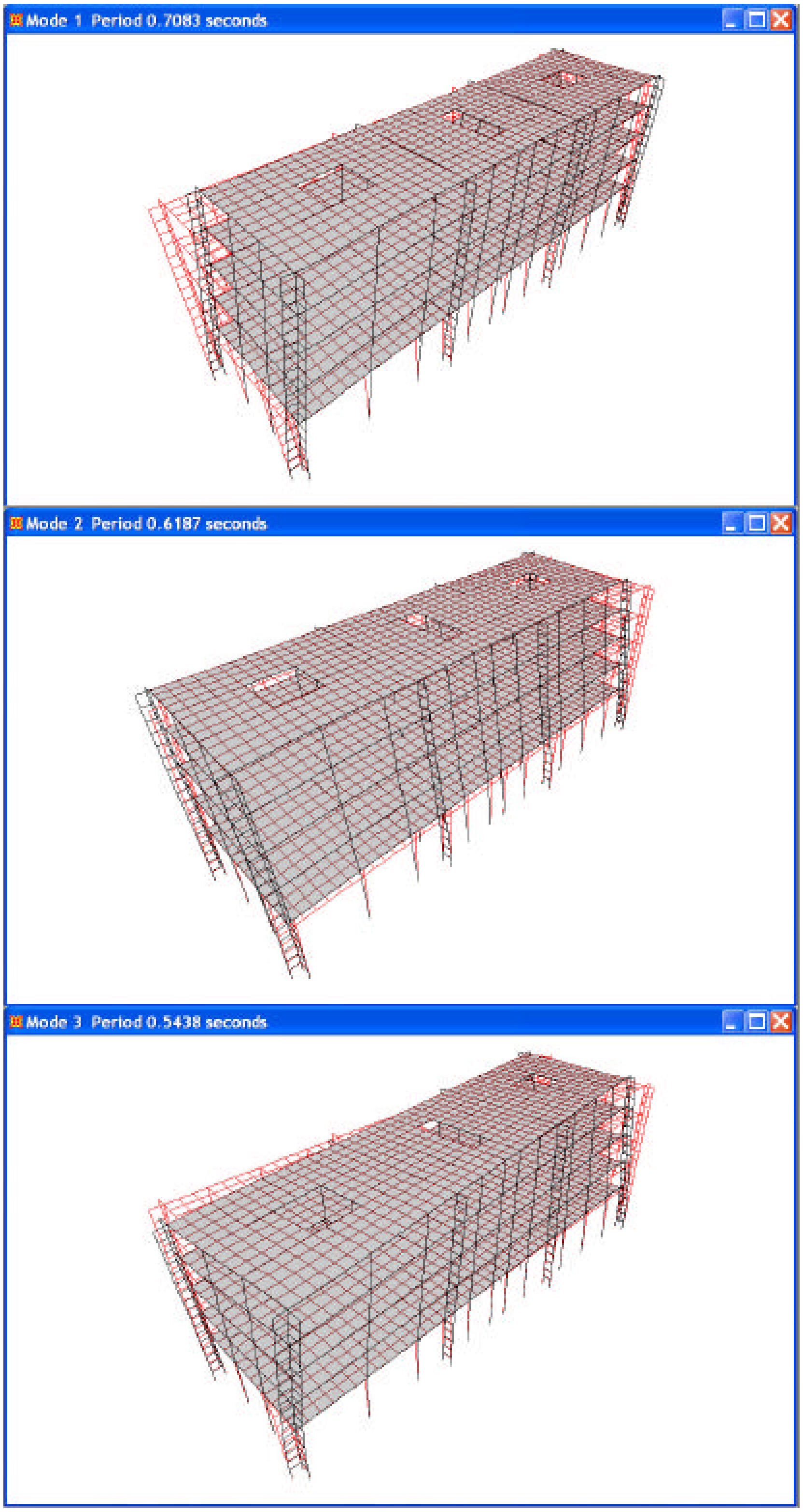


Figure 4.6: The mode shapes of the model of the adjacent buildings with shear walls

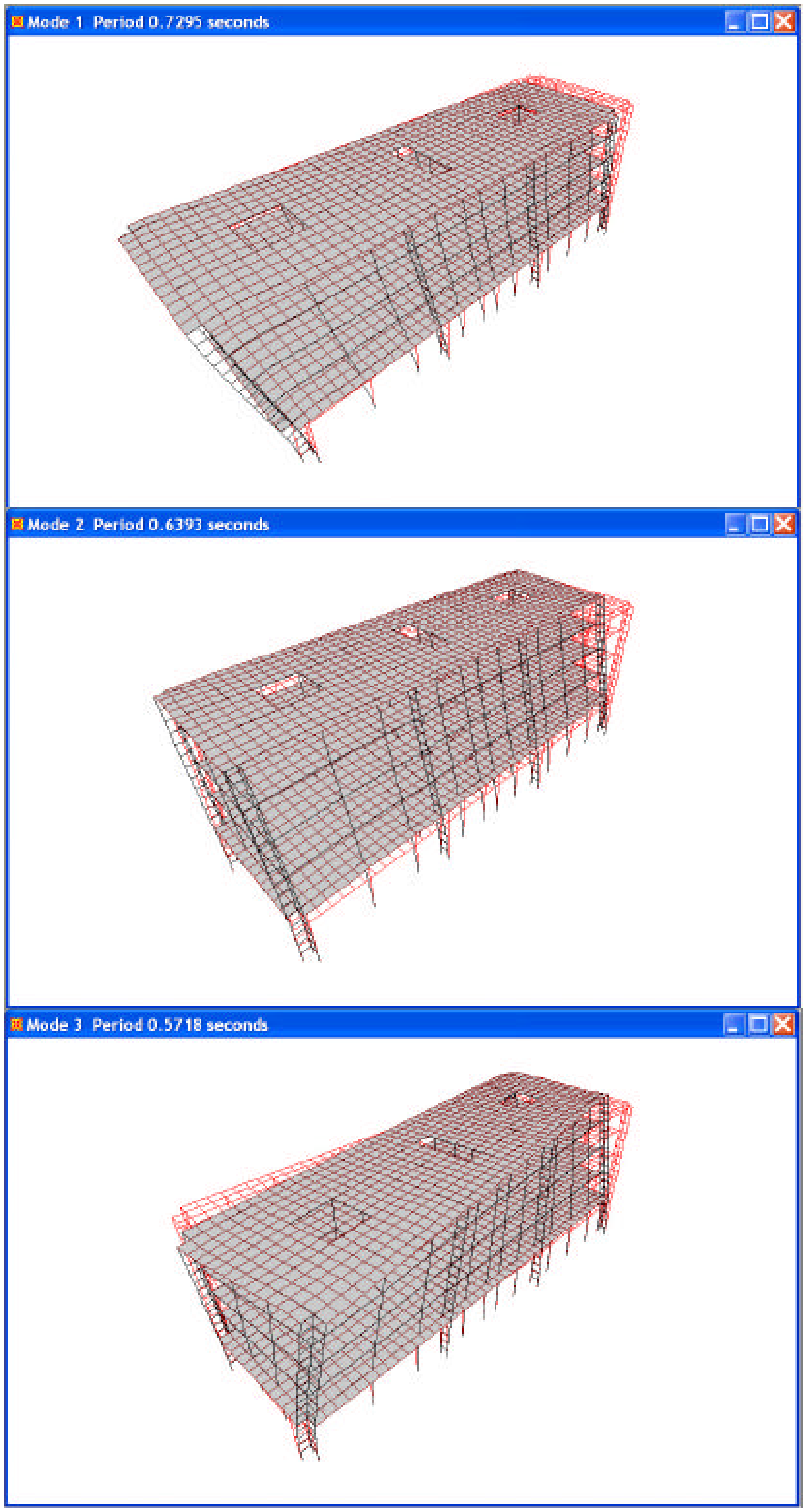


Figure 4.7: The mode shapes of the model of the adjacent buildings with shear walls and diaphragms

By referring to the figures given above, it is possible to understand the positive effects of the additional members on the seismic behavior of the models in terms of time periods. When the single building is in question, it is possible to observe the decrease of about 53 % between the values 1.2301 sec and 0.5837 sec because of the shear walls. On the other hand there does not seem to be a significant change due to the addition of the diaphragms. The time period of the last model of the single arrangement was observed to be 0.6093 second. The slight rise in the time periods is because of the increase in mass due to the diaphragms.

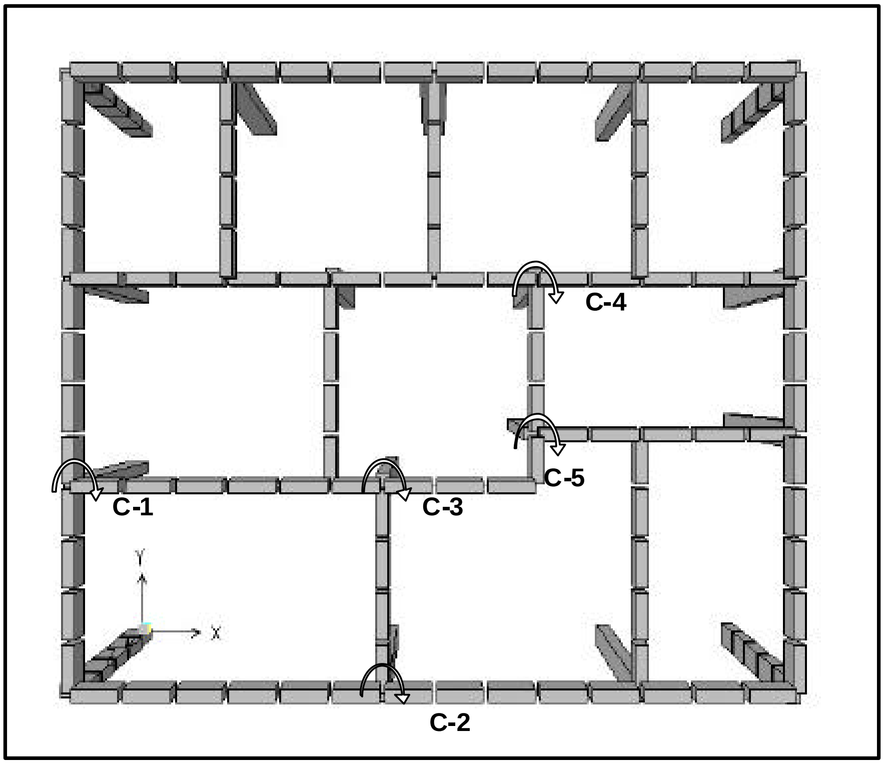


Figure 4.8: The selected columns on the model of the single building

In the following set of tables from 4.1 to 4.5, the results of the analyses for the five selected columns are given. Following the time periods, the values for the deformations in X, Y and Z directions are listed. Then, the shear forces for X and Y directions and consequently the bending moment values for the same directions on the top and bottom parts of the columns in question were explored.

Table 4.1: Results of Analyses for Column 1

COLUMN 1	**Single Building** No Strengthening	**Single Building** Shear Walls	**Single Building** SW + Diaphragms	**Attached Building** Shear Walls	**Attached Building** S W + Diaphragms
MODE 1 (sec)	1.2301	0.5837	0.6093	0.7083	0.7260
MODE 2 (sec)	1.1098	0.5766	0.6017	0.6187	0.6375
MODE 3 (sec)	0.8384	0.3894	0.4176	0.5438	0.5689
Δ_x (m)	0.16610	0.02140	0.02250	0.04104	0.04158
Δ_y (m)	0.22522	0.02181	0.02304	0.02524	0.02636
Δ_z (m)	0.00161	0.00126	0.00146	0.00138	0.00155
Shear (X) (kN)	719.93	56.61	57.69	131.50	128.99
Shear (Y) (kN)	3713.8	38.02	41.23	44.33	47.45
B. Moment $(X)_{top}$ (kN.m)	1432.26	63.15	60.55	198.11	186.57
B. Moment $(X)_{bottom}$ (kN.m)	2167.40	219.93	228.20	459.41	458.48
B. Moment $(Y)_{top}$ (kN.m)	906.03	94.72	103.62	110.80	119.56
B. Moment $(Y)_{bottom}$ (kN.m)	950.85	95.45	102.60	110.94	117.79

Table 4.2: Results of Analyses for Column 2

COLUMN 2	**Single Building** No Strengthening	**Single Building** Shear Walls	**Single Building** SW + Diaphragms	**Attached Building** Shear Walls	**Attached Building** S W + Diaphragms
MODE 1 (sec)	1.2301	0.5837	0.6093	0.7083	0.7260
MODE 2 (sec)	1.1098	0.5766	0.6017	0.6187	0.6375
MODE 3 (sec)	0.8384	0.3894	0.4176	0.5438	0.5689
Δ_x (m)	0.20314	0.02208	0.02330	0.04097	0.04160
Δ_y (m)	0.14890	0.02104	0.02206	0.02696	0.02799
Δ_z (m)	0.00332	0.00169	0.00185	0.00189	0.00203
Shear (X) (kN)	336.15	35.54	38.82	67.44	70.51
Shear (Y) (kN)	722.04	69.91	71.64	94.21	96.30
B. Moment $(X)_{top}$ (kN.m)	821.15	85.96	95.11	164.47	173.79
B. Moment $(X)_{bottom}$ (kN.m)	859.60	91.75	99.01	172.76	178.80
B. Moment $(Y)_{top}$ (kN.m)	1541.59	109.94	109.68	156.40	157.31
B. Moment $(Y)_{bottom}$ (kN.m)	2068.69	239.59	248.52	314.66	324.20

Table 4.3: Results of Analyses for Column 3

COLUMN 3	**Single Building** No Strengthening	**Single Building** Shear Walls	**Single Building** SW + Diaphragms	**Attached Building** Shear Walls	**Attached Building** S W + Diaphragms
MODE 1 (sec)	1.2301	0.5837	0.6093	0.7083	0.7260
MODE 2 (sec)	1.1098	0.5766	0.6017	0.6187	0.6375
MODE 3 (sec)	0.8384	0.3894	0.4176	0.5438	0.5689
Δ_x (m)	0.16632	0.02137	0.02248	0.04108	0.04165
Δ_y (m)	0.14893	0.02104	0.02208	0.02697	0.02800
Δ_z (m)	0.00113	6.449 E-04	7.079 E-04	7.298 E-04	7.869 E-04
Shear (X) (kN)	276.25	33.42	35.21	65.55	66.47
Shear (Y) (kN)	752.88	77.80	80.98	103.83	107.45
B. Moment $(X)_{top}$ (kN.m)	675.81	79.90	84.22	157.96	160.17
B. Moment $(X)_{bottom}$ (kN.m)	705.48	87.20	91.82	169.81	172.18
B. Moment $(Y)_{top}$ (kN.m)	1644.96	136.45	140.99	188.68	194.71
B. Moment $(Y)_{bottom}$ (kN.m)	2119.48	252.58	263.95	330.45	342.55

Table 4.4: Results of Analyses for Column 4

COLUMN 4	**Single Building** No Strengthening	**Single Building** Shear Walls	**Single Building** SW + Diaphragms	**Attached Building** Shear Walls	**Attached Building** S W + Diaphragms
MODE 1 (sec)	1.2301	0.5837	0.6093	0.7083	0.7260
MODE 2 (sec)	1.1098	0.5766	0.6017	0.6187	0.6375
MODE 3 (sec)	0.8384	0.3894	0.4176	0.5438	0.5689
Δ_x (m)	0.14672	0.02070	0.02170	0.04113	0.04166
Δ_y (m)	0.11934	0.02048	0.02145	0.02769	0.02870
Δ_z (m)	8.96 E-04	4.729 E-04	5.063 E-04	5.403 E-04	5.622 E-04
Shear (X) (kN)	235.56	30.83	32.37	62.34	62.83
Shear (Y) (kN)	585.60	73.85	76.50	104.97	108.15
B. Moment $(X)_{top}$ (kN.m)	568.97	72.28	75.94	147.17	148.03
B. Moment $(X)_{bottom}$ (kN.m)	608.83	81.90	85.93	164.53	166.14
B. Moment $(Y)_{top}$ (kN.m)	1258.74	126.56	129.70	188.30	193.00
B. Moment $(Y)_{bottom}$ (kN.m)	1669.33	242.71	252.82	336.59	347.83

Table 4.5: Results of Analyses for Column 5

COLUMN 5	**Single Building** No Strengthening	**Single Building** Shear Walls	**Single Building** SW + Diaphragms	**Attached Building** Shear Walls	**Attached Building** S W + Diaphragms
MODE 1 (sec)	1.2301	0.5837	0.6093	0.7083	0.7260
MODE 2 (sec)	1.1098	0.5766	0.6017	0.6187	0.6375
MODE 3 (sec)	0.8384	0.3894	0.4176	0.5438	0.5689
Δ_x (m)	0.15943	0.02128	0.02236	0.04125	0.04181
Δ_y (m)	0.11937	0.0246	0.02144	0.02769	0.02871
Δ_z (m)	0.00145	7.942 E-04	8.613 E-04	9.060 E-04	9.530 E-04
Shear (X) (kN)	752.10	70.35	73.57	156.01	155.14
Shear (Y) (kN)	202.21	32.55	34.07	44.47	46.10
B. Moment $(X)_{top}$ (kN.m)	1580.08	110.06	114.49	279.22	272.98
B. Moment $(X)_{bottom}$ (kN.m)	2180.51	241.77	253.42	500.86	502.75
B. Moment $(Y)_{top}$ (kN.m)	498.30	78.35	81.99	107.49	111.43
B. Moment $(Y)_{bottom}$ (kN.m)	512.82	84.39	88.36	114.89	119.10

Referring to the tables and figures above, it is possible to identify the effects of additional shear walls and diaphragms on seismic performance. The outputs of the analyses carried out on three structural configurations of the model of the single building are also given in the set of figures from 4.9 to 4.15. As it could be seen in the Table 4.1, $?_x$=166 mm and $?_y$=225 mm for C-1. These are the highest values among those of the selected columns. However, the excessive deformation as the sign of fatal damage in case of an earthquake is more clearly seen in the Figure 4.9 as $?_x$=296 mm and $?_y$=435 mm. It is for sure that these excessive deformations are indications of serious danger in case of an earthquake so that the building would fatally be damaged. These values are seen as $?_x$=108 mm and $?_y$=124 mm when shear walls are added to the frame. The results of the third part of the analyses performed on the single model display that the displacements raise a little when diaphragms are added to the structure. This increase should be seen as normal according to the increase in weight.

The effect of shear walls and the diaphragms are more clearly seen in the results related to the distribution of shear forces and bending moments in the set of figures from 4.10 to 4.15. Figure 4.10 gives distribution of shear forces on the selected columns on the ground floor level. As it is seen in this figure and Table 4.5, the most critical columns are C-5 with V_{xx}=752.1 kN and V_{yy}=752.88 kN. When the model includes shear walls, these values are seen as V_{xx}=70.35 kN for C-5 and V_{yy}=77.80 kN for C-3 in the Figure 4.11. Figure 4.12 gives the results related to shear force distribution on the model with the diaphragms as V_{xx}=72.94 kN for C-5 and V_{yy}=79.66 kN for C-3.

Figures 4.13, 4.14 and 4.15 give the results of bending moment distributions on the model of the single layout. As it is seen in Figure 4.13, the most critical columns are, again, C-5 with M_{xx}=2180.51 kN.m and C-3 with M_{yy}=2119.48 kN.m in terms of bending moment distributions in X and Y directions, respectively. In Figure 4.14, which gives the results on the model with shear walls, these values decrease to M_{xx}=241.77 kN.m and M_{yy}=252.58 kN.m. And, as the final of the first group analyses, Figure 4.15 displays the bending moment distribution on the model of single layout as M_{xx}=249.58 kN.m and M_{yy}=259 kN.m for the columns in question.

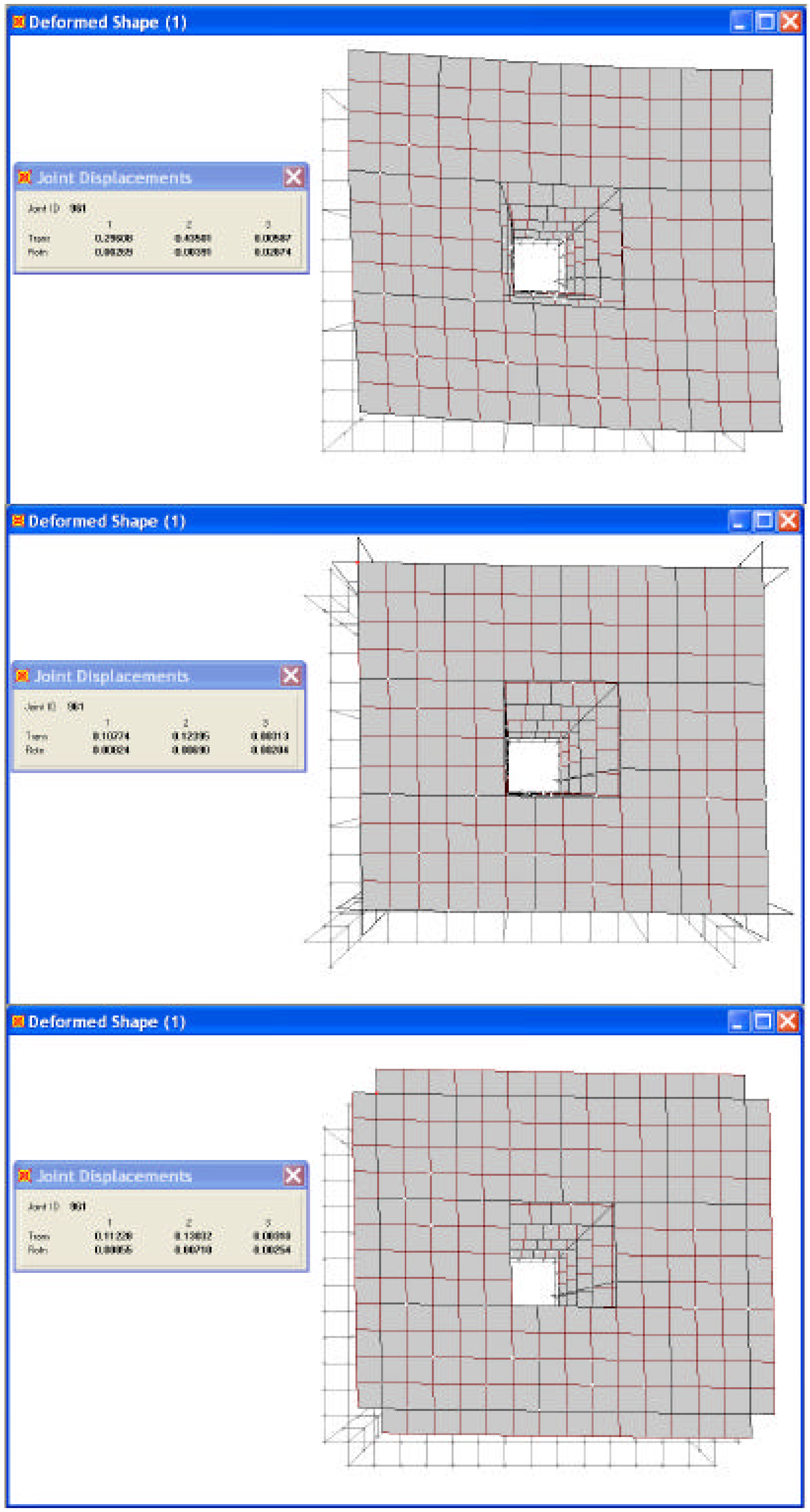
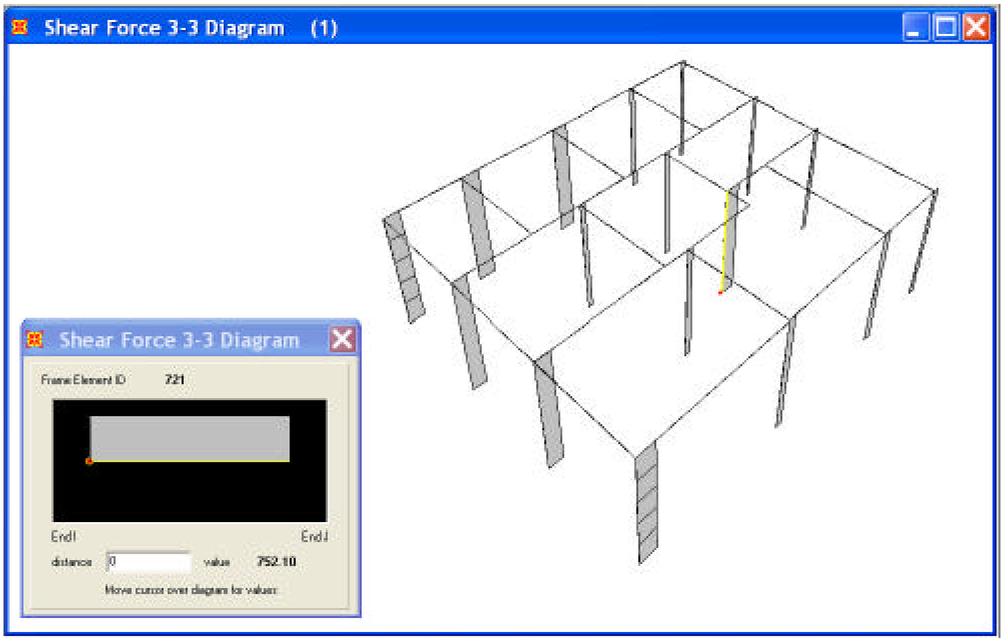


Figure 4.9: The critical deformations on the three configurations of the single building model



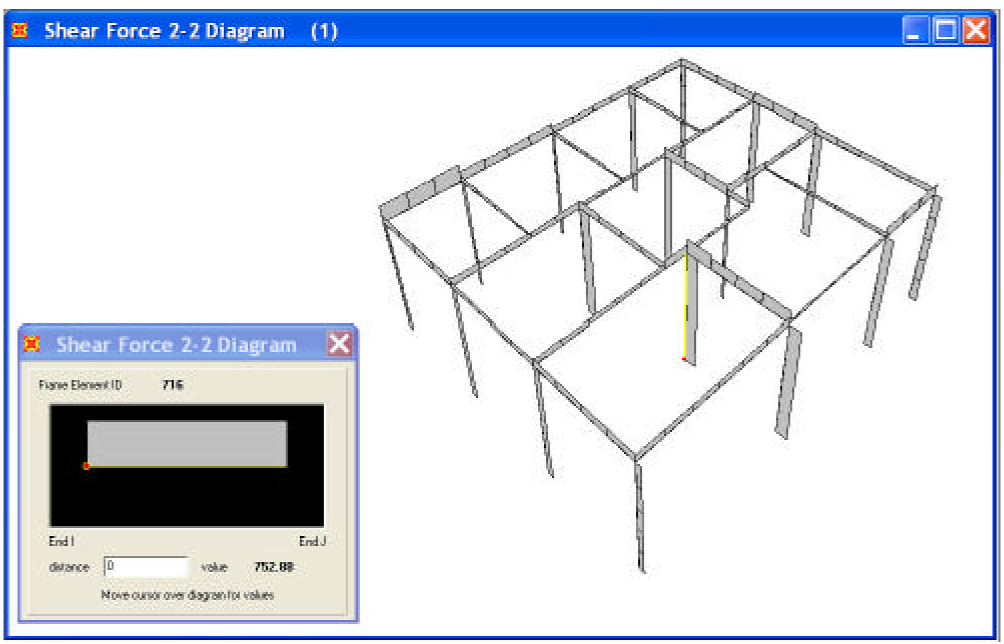


Figure 4.10: Shear force distributions in X and Y directions on the model of the single building without strengthening

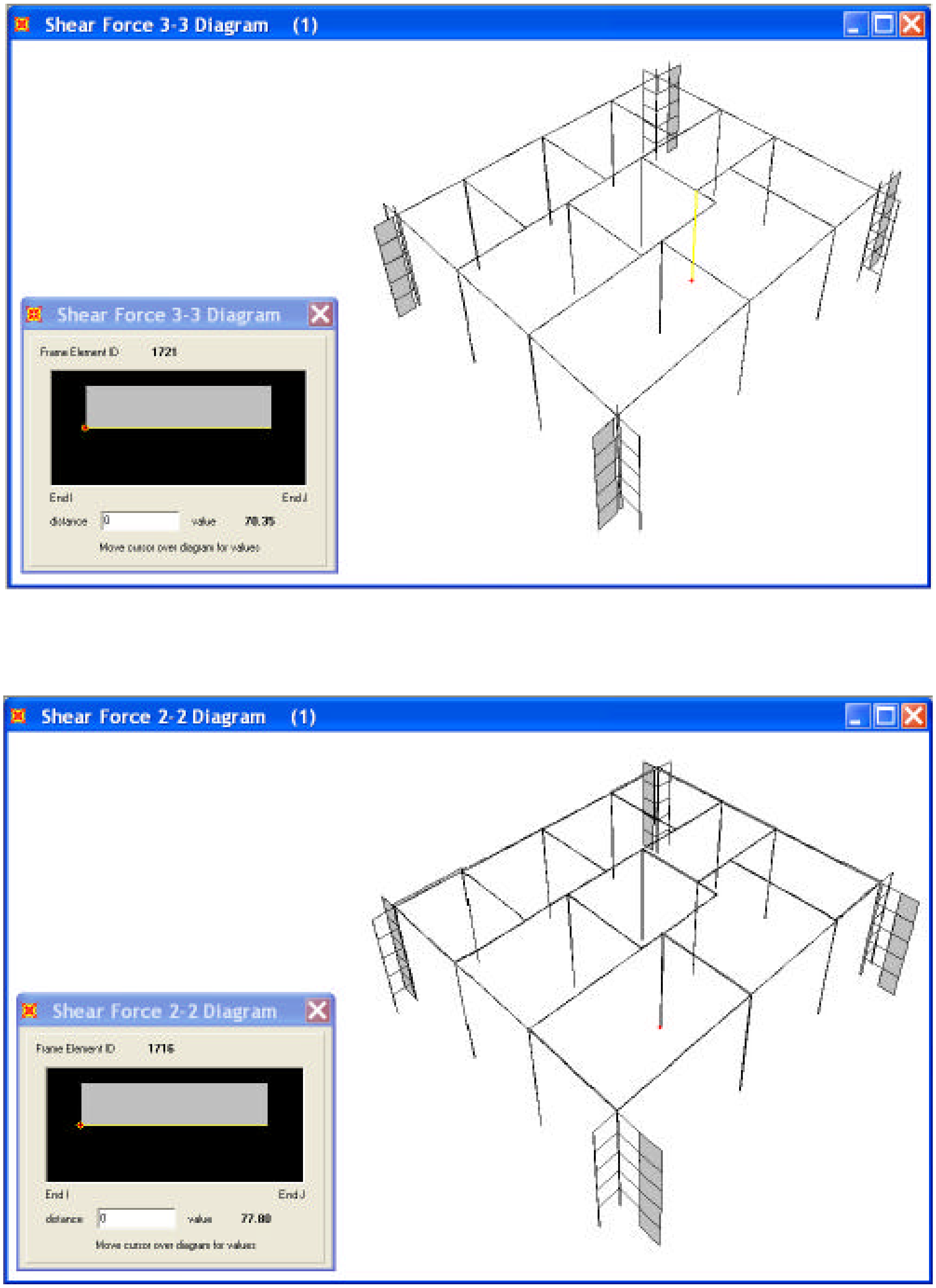
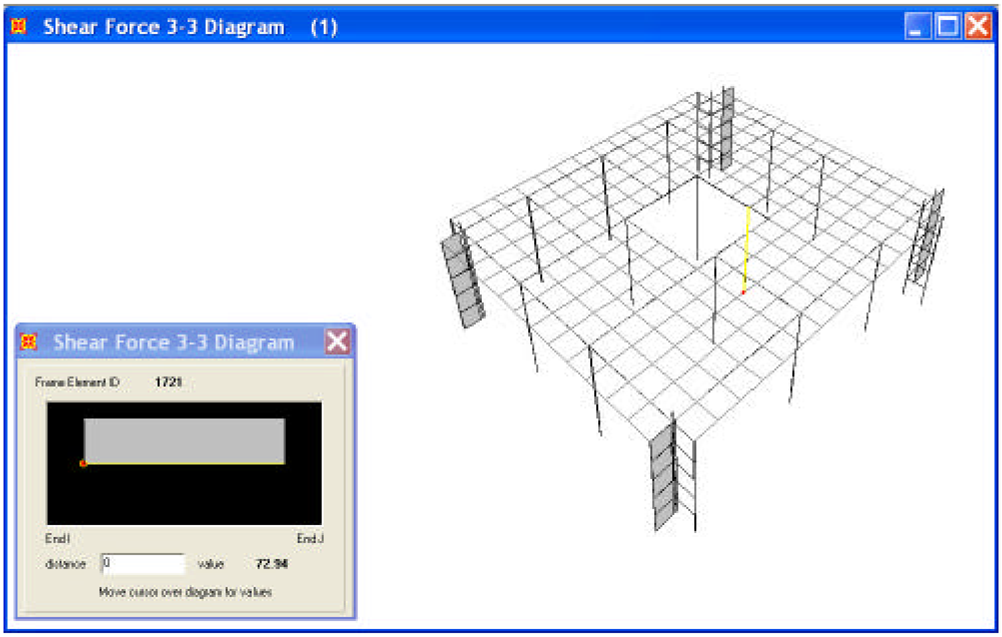


Figure 4.11: Shear force distributions in X and Y directions on the model of the single building with shear walls



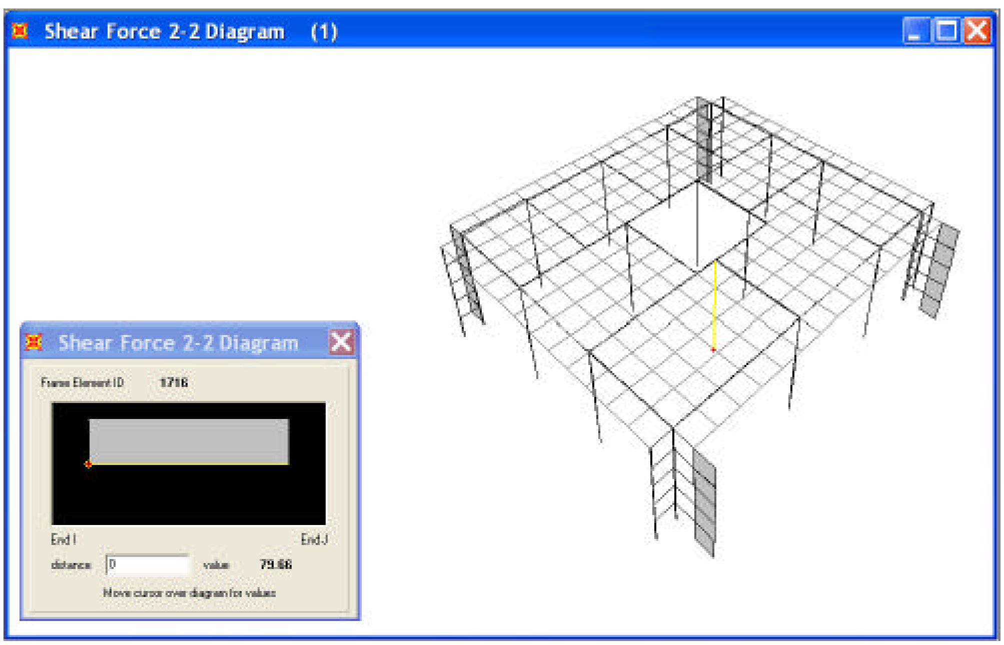
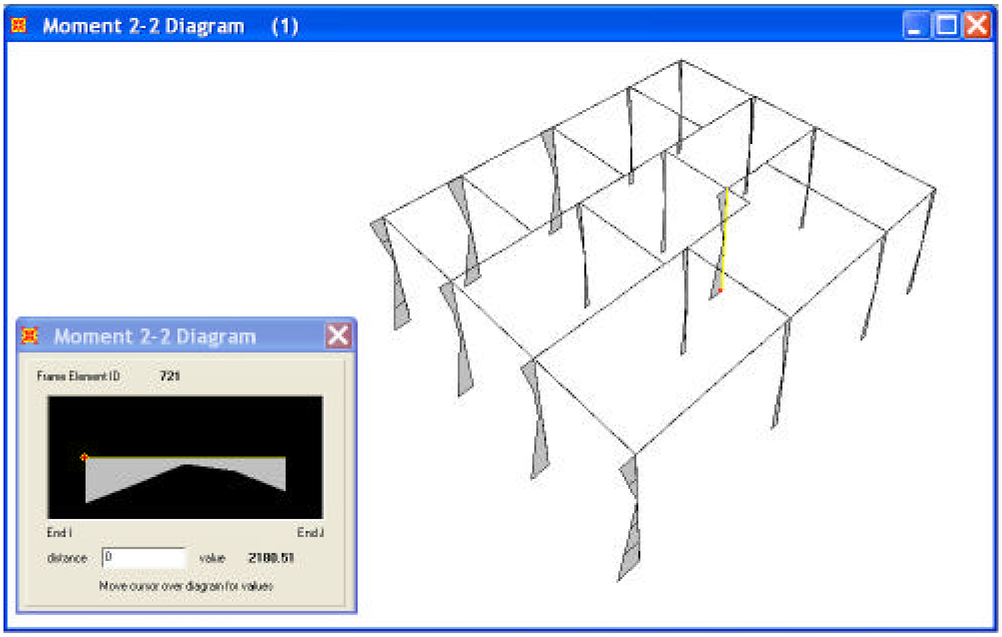


Figure 4.12: Shear force distributions in X and Y directions on the model of the single building with shear walls and diaphragms



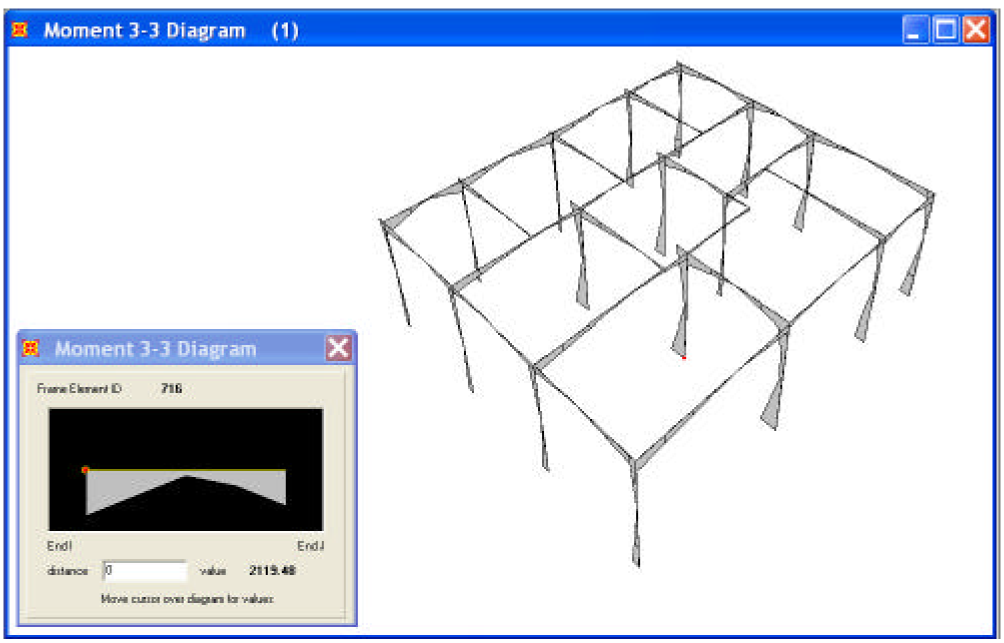
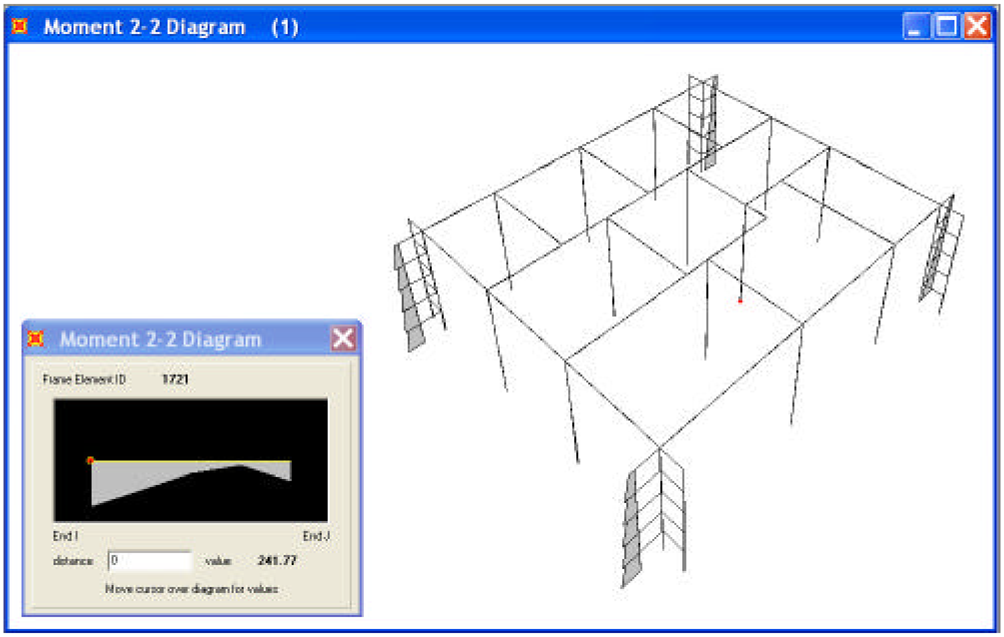


Figure 4.13: Bending moment distributions in X and Y directions on the model of the single building without strengthening



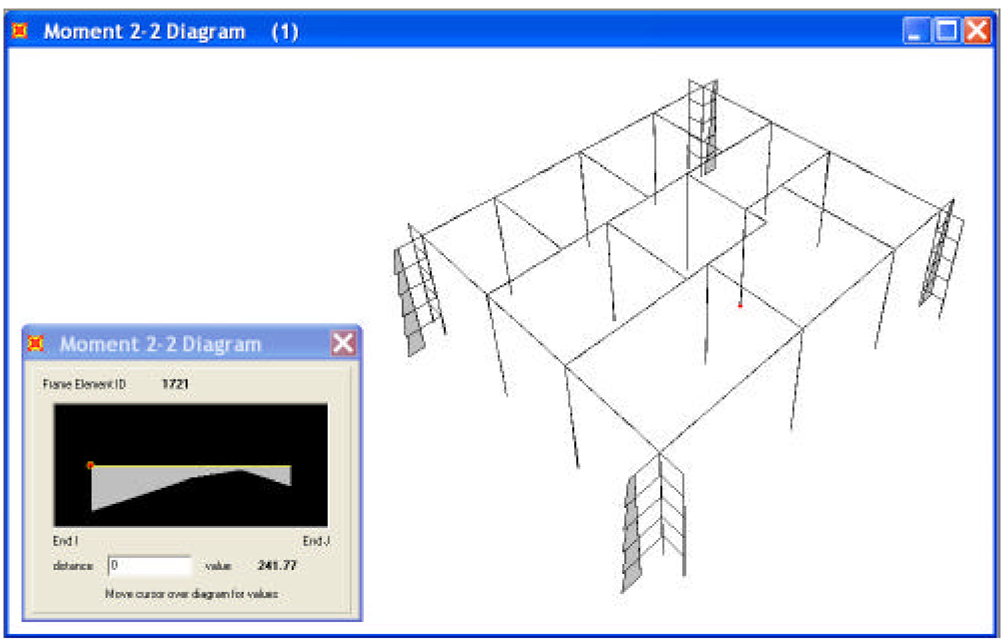
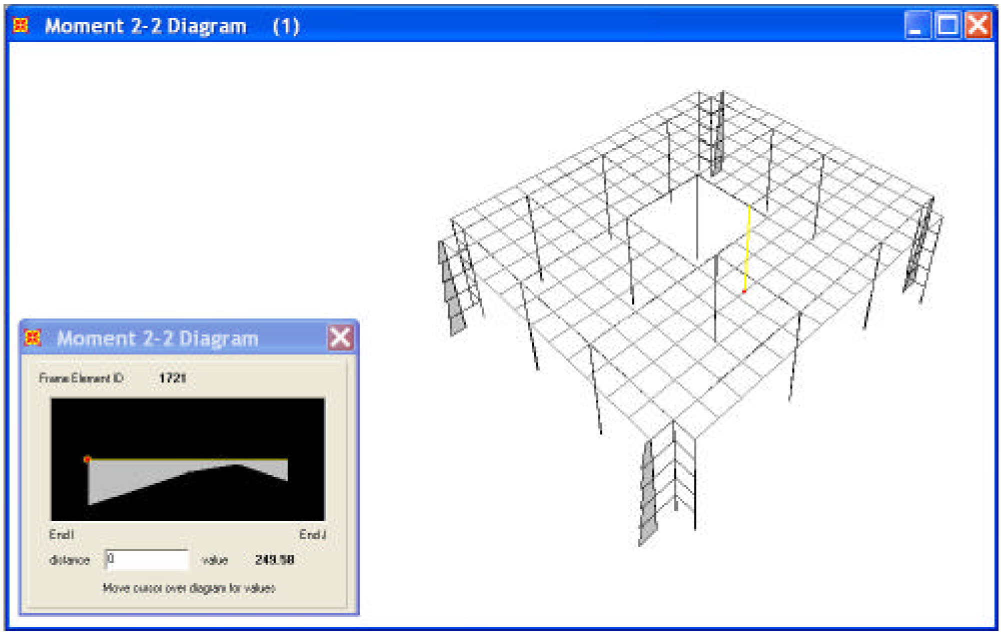


Figure 4.14: Bending moment distributions in X and Y directions on the model of the single building with shear walls



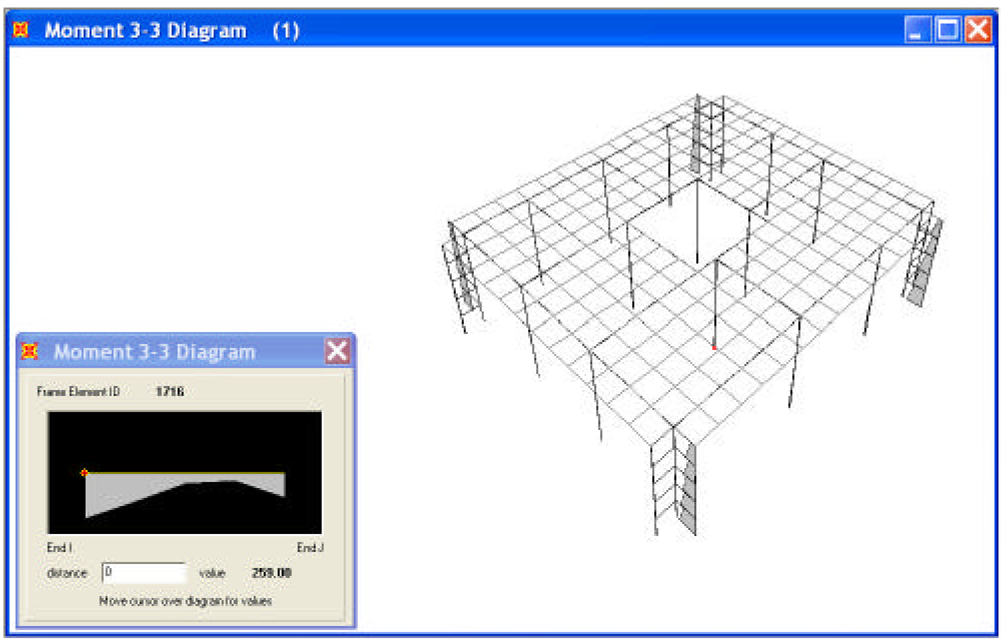


Figure 4.15: Bending moment distributions in X and Y directions on the model of the single building with shear walls and diaphragms

The rest of figures from 4.16 to 4.20 give the results of the analyses of the second group, which are those performed on the model of the attached layout. The values that were obtained for the selected columns in the first group of analyses are still relevant as the basis for comparison. When the results that are given in the Figure 4.9 are compared to those given in the Figure 4.16, the maximum displacements are seen to decrease from $?_x$=296 mm to $?_x$=165 mm and from $?_y$=435 mm to $?_y$=131 mm in the model with shear walls. The maximum displacements are given as $?_x$=174 mm and $?_y$=139 mm on the model that also has the diaphragms.

Similarly, the set of figures from 4.17 to 4.20 give the results related to shear force and bending moment distributions. Again, considering the results of the analyses of the first group and referring to Figure 4.10, it is possible to figure out the effects of additional structural members on shear force distribution. Figure 4.17 shows the significant decrease on the shear force values, which were V_{xx}=752.1 kN on C-5 and V_{yy}=752.88 kN in C-3, as V_{xx}=156.01 kN and V_{yy}=103.83 kN. Due to the increase in mass, Figure 4.18 gives the results in slightly higher values as V_{xx}=158.14 kN and V_{yy}=108.05 kN on the same columns.

As the results of the final step of the analyses, Figure 4.19 and Figure 4.20 show the distributions of bending moments, the flow of which are similar to that of shear forces. The values show a significant decrease in the selected columns since the shear walls attract most of the bending moments in the structure. The addition of diaphragms causes a little move up in these values due to the increase in mass; however, when this increase is compared to the values on the overall structure, it could be said that the diaphragms provide the columns to get rid of the majority of the bending moments. The most critical bending moment value in X direction was mentioned to be M_{xx}=2180.51 kN.m for C-5 and M_{yy}=2119.48 kN.m for C-3 on the basic model. In Figure 4.19, these values are seen to decrease to M_{xx}=500.86 kN.m and M_{yy}=330.45 kN.m in the model with shear walls. The slight increase is observed as M_{xx}=511.31 kN.m and M_{yy}=344.66 kN.m in the model strengthened by both shear walls and diaphragms in Figure 4.20.

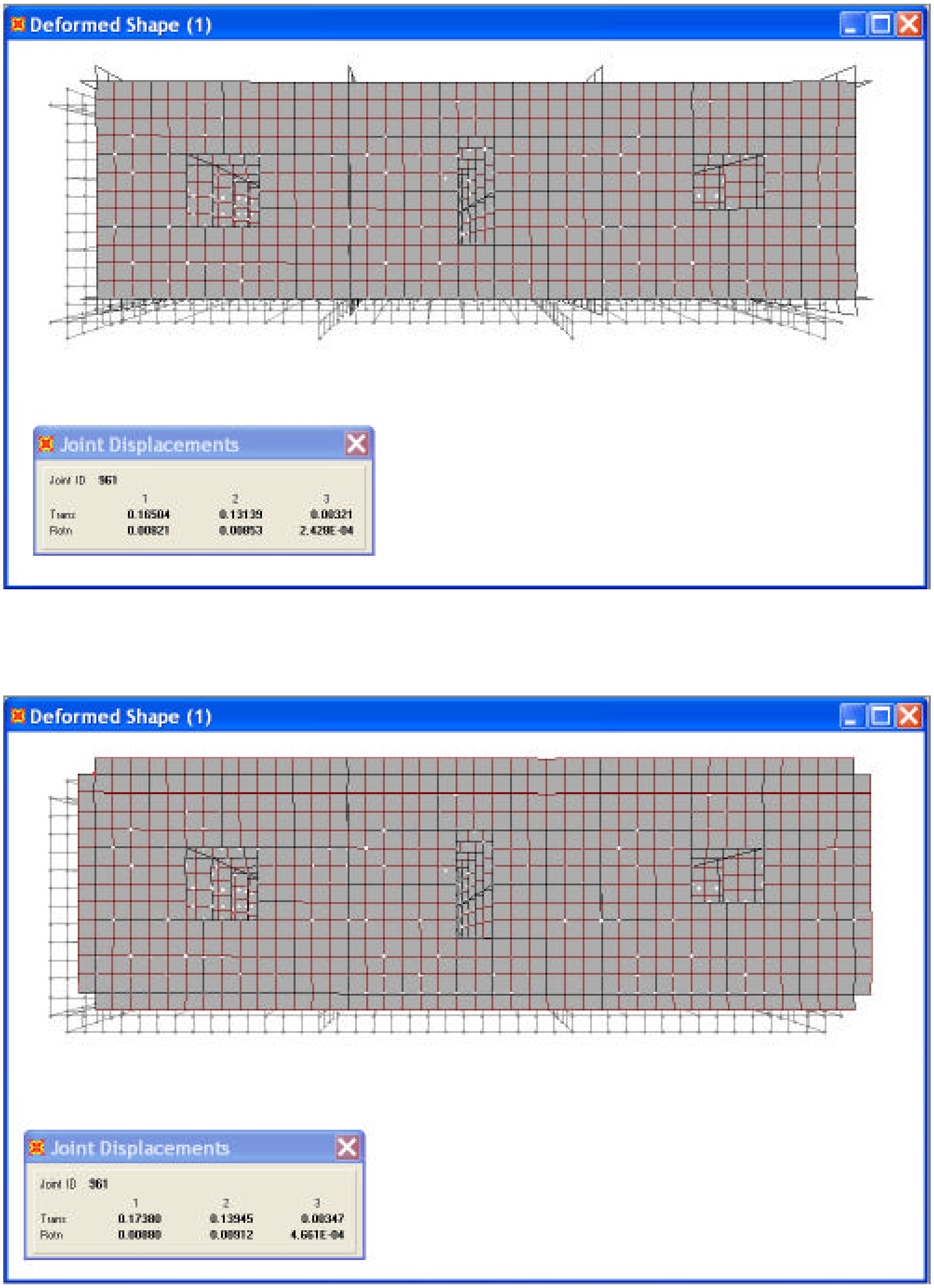
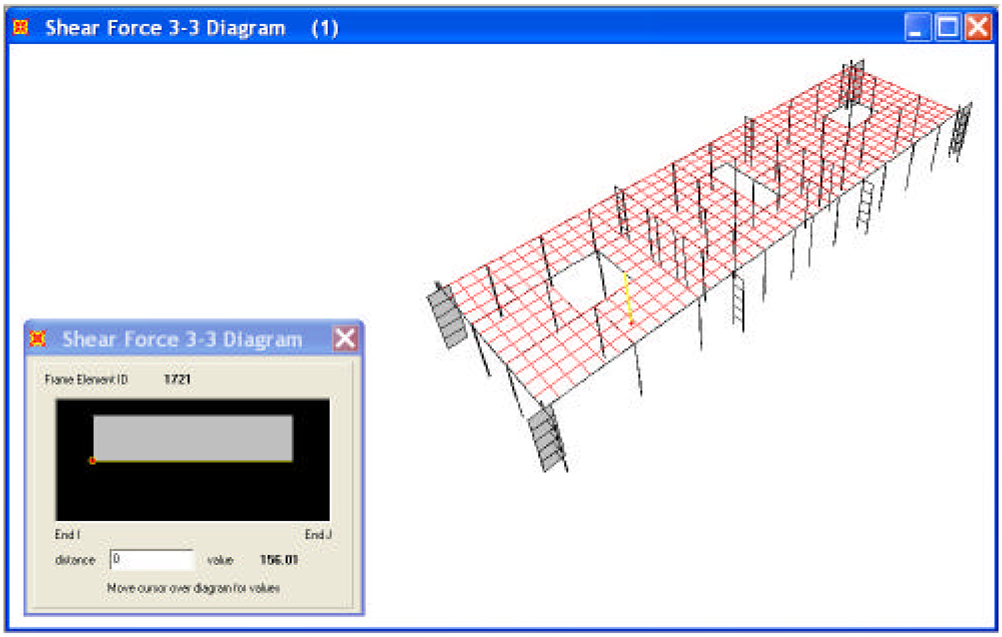


Figure 4.16: The critical deformations on the attached building model



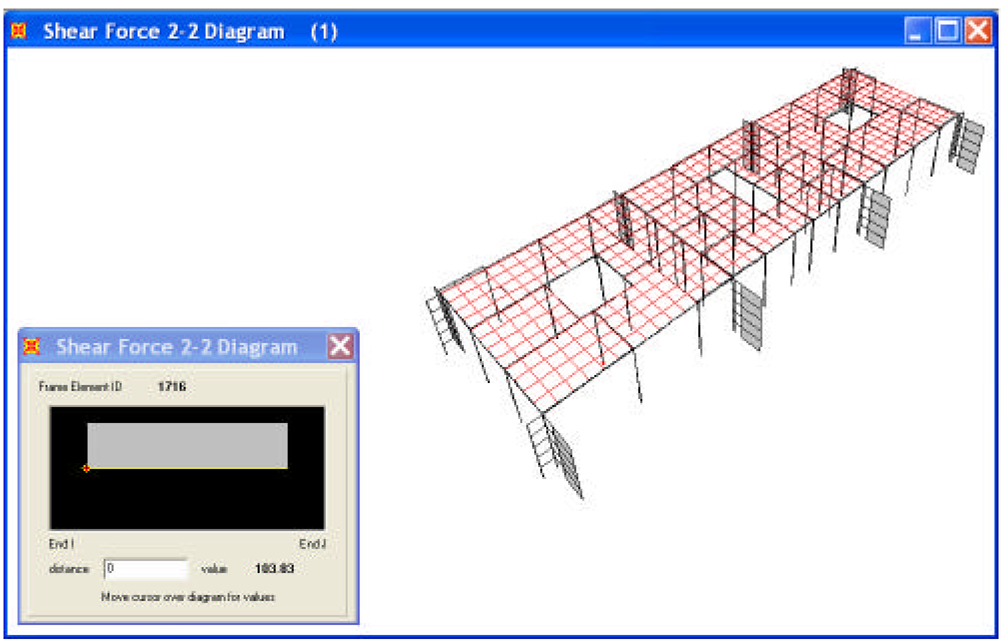
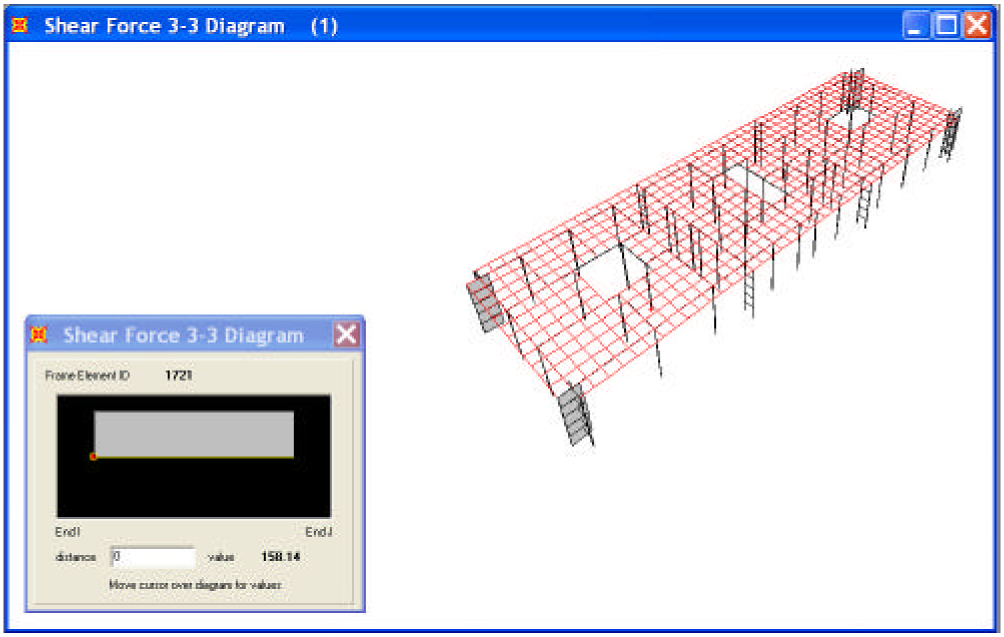


Figure 4.17: Shear force distributions in X and Y directions on the model of attached layout with shear walls



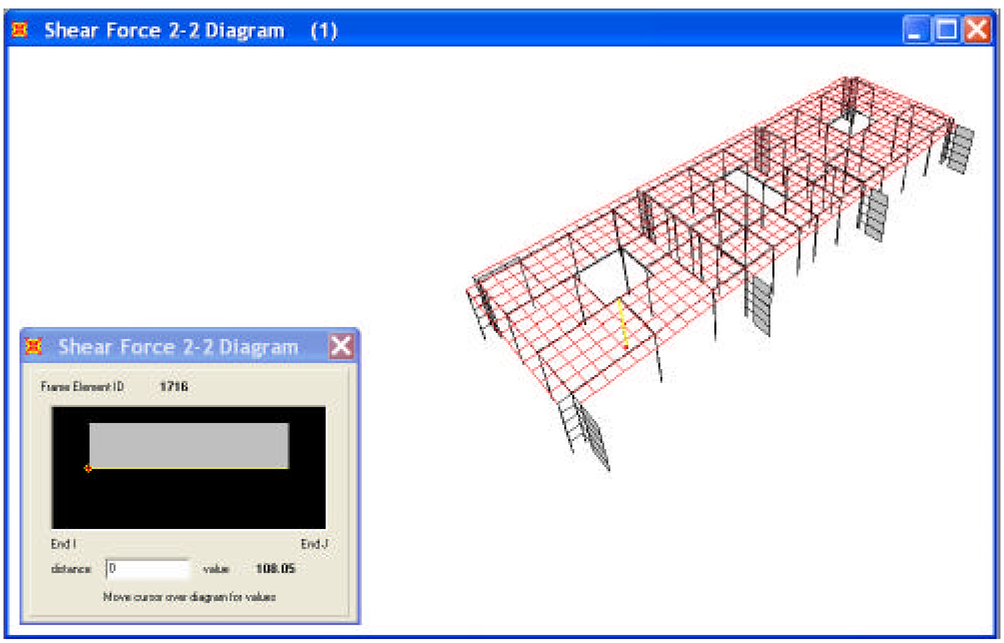
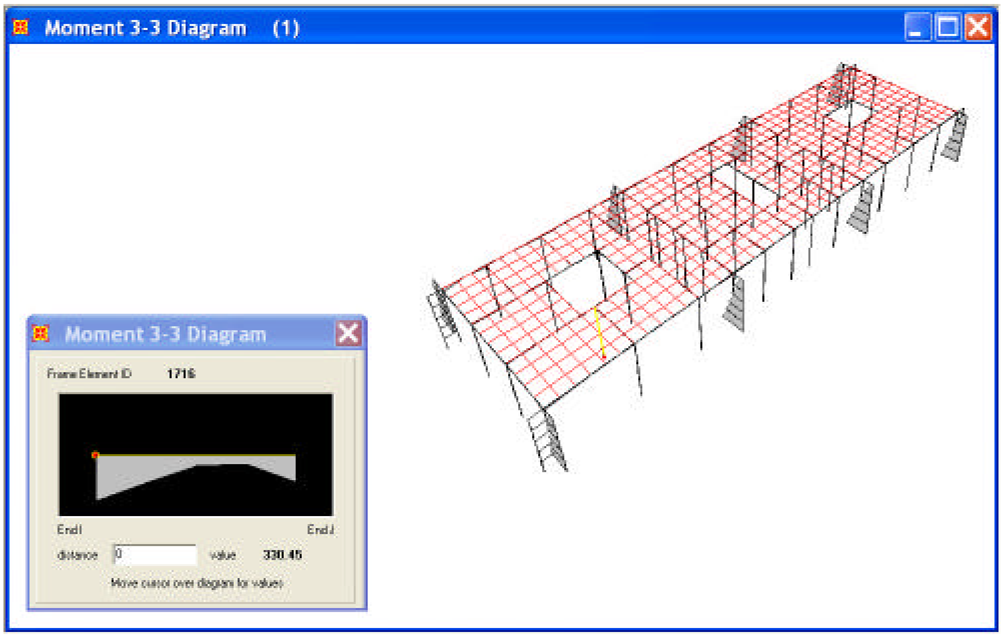


Figure 4.18: Shear force distributions in X and Y directions on the model of attached layout with both shear walls and diaphragms



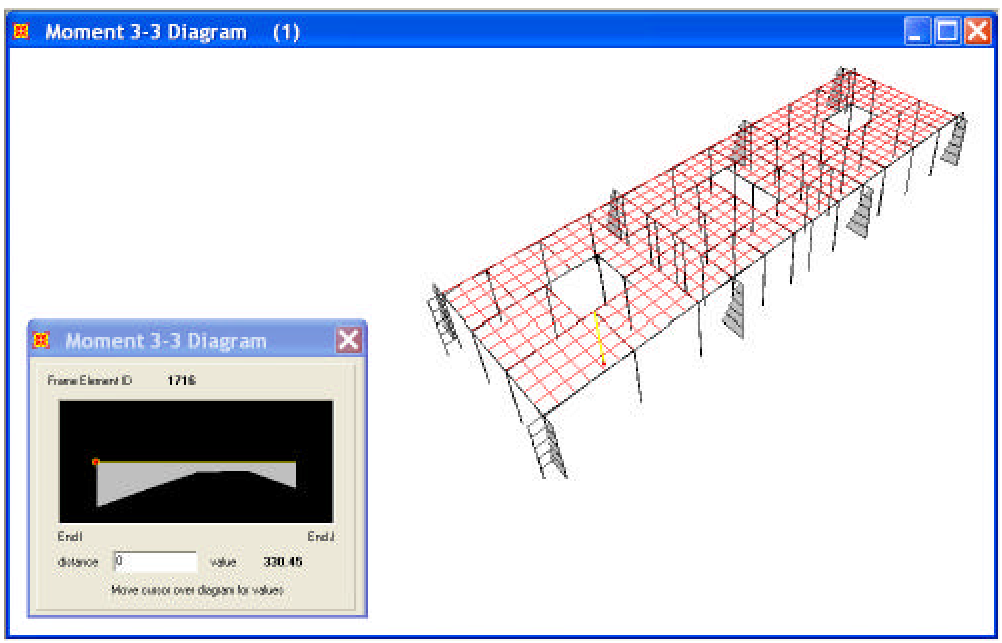
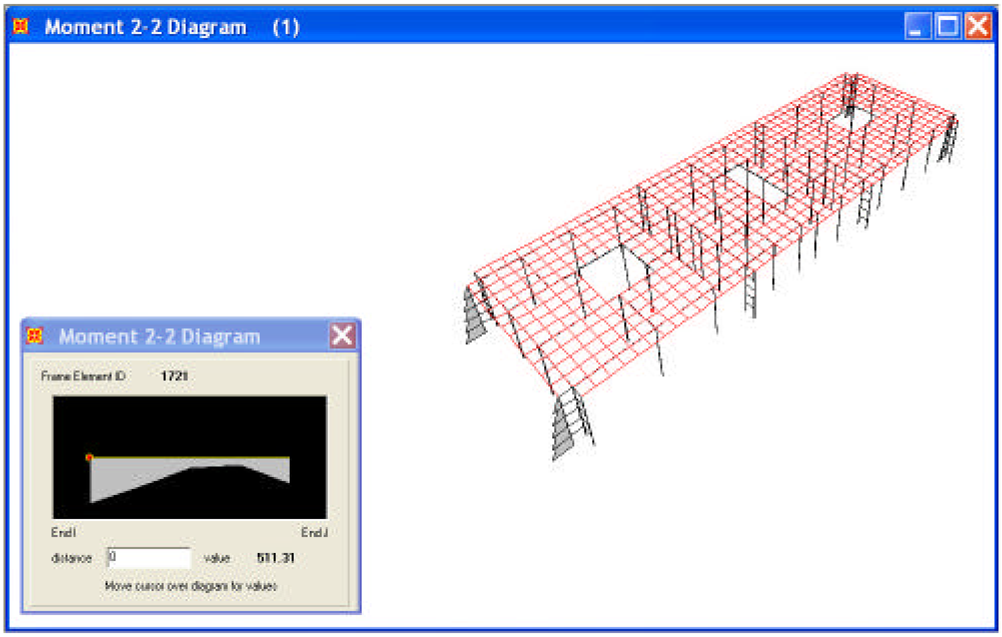


Figure 4.19: Bending moment distributions in X and Y directions on the model of attached layout with shear walls



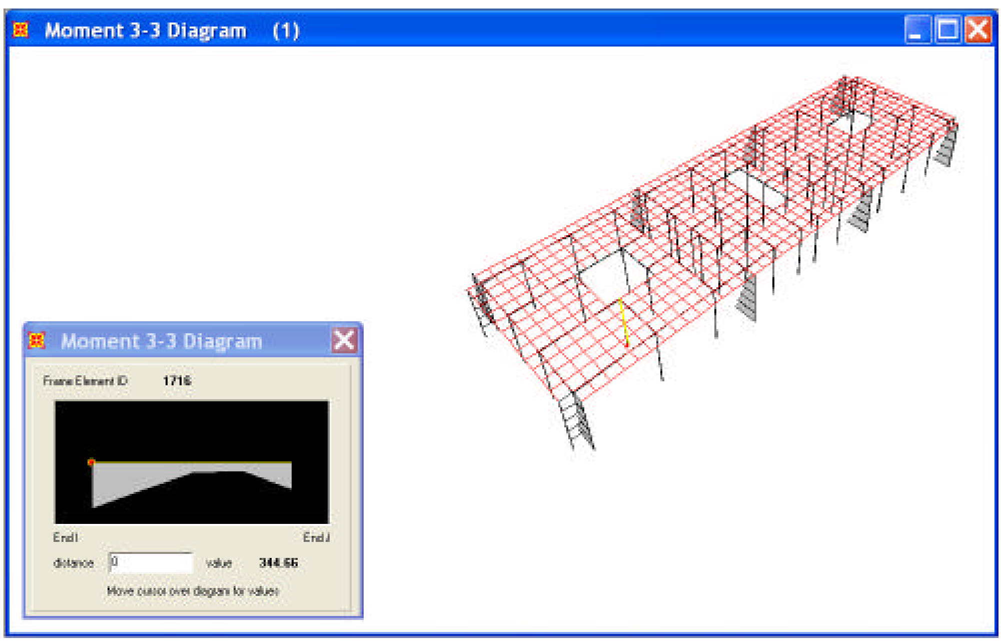


Figure 4.20: Bending moment distributions in X and Y directions on the model of attached layout with both shear walls and diaphragms

When the results of the analyses of the models are compared for each of the selected models, it is possible to mention that the shear walls are effective means to provide a significant increase in the seismic performance of the buildings. However, the increase in the shear forces and bending moments in the columns should be considered before the application. It seems that the diaphragms result in a rise in the values of time periods, displacements, shear forces and the bending moments in the columns that the building includes itself. This could be related to the proportional increase in the weight of the structure. However, it could be claimed that the increase in the time periods, deformations and distributions of shear forces and bending moments are very small when the increase in mass is considered. Thus, various analyses on different structural configurations should be performed by the experts of the subject before general and certain comments and interpretations about advantages or disadvantages of their utilization.

4.3. Evaluation of the Proposed Strengthening Method and a Comparative Study with the Existing Methods

Although the analyses results give positive opinions about the effectiveness of the additional structural members for the strengthening of reinforced concrete buildings in terms of seismic performance, there exist several parameters that determine the feasibility of the proposed method, since strengthening processes generally require serious modifications, which are not even considered before, on the structure. When a building is started to be designed, many items such as cost, function and aesthetics are taken into consideration. These parameters are all parts of the expected work and should be judged together. In other words, none of them is independent from each other, or could be added on the work after it is completed. It is unavoidable that some parameters would have the priority according to different circumstances. However, unfortunately, the situation is rather disappointing when the majority of the residential buildings in Turkey are considered. It would be misleading to accuse the builders for all the negative aspects in the urban layout of the settlements in the country since there are many other parameters such as Town Planning Codes and economical restraints for the construction of the buildings; however, it is actual that the main parameter, even more than the safety of human life, has become the economy and the most effective utilization of the land not only in the rapid and unhealthy urbanization period but also in the recent years. Most of the architectural design faults also could be related these restraints as well as the unconsciousness of the importance of selection and configuration of structural system. The tendency to create the maximum area leads to carelessly designed cantilevers and projections, which might be inconvenient in terms of seismic performance. Moreover, the contracts between the landowner and the builder for proposed flats lead the builders to use the most economic and simple way to construct a building. As a result, the majority of the urban settlements in Turkey consist of buildings, of which the main considerations are economy and maximum efficiency in terms of land use, whereas other determinants and characteristics such as functionality, aesthetics and, most importantly, safety are neglected to some extent.

These parameters also come out when a strengthening process is considered; however, the importance and determinacy of the parameters rather differ. When a strengthening process is in progress, the situation is mostly related with safety of human life. On the other hand, there still exist other parameters, which are determinant on the selection of the most convenient method.

As mentioned in the previous chapter, there exists several ways of strengthening, each of which might be powerful or convenient for different situations. Strengthening might be a process of high cost since it includes many items such as workmanship, material and design of the application. However, the principle concern of any strengthening process required and/or applied for the rehabilitation of the existing buildings in the risky zones in terms of seismology, is to provide safety of the users. On the other hand, in order to provide the most economical and the most convenient method, there are always other criteria to consider, the most important of which could be listed as economy, functionality, social aspects and architectural decisions.

4.3.1. Cost

Due to the rapid and irregular urbanization, especially in the 1950-1960s, there are more than hundred thousands of buildings to be strengthened in Turkey, since most of them were built out of the safety regulations. It is for sure that these buildings, especially those, which are located in the highly risky seismic zones, somehow require structural modifications or additions to provide a sound seismic performance. The other way to obtain structurally sound buildings is to demolish and build up again. Nevertheless, this would cost rather highly when compared with any strengthening process, which might be considered to be expensive.

The type and application of any process -related to the structural performance of any building- depend on some criteria such as economy, functionality, time and aesthetics as well as the location, history and existing structural performance of the building. In many aspects it seems to be more feasible and economic to strengthen a building rather than demolishing and building up again. The first of these reasons is that, demolishing a building so as to make a replacement with a structurally sound one is a rather time consuming way. This aspect is covered in the following parts of the study. However, it should be convenient to consider about the cost for the accommodation of the residents of the buildings to be demolished within the construction time, which is around 1.5-2 years. Moreover, it would be rather expensive since a strengthening process is principally related to and applied on the structural members of the building, and it includes very little modifications to the rest of the construction. In most of the residential buildings, the majority of the cost is generated by the so-called architectural articulations and interior design members. The construction of structural members of any building frame requires –very roughly- 40% of the cost. This case is generally relevant for the construction of apartment buildings, which are planned to be sold immediately. The ratio of the cost of structural members to the rest of the building decreases when the building constructed is articulated by means of materials of more quality and preciseness inside. To rebuild a structure means the construction of all these nonstructural and articulation elements as well, although there is no need when the case to be considered is seismic strengthening.

On the other hand, strengthening may not only cover the modification of structural members. The additions or modifications on the structural elements of a building unavoidably would have effects also on the partition walls or fenestration units around. When the selected process is to enlarge the sections of columns, it would be necessary to, at least partially, tear down the walls around. When the process is over, the wall should be built up, be plastered, and be painted. The same is relevant for the strengthening of the beams, which are mostly placed on top of partition walls. When the selected process is addition of shear walls within the building, the case includes the renewal of the floor coverings as well. From this point of view, it might seem to be convenient to reconstruct the overall building; however, the crucial point is that the degree of strengthening differs according to the existing structural capacity of the building. In other words, the building might perform well with a very little structural modification or addition. Especially in multi-storey buildings, demolition, which would result in a great amount of waste material, is also a costly process. This would destruct the economy of both the owner(s) of the building and the country.

When the proposed method is compared to the other strengthening methods in terms of cost, the case differs in some aspects. Initially, the exterior application, which is only to the exterior corner columns, would not affect the rest of the building. The process only requires the construction and plaster of the additional shear walls and the diaphragms. Moreover, the amount of concrete and steel used in the process would approximately be equal to that of a structurally sound building should have according to the regulations of Turkish Earthquake Code. The crucial point in this method, is that the amount of the materials to be used in the application and workmanship. Basically, concrete, steel and the bonding material between the existing and the new structural members could be thought to be the building materials. Eight shear walls of 0.25 x 1.80 meter with a total area of 3.6 m^2 are proposed to be placed at the corners of the single building, which has a floor area of 352 m^2. According to the regulations of the Turkish Earthquake Codes, this building must have 3.5 m^2 of shear walls already. The difference in between the two values could be thought to be the extra cost of the proposed method. The percentage of the additional shear walls decrease when the attached buildings are in case since the shear walls are placed only in one direction at the connection points of two buildings and is used by the two buildings in common. Here, it could be said that in terms of material, the only extra cost is for the bonding material to connect the existing and the new structural members to provide the interaction in between. However, these parameters go beyond the scope of the study, since the basic aim in this study is to explore the structural contribution of the proposed method focusing on mostly the architectural aspects.

4.3.2. Function

Although a strengthening process is designed according to some parameters, it should be kept in mind that the principle of any interruption to the structure is related to the safety of human life. The function of additional elements to the building is to provide a stronger behavior against earthquakes. When the columns are widened, or extra shear walls are added, the building is aimed to be more rigid than it has ever been. Increasing the moment arm and the amount of reinforcement aims to increase the moment capacity. Enlarging the cross sectional dimensions of the beams and placing extra reinforcement improve the shear resistance. As a whole, the basic principle is to prevent the collapse of the building. More or less, every strengthening method has powerful effects on the seismic performance of a building. The important point is that every building requires different methods according to its present structural condition.

The results of the analyses demonstrate the powerful effect of shear walls and the diaphragms on the seismic performance of a building. However, there are still some parameters to be considered such as the interaction between the existing and the new building materials and the foundations. The most important problems seem to be the foundations of the shear walls since they are to be constructed as close as possible to the building and provision of interaction between the existing and the new materials. In this study, as a starting point the foundations are proposed to be built upon mini-piles as shown in Figure 4.21 [46]. Referring to the previous parts of the study, in which the existing strengthening methods are explored- epoxy that should be inserted in through the holes at every 20-30 centimeters, is considered to be the material for binding. However, these points are beyond the scope of the study and should be explored by the experts of each field.

According to the analyses results, it seems that the basic principle is achieved by the proposed method. Thus, it would be useful to handle its functionality in different aspects. The diaphragms, which are used around the building once a two or three storey, create a space of about 0.90-meter width. The alternative utilization of these spaces according to the application in several configurations will be explored. Use of these spaces would alter according to the rooms behind as well as relation of the building with the environment. If the shear walls alone could perform well, there would be no need to add the diaphragms. Or, they should be used in only two sides when the building is attached on both sides. According to the rooms behind, it would be possible to utilize these spaces alternatively. If the room behind is a common living space, then it would be possible to either include the building within the existing space or utilize as a balcony. For more and the most private spaces such as bedrooms and bathrooms, it might be more convenient to include the space within the existing rooms as an enlargement. For configurations, which have rooms with different privacy degrees on the same elevation, it is also possible to develop more alternatives. However, the cost and difficulty of modifications on the elevation should be considered. When the enlargement of the spaces behind is thought, it contradicts to the main purpose of this study, which is to strengthen a building without evacuation. Moreover, the strengthening method does not offer the same opportunity for all the users in a residential building since the diaphragms do not repeat in all the floors of a building.

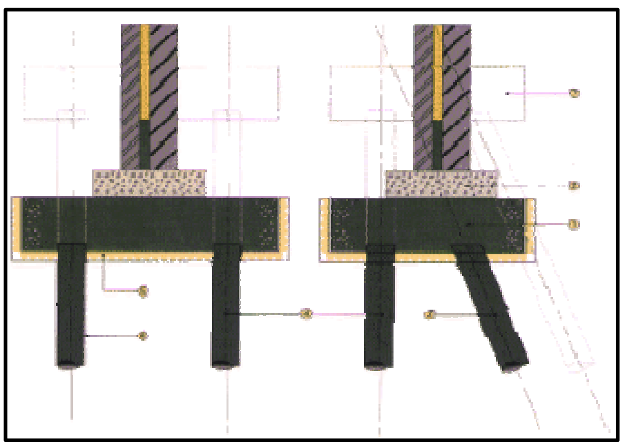


Figure 4.21: Foundation upon mini-piles

As mentioned before, the best way to utilize the shear walls and the diaphragms could be the differentiation between the commercial and residential parts in a building if the building is located in a commercial area. For those, which have shops or offices at the ground floor level, the diaphragms could be used as a means of separation between these two parts. This aspect is considered to have been related to architectural considerations rather than functional aspects and was discussed in detail.

4.3.4. Social Aspects

The recent earthquakes that Turkey suffered in the recent years have demonstrated not only the poor seismic performance of reinforced concrete buildings, but also the sensitivity of people about the safety of their houses. The strength of the buildings, even of those, which had overcome the earthquakes, became a matter of concern and suspect. It is for sure here is that this hazard will repeat in seismic zones; the crucial point is that the buildings located in these zones might not be able to overcome an earthquake of the same magnitude. Recalling the urbanization period of Turkey in 1950s and onwards, it could be understood that the buildings located in the seismic zones in any other region of Turkey would behave more or like the same as the ones in Marmara Region did since most of the buildings in the urban settlements were built before the revision of Turkey Earthquake Codes. They should either be demolished in order to be replaced by structurally sound buildings in terms of seismic behavior, or be strengthened. The former is rather time consuming so that it is probable to face with another hazard before completion of construction. Moreover, considering the fact accommodation of the residents of buildings, which were demolished or collapsed just after or during the earthquakes, is already a problem itself, it would create more problems to demolish all the buildings that could perform better by means of even simple strengthening methods. Nevertheless, in extreme cases, such as that the building is severely damaged from a previous earthquake or that the building is over its lifetime period, it might be more convenient method to replace it with a new one. It is clear that demolition of buildings had negatively affected the morality and economy of the residents and owners. Unless it is claimed by the experts that the building cannot serve any more, it becomes a problem to convince all the owners of a building to replace with another one, especially if there exists an easier and more economical way to solve the problem.

Another important point here is that, although it is the human life, which has the priority, the appearance of the buildings has a significant effect on the psychology of people. The proposed method covers serious modifications on the appearance of the buildings as well as the environment that the building is located in. Before applying a strengthening method, the owner(s) of the building must be informed about the situation of the building after the process is completed. If the building is single and it is located in a relatively larger area, the construction of the shear walls would not disturb the environment. On the other hand, if the buildings are attached, the owners of each of the buildings must agree with each other in the application of the strengthening method. Moreover, this method might require important modifications in the environment as well. Generally, the attached buildings are located on narrow parcels that have a very few distance between the construction area and the pavements. This situation would probably necessitate enlarging the pavements, and consequently narrowing the streets.

CHAPTER 5

CONCLUSIONS

5.1. Summary

The last earthquakes that Turkey has been suffering in the recent years brought up the questions about seismic performance of buildings. Considering the facts that Turkey is located on a highly risky zone in terms of seismology, and most of the buildings in the country are constructed of reinforced concrete, this study aims to propose a new approach for strengthening of this type of buildings.

There are various methods developed for strengthening of buildings. However, what is common in all the existing methods is that these processes require empty spaces to be performed. This creates serious problems since the need for a second place to accommodate arises. This dissertation is based upon the aim to realize the process without evacuation of the buildings to be strengthened.

In order to be able to propose a new approach for strengthening of reinforced concrete buildings, explorations were carried out about the general characteristics of this type of buildings in Turkey. There are many reasons why the strengthening method is proposed for residential buildings. Beside the intent to develop an approach without evacuating the space, one of these reasons might be claimed as that most of the built environment constitutes of residential buildings that are to face with probable earthquakes. Since most of them were constructed before the regulations of Turkish Earthquake Codes (1997) was brought into force, and especially in large-scale cities, an important portion of these buildings are not legal, in other words, they are not the works of architects and/or engineers, they strictly require strengthening to resist an earthquake of a high magnitude without failure. Another reason is that it has always been the residential buildings that suffer from the earthquakes most among all types so that there appears to be an urgent need for strengthening of these buildings. And finally, another reason could be mentioned as that there is a need to investigate its feasibility in many aspects so that it is required to develop a categorization, which may not be possible for any other type of buildings, on the characteristics of buildings. On the other hand, the method could be developed or modified for other types of buildings according to their characteristics in further studies.

The explorations about the characteristics of reinforced concrete residential buildings were carried out to understand the common faults in their architectural and structural designs. The leading factors for the poor performance of structures were researched and explained. According to these researches, it might be possible to claim that the rapid and unhealthy urbanization, which started in the 1920s and reached its peak point in the 1950s and 1960s, is the main reason for uncontrolled spread of built environment. Besides the lack of local authority to control the erection of structures, Town Planning Codes is seen to allow construction of defective buildings as well. Based upon the studies related to seismic performance of reinforced concrete structures after the recent earthquakes, the method has been developed in such a way that it would compensate these structural deficiencies. The other features that influence the seismic performance of buildings such as workmanship, material quality, soil conditions, or the amount of reinforcement within the structural members, are out of the content and scope of the study.

Before suggesting a new approach for strengthening of reinforced concrete buildings, the study also covered the principles of strengthening and existing strengthening methods with the probable cases that they could be used. Besides, the advantages and disadvantages of these methods are given with facilities and difficulties in their application. This part was explored in detail in order to have an idea about possible problems in construction of the proposed approach as well.

The study suggests connecting shear walls to the existing corner columns of a structure. Continuity of shear walls is proposed to be provided by means of diaphragms that surround the structure. This approach covers great modifications on the structural configuration of the buildings as every strengthening method does; moreover, it seriously changes the appearance as well. The analyses that were performed on both single and attached arrangements with several deficiencies in terms of seismic design indicated that the additional members have positive effects on behavior of structures.

5.2. Potential Cases for the Application of the Proposed Method

The proposed method has basically been developed to increase the seismic performance of reinforced concrete buildings. As mentioned before, shear walls are supposed to be connected to the existing columns whereas the diaphragms are proposed to be connected to the existing slabs all around the building. Thus, the structural configuration of the building to be strengthened is of utmost importance for the application of the proposed method. It was previously mentioned that the application points and cases of each strengthening method might differ, so that it would be better to focus on the buildings that have the convenient structural configuration for the application of the proposed method.

The proposed method suggests the addition of the shear walls to the existing columns of the building on four exterior corners. For the buildings that have no projections on either direction, there seems to be no problem for the application in terms of the location of existing structural members. The other points, which are related to the construction process such as technique, foundations, and materials to be used, are beyond the scope of this study and could be explored in further researches.

As previously mentioned, the arrangement of the exterior columns is of prior importance for the applicability of the proposed method. The shear walls are to be connected to these existing columns on the exterior surfaces. If the building has a similar structural configuration –in terms of exterior columns at the corners- similar to the layout as shown in the Figure 5.1, there seems to be no problem for the application of the method. In other words, if the exterior columns take place at the corner and the building has no projections or balconies, the shear walls can be added to the exterior surfaces of the existing columns and can be connected to each other by means of diaphragms.

However, considering the fact that the majority of the reinforced concrete residential buildings in Turkey have projections –as shown in Figure 5.2- due to the purpose of the most effective utilization of land, the cases for the application of the proposed method might seem to be limited in number. Hence, it might be useful to suggest a different way of application of the method for the buildings, the exterior columns of which do not take place at the corner. If the building has projection(s) after the ground floor level, then it would be appropriate to create an area to perform the process. This could be done by placing a separation at the end line of the column and demolishing the rest of the exterior wall after this line in order to expose the exterior surface of the column. This separation would help to obtain the desired working area for the application without breaking the objective of the proposed method, which is to propose a method that could be applied without evacuating the building. One advantage in the buildings with projections is that the existing slabs of the projecting parts would undertake the function of the additional diaphragms. They would be utilized to connect the shear walls so that there wouldn't be a need to add the diaphragms.

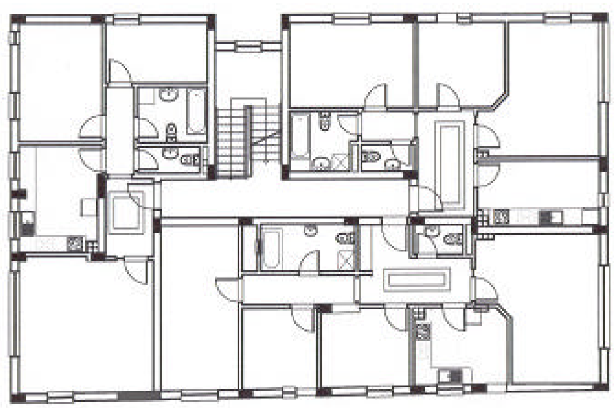


Figure 5.1: Example for appropriate layout for the application of the method

The same problem to obtain the continuity of the structural members is also seen in the buildings that have balconies as well. Since it is strictly required to connect the shear walls to the exterior columns and the diaphragms to the existing slabs, the method unfortunately proposes demolition of the balconies. Not only the balconies or terraces that take place at the line of the exterior columns but also the ones in between the existing structural members prevent the continuity of the new structural members. The set of figures from 5.3 to 5.5 displays the preparation and construction steps for the application of the proposed method.

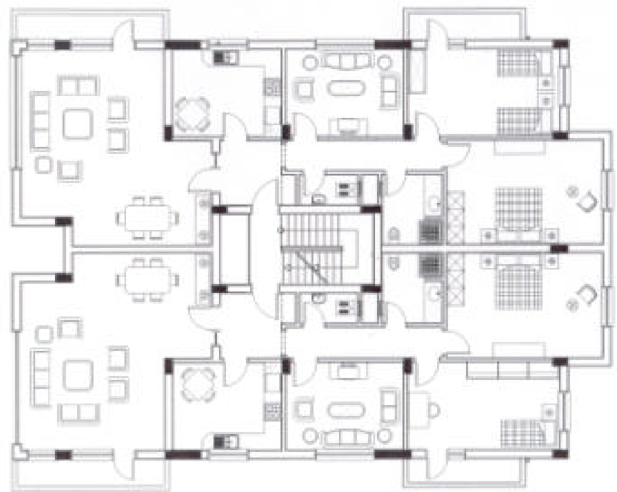


Figure 5.2: Example for inappropriate layout for the application of the method

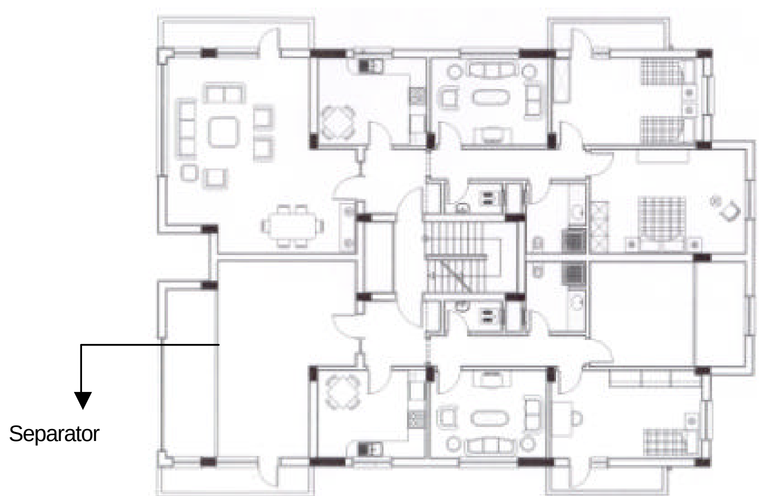


Figure 5.3: The first step for the application of the proposed method: Placing the separators by means of light partitions

Apart from the configuration of the corner columns, there are other important common parameters for application of the proposed method. All the models that have been selected as the potential cases include some design faults that lead to poor seismic behavior. These faults could be listed as follows:

- Irregularity, dislocation, and discontinuity of columns, beams, slabs and shear walls

- Floor discontinuities
- Projections in plan
- Soft storey irregularity
- Pounding effect
- Weak column-strong beam connections

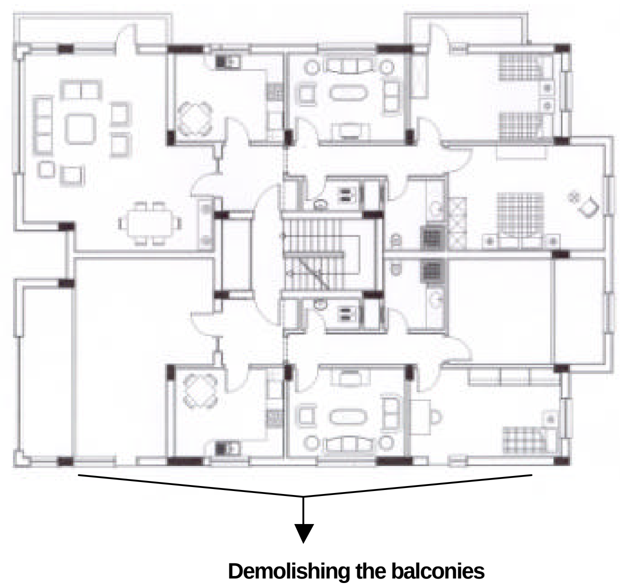


Figure 5.4: The second step for the application of the proposed method: Removing the balconies

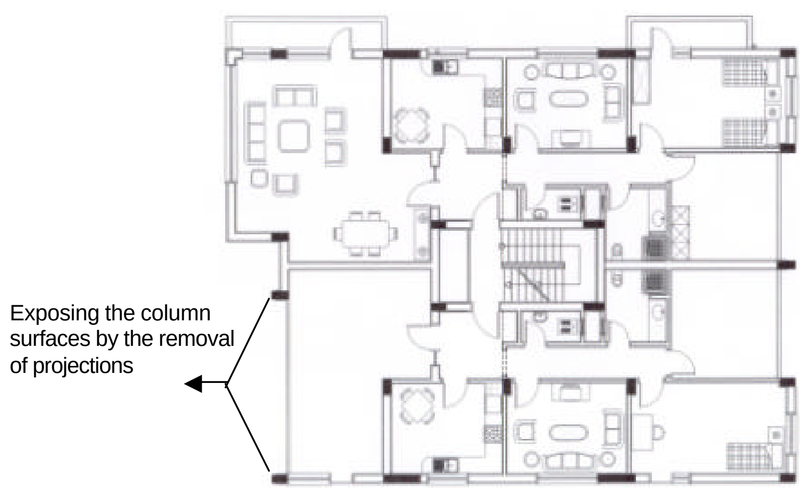


Figure 5.5: The third step for the application of the proposed method: Exposing the column surfaces

The structural deficiencies listed above are the most common design faults that result as poor seismic behavior in most of the reinforced concrete residential buildings. Irregularity, discontinuity and dislocation of structural members are mostly seen as the result of the intention to hide the beams sagging within the spaces created. In order to have the beams above the partition walls, the beam connections may not always be supported by columns. Projections, as another common characteristic of residential buildings due to the most efficient utilization of land, are the other cases where beam connections are not supported by columns. And finally, soft storey formation includes irregularity on structural members since the columns of the ground floor level are more slender than those of the upper storeys.

As a whole, it is possible to say that shear walls and diaphragms are seen as the effective means to obtain seismically strong behavior. The seismic design faults, which are given above are common in most of the buildings in question. Thus, the proposed method is seen to be applicable to reinforced concrete residential buildings that have the seismic design faults listed above.

5.3. Significant Remarks about the Applicability of the Proposed Method

As far as the analyses results show, the method seems to be feasible as a new approach for strengthening of reinforced concrete residential buildings without evacuation. However, there are some indefinite and/or important points, which are listed as follows, should be considered about the application of the method:

1. For the applicability of the proposed method without interrupting the inner space, the basic condition is a proper structural layout. The exterior columns are required to be at the corners. If not, a working area could be created by means of separations at the beginning of the process. This might cover obstructions within the space. On the other hand, this would provide getting rid of constructing diaphragms since the existing slabs on the projecting part of the building would undertake the diaphragms' function, which is to connect the shear walls.

2. The additional members might block the view and sunlight especially in the lower floor levels.

3. Construction details are of utmost importance:

   a) The proposed shear walls must have footings as the existing columns do, but to construct the footings nearby the existing ones might create problems.

   b) Connection details between the existing and new structural members must be developed. The proposed shear walls must be connected to the existing columns, and the diaphragms must be connected to the existing slabs.

   c) The means –such as profiles- and materials to bond/connect the existing and new structural members must properly be selected and designed. Particularities such as frequency and design of joints are of utmost importance.

4. As far as the results of the analyses indicate, the method seem to be feasible to be applied in typical reinforced concrete residential buildings of medium height in the way it is proposed; however, even a slight change in the structural arrangement of buildings might result different. These changes might be other structural deficiencies than those taken into consideration for the analyses or number of storeys. Extra structural members might be required or some of them might be eliminated. Thus, each configuration needs to be analyzed before application. This, consequently, requires reevaluation of the method in terms of basic parameters such as architectural aspects, time, cost, etc.

5. Before the application of the method, determinants such as assessment of the building, time, cost, architectural features must be well-analyzed since sometimes it might not be that practical to strengthen a building, which is severely damaged or of very poor performance.

6. There are many other parameters that are not covered within the scope of the study. These are soil conditions, material quality, preciseness and workmanship.

7. Inhabitants or owners of the building in question should be well-informed about the final situation since the proposed method includes great modifications on the architectural form of the building.

8. The additional members might create problems in circulation around the building, since shear walls project out from the borders of the building in both directions. Pavements and sidewalks, and consequently the roads and streets would either be narrowed or be no more in use.

9. Projection of shear walls might be undesired and/or unallowable in terms of legal regulations such as Town Planning Codes since they exceed the construction site within the parcels. Since there are hundred thousands of buildings to be strengthened, modifications related to the neighborhoods of the buildings in question are required. Suggestions related to the revisions of Town Planning Codes are given in the following parts.

Provided that the items listed above are taken into consideration, it could be said that the proposed method achieved its main objectives within the frame of the study. It enables to obtain a structurally sound building without evacuation.

5.4. Suggestions Concerning the Revision of Town Planning Codes for the Application of the Method

It was previously mentioned that the proposed method involves great modifications on the architectural form of the building. But these modifications are not only related to the architectural form of the building itself but also to the nearby of the building. Under this circumstance, there are some necessary precautions to be taken in order to make an effective use of the method.

This study could be utilized as a basis for the necessary modifications on Town Planning Codes in two aspects. The first aspect could be based on the necessary arrangements assuming that the method would be applied. Considering the fact that there are many buildings that need strengthening, and that it is impossible to reconstruct them, there should be some preparations in order to avoid further problems that could be faced after the application of the proposed method. Since the method covers great interruptions to the nearby of the building in question, the neighborhood becomes important as well. Shear walls are solid members that do not allow passing through; thus they would seem as 1.80 m projections beyond the construction limits of the building on pavements and streets. Necessary safety measures should be taken around the building so as not to disturb circulation. These precautions might be a change in the dimensions of the pavements, and consequently the streets. The pavements should be enlarged and the streets should be narrowed. Otherwise it would be impossible to continue circulation around the building on the pavements. However, narrowing down the streets might create problems on traffic.

The codes related to the arrangements on the Town Planning Codes concerning the application of the method are given in articles 29 and 30 in Chapter 4 of the Town Planning Codes of the Greater Municipality of Ankara. For the rest of the study, the item numbers related to Town Planning Codes are taken from the specifications of the Greater Municipality of Ankara [58]. The width of the parcels and the width of gardens at the front, side and back parts are specified in relation to the number of floors and heights of the buildings in these items. In other words, the allowable construction areas are all specified in these articles and cannot be ignored unless the necessary revisions are done. This means the items 29 and 30 given in 4th Chapter of the Town Planning Codes of the Greater Municipality of Ankara –and the corresponding items in the Town Planning Codes of each city- should be modified so that they would allow construction beyond the specified limits. This should be done due to the fact that the shear walls are constructed as additions to the structure, which is probably used all the available area already. In other words, it is almost certain that the additional members would exceed the construction limits. Under these circumstances, they should be evaluated as not constructions but necessary additions to the structure for seismic reliability.

The other aspect that the study might be utilized as a basis for revision is that some of the problems related to seismic performance of the buildings result from the regulations of Town Planning Codes. Although the Turkish Earthquake Codes regulate the structural design and detailing of buildings that have been constructed after 1997, there certainly are some configurations that should not be allowed. For example, soft storey problem, which is a very common characteristic of damaged buildings in the recent earthquakes, comes out due to the arrangements that propose commercial and residential units in the same building without any restrictions related to floor level differences. The article 45-1 in Chapter 5 of Town Planning Codes of the Greater Municipality of Ankara specifies that the ground floor could be utilized as commercial units. The soft storey problem could easily be understood when the item 47-2 is considered. This article gives the specifications related to mezzanine in ground floor considering the clear heights and ratio of its floor area to that of the ground floor. It claims that the clear height of the ground floor, in which the mezzanine floor would take place, could not be less than 5.20 m whereas the clear height of the mezzanine floor could not be less than 2.40 m. Besides, the article 48-1 specifies the minimum clear floor heights as 2.40 m, but does not give any clues related to the maximum height. The overall height of buildings is specified different in each zone, but there is no item proposing that the floors should be identical in terms of clear height [58].

As another precaution that should be taken for earthquake resistant building design requires the revision of Town Planning Codes in article 43. Projections, which are utilized in the majority of the buildings for the most efficient use of land, create irregularities in structural members. This irregularity, which is allowed by the item with number 43-1 leads to poor load transfer mechanism, and consequently poor seismic performance of the building. Thus, Town Planning Codes seem to need revision for the necessary restrictions to prevent inconvenient layouts [58].

The method may not be convenient for all the residential buildings, but especially for the buildings on a particular zone, it might be applicable in general since there should be some common characteristics in terms of structural and architectural aspects. The additional members give the potential buildings a characteristic appearance. Especially for those, which are used as both commercial and residential purposes, the diaphragms are seen to be good means for separation. If the method were applied for the buildings on a particular zone, it would be possible to obtain uniformity, which should also be in harmony with the nearby environment.

5.5. Architectural Aspects in the Application of the Proposed Method

There always have been discussions between the fields of architecture and engineering due to the distance in between these two disciplines. This distance comes out in case of strengthening as well. However, in strengthening process structural safety of the building has the priority so that even the great alterations could be tolerated in the architectural features of the buildings. The level of these changes differs according to each strengthening method. Steel lattice might not require great changes in the appearance of the building whereas converting a partition wall into a shear wall might lead to close some window and door openings. In order not to face with these kinds of problems, the best way is to have a good collaboration between the architect and the engineer at the very beginning stage of the initial design process. The architect is as responsible as the engineer with the initial decision that is taken at the very beginning of the design for the selection of the structural system and locations of the structural members. Otherwise, a strengthening process, which would probably cover undesired modifications and configurations, would be required for the building.

Strengthening methods may sometimes be unaesthetic due to additions or processes that were not preliminarily considered in the design stage. These additions and processes generally negatively affect the aesthetics of the building and the flow within the structure; however, when human life is in question, they must be tolerated. In this study, one of the main intentions has been to explore the proposed method in terms of architectural considerations. It is usual that the additional members are not desired; but it might not be that pretentious to claim that they may also have contributions to the buildings especially when the overall characteristics of the reinforced concrete buildings in Turkey are considered. It may not always be possible to find the best solution to keep the origin of the building after strengthening; however, considering the general situation of the reinforced concrete residential buildings in Turkey, it is possible to claim that most of the members of the built environment do not have much to lose in terms of architecture in its origin. The same insensitive and unaesthetic approach in the urban settlements of nearly the overall country is an evidence for this statement. The situation becomes more distressing when considering the fact that aesthetics could not be added to a building afterwards since it is a part of the very initial design steps. This part of the study explores the effects of the proposed strengthening method on the general appearance of the buildings in question.

The exterior applicability of the proposed method includes great modifications and interruptions to the architectural form of the building. The set of figures from 5.6 to 5.9 show the appearances of buildings before and after the application of the proposed method. The examples for these images are taken from Ankara and Eskisehir in order to have an idea about appearance before and after the application of the method on both single and attached buildings. When these figures are compared, it could be seen that these additions could be utilized positively especially when the proposed method is applied on all the buildings on a specific area. Although all of the buildings in Turkey are built according to very strict regulations and on almost identical parcels in terms of surface area, there still seems to be an irregularity in the built environments. In other words, the residential buildings in Turkey unfortunately could not be said to have a harmonious appearance. It is impossible to mention about the characteristics of a typology, which was seen in the older periods before the very rapid and unhealthy urbanization period. Although the buildings are very similar to each other in many aspects, the inharmonious appearance dominates over the overall silhouette of the urban settlement zones. Thus, the proposed method might be helpful to gather the buildings in a common style, which could be obtained by means of the shear walls and diaphragms. Especially in a zone, where all the buildings have shops or offices in the ground floor level as seen in the Figure 5.8 and 5.9, the diaphragms at the first floor level helps to develop an order and harmony in the built environment. In other words, they could be utilized as a separator between the commercial and residential parts of a building so that the unsystematic appearance due to the shops, which are usually higher than the rest of the storeys, would be prevented. These horizontal members could also be used as the means to create the effect of larger eaves, which were mentioned to be meaningful in two or three storeys, but pointless in multi-storey buildings in the previous parts of the study.

Figure 5.6: Appearance of the buildings in Sincan before and after the application of the proposed method

Figure 5.7: Appearance of the buildings in Sincan before and after the application of the proposed method

Figure 5.8: Appearance of the buildings in Eskisehir before and after the application of the proposed method

Figure 5.9: Appearance of the buildings in Eskisehir before and after the application of the proposed method

There is another possibility to treat the repetitive application of these additional horizontal members in an approach to achieve a solid-void interaction in a rhythm through the overall height of the building. The balconies are the basic elements to break the monotonous effect of the facades in general; however, the situation that is observed in the eaves is again in question in a different viewpoint. The functionality of the eaves in two or three storey buildings becomes just visual when they are used in multi-storey structures. On the other hand, the balconies, which could be utilized both functional and aesthetic aspects in low buildings, could be used only functionally in multi-storey buildings. In other words they become incapable of breaking the monotonous effect on the facades. The horizontal members proposed in this study would be helpful to obtain an altering appearance.

Another important point in the application of the proposed method is that it greatly affects not only the building itself but also the environment in which the building takes place. There might be a need for serious changes in the environment since the shear walls may be thought to be great interruptions especially on the pavements or on the streets. Thus, as mentioned before, it may be required to make some changes in the Town Planning Codes. With the application of the proposed method in this study, the buildings are to cover more than the area than they are allowed. The pavements could be enlarged or completely removed, and in some cases the streets could be converted to be pedestrian without any vehicle traffic. In other words, this consequently requires reorganization of the urban zones.

As the distance between the fields of architecture and engineering comes out in any strengthening process, the gap between the fields of architecture and planning comes out when the nearby environment of the building is also in question. The reason why the gap between architecture and planning is mentioned in this study is that the proposed method greatly interrupts the nearby of the building so that necessary arrangements should be done in order not to face with problems after the application of the method.

In Turkey, since these two disciplines are distant from each other, there seems to be a dominancy of inharmonious appearance all through the settlement zones.

Actually, this case is different in the other countries of the world so that the disciplines of planning and architecture are close to and in collaboration with each other. This collaboration is understood to be strictly necessary however; the gap in between these two fields is still in question in Turkey. This study does not focus on all the members of planning; it only suggests that the environment should be considered as a whole with all of its constituents. Affecting the arrangement of pavements and consequently the streets, the method is to cover the interaction between architecture and planning. Considering that the method could be applied to a great amount of residential buildings with common design faults and common characteristics in Turkey, and consequently that it could be applied to many buildings on a specific location, the case grows from the scale of a single building and its nearby environment to the scale of urbanism.

As the figures above display, the method could be utilized as a means to give the built environment on a specific area a common and a more characteristic appearance. The shear walls and the diaphragms are dominant means on the building. They would effectively be used as the common members if the method were applied on all the buildings on a specific area. On the other hand, as seen in the figures, it is certain that the originality of the buildings is still kept.

It was previously mentioned that although they have many common characteristics, it is impossible to claim that the residential buildings constitute a harmonious appearance when they come together. Several reasons could be listed for these unhealthy appearances since there are many parameters neglected such as environmental factors and climatic conditions. The characteristics of typical buildings of the older times have been lost or have become meaningless repetitions. Under these circumstances it could be thought that structure could be used as the means to obtain a common appearance however; structure become the means to make the building stand rather than being utilized as an aesthetic feature.

Proposing additional structural members that are very dominant in terms of appearance, this method could effectively be utilized on the buildings on a specific zone in order to obtain a common building type. Since the method requires arrangements on the nearby environment of the building and revisions on the Town Planning Codes, it would be possible to obtain a healthy environment in terms of urbanism. The shear walls and diaphragms would be the common means in all of the buildings and same arrangements on the nearby environment would be handled on a particular zone. Thus, it would be possible to obtain a regular and harmonious environment that constitutes of buildings with common appearances. As a result, this thesis could be utilized to provide continuity between the fields of architecture and structure as well as between the fields of architecture and planning. The important point here becomes the potential cases for the application of the method. If the floor levels of the buildings that are adjacent to each other are different, then it may not be possible to mention about applicability of the method. Then there should be other precautions and arrangements taken to obtain a regular environment that constitutes of members with common characteristics, however; this case is out of the scope of the study. This study has dealt with specifying the applicability of the method and evaluates it in terms of architectural, functional, economic and aesthetic features on only the potential cases. It has also focused on how the necessary arrangements and revisions could be done considering that the method would be applied.

The other important point for strengthening processes is that if the building had more than one owner or inhabitant, all of them should agree with the application. It might be difficult to obtain a consensus between these people, but when the case is safety, it might be possible to provide the agreement. However, this time, problems could be faced with the selection of the most appropriate method. If a common way of strengthening were developed or were selected among the existing ones for buildings of common seismic design faults and similar seismic performances, it might be easier to organize and arrange the application. This method is thought to be most effective means to obtain the desired harmonious and regular appearance with the least difficulty. Assuming that the necessary arrangements are done, and the method would be applied to a group of buildings on a particular zone with the agreement of the owners of all the buildings that are attached to each other, the proposed method is seen to be advantageous since it doesn’t require evacuation of space and provides a healthy and regular environment on the area that the buildings are located.

5.6. Recommendations for Further Studies

As mentioned before, there are some important points that are not covered within the frame of this study. These details such as footings, material selection and connecting details could be explored in future studies.

The method could also be developed according to building typologies other than residential buildings. Moreover, the problems, such as the limitations in the possible cases for the application of this method could be studied in order to expand the application field.

Further studies could also be related to the revision of Town Planning Codes. Inconvenient layouts could be revealed by means of experiments and analyses in order to prevent the ongoing deficiencies for the buildings that would be constructed in the future. Moreover, considering the effects of the proposed method, different arrangements could be prepared for the environmental design of either a single building on a parcel or a group of buildings on a particular zone. These studies seem to be appropriate after specifying the building(s) to be strengthened since the parameters differ for each case.

REFERENCES

1. Celep, Z. and Kumbasar, N., 2000. *Deprem Mühendisligine Giris ve Depreme Dayanikli Yapi Tasarimi*,Istanbul: Beta Dagitim

2. Karaesmen, E.,2002. *2002 Türkiye Penceresinden Deprem Olayi*, Ankara: Türkiye Müteahhitler Birligi Yayini

3. "Türkiyede Deprem", Retrieved in October 20 2002, [Internet, WWW], ADDRESS: http://www.sigortacity.com/download/deprem.doc

4. Karaesmen, E., 2002. *Öncesiyle Sonrasiyla Deprem* , Istanbul: Atilim Üniversitesi Yayini

5. T.C Basbakanlik Kriz Yönetim Merkezi, 1999. "Basin Bildirisi", Retrieved in October 12, 2002, [Internet, WWW], ADDRESS: http://www.basbakanlik.gov.tr/krizyonetimmerkezi/26aralikbasinbildirisi.htm

6. Deprem Arastirma Dairesi, 1999. "Türkiye'de Hasar Yapan Depremler", Retrieved in October 13, 2002, [Internet, WWW], ADDRESS: http://www.deprem.gov.tr/yikicidepremler.htm

7. National Earthquake Information Center, 1999. "Major Earthquakes", Retrieved in October 2, 2002, [Internet, WWW] ADDRESS: http://www.neic.usgs.gov/neis/eqlists/eqsmajr.html

8. TEKELI, I., "Yetmis Yil Içinde Türkiye'nin Konut Sorununa Nasil Çözüm Arandi", *Konut Arastirmalari Sempozyumu*, TC Basbakanlik Toplu Konut Idaresi Baskanligi ODTÜ Konut Arastirmalar Merkezi, ODTÜ Basim Isligi, Ankara, 1995

9. Karanci, N., "Afetlerin Psiko-Sosyal Boyutlari", ed. Aktüre, T., *"Deprem Güvenli Konut" Sempozyumu*, Ankara: Mesa Yayinlari, 1999. pp: 95-99

10. Biçki, D., "Kentlesme Sorunlari ve Türkiye Özelinde Çözüm Önerileri", *Endüstri Iliskileri ve Insan Kaynaklari Dergisi*, Cilt:5, Sayi:2, 2003, Retrieved in January 14, 2004 [Internet, WWW] ADDRESS: http://www.isguc.org/arc_view.php?ex=145

11. Ankara Valiligi, 2002. "Kentlesme", Retrieved in January 10, 2004, [Internet, WWW] ADDRESS: http://www.ankara.gov.tr/index.php?site=&module=cmsPage&page=page&cmsPage=291

12. Tanyeli, U., 2001. "Içeriksiz Dogrular 1: Çarpik Kentlesme", Retrieved in July 24, 2003, [Internet, WWW] ADDRESS: http://www.arkitera.com/diyalog/ugurtanyeli/makale02.htm

13. Bilgin, I., 2002. "Türkiye'de Toplu Konut Üretimi ve Mimarlik", Retrieved in July 24, 2003, [Internet, WWW] ADDRESS: http://www.arkitera.com.tr/platform/konut/ihsanbilgin2.htm

14. Gülkan, P., "Afetlere Karsi Hazirlikli Olma: Planlama ve Yapim Denetimi", ed. Aktüre, T., *"Deprem Güvenli Konut" Sempozyumu*, Ankara: Mesa Yayinlari, 1999. pp: 101-109

15. Ulusoy, A., Vural, T., 2001. "Kentlesmenin Sosyo Ekonomik Etkileri", *Belediye Dergisi*, Cilt:7, Sayi:2, 2001, Retrieved in February 24, 2004, [Internet, WWW] ADDRESS: http://www.ceterisparibus.net/arsiv/ulusoy_vural3.doc

16. Mona, 2002. "Konut Tercihlerideki Degisim", Retrieved in July 24, 2003, [Internet, WWW] ADDRESS: http://www.arkitera.com.tr/forum/showthread.php?s=c73ad272587bdb8d1ba2282387840292&threadid=980

17. Kaya, E., “Kentlesme Kentlilesme”, Retrieved in March 16, 2004, [Internet, WWW] ADDRESS: http://www.erolkaya.org/docs/KENTESME_KENTLILESME.asp

18. Özer, U., Cebe, M., Güçer, S., ve ark., 1997. “Bursa ve Çevresinin Kirlilik ve Kentlesme Profili”, in *I. Uludag Çevre Mühendisligi Sempozyumu*, Bursa: Uludag Üniversitesi Basimevi, 1997. pp: 821-844, Retrieved in April 2 2004, [Internet, WWW] ADDRESS: http://ulucam.uludag.edu.tr/kent.html

19. Bilgin, I., 2002. “”Siradan" Olanin Yeniden-Üretimi ve Konut Sorunu”, Retrieved in July 24, 2003, [Internet, WWW] ADDRESS: http://www.arkitera.com.tr/platform/konut/ihsanbilgin3.htm

20. Bilgin, I., 2002. “20. Yüzyil Mimarisi, Barinma Kültürünün Hassas Dengeleri Ile Nasil Yüzlesti?”, Retrieved in July 24, 2003, [Internet, WWW] ADDRESS: http://www.arkitera.com.tr/platform/konut/ihsanbilgin4.htm

21. Dostoglu, N. T., 1990. “Regionalism vs Universalism: Architectural Imports in Developing Countries” in *IAPS 11 Culture Space History Congress*, METU, 8-12 July, Ankara, 1990. pp: 152-161, Retrieved in April 2 2004, [Internet, WWW] ADDRESS: http://ulucam.uludag.edu.tr/kent.html

22. Dostoglu, N. T., “Modern Sonrasi Mimarlik Anlayislari”, *Mimarlik Dergisi*, Sayi: 263, 1995, pp: 46-50, Retrieved in April 2 2004, [Internet, WWW] ADDRESS: http://ulucam.uludag.edu.tr/kent.html

23. Bilgin, I., 2002. “Türkiye’nin Modernlesme Süreci Içinde Konut Üretimi”, Retrieved in July 24, 2003, [Internet, WWW] ADDRESS: http://www.arkitera.com.tr/platform/konut/ihsanbilgin1.htm

24. Keyder, Ç., (1999). "Konut Piyasasi: Informelden Küresele", *Defter,* No: 35, pp. 73-93, 1999, Istanbul: Metis Yayinlari

25. Bilgin, I., 2002. "20. Yüzyil Mimarisi, Barinma Kültürünün Hassas Dengeleri Ile Nasil Yüzlesti?", Retrieved in July 24, 2003, [Internet, WWW] ADDRESS: http://www.arkitera.com.tr/platform/konut/ihsanbilgin4b.htm

26. Ünal, E., 1997. *Imar Kanunlari Yönetmelikleri Genelgeleri,* Ankara: Mahalli Idareler Dernegi

27. Orta Dogu Teknik Üniversitesi Deprem Mühendisligi Arastirma Merkezi, 1998. *3194 Sayili Imar Kanunu ve Yönetmeliklerinin Yeni bir Yapi Kontrol Sistemi ve Afetlere Karsi Dayanikliligi Saglayacak Önlemleri Içermek Üzere Revizyonu Arastirmasi Müsavirlik Hizmetleri*, Ön Rapor, Cilt 1 ve 2, Ankara: Mesleki Egitim ve Gelistirme Dairesi Baskanligi Baski Tesisleri

28. Lagorio, H.J., 1990. *Earthquakes An Architect's Guide To Nonstructural Seismic Hazards*, New York, Chichester: John Wiley & Sons Inc.

29. Demiralp, Ö., 1996. *Seismic Performance of an Improved Precast Concrete Connection Used in Single Storey Buildings*, Unpublished Master's Thesis, METU, Ankara

30. Ögretmenler Sitesi, "17 Agustos Depremine ait Fotograf Galerisi", Retrieved in September 18, 2002, [Internet, WWW] ADDRESS: http://www.ogretmenlersitesi.com/deprem/resim/default.asp?strID=18

31. Tuna, M. E., 2000. *Depreme Dayanikli Yapi Tasarimi*, Ankara: Tuna Egitim ve Kültür Vakfi Pub.

32. Unay, A.I., and Atimtay, E., "Developing Earthquake Consciousness in the Architect", ed. Voyatzaki, M., *Architecture and Engineering the*

Teaching of Architecture for Multidisciplinary Practice, Transactions on Architectural Education, No 05, Greece: Art of Text s.a., pp. 267-270.

33. Özmen, C., 2002. *Commonly Encountered Seismic Design Faults in Reinforced Concrete Residential Architecture in Turkey*, Unpublished Master's Thesis, METU, Ankara

34. Ersoy, U., "Binalarin Mimarisinin ve Tasiyici Sisteminin Deprem Dayanimina Etkisi", ed. Aktüre, T., *"Deprem Güvenli Konut" Sempozyumu*, Ankara: Mesa Yayinlari, 1999. pp: 65-77

35. Ersoy, U., Ersoy, A., "Binalarin Deprem Dayanimina Mimarinin Önemi", *Yapi*, Sayi:125, 1992

36. Atimtay, E., 2000. *Açiklamalar ve Örneklerle Afet Bölgelerinde Yapilacak Yapilar Hakkinda Yönetmelik*, 2.vols. Ankara: Bizim Büro Basimevi, Vol 1 and 2.

37. Atimtay, E., 2001,. *Çerçeveli ve Perdeli Betonarme Sistemlerin Tasarimi*, 2 vols. Ankara: METU Press, Vol 1 and 2.

38. Turkish Earthquake Code, 1998. *Afet Bölgelerinde Yapilacak Yapilar Hakkinda Yönetmelik* , Ankara

39. Unay, A.I., Tuna M.E., (2000). "Deprem Sirasinda Olusan Yumusak Kat Davranisinin Analitik Modelle Incelenmesi", *Gazi Üniversitesi FBE Dergisi*, No:3, Vol:13, July 2000

40. ODTÜ-Mimarlik Fakültesi-Sehir ve Bölge Planlama Bölümü, 1999. *17 Agustos 1999 Körfez Depremi*, CD-ROM

41. Gönençen, K., 2000. *Mimari Proje Tasariminda Depreme Karsi Yapi Dayaniminin Düzenlenmesi*, Ankara: Teknik Yayinevi Pub.

42. TUBITAK, 1999. *Rapor: Deprem sonrasinda Betonarme Binalarin Güçlendirilmesi*, TUBITAK Yayinlari

43. Middle East Technical University Earthquake Engineering Research Center, 1999. *Rehabilitation of Moderately Damaged R/C Buildings after the 1 October 1995 Dinar Earthquake*, ed. Wasti, T., Sucuoglu, H., Ankara: Report No: METU/EERC 99-01,

44. Fukuyama, H., Sugano, S., (2000). "Japanese Seismic Rahabilitation of Reinforced Concrete Buildings after the Hyogoken-Nanbu Earthquake", *Cement & Concrete Composites 22*, 2000, Great Britain: Elsevier Science Ltd., pp: 59-79

45. Oliveto, G., Decanini, L. D., (1996). "Repair and Retrofit of A Six Stprey Reinforced Concrete Building Damaged by the Earthquake in South-East Sicily on the 13th December 1990", *Soil Dynamics and Earthquake Engineering 17*, 1998, Great Britain: Elsevier Science Ltd., pp: 57-71

46. Bayülke, N., 1999. *Depremlerde Hasar Gören Yapilarin Onarim ve Güçlendirilmesi*, 7th ed., first edited in 1984. Izmir: Insaat Mühendisleri Odasi Pub.

47. Skjaerbaek, P. S., Taskin, B., Kirkegaard, P. H., Nielsen, S. R. K., (1997). "An Experimental Study of A Midbroken 2-Bay, 6-Storey Reinforced Concrete Frame Subject to Earthquakes", *Soil Dynamics and Earthquake Engineering 16,* 1997, Great Britain: Elsevier Science Ltd., pp: 373-384

48. Sezen, H., Whittaker, A. S., Elwood, K. J., Mosalam, K. M., (2002). "Performance of Reinforced Concrete Buildings during the August 17, 1999, Kocaeli, Turkey Earthquake, and Seismic Design and Construction Practise in Turkey", *Engineering Structures 25,* 2003, Great Britain: Elsevier Science Ltd., pp: 103-114

49. Ghobarah, A., Said, A., (2001). "Shear Strengthening of Beam-Column Joints", *Engineering Structures 24,* 2003, Great Britain: Elsevier Science Ltd., pp: 881-888

50. Tankut, T., "Betonarme Yapilarin Deprem Dayanimi Bakimindan Degerlendirilmesi ve Güçlendirilmesi", ed. Aktüre, T., *"Deprem Güvenli Konut" Sempozyumu*, Ankara: Mesa Yayinlari, 1999. pp: 87-94

51. Fukuyama, K., Higashibata, Y., Miyauchi, Y., (2000). "Studies on Repair and Strengthening Methods of Damaged Reinforced Concrete Columns", *Cement & Concrete Composites 22*, 2003, Great Britain: Elsevier Science Ltd., pp: 81-88

52. Wilson, E. L., 1999. *Three Static and Dynamic Finite Element Analysis and Design of Structures, A Physical Approach with Emphasis on Earthquake Engineering*, Berkeley: Computers and Structures, Inc.

53. Wilson, E. L., 1999. *Three Static and Dynamic Finite Element Analysis and Design of Structures, Tutorial Manuals*, Berkeley: Computers and Structures, Inc.

54. Wilson, E. L., 1999. *Three Static and Dynamic Finite Element Analysis and Design of Structures, Concrete Design Manuals*, Berkeley: Computers and Structures, Inc.

55. Wilson, E. L., 1999. *Three Static and Dynamic Finite Element Analysis and Design of Structures, Analysis Reference*, Berkeley: Computers and Structures, Inc.

56. *SAP2000 NONLINEAR Version 7.1 Three Static and Dynamic Finite Element Analysis and Design of Structures, Integrated Finite Element Analysis and Design of Structures, Integrated Structural Analysis and Design Software*, Product of Computers and Structures, Inc.

57. Anvil Foundations, “Technical Information”, Retrieved in April 10, 2004 [Internet, WWW] ADDRESS: http://www.anvil-co.demon.co.uk/mu.htm

58. T.C. Ankara Büyüksehir Belediye Baskanligi Imar Daire Baskanligi Yapi Uygulama ve Denetim Sube Müdürlügü, “Ankara Büyüksehir Belediyesi Imar Yönetmeligi”, 2003. Retrieved in April 18, 2004, [Internet, WWW] ADDRESS: http://www.ankara-bel.gov.tr/lib/ccc3.pdf

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