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Sustainable building design in Duzce case with reference to earthquake resistant building design

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After the Duzce earthquake in November, 1999, 12, 70% of the built environment was ruined in the Urban area. After the removal of the ruins that Urban area was turned into a huge open space. This was not the first earthquake in Duzce. The earliest earthquake occurred in 1967. However, although it was large, there was no serious damage or death in Duzce because of the high density of traditional timber skeleton structures in the Urban area that have been mainly replaced with apartment blocks. In the following period, the rapid increase of the density of the high rise buildings and apartments in the urban center caused the loss of old traditional houses of the region. So, by the following earthquake in 1999, Duzce's Urban center was ruined and after the removal of the ruins, the city became a huge open space. The mass housing and construction activities are continuing in the new settlement areas selected due to the ground qualities of the land outside the city center. This paper is based on research dealing with urban renewal activities after the earthquake in Duzce. In this paper, sustainable Urban and building design parameters and their application possibilities for Duzce's Urban center in the frame of Urban renewal activities were studied. Establishing a sustainable and ecological building construction systems and qualified housing areas convenient for a settlement subject to earthquakes is discussed. Ways to design quality housing and lots in new urban centers linked with regeneration of the affected areas have been determined. The traditional/vernacular housing and building structure of the region was introduced. The hints for actual housing design from the traditional housing applications and the development of comfortable and safe reconstruction housing areas will be proposed for such a sustainable and disaster managed urban environment both in general scale and for the Duzce case. The evaluation of traditional architectural values formed through centuries shaped due to environmental factors in recent uses was emphasized.

Key words: Earthquake resistant building design, Duzce earthquake, housing, sustainable building design.

INTRODUCTION

Turkey, which is one of the most seismically active areas in Europe, is a link between Europe and the Near and Middle East with about 3% of its land area in Europe and 97% in Asia (Anatolia). Turkey has a long history of large earthquakes that often occur with progressive adjacent earthquakes. Most earthquakes in Turkey are associated with tectonic elements. Turkey is located in a seismically active region within the Mediterranean sector of the Alpine Himalayan orogenic system. This West-east running system extends from the Mediterranean to Asia and is one of the world's most seismically active continental regions. The Alpine orogeny is a result of the compressional motion between the Eurasian plate and the African plate (Schmidt, 2002).

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The majority of the region of Anatolia (Turkey) and the Aegean Sea are located on the Anatolian (Turkish) plate. The Northward motion of the Arabian plate and African plate against the Eurasian plate squeezes the small Anatolian microplate Westward relative to the Eurasian plate, causing earthquakes along the North Anatolian fault. The North Anatolian fault constitutes the Northern boundary of the Anatolian plate. The Southern boundary is formed by the East Anatolian fault, which joins the North Anatolian fault at Karlivo and the Hellenic Arc to the South of Cyprus. The Westward movement of the Anatolian plate and the collision of the African plate with the Eurasian plate cause compression, which produces a subduction zone in the Aegean region (Schmidt, 2002).

The North Anatolian fault is about 1.200 kilometers long and extends in an East-west direction across the Northern part of Turkey, parallel to the Black Sea coast. Since 1939, this fault produced a sequence of major earthquakes, of which the 1999 event is the 11th with a magnitude greater than or equal to 6.7. The earthquake locations have moved in both Eastward and Westward directions. The Westward migration was particularly active and ruptured 600 km of contiguous fault between 1939 and 1944. This westward propagation of earthquakes then slowed and ruptured an additional adjacent 100 km of fault in events during 1957 and 1967, with separate activity further west during 1963 and 1964. The August 17, 1999 event in Duzce fills in a 100 to 150 km long gap between the 1967 event and the 1963 - 1964 events and also affecting Duzce city. On the other hand, it was estimated that there was a 12% chance of this earthquake occurring in the 30 years from 1996 to 2026 (U.S.G.S, 2008).

Duzce which has been a settlement center for Phyrigian, Lycian, Persian, Roman, Byzantin, Seljuk and Ottoman civilizations and has been a significant centre since 800 BC. However, the most important periods for the region are the Bithinian, Roman-Byzantin, Ottoman and Republic periods. Duzce, situated in west Black Sea region, is surrounded by Zonguldak City in the North, Bolu City to the East and South and Sakarya City to the west. The Black Sea is about 30 km to the North of the city. The city was established on the Southwest plains of Bolu Plateau covered with forests and surrounded by mountains and hills leveling 120 km above sea level.

The settlement is situated on D-100 in the middle of Ankara-İstanbul highway from North to South and TEM highway passes to the South side of the settlement. Besides the highway connecting Zonguldak, Ereğli, Akçakoca to D-100 is passing in the North on the settlement. As the settlement is located on the Istanbul-Ankara highway, the urbanization and its environs caused the development of the region; so that the settlement has been declared as a city by the government with 20 neighborhoods, 97 villages and 7 districts on December, 9, 1999 after the earthquake.

Duzce is located on the active earthquake zone and the land has not been stabilized well yet (Figure 1). Besides, the city center of Duzce has been developed 5 km from the main rocky land. Duzce has been located on the flat Duzce plateau at an altitude of 120 m with 0.5 - 3 degree slope through the Southwest direction. Asar Water and Melen Stream are passing through the city center. Lithologically, land is composed of silt, clay, sand and gravel, which is vulnerable to earthquake forces.

Eighty-seven days after the 17 August Marmara Earthquake, the great Duzce Earthquake occurred at 18.57 on 12 November, 1999, with a magnitude equal to 7.2, leaving virtually the entire city in ruins in 30 s. The Duzce fault that produced the 12 November earthquake is approximately 73 km long and the 17 August 1999 earthquake ruptured the 30 km length of west part of this fault. The greatest construction damages were seen in Golyaka-Kaynaşlı and Duzce districts. Damaged zones are probably on the old stream bases, which have a high groundwater level. Poor construction, deficient building materials and non-observance of building codes contributed to the damage caused (Figure 2).

The earthquake caused 980 deaths and destroyed 12,562 houses and 3,055 office buildings completely and 7,897 houses and 2,136 office buildings partially. 8,237 houses and 1,219 office buildings were less damaged in Duzce and its vicinity, namely Cumayeri, Cilimli, Golyaka, Gumusova, Kaynaslı and Yıgılca (Anonymous, 2002a).

A public survey after the earthquake indicates that 93.40% of the inhabitants did not immigrate to other regions; only 6.6% had left the area, which is a positive phenomenon for the region (Anonymous, 1999).

MATERIAL AND METHODS

The main material of this research comprises the governmental borders of Duzce city including all the villages, natural and cultural resources of the vicinity. Research made after the earthquake of the existing situation of the settlement form the basic material of the study.

This paper, is part of the completed research project "urban renewal researches for Duzce after the earthquake", concentrates on the housing areas of the whole research area. The methodology of the research is formed of three phases, literature works, site analysis studies and evaluation of these data in computer media by the help of related software. (1) Literature studies comprising the earthquake background of the region and the urban development of the settlement through history. The researches done by the United States Geological Survey Organization about the earthquake and settlement subjects both at national and international scales were examined to make a comparison. (2) Site analysis studies; the natural, environmental and structural damages originating from the earthquake will be determined to make a comparison with the original pattern of the settlement. Urban design proposals have

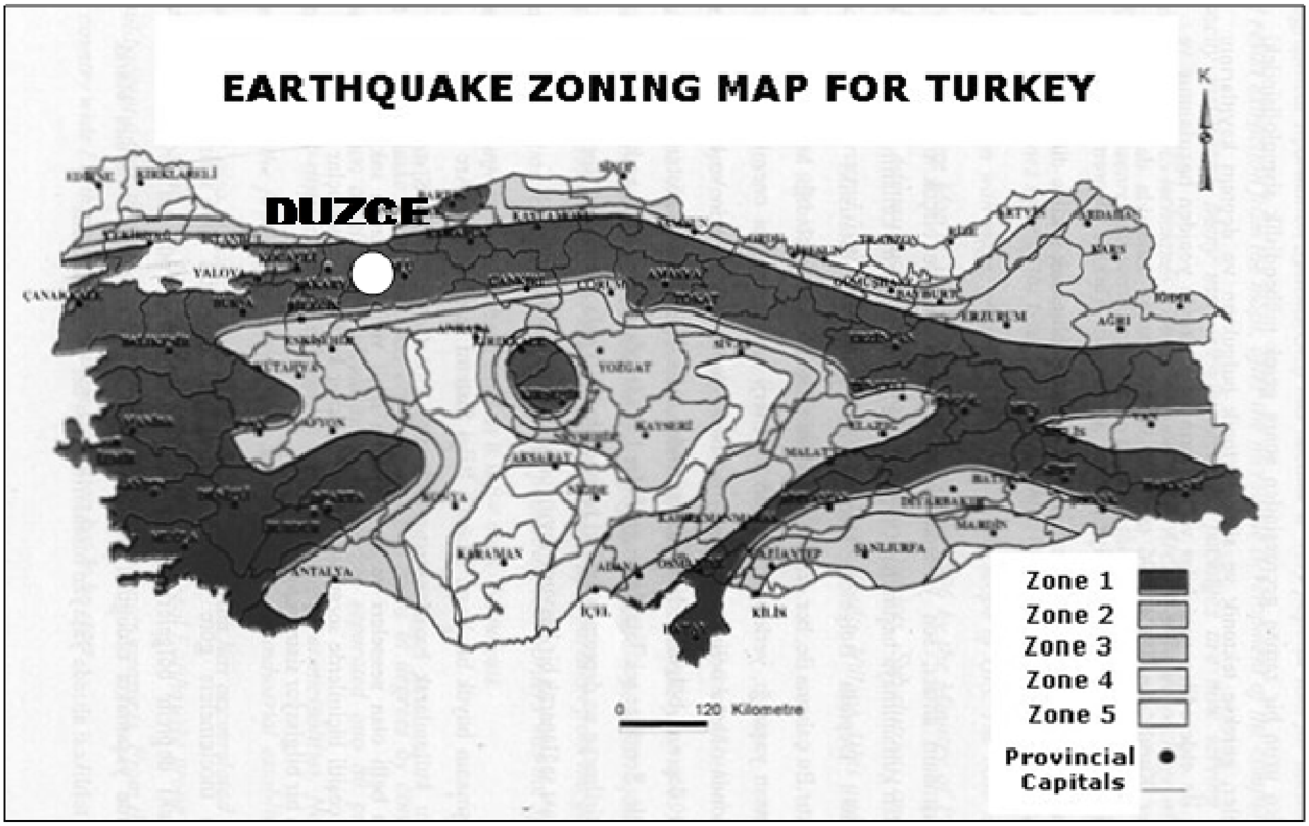

Figure 1. Location of Duzce on the earthquake zoning map of Turkey.

been prepared for certain parts of the urban area. (3) Evaluation of the topographic, geological, geomorphologic and soil data of the settlement overlapped and evaluated by the help of Arcview, MapInfo and Netcad softwares to propose new alternative land uses in the frame of land use decisions and urban renewal applications. After the evaluation of the data at urban scale, the design principles and building technology for a sustainable environment were proposed for Duzce.

The existing urban environment

As the settlement area of Duzce has been a marshland in the past, the first building activities has been developed on the skirts of the mountains bordering the plateau. Konuralp which has been the oldest city center of Duzce is one of the most important villages of Duzce with its rich cultural assets dating back to Roman period. Duzce which was a small market place with a mosque and 2 ‘han’ buildings in the 16thC gained its main urban characteristics in the 19thC.

The first construction plan of Duzce was made in 1950. Until then, the city developed for the most part, along the old İstanbul-Ankara highway. After removing this road to the North, the development of the city diverged largely to the North in the period between 1950 - 1960. The second construction plan, made by the Bank of Provinces, was approved and put into force in 1963. This plan targeted the year 1990 and was preparing for a population of 32,000. Building permission was given for a maximum of three floors. In the construction plan, housing development areas were suggested mostly to be established in the direction of the Northeast and partly in the West and the North directions. Because of the fault, there were no extensions proposed to the south. However, when the existing land situation is compared with the construction plan, it can be seen that the construction plan was not applied. It failed to lead to appropriate settlement of the city. Main connection and peripheral roads and public building areas were not developed in the Northeast. Touristic areas are widespread along the İstanbul-Ankara highway and Akçakoca situated on the Black Sea shoreline of Duzce. Although the plan suggests stopping the extension to the South because of the geological

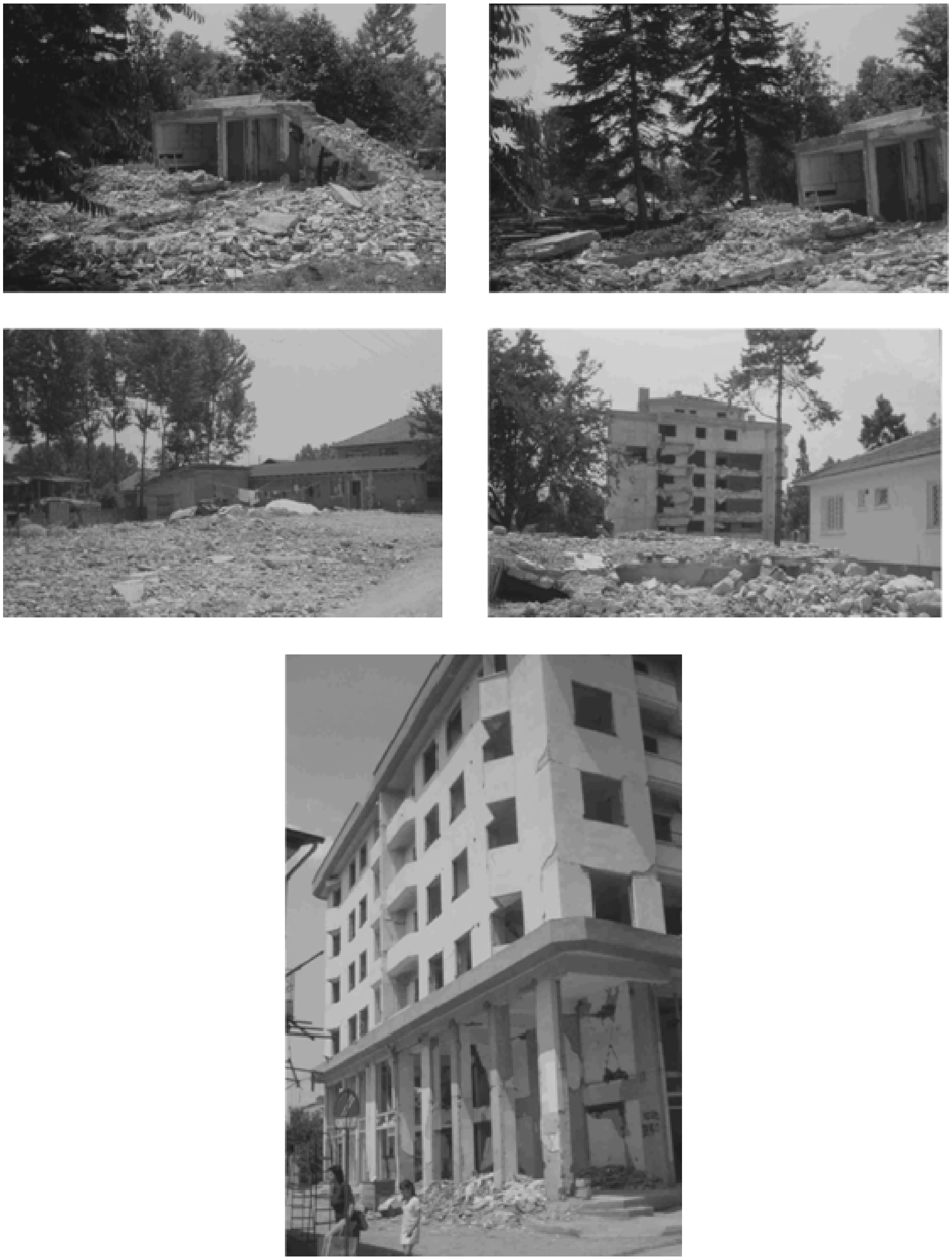

Figure 2. Duzce after the earthquake

disadvantages, these areas have developed rapidly. Since 1978, some changes have been made in the construction plan. In this period, multi-floored constructions started to be built and up to 4, 5 and even 6 floors were allowed.

In 1985, a new construction plan was prepared targeting 2005 and foreseeing a 160,000 population. It was put into force in 1987. By the plan, urban development moved to the West, East and North besides filling the spaces in the existing pattern. Development towards the South was not suggested because of the permanent rise of the level of underground water. Until the earthquakes, almost 2,000 changes have been made in the plan and the city development could not be shift in a safer direction. In particular, in the city center, density increased through the buildings with more floors. In 1994, after the changes in the construction plan and in order to ensure the unity of the plan again, it was revised and an additional construction master plan was made. However, building activities continued in a speedy manner while disregarding site selection criteria and safety against collapses.

The existing construction plan of Duzce was evaluated and reorganized by the Ministry of Construction after the earthquake because of the changing conditions in 2001. It was revised according to the results of the geological, geophysical and geotechnical reports. Demographic structure and its growth were examined though to 2020 with objectives to direct the structural plan of the city. Commercial and residential areas, open-green spaces, new construction regulations; construction in disjunctive order rather than continuous row housing and building system was ordered. The width of the streets was increased and the use of continuous and radiageneal type of foundations were proposed as necessities in the last construction plan of Duzce.

Today, the urban center exhibits a complex structure. As ruins were removed, there are many gaps and hut-like buildings constructed in these areas. So, there is chaos in the whole urban silhouette. After the Duzce earthquake, 12,000 tents were established in 20 different settlements in Duzce. Besides prefabricated temporary houses, offices, educational and commercial buildings were built. 3,200 of them were built by the Ministry of Construction. Hundreds of prefabricated buildings that were built by various organizations still exist in the city and its near environs. They have to be removed and reorganized (EUP, 2001).

The occurrence of the Duzce Earthquake on 12 November, 1999 made Turkey reconsider many issues. The main idea about how to create a city has been questioned here. The aim has to be:

i. Preparation of a reconstruction plan.
ii. Creation of a disaster-resilient city.

The responses to disaster can be classified into four phases: (Obata, 2002):

a. Precautionary period: Lack of precautionary phase both in terms of awareness and disaster prevention measures. No preparation was made against an earthquake in Duzce so that, the results of the earthquake were disastrous. In a country like Turkey, subject to earthquakes should be always ready for this type of disasters.

b. Period of emergency and temporary measures: Municipalities confused and had no plans in place against a disaster. The highest priority has to be given to ensure uninterrupted provision of gas, water and electricity supplies. Local authorities supplying urban services and facilities should sustain urban environments and settlements under such conditions. The local authorities of Duzce were unable to supply these services.

c. Restoration phase: Great effort has to be made to reduce the inadequacies of temporary housing. Ruin disposal and fundamental plans for earthquake reconstruction have to be proposed and the city must be restored as soon as possible. Temporary housing areas were formed rapidly and the residential areas are now almost completed in Duzce.

d. Reconstruction phase: Reconstruction measures have to be defined and held after the restoration period. Reconstruction plans for a new city need to be developed. Reconstruction of the urban environment brings new dimensions, so macro level issues appear in this phase. This phase has not been completed in Duzce. The construction practices were improved at the building scale, but not completed at the urban and city scales.

Creation of the disaster-resilient city gains importance here. In order to realize this, it is necessary to understand the structural problems created by the earthquake. These problems can be classified in a broad sense as:

i. Safety of densely built-up areas.
ii. Increase of aging, population in inner-city and children.
iii. Community consciousness.
iv. Earthquake-proof structures for residences and densely built-up areas.
v. Earthquake-proof expressways.
vi. Earthquake-proofing of pipelines and water reservoirs.

Besides, strategies for long term mitigation have to be developed. First of all, the housing stock has to be strengthened. Low quality of (the) housing has to be upgraded and programs to educate people about appropriate building practices should be provided.

Sustainable land use patterns should be developed and in order to supply environmental protection and natural mitigation disaster planning can and should be integrated with environmental management and protection which is the overall goal of sustainable development.

The vision of a sustainable future seeks to direct people and social investments away from high-hazard areas, to protect and sustain the ecology and to balance short term needs and long term goals.

Earthquake and sustainable building design

In order to determine the parameters of sustainable building design for the settlements subject to earthquakes, the phenomenon should be discussed in a broader sense at urban scale in priority.

Sustainable development of a settlement means to search for an alternative development process with the following principles:

i. Transferring the urban environment and the building stock from generation to generation.
ii. A balance among settlements; cities and villages and socio-economic sense.
iii. Nature, environment, building interaction and their integration.

In the frame of these ideas, the following principles are necessary for the building of a disaster-resilient city:

i. A city where future generations can lead safe and secure lives.
ii. Independent and circulating city putting less stress on the environment.
iii. Spatial city, preservation of green and open areas.
iv. Preservation of historical buildings.
v. Decentralization of urban functions and the formation of a network.
vi. Barrier-free urban design.
vii. Balance between suburban development and the upgrading of inner-city areas.
viii. A comprehensive zoning including environmental preservation.
ix. Constructing an industrial structure imitating ecological circulation.
x. A city utilizing the ecological and environmental assets like parks, woods and rivers.

Severely damaging earthquakes in Turkey have repeatedly demonstrated the importance of improving the quality of urban environments, earthquake designs and construction systems. Avoiding serious damage has to be the main goal of earthquake-resistant construction. The seismic-resistant design provisions of most approaches are concerned only with assuring an effective design and construction of structures against damage that might be induced by the vibratory response of the structure to the shaking introduced at their foundations by the ground. While in certain cases of ground failure it is possible to design safe structures by proper design of their foundation, while in other cases the only natural solution is a change of site.

Sustainable building design which covers both long-term and short-term design criteria is the establishment of new buildings or the conservation of existing ones to sustain their existence fulfilling the requirements of actual uses while compromising the needs of the future uses. The geotechnical aspects should be considered at every phase of building process. From site selection to design and constructions, geotechnical information is crucial in the decision making. Besides, the geology of the region, the site, it's relation to the subsurface conditions, the ground water levels, local construction practice, the location of sources of fill materials should be analyzed before the design phase of the buildings.

Even recently constructed houses, there are features that have proven to be vulnerable to earthquake damage, most of them relate to the building configuration particular configurations have been associated with damage in past earthquakes: house over garage, many large windows or doors particularly at building corners, large overhangs, split levels and complex geometry, silts supporting structure (as on a hillside site). Unusual configurations are not necassarily hazardous but if they are designed or constructed poorly they can be particularly vulnerable to earthquake damage (Martin, 2008).

In order to obtain sustainable buildings resistant to earthquakes:

i. In the case of a structure built at a site with poor, loose, saturated, granular soil, where strong ground-shaking involving several cycles may cause permanent horizontal displacements due to lateral spreading or subsidence of the ground. When the surface soils are very soft or can liquefy piles can be used to advantage but have to be designed properly. Besides, piles should be able to carry not only axial but also shear and bending forces so that, reinforced longitudinally but also confirmed by suitable lateral reinforcement.
ii. Earthquake-resistant foundation design should be provided.
iii. Building should be light; the smaller the reactive masses, the smaller the earthquake forces (inertia forces) So, the use of unnecessary masses should be avoided; any mass used in the building should have a seismic-resistant function. The use of unnecessary heavy roofs and reinforced masonry should be avoided. The amount and the distribution of the reactive masses (masses that will react to the shaking of the building foundation) can be controlled by the selection of the structural system.
iv. Buildings (both the superstructure and non-structural components) should be light to avoid unnecessary masses.

v. Heavy earth fill roofs, roof gardens, water elements on roofs should be avoided.
vi. While selecting the structural material, it is necessary to analyze the mechanical characteristics of building material.
vii. Connections should be adequate and have to tie together all the components of the buildings properly because lack of proper connection easily causes damages due to the forces formed during earthquakes.
viii. Poorly reinforced columns also cause damages or deformations in columns
ix. Buildings should be simple, symmetric and regular both in plan and elevation to prevent significant torsional forces.
x. The simpler the building the better the earthquake behavior than complicated ones. Symmetry is important in both directions of plan. Lack of symmetry in mass distribution, in stiffness, strength and ductility loads to torsional effects which can be destructive in earthquakes.
xi. The design can not be based on a single deterministic analysis of a single selected model (Seismic-resistant design procedure).
xii. In order to obtain good performance of structures during severe seismic ground shaking it is necessary to analyze thoroughly the dynamic characteristics of the real three-dimensional soil-foundation (substructure) superstructure system.
xiii. The basic rule for earthquake resistant design is to achieve integral action of each of the main parts of the system and between. These main parts, that is the whole substructure and superstructure should be tied together so that they can work as a unit.
xiv. Buildings should have a uniform and continuous distribution of mass, stiffness, strength and ductility to avoid damages by the formation of a soft structure.
xv. The use of long cantilevers should be avoided.
xvi. Non-structural elements should be well separated in order not to interact with the rest of the structure or should be integrated with the structure.
xvii. The structure should have sufficient lateral stiffness to avoid damages under earthquake shakings.
xviii. Superstructure should be detailed to control the inelastic deformations and it should have balanced stiffness and strength between its members and connections and also with the stiffness and strength of the soil foundation.
xix. The simpler the building, the better the behavior so that, the buildings should be simple rather than a complex one.
xx. A plan layout with reentrant angles should be avoided. Irregularly shaped buildings were subject to torsional effects.
xxi. Buildings should have a uniform, balanced and continuous distribution of mass, stiffness, strength and ductility between its members, connections and supports.
xxii. Some building components such as architectural, mechanical and electrical can become very responsive during the earthquake. The more flexible the basic structural system, the worse the effects of the non-structural components will be. A properly designed infrastructure system is essential.

Timber frame houses

The seismic forces that develop during the vibratory response of a structure to earthquake ground-shaking of its foundation are inertia forces whose intensity depends on the product of the mass and acceleration. Hence, it is of the utmost importance to reduce the mass of the structure to a minimum. Thus, when the designer is confronted with the problem of selecting the structural material, it is necessary to analyze the mechanical characteristics of building materials (Anonymous, 2002b). Timber frame structures have superior capacity to the forces formed during the earthquakes. Timber skeleton structures can constrain inelastic deformation have sufficient lateral stiffness to avoid damages. They have a uniform and continuous distribution of mass and strength and as they were always planned symmetrically, also prevent significant torsional forces. So it becomes evident that among the traditional structural materials in Anatolia such as timber, stone, brick and mud-brick, the most efficient earthquake resistant material for low-rise buildings is timber especially for low-rise buildings and houses. However, these buildings should be designed properly against forces; proper lateral bracing and all of their components have to be tied together from the foundation to the roof as seen in Anatolian traditional timber frame houses that have been common also in Duzce.

The concept and form of the traditional houses came into being in accordance with a number of factors-tradition, economic conditions, regional and physical influences. The physical characteristics of West Black Sea Region clearly had a great influence on the formation of the traditional Duzce house and especially on the details of its construction. One of the main characteristics of the traditional Duzce house is the integration of the building with nature. So while conforming some basic living concepts, Turkish houses display formal differences through Anatolia in its different regions. Natural factors had directly influence the formation of houses. As Anatolia has several climatic regions; each region has its own particular methods of building.

Houses of Duzce/Black Sea and Northern Anatolian region are adapted to the topography and the climate of the region. There are two main types of plans namely

Figure 3. Duzce and traditional houses of the region.

open sofa and closed sofa houses with symmetrical plan schemes. However, the most important feature of the houses of the Northern Anatolia is the structure rather than the plan. The superstructure of the houses was set on massive foundation walls constructed with stone and sometimes built up to the first floors. Upper floors were timber framed structures with stone or brick infill (Figure 3).

The wall and corner posts of the first story were massive timbers and the intermediate studs were kept fairly closed one another. The existence of timber in the region encouraged another type of timber structure mostly seen in rural areas in the settlement. Some houses in Duzce region are clad with horizontal boards.

The typical timber frame houses consist of ground floors, over this optional mezzanine floors, main first floors and sometimes have second floors. The ground floors are isolated from streets and all exterior effects and are basically built with stone. The stone foundation walls act as massive bases for the timber frame upper structures. Timber posts are erected at close intervals supported by struts and cross braces. Tie braces are kept to a minimum and brick coursing or stone infillings are arranged between the posts in either decorative brick panels or mortared facades. Cantilevers are set on consoles which are simple diagonal struts. The structure of the upper stories rests on the substructure of beams and joists over the ground floors.

The traditional houses situated in the city center of Duzce are constructed either side by side or in separate locations but have gardens in both cases. However in the peripheries of the city center and the rural areas similar houses set in their own grounds where agricultural activities are continuing.

DISCUSSION AND CONCLUSION

There were mainly two types of structures in Duzce as far as structural systems were concerned. The first group was the multi-story reinforced concrete buildings seen very commonly in all types of buildings designed improperly both in cases of architecture and engineering. The second group was the traditional one or two story timber frame structures seen only as houses. However, although they are less in number today, the major traditional building type of Duzce was timber skeleton/timber frame structure with brick or stone infill. These timber framed structures seen in Duzce can be analyzed into two groups. The first one is called as “hımış” in which the timber frame (skeleton) is filled with stone, adobe or brick. The second one is called as “bağdadi” in which the voids between the timber frame structural elements are filled with lighter construction elements such as lime mortar and plaster applied on timber laths. Both timber skeleton construction systems have good earthquake resistance. However “bağdadi” has a clear superiority over “hımış” (Ergunay and Gulkan, 1990).

During the M:7.2 November 12, 1999 Duzce Earthquake, numerous apartment blocks constructed with reinforced concrete were severely damaged or ruined because of improper reinforcement, which could not be considered as seismic-resistant construction, and also land failures. On the other hand, many of the structures existing after the earthquake were the traditional timber skeleton structures built in local character. These types of constructions easily mitigate earthquake hazards. They can be considered as earthquake-resistant structures in a way that can easily built with the local material by the builders and sustained by the qualities and properties that they are carrying. General goals in seismic-resistant design and construction are:

i. To prevent non-structural damage in frequent minor ground shaking.
ii. To prevent structural damage and minimize non-structural damage in occasional moderate ground shaking.
iii. To avoid collapse or serious damage in rare ground shaking.

This can be easily fulfilled by the traditional Duzce houses, which were mainly abandoned by the local people in the name of contemporary architecture and urban development.

Huge/large scale new settlement areas consisting 3 - 4 story apartment blocks, single story houses for disabled and elderly parks, children play grounds and other social-cultural structures were built in organized new settlement areas apart from the city center which can be considered as satellite settlements in a way. They were well-organized, contemporary residential areas. However Duzce needs an inner-city revitalization as soon as possible. The construction activities were realized but, they have to be carried out to urban and city scales. All the structural activities should be combined in an integrated urban development plan. Besides, the existing traditional sustainable houses have to be conserved and the construction of new ones should be encouraged as earthquake-resilient structures. The main objective has to be to ensure, both for present and future generations, a healthy and safe environment. This environment can be attained by appropriate land use, zoning and complying with building regulations.

Very high risk areas should be used for agricultural or recreational purposes, industrial zones should be isolated from the residential areas by means of green belts, green corridors or greenways and high density areas should be limited into smaller zones and building density should be kept as low as possible at high risk areas. Spacing between building blocks should be supplied. Thus, in the light of these discussions best simple, regular, symmetric, earthquake-resistant proper building design for Duzce is the vernacular/traditional timber frame houses of the region which can be flexible and easily adapted actual and future needs of life. Besides, rigid but light, 2 - 3 story timber-frame houses of Duzce which can easily absorb the earthquake forces are mainly earthquake-resilient structures. Large scale public or social buildings can be built with proposed earthquake-resilient structural systems. However, vernacular character of the region can be easily sustained in housing areas as timber is a very common building material in the region and suitable to the general character and silhouette of a traditional Anatolian settlement. Simple solution is the best solution also in earthquake-resistant, sustainable building design.

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