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Historical Development of Traditional Earthquake-Resistant Construction Techniques in Anatolia

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ABSTRACT: This paper has been written to provide a general overview on construction techniques in Anatolia which were developed to resist earthquakes, which are common occurrences in their geographical location.

The aim of this progressive approach to the use of traditional materials, aesthetics and structural perfection of the structures in this cradle of different civilisations, is to advance alternatives for producing earthquake-resistant dwellings which will last for many generations.

1 INTRODUCTION

Because of the continuous movement of different continental plates, for thousands of years Anatolia has been confronted with great earthquakes. Historically, it has also been the location of choice for migrating tribes because of its unique geographical position, climate and fertile soils.

As the area developed, partly due to the improvement of agricultural techniques, settlements were established and different types of houses were built by various cultures to escape the dangers of outside life. The construction materials of these buildings generally included natural materials like wood, mud brick, and stone. In time, the composite use of masonry and wood became common as people realized the superior efficiency of this combination of materials.

The resistance to earthquake damage of traditional wood-only and mason-wood structures was shown to be very effective after the 1999 Kocaeli earthquake. For this reason the structural properties of traditional Anatolian houses, built using structural techniques against earthquakes which have been improved throughout history, will be investigated and related in subsequent pages.

2 THE EARTH'S ACTIVE FAULT LINES AND THEIR EFFECTS ON THE ANATOLIAN PENINSULA

In astenosphere which is located under the lithosphere that contains the oceans and continents, radioactive energy caused the earth's stone shell to be break and consequently divide into plates (http://www.deprem.gov.tr.; Celep, Kumbasar, 2004). Earthquakes are vibrations, which occur as a result of the relative movements of the fault lines against each other. The plates and their shifting movements that cause earthquakes can be seen in Fig. 1.

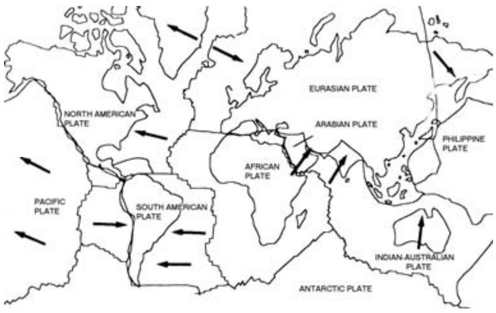

Figure 1: The world's earthquake plates and their movement directions (Celep, Kumbasar, 2004)

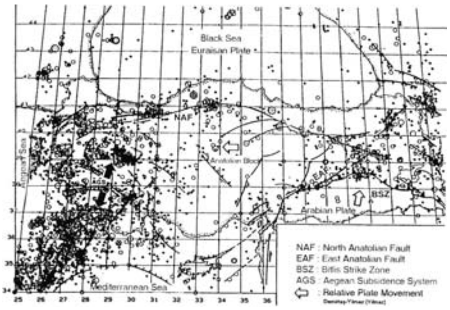

Figure 2 : The motion of fault lines and effective earthquake fields in Turkey (Ercan, 2001)

The movement of Arabian Plate causes the majority of earthquakes in Anatolia. The Northern and Eastern Anatolian fault lines were formed as a result of the motion of Eurasian plate against the Arabian plate. The Aegean Subsidence Zone was formed due to the tendency of the African plate to plunge under the Eurasian plate, see Fig. 2, (Ercan, 2001). The Northern Anatolian fault line which is the reason why %92 of the area of Turkey is an earthquake zone (http://www.deprem.gov.tr/deprem.htm), is split into three parts, i.e., the Northern, Middle and Southern. The Northern part forms a movement field that stretches from Anatolia to the Sea of Marmara (Çamlıbel, 1990) and from there to Greece and Italy (Celep, Kumbasar, 2004).

Destructive earthquakes recorded after AD 32 (Ambraseys and Finkel, 1991), the latest one in Bingöl, Karlıova show how the region is at great risk for earthquakes.

3 EFFECTS OF EARTHQUAKES ON STRUCTURES

Earthquake effects occur due to lateral forces on the building because of the weight of the structure. These forces aren't external forces but inertial forces resulting from the building's resistance to earthquake vibrations; see Fig. 3, (Ünay, 2002). In spite of the heavy and inflexible nature of masonry and because wood is a light and ductile material, a building made of wood alone or of both wood and masonry, provides great structural integrity against earthquakes. On the contrary: "*Large response of soft ground; lack of integrity of substructures; asymmetry of the structural form; insufficient strength of chimneys; inadequate structural connections; use of heavy roofs without appropriate strength of supporting frame; deterioration of timber strength through decay or pest attack; inadequate resistance to post earthquake fires* (Dowrick, 1987); and the negative affect of fire wall loads in the structure (Dışkaya, 2004) can be listed as reasons for the inadequacy of buildings against earthquake. In Fig. 3 the momentum effect of the earthquake forces on a structure can be seen.

This effect affiliated with inadequate structural connections is seen in the photograph taken after the 1912 Mürefte Earthquake, see Fig. 4 (Cogito, 1999).

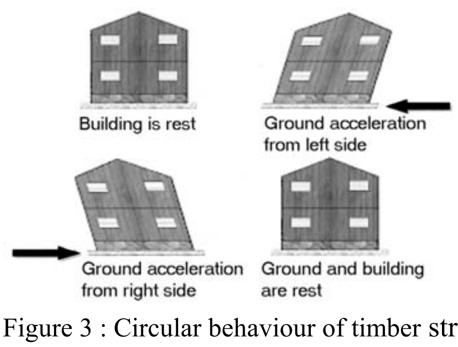

Figure 3 : Circular behaviour of timber structures during earthquake (ATC/SEAOC)

Figure 4 : A damaged traditional timber frame house, in the Mürefte earthquake in 1912 (Cogito, 1999)

4 CONSTRUCTION TECHNIQUES THROUGHOUT HISTORY IN ANATOLIA

In Neolithic period, after the invention of irrigated cultivation, human beings shifted from nomadic life to settled life and established the first cities, building the first houses for protection from the force of nature. The development and spread of agriculture in Near East and Mesopotamia can be seen in Fig. 5, (Güvenç, 1972). This situation can also be considered as a clue regarding the geographical locations of the first houses.

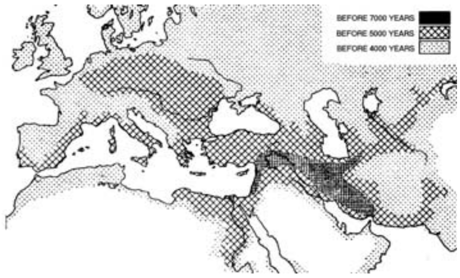

Figure 5 : Invention of agriculture in Near East, Mesopotamia and its spread area (Güvenç, 1972)

The use of wood, together with natural materials like stone and mud brick, has existed since 4000 B.C. in Anatolia (Naumann, 1985), that its history dates back 12000 years from today (Soysal, 1996). Generally wooden joists (hatıl) and studs were used in the stone foundations of these buildings, and the walls were built with mud brick and rarely, baked brick. The use of wooden joists in the wall was thought to dissipate the weight of the building on the wall, to carry the roof weight or to provide the props which were carrying the building projections (Naumann, 1985). The evidence of the use of wood in buildings is the joists in the masonry or fire traces and also cuneiform writing descriptions which have been found in archaeological excavations (Naumann, 1985). The usage of wooden joists in stone foundations is seen in the restitution of the mud brick walls in Boğazköy which was done by Bittel, see Fig. 6, (Darga, 1985).

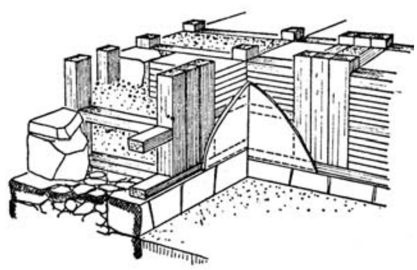

Figure 6 : The wall restitution made by Bittel in Boğazköy (Darga, 1985)

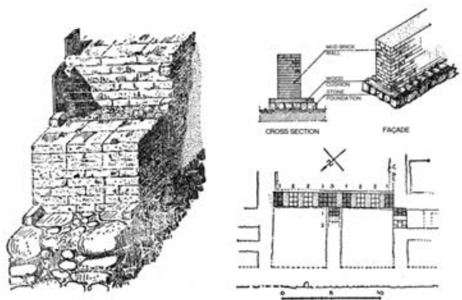

Figure 7 : Wood made cushions on stone foundation in Boğazköy and Acem Höyük excavations (Darga)

The same wall construction of Boğazköy Büyükkale is also found in the walls of the lower Palace in Zincirli (B.C.9th century), see in Fig. 8, (Naumann, 1985).

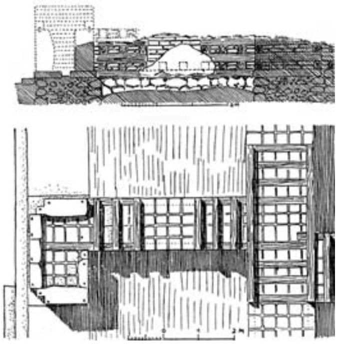

Figure 8 : Zincirli, lower palace wall with wooden grid (Naumann, 1985)

The historical progress in the use of masonry-wood materials in construction can also be seen on descriptions on ceramic objects like vases and pots, obtained from archaeological excavations. For example, on an 18^{th} century B.C. bath pot piece found at Acem Höyük, there is an informative description from that period about a monumental building: *wooden joists on cushions which stand on wooden posts and parapets were set on cross joists and mud brick-filled wall.* See in Fig. 9 (Darga, 1985).

Figure 9 : 18^{th} century B.C. Hittite bath pot with structural description (Darga, 1985)

In view of the historical development of traditional wooden construction techniques, when compared to architectural development there was not much structural difference between the houses produced in rural settlements, see in Fig. 10, (Naumann, 1985) and urban settlements, see Fig. 11, (Eldem, 1984). The similarity between the Hittite era ceramic descriptions of these buildings may be a sign of interactions and continuity in construction techniques in Anatolia. However, when Hittites came into Anatolia the language and construction techniques of the local Hatti people were used (Darga, 1984), this interaction could be accepted as an intercultural structure tradition.

Figure 10 : An infilled wooden structure under construction in Boğazköy in 1957 (Naumann, 1985)

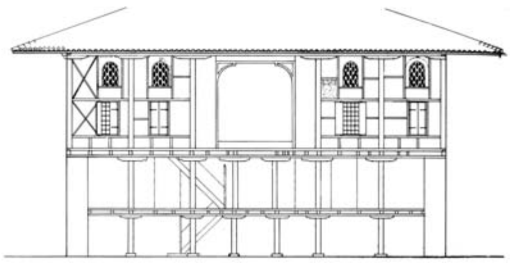

Figure 11: Halil Aga House in Mudanya (1634) (Eldem, 1984)

Distribution area of vernacular buildings in Anatolia and Balkans could be seen in Fig. 12 (Eruzun, 1990).

Figure 12 **:** Distribution of Anatolian traditional houses in the Balkans and Turkey (Eruzun, 1990)

4.1 Structural analysis of a traditional wooden house

When artifacts which have survived are investigated, it is obvious that the traditional timber skeleton house is generally composed of 2 or 3 storeys consisting of a wooden frame structure settled on a masonry foundation, basement or first floor, see in Fig. 13, (Çobancaoğlu, 1998).

Figure 13 : Timber-Framed Structure Setting on Masonry Foundation (Çobancaoğlu, 1998)

In order to stabilize the basement or first floor walls, wooden joists (hatıl) needed to be installed at 1-meter intervals along the height of the wall. These joists are placed on both sides of the wall and are connected to each other by the use of perpendicular joists, see in Fig. 14, (Eldem, pp.B2,3).

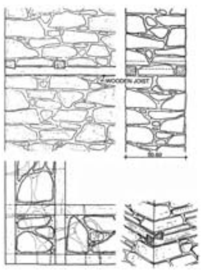

Figure 14 : Rubble Stone wall with wooden joists (Eldem)

The masonry walls of the building provide stability for the side walls and the timber skeleton, along with the masonry wall, and are joined together with iron laths, see in Fig. 15, (Eldem, pp.F3,1,2).

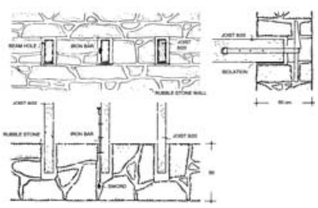

Figure 15 : Tying wooden floor joists to the masonry structure with metal laths (Eldem)

Timber skeleton constructions are half-overlapped with sole plates in the corners of the sub-structure. The posts, which are placed in the corners, are supported with props. The posts, props and the secondary posts are tied together with the lintels (kuşak) Fig. 16, (Eldem, pp.G3,1). This works like a truss frame system by transferring the inner and outer loads onto the foundation see in, Fig. 17, (Dışkaya).

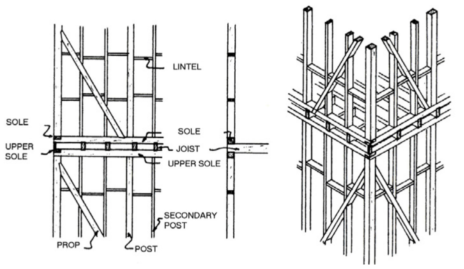

Figure 16 : Timber-framed structure with double sole on both sides (Eldem)

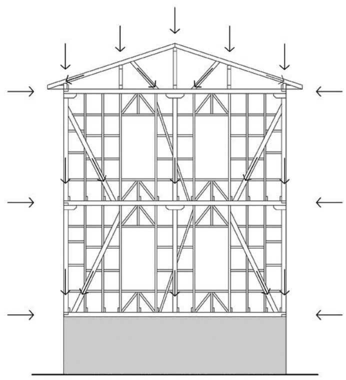

Figure 17 : The load dissipation in a traditional timber framed building (Dışkaya)

The building's internal skeleton system is generally enclosed by bağdadi laths, see in Fig. 18a, (Güngör, 1969). On the outside of the building bağdadi laths with plaster or boarding planks 2-2,5 cm in thickness are used, see in Fig. 18b, (Günay, 2002).

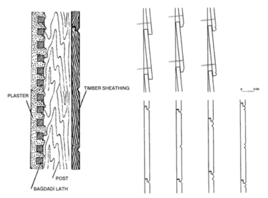

Figure 18 : (a) Bagdadi plaster (Güngör, 1969) (b)Timber sheathing (Günay, 2002)

This boarding system wraps around the building and acts like a curtain wall. See the views and construction of these buildings in Fig. 18, (Dışkaya, 2004) the simple roof structure of a 19th century building system detail in an Ottoman house is given as an example.

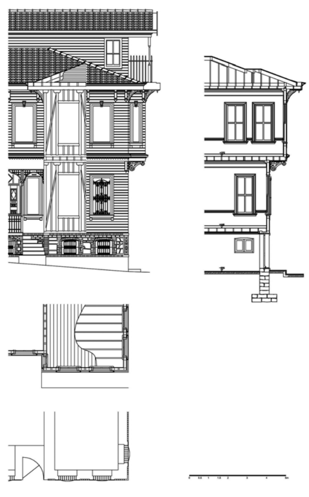

Figure 19 : 19th century traditional timber house system detail (Dışkaya)

5 EARTHQUAKE BEHAVIOURS OF TRADITIONAL TIMBER FRAMED HOUSES

The high performance of the remaining traditional houses of Anatolia built by using traditional building techniques could be observed during the severe earthquakes in past years. In the 1999 earthquakes in Kocaeli and Düzce, casualties and destruction in modern reinforced concrete buildings was extremely high when compared to the traditionally built houses (Gülhan, Güney, 2000). Despite being extremely old, traditional buildings survived the devastating effects of the earthquake. The minimal amount of damage to the infilled timber framed buildings close to the fault line, in the Düzce earthquake, can be seen clearly in Fig. 20, (Sezgin, 1999). On the other hand, in Fig. 21 the level of damage to a collapsed reinforced concrete building during the same earthquake is shown (Askun, 1999).The fact that these houses which were initially built to protect people against the forces of nature have become graves, is scientifically mind boggling.

Figure 20 : An infilled timber framed house with a little damage after 1999 Düzce earthquake (Archives: Sezgin, H.)

Figure 21 : A damaged reinforced concrete building after 1999 Düzce earthquake (Archives: Aşkun, İ. Y.)

6 CONCLUSIONS

The purpose of this paper is to study the development of construction techniques devised using the knowledge gathered for thousands of years against the destructive effects of earthquakes in Anatolia. Due to the change in the way of production and the invention of new construction materials after the Industrial Revolution, the type of settlements has also been changed. Because of these changing attitudes traditional building techniques were almost abandoned and the buildings constructed with the new technology and materials were not as durable against earthquake as the timber framed ones.

Traditional buildings are unique reflections of living styles and cultures of the past. Anatolia is a great important region in the history of civilization. The houses and the settlements have been survived up till now with the solutions developed to prevent the climatic and physical damages. Earthquake causes major destructions and casualties in houses constructed without this traditional knowledge. Therefore, life styles shaped with this point of view are very important in creating a collective behaviour geared at conservation. The aim of this study is to show that the sustainability of cultures is the solid bases of the future. To understand the cultural aspect of the structural development in Anatolia, can promote positive approaches in contemporary preservation principals and produce of new earthquake-safe building types for future generations.

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