STRUCTURAL BEHAVIOR OF TRADITIONAL TIMBER BUILDINGS AGAINST NATURAL DISASTERS FROM DIFFERENT REGIONS OF TURKEY

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ABSTRACT: Climate is a factor, which affects construction materials, construction technique, details, plan layout and even spatial requirements of a building in Turkey. This is true for especially traditional construction in the country. Experiences from past earthquakes show that consciously designed traditional timber structures exhibit good performance. The structural systems of the timber-framed buildings demonstrate different characteristics according to climate region. In this paper, structural behaviour of traditional timber-framed structures from different climatic regions of Turkey is examined by computer analysis. The aim of this study is to understand whether there is a difference in structural behaviour of different traditional structural systems in Turkey or not. As a result it can be said that use of different construction techniques and materials in different climatic regions is an important factor, which determines the structural behavior of buildings against natural disasters in these regions.
Keywords – Climate, earthquake, timber, Turkey, traditional construction.

1. INTRODUCTION

For centuries Turkey has been the scene of many natural disasters such as earthquakes, floods, mud slides, avalanches etc. Earthquakes are the most frequent and the most destructive among all disasters that strike this region. Turkey is located on the Mediterranean-Himalayan seismic belt, which is one of the most active earthquake prone areas on earth.

Understanding the behaviour of a structure during an earthquake is the first step required in the design of earthquake resistant structures. Experiences from past earthquakes show that consciously designed traditional timber structures exhibit good performance. This phenomena brings to mind certain questions regarding the characteristics of these buildings which ensure earthquake resistance. According to Tarabia (1994) this is due to a number of factors, particularly the high strength-to-weight ratio of timber as a material, due to its enhanced strength under short term loading and due to the ability to dissipate large amount of energy without collapsing. In addition to these characteristics of timber, i.e. its lightness and resistance to tensile stress, it can cover considerable spans.

Climate is a factor, which affects construction materials, construction techniques, details, plan layouts and even spatial requirements of traditional construction in Turkey. Traditional timber-framed structures are the products of cultural heritage of people who live in Anatolia. These structures have performed well in earthquakes throughout history. As a result, this study intends to investigate the effects of lateral forces on these structures with the help of computer-generated models. In this paper, structural performance of traditional Turkish timber-framed buildings is examined by computer analysis.

2. GENERAL CHARACTERISTICS OF TRADITIONAL TIMBER FRAMED STRUCTURES IN TURKEY

Traditional structures in Turkey are products of man's direct relations and experiences with the environment, hence they are skilfully responsive to the environmental forces; and they display respect for other people and their environment. General characteristics of these structures are: lack of engineering assistance; working with the site and microclimate; respect for other people and their houses and hence for the total environment, man-made as well as natural. They are not the products of certain fashion periods; they are flexible enough to stand alterations that are imposed by changes in the social forces; they exhibit, characteristics that require a relative continuity in the totality of the building process –tools, materials, structural systems, construction methods, etc. - as opposed to the discontinuity observed in the building process of societies with market economies (Tosun, 1983). Building materials and construction systems of such structures are described below.

Building Materials: Building materials used into traditional structures are mainly timber, adobe, stone, brick and building blocks. According to Sahinkaya (1973) building material used in these structures varies in accordance with location and climate of the area. Adobe is mostly used in plains while in mountainous and rainy regions timber houses are more common. The stone used in the foundation and ground floor walls is abundantly available in every region. Infill materials can be stone, adobe, brick or wood. While mud and lime are usually used as mortar and plaster, clay tiles are widely used for cladding timber roofs. In some regions only cut stone is used in while in others rubble stone with wooden lintels is more commonly used. Generally, in humid and windy coastal areas the exterior is cladded with timber siding while in others the buildings are finished with lime plaster. In forested areas the roof is cladded with wooden shingles while in most of the other regions convex clay roofing tiles are used. On the other hand, in dry areas where wood is scarce, flat earth roofs are often preferred (Gunay, 1998). Floors are mostly finished with compacted earth or wooden planks but this differs according to the climatic characteristics of the region and proximity to forests (Sahinkaya, 1973).

Construction Systems: Construction systems can be divided in three types, as masonry, skeleton and composite structures. Masonry structures are built with timber, stone, adobe, brick and blocks:

- Timber Masonry Buildings: Timber masonry buildings are constructed with logs of diameters 20-25 cm., laid side-by-side and one on the top of the other
- Stone Masonry Buildings: There are examples of stone masonry buildings constructed with field or hewn stone. Field stones are used without shaping and the walls are built with or without mud or mortar in between the joints. This type of structure is generally covered with a mud roof which is constructed with the help of wooden battens laid parallel to each other, on which straw mats are laid before covering with a layer of compressed earth approximately 50 cm. in thickness. This is further water proofed with a layer of clay. Hewn stone is pre-shaped, so that the geometry of the wall is smoother.
- Brick and Briquette etc. Masonry Buildings: In this type walls are made of brick, blocks, etc. and the mortar can be either sand, cement or lime.
- Adobe Masonry Buildings: Adobe is made locally by mixing earth or mud with hay. Although it is not as strong as clay brick, it is light, easy and cheap to produce. Heat insulation is excellent in such structures. It can be used in load bearing walls of single storied buildings and in filling timber frames. Mud mortar is used with it. It requires repair after heavy rains and earthquakes (Aytun, 1973).

Skeleton structures can be divided into two types: timber-framed and reinforced concrete. Use of reinforced concrete in traditional construction is very limited. Gunay (1998) declares that the timber-framed buildings can be grouped into two:

- *'Himis'* (read as himish) Buildings: The infill material in timber frame structures can be stone, brick and adobe (Figure 2.1). Timber is a very difficult material to hold plaster so the joints between timber and the masonry blocks can be weak. Connecting wires are nailed to the timber to hold the infill. *'Himis'* structures will be described in detail the following section.

- Bagdadi Buildings: The studs, posts and diagonal members are connected by nailing wood-lath siding. This is done at both inner and outer surfaces of the walls. The space between the sidings is sometimes filled with loose material such as earth or gravel for insulation, or left empty. The sidings are covered with plaster (Figure 2.2). In addition to insulation value the wood-lath siding retains the filling material. These types can be seen in the different regions of Turkey in accordance to the regions' environmental and geographical characteristics and economic conditions. Mixed structures are the structures consisting of at least two different systems. Most frequently used composite system in majority of the traditional houses in Turkey consists of ground floor built with stone masonry and upper floor of timber frame with stone, adobe or brick infill.

Figure 2.1. 'Himis' structure
Source: Sozen and Eruzun (1992:144)

Figure 2.2. Bagdadi structure
Source: Bektas (1996:55)

3. EFFECTS OF LATERAL FORCES ON TRADITIONAL TIMBER BUILDINGS: A CASE STUDY

Traditional construction techniques used in timber-framed buildings have shown good performance in past earthquakes. Therefore, these structures can be the key to many solutions for the houses that will be built in the future. In this study, *'Himis'* systems from different climatic regions in Turkey are investigated and a computer model is generated with their help.

In traditional timber structures, generally surface of the interior walls are plastered, whereas the exterior walls are sometimes unplastered. Roof and bearers are the main parts of the *'himis'* structures. Walls transfer the loads coming from the roof to the foundations. The main posts, studs, braces and beams are the primary structural elements of *'himis'* structures. Furthermore, the diagonal members of this system are of great importance in increasing the lateral strength of timber fill structures. The lack of these elements in the frame parallel to the direction of vibration causes inelastic deformations. Stone is used for the foundations that are usually continual stone bases with a 1.00 to 1.50 meter height. According to the characteristics of the region some variations are observed between structures in different areas such as infill material, types of wood used in the system, foundation types etc. According to the availability and existence of timber, construction methods used in traditional Turkish wooden houses change from region to region such as *'himis'* and bagdadi (Yarar, 1978). Moreover, there are various types of wall infill systems like *'muskali dolma'* (triangular), *'goz dolmasi'* (cubby-hole) that can be seen in Figure 3.1 and 3.2. The walls of *'himis'* systems were usually described in four different groups according to infill material that are brick fill, sun-dried brick fill, stone fill, twigs and mud fill**.**

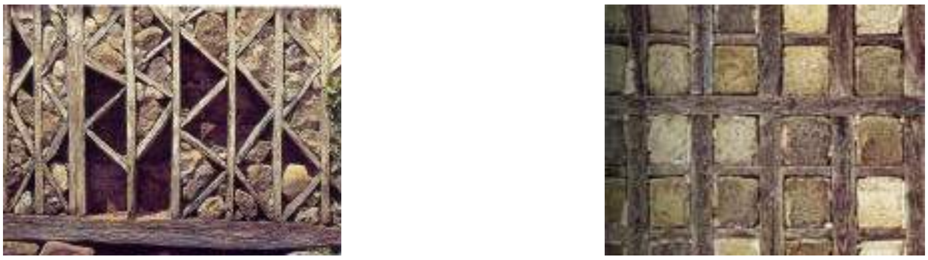

Figure 3.1. Wall infill systems in 'himis' structures
Source: Gunay (1998:71)

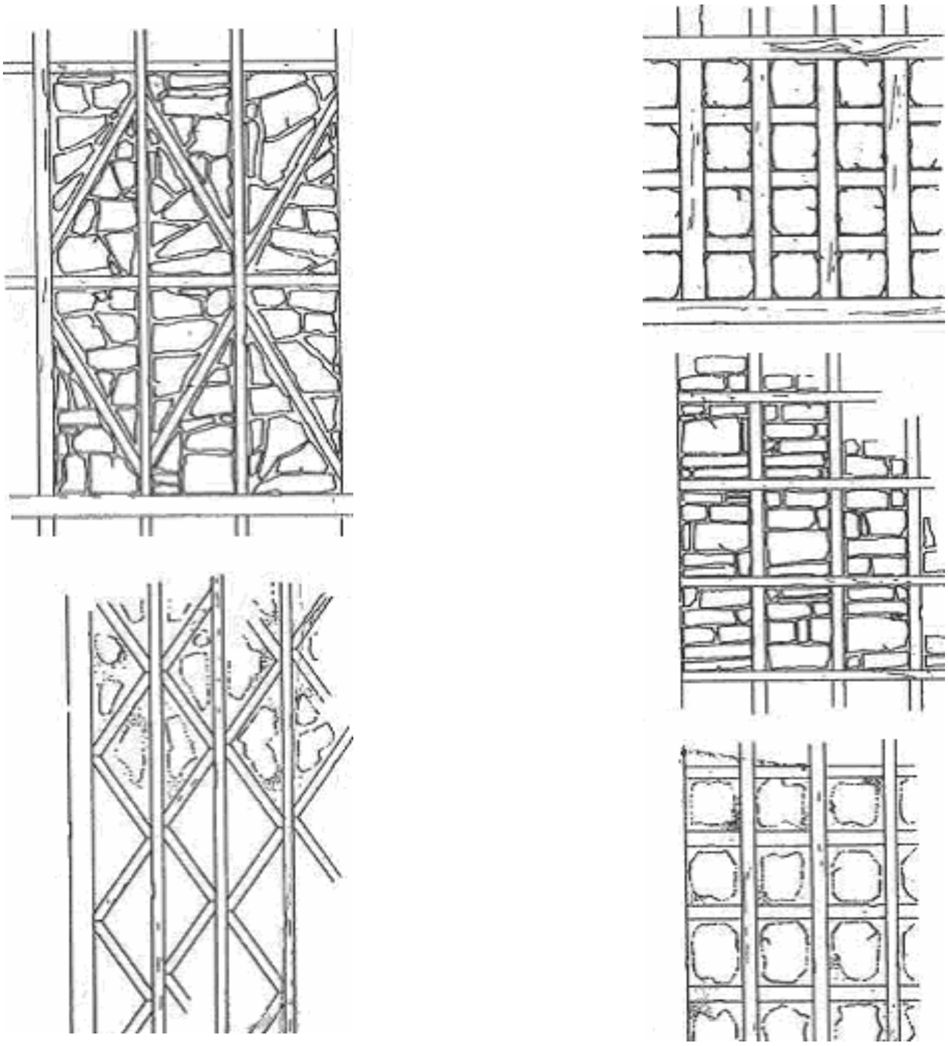

Figure 3.2. Wall infill systems in 'himis' structures
Source: Ozguner (1970:25)

For the case study *'himis'* systems of two regions, Central Anatolia and West Black Sea that have different climatic conditions are examined (Figure 3.3 and 3.4).

Figure 3.3. 'Himis' structure with sun-dried brick infill from Central Anatolia

Figure 3.4. 'Himis' structure with brick infill from Western Black Sea region

Timber-frames of these structures are similar, whereas infill materials differ. Therefore, finite element model of a general wall frame was generated. In this model, brick and sun-dried brick are used for infill. To perform the study in a comparative manner, the frame dimensions of these infill materials are assumed to be the same. The thickness of the wall was taken 400 mm for adobe infill and 200 mm for brick infill. The dimensions of elements representing the main posts and beams are 100/150 mm, and braces and studs are 100/100 mm. The wall of the structure is modelled with shell elements while frame elements are used to model posts, studs, beams etc. (Figure 3.5-3.7.). Firstly, structures were analysed under lateral loads and secondly they are analysed for 10 mm of support settlements. Using SAP2000 programme, the first model shown in the Figure 3.8-3.11 is analysed under lateral loads. According to results of this analysis 0.24 mm and 1.48 mm displacement are observed at point A in the models respectively (Figure 3.8 and 3.9). In addition, outputs show that the highest stresses are especially at points B, C and D in both two structures. Maximum stress value is 560 kN/m^2 in the first structure at point B, whereas this value is 177 kN/m^2 in the second one at point D. Values of these distributions can be seen in Figure 3.10 and 3.11 and Table 3.1. On the other hand in the support settlement analysis displacement at point A in *'himis'* structure with brick infill is 85.44 mm and it is 81.15 mm in *'himis'* structure with adobe infill. Furthermore, maximum stress is observed at point C as 4150 kN/m in the first one and 1343 kN/m in the second one (Figure 3.14 and 3.15 and Table 3.2). Results of the analyses show that *'himis'* structure with adobe infill has responded lateral forces better than *'himis'* structure with brick infill. The reason for this difference could be claimed as the increase in weight due to the brick infill of the himis structure.

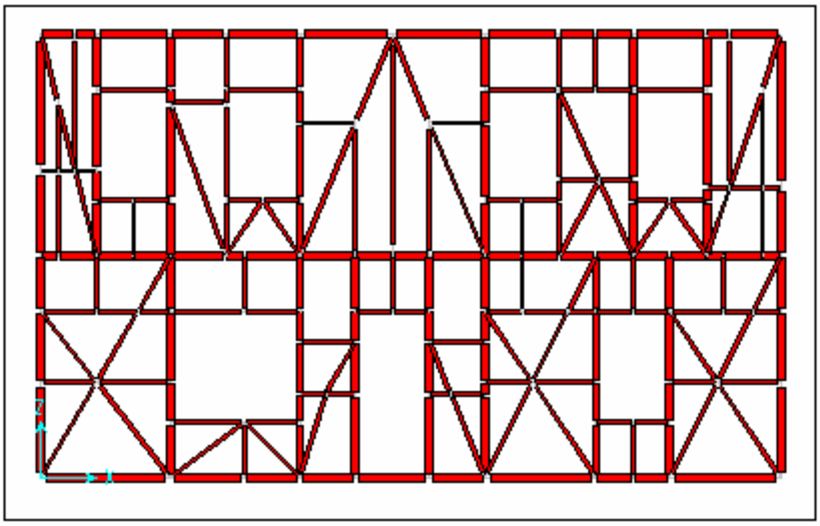

Figure 3.5. 'Himis' structure

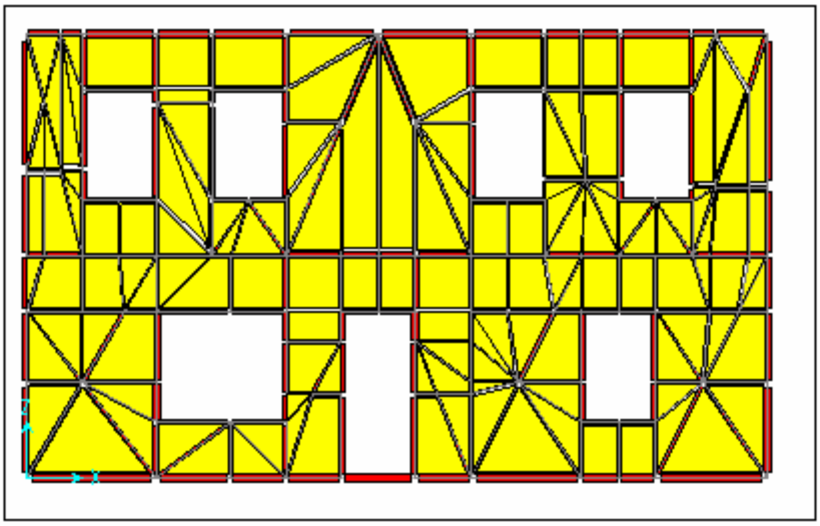

Figure 3.6. 'Himis' structure

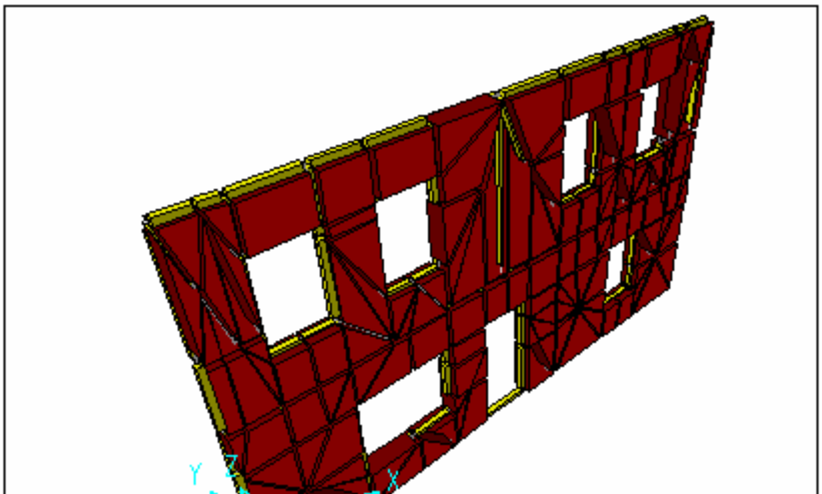

Figure 3.7. 'Himis' structure

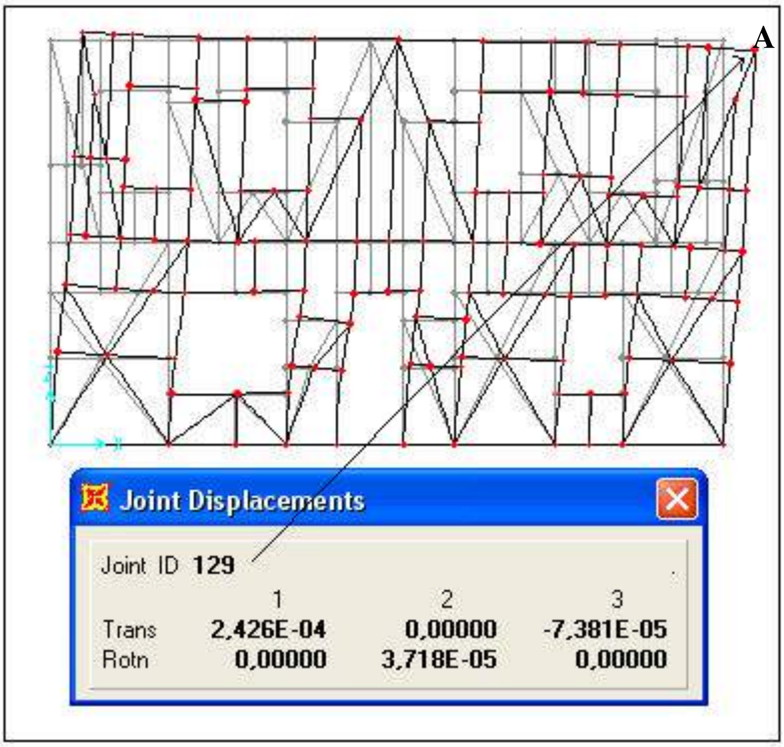

Figure 3.8. Displacements in 'himis' structure with brick infill under lateral loads

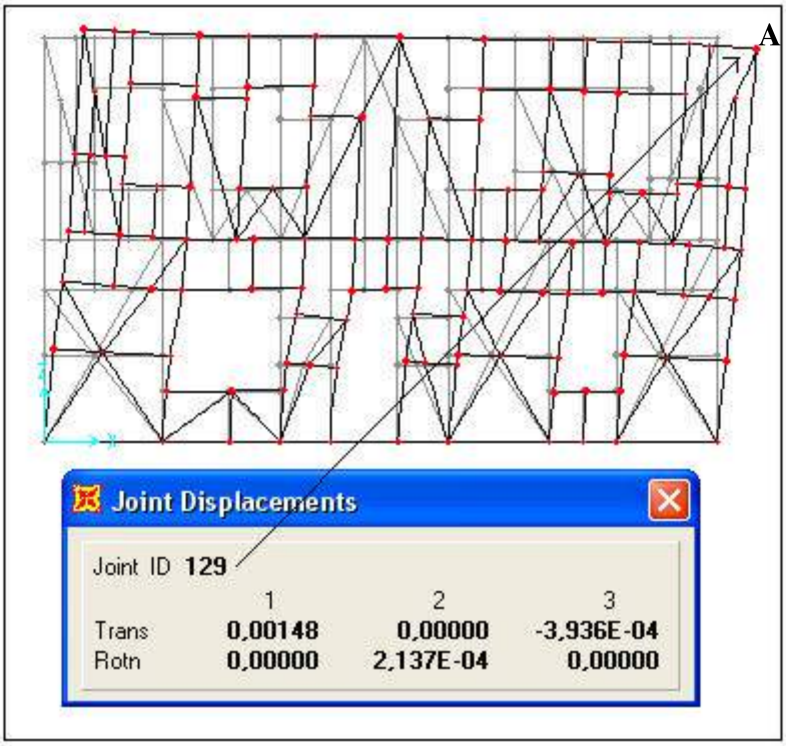

Figure 3.9. Displacements in 'himis' structure with adobe infill under lateral loads

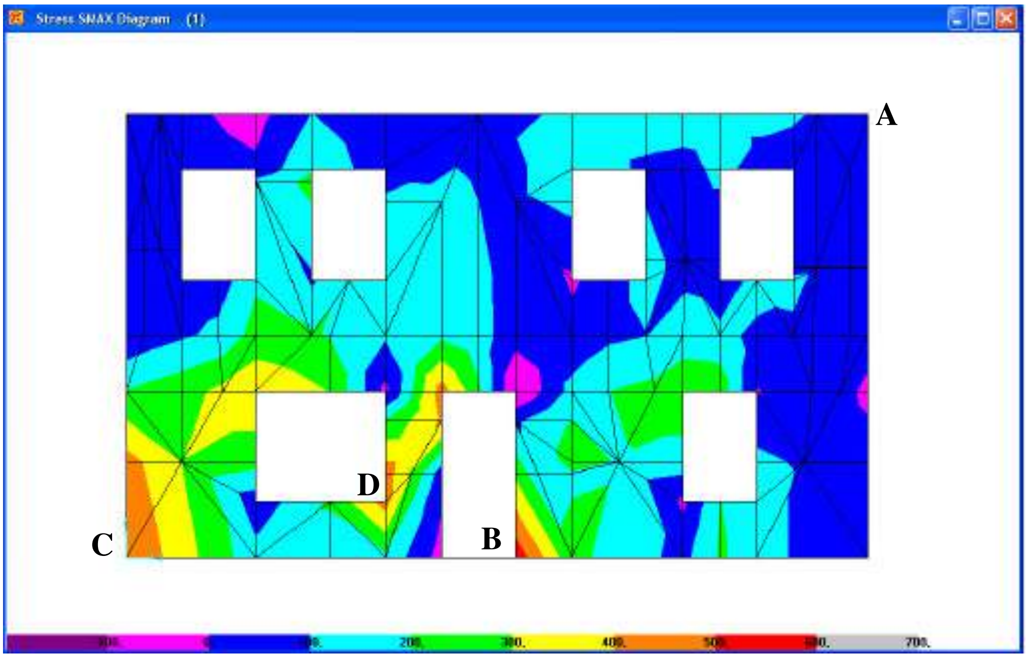

Figure 3.10. Stress distributions in 'himis' structure with brick infill under lateral loads

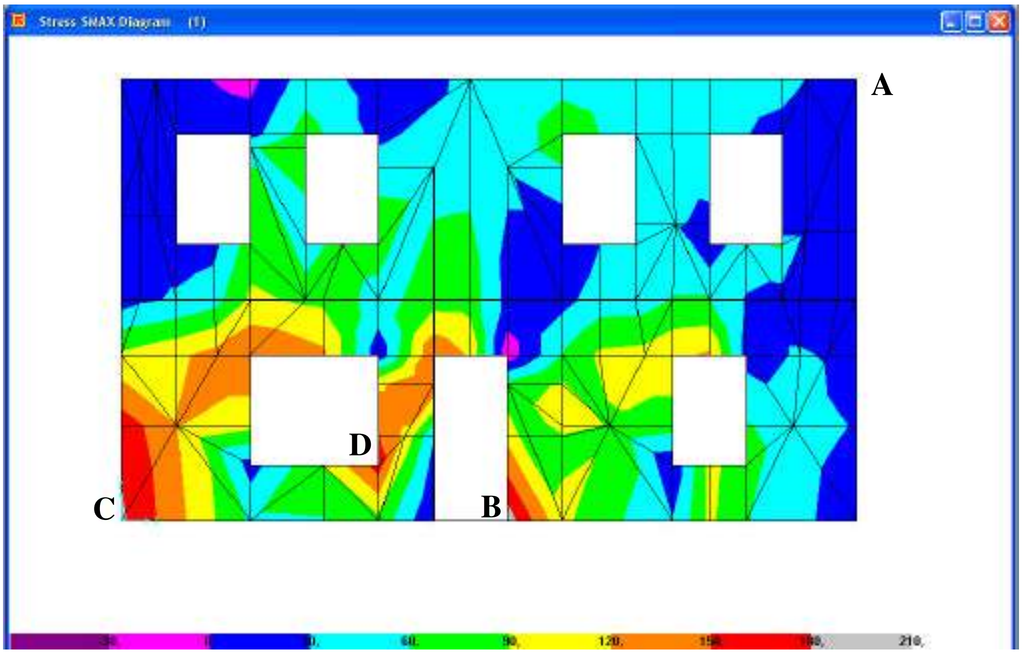

Figure 3.11. Stress distributions in 'himis' structure with adobe infill under lateral loads

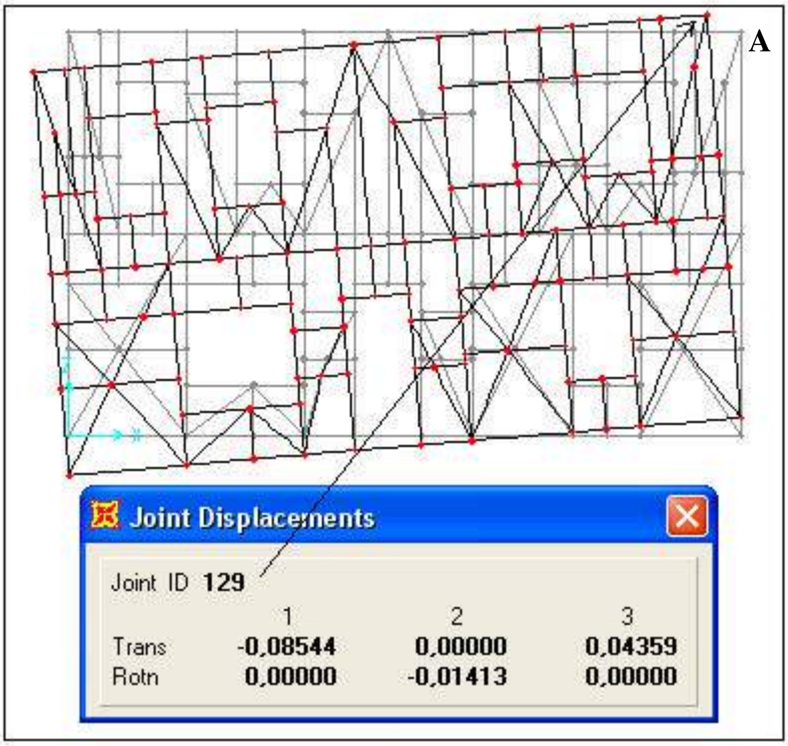

Figure 3.12. Displacements in 'himis' structure with brick infill in support settlement analysis

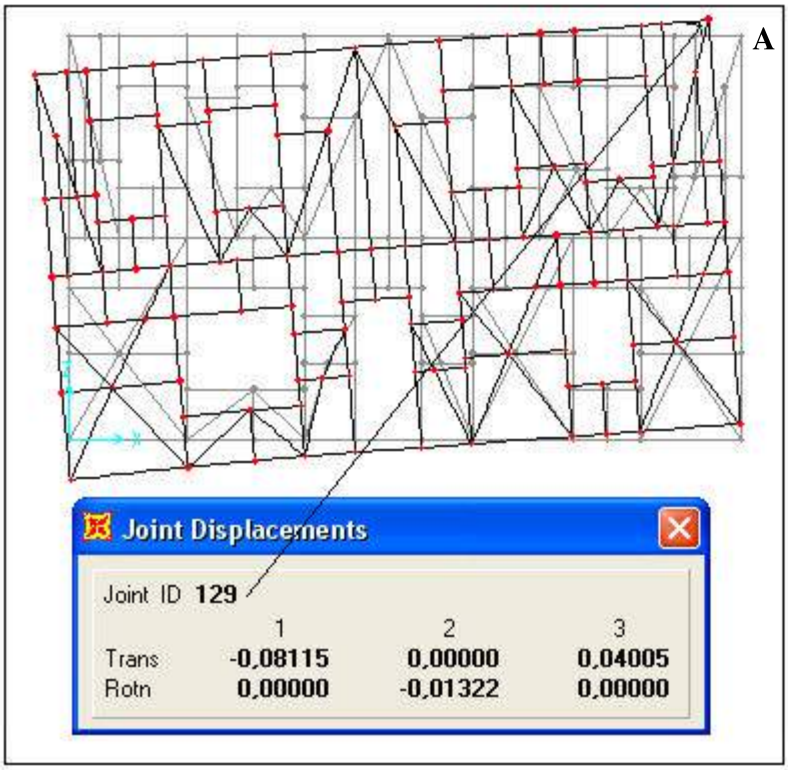

Figure 3.13. Displacements in 'himis' structure with adobe infill in support settlement analysis

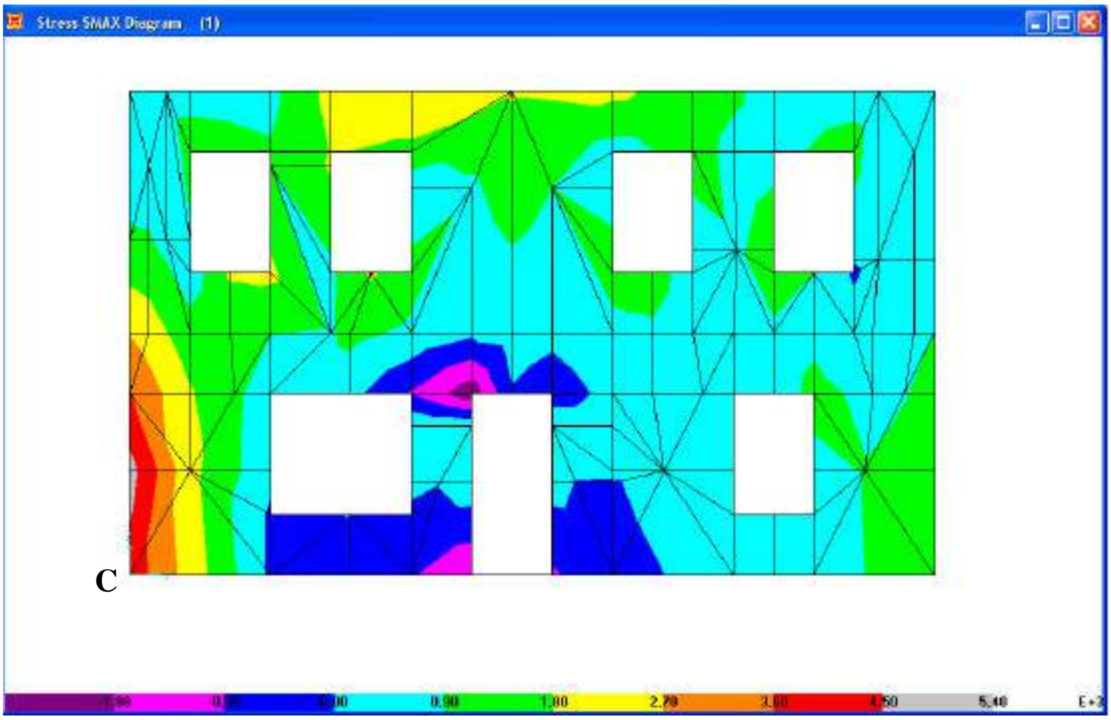

Figure 3.14. Stress distributions in 'himis' structure with brick infill in support settlement analysis

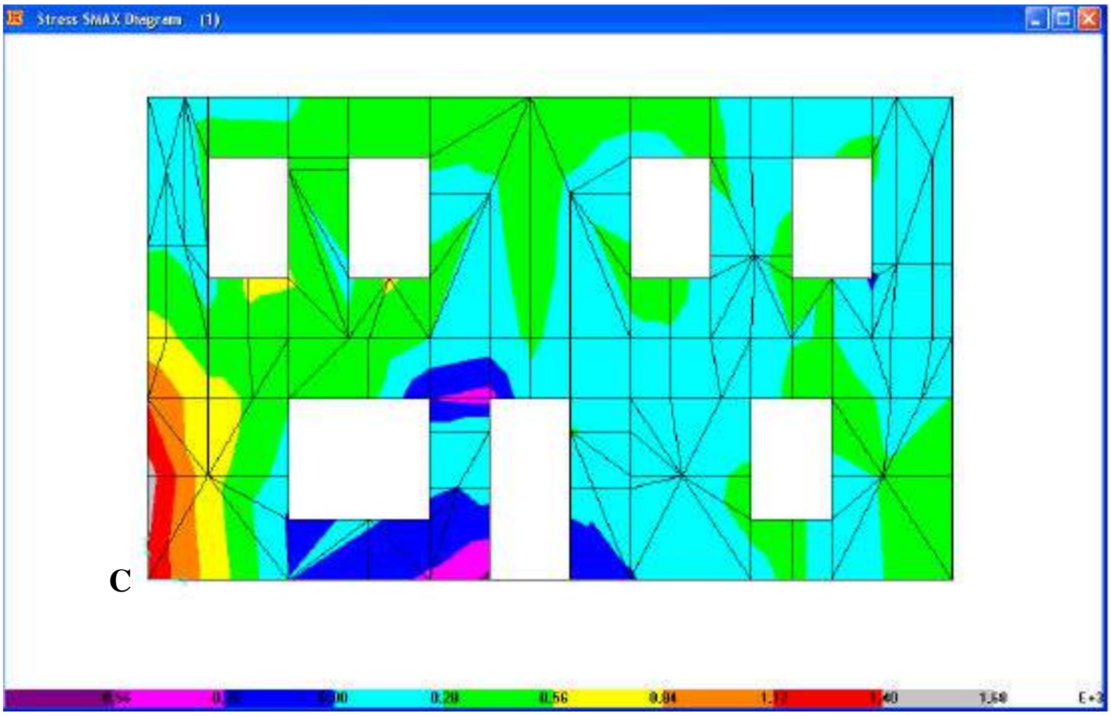

Figure 3.15. Stress distributions in 'himis' structure with adobe infill in support settlement analysis

Table 3.1. Results of lateral load analysis

Lateral Load Analysis	Maximum Displacement Δ Max (mm)	Maximum Stress Values δ Max (kN/m^2)
'Himis' Structure with Brick Infill	0.24	560
Himis Structure with Adobe Infill	1.48	177

Table 3.2. Results of support settlement analysis

Support Settlement Analysis	Maximum Displacement Δ max (mm)	Maximum Stress Values δ max (kN/m^2)
'Himis' Structure with Brick Infill	85,44	4150
'Himis' Structure with Adobe Infill	81,15	1343

4. CONCLUSIONS

Climate is an important factor that affects construction materials, construction technique, details, plan layout and even spatial requirements of buildings. In this paper, structural behaviour of traditional timber-framed structures from different climatic regions of Turkey is examined by means of computer analysis. As a result of this analysis, for *'himis'* structures with different infill materials, stress distribution and displacements vary greatly for lateral loads and support settlement analyse. It is observed that lateral displacement in *'himis'* structure with brick infill is lower than that of *'himis'* structure with adobe infill due to the 400 mm thickness of the adobe infill wall. In addition, stress distributions of these structures in support settlement analysis are quite different from each other. As a result it can be said that use of different construction techniques and materials in different climatic regions is an important factor, which determines the structural behavior of buildings against natural disasters in these regions.

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