Seismic Rehabilitation Study in Turkey for Existing Earthen Construction

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Abstract: *Earthen architecture shows diversity according to cultural and geographical environment. Earthen masonry building and hımış (hımısh) are the main types of earthen architecture in Turkey. A hımış building is a wood-framed structure filled with earthen blocks; an earthen building is a load-bearing, solid-masonry-wall structure. Earthen masonry buildings are fragile, whereas wooden-framed structures are safe in seismic regions. Even a 150-year-old building can remain without maintenance, showing durability and stability.*

In the last century, earthen construction was produced without technological support; many people suffered from insufficient building performance. However, hımış buildings constructed by unskilled local craftsmen and without inspection withstood the 1999 Adapazarı earthquake, and the people living in these houses survived.

The structural safety of earthen buildings depends on the design principles of the building and the properties of the material used. Since 1978 research at Istanbul Technical University (ITU) has focused on upgrading material durability by mixing gypsum with soil; research has simultaneously focused on improving seismic response of the structure.

This paper discusses a survey that has been carried out on design principles for earthen masonry and hımış buildings to investigate their seismic response. Corresponding chapters of the Turkish Earthquake Code are highlighted for further rehabilitation measures.

Introduction to Earthen Construction in Turkey

Wooden frame houses and earthen buildings in Turkey are part of a heritage stretching back thousands of years and covering a wide geographical and cultural diversity. Existing structures in Turkey are mainly of earthen masonry and are of the hımış type. Solid bearing-wall buildings of earthen materials are more fragile than these wood-framed structures. Most of Turkey (92%) is in a seismic region where the safety of buildings during earthquakes is essential.

When discussing earthen structures, it is necessary to mention that earthen buildings in Turkey are rarely constructed these days, but when they are, it is often without technical support, since the necessary knowledge is not in the higher education curriculum, and industrialized construction materials have saturated the market. Education and market trends focus mainly on reinforced concrete, for which steel rebar is the predominant reinforcing material.

This study is on existing structures of hımış and bearing-wall earthen buildings in Turkey, which have been subjected to severe earthquakes over the last hundred years. It will discuss the need for rehabilitation measures.

Wood-Frame Buildings in Turkey

Traditional wood-frame buildings in Turkey vary according to the structural system, veneer, infill of the structure, and basement (Isik 2000). Locally available

FIGURE 1 Detail of a hımış building with stone infill.

FIGURE 2 Detail of a hımış building with earthen block construction.

material such as stone, wood, and brick or earthen block can be used as infill (figs. 1 and 2).

Another well-known traditional wood-frame construction is called *Baghdadi*. In this method, a wooden framework is covered with plaster siding, and laths are nailed onto the studs to create a plastering surface (fig. 3). Baghdadi buildings can also be plastered from only the inside, with wood siding on the exterior of the wall. This kind of wall does not have infill. A comfortable indoor climate is created by the thick Baghdadi plaster.

The buildings are mainly of one to three stories (fig. 4). If the first floor is constructed out of stone, it is used for utility or domestic animals but not for living (fig. 5). Wooden houses may have a basement if there is a slope to the land so that the basement level can be constructed half above ground, allowing windows for lighting.

Design of Hımış (Wood-Frame) Building in Turkey

A Turkish wood-frame house is characteristically symmetrical in plan. Rooms (four in most cases) are situated around a central space, called the *sofa*. The sofa

FIGURE 3 Wall constructed using the Baghdadi method: wood frame with lath and plaster siding.

FIGURE 4 Hımış structure in Tarakli, Turkey.

FIGURE 5 Hımış structure in Ayas, Turkey. The ground floor is constructed of stone and used for utility or domestic animals rather than for human habitation.

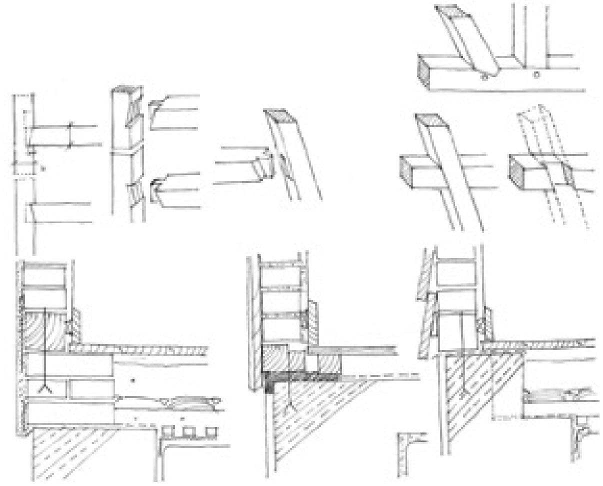

FIGURE 6 Joints in hımış framework.

is emphasized from the outside with a bay window or a balcony. The *sofa* can be an enclosed space or it can be open-air, depending upon the climate of the region. Each room is designed to be multifunctional, with utility spaces between two rooms. This enables living in the daytime and sleeping at night. Utility spaces are furnished with a small bathroom and with storage for the bed, linens, and wardrobe.

Structure of the Hımış Building

The wall of a hımış building consists of a load-bearing wooden skeleton or framework, infill material, and a veneer on both external surfaces. Historically, buildings have used varying dimensions of timber according to particular needs.

The design of the framework involves a header (head beam) and footer (foot beam), which carry vertical wooden posts at 1.5 m (59 in.) intervals (fig. 6). Between these load-bearing main posts and running every 60 cm (about 23 in.), there are intermediate vertical posts and intermediate horizontal beams for holding the infill and veneer. The cross section of the main post is about 12 × 12 cm (4.7 × 4.7 in.) to 15 × 15 cm (5.9 × 5.9 in.); the intermediate post ranges from 6 x 12 cm (2.3 × 4.7 in.) to 6 × 15 cm (2.3 × 5.9 in.). Diagonal braces connect the foot beam to the main post (fig. 7), creating a triangle for the wall's stability. These diagonal braces (fig. 8), which have the same cross-sectional dimension as the main post, carry the horizontal load. It is therefore important that a diagonal brace be one continuous piece of wood and not divided where it intersects intermediate posts or beams.

Floor framework carries the loads of the building from wall to wall. In this case each beam has a larger dimension than the posts. Beams are placed equidistant from one another at 40–60 cm (15.6–23.4 in.) intervals. Head beams on the wall studs carry all floor beams. The floor framework is rigid and acts as a horizontal diaphragm. In the last century, standardization has led to limited lumber dimensions for ease of production and delivery.

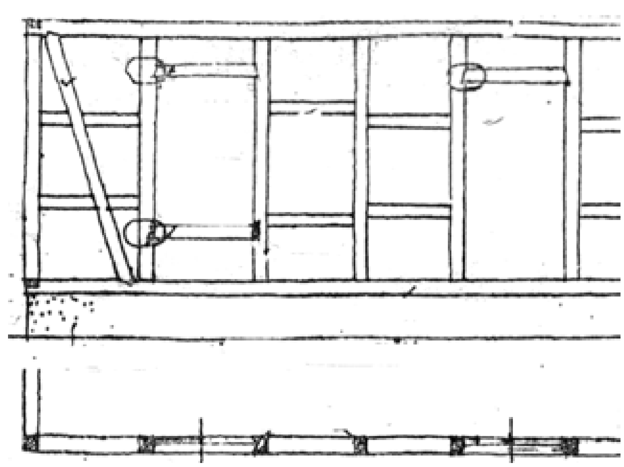

FIGURE 7 Hımış frame wall construction.

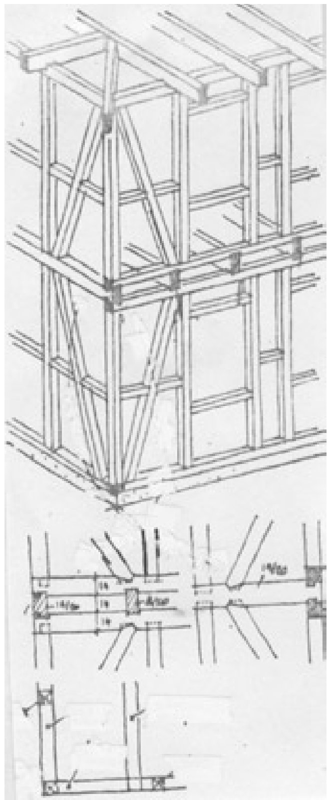

FIGURE 8 Two-story hımış structure with wooden framing.

FIGURE 9 Earthen bearing-wall system in Cyprus.

FIGURE 10 Earthen bearing-wall system in Güre, on the Aegean coast of Turkey.

The walls of the upper floors are situated on top of and are carried by the walls of the lower floor (fig. 7). Floors of the whole building, whether located on the ground or between the stories, function together as diaphragms. Along with the walls, they establish the stability of the whole building. Roofs are pitched and covered with ceramic tiles.

Earthen Bearing-Wall Buildings

Earthen bearing-wall buildings are constructed of unburned bricks. Mainly they have one or two stories. In some parts of the country, buildings do not have wooden structures, even though wood is available. Climate, workmanship, and safety are among the criteria determining whether buildings are wood framed or made with a solid earthen bearing-wall system (figs. 9 and 10).

Design of Earthen Bearing-Wall Buildings

Earthen bearing-wall buildings are smaller than hımış buildings. The number and dimensions of the rooms are smaller. Wooden beams for flooring and roofing are shorter. If the building is two-storied, there are generally two rooms on each level. Most earthen bearing-wall buildings do not have basements. They are constructed directly on the ground with stone foundations, and window openings are small.

Structure of Earthen Bearing-Wall Buildings

Door and window openings are structurally framed with wooden lintels. Floor or roof levels have wooden bond beams. A flat roof is often used on earthen bearing-wall buildings (fig. 11). Skilled labor is needed to construct

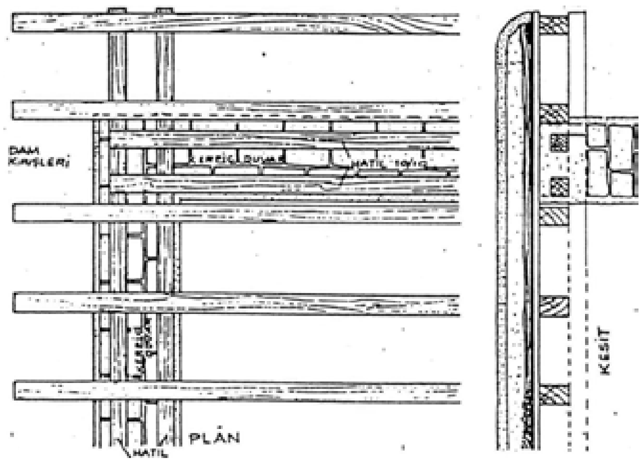

FIGURE 11 Wooden construction with a flat roof and tie beam.

the floors, which function as diaphragms, holding the structure together while allowing the horizontal forces to move loose and round joists. If a flat roof has a thick earth layer for heat insulation, loose elements of the structure move with more acceleration, resulting in fatal collapse. On the other hand, heavy loading on rigid diaphragm flooring contributes to the stability of the bearing-wall building.

Seismic Response of Earthen Buildings

Existing earthen buildings are heritage from the last century. Good examples in city centers have been demolished to make way for new structures of reinforced concrete. Existing buildings remain in small towns and at the edges of cities. Only a small number of earthen buildings are being conserved. There is a need for research and education on design and construction of earthen buildings.

Seismic Response of Traditional and New Wood-Frame Building

Wood as a structural material is easy to carry and handle during construction, and it offers advantages in earthquake performance. It is lightweight; thus, earthquake acceleration generates less energy than with other structural materials. The material and structures are flexible and are consequently able to absorb and dissipate seismic energy.

New design principles for wood-frame buildings depend on industrialized wooden products. Posts are available in standardized lumber sizes and are smaller; therefore, they can be spaced more closely. If necessary, larger dimensions of posts or beams can be obtained by multiple connections. Shear walls are designed using panel products such as plywood or oriented strand board, instead of diagonal braces between vertical posts. This kind of design is also called platform framing. Floor framing is anchored to the foundation with bolts. Shear walls underpin the roof.

Traditional wood-frame construction in Turkey uses lumber of specific dimensions. The size of the main post varies according to the loads and function. Braces carry the lateral forces from header to footer and are of the same size as the main post. There is no reason, except visual image, for holding onto this traditional method. It would be logical to use standardized lumber for new buildings.

There are remarkable differences in the foundations of these two building systems. As opposed to the more modern platform framing technique, traditional wood-frame buildings have foundations of natural round stones with a soil mortar, and the rigid building structure sits loosely on this foundation (fig. 12).

According to the Turkish Earthquake Code, the design of traditional wall framing has been

FIGURE 12 Traditional wood-frame building with stone foundation.

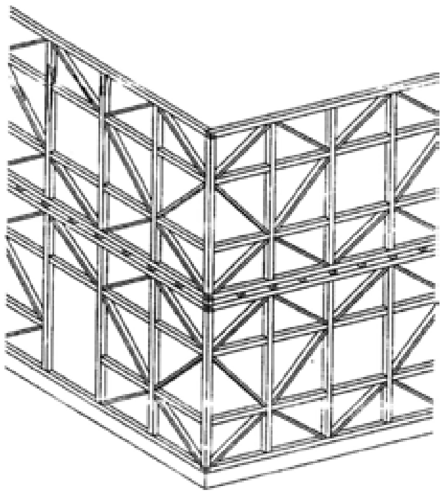

FIGURE 13 Diagonal bracing, as illustrated in the Turkish Earthquake Code.

revised in the following ways (T.C. Bayindirlik ve Iskan Bakanligi 1996):

1. posts with maximum 1.5 m (59 in.) spacing
2. base beams to be placed under the posts
3. head beams to be placed above the posts
4. horizontal intermediate beams connecting posts along the wall together with base and head beams, to form rectangular areas in the wall
5. diagonal braces converting rectangular areas into triangular areas (fig. 13)

These measures seem to be unnecessary, and they generate design problems for wall openings such as windows and doors. Traditional buildings throughout history have shown a secure response to earthquake forces, although they are simple in design. Traditional existing hımış buildings seem to have sufficient protection against earthquakes.

Lack of durability and maintenance can be mentioned as seismic vulnerabilities. Exposing hımış buildings to external conditions can cause plaster to spall, earthen infill blocks to deteriorate, and wooden parts to decay (fig. 2). Maintenance is therefore essential and can sustain the designed earthquake response properties of the hımış building type.

Seismic Response of Earthen Bearing-Wall Buildings

Structural reliability is gained through material and design properties. Unlike wood used for frame structures, earthen material is low in strength and has markedly lower tensile strength than other structural materials.

Research into Earthen Construction Systems at Istanbul Technical University

Global research on earthen material has focused mainly on improving its strength. In the last century, earth was mainly stabilized with cement. This practice conflicts with an ecological environment and healthy living. Cement is an energy consuming material, and the physical characteristics of the earth and cement composite are similar to those of concrete—far from the properties of natural earthen materials.

On the other hand, natural earthen materials produced by skilled craftsmen have the required compressive strength, unless exposed to moisture. In order to address adobe's vulnerability to moisture, further research into the effects of added materials other than cement on water-resistant stabilization is needed.

Basic Materials Research

To reduce the water vulnerability of earthen building material, the Architectural Faculty of Istanbul Technical University instituted Project MAG 505 (Kafesçioðlu et. al 1980), sponsored by TÜBİTAK (Scientific and Technology Research Council of Turkey). This was the first study in which earth was mixed with gypsum in different percentages. The mixture hardens in a few minutes and becomes load bearing, while traditional adobe must be stored and dried in the sun for several days before it is taken into the next construction stage. Also, the shrinkage decreases to 1% of the length, and appearance becomes smoother. Compressive strength of the dried (for 15 days) gypsum-stabilized earthen material is 2–4 N/mm^2 (290.1–580.2 psi). Flexural strength of this material is 1.1 N/mm^2 (159.5 psi), which is higher than that of bricks made of earth alone. The most remarkable result is that the new composite is more water resistant, due to chemical reaction between gypsum and clay. Deterioration due to rain is not notable.

Earthquake Rehabilitation Measures on Bearing-Wall Buildings

Better water resistance will increase the material's strength in case of water penetration and humid conditions, but earthen material is still of low strength when compared with the other types of structural materials that engineers are accustomed to working with. Consequently, constructing with low-strength material is confusing, and a lack of clear understanding can lead to failure.

Obviously this peculiarity of earthen material must be considered in building design. The theory of energy dissipation as a seismic measure in civil engineering can be adapted to earthen bearing-wall structures. This means that the structural design will not depend solely on the degree to which earthen bearing walls resist the severe lateral forces of an earthquake; in addition, the design will introduce some energy absorbing and dissipating features. Figure 14 shows a low-strength structure in Bam, Iran, destroyed by the 2003 earthquake. The building, which was compressed between the resisting cross wall and vertical seismic force, collapsed.

Studies at Istanbul Technical University showed that this energy-dissipating feature is ripe for further design and applications. A rammed earth wall sample was produced with horizontal joints. Biaxial loading, representing gravity and lateral earthquake forces, was applied. The wall sample cracked horizontally at the joints created by the geomesh layer, while the wall parts between the joints were undamaged (fig. 15). Geomesh was applied horizontally, in 17 cm (6.6 in.) intervals during the ramming process, and it is expected to take the tensile forces in the wall during an earthquake. Tests showed that the mesh layer performed as a friction surface.

Conclusion

Earthen material has been used up until the last century in bearing-wall systems and as infill within a wooden framework in the hımış construction system. In the seismic arena, wood-framework response is ductile under lateral forces, whereas bearing earthen walls are more rigid. Although earthen material is energy dissipating to some extent, earthen walls cannot resist lateral forces of earthquakes.

Existing measures for improving lateral resistance of bearing-wall systems include cross walls constructed perpendicular to the forces to impede movement of the building. The problem with this attempted solution is that the cross walls can remain without deformation, while the earthen building body itself can be destroyed by the action of earthquake forces and the reaction of the cross walls.

Studies at Istanbul Technical University showed that it is logical to design the bearing-wall systems to

FIGURE 14 Building collapse due to earthquake, Bam, Iran, 2003. Photo: © Randolph Langenbach, 2004.

FIGURE 15 Horizontal joints in an earthen wall sample and their response to lateral forces.

be energy dissipating. Working joints can function as energy absorbers and dissipate lateral forces.

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