ADOBE CONSTRUCTION

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BACKGROUND

Adobe mud blocks are one of the oldest and most widely used building materials. Use of these sun-dried blocks dates back to 8000 B.C. (Houben and Guillard 1994, referenced in EERI adobe tutorial). The use of adobe is very common in some of the world's most hazard-prone regions, such as Latin America, Africa, the Indian subcontinent and other parts of Asia, the Middle East, and southern Europe. Around 30% of the world's population live in earth-made construction (Houben and Guillard 1994). Approximately 50% of the population in developing countries, including the majority of the rural population and at least 20% of the urban and suburban population, live in earthen dwellings (Houben and Guillard 1994). By and large, mainly low-income rural populations use this type of construction.

BUILDING IN ADOBE

Adobe is a low-cost, readily available construction material, usually manufactured by local communities. Typical cost of a new adobe house in Peru is about US$20/m^2 (WHE Report 52, Peru) and US$11/m^2 in India (WHE Report 23, India). Adobe structures are generally self-made because the construction practice is simple and does not require additional energy resources. Often the blocks are made from local soil in a homeowner's yard or nearby. Mud mortar is typically used between the blocks. Skilled technicians (engineers and architects) are generally not involved in this type of construction; hence the term, "nonengineered construction," is used to describe the result.

Worldwide use of adobe is mainly in rural areas, where houses are typically one story, 3 m high, with wall thicknesses ranging from 0.25 m to 0.80 m. In mountainous regions with steep hillsides, such as the Andes, houses can be up to three stories high. In parts of the Middle East, one finds that the roof of one house is used as the floor of the house above. Urban adobe houses are found in most developing countries. However, they are not permitted by building codes in countries like Argentina, or in specific cities like San Salvador due to their poor seismic behavior.

Figure 1: Typical adobe house
(WHE Report 52, Peru)

Figure 2: Typical adobe house
(WHE Report 89, Argentina)

In Latin America, adobe is mainly used by low-income families, whereas in the Middle East (e.g., Iran), it is used both by wealthy families in luxurious residences as well as by poor families in modest houses.

Architectural characteristics are similar in most countries: the rectangular plan, single door, and small lateral windows are predominant. Quality of construction in urban areas is generally superior to that in rural areas. The foundation, if present, is made of medium-to-large stones joined with mud or coarse mortar. Walls are made with adobe blocks joined with mud mortar. Sometimes straw or wheat husk (WHE Report 23, India) is added to the soil used to make the blocks and mortar. The size of adobe blocks varies from region to region. In traditional constructions, wall thickness depends on the weather conditions of the region. Thus, in coastal areas with a mild climate, walls are thinner than in the cold highlands or in the hottest deserts. The roof is made of wood joists (usually from locally available tree trunks) resting directly on the walls or supported inside indentations on top of the walls. Roof covering may be corrugated zinc sheets or clay tiles, depending on the economic situation of the owner and the cultural inclinations of the region.
A traditional adobe house that exhibits good seismic behavior is the *bhonga* type,

Figure 3: Typical adobe house in the coastal area

Figure 4: Typical adobe house in the highland area

typical of the Gujarat state in India. It consists of a single cylindrically shaped room with conical roof supported by cylindrical walls. It also has reinforcing bonds at the lintel and collar level, made of bamboo or reinforced concrete.

Figure 5: Typical adobe *bhonga* in India
(WHE Report 72)

EARTHQUAKE PERFORMANCE

In addition to its low cost and simple construction technology, adobe construction has other advantages, such as excellent thermal and acoustic properties. However, most traditional adobe construction responds very poorly to earthquake ground shaking, suffering serious structural damage or collapse and causing a significant loss of life and property. In the 2001 earthquakes in El Salvador, 1,100 people died, more than 150,000 adobe buildings were severely damaged or collapsed, and over 1,600,000 people were affected (Dowling 2004a). That same year, an earthquake in the south of Peru caused the deaths of 81 people, the destruction of almost 25,000 adobe houses, and damage to another 36,000 houses (EERI adobe tutorial). In the latest 2003 Bam earthquake, more than 26,000 people died and over 60,000 were left without shelter, primarily due to the collapse of adobe houses (EERI 2004).

Adobe buildings are not safe in seismic areas because their walls are heavy and they have low strength and brittle behavior. During strong earthquakes, due to their large mass, these structures develop high levels of seismic forces, which they are unable to resist, and therefore they fail abruptly. Typical modes of failure during earthquakes are severe cracking and disintegration of walls, separation of walls at the corners, and separation of roofs from the walls, which can lead to collapse. Seismic deficiencies characteristic of adobe construction are summarized in the table below.

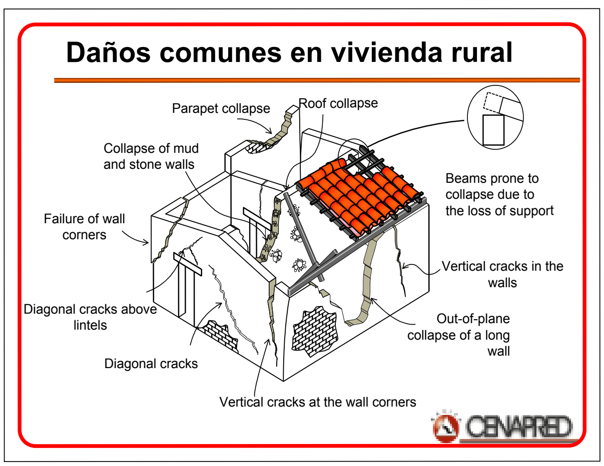

Figure 6: Typical modes of failure in adobe structures (CENAPRED)

Typical patterns of damage have been identified in several reports in the World Housing Encyclopedia (see India [WHE Report 23], Peru [WHE Report 52], El Salvador [WHE Report 14] and Iran [WHE Report 104]).

IMPROVED SEISMIC RESISTANCE OF NEW CONSTRUCTION

Due to its low cost, adobe construction will continue to be used in high-risk seismic areas of the world. Development of cost-effective building technologies leading to improved seismic performance of adobe construction is of utmost importance to a substantial percentage of the global population living in adobe buildings.

The key factors for improved seismic behavior are as follows:

1. Seismic reinforcement

The most important factor for the improved seismic performance of adobe construction is to provide reinforcement for the walls. Earthquake shaking will cause adobe walls to crack at the corners and to break up in large blocks. The role of the reinforcement therefore is to keep these large pieces of adobe wall together. A ring beam (also known as a crown, collar, bond, or tie-beam, or seismic band) that ties the walls in a box-like structure is one of the most essential components of earthquake resistance for load-bearing masonry construction. The ring beam must be strong, continuous, and well tied to the walls, and it must receive and support the roof. The ring beam can be made of concrete or timber.

Figure 7: Crown beam made of eucalyptus trunks (Blondet et al. 2002, referenced in EERI adobe tutorial)

Figure 8: Tying adobe reinforcement (Blondet et al. 2002, referenced in EERI adobe tutorial)

Additional wall reinforcement should also be provided. This reinforcement can be made of any strong, ductile material, such as bamboo, cane, reeds, vines, rope, timber, chicken wire, barbed wire, or steel bars. Vertical reinforcement helps to tie the wall to the foundation and to the ring beam and restrains out-of-plane bending and in-plane shear. Horizontal reinforcement helps to transmit the out-of-plane forces in transverse walls to the supporting shear walls, as well as to restrain the shear stresses between adjoining walls and to minimize vertical crack propagation. The horizontal and vertical reinforcement should be tied together and to the other structural elements to provide a stable matrix that will maintain the integrity of the walls after they have broken into large pieces.

Use of buttresses and pilasters in the critical parts of a structure increases stability and stress resistance. Buttresses act as counter supports that may prevent inward or outward overturning of the wall. Buttresses and pilasters may also enhance the interlocking of the corner bricks.

Some building codes have incorporated these recommendations for the construction of new adobe houses, such as the Adobe Construction Regulations of the province of San Juan, Argentina, that have incorporated the use of the ring beam, and the Peruvian Adobe Code that incorporated a ring beam together with vertical and horizontal reinforcement.

2. Other considerations

The walls are the main earthquake-resisting elements of adobe houses; therefore they need to be abundant and very stable. They should be tied together to ensure mutual support and should have some reinforcement to keep them together after they have broken due to the seismic forces. The following recommendations are useful to achieve an earthquake-resistant adobe house:

- Build only one-story houses
- Use an insulated lightweight roof instead of a heavy roof (clay tiles or compacted earth)
- Keep the openings in the walls small and well spaced
- Build on firm soil and provide a concrete or stone foundation

The soil used to fabricate the adobe blocks and the mud mortar must contain clay, since it provides strength to the dry materials. Unfortunately, clay shrinks during drying; therefore an excessive amount of clay will cause cracking of the blocks and mortar due to shrinkage, and loss of strength in the adobe masonry. Straw, wheat husk, and to a lesser extent, coarse sand can be used as additives to control this cracking and thus to improve the strength of adobe masonry. The quality of workmanship also plays an important role in obtaining strong adobe masonry. Good workmanship can improve the strength of adobe masonry by up to 100% (WHE adobe tutorial).

SEISMIC STRENGTHENING OF EXISTING ADOBE BUILDINGS

Dynamic tests conducted by researchers in Peru have demonstrated that a good solution for existing adobe houses is an external reinforcement consisting of wide strips of wire mesh (1 mm wires spaced at ¾ inches) nailed with metallic bottle caps against the adobe as shown in the figure below (Zegarra et al. 1997, referenced in WHE adobe tutorial). The mesh is placed in horizontal and vertical strips simulating beams and columns and is covered with cement and sand mortar. Several houses reinforced with this technique did not suffer any damage during the 2001 earthquake in the south of Peru, even though similar unreinforced houses in the vicinity collapsed or suffered significant damage.

Figure 9: Nailing the wire mesh (Zegarra et al. 1997, referenced in the EERI adobe tutorial)

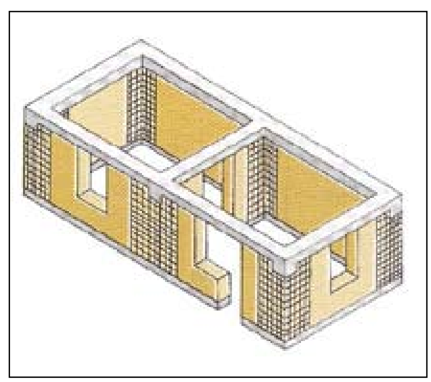

Figure 10: Layout of the wire mesh reinforcement (Zegarra et al. 1997, referenced in the EERI adobe tutorial)

Historic adobe buildings, regardless of their important architectural or cultural value, are also prone to suffer damage during strong earthquakes. Thus, it is important to provide adequate upgrading to these buildings to ensure life-safety protection and at the same time to preserve their authenticity. The Getty Conservation Institute recently carried out a project to develop technical procedures to prevent the structural instability of historic adobe buildings during earthquakes, with minimal intervention to their original fabric (Tolles et al. 2002). Nine small-scale (1:5) and two large-scale (1:2) model buildings were subjected to shaking table tests to compare different reinforcement systems. An effective retrofit system was developed, consisting of straps made of woven nylon placed horizontally or vertically, forming loops around the entire building or around individual walls. Nylon cross-ties were added to hold these straps. Vertical steel rods drilled directly into the adobe walls were effective in delaying and limiting both the in-plane and out-of-plane wall damage. Wood bond-beams or partial wood diaphragms were placed to achieve integral participation of the walls.

ENDNOTES

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