RETROFITTING ADOBE HOMES

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v.1

1. Preface

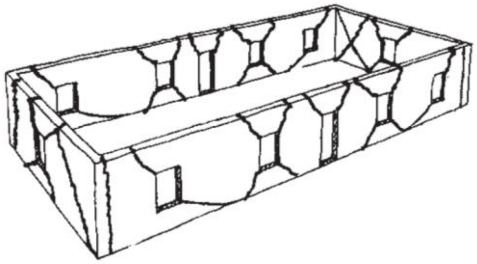
1.1. About this Guide

This guide serves as a research project on how best to retrofit earth built adobe homes: it culminates my research on the subject matter. In this guide I first provide an overview of the process of traditional adobe home building and how adobe homes hold up in earthquakes. Next, I cover the principles of retrofit design for earth built adobe homes. Thirdly, I list the most effective, minimally invasive, retrofit solutions. And lastly, I suggest some researched pro-poor, alternative retrofit solutions that utilize the principles of retrofit design for adobe homes.

2. Section 2: Adobe Home Building and Earthquakes

Earth structures made of adobe are traditionally built using unfired bricks made of earth, bound together using mud mortar (though in different regions there can be process variations). These bricks are formed by manually loading moist soil into a small to large brick formwork. “The soil used for the bricks typically has a clay content that ranges from 10% to 30%, and organic material such as straw or manure is usually added before the bricks are formed.” (Planning and Engineering 39). This guide will evaluate three types of adobe buildings based on their wall height to thickness ratio (Slenderness): thick- S_L<6, moderate- S_L=6-8, and thin- S_L>8.

Adobe is a brittle building material; once cracks start to form in adobe structures, the walls, though losing tensile strength, still hold vertical loads. Because of this characteristic, “The seismic behavior of adobe buildings—as well as those made of stone and other types of unreinforced masonry—is commonly characterized by sudden and dramatic failure. A high likelihood of serious injuries and loss of life usually accompanies the local or general collapse of such structures.” (Seismic Stabilization: Final Report 1). Again, this is because adobe is not as ductile as other, more modern, building materials such as, steel and wood, which continue to have elastic tendencies after an initial failure.



(Planning and Engineering 78)

Cracked walls are common in most pre-established adobe structures resulting, most often, from flexure and shear forces at corners of openings, doors and windows. Flexure forces are out-of-plane forces, or forces perpendicular to the wall, and shear forces are in-plane forces or forces parallel to the adobe structure. These forces also cause stress in areas where two walls intersect or at the base of walls (Planning and Engineering 50).

3. Section 3: Principles of Retrofitting

Whenever formulating retrofit solutions, one should look at the area in which the retrofit will be implemented. Consider locally available or cheap resources if the retrofit is intended for a developing area. One should also consider the skill the retrofit requires, as in some areas local craftsmen may be the only builders.

“In the design of a retrofit system, providing continuity throughout the structure is the most important aspect of the design, and in general the performance of the overall system is secondarily affected by wall thickness” (Planning and Engineering 71). When continuity of a structure comes to be an issue it means there are certain areas where there is an imbalance of strength. Areas of high and low strength near one another on a wall, contribute to a wall’s weakness because those certain strong spots can hold vertical loads, but eventually the weak spots fail and give way to the strong spots, making the wall as a whole fail. The continuity can be affected/improved in several ways. These include

- upper wall horizontal elements,
- vertical wall elements, and
- lower wall horizontal elements

Relating the thickness aspect to adobe houses means that retrofit solutions for thick walled adobe buildings should be less drastic than retrofit solutions for thin to medium walled adobe structures. The reason for this, in short, is because thick walled adobe structures have more ductile and elastic tendencies than their thinner counterparts, making them less vulnerable to shear and flexure stresses.

4. Section 4: Retrofitting Adobe Homes

Again, the three elements that contribute to a structure’s continuity are upper wall horizontal elements, vertical elements, and lower wall horizontal elements. The most important of these three elements is the upper wall horizontal elements, followed by vertical and lower wall horizontal elements, which are more important for medium to thin walled structures than for thick walled structures. With the vertical elements it is important that they are placed at regular intervals in walls to establish that concept of continuity in the wall’s strength.

4.1. Upper Wall Horizontal Elements

Upper wall horizontal elements are the most important retrofit elements for an adobe built structure because they help prevent walls from overturning (collapse) - the most common type of wall failure for adobe structures. These elements:

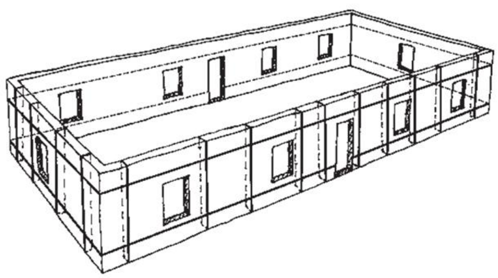
- provide anchorage to the roof or floor
- provide out-of-plane strength and stiffness
- establish in-plane continuity

(Planning and Engineering 75)

The in-plane continuity aspect prevents cracks at the upper wall section from moving apart.

The most economically viable upper wall elements is a partial plywood diaphragm, which should, “consist merely of a 4-foot width of plywood nailed along the tops of the joists” (Planning and Engineering 76)

4.2. Vertical Wall Elements



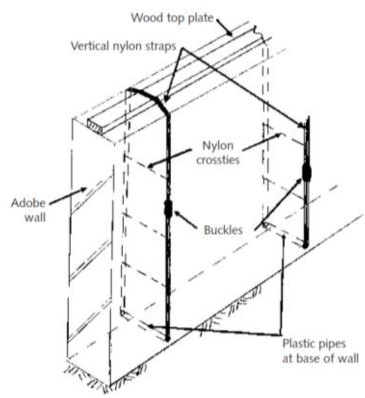
(Planning and Engineering 76)

Vertical wall elements, most necessary for thin walled structures, significantly improve the out-of-plane stability and ductility of a structure. They come in the form of nylon/steel straps or center core rods.

The figure shows all three retrofit elements, upper wall horizontal, vertical, and lower wall horizontal elements.

4.2.1. Vertical Straps

Vertical straps, most commonly made of nylon or steel, should be applied to both sides of the wall. This retrofit option is most effective on moderate and thin walls.



(Planning and Engineering 77)

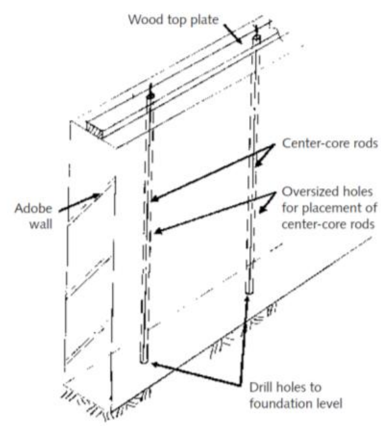
4.2.2. Vertical Center Core Rods

Vertical center core rods are helpful in limiting both shear and flexure forces. Thus they are effective in every wall type: in the moderate and thin walls they are effective in preventing shear and flexure forces, and in thick walls they are solely useful for preventing shear forces.

In using center core rods, it is important that they have a hold in the wall. For this reason it is recommended that center core rods are grouted (with epoxy or similar mortar) into oversized holes so there is positive attachment between the rods and the wall. “Grouted center-core rods bond well to adobe because the grout material is absorbed irregularly into the adobe.” (Planning and Engineering 76)

“The diameter of center-core rods used in full-scale walls can range from 12 to 25 mm (0.5–1 in.), and the rods should be inserted in holes that are sized according to the needs of the material used for anchoring the center-core rods.” (Planning and Engineering 77)

As with the other elements, it is imperative that vertical center core rods be placed at regular and even intervals to ensure the continuity of the adobe wall, such as every 1-2 meters.

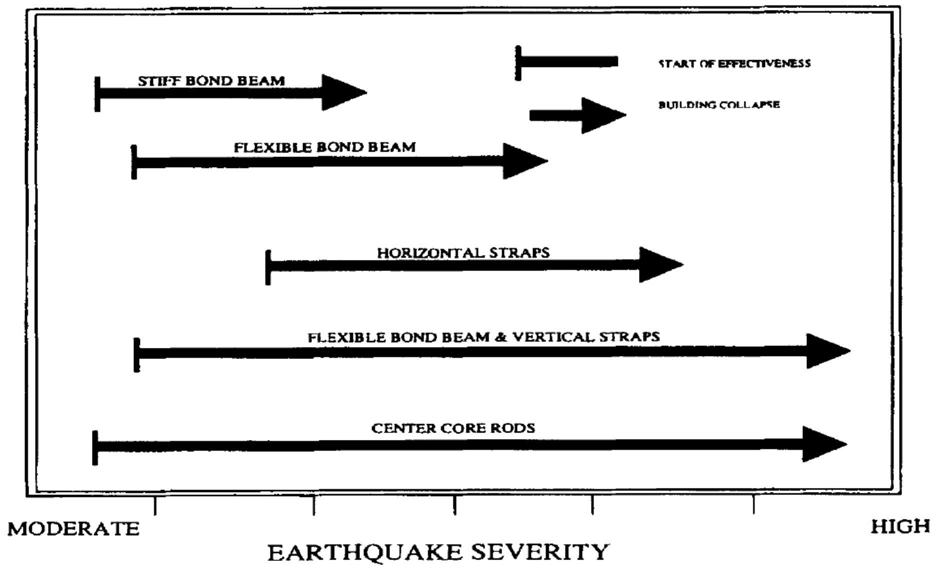


(Planning and Engineering 77)

4.3. Lower Wall Horizontal Elements

"Lower-wall horizontal elements can be used to improve the performance of adobe walls by preventing cracked wall sections from "kicking out" in plane, along the length of the wall…Lower-wall horizontal elements can consist of straps or cable elements or even buttresses" (Planning and Engineering 77)

These elements, like vertical straps, may be made out of nylon or steel.



(Seismic Stabilization 153)

The diagram emphasizes the effectiveness upper wall elements (vertical straps and center core rods), and lower wall horizontal elements (horizontal straps).

4.4. Specific Retrofit Solutions

For thick walled structures, S_L<6, the most important aspect of retrofit is roof anchors, because thick walls are still prone to overturning.

The retrofit solution, then, for a thick walled structure would include only roof anchors. These roof anchors should be in the form of a partial wood diaphragm- which in the minimum would "consist merely of a 4-foot width of plywood nailed along the tops of the joists" (Planning and Engineering 76). This system would limit flexure forces that act at the top of the massively heavy thick adobe walls.

Moderately thick walls, S_L=6-8, are susceptible to both flexure and shear forces. The flexure forces working on a moderately thick walled structure are more prevalent than shear forces thus a retrofit solution must make use of preventative measures for both weaknesses, but primarily to address flexure forces.

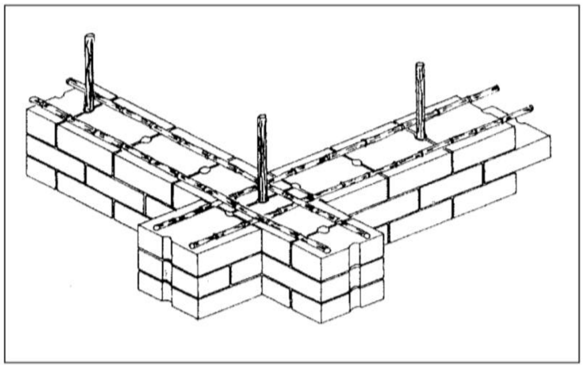
To prevent flexure forces, the retrofit solution will include the upper wall horizontal element of a roof anchor (the same as described above). Secondarily important are the elements that limit shear forces. With moderately thick walls this should be vertical straps (steel, nylon, or the like) placed at regular intervals, such as every 1-2 meters.

Thin walled adobe structures, S_L>8, are very unstable, and have both strong shear forces and flexure forces working on them in seismic events. The retrofit solution then, must limit both in and out-of-plane failure.

Preventing flexure forces should be done in the same way as above, using wooden roof anchors. But to maintain a stable structure in-plane, grouted center core rods will be required at regular intervals along the walls, every 1-2 meters. These center core rods are generally made of steel, and should be between 12 to 25 mm. They should also be placed into oversized holes with a cementious grout to ensure a positive connection between the adobe and rods. The center core rods serve to prevent both out-of-plane and in-plane failure.

5. Section 5: Alternative Retrofitting Option

The retrofitting solutions mentioned above require very little resource to enact, save for the steel center core rods, which may be inaccessible or too expensive for certain areas of the developing world. As such, I have included a pro-poor alternative which should be cheaper or easier to acquire.



7-5 System ININVI, Perú

(Construction Manual 24)

The solution is to replace steel center core rods with bamboo center core rods. For this alternative, it is also important there be a positive connection between the adobe wall material and the rod itself. It is recommended by Gernot Minke that the rods of bamboo be placed in holes 5 cm in diameter with 2 cm of grout, same as that used for steel center core rods (epoxy or other cementious grout) (Construction Manual 24).

Works Cited

Minke, Gernot. *"Earthquake - Resistant Houses: Construction Manual for Earthquake-Resistant Houses Built of Earth.*" Appropriate Technology 30.1 (2003): 64-. ABI/INFORM Complete; ABI/INFORM Complete; ProQuest Research Library; ProQuest Research Library. Web. 20 Nov. 2012.

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