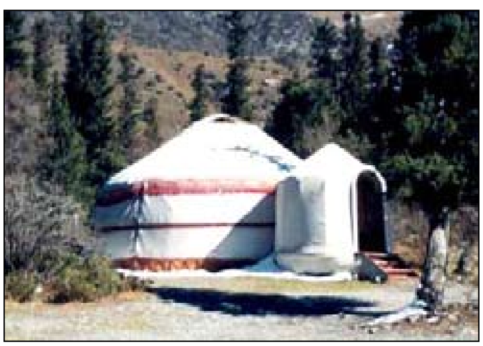
VERNACULAR HOUSING CONSTRUCTION

Mauro Sassu, University of Pisa, Italy

BACKGROUND

Some forms of vernacular or traditional housing construction use building practices, materials, and elements that result in good seismic performance. Such forms are particularly common for regions of high seismic risk: countries like Turkey, India, Japan, El Salvador, Peru, Kyrgyzstan, Portugal, Italy, etc. In many cases, good results have been achieved without any specific technical knowledge, but rather through a type of "natural selection" process applied to building construction. Because of the constant threat of earthquakes, the local population has learned the principles of earthquake-resistant construction through a "trial and error" process. Poor earthquake performance of some construction practices resulted in their discontinued future use. On the other hand, the building practices that performed well were replicated and further improved after each new earthquake. Such a process has occurred across several earthquake-prone geographical areas and cultures. Interestingly, a number of different cultures, living in similar circumstances, independently arrived at similar building techniques, without any known communication or exchange of technical know-how (not to mention conferences, workshops, technical journals, etc.!).



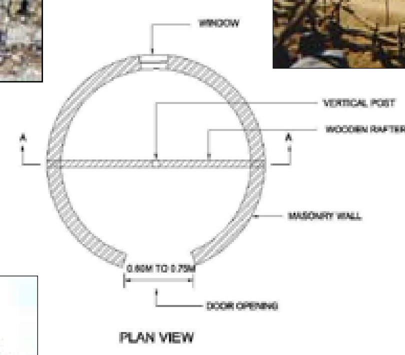


Figure 1: Examples of houses around the world that all developed a building style with a circular plan, which performs well in earthquakes

Top left: (WHE Report 35, Kyrgyzstan)
Top right: (WHE Report 72, India)
Bottom left: (WHE Report 43, Malawi)
Center: (WHE Report 72, India)

FACTORS INFLUENCING VERNACULAR CONSTRUCTION

Locally Available Materials
The first factor influencing the development of vernacular construction practices is related to the availability of local building materials. In many areas, the locally available resources have governed the use of the following constituent materials for walls:

- Adobe (mud blocks or whole walls)
- Masonry (stone, clay, or concrete blocks)
- Timber

Frequently, a combination of materials has been used in the construction. For example, the use of timber elements within walls found in Pombalino buildings in Portugal (WHE Report 92) and in traditional construction in Turkey and India has been crucial in ensuring the satisfactory earthquake performance these buildings are known for.

Building Layout
Another determining factor is the building layout, that is, the typical shape of a building plan, usually related to many cultural, historical, and urban planning traditions. Three main plan shapes have been identified in traditional buildings:

- Circular plan
- Rectangular plan
- Linear plan (row houses or wagon-houses in Romania)

The circular floor plan offers the best resistance to earthquake forces.

Building Size
The third and final aspect relates to the size of a building. Based on their size, these buildings can be classified as:

- Single story
- Multistory buildings

The size of the building is governed by its particular use. For example, a dwelling can be used for sleeping only, for sleeping and eating, or for mixed use (sleeping, eating, and working). Clearly, the mixed-use buildings necessitate construction of an additional floor, which calls for increased wall load-bearing capacity, especially if these walls also need to withstand earthquake effects. It should be noted that the building size is also related to the population pattern and housing density in a given area. For example, single-story buildings are common for rural areas, whereas multistory buildings are most often found in densely populated urban areas.

EARTHEN CONSTRUCTION

Earthen dwellings utilize mud walls or adobe block walls. This type of construction is widespread in many different cultures, especially among poor populations that do not have access to more sophisticated building materials. Adobe construction offers a very limited seismic resistance; however, there are a few strategies for improved earthquake resistance of these buildings.

These strategies are as follows:

- Good choice of building shape (preferably a circular floor plan). In order to achieve desirable seismic performance, it is crucial that the floor plan be absolutely regular. If possible, it should be symmetrical in both orthogonal directions.
- Use of timber to reinforce earthen walls. Timber reinforcement can be added to increase ductility and secure the connections. Timber reinforcement must be adequately protected against humidity and insects (such as termites in Africa and India) in order to ensure long-term structural integrity.
- Use of a lightweight roof to reduce the mass on top of the walls; a secure roof-to-wall connection is essential for satisfactory earthquake performance.

Figure 2: Earthquake-resistant bhonga houses in India: traditional thatched roof (left) and modern clay tile roof (right) (WHE Report 72)

The *bhonga* house in Gujarat, India (WHE Report 72, shown in Figure 2) and the *yomata* house in Malawi (WHE Report 43) are typical examples of traditional earthen dwellings. Two versions of bhonga roofs have been identified: the traditional thatched roof, and a more modern clay tile roof. Clay tile roofing has probably been adopted because it provides superior thermal comfort when compared to the thatched roof. However, it adversely affects the seismic response of these buildings because of larger overhead masses; also, the tiles pose a hazard as they often fall if they are not properly attached to the roof structure.

The importance of the roof type in traditional adobe buildings has been confirmed in earthquakes. A lightweight roof, such as the thatched roof typical for traditional housing construction in Malawi (Figure 3, left), results in much superior seismic performance when compared to the heavy roofs found in the traditional adobe construction in Bam, Iran, which was devastated by an earthquake in December 2003 that killed at least 26,000 people (M 6.5), as shown in Figure 3.

Modification in the shape of the building plan from circular to rectangular improves living conditions; however, it is less desirable in terms of earthquake resistance. Mud construction can be practiced using a rectangular building plan, as reported in El Salvador (WHE Report 14), Iran (WHE Report 104), India (WHE Report 23), and Malawi (WHE Reports 43 and 45). However, the rectangular shape creates problems with wall separation at the corners and out-of-plane collapse during an earthquake.

Figure 3: A traditional yomata with thatched roof in Malawi (left) (WHE Report 43) and traditional adobe house in Bam, Iran (WHE Report 104) (right)

STONE AND BRICK MASONRY CONSTRUCTION

The most widespread vernacular housing construction involves the use of masonry walls as the load-bearing structure. The simplest technique is based on the use of sun-baked blocks, generally classified as adobe, described in the previous section. The use of burnt-clay bricks is widespread where wood or coal fuel is available. Clay brick is a traditional building material used for centuries in many parts of the world. Stone is the locally available material in some regions. Unshaped stone blocks collected in the field have also been used for housing construction for centuries, mainly in the form of uncoursed (random) stone-rubble construction. In some cases, the stones have been shaped, usually by hand tools. Such construction is called "dressed-stone masonry." Examples of this construction are found in Nepal (WHE Report 74, WHE Report 47), India (WHE Report 18, WHE Report 80), and Slovenia (WHE Report 58). (See Figure 4.)

Figure 4: Traditional stone masonry construction is practiced in rural areas (India, WHE Report 80) and urban areas (Italy, WHE Report 28)

Masonry buildings are generally highly vulnerable to earthquake effects and often experience significant damage during earthquakes. They are characterized by rather brittle behavior, heavy masses that attract larger seismic forces, and often by weak connections. In addition to the above, great variation in the quality of the masonry units and of the mortar used, and their intrinsic vulnerability to out-of-plane earthquake actions are underlying causes of the collapse of many masonry structures.

Common techniques used to improve seismic resistance of masonry structures include the addition of reinforcement, usually in the form of wooden planks, or steel bars or ties connecting the walls to the floors, and ring beams ensuring structural integrity[1]. As in the case of earthen structures, the use of regular and symmetrical floor plans is also desired for improved seismic performance.

TIMBER CONSTRUCTION

Examples of traditional wooden houses are found throughout Japan (WHE Report 88) and the Russian Federation (WHE Report 56). The advantages of timber housing construction stem from the use of timber, a lightweight and ductile building material. A critical issue in timber construction is related to the connections (floor-beam, column–beam or panel-beam) and their ability to transfer the forces from one building member to another and then down to the foundation. It should be noted that the wood is quite vulnerable to the effects of humidity and insects. Moreover, the use of timber construction is limited by the local availability of suitable wood materials.

Yurta, a traditional dwelling in Kyrgyzstan, is an example of earthquake-resistant timber construction. The load-bearing structure consists of wooden poles forming a frame enclosed by felt tension cloth. These dwellings consist of a circular plan and are extremely lightweight (Kyrgyzstan, WHE Report 35).

The *Pombalino* buildings (Portugal, WHE Report 92) have been used in Portugal since the great 1755 Lisbon earthquake. They represent an early form of braced frame timber construction, where the wooden frame is infilled with brick masonry or adobe blocks, as shown in Figure 5. Similar forms of earthquake-resilient vernacular construction, timber-braced frame construction with masonry infills, are found in Turkey (*himis*), Kashmir, India (*dhajji-dewari*)[2], and also in Northern Europe and Italy (where they have even been included in seismic regulations).

Figure 5: The exterior of a Pombalino building (left) and details of timber bracing (right) (WHE Report 92, Portugal)

Bahareque, a traditional construction found in El Salvador, consists of timber studs, with wood or bamboo lath forming a mud-filled pocket in the wall (somewhat similar to the North American form of timber construction). This type of construction has also been exposed to numerous earthquakes in the region and has generally performed very well[1].

STRATEGIES FOR EARTHQUAKE-RESISTANT VERNACULAR CONSTRUCTION

Most existing vernacular housing types have developed earthquake-resistant features over time throughout several generations. Modern housing construction practices are undergoing a continuous change due to increased globalization and easy access to information. However, it is important to recognize and identify the main features that enhance seismic performance of traditional buildings. The WHE reports on vernacular earthquake-resistant housing have provided an opportunity to share information on the best practices for building simple, low-cost earthen, masonry, or timber houses to achieve optimal seismic performance.

General strategies for satisfactory seismic performance of vernacular housing construction are summarized below.

1. Construction with ductile materials
    - Ductile reinforcement in walls (wood or steel) to avoid out-of-plane collapse
    - Proper maintenance to prevent decay of wooden materials
    - Selected materials (brick-mortar-wood)
2. Construction with robust architectural forms
    - Regular floor plan (shape-distribution of walls)
    - Uniform openings (small and well-spaced)
3. Construction with resilient structural configuration
    - Efficient connections (wall-wall, floor-wall, wall-foundation, etc.)
    - Precisely built wall textures to provide bracing and shear resistance
    - Continuous foundation to avoid settlement and cracking from below
    - Good workmanship (manufacturers, builders)
4. Construction that reduces seismic forces
    - Lightweight roof
    - Low-rise houses (one- or two-stories high)

In addition to the above conventional strategies, advanced technologies such as seismic isolation are emerging and can be used to protect vulnerable masonry construction from earthquake effects[3].

ENDNOTES

[1] Timber "runner beams" called *hatils* found in stone masonry construction in Turkey and Greece represent early form of bond beams characteristic for contemporary masonry construction. (Homan, J. and Eastwood, W.J., 2001. "The 17 August 1999 Kocaeli (Izmit) earthquake: historical records and seismic culture." *Earthquake Spectra*, Earthquake Engineering Research Institute, **17** (4), 617–634.)

[2] Langenbach, R., 2000. Intuition from the past: What can we learn from traditional construction in seismic areas, *Proceedings of UNESCO/ICOMOS International Conference on the Seismic Performance of Traditional Buildings,* Istanbul, Turkey.

[3] Sassu, M., Mariani, G., and Mattafirri, D., 2004. Mechanical behavior of simple masonry buildings with low-cost dissipators distributed throughout the basement. *Proceedings, 13th World Conference on Earthquake Engineering,* Vancouver, Canada, Paper 3397.