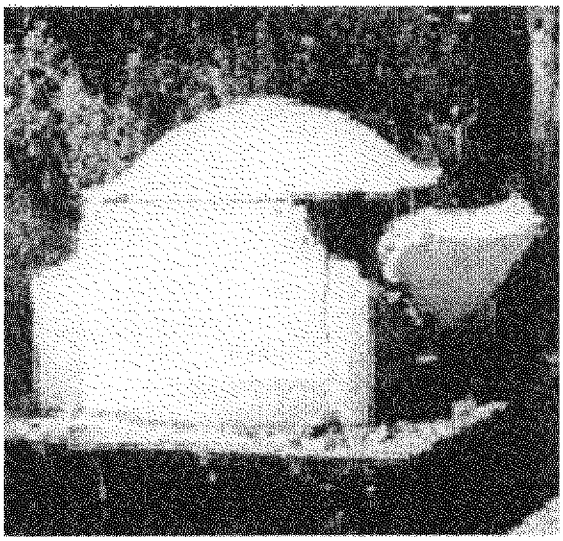
5. Structural design aspects

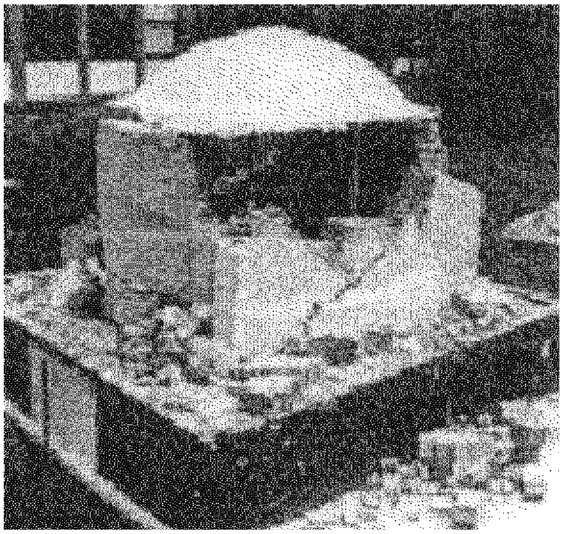
There are three general principles for designing an earthquake-resistant structure:

1. Walls and roof are well interconnected and so rigid that no deformation occurs in the earthquake.
2. Walls are flexible enough, so that the kinetic energy of the earthquake is absorbed by deformation. In this case a ring beam, which is able to take bending forces, is necessary and the joints between wall and ring beam and ring beam and roof must be strong enough.
3. The walls are designed as mentioned in case 2, but the roof is fixed to columns separated from the wall, so that both structural systems can move independently as they have different frequencies.

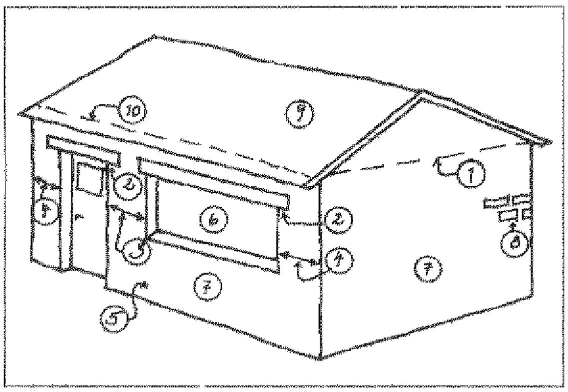
Case 1 can be a house with very thick rammed earth wall or a reinforced concrete frame structure with moment-stiff corners at the top and at the bottom, and infills of bricks, cement blocks or adobes.

A variation of a nonflexible structure is a timber frame structure which has less moment-stiff corners and is therefore stabilized by crossing diagonals of steel. In this case the danger exists that the connection of the diagonal or the elements itself may not be strong enough to withstand the concentration of stresses at the corner and breaks, causing the collapse of the wall, see Fig. 5-1.





4-5 and 4-6. Models of the house in Fig. 4-4 after seismic movements (Sibtain, 1982)

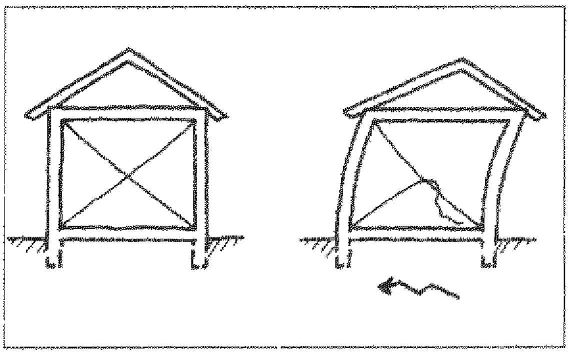


4-7 Typical design mistakes which might lead to the collapse of the house

1. Ring beam is lacking
2. Lintels do not reach deeply enough into masonry.
3. The distance between door and window is too small
4. The distance between openings and wall corner is too small.
5. Plinth is lacking.
6. The window is too wide in proportion to its height
7. The wall is too thin in relation to its height.
8. The quality of the mortar is too poor, the vertical joints are not totally filled, the horizontal joints are too thick (more than 15 mm).
9. The roof is too heavy
10. The roof is not sufficiently fixed to the wall

The systems of case 2 and 3 can be built without concrete and steel and in most regions are much more economic. Walls built with the system of "wattle and daub" (in Spanish: "bahareque" or "quincha") show extreme flexibility. Fig. 5-2 shows a house which suffered under a heavy earthquake in Guatemala, but did not collapse.

As the vertical forces created by the earthquake are less important, we have to decide how the walls withstand the horizontal forces. There are two types of impacts to be considered: those forces, which act parallel to the wall and those which act perpendicular to it. (Forces acting at an inclined angle to the wall can be divided into two components, one parallel and one perpendicular to the wall.)
The perpendicular forces create a moment which might provoke a collapse of the wall if it is not stabilized by intermediate walls, buttresses and ring beams. If the walls are very thin and high, they might collapse even though stabilized, due to the bending forces that create buckling. The parallel forces are less dangerous. They produce thrust within walls which in the case of adobe walls with poor mortar create the typical diagonal cracks, shown in Fig. 4-1 and 4-2.
The most dangerous effects result when the walls fall outwards and the roofs collapse. Therefore the safest solution is to place the roof on a separate structure independent of the walls, see chapter 12.
When designing earthquake-resistant houses, we must consider that the horizontal force ("equivalent force") to be calculated is proportional to the mass of the structure and the higher the walls, the higher their displacement.



5-1

5-2 Wattle and daub structure, after a heavy earthquake in Guatemala (Minke, 2000)