



EARTHQUAKE PROTECTION FOR POOR PEOPLE'S HOUSES

Adopting the sophisticated building regulations of the developed world in poor countries has done little to prevent poor people's housing from collapsing in earthquakes. Theo Schilderman suggests, however, that there are many ways of making stone and adobe buildings better able to resist earthquakes which are within the reach of people on low incomes.

Earthquakes cause a lot of casualties and damage. In the twentieth century alone, they have accounted for around 1.5 million casualties, 90 per cent of which occurred in housing for people with a low income. The economic losses have been staggering as well: they may have exceeded one trillion US dollars.

The particular vulnerability of poor people's housing is caused by a number of factors, of which the most important are:

- Poverty, which prevents the use of better materials or skills. It also makes people extend and improve their houses in stages, and in the case of a house that has got off to a bad start it is often hard to improve its earthquake resistance.
- A lack of political power, which stops people building on more secure sites or gaining assistance.
- Scarcity of both appropriate materials and skills for earthquake-resistant construction.
- A lack of disaster consciousness in situations where daily survival is a major problem, and where, for example, the removal of subsidies on food is a much greater disaster for poor people than the eventual earthquake.

Any effort that helps to reduce the vulnerability of poor people to disasters, and thereby also reduce casualties and future economic losses, is worthwhile in itself. As in the area of medicine, where money spent on the prevention of a disease reduces the amount required for its cure, so aid agencies as well as local governments should spend larger parts of their disaster budgets on reducing vulnerability instead of on relief. If one looks at the factors listed earlier, it becomes clear that only long-term development work will considerably reduce vulnerability: if poor people gain more resources and more power they will become less vulnerable. And it often does not need large sums to get this process going, as Andrew Maskrey describes in his excellent book.

Better technologies are needed to reduce the vulnerability to earthquakes of the housing of low-income groups, but we cannot impose such technologies upon people. The approach that most developing countries have attempted is simply to adopt a set of standards and regulations with respect to the earthquake resistance of buildings which are directly derived from the ones used in the USA, Britain or France. They usually prescribe reinforced-concrete frames or some other technology that is unaffordable by the poor, and like other standards, they have been ignored by the poor. Engineers should learn not to aim for the ideal solution,

but for the affordable and appropriate solution; they have to allow a higher level of risk than standards usually permit, and they may have to set priorities.

An example of such a priority might be the prevention of casualties as a result of roof collapse, and some engineers have actually designed separate roof-supporting systems, accepting that if masonry walls fall down, they can be rebuilt afterwards.

The best approach to increasing earthquake resistance is usually to learn from the earthquake performance of dwellings in a given area, noticing problem areas and sometimes better technologies, and then to use mainly local resources for further improvement. The rest of this article gives some examples of improvements to two types of construction that can be particularly vulnerable: stone masonry and adobe masonry.

Earthquake performance

Earthquakes make buildings shake; the resulting lateral forces are determined by the mass of the building. Dwellings with heavy walls and roofs therefore run the greatest risks, and these are very common in the major earthquake belts that encircle our globe, such as Central and South America, the Mediterranean, the Near East and China.

Heavy walls may be damaged as a result of:

- shear stress, caused by forces parallel to the plane of the wall, and resulting in diagonal cracks developing in high-stress areas, such as corners, intersections or openings;
- forces perpendicular to the wall, causing bending out of plane;
- a combination of these two stresses.

Random stone masonry, which occurs widely in the Mediterranean and the Near East, is very dangerous in earthquakes. These walls lack internal cohesion and even disintegrate during moderate earthquakes; this has happened during earthquakes in Lice, Turkey; in the Yemen; and in Iran.

Adobe, or soil-block masonry, is even more common in poor people's housing. The cohesion and the tensile strength of adobe walls are often insufficient to resist even a moderate earthquake: walls shear apart in high-stress areas, they incline and are pushed outwards by the roof, which then may fall on the inhabitants. Adobe structures have contributed most to the number of earthquake casualties, particularly in Latin America, the Near East and China. Bad performance has often been caused by such factors as poor adobe quality, poor bonding and poor workmanship, a lack of maintenance and the presence of humidity in the walls.

Some design guidelines

The study of the performance of buildings during earthquakes tells us something about the relative resistance of various building technologies. Even with the same technologies, however, we often notice variations, caused by other factors, such as the design or location.

Improvements to the technologies would be less effective if these factors were not taken into account. It is not possible to treat them in detail here, but some major guidelines are:

- Select a solid site; avoid landfills and risky slopes.
- Reduce the overall mass of individual dwellings and particularly of the roof.
- Design a strong and regular dwelling. Divide the mass among the walls evenly; design the building without a fancy shape.
- Avoid long walls without intermediate support; tie walls together at the top, avoid high walls and heavy gables; use small openings evenly distributed and not close to corners or wall intersections.
- Make strong connections; particularly between the roof and the walls.
- Control the quality of the materials used.
- Improve the workmanship, particularly in mortar preparation, masonry and connections.
- Maintain a house well masonry.

Improving stone masonry

In the Near East, the reinforcement of masonry has much improved the performance of stone. The materials used for reinforcement are concrete or timber, the latter being far cheaper. Horizontal tie-beams are essential, and they can be combined with a vertical frame, and, in the case of timber, diagonal bracing.

Horizontal tie-beams should appear at roof level, above windows and doors, and sometimes also below windows and on top of the foundations. Full frames are an expensive way of reinforcing a building, however; it is more affordable, but also more risky, to reinforce only the high-stress areas-near openings, corners or intersections -with shorter pieces of timber or steel

A better quality of materials also increases resistance. Round stones should be avoided; angular stones, preferably dressed, will considerably improve the internal bond in a wall. The use of flatter stones, such as slate, will help as well, as long as they are placed flat, not on their side. Better mortars increase the bonding, which is particularly important for corners and intersections and around openings. Wherever available and affordable, the use of cement, lime pozzolana, lime or gypsum mortar - in that order of preference - should be encouraged. (A pozzolana is a substance which, when mixed with lime and water, hardens as a cement.)

Finally, a high level of construction quality is important, particularly to improve bonding and therefore resistance to movement. The practice of building double- faced walls, without tie stones and with rubble infill should be strictly avoided. Stones should always be placed as flat as possible, and dressed whenever needed to fit specific gaps, rather than using large quantities of mortar and small stones to fill up voids. Masonry walls should occasionally have stones that reach through the entire thickness of the wall ('through-stones',) which perform the same tying functions as the dowels (steel or wooden connecting pieces). Finally, walls should be neither too thin, which makes good masonry patterns very hard to realize, nor too thick, since that would unnecessarily increase the mass. A reasonable thickness for masonry with irregularly shaped stones is in the order of 40 to 50cm.

Adobe masonry

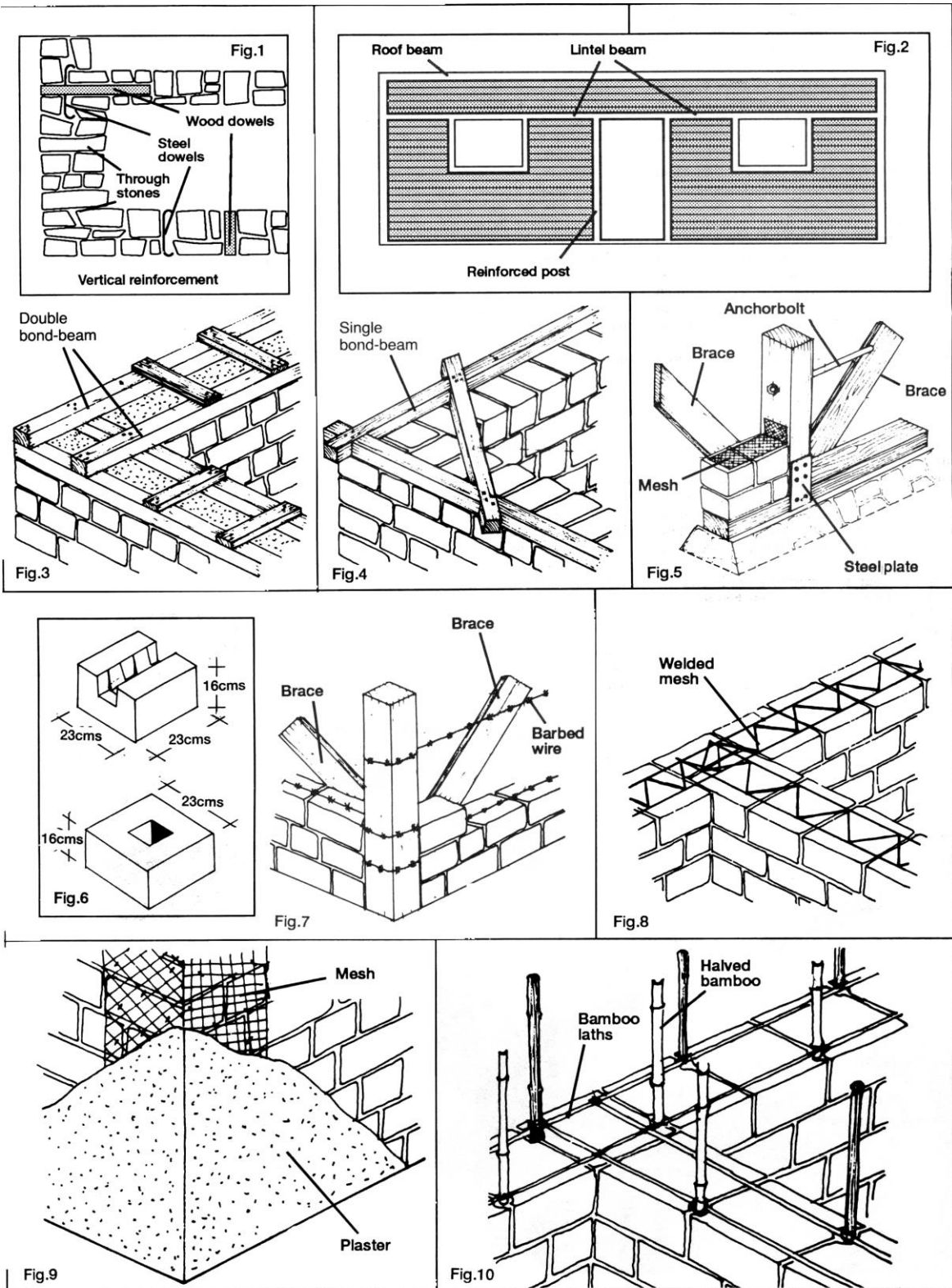
For adobe also, reinforcement often provides the biggest improvement to the masonry .A continuous ring-beam is very desirable, particularly at roof level; it helps to tie the tops of the walls together and provides a fixed base for the roof. If there are many openings, a similar ring-beam at lintel level is recommended. With only horizontal reinforcement, however, and unable to resist great lateral forces themselves, walls may still move sideways during earthquakes, unless vertical reinforcement is added to tie them to the foundations and to increase bending resistance. Vertical reinforcement is particularly useful in high-stress areas: at corners or intersections of walls and along openings. A picture of an ideal combination of reinforcement is shown in Figure 2.

Reinforcement may take many shapes:

- Concrete columns and beams are the most expensive solution.
- Timber beams, on top of and within the walls are usually much cheaper. The Turkish building code suggests the use of horizontal timber bond-beams at four levels: at the basement, under and above windows, and under the roof. These bond-beams can be double, with a 10 x 10cm timber profile at each side of the wall, connected by 5 x 10cm ties at 50cm intervals (Figure 3). They can also be single, on the outer face of the wall, and braced in the corners (Figure 4).
- Timber frames were also suggested after the 1976 earthquake in Guatemala, where the traditional adobe wall is much thinner, provides little structural support, and acts as more of an infill than elsewhere. The frame should consist of horizontal beams at roof and basement levels with vertical posts at corners and intersections, and braces to make the frame more rigid (Figure 5). Such wooden frames require good connections with the adobe masonry, through anchor bolts, nails or wire mesh.
- In Mexico, U-shaped or hollow adobes have been suggested, to incorporate timber or concrete reinforcement more easily (Figure 6).

- Steel bars can be used, in horizontal or vertical joints, to tie walls together or to the foundation, but they are expensive. In Ecuador and Honduras barbed wire or other steel wire has therefore been suggested for use in combination with a timber frame (Figure 7).
- Welded mesh in the joints is an alternative commonly used in the south west of the USA and in southern Africa (Figure 8). Wire mesh incorporated into a plaster becomes ferrocement, and can be used to reinforce high-stress areas, around corners or openings (Figure 9).
- Reinforcement. The Turkish code allows the wooden bond-beams to be replaced by canes 5cm apart, tied every 50cm. In Peru, both vertical and horizontal reinforcements with reeds and bamboo are used. One method uses bitumen-stabilized adobes (bitumen is mixed in with the soil), with small holes in the vertical joints for a halved bamboo (also painted with bitumen) to pass through. Horizontal reinforcement then consists of quartered bamboo laths (Figure 10).
- In India, split bamboo mesh, dipped in bitumen, is used as a reinforcement of the plaster on adobe walls.

Apart from these continuous reinforcements, which may be expensive and not necessary in all cases, local reinforcements can be placed in high-stress areas only. These might consist of wooden or steel dowels which are braced, or of wire-mesh or bamboo strips laid in horizontal joints over a short distance, for example, 50-100cm along the walls next to a corner.



Mortar

- Good-quality blocks and mortar are also crucial. Since the mortar takes care of the bond, it should be of at least as high a quality as the blocks. The abundant documentation that is available on earth construction provides all the details; but here are some key points:
- Select your soil carefully, with enough clay to bind it, but not so much as to cause shrinkage, and enough sand to provide strength.
- Break and mix the soil well; do not use too much water in the block production, and cure blocks gradually, under cover.
- Include some grass, straw or bagasse (sugar-cane residue) to help prevent cracks and to increase the strength of the adobe.
- Increase the compaction to improve strength: instead of hand-moulding, a steel press, such as a Cinvaram or Terstaram, can be used.
- Stabilize the soil to increase the strength and water resistance further; possible stabilizers are cement, lime, lime pozzolanas, bitumen and gypsum, and these can be added to the soil in the proportions of between 5 and 10 per cent by volume.
- Make adobe blocks quite shallow (less than 10cm deep) and large, to achieve a good bond in walls.

Construction details and quality can also make a lot of difference. Adobes should always be protected from humidity, which greatly affects their resistance to movement. It may help to plaster the walls or to stabilize the adobes. A very crucial area is the base of the walls, which is usually less protected by the roof's overhang, and is hit by rain and splashing water. It is always better to design the base in a more water-resistant material, such as stone or brick masonry, and to include a damp-proof course, for example asphalt paper, between the base and the adobe masonry on top. During construction, no uncured adobes should be used, because these still need time to shrink and they would make the walls crack. Masonry should not be constructed too fast, but time should be allowed for it to settle and harden.

It is also crucial to achieve a good masonry pattern, with sufficient horizontal overlaps and avoiding continuous vertical joints, especially at corners and intersections. Walls should have sufficient thickness (at least 30cm), but not be too high, certainly not higher than eight times the thickness. Loose gable walls made of adobe should be avoided because they are prone to collapsing outwards during an earthquake; either gables should be avoided in the design or, if this is impossible, they should be tied securely into the roof structure. The length of a wall between its supports should not be more than ten times its thickness. Roof beams should not rest directly on the walls, but on a continuous beam or a wall plate, to spread their weight; this wall plate needs good anchoring in the masonry.

The improvements to materials, construction techniques or design suggested in this article are to a large extent a compilation of lessons learnt from past earthquakes in various regions of the world. Fieldworkers in earthquake-prone countries will learn their own lessons, through observation. They may not, however, always be well informed about better technologies that have been suggested elsewhere, where similar conditions prevail; so I hope this article provides them with some new ideas.

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