EARTHQUAKE RESISTANT HOUSING

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. 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.

Figure 1 - Typical domestic tapial dwelling destroyed by earthquake (Megan Lloyd-Laney)

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

Figure 2 – Earthquake resistant quincha house (Theo Schilderman)

- 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.

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technical brief

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 *Disaster Mitigation – a community based approach*.

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 three types of construction: stone masonry, adobe masonry and quincha.

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 Yemen; in Pakistan; 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.

Mud and pole construction is a method that occurs independently in many developing countries. It consists of a round pole frame which was set directly into the ground, infilled with smaller wooden poles and interwoven to form a matrix which is then plastered with one or more layers of earth. Timber buildings in a seismic area usually fare better in an earthquake due to the flexibility of the material and the buildings and their light weight compared to concrete or steel. Weaknesses in this type of construction lie in the weakening of the timber poles due to rot, insect and fungal attack, and often in poor connections in the timber frame. Deterioration of the frame can be avoided by preventing exposure of the timber poles to moisture by using preservative treatment and preventing contact with the soil moisture at foundation level.

In Peru, this type of construction is known as *quincha*. Many heritage earthen buildings higher than one storey usually have a lighter second storey constructed in *quincha* in response to the 1746 earthquake in Lima. Some newly constructed adobe buildings designed to be seismically resistant have also included a second storey made of *quincha*. It significantly reduces the mass of the second storey and attracts less seismic forces on the building.

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. Some major guidelines are:

- Carry out a site investigation;
- Select a solid site; avoid landfills, flood plains, drainage paths and steep slopes;
- Position the foundations on rock or firm soil, avoid stepped foundations;
- Design compact buildings with a symmetrical shape and closely spaced walls in both directions. If that cannot be done, design them in separate, regular blocks;
- Build one-storey houses where possible;
- If buildings have more than one floor, opt for similar floor shapes and designs;
- Separate adjacent small buildings by at least 75 mm;
- Make walls light to reduce the horizontal forces caused by earthquakes;
- Walls should not exceed 3.5m in height, unsupported lengths of wall should not exceed 7m;
- Make roofs light to avoid them pushing walls sideways and falling-in on people;
- Avoid gables, they may fall inwards;
- Avoid long walls without intermediate support and tie walls together at the top
- Keep openings to a minimum, well distributed over the building and within walls; keep them centrally positioned, at least 60 cm away from the inside of corners and intersections and from the nearest other opening.
- Openings should not be wider than 1.2m and bearings of lintels should be at least 500mm either side of the opening;
- Provide strong joints between structural components; use a ring beam and a plinth beam where possible; use bracing at corners;
- If masonry walls are used, create good bond especially at corners and intersections;
- If concrete pillars are used, lap vertical reinforcements mid way between floors and not just above floors;
- Control the quality of the materials used.
- Improve the workmanship, particularly in mortar preparation, masonry and connections.

For an illustrated guide of the above points and more useful advice on good practice, the Earthquake Reconstruction and Rehabilitation Authority in Pakistan have published a guidelines document.

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. 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.)

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. Vertical joints should be staggered so that large vertical cracks do not occur. 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.

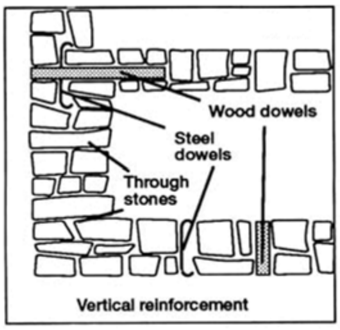

Figure 3

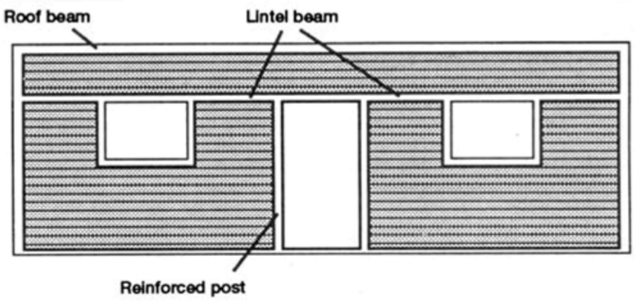

Figure 4

Adobe masonry

For adobe 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. Continuity can be ensured by lapping the reinforcement or splicing the timber. If there are many openings, or if walls are greater than 2.5m in height, a similar ring-beam at lintel level is recommended. If 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 for ring beams 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.

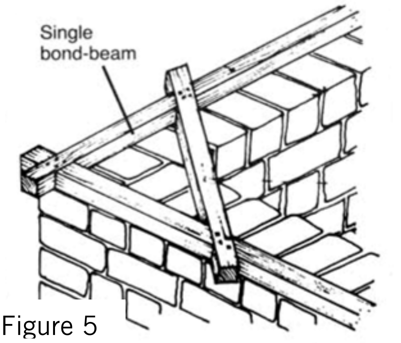

Figure 5

- In Mexico, U-shaped or hollow adobes have been suggested, to incorporate timber or concrete reinforcement more easily (Figure 6).

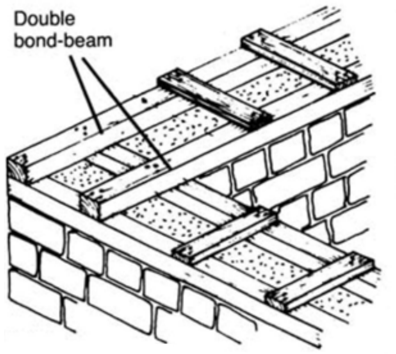

Figure 6

- 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).

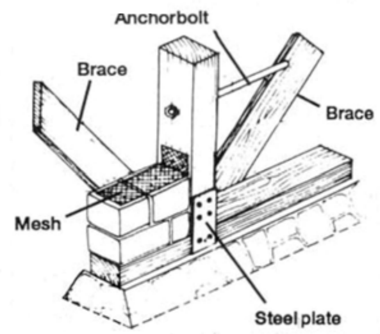

Figure 7

- 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).
- 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.

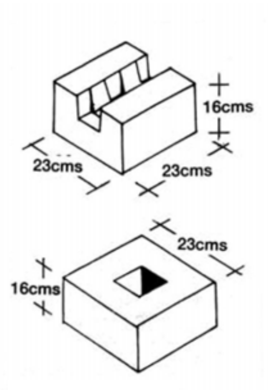

Figure 8

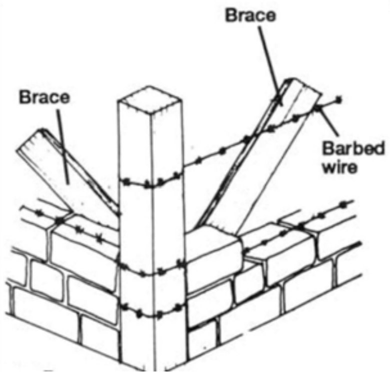

Figure 9

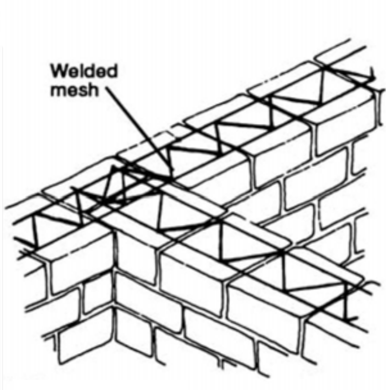

Figure 10

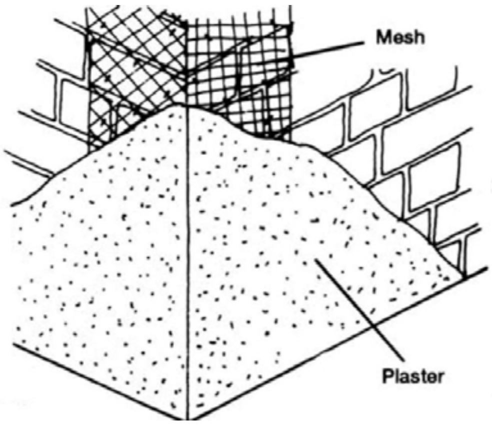

Figure 11

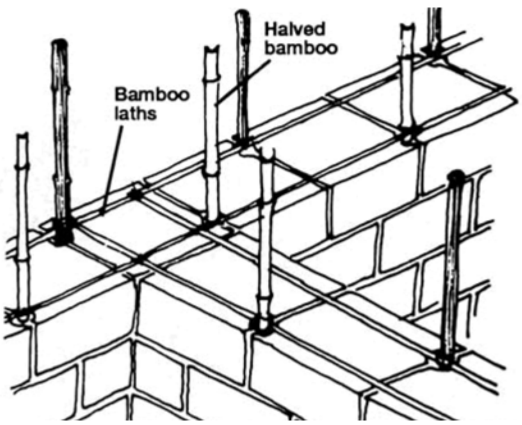

Figure 12

Each separate roof member should be tied to the ring beam and if a lightweight roof is used the ring beam should be tied to the wall at regular intervals. The ring bean should also be strengthened at all corners.

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.

Blocks and 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. There is a lot of literature available on earth construction which will go into further detail; 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 thick) and large, to achieve a good bond in walls.

- Build adobe on a course of stone or brick in order to prevent moisture from weakening the base of the wall and prevent water penetrating the wall from the roof.

Detailing

Construction details and quality of materials can also make a vast difference to the performance of a building in an earthquake. Adobe buildings 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.

In the case of *quincha* it is vital to have strong connections in the timber components. Under earthquake loads the connections undergo large stresses and movement, so connections must be strong in tension and ductile. Bolts and straps can be used to strengthen connections which would be very cost-effective. Connections should be strong between the foundations and the frame, at corners, between walls and floors and between the roof and the structural frame.

Improved Quincha

An earthquake in 1970 produced renewed interest in earthquake-resistant building technologies. During the 1980s researchers at the Catholic University, the National Engineering University and the National Institute of Housing of Peru, supported by the United States Agency for International Development, investigated ways of improving upon traditional building materials and housing systems: they focused in particular on *quincha* technology.

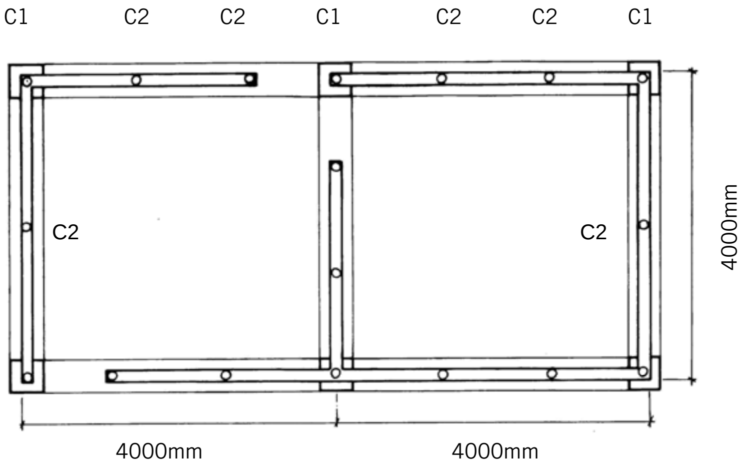

Figure 13: Plan view Illustration by Duval Zambrano/J. Cuizano

An improved method of constructing *quincha* was carried out by Practical Action during a rebuild in Alto Mayo, Peru in 1990. Improved quincha has the following characteristics over traditional quincha:

- concrete foundations to give greater stability;
- wooden columns treated with tar or pitch to protect against humidity, concreted into the ground with nails embedded in the wood at the base to give extra anchorage;
- use of concrete wall bases to prevent humidity affecting the wood and the canes in the walls;
- careful jointing between columns and beams to improve structural integrity;
- canes woven in a vertical fashion to provide greater stability;
- lightweight metal sheet roofing or micro concrete roofing to reduce potential danger to occupants from falling tiles;
- nailing of roofing material to roof-beams; tying of beams and columns with roof wires to guard against strong winds and earth movements;
- roof eaves of sufficient width to ensure protection of walls against heavy rains;

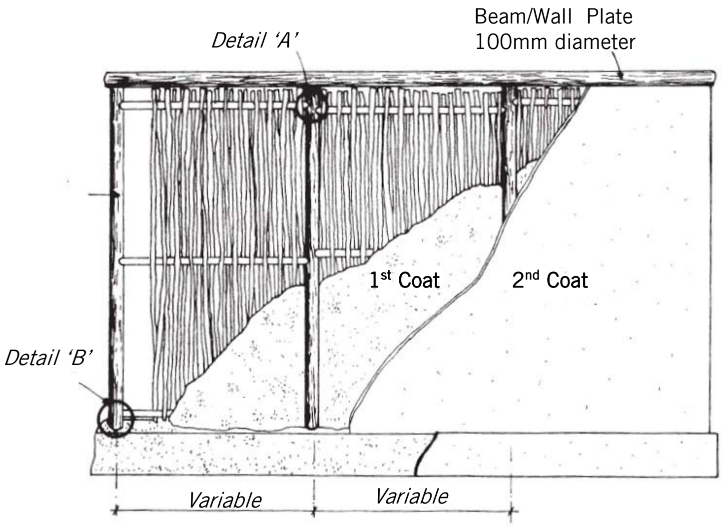

Figure 14: Wall construction Illustration by Duval Zambrano/J. Cuizano

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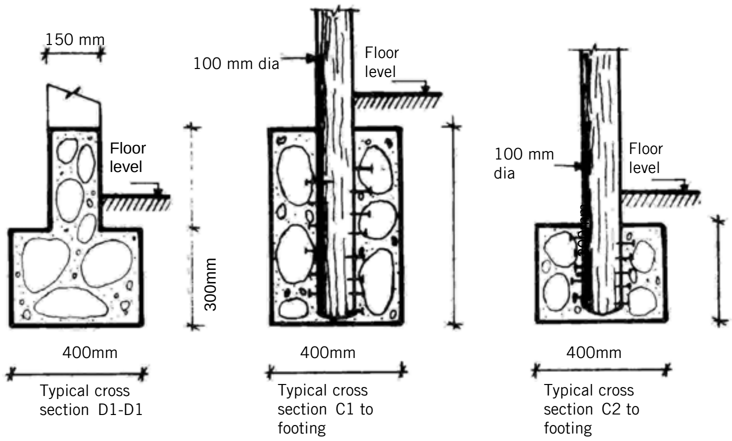
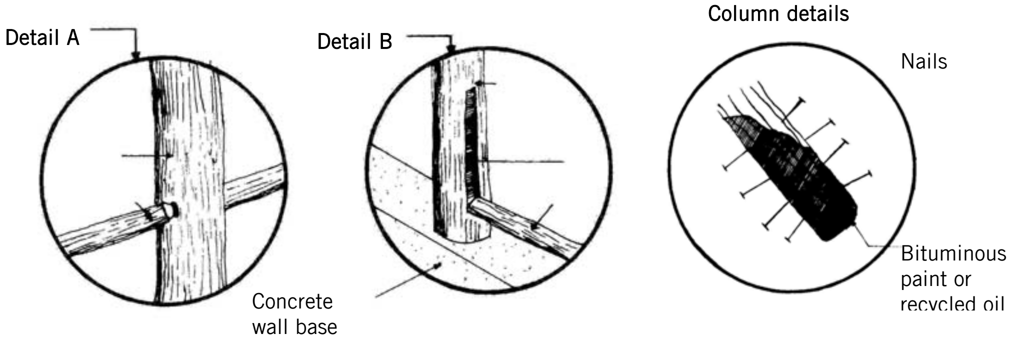


Figure 15: Details of the footings
Illustraion by Duval Zambrano/J. Cuizano



Improved *quincha* has many advantages in addition to earthquake resistance. The local availability of timber poles, bamboo and earth means that improved *quincha* is well suited to a self-help building programme than many alternatives. For more detail on how to implement People-Centred Reconstruction (PCR), there are guides under the *PCR Tools* series published by Practical Action. *PCR Tool 8: Participatory Design* and *PCR Too1 10: Quality Control* are of most relevance to designing appropriate structures.

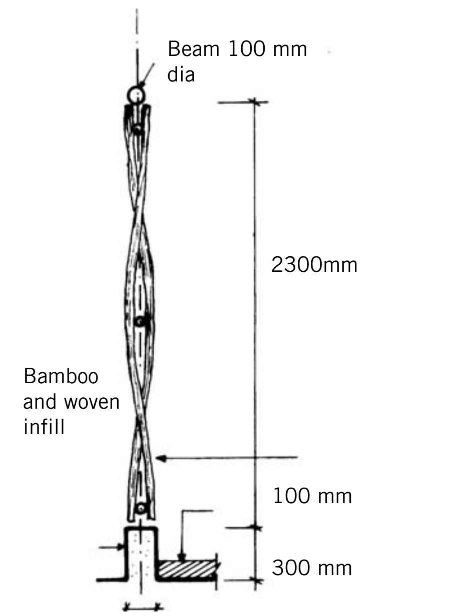


Figure 16: Cross section, Illustration by Duval Zambrano/J. Cuizano

<u>Specifications</u>
Concrete pad and strip foundations:
Mix – 1:10 (cement: aggregate)
+30 % large stones
Concrete wall base
Mix – 1: 8 (Cement: aggregate)
Wood is structural quality poles

<u>Render</u>
1st coat – mud: straw
Mix – 100kg: 50kg
2nd coat – cement: lime: sand: or sieved soil
Mix – 1:1: 5
or cement: gypsum: sand
Mix – 1:1:5
*ratios are by volume

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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; hopefully this article has provided some new ideas.

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