EARTHQUAKE ENGINEERING FOR THE SMALLER DWELLING

by

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SYNOPSIS

If the primary goal of earthquake engineering is the prevention of human suffering, improvement in the seismic resistance of smaller dwellings merits the highest priority. Hardly a year passes without an earthquake which destroys hundreds of poorly built homes, causing many casualties and leaving thousands homeless. Adobe and masonry are objectionable construction forms, but some improvement in their earthquake resistance is possible. The quincha type of construction common in Peru behaved well in the 1970 earthquake and merits wider use. Reinforced masonry and timber are superior, but demand knowledgeable design and careful construction.

SOCIO-ECONOMIC ASPECTS

For a developing country a balance must be struck between the desirable and the feasible. The first need is education: Away from a passive attitude to natural disasters and towards the best use of available skills and materials. The craft mystique must be replaced by the concept of the artisan, whose practical skill is backed by sound theory learned in a trade school. A cadre of competent supervisors must be created. The geology must be mapped and resources of native materials surveyed. Economic development plans should give high priority to establishing cement works, and to making available steel reinforcement, graded timber, and lightweight roofing materials.

EARTHQUAKE-RESISTANT REGULATIONS

These can only supplement, not replace the conventional building code, which must be refined as the earthquake-resistant regulations are developed. It must cover all the forms of construction to be used, and include adequate fire-resistant provisions, particularly for timber dwellings.

The static basis of design, using seismic coefficients, is generally appropriate for the smaller dwelling. However, recent thinking suggests that, for country where a great earthquake and hence prolonged ground shaking might occur, a seismic energy input factor may be preferable. This would be derived from probable maximum values for earthquake duration and for wave amplitude and velocity. Strong vertical motion occurred in the 1971 San Fernando earthquake (1) and is believed to have occurred in the 1972 Nicaragua earthquake. New codes should require the use of vertical as well as horizontal seismic coefficients. Pending more authoritative views on this subject, vertical coefficient values of 0.25 to 0.33 the horizontal coefficient may be considered realistic for small dwellings. The codes of many countries now require the use of a ground factor, and recent earthquake damage reinforces the need for this. Also, some

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construction forms are known to have low earthquake-resistance when located on certain types of ground, eg. masonry buildings on rock, and timber buildings on alluvium. In the Taiwan earthquake of 1964 timber dwellings on alluvial ground were badly damaged, as were masonry dwellings on rocky ground (2). The use of a corrective factor is therefore advocated. Its effect would be to load the seismic coefficients used for dwellings located in such unfavorable conditions.

TYPES OF CONSTRUCTION

ADOBE. This, the cheapest form of construction, will continue in use from economic necessity. It should be prohibited unless stabilized with portland cement or emulsified asphalt. One part cement to twelve parts soil is suitable. Only enough water should be added to give a workable mix. Blocks should be damp cured for at least 7 days. Ones made in a hand-powered machine press are stronger and more uniform in size than those hand-moulded (3). Blocks should be laid on a stone or concrete foundation rising at least 9ins (23cm) above ground, or capillary movement of moisture will disintegrate the lower courses. Mud mortar should be prohibited. Stabilized soil should be used or, preferably, a cement - lime - sand mortar.

Two stories should be the limit; one in a region of severe seismicity. A simple rectangular floor plan should be mandatory. The lower walls of a two-story dwelling should be at least 18ins (46cm) thick, and the upper walls, or the bearing walls of a one-story dwelling, at least 12ins (30cm) thick. No wall should be higher than 8 times its thickness, and no unsupported wall longer than 15 times its thickness. Lintels should have at least 12ins (30cm) bearing. There should be at least two internal cross walls, and all wall junctions should be bonded together. Any available reinforcement, however modest, should be utilized. Even steel bands from packing cases, cranked vertically from one block course to the next, will add to wall strength, especially if located near openings. Lightweight roof construction is essential.

QUINCHA. The Peru earthquake of 1970 showed this form of construction to be much superior to adobe. A quincha wall consists of vertical wood poles about 1 metre apart, with bottom bracing and a horizontal cap pole. Several equally-spaced horizontals complete the basic frame. Vertical canes are closely woven between the poles and the assembly is then plastered both sides with mud (4). This form of construction deserves wider use. It could be improved by spacing the vertical canes openly, fixing externally expanded metal lath or chicken wire as backing for the plaster, and using for the latter stabilized soil, as mixed for adobe.

MASONRY (Unreinforced). Ideally this would be banned. It is brittle. Its strength is low in relation to its weight. Low-cost masonry dwellings are usually on rocky ground - near where the stone is quarried - and tend to vibrate in resonance with it. They are best located on soft ground. Two stories should be the limit; one in a highly seismic region. Coursed stones are preferable to rubble. With rubble masonry the mortar volume becomes great and its shrinkage significant. The best mortar is composed of 1 part portland cement,

$\frac{1}{4}$ to $\frac{1}{2}$ part lime, with sand $2\frac{1}{2}$ times the combined volume of cement and lime. This possesses strength, elasticity, and low shrinkage. Some aids to earthquake-resistant construction are:-

(1) A simple rectangular plan. At least two internal cross walls at right angles, bonded to each other and to the outer walls, and having minimal openings.
(2) Wall thickness at least 12ins (30cm) for a one-story dwelling or 16ins (40cm) for the lower walls of a two-story dwelling.
(3) Vertical bonders running through two or more courses at foundation level and at door and window openings, to increase the shear capacity of the wall.
(4) Openings no closer than 5ft (1.5m) to a corner or to each other. Lintels with at least 15ins (38cm) bearing.
(5) Buttresses, located at corners in line with end walls, and elsewhere in line with internal cross walls. Slope angles not more than 70 degrees, with mortar joints at right angles to slope.
(6) Any available reinforcement should be utilized. Even small amounts will assist a wall to deform without collapse to an extent far beyond an unreinforced wall.
(7) Lightweight roofing.

REINFORCED MASONRY. Reinforced concrete framing with brick or block infilling behaves well in hurricanes. It is less able to resist the rapid stress reversals induced by earthquakes. Infilling may fall from the framing and cause casualties, or its sudden failure may induce sharp stress increases at the ends of framing columns, where shear failure may occur.

Reinforced hollow unit masonry is preferable. It acts monolithically. Masons skilled in traditional work can quickly learn the construction techniques. It is suitable for low-cost housing schemes. The procedures for earthquake-resistant design are not complex, but good quality materials and workmanship are essential. Some rules for earthquake-resistant construction are:-

(1) Uniform block size. In California a block measuring 8ins x 8ins x 16ins (20cm x 20cm x 40cm) is commonly used. Two end and two internal membranes divide it into three cells. The tops of the membranes are recessed to receive horizontal reinforcing bars.
(2) A gauged cement, lime, sand mortar - See MASONRY (Unreinfd.)
(3) A grout fill attaining a strength of 2000 pounds per square inch (140kg per sq.cm) at 28 days. A good specification is 1 part portland cement, $\frac{1}{4}$ part lime, $2\frac{1}{2}$ parts sand, and 2 parts fine gravel.
(4) The wall bases must be tied to the footings with vertical dowel bars not more than 24ins (60cm) apart.
(5) Reinforcement: Vertical bars should be not more than 24ins apart; horizontal bars in pairs not more than 4 feet (1.2m) apart vertically. For a two-story apartment building, 5/8inch (16mm) diameter vertical bars, and $\frac{1}{2}$inch (13mm) diameter horizontal bars in pairs, might be typical. At all corners four extra vertical bars should be placed to give a

column effect, and pairs of L shaped horizontal bars every feet. Two L bars, pointing opposite ways, are also needed every 4 feet at all wall junctions. Reinforcement must be provided at the sides of all wall openings, and a good rule is to have at least as much vertical steel each side as in the lintel above.

(6) Precast concrete beams with an in-place concrete topping are suitable for suspended floors. However, adequate reinforcement must be provided to give structural continuity at all wall to floor junctions.

(7) Grout fill must be made to flow thoroughly into all interstices by punning or vibration.

TIMBER. Although the principles which should govern timber construction are widely understood, careless detailing and execution often lead to poor aseismic performance. In the San Fernando earthquake there were some surprising instances of the near collapse of modern, timber-framed houses. Timber dwellings on soft ground are highly vulnerable, and if a choice of site can be made, rock at or near the surface is preferable to thicker soft deposits.

Anchor bolts must be appropriately sized and spaced, be well embedded in the concrete footings, and have plates or washers of sufficient size to prevent bolts pulling through the ground sills. All connections should be carefully detailed and formed. Metal corner plates (hurricane braces) or toothed steel connectors are better than joints formed in the timber. Equally vital is a sufficient number of diagonal braces. These should be notched into all adjoining vertical members, and carefully nailed at their ends. To prevent splitting of timber, all nail holes should be predrilled to a diameter slightly smaller than the nail. In the design, no nails driven parallel to the grain should be considered to resist withdrawal.

Plaster wall cladding should have a backing of metal lath or chicken wire, since this adds to the frame strength. No really satisfactory bedding for window glass has yet appeared, and in the San Fernando earthquake many injuries were caused by glass breakage. A soft plastic or rubber moulding would be suitable, permitting some window frame distortion before the glass cracks. Roofing should be as light as possible. A heavy roof not only increases the horizontal base shear. As wall frame distortion in the vertical plane becomes appreciable, the downward weight of the roof goes to increase the sum of the moments inducing frame collapse.

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