EARTHQUAKE RESISTANT CONSTRUCTION OF EARTHEN HOUSING

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ABSTRACT

Earthen buildings are traditionally constructed since prehistoric times in all parts of the world. Yet there is practically no standardisation attempted so far. As usually constructed, they are weak and most vulnerable to complete collapse as observed during earthquakes in the past. An attempt has been made here to identify the main defects and structural weaknesses in such constructions. Then suggestions are given to improve their behaviour under normal conditions and to increase their resistance to earthquakes. It is recognised that no test results are yet available to evaluate such recommendations. The need to carryout properly planned investigations is therefore emphasised.

The recommendations for earthquake resistant construction of adobe buildings as made by IAEE Committee are reproduced in an appendix to the paper for ready reference.

INTRODUCTION

Earthen huts, consisting of walls built in clay mud and roofs made of thatch or tiles or clayey earth placed over wooden poles and bushes, have been constructed since prehistoric times in all parts of the earth. In spite of unprecedented technological advances made in the world, large proportions of populations, particularly in the rural areas of developing countries, still continue to live in such earthen huts. Many of these areas lie in moderate to severe seismic zones and the earthen houses pose a very severe earthquake hazard to the lives of the occupants and to whatever little belongings they have. By their very nature, these houses are also seriously threatened by the action of water whether through beating of rain or through inundation. Earthen walls softened by moisture penetration are left with little strength and even light ground shaking would be sufficient to cause their collapse in a heap of earth.

Another aspect of the earthen houses is their very small initial cost input, since the construction are usually done by the villagers themselves with the help of a village mason, the clay mud being obtained from nearby water ponds or fields, and wood and roof covering that are usually the only materials to be purchased. Therefore, any methods which should be suggested for improving their earthquake resistance capability must satisfy three requirements - firstly, the material to be used must be as cheaply available as used in making the hut; secondly, the total additional cost must be a small proportion of the cost of the hut; and thirdly, the technique should be such as can easily be adopted by the village masons and that most of the work can be done by unsupervised labor.

This paper outlines the main weaknesses of earthen houses leading to their collapse during earthquakes and presents simple and cheap techniques to reinforce them so as to make them reasonable stable.

BEHAVIOUR OF ADOBE BUILDINGS DURING PAST EARTHQUAKES

The performance of adobe, brick or stone buildings as observed during the earthquakes in India, Afghanistan, Iran, Chile, Italy, Turkey and elsewhere clearly shows that all unreinforced construction in clay mud mortar with any building units are extremely weak againt lateral loads. Even at moderate seismic intensities MM VII to VIII, a large percentage of adobe buildings, even to the extent of 30% are completely collapsed and another 30 to 40% become dangerously damaged which must be destroyed and rebuilt. The results presented in Table 1(7) and Figure 1 [6] based on studies on Chilean earthquakes are representative and indicative of the real situation about the earthquake vulnerabulity of the earthen buildings in relation to other non-engineered buildings. The main defects and structural weakness responsible for this poor earthquake behaviour are listed below.

MAIN STRUCTURAL WEAKNESS

1) Material Strength

There are no standards yet available for the compressive, tensile or bearing strength of earthen walls. It can, of course, be imagined that all these strength values would be very small. Also, since used in a non-standard fashion according to local traditions, the material strength will be widely variable.

Moreover, the strength of walls may vary from season to season during the year. The material would behave as 'hard' in dry weather and in arid climatic zones but relatively soft in moist or rainy weather and in wet areas. Due to the low strength values, only small size constructions, both in terms of span as well as height, could be safely built with earthen walls.

2) Shrinkage Cracks

The earth used to build walls is necessarily clayey so that it has enough cohesion to keep the various layers together. Associated with the cohesion is high shrinkage on drying which frequently results in vertical cracks particularly near the opening corners and junctions of long and cross walls. These structural cracks remain in-built in the walls although they may be plastered over on both faces and are a source of much weakness in their lateral as well as inplane strength.

3) Planning and Construction Defects

There are a number of planning and construction defects that can occur in earthen buildings such as the following and must be guarded against :

a) two storey construction is undesirable due to low strength of materials;

b) too high and too distant spacing of cross walls will pose stability problem in walls;

c) too large openings cause too much weakening of walls;

d) openings too close to corners of walls or too close to each other give rise to weak piers;

e) lack of proper foundation and firm plinth may cause spreading of wall at base when softened due to water;

f) too small bearing of door and window lintels may lead to crushing of jambs;

g) lack of proper bond between walls at right angles to each other may result in complete collapse of the building during ground shaking;

h) lack of proper bond between adobe units where such units are used with clay mortar;

i) poor quality of adobe units;

j) roof rafters directly placed on adobe wall create high stress concentration;

k) accessibility to water, wetting the wall near its base or rain water soaking into the walls from top, will cause large reduction in compressive and bearing strengths.

EARTHQUAKE RESISTANCE FEATURES

In order to achieve resistance to collapse of earthen buildings, new constructions should be planned and constructed in a manner that the defects pointed out above are avoided. Also some new features may be built into them for earthquake resistance as indicated below :

a) The earthen construction may be restricted to single storey. Where a pitched roof is adopted, the attic space only may be used for light storage purposes.

b) The uniform wall thickness should not be less than about 35 cm and its height not more than 8 times the thickness, that is the wall height may be restricted to about 2,8 m above plinth or floor level.

c) The length of wall between consecutive cross-walls may be less than about 10 times the wall thickness, that is about 3,5 m. In villages, where single room tenements are commonly adopted, the lengths are usually more than 3,5 m and may go even up to 6 to 7 m. In such cases, either buttresses should be built on the outside of long walls or a sort of partition in between may be used as shown in Figure 2.

d) The window and door openings in walls should be of small width and as centrally placed as possible. Larger widths reduce the wall strength appreciably and the lintel loads also become high. Doors and windows of about 0,9 to 1,0 m width should normally suffice.

e) The lintels over openings, which usually consist of wooden planks or half-sawn poles, should have a long bearing length on mud-walls to save them from crushing. A bearing length equal to about 40 to 50 cm should be adequate.

f) To avoid the crushing or splitting of walls under the concentrated loads of roof beams or rafters, their load should be distributed on the wall either through two courses of burnt bricks or through sawn timbers used as wall plates.

g) Suitable precautions should be taken for maintaining the walls in dry state, so that the strength of the wall is not lost.

h) For achieving box-like integral action of long and cross walls together, their mechanical connection is essential. For this purpose the following schemes are suggested :

(i) Wooden dowels may be inserted at all corners and junction of walls to go into all walls meeting at the junction by a minimum of about the wall thickness. Such dowels may be placed every 60 cm along the height and may consist of half sawn poles or bamboos (Figure 3.)

(ii) A collar beam should be placed going round over all the walls which may consist of timber of sufficient width with diagonal braces at all corners or two lumbers going round in parallel and well interconnected at the junctions. (See Fig. 5.5 of Appendix)

When the dowels are provided as in (i) above, the collar beam may be provided at top of walls and may serve as wall plate as well. If dowels are not used, the collar beam should be used at lintel level serving also as lintels over the openings and the wall plate used separately at the top of walls.

For economy half-split bamboos may be used instead of wood poles or sleepers. But it must be emphasized that since clay walls can be infested with white ants, that wooden element embedded in them must be suitably treated against termites. As an alternative to wooden dowels, expanded metal or welded wire fabric could be used where cost and availability would permit.

i) As a poorer alternative to the use of wooden members for reinforcing the walls, outside earthen buttresses may be used to strengthen the corners and junctions of walls as shown in Figure 4.

j) The earthen construction will become much stronger if the dowels and buttresses could be used together where in the dowels pass through the buttresses as well as shown in Figure 4(b).

k) Another way to strengthen the wall against earthquakes is to use tapering wall thickness with about 60 cm at bottom and 35 cm at top.

l) In view of the limited wall strengths, the roof should be kept as light as possible. The thatched roofs are initially light but become heavy when soaked with water. Earth-covered roofs are naturally very heavy. Any kind of sheeted or tiled roofs would be preferrable.

DETAILED RECOMMENDATIONS

Detailed recommendations for construction of adobe houses are contained in 'Manual para la construccion de Viviendas con Adobe' prepared by Commision de Reconstruccion y Rehabilitacion de la Zone Afectada (CRYRZA) and proyects Experimental da Vivienda (PREVI) (Ministerio de Vivienda-Naciones Unidas)(5) which resulted from the observations, analysis and conclusions of National and Foreign Experts on the Seismic Effects in Peru on May 31, 1970, and the experience in adobe building put into practice successfully in other countries. Taking these and other information (2,3) into account, Committee II of International Association for Earthquake Engineering (IAEE) on Basic Concepts of Seismic Codes Non-Engineered Construction has prepared a chapter on "Buildings in Clay Mud or Adobe" as part of the total recommendations (4). This chapter is reproduced here in an Appendix to this paper for ready reference.

NEEDED STUDIES

Research investigations are needed to determine the earthen wall strengths, shrinkage properties and water soaking characteristics etc. which should also be related to the basic soil properties. Appropriate and economical admixtures are to be found which would improve the characteristics in a desired manner. The simple recommendations as presented in this paper are yet to be investigated by actual tests so as to determine their real value for earthquake resistance. Then only the real factors of safety of earthen buildings under severe earthquake conditions could be known.

CONCLUSIONS

Until actual test results become available, it is expected that the simple and very economical methods of construction and strengthening of the earthen houses suggested in this paper should go a long way in achieving safety against collapse of such houses in moderate earthquake intensities. These are strongly recommended for general adoption.

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4. "Basic Concepts of Seismic Codes" The International Association for Earthquake Engineering, 1980, Vol. I, Part 2, Chapter 5, pp. 83-89.

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7. Steinbrugge, K.V. and Flores R., "The Chilean Earthquakes of May 1960, A Structural Engineering View Point, "Bull. Seismological Society of America, Vol. 53, No. 2, Feb. 1963, pp. 225-307.

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TABLE 1

Comparative Study of Damage in Different Constructions (7,1)

Sl. No.	Type of Construction	Total Number of Dwellings	Repairable damaged %	Dangerous, must be dismantled %	Destroyed %	Total of Damaged ones %	Order of Usefulness with respect to Dangerous Destroyed
1.	Reinforced Brickwork	1781	8,3	1,4	0,8	10,5	2nd
2.	Reinforced Concrete Blockwork	5	20,0	0,0	0,0	20,0	1st
3.	Unreinforced Brickwork	1149	37,6	33,6	11,6	82,8	6th
4.	Unreinforced Concrete Blockwork	6	16,7	33,3	16,7	66,7	7th
5.	Combined reinforced and unreinforced brickwork	1334	37,7	20,8	3,5	52,0	5th
6.	Wood Frame with Masonry	147	53,0	19,7	3,5	76,2	4th
7.	Wood Frame	1516	24,8	8,0	1,9	34,7	3rd
8.	Adobe	187	17,0	52,5	23,0	92,5	8th
	Total dwellings considered	6125					

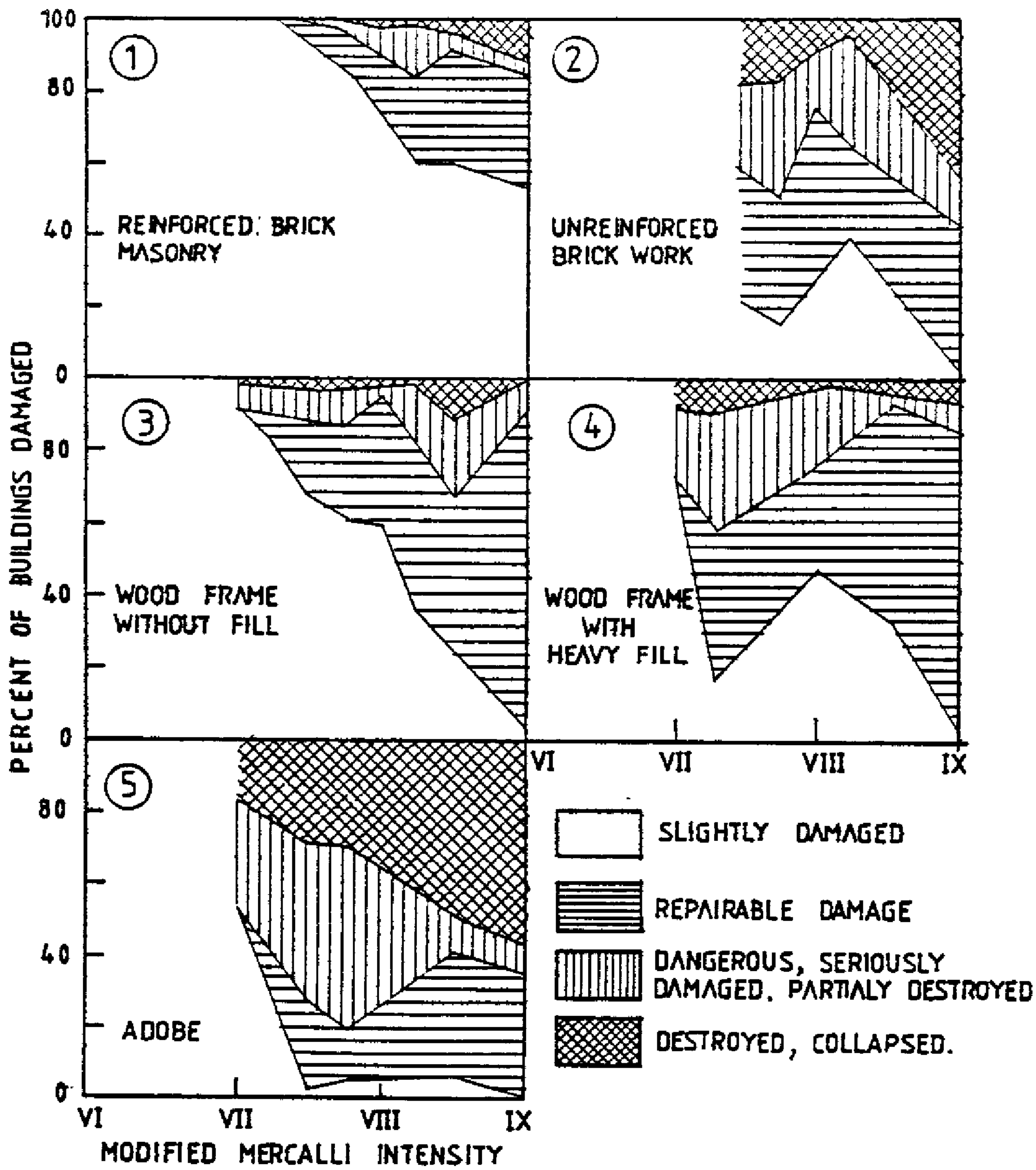


FIG. 1 – DEGREE OF DAMAGE IN BUILDINGS

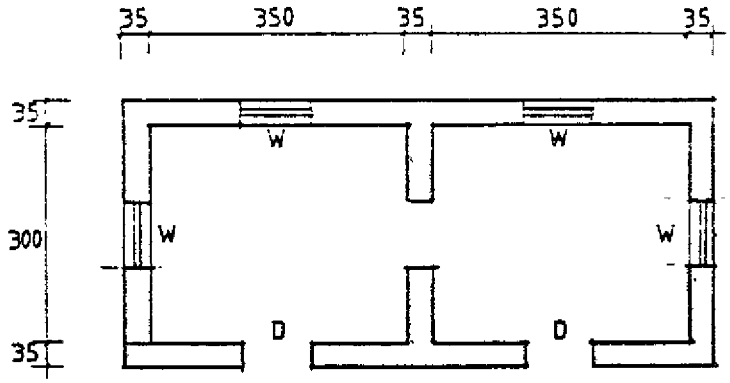


FIG. 2 _ INTERMEDIATE PARTITION IN LONG ROOMS

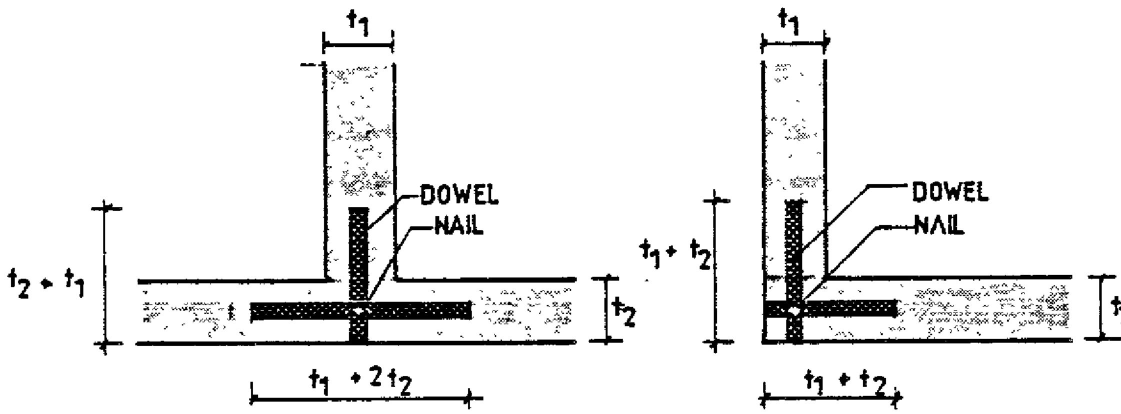


FIG. 3. DOWELS AT CORNERS AND JUNCTIONS OF WALLS

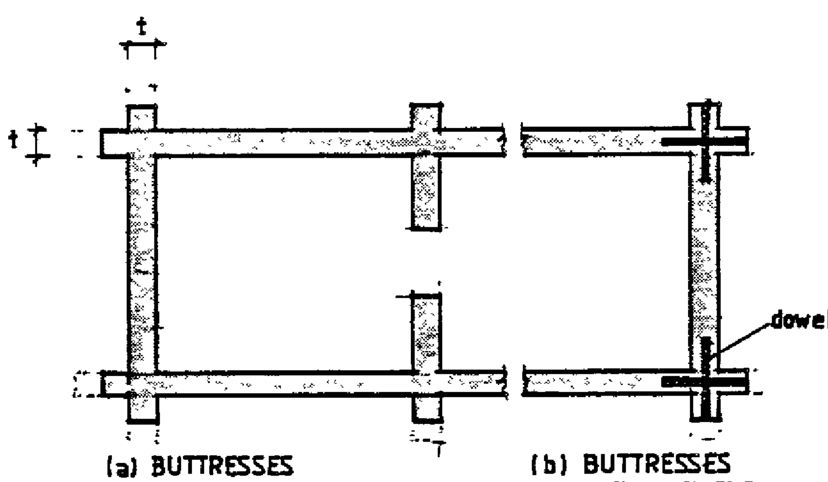


FIG. 4. ARRANGEMENT OF BUTTRESSES

CHAPTER 5

BUILDINGS IN CLAY MUD OR ADOBE

5.1 INTRODUCTION

There are many areas in the World where either the small buildings are constructed in clay mud; or unburnt sundried bricks are laid in mud mortar what is called as Adobe construction. Due to negligible tensile and shear strength and heavy weight such buildings are quite unsuitable in seismic zones A, B and C. Yet economic condition of the people may oblige them to continue to build their houses and cattle sheds in this way. Therefore, although the safety considerations in earthquake zones will demand prohibitation of such constructions, practical necessity of providing at least a shelter accomodation to the people will justify their continuation in future. With this view suggestions are given here to incorporate at least some earthquake resistance in such buildings.

Recognising that methods of forming, drying, stacking and transforting the adobe are peculiar to local conditions, recommendations are made here in those respects only which will have general application.

5.2 CAUSES OF FAILURE OF ADOBE BUILDINGS

The main causes of failure of adobe buildings in earthquake are briefly illustrated in Fig. 5.1.

5.3 DESIRABLE CONSTRUCTION FEATURES

5.3.1 Quality of Adobe

The earth used in mud houses and adobe (sundried bricks or blocks) should be of good quality as follows:

a) A mud paste made with small quantity of water so that the mud does not stick to hands should be capable of being rolled in the form of a thin thread between 5 and 15 cm long without cracking. If it cracks below 5 cm, clay is to be added; if it does not crack below 15 cm, sand is to be added.

b) Sufficient quantity of fibrous materials (straw, cane baggasse, horse hair, etc) should be added to the clay before making adobes.

c) After 4 weeks of sundrying the adobe it should be strong enough to support in bending the weight of a man (Fig. 5.2). If it breaks, more clay and fibrous material is to be added.

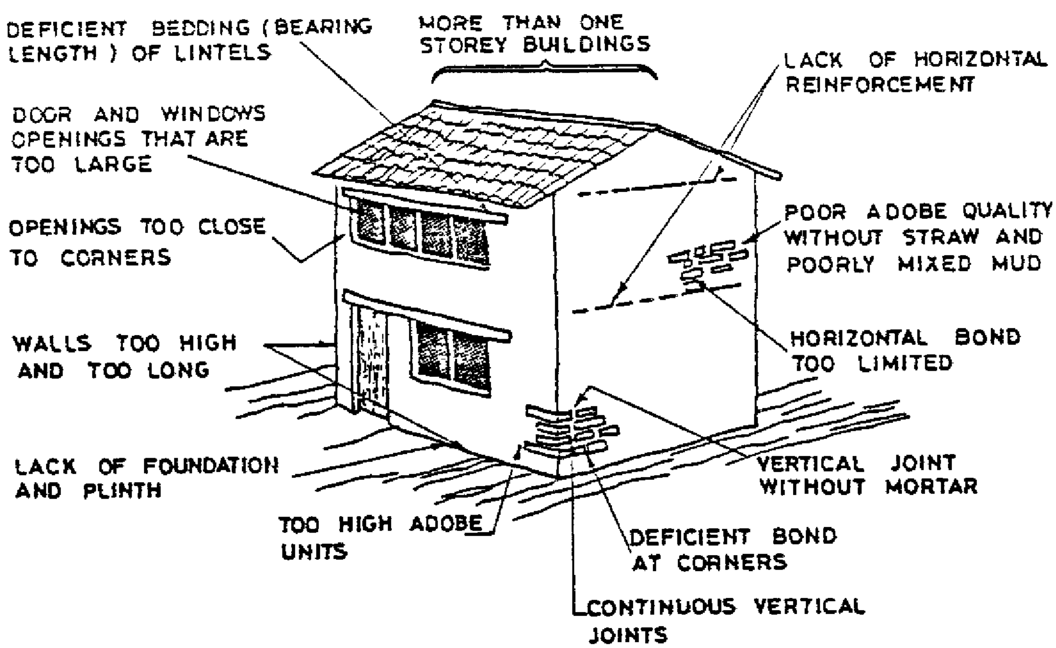


FIG. 5.1 - GRAPHIC SUMMARY OF CAUSES OF FAILURE

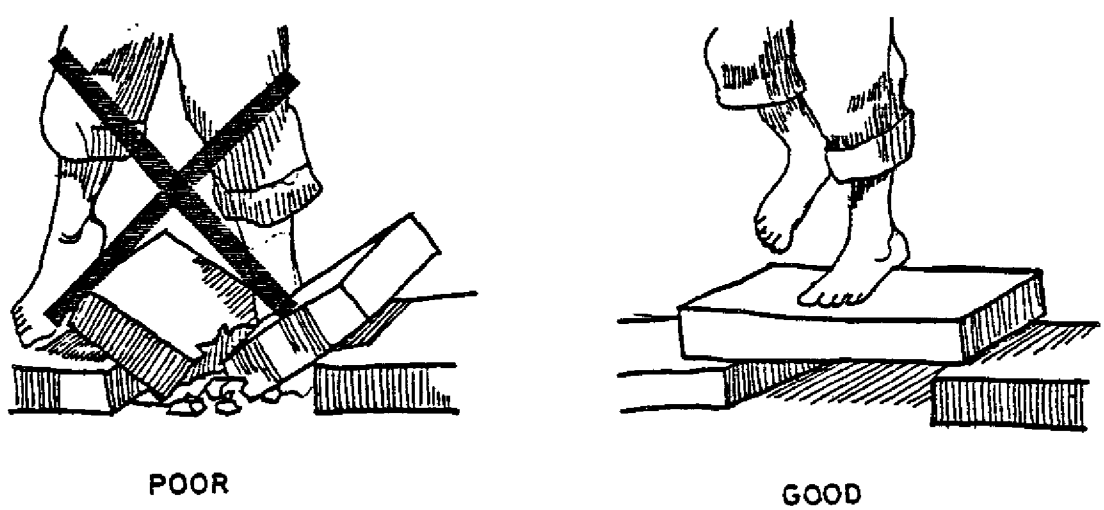


FIG. 5. 2 - TESTING STRENGTH OF ADOBE

5.3.2 Foundations

a) The strip foundation for the walls should have its width at least 1 1/2 times the thickness of wall and its depth a minimum of 40 cm below ground level.

b) The foundation should preferably be made in lean cement concrete with plums (cement:sand:gravel:stones as 1:4:6:10). Lime could be used in place of cement in the ratio lime:sand:gravel as 1:4:8.

5.3.3 Plinth Masonry

The wall above foundation up to plinth level should preferably be constructed from stone or burnt bricks laid in lime mortar 1:3 or clay mud. The height of plinth should be above the flood water line or a minimum of 30 cm above ground level. It will be preferable to use a water proofing layer (see 5.4.3b) at the plinth level before starting the construction of superstructure wall. If adobe itself is used, the outside face of plinth should be protected against damage by water by suitable facia or plaster. A water drain should be made slightly away from the wall to save it from seepage.

5.3.4 Construction of Walls.

The usual good principles of bonds in masonry should be adopted for construction of adobe walls, that is,

a) all courses should be laid level.

b) the vertical joints should be broken between two consecutive courses by overlap of adobes.

c) the clay mud should be the same as used in making the adobe.

d) the right angle joints between walls should be made such that the walls are properly joined together and a through vertical joint is avoided.

e) the walls should be covered with water repellent plaster on the outside by mixing bitumen cut-back in mud-mortar (See 5.4.3).

5.3.5 Dimensions of Walls

a) The length of a wall, between two consecutive walls at right angles to it, should not be greater than 10 times the wall thickness.

b) When a longer wall is required, the walls should be strenthered by intermediate vertical buttresses.

c) The height of the wall should not be greater than 8 times its thickness.

d) The thickness of load bearing walls may be kept one, 1 1/2, 2 or more units of the adobe length depending on the desired length and height of wall. In the case of clay mud walls, parabolically tapering thickness will be seismically better (Fig. 5.3).

e) The height of the adobe building should be restricted to one storey plus attic only.

5.3.6 Openings in Walls

a) The width of an opening should not be greater than 1.20 m.

b) The distance between an outside sorner and the opening should be not less than 1,2 m.

c) The sum of the widths of openings in a wall should not exceed one-third of the total wall length.

d) The bearing length (embedment) of lintels on each side of an opening should not be less than 50 cm.

5.4 SEISMIC STRENGTHENING FEATURES

5.4.1 Collar Beam or Lintel Band

A horizontal continuous reinforcing and binding tie should be placed coinciding with lintels of door and window openings in all walls. Proper connection of ties placed at right angles at the corners and junctions of walls should be ensured. These could be in the following forms:

a) Unifinished rough cut lumber in single pieces provided with diagonal members for bracing at corners (Fig. 5.4a).

b) Unifinished rough cut lumbers two pieces in parallel with halved joints at corners and junctions of walls (Fig. 5.4b). The lumbers may be half round.

c) Sawn lumber 5 x 10 cm in section placed in parallel as in b) above (Fig. 5.4b).

The whole assembly is to be covered with the clay mud and minimum two but maximum four courses of adobe laid over it before placing the roof.

5.4.2 Buttresses

Contruction of buttresses by projecting walls beyond the corner and T-junctions will help to retain the integral action of walls and facilitate the connection of collar beams with each other (Fig. 5.5).

5.4.3 Roof

a) The roof should preferably be of light material, like sheeting of any type.

b) If thatch is used for roof covering, it should better be made water proof and fire resistant by applying mud plaster mixed with bitumen cut-back on both surfaces of the thatch+.

c) The roof beams or rafters should preferably be rested on longitudinal wooden elements for distributing the load on adobe (Fig. 5.6). Preferably two top courses of burnt bricks may be laid instead of adobe for resting the longitudinal wooden elements.

d) The roof beams or rafters should be located to avoid their position above door or window lintels. Otherwise, the lintel should be reinforced by an additional lumber (Fig. 5.7.).

5.5 SUMMARY

The desirable features for earthquake resistance of adobe houses are briefly illustrated in Fig. 5.8.

\+ Cut-back is prepared by mixing bitumen 80/100 grade, Kerosene oil and paraffin wax in the ratio 100:20:1. For 1.8 kg cut-back, 1.5 kg bitumen is melted with 15 grams of wax and this mixture is poured in a container having 300 millimetre Kerosene oil with constant stirring till all ingredients are mixed.
This mixture can now be mixed with 0.03 m^3 of mud mortar to make it both water repellent as were as fire protection of thatch.

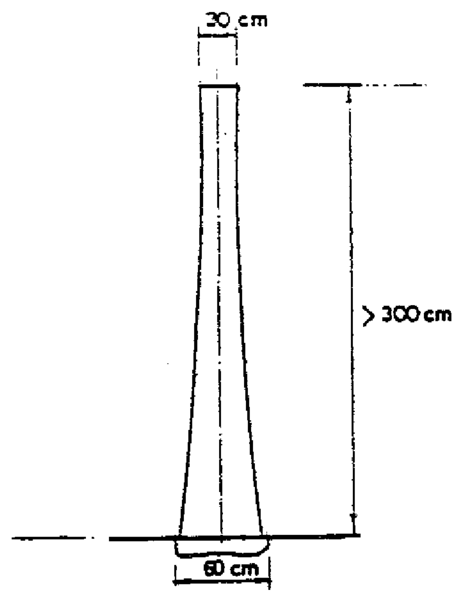
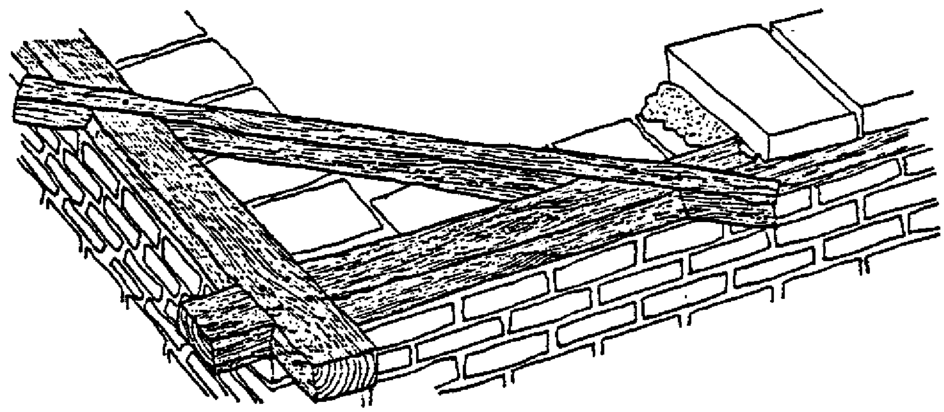
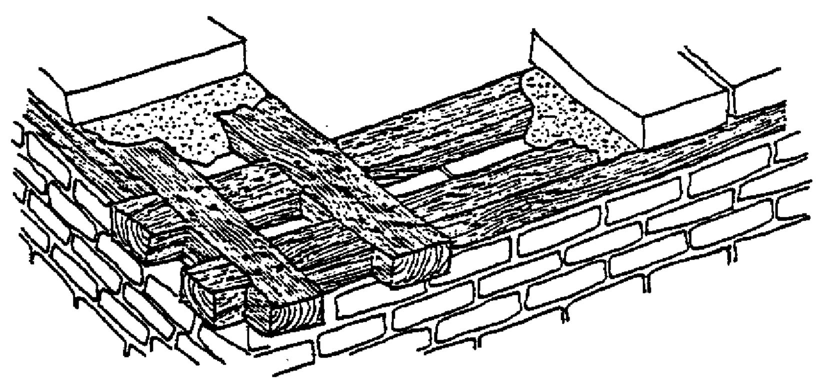


FIG. 5.3- CLAY MUD WALL



(a) ROUGH CUT LUMBER IN SINGLE PIECE WITH CORNER DIAGONAL



(b) ROUGH CUT LUMBERS IN PARALLEL

FIG. 5.4- COLLAR BAND IN WALLS AT LINTEL LEVEL

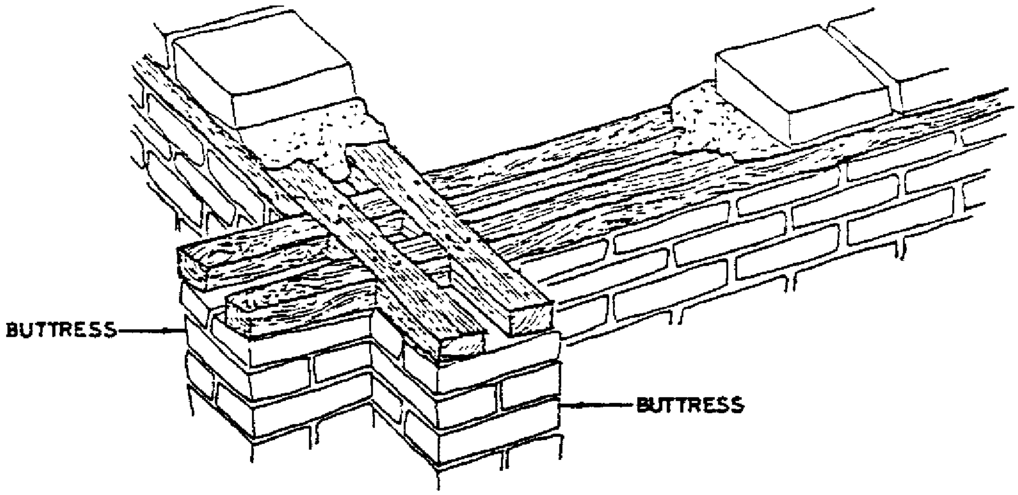


FIG .5.5 - USE OF BUTTRESSES

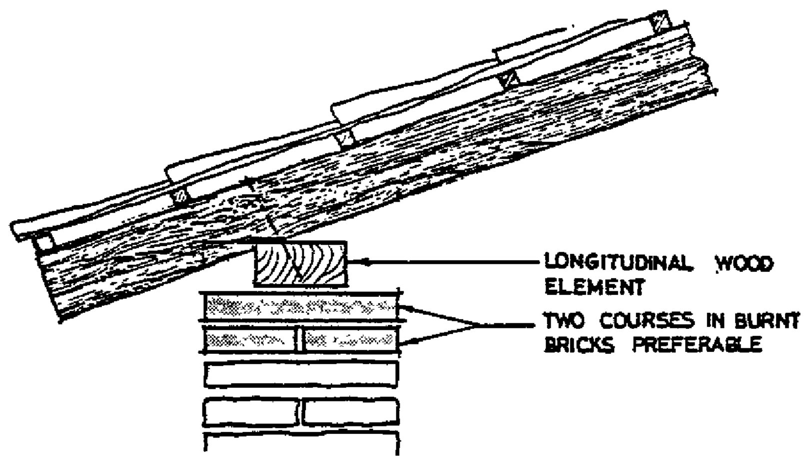


FIG. 5.6 USE OF LONGITUDINAL WOOD UNDER ROOF RAFTERS

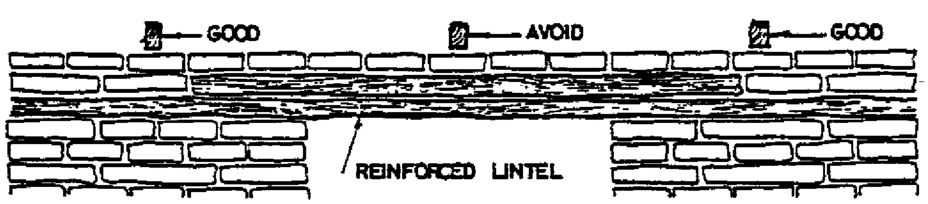


FIG .5.7 - REINFORCING LINTEL UNDER FLOOR BEAM.

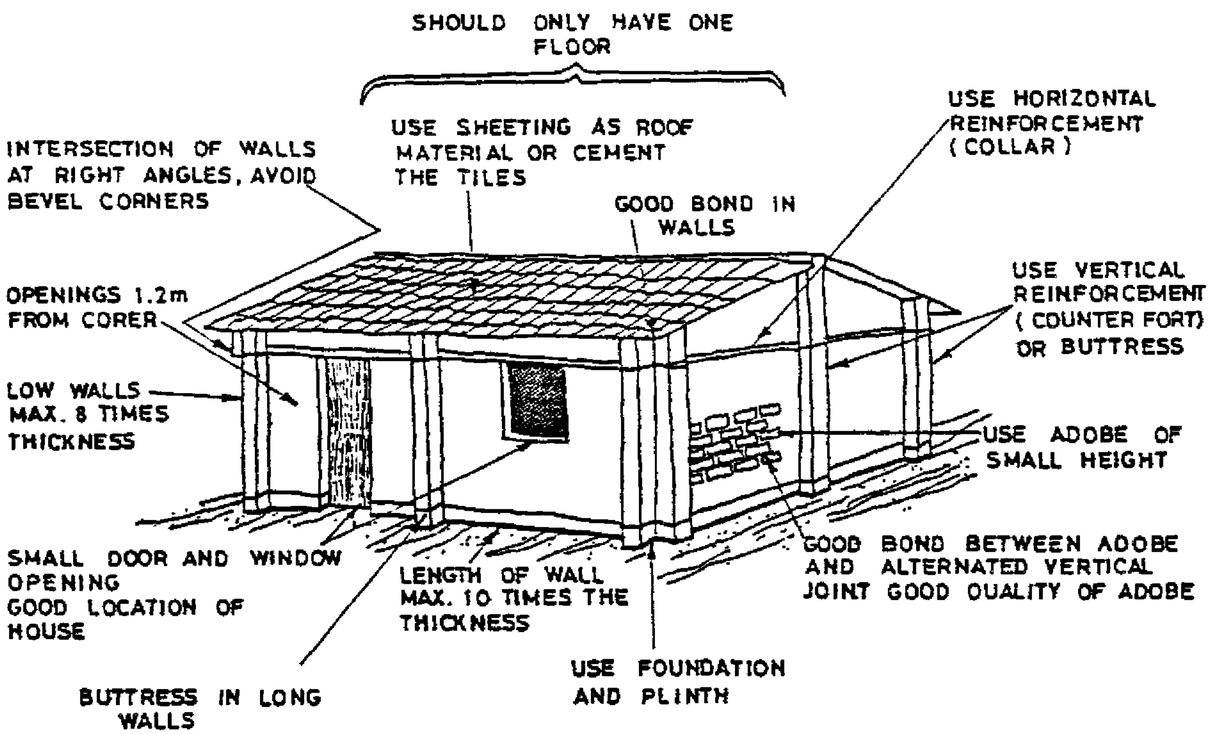


FIG. 5.8 - GOOD FEATURES OF EARTQUAKE RESISTANT CONSTRUCTION.