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EARTHQUAKE RESISTANT CONSTRUCTION FEATURES IN LOW COST BUILDINGS

By

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Introduction

'Low cost' building is a relative term. The standard of construction indicated by it will differ from region to region and country to country depending upon the level of socio-economic development. One common fact is however observed that usually the low cost construction, besides having inferior specifications, has poor quality of construction as well. In seismicallv active areas the results are diastrous as has been amply exemplified by the recent earthquakes in Chile, India, Iran and Turkey. Assuming that in most countries, adobe, unreinforced brick and stone masonry and timber constructions will continue to constitute low cost structures, their earthquake resistant construction features are discussed in this paper.

The problem of earthquake resistant construction of small building has attracted the attention of several research workers during the last few years and a number of papers have been published on the subject.[1-8] The reports regarding damage to structures during the past earthquakes have brought out the weaknesses in construction and suggested improvements for future construction such as those contained in the reports[9,10] of Bihar earthquake of 1934 and Koyna earthquake of December 11, 1967. The aim of this paper is to review briefly the available information and summarize the main principles of earthquake resistant construction.

Behavior of Different Construction in the Past Earthquakes.

The random vibrations which are associated with earthquake motions and propagated in all directions at speeds of about 5 km per second actually subject the structures to large scale field tests. As a result, the poor constructions collapse, weak ones suffer the damage to a large extent, strong ones get away with minor damage and the exceptionally sound constructions remain intact. Since all parts of a structure are shaken, the weak links can not escape damage. They give in first and in turn lead to distressing of stronger parts as well.

Earthquakes have been occurring in most parts of the world. Therefore, all types of constructions have been put to this type of severe test in one or the other earthquake. For instance, in India, the buildings constructed from brick, stone, mud, timber or a combination thereof have been usually involved in the seismic regions.[9,10,11] Occasionally some reinforced concrete buildings have also been present in earthquake affected area and their behavior has presented a striking contrast to that of the masonry constructions. The old Japanese earthquakes present the behavior of wood framed buildings with or without brick panel filling.[12] Reinforced concrete-block constructions and reinforced concrete framed constructions are more recent examples in earthquake behavior.[13,23] The Alaska earthquake of 1964 presented full size tests of framed constructions as well as that of prefabricated constructions in reinforced and prestressed concrete.[14] The Caracas earthquake of 1967 tested multi-storyed reinforced concrete buildings with hollow-brick panel fillings,[15] the kinds of which are being used in Yugoslavia and in India too but using the solid bricks. At many places the shaking of the structures has been the reason for its damage or collapse but in others, the foundation has been the villain as its settlement led to the straining of the structure. Thus the behavior of most types of constructions can be studied separately. The Chilean earthquake of May 22, 1960 offers at one place a comparative study of various constructions which are particularly used in buildings of a few storys height.[16] During this earthquake, about 45000 dwellings of various types were damaged of which about 10% were damaged beyond repairs. Table 1 presents a comparison of their earthquake behavior. The percentages given in the Table refer to the total number of buildings of a particular type. The order of usefulness with respect to loss of life as indicated therein has been worked out on the basis of percentages of 'dangerous' and 'destroyed' buildings combined. Another survey of damage to such buildings in ten chilean earthquakes is summarised in Figure 1 showing the percentages of houses developing different degrees of damage in zones of various seismic intensities.[25] These generalized results confirm the results of Table 1. Similar behavior has also been seen in the earthquakes in India where frequently adobe, random rubble masonry and composite constructions of unburnt and burnt bricks are often encountered.[9-11] These types may at best be graded slightly higher than unreinforced adobe but below unreinforced brickwork. The diagonally braced timber frames as often used in old houses in Kashmir valley[17] with or without brick nogging (see Fig. 2) are highly resistant to earthquakes and may be classed with the first two types in Table 1.

From the numerous observations of damage and non-damage during earthquakes such as the Chilean earthquake described above the constructions can be divided in the following four categories indicating their suitability.

(i) Highly suitable constructions are steel or reinforced concrete rigid frames and diagonally braced timber buildings. Such buildings have minimum weight, high strength to lateral forces and high ductility or deformation capacity which are the most desirable qualities for resisting the applied forces and absorbing the kinetic energy fed into the structure by the ground shaking.

(ii) Moderately suitable construction are reinforced block or reinforced brick masonry and timber frames with

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brick nogging or sufficient brick walling acting with it. These buildings have moderate weight, high lateral lead resistance and moderate ductility.

(iii) Feebly suitable constructions are unreinforced brick, block or stone masonry buildings with horizontal runners of timber, reinforced concrete or reinforced brickwork at plinth, floor and roof levels having proper connections at corners; or the same type of buildings without the runners but constructed in good cement or lime mortars and having flat roofs like reinforced concrete slabs. These buildings have large weight, some amount of lateral strength and little ductility. They can be much improved by introducing vertical steel bars at corners and junctions of longitudinal and cross walls and reinforced concrete band at lintel levels of all storys as recommended in Is: 4326-1967 Code of Practice for Earthquake Resistant Construction of Buildings.[18] These provisions have been found to cost about 4 to 8 percent of the cost of buildings in areas of moderate seismicity having Modified Mercalli Intensity VIII (19). With such strengthening measures the buildings can be brought to almost the same level of suitability as reinforced block or reinforced brick masonry.

The beneficial effect of introducing small amounts of reinforcement at critical locations will be evident from the test results on three storyed building models made to one-third scale shown in Figure 3.[26] All models were constructed in 1:6 cement-sand mortar. First model (WR) was constructed without reinforcement, second (CR) with .05% reinforcement located at corners, third (CLR) with similar steel at corners plus reinforcement all round at lintel level forming a band, and fourth (CLJR) having vertical reinforcement at corners and jambs of operings as well as lintel level band. The ultimate loads taken by the four models are compared in Figure 4. A typical load deflection curve of models CR is shown in Figure 5. The load-deflection curves of models CR and CLRJ were similar but that of WR was almost a straight line upto the load when first story cracked in flexural tension. Thus it is seen that even with small percentage of vertical steel at corners and ductility of the construction is increased which provides energy absorption capacity into the structure enabling it to withstand large shocks without collapse. Addition of lintel band steel along with the vertical steel resulted in increased strength as well as increase in ductility. For severe seismic zones this combination is recommended.

(iv) Unsuitable constructions are unreinforced brick or block or stone masonry construction in mud or weak mortars, composite constructions, adobe and mud huts. Such buildings have large weight, little or no lateral strength and almost no ductility. The lateral strength of brick or block constructions can be improved by constructing the jambs of openings and a few courses at plinth and floor levels in cement sand mortar and using reinforced concrete or reinforced brick lintels over openings with sufficient length of bearing say 20 to 25 cm, over the jambs as shown in Figure 6. Jack or flat arches for covering openings must be avoided, or otherwise, tie rods used for keeping them intact.

Besided the factors of weight, strength and ductility, the other important factor is quality of workmanship. Damage is found to be less in well constructed buildings following the standard specifications than in the poorly constructed buildings. Incidentally, the quality of construction also drops down generally with the order of suitability mentioned above because of the nature of materials involved and the skill required to do the job. For example, a reinforced brick construction will usually have better workmanship than unreinforced one.

Effect of foundation Soil upon Structural Behavior.

Softness of soil has been observed to have pronounced effect on the structural behavior of buildings during earthquake as evidenced in the Bihar earthquake of 1934[9] and Kern County (USA) earthquake of 1952.[20] In the former, houses founded on rock out-crops suffered much less damage than similar buildings in the valleys resting on alluvial deposits. Table 2 shows the behavior of different types of construction resting on different types of foundation materials as observed in the Kern County earthquake.

The general trend of damage observed in most earthquake is similar to that shown in Table 2, that is, the damage increased with the softness of ground. But the reverse also happens sometimes as in the case of Long Beach (USA) earthquake of 1933[21] where the damage to buildings on soft soil on the beach was somewhat less than those on more firm ground. It appears that the short period structures suffered more damage in that earthquake than long period ones due to the short period characteristics of the earthquake.

Some soils like poorly graded sands and sand-gravel mixtures are found to loose their structure when vibrated in dry condition causing large amount of settlement and they liquefy and lose their shear strength if saturated with water and subjected to vibrations. In this condition, the buildings sink into the ground. The same type of behavior is seen with the water bearing soft alluvial soils. Large areas liquefied during the Bihar earthquake of 1934 and Dhubri (Assam) earthquake of 1930.[22] Most striking examples of liquefaction of soil and sinking of buildings occurred in Niigatta (Japan) earthquake of 1964.[23] The contrast in the behavior of structures founded differently also provided the remedy against such failures. The buildings which were founded on bearing piles remained standing vertical although the soil slumped down at the surface whereas those having shallow footings sank, tilted or overturned. Therefore, point bearing piles must be used where loose soils having Standard Penetration value N less than 10 are encountered. Driven piles are to be preferred since the vibrations and compaction caused by them will improve the soil through which they pass. Friction piles may be used in the case of soft clays.

It, therefore, follows that from the point of view of behavior during earthquake, buildings should be founded on rock where available. Otherwise, the following types of foundations may be adopted in the decreasing order of preference depending upon the height, size and importance of the building:

(1) Bearing piles in cohesionless material resting on stiff soil having high N value.

(2) Friction piles in cohesive material.

(3) Solid raft under the whole building.

(4) Continuous reinforced concrete strip footings running in both directions interesting and monolithic with each other.

(5) Individual reinforced concrete footings connected together by plinth beams.

(6) Continuous unreinforced strip footings with plinth level band (reinforced concrete runner).

(7) Unconnected individual footings or unreinforced strip footings.

Sand piles may be used for compacting, draining and consolidating loose soft fills.

General Planning and Details

In addition to the main factors of type and quality of construction of structure and its foundation, there are other more or less important factors influencing the behavior of buildings during earthquakes. These are briefly stated in the following:

(a) Plan and elevations - Buildings irregular in plan or elevation are found to develop torsional stresses. Therefore, those having symmetry in plan and elevation are better. Compact plans are seismically better than extended plans with several projections. E, U, T or L shaped plans must be provided with 'separation sections'[2,18] so as to reduce them to an assemblage of rectangular units.

(b) Roofs and Floors - Roofing and flooring units, where used instead of monolithic slabs, are to be tied together and fixed to the supporting members so as to prevent their dislodging due to shaking. Therefore, corrugated iron or asbestos sheets are better than earthen tiles, slates etc. Joists of timber or reinforced concrete, if used for supporting flooring units, should be blocked at ends and tied together so as not to allow any relative displacement between them. Jack arched roofs are to be avoided unless ties are used in every span.

(c) Load Bearing Walls - The damage is found to increase with height and the collapse of a multi-storyed building is much more disastrous in terms of loss of life and property. Therefore, height of masonry buildings may be restricted to about three storys.

Studies carried out on the effect of openings on the strength of walls indicate that they should be small and more centrally located.[1,24] IS: 4326-1967[18] provides the following restrictions on the size and position of openings:

(i) The openings shall preferably be located away from the corner by a clear distance equal to at least 1/4 of the height of opening.

(ii) The length of opening shall not be more than half the length of the wall between consecutive cross walls.

(iii) The horizontal distance (pier width) between two openings shall not be less than 1/2 of the height of the shorter opening.

(iv) Where the openings do not comply with the above requirements, they should either be boxed in reinforced concrete or reinforcing bars provided all round them through the masonry.

(d) Projecting Parts - Overhanging parts such as projecting cornices, balconies, parapets and chimneys are the first to fall during an earthquake. Not only that there is damage to the building but such parts, when they fall, injure the people who may be running out of the houses or moving on the streets. Such projecting and overhanging parts should be avoided as far as possible or enough care should be taken to reinforce them and anchor them to the main structure adequately.

(e) Suspended Ceilings - Suspended ceilings often used for aesthetic reasons, are usually brittle and weak and incapable of resisting horizontal forces with the result that during an earthquake they crumble and fall down. Thus special care is required in the design of suspended ceilings if they cannot be avoided. They should be strong and rigidly tied to the roof or be ductile enough to withstand the strains during ground motion.

Similarly, the plaster on the ceiling frequently falls down.[11] The thickness of such plaster should be kept to a minimum.

(f) Damage to Non-Structural Parts - During the past earthquakes it has sometimes happened that whereas the structural frame was strong enough to resist the earthquake forces, the non-structural elements like brick filling in a timber frame, which is not supposed to carry any other loads besides its own weight, have fallen out of the frame.[11] Therefore, it is necessary that the non-structural parts should be well tied to the structural framing. To avoid damage to window feames or glazing, the drift in buildings should also be limited to about 1.5 cm per story height.

Conclusions

From the behavior of buildings during past earthquakes as presented above, it may be concluded that the most desirable qualities for earthquake resistance are light weight, high lateral load resistance, large ductility and non-yielding foundation. Besides the building should have simple regular plan and elevations, well integrated construction of all units, with as few openings in walls and as few projecting parts as possible.

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TABLE 1

COmparative Study of Damage in Different Constructions

Sl. No.	Type of construction	Total Number of Dwellings	Repairably damaged %	Dangerous must be dismentled %	Destroyed %	Total of Damaged ones %	Order of Usefulness with respect to loss of life.
1.	Reinforced Brickwork	1781	8.3	1.4	0.8	10.5	II
2.	Reinforced Concrete Blockwork	5	20.0	0.0	0.0	20.0	I
3.	Unreinforced brickwork	1149	37.6	33.6	11.6	82.8	VI
4.	Unreinforced Concrete Blockwork	6	16.7	33.3	16.7	66.7	VII
5.	Combined reinforced and unreinforced brickwork	1334	37.7	20.8	3.5	52.0	V
6.	Wood Frame	1516	24.8	8.0	1.9	34.7	III
7.	Wood frame with Masonry	147	53.0	19.7	3.5	76.2	IV
8.	Adobe	187	17.0	52.5	23.0	92.5	VIII
	Total dwellings considered	6125					

TABLE 2

Effect of Foundation Material on Damage

Sl. No.	Type of Building	Foundation Material	Damage
1.	Steel or Reinforced concrete	Thick alluvium	None
2.	Framed Building	-do-	Little or no damage
3.	Reinforced Block	-do-	Little or no damage except for cracking of unsupported facade
4.	Unreinforced Brick or Block	-do-	Extensive damage or collapse
5.	Stone masonry	i) Thick alluvium ii) Rock	Moderate damage to collapse Little or no damage
6.	Adobe	i)Thick alluvium ii)About 3m deposit iii)Rock	Collapse Extensive cracking slight cracking or no damage

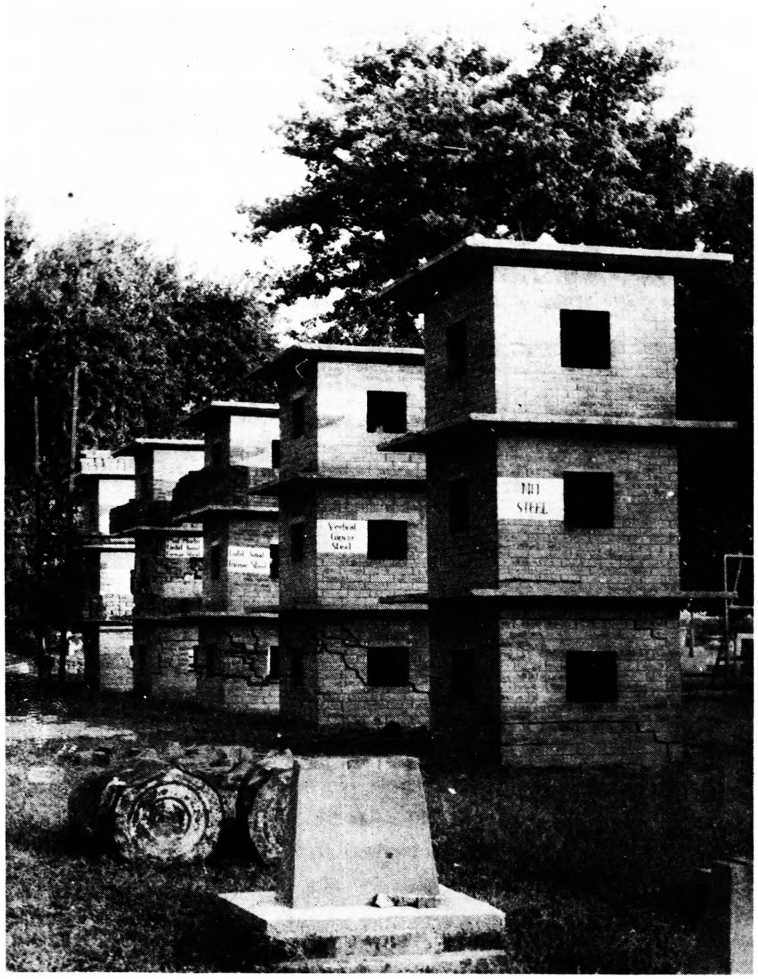

Fig. 3 (a) Three storeyed models, after tests

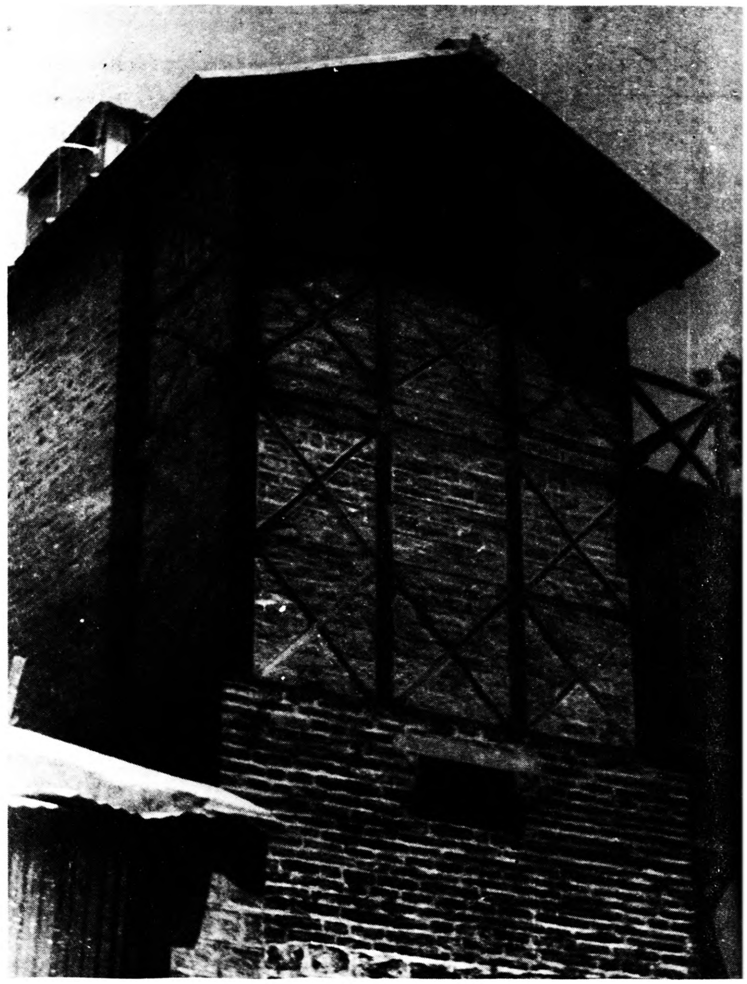

Fig. 2 Wooden house with brick nogging

Fig. 3 (b) Three storeyed models, simulation of dead load, loaded horizontally for ultimate strength

DETAILS	MODEL WR WITHOUT REINFORCEMENT	MODEL CR WITH REINFORCEMENT AT CORNERS	MODEL CLR WITH CORNER STEEL AND LINTEL BAND	MODEL CLJR WITH CORNER STEEL AND LINTEL BAND & JAMB STEEL
ULTIMATE LOADS AT FAILURE	2200 lb. 2750 lb. 2750 lb.	0 lb. 4620 lb. 7920 lb.	1320 lb. 4950 lb. 8140 lb.	2200 lb. 4950 lb. 4950 lb.
S: TOTAL SHEAR @ A	7700 lb.	12540 lb.	14410 lb.	12100 lb.
M: TOTAL MOMENT @ A	50350 lb. ft.	52900 lb. ft.	70100 lb. ft.	71300 lb. ft.

FIG. 4 – COMPARISON OF EXPERIMENTAL RESULTS OF ULTIMATE LOAD TESTS.

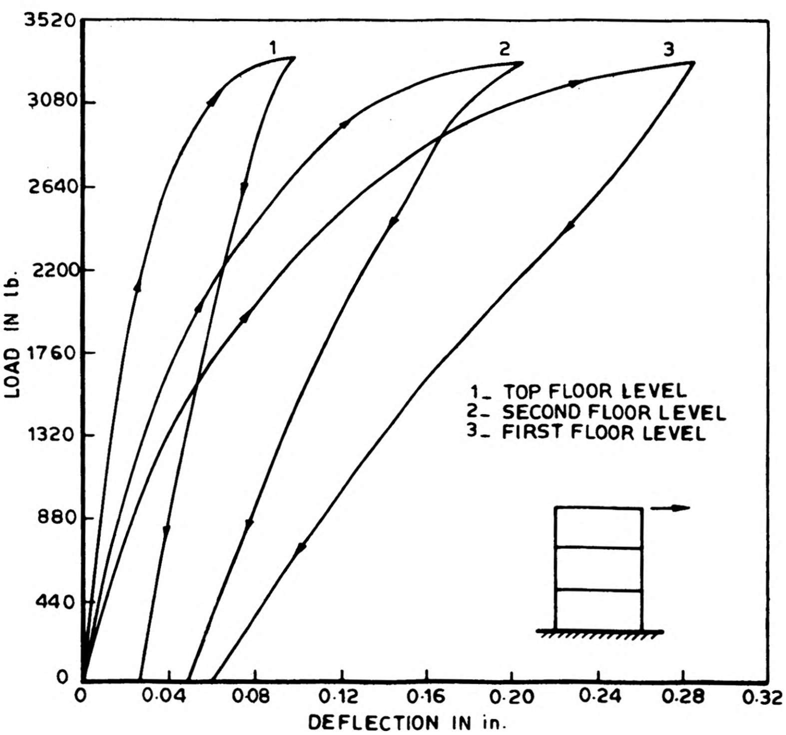

FIG. 5 _LOAD-DEFLECTION CURVES (MODEL CR)

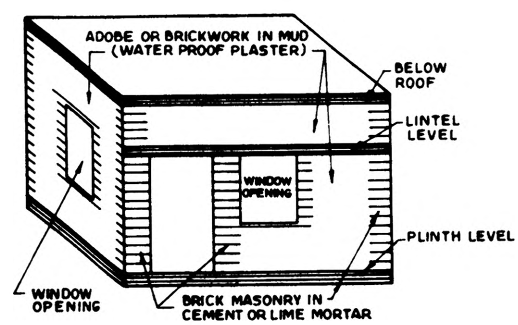

FIG. 6 _STRENGTHENING ADOBE OR BRICK-WORK IN MUD

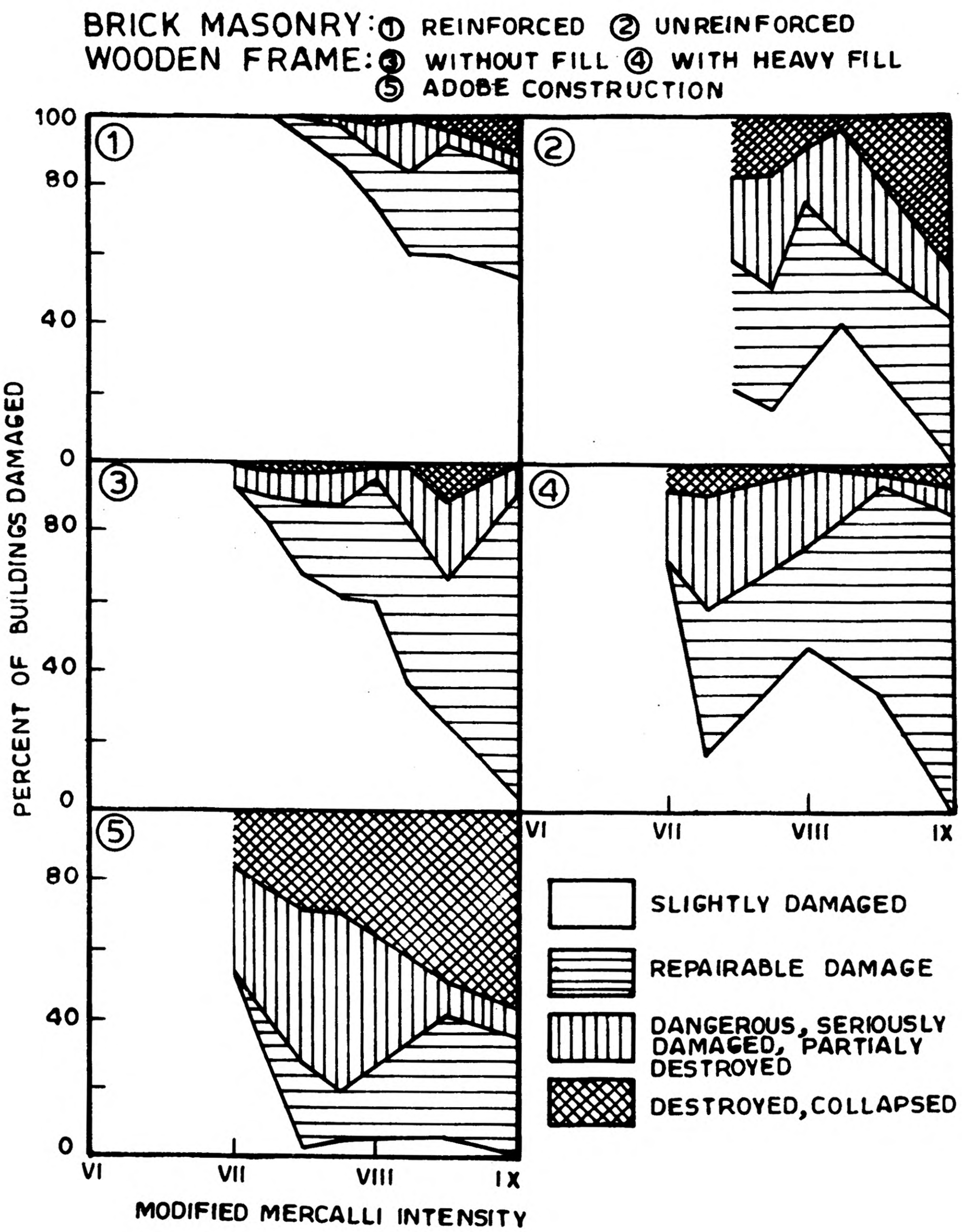

FIG. 1 _DEGREE OF DAMAGE IN BUILDINGS