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EARTHQUAKE RESISTANT HOUSES IN SEISMIC AREAS

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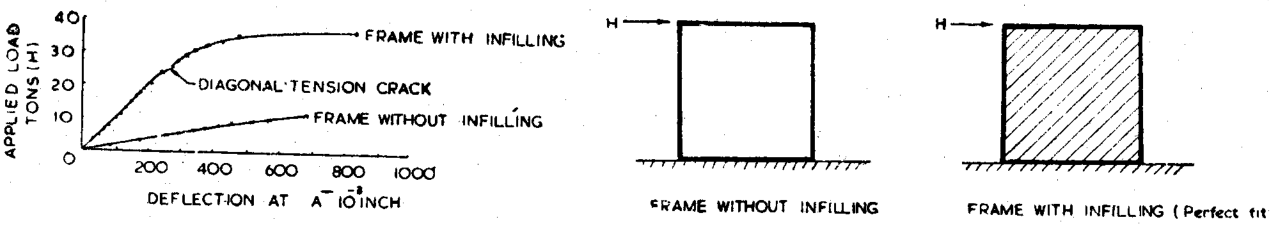
INTRODUCTION

India has been divided into various Seismic Zones[1]. In the most active zone, it may be envisaged that more than 80% of the population lives in villages. The majority of houses in villages have walls of mud mixed with straw together with thatched roofs on timber or bamboo framing. The other common type of construction favoured in villages is stone or brick masonry houses with flat or sloping roof with wooden trusses directly resting on walls. Such a type of construction by itself offers very less resistance to earthquake because the binding mortar has very little tensile strength. I. S. Code 1893-1966 recommends that masonry, particularly mud and rubble masonry, should be avoided in preference to braced timber framed structure which are known to withstand seismic effects better. It has been found that the brick walls enclosed by frames have considerable lateral strength than the wall or the frame acting alone. Fig. 1 shows that the presence of a boundary frame considerably increases the inplane stiffness of the wall. The increase in the stiffness of frame may be directly conceived due to the following reasons :



FRAME WITHOUT INFILLING

FRAME WITH INFILLING (Perfect fit

Figure 1. Single Storey Frame with Concrete Infilling

1. Presence of interaction forces, causing a bi-stress condition, (shear and normal stresses) modifies the mode of deflection of the infilled frames.

2. The inplane moment of inertia of the frame is considerably increased.

December 1967 earthquake in Koyna Nagar revealed that most of the houses in that area were of mud or rubble masonry and suffered very heavy damage. The temporary residential colony for the staff working at the dam site was also constructed with rubble masonry with tiled roof on hinge joined timber trusses which subsequently rested on side walls. In the design and construction of these houses no precautions against the future earthquakes had been incorporated because the Decean Plateau was considered to be one of the most stable regions from geological point of view. In most houses, the end diaphragm walls were merely the filler walls having negligible out of plane stiffness. Only in very few cases, like the guest house, were the trusses supported on columns forming a gable frame structure placed behind each other and connected by longitudinal wooden member at the knee level. Wherever such a frame type construction had been adopted, neither the roof collapsed nor the wall between the columns gave away completely (Fig. 2).

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These observations indicated that the walls confined inside the frame offer a great deal of resistance. Also timber frame structures resist seismic forces better due to their light weight. Concrete structures can resist earthquake forces better due to their elasto plastic behaviour. A brick walled temple which was built at one end of an open hall consisting of a R. C. C. slab supported on R. C. C. columns showed definite signs of cracks at the junction with the roof slab. The R.C.C. structure withstood the shock without any damage.

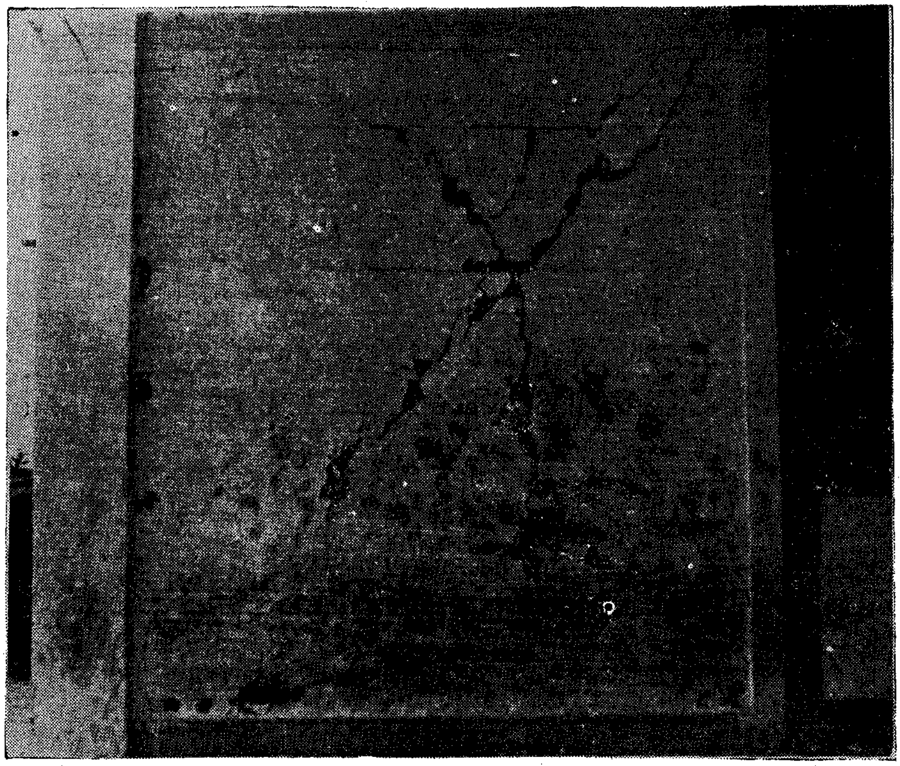


Figure 2. Infilled Frame with Brick Infilling
Koyna Nagar Earthquake

TRADITIONAL CONSTRUCTION IN A SEISMIC ZONE

The conventional mode of construction in several active seismic areas like Kashmir Valley, Himachal Pradesh and Assam consisted of timber frames with the brick infilling. Such frames were also diagonally braced to make them laterally very stiff Although this type of construction is good for resisting earthquake, but it does not offer much protection against severe cold in these regions and has become very expensive due to the high cost of timber and labour.

As mentioned before, the other most common type of houses were of mud or rubble masonry. But the trend during the past 15 years has been to build brick houses in preference to rubble masonry or mud houses But, again the brick work is very heavy and has very little tensile strength. It does not fulfil the requirement of earthquake resistant houses like light in weight and increased inplane lateral strength.

The proposition before an engineer is not only to design earthquake resistant houses but also to ensure that these houses are comfortable to live in. It is also important for the designer to realise that the inhabitants should be ensured a feeling of security in these houses.

The lateral force is a function of time period of the structure and the amount of damping present in the system. It can be seen from average acceleration spectrum curves shown in Fig. 3 that flexible structures are more desirable and damping in these structures does not seem to play a very important part. For 10% damping, the values of average acceleration remain almost constant for structures having time period varying from 1.6 to 2.8 seconds. During normal mode vibrations, the displacements are inversely proportional to square of frequency or are directly proportional to the square of the time period. Thus flexible structures with large time period will experience large deflections, causing a sense of continuous insecurity to the residents. On the other hand if the structure is a rigid structure, accelerations induced will be large and consquently large lateral forces will be experienced. To reduce the inertia forces for rigid structure either the structure should be light weight or it should possess considerable energy dissipation mechanism. An actual earthquake movement contains energy within a large frequency band and if there were no damping most structures would suffer damage in an earthquake owing to resonance. A sufficiently stiff structures having energy dissipation mechanism incorporated in them should be preferred. But it should be borne in mind that resonant conditions are avoided as far as possible.

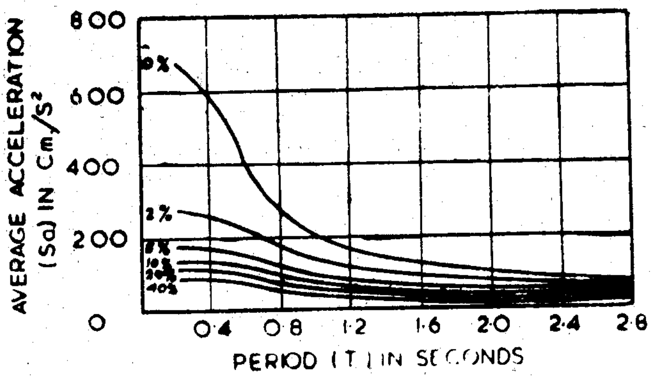
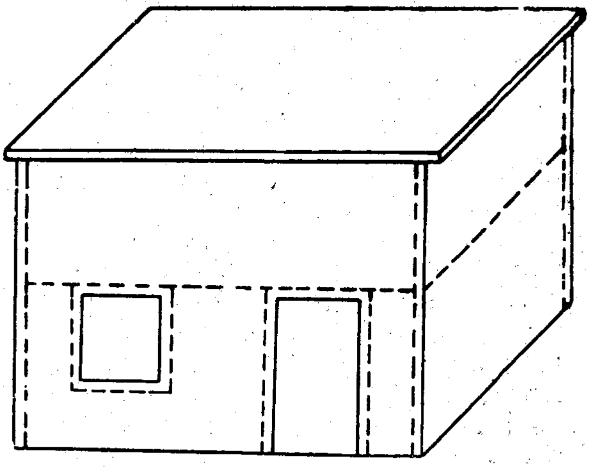


Figure 3. Average Acceleration Spectrum Curves



Reinforced Brick House with Lintel Band and Vertical Steel at Corners and Jambs. (Steel bars shown in dotted lines)

Figure 4. Reinforced Brick Buildings

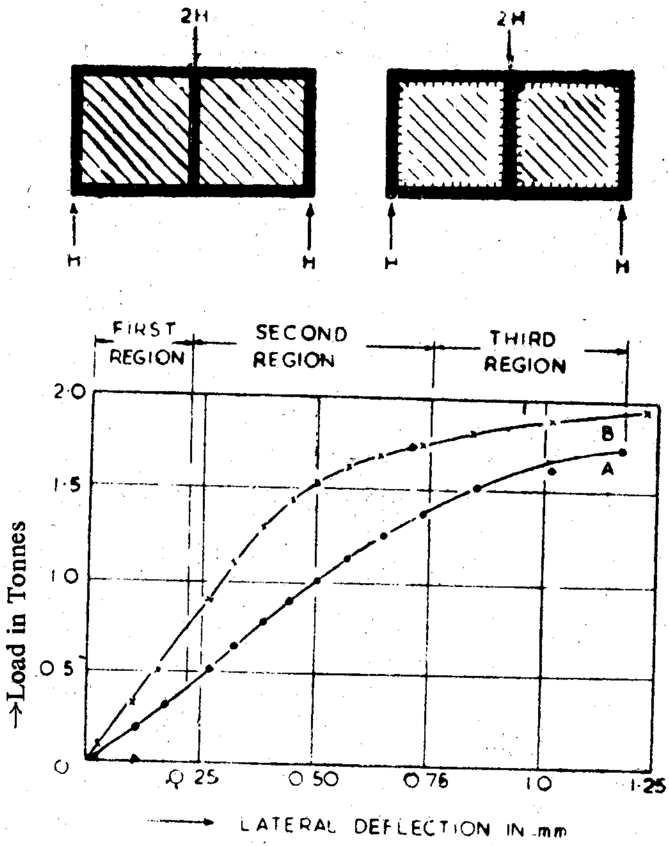
The above discussion deals with the sensitivity vibrations of people living in seismic areas. As regards the comforts of inhabitants, the walls should as well act insulators against heat and severe cold.

Desirable characteristics of a good house which a designer should keep in mind are that these houses should be :

1. Light in weight so that inertia forces are decreased.
2. Structurally sound, that is, possess considerable lateral resistance.
3. During a very heavy shock. the structure may suffer damage but not a complete collapse. Provision for energy absorbing elements be made.
4. The walls should act as insulators against heat and cold.
5. The structure should be economical.

The School of Research and Training in Earthquake Engineering at Roorkee has given some recommendations[2] on the method of strengthening houses against earthquake forces. They suggest that the mud houses should be reinforced by placing a bamboo *jafri* in the middle of the mud wall and, also by damp proof plastering of mud walls developed by C. B. R. I., Roorkee. Further, it is proposed that the joints of the bamboo trusses used for supporting the thatched roofs should be rigid. It is also recommended that for the houses to be built in bricks, a rich mortar should be used. The walls can be further strengthened by providing steel bars as reinforcement at locations indicated in Figure 4. Vertical steel at corners is the most suitable form of reinforcement. In important buildings, vertical steel at door jambs should also be included. This method of strengthening is recommended for the construction of buildings upto three storeys in seismic zones without the fear of suffering heavy damage. However, for more than three storeys they heve recommended use of reinforced concrete or steel frames.

Taking into account the various factors which influence the design of earthquake resistant structures, the author recommends an extensive use of infilled frame construction. It is well known that the action of infilling in a framed structure is to increase the stiffness and strength of the structure. It is because the containment of the brick or concrete infilling serves to increase the strength by holding the wall together after cracking, whilst the infill, by virtue of its very high stiffness, increases the lateral stiffness of frames, which in the bare state is mainly due to the rigidity of joints Fig 5 shows the load-deflection curve for an infilled frame obtained experimentally. It consists of three regions. The first where the lateral stiffness of the infilled frame is small, is applicable for the lower values of the applied load. The lateral stiffness of an infilled frame is defined as the lateral load required to produce unit deflection at the girder level in the plane of the frame. This reduced stiffness is due mainly to lack of fit between the frame and the infill due to shrinkage. As the load is increased the infilled frame behaves essentially as one composite frame and there are no boundary cracks along the junction between the frame and the infill.



A—Without Shear Connectors
B—With shear Connectors

Figure 5. Load Defletion of Square Infilled Frame without Opening

The second region corresponds to a stage in which the separation between the frame and the infill along the unloaded corners has occurred. The length of contact between the frame and the infill depends upon the relative stiffness of the frame and the infill. It is found that for a given panel, the length of contact increases with the stiffness of the frame.

The third region shows the response of the composite frame near failure. The drop in stiffness near failure is due to the decrease in the value of E of the infill material which corresponds to the non-linear part of the stress-strain curve of the infill material.

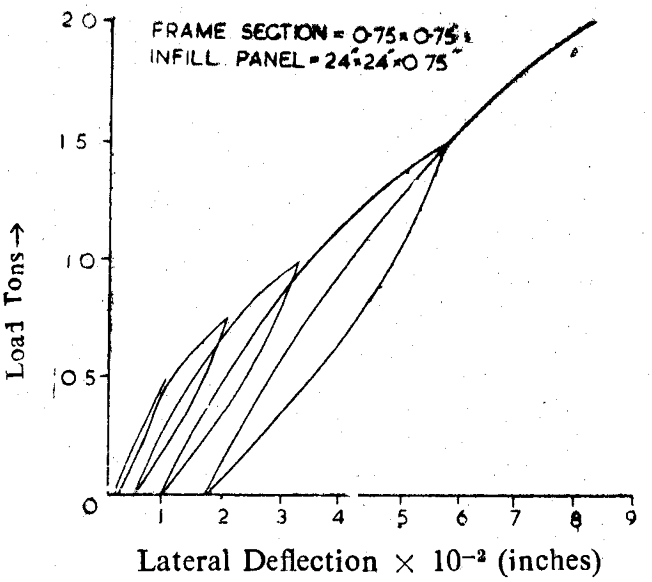


Figure 6. Plot of Half Cyclic Load Tests on An Infilled Frame without Shear Connectors

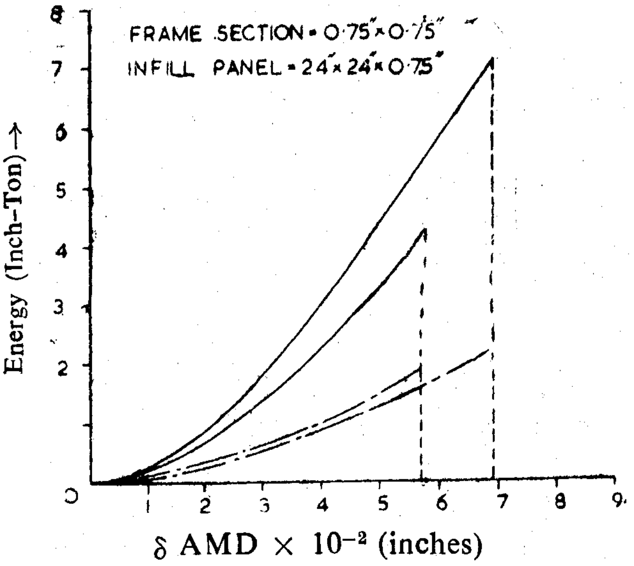


Figure 7. Energy Absorption and Energy Capacity Curves Per Half Cycle

Another great advantage of such a construction from dynamic consideration is their energy absorption capacity. Figure 6 shows the plot of half cyclic load tests on an infilled frame which is not bonded to the frame. Figure 7 shows the energy absorption and energy capacity curves per half cycle for the same frame.

MODES OF FAILURE

For the present study of infilled frames it is assumed that the boundary frames have been adequately designed, so as to cause the infill to fail first. Two modes of failure were observed :

1. Failure due to an infill panel cracking diagonally in the tensile stress zone.

2. Failure due to yielding of one of the loaded corners.

These two modes of failure were as shown in Figures. 8 and 9. It was also observed that if the failure was due to a panel cracking diagonally then-the applied load could be increased again after a sudden drop in its value until yielding of one of the loaded corners occurred. But the reverse was not true.

The pattern of failure for rectangular infilled frames was generally due to yielding of one of the loaded corners.

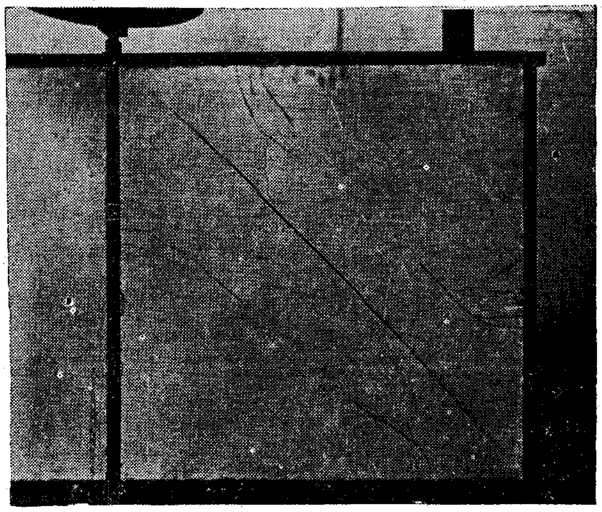


Figure 8 Diagonal Tension Crack

PRACTICAL FEASIBILITY

Infilled frame construction has been used very commonly in seismic and non-seismic zones. But structural engineers had been reluctant to make use of stiffening and strengthening influence of infilling on bare frame. Such an attitude seems to be due to the following two reasons :

Firstly the practical difficulty of achieving a tight fit between the frame and the infill, to ensure that a reasonable degree of composite action occurs when the loads are applied.

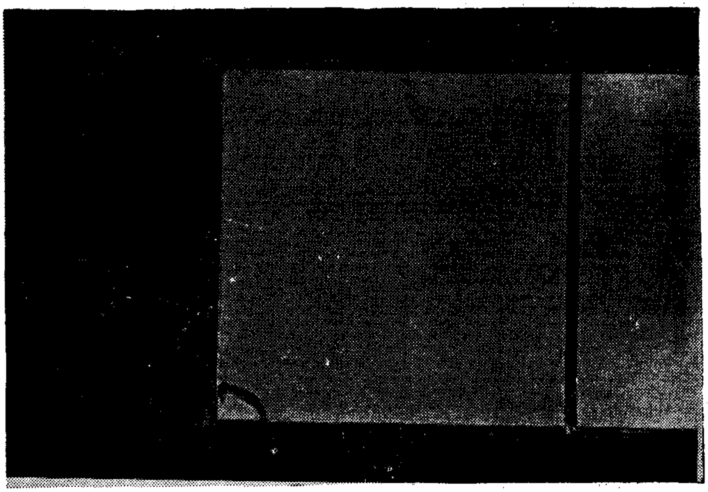


Figure 9. Compression Failure

Secondly perhaps most essential, due to the fear that at some subsequent date the infill may be regarded mainly as a form of partition with the risk of its being perforated or removed completely for some functional reason

Another fear is that in the conventional infilled frame construction, where the brick panel is contained in a reinforced concrete or steel frame, the failure by yielding on one of the corner is sudden and without warning. Once this type of failure has occurred, the infilling becomes ineffective and then the stiffness and strength of the structure is basically that of the bare frame.

If the decision on the plan of a building regarding the position of walls, which will ultimately resist lateral loads has been carefully taken, then the above mentioned fears and difficulties are overcome by using infilled frames with shear stiffeners. For brick masonry panels these stiffeners can be strips projecting from the columns and penetrating into the seams of brick panels at definite spacing. For concrete panels, the reinforcing mesh can be connected to column which will almost serve the same pupose. The presence of shear stiffners or reinforcement increases the length of contact along the loaded corners and hence the distribution of stress is changed thus increasing the stiffness of an infilled frame. Figure 5 shows the load deflection curve of an infilled frame with shear connectors. The author has carried out number of tests on laterally loaded infilled frames with and without shear connectors. For infilled frames with shear stiffeners the following observations have been recorded.

1. The lateral stiffness of these frames is higher than that of the frames without shear connectors.
2. The provision of shear connectors does not necessarily increase the ultimate load.
3. The mode of failure in these frames was invariably that of diagonal cracking The load could be further increased after the appearance of diagonal cracking until yielding of the infill material occurred This means that the infilling will fail with a warning which is most desirable from designer's point of view.
4. The source of energy absorption in these frames is primarily due to the material damping of the infilled frames without shear connectors. The energy absorption capacity is

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THIRD ANNUAL GENERAL MEETING

December 23, 1969

New Delhi

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Delegates