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MASONRY BUILDINGS IN SEISMIC AREAS

By

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ABSTRACT

The paper highlights the weaknesses of masonry buildings as commonly built in most parts of the globe and emphasizes the need to implement seismic strengthening measures for such construction. It is brought out that the technology and methodology for improving seismic strength and behaviour of masonry buildings exist but there is need to translate these into practice. Awareness amongst the practicing engineers/architects as well as others associated with construction needs to be created for successful implementation of strengthening measures.

INTRODUCTION

Experience has shown that collapse of masonry buildings is the single largest factor contributing to the huge losses and casualties during earthquakes. Unfortunately, however, the subject of design/strengthening of such buildings has not received the attention it deserves and the construction practices continue mostly ignoring the warnings issued by nature from time to time. These buildings are usually constructed by people through local masons with practically no inputs from professional people and are termed as non-engineered for this reason. The modern looking load bearing brick buildings also fall in this category since such systems are usually undesigned. These have poor tensile resistance and brittle behaviour which leads to its cracking and collapse resulting in disaster. It is therefore necessary that such buildings must incorporate appropriate features to improve and strengthen the structure without changing its basic character and without adding much to the cost. Good amount of work has been done in this direction (Ref. 1,2,3,4,5,6) which can be usefully utilized in planning, design and construction of such buildings. The present paper explains the features which aim to achieve earthquake resistant masonry buildings.

EARTHQUAKE FORCE

Earthquake 'force' is a misnomer in the sense of an 'external' load acting on a structure. Earthquake by itself consists of a set of compressional and shear waves passing through the earth's crust shaking the structure up and down as well sideways in a random manner. Forces are caused 'internally' in the structure due to the inertia of its masses at any instant of time.

The earthquake-structure interaction is best represented by acceleration response spectra shown in Fig. 1. Here it will be relevant to state a few important points :

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(a) For most small buildings, the time periods will lie in the short period range, less than 0.5 sec, and the maximum elastic response accelerations will be several times the peak ground acceleration value (Ref. 8).

(b) In most earthquake codes of the world (Ref. 9) the design seismic coefficients are a small fraction of the values indicated by elastic response spectra, which may usually be four or more times the former.

(c) The gap between the maximum and design acceleration values is explained by several factors, viz., occasional nature of the earthquakes, energy dissipation through plastic deformations, damage of non-strcutural elements, etc. To avoid collapse, therefore, ductility or plastic deformation capacity is a vital requirement of the structural systems.

The supporting members, walls, piers and columns, which would carry basically vertical loads without earthquake (or wind) are subjected to horizontal bending and overturning effects as well, under these forces. The stress condition in a typical pier will change from uniform compression to that of compression, bending and shearing combined. An important point to note here is that whereas the compressive stress before earthquake remains fixed in value, the bending and shearing stresses due to earthquake increase proportionately to their magnitude. Hence the net tensile stress increase is out of proportion to the lateral force, the increase being much faster. Thus checking of brittle structures at low values of design seismic coefficients gives little guidance about their safety in real earthquakes. It is for this reason that higher seismic coefficients are used for checking the reinforcing requirements of brittle structures.

MATERIAL PROPERTIES

From the seismic view point, the following material properties and characteristics are most important :

(i) Unit Weight - lighter the material consistent with strength, the better it is.

(ii) Strength in compression, tension and shear including dynamic effects, if any, for strain rates as induced during earthquake motions.

(iii) Modulus of elasticity including strain-rate effects.

(iv) Damping value at various strain levels - the higher the better.

(v) Lateral load - displacement characteristics of elements and components under reversed loading including plastic deformation.

(vi) Durability, that is, resistance against weathering action, corrosion, insect attack, etc.

(vii) Fire Resistance.

STRUCTURAL SYSTEMS

There are three main components of the structure of a dwelling - foundation, wall, and roof. Whereas the roof structure is practically independent, the type of foundation is closely related with the wall types. Those commonly used for dwellings in most developing countries along with some variations in their details are decribed elsewhere (Ref. 8, 10).

IMPROVING SEISMIC BEHAVIOUR OF MASONRY BUILDINGS

In the following sections, information is very briefly presented regarding the weaknesses of masonry construction and simplified practical measures are suggested to improve the behaviour of buildings in earthquakes.

Burnt Brick Buildings

Weaknesses : The following are the weaknesses identified in brick buildings from the seismic behaviour viewpoint :

- Poor strength of material in tension and shear, particularly where mud mortar or lime-sand mortar weaker than 1:3 or cement mortar weaker than 1:6 is used.
- Toothed joint causing a vertical plane of weakness between perpendicular walls.
- Large openings and their placement too close to the corners.
- Eroded mud mortar due to lack of protections or maintenance.
- Very long rooms having long walls unsupported by cross-walls.
- Unsymmetrical plan of building, or with too many projections.
- Use of heavy roofs having flexibility in plan.
- Use of light roofs with little binding effects on heavy masonry walls.
- Poor quality of construction.

Earthquake Protection Measures : For resistance the following measures have been found effective not only in preventing collapse but controlling the propagation and widening of cracks :

- Symmetry and rectangularity of building in plan.
- Symmetry in the location of openings in the walls.
- Simplicity in elevation, that is, avoidance or ornamentations, large cornices, etc.
- Presence of intersecting internal walls in good number so as to divide the total plan in squarish enclosures, the length of a wall between cross walls being not more than about 6 m in any case.
- Total width of openings in a wall not more than 50% of wall length in one storeyed, 42% in two storeyed and not more than 33% in three storeyed buildings.
- Width of piers between openings or from opening to wall corner not less than half the height of openings nor 60 cm.
- Use of steel or wooden dowels going into walls meeting at corners or T-junctions to provide effective bonding between them, say, every fourth course.

- Use of bond beam or band of reinforced concrete at lintel levels of openings and serving as lintel too. This is one single feature which is most effective in ensuring the integrity of enclosures like a rigid box.

- Section of the building, viz., corners and junctions of walls and jambs of openings, to be reinforced by vertical steel bars going from foundation into the floor and roof slab, so as to provide strength and ductility to the shear walls.

Seismic analysis of 3 to 5 storeyed residential flat type buildings constructed in brick work in cement or lime mortar situated in a zone of seismic intensity VIII on Modified Mercalli Scale, indicates that tensile and shear stresses increase rapidly in the shear wall piers as the building height increases (Ref. 4). It will therefore be advisable to restrict the building height to three storeys in MM IX zone and to four storeyed in MM VIII zone unless masonry is fully horizontally and vertically strengthened duly supported by appropriate engineering analysis.

Stone Masonry Building

Weaknesses : The following are the weaknesses identified in stone masonry buildings of random rubble or half-dressed types which are usually present in constructions and are detrimental to it during an earthquake :

- Weak in tension and shear and unstable configuration of stone when shaken from initially constructed position making the wall collapse due to heavy vertical loads.

- Very weak bond between walls at right angles to each other leads to very easy separation.

- Delamination of wall into separate outer and inner wythes due to absence of through or 'bond' stones.

- Easy shattering and collapse of stone gables.

- Poor state of maintenance.

- Very heavy mass.

- Flexible floors and roof, little binding effect on walls, no diphragm action.

- Poor quality of construction.

Earthquake Protection Measures : For stone masonry buildings, all the protective measures as for brick buildings are found useful. For random rubble and half dressed stone masonry, the following measures are absolutely necessary.

- Provision of 'through' stones or 'bonding' elements along the wall thickness at regular intervals of about one element per sq. m of wall.

- Restriction of the thickness to not more than 45 cm since larger thickness encourages undesirable filling material inside, adding to mass but reducing strength.

EFFECTIVENESS OF SEISMIC STRENGTHENING FEATURES

Most of the features mentioned in this paper have been included in some of the building codes and manuals (Ref. 9,10). However, very few experimental studies have been reported in literature to verify the effectiveness of these. Dynamic tests on half scale brick building models have been carried out towards this objective (Ref. 7). The results show that provision of lintel bank and vertical steel reinforcement is quite effective in imparting the necessary strength and energy absorbing capacity to the building and the quantity of steel reinforcement as provided in the Indian Code will be found to be generally adequate. Test data in respect of stone masonry is not available, but results similar to brick buildings can be expected here also.

ECONOMICS OF EARTHQUAKE RESISTANT MEASURES

It is sometimes made out that incorporation of seismic safety in buildings and structures would increase the cost considerably. The fact is that absolute safety to the extent of 'not even a crack' may, indeed, require not only heavy cost put also change of the construction material from brick or stone to reinforced concrete walls. However, the practical level of safety for preventing collapse and limiting damage to repairable stage can be achieved even in masonry buildings at rather low additional cost. The measures outlined here above can be divided in two groups. The planning suggestions for improving seismic behaviour of buildings are in fact 'not cost' measures. The seismic strengthening measures in the form of 'lintel level bands' and vertical reinforcing elements at corners and junctions of walls and at the jambs of openings are the ones that will involve extra cost which may be of the order of 4-6% in MM IX area. Considering that the repair and strengthening cost of a damaged building could be as much as 25 to 50% of the cost of reconstruction as experienced in Tashkent earthquake in USSR and Friuli earthquake in Italy, the initial strengthening is not only economically sound but also highly desirable looking to the assurance of safety provided to the inmates and the dislocation to the community it would avoid after an earthquake.

CONCLUSIONS

Buildings constructed according to tradition generally require only minor and low cost modifications and strengthening measures for raising their seismic resistance levels sufficiently to prevent their collapse. Guidelines in this regard are already available. Implementation efforts are to be made in various places to derive the benefits of the scientific work in order to contribute to disaster mitigation. Experimental test data is still required in regard to stone masonry construction to prove the strengthening measures.

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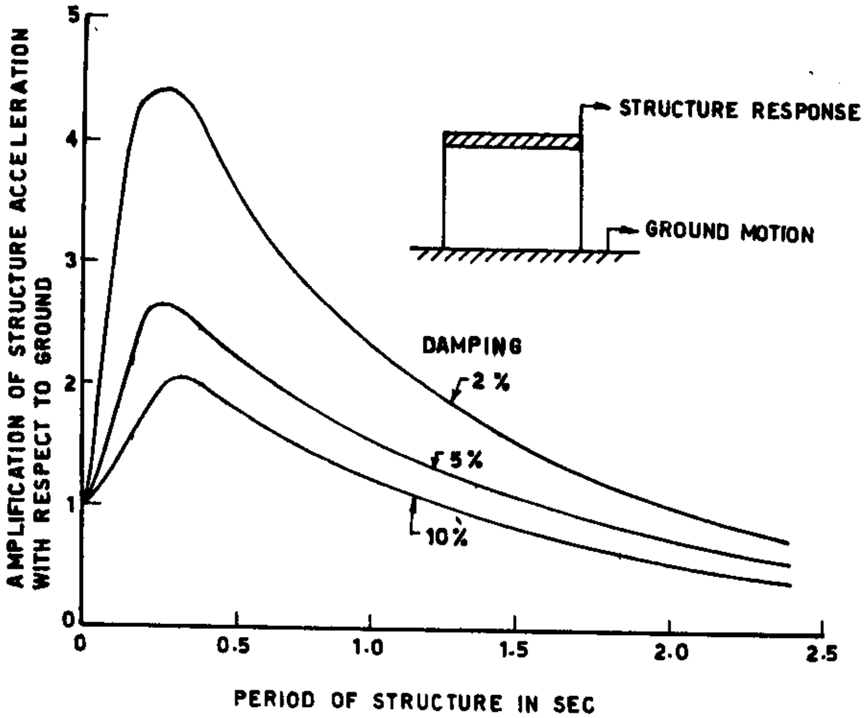

FIG.1 _ ACCELERATION RESPONSE SPECTRA OF EARTHQUAKE GROUND MOTION

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rang, page 13, para 4, line 12	range
varlous, page 16, para 1, line 11	various
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spedtra, page 18, line 11	spectra
speetra, page 18, line 14	spectra
shorf, page 18, page 1, line 2	short
Interpretlng, Ref. 5, line 1	Interpreting
Trifunace, Ref. 7, line 1	Trifunac
Meghalaya Earthquake Engg., Ref. 11, page 19, line 2	Meghalaya Earthquake of Sept. 10, 1986. "Report EQ 88-12R, Department of Earthquake Engg.,
89-24, Ref. 12, line 3	89-23
89-14, Ref. 13, line 3	89-24
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Bhawarana, page 27, S.No. 3	Bhawarna
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