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STUDY ON EMPIRICAL SEISMIC CODAL GUIDELINES FOR MASONRY BUILDINGS IN KOLLAM, KERALA, INDIA

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Abstract

Masonry structures fail miserably due to lateral loads. Recent earthquakes in India and the world and the resulting losses highlighted the structural inadequacy of masonry buildings to seismic loads. Increase in frequency of earthquake in Kerala recently and increasing concern motivated the study. Localized survey at Kollam town in Kerala found that most of the structures were masonry. Kerala falls in Zones II and III. IS 13828 and IS 4326 provides masonry structures' empirical design and construction features which may raise the earthquake resistance. The study is concerned with the numerical analysis of brick masonry walls (with and without seismic resistive features) subjected to dynamic loading with emphasis on their non-linear behaviour. Mechanical properties of three varieties of brick and three different mix proportion of mortar were determined. Using the material properties, nonlinear dynamic analysis of a masonry wall panel was done using ANSYS software and the ground motion record of Bhuj earthquake. The effect of size and position of openings in the masonry walls, the pier size, provision of lintels and the effect of mortar on resistance of walls under dynamic loads are discussed and possible retrofitting measures are suggested to strengthen the masonry brick wall.

Keywords: Localised survey, Masonry structures, Empirical guidelines, Seismic resistance, Dynamic analysis, Wall model.

1. Introduction

In different parts of world and India the occurrence of high intensity earthquakes have received more attention recently. The resulting losses have highlighted the structural inadequacy of buildings to carry seismic loads. The post-earthquake surveys have proved that the masonry buildings (compared to other types of buildings) are most vulnerable and have suffered maximum damages in the

Nomenclatures

CM	Cement Mortar
d	Door
"g"	Gravitational acceleration
GOK	Government of Kerala
MW	Masonry Wall
ND	Not Done
RCC	Reinforced Cement Concrete
UNDP	United Nations Development Fund
URM	Unreinforced Masonry
w	Window

past earthquakes [1]. Masonry buildings of brick and stone are superior with respect to durability, fire and heat resistance and formative effects [1, 2]. Because of the easy availability of materials, economic reasons and merits mentioned above this type of construction is employed in the rural, urban and hilly regions. It is flexible enough to accommodate itself according to the prevailing environmental conditions. Surveys of the affected areas in past earthquakes in India like Bhuj in 2001, Chamoli in 1999, Jabalpur in 1997, Killari in 1993, Uttarkashi in 1991 and Bihar - Nepal 1988 has clearly demonstrated that the major losses of lives were due to collapse of low strength masonry buildings [1].

Based on these experiences, low strength masonry was advised to be avoided in seismic zones. The Indian Standards IS 13828 states that inclusion of special earthquake design and construction features may raise the earth quake resistance of the masonry structures [3]. This type of construction is treated as non-engineered construction. The plight is that even after gaining knowledge of earthquake engineering during the last three decades, a proper method has not been developed for seismic analysis and design of masonry buildings in spite of the fact that 90% of the population lives in masonry buildings [1]. Masonry buildings in India are generally designed on the basis of IS 1905 [4]. The procedure for seismic analysis and design of masonry buildings has still not received adequate attention in India. There is an urgent need for assessment of the present condition of components of the buildings and the strength of materials. IS 4326 [5], IS 13827 [6] and IS 13828 [3] provide guidance on seismic resistant construction of structures. However, the efficiency of these guidelines has not been examined in detail. The research reported in this paper covers the following objectives: (1) The extend of compliance of the buildings in Kollam (as a case study) to the empirical seismic resistant guidelines in the codes, (2) Examination of properties of masonry materials (masonry units and mortar), and (3) Evaluation of the guidelines through a non- linear dynamic analysis of a typical masonry wall with and without compliance to the guidelines.

2. Literature Review

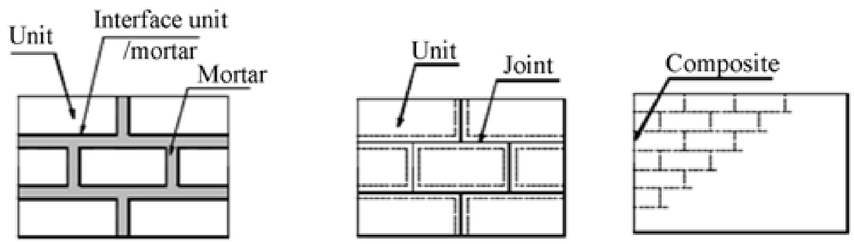
The empirical seismic provisions in the codes required for preparation of the questionnaire were identified. The response to the questionnaire will identify the extent of compliance to the codes. The methods of determining the properties of masonry units and mortar were identified. The parameters (which are important for modelling masonry walls using Finite Element namely compressive strength, water absorption, modulus of elasticity, Poisson Ratio, density of brick and mortar) were identified from the review of earlier works.

Studies conducted on seismic events in Kerala indicate that intensity varies according to region [7]. Their studies revealed that Pathanamthitta, Kottayam, Alapuzha and Ernakulam districts showed highest value of PGA ranging from 0.234g to 0.278g; which indicates that these regions are more susceptible to high magnitude earthquakes. It also showed that North and South Kerala regions are of low seismicity. The vulnerability of Kerala as an earthquake-prone state was highlighted at a meeting of Government and non-government organizations held recently in association with UNDP [8]. The density of population is 819 persons per sq. km which is the second highest density in the country [9]. Jaya and Remmya [10] carried out seismic micro zonation of Thiruvananthapuram. Seismic Micro-zonation studies of Kochi are being undertaken by Centre for Earth Science Studies. The aim is to identify sites prone to ground motion amplification based on available information on geology, geomorphology, lineament pattern, soil/ lithology, structural features, earthquakes, etc. [11].

Masonry is the most common type of construction for housing in Kerala. Walls were of load bearing type. Though stone, cut laterite blocks, clay bricks, mud blocks with lime mortar or cement mortar were used, in last two decades, brick wall construction became more popular. The scarcity of good quality clay has led to alternatives like hollow concrete block, solid concrete blocks, interlocking blocks, whose their strength varies with manufacturer [12].

When dealing with masonry structures, the most common idealizations of material behaviour are elastic behaviour, plastic behaviour and nonlinear behaviour. By adopting a nonlinear analysis instead of a linear analysis, a more comprehensive insight into the structural response can be obtained, with a higher cost, both in terms of necessary input data and required knowledge of the analyst [13]. Different modelling methods are available, depending on the level of accuracy, the simplicity desired and the application field [14-16]. The present research uses detailed micro modelling, in which units and mortar joints are represented by continuum elements whereas the unit-brick interface is represented by discontinuous elements. Figure 1(a) shows the detailed micro modelling. The main advantage of detailed micro modelling is that almost all the failure modes can be considered. But it is not convenient for the modelling of large scale masonry structure, because the number of elements that must be used can be huge, and consequently the cost of calculation time increase tremendously. Memory requirements are also very high. In Simplified Micro modelling, expanded units are represented by continuum elements whereas the behaviour of the mortar joints and unit-mortar interface is lumped in discontinuous elements. These interface elements represent the preferential crack locations where tensile and shear cracking occur.

Figure 1(b) shows the simplified micro modelling. In Macro modelling, the units, mortar and unit-mortar interface are smeared out in the continuum. Figure 1(c) shows the Macro modelling. Macro modelling is more practice oriented due to the reduced time and memory requirements as well as user friendly mesh generation. This type of modelling is most valuable when a compromise between accuracy and efficiency is needed [13-16]. More details are reported in Potty and Sirajuddin [17].



(a)Detailed Micro modelling **(b) Simplified micro modelling** **(c) Macro modelling**

Fig. 1. Finite Element Modelling of Masonry [13-16].

Numerical investigation method has been used by many researchers to study the behaviour and performance of walls. Rao [18] studied the behaviour of whole building. Lam et al. [19], Alessandro et al. [20], Oliviera [13], Bakhteri et al. [21], Augenti and Parisi [22], Nirmala [23], Mistler et al. [24] , Haach et al. [25], Nachin et al. [26], Shariq et al. [27], and Keyvani and Farzadi [28] used the FE approach in their studies.

Rao [18] presented the FE models of building without roof, with openings and also building with roof and openings along with their fundamental mode shapes and frequencies as shown in Table 1.

Table 1. Natural Frequencies (Hz) of Buildings [15].

Mode no.	**Buildings without roof**		**Buildings with roof**
	B-1	**B-2**	
1	6.43	8.17	14.87
2	6.88	9.05	17.11
3	14.01	18.61	18.95
4	15.92	20.12	20.03

3. Methodology

The methodology consists of preparation and conduct of questionnaire survey and analysis of results, experimental testing of masonry units and mortar and non - linear analysis of masonry walls. Figure 2 shows the methodology using a flow chart.

The main aim of the questionnaire survey and visual examination was to identify buildings that are vulnerable to earthquake in Kollam district of Kerala by carrying out a localized survey on the methods of construction, materials used for construction, general pattern of the structures, etc. The important seismic guidelines in the codes were identified and the compliance of the structures to those guidelines was assessed through the questionnaire. The main codes are: IS 1893 [29, 30], IS 13828 [3] and IS 4326 [5]. Kollam Corporation spans 52 wards having estimated one lakh legal licensed structures. The sampling was done in such a way as to cover all the wards and the different parameters in the questionnaire which included type of soil, type of structure (number of floors, floor areas, height of walls, etc.), use of the building, strategic importance of buildings, general strength of masonry (considering types of masonry, mortar composition, plastering, length of longest wall, use of water proof plaster, etc.), size and positions of openings in bearing walls (most important criteria in IS 4326 [5] and IS 13828 [3]). Similarly the pier width between consecutive openings, distance of the first opening from inside corner of outside wall, etc., were included.

Various materials are nowadays used as building blocks. So laterite, wire cut and country burnt bricks, Hollow cement block, solid cement block, Random Rubble masonry, Interlocking bricks, wooden planks, etc., were included. Type of roof, provision of all round lintel and lintel thickness, symmetry and age of structure, type of sub structure, average number of occupants, use of the structure, soft storey, presence and placement of high weight RCC overhead tanks (placement of water tank at the geometric centroid of plan area and importance of tying it to the structure were also considered). Further the type of water tank (Fibre reinforced, RCC or masonry) was also noted. The presence of high rise towers adjacent to the assessed structure, attachment of staircase to the structure, loss of symmetry due to expansion of the building and quality of work and long term durability was also considered. The questionnaire was prepared based on the detailed study of IS 1893 [29], IS 4326 [5], IS 13827 [6], IS 13828 [7], IS 13920 [31] and IS 1905 [4]. The questionnaire had 30 questions.

The experimental work consists of two parts. Evaluation of properties of wall materials included the compressive strength, water absorption and efflorescence of laterite blocks, country burnt bricks, wire-cut bricks, concrete blocks, hollow blocks and interlocking blocks. Evaluation of the basic material properties of brick units and mortar units such as Poisson's ratio, modulus of elasticity and compressive strength are necessary for numerical modelling and seismic analysis of masonry wall. Only bricks were considered in the numerical modelling since they constitute the major share of the building stock (44.9% of the total housing stock). Experimental study was conducted on three varieties of brick units which included two types of wire cut bricks and one type of country burnt brick, collected from different kilns of Kollam District. The properties of brick and mortar were evaluated (and not the wall) since for the numerical modelling the micro – modelling approach of brick and mortar was used. In the assessment of safety of the walls under applied loads, a permissible compressive stress of 0.35 N/m^2 was assumed based on Varghese [32] and IS 13828 [7].

Test on compressive strength and water absorption test were carried out as per IS 3495 (part 1 to 4) [33]. The strength of masonry depends on strength of brick and mix proportion of mortar. In India, lower mix proportion of cement and sand is often used. But IS 4326 [5] recommends minimum 1:6 mix proportion of cement and sand. In this experimental study, three different mix proportions of cement and sand were considered for the mortar preparation.

The finite element method and ANSYS [34] was used for the numerical investigation of masonry walls. The numerical investigation of wall consisted of two stages (1) Modal analysis – which was used to study the mode shapes and natural frequency of vibration of masonry wall models. The modal analyses of masonry walls without opening were carried out for various mortar mixes such as 1:4 mix, 1:6 mix and 1:8 mix. Model 1 was used for this part of study (2) The nonlinear dynamic analysis of wall model with and without incorporating some prescriptive guidelines provided in the codes for checking their efficacy was carried out in three sub - phases.

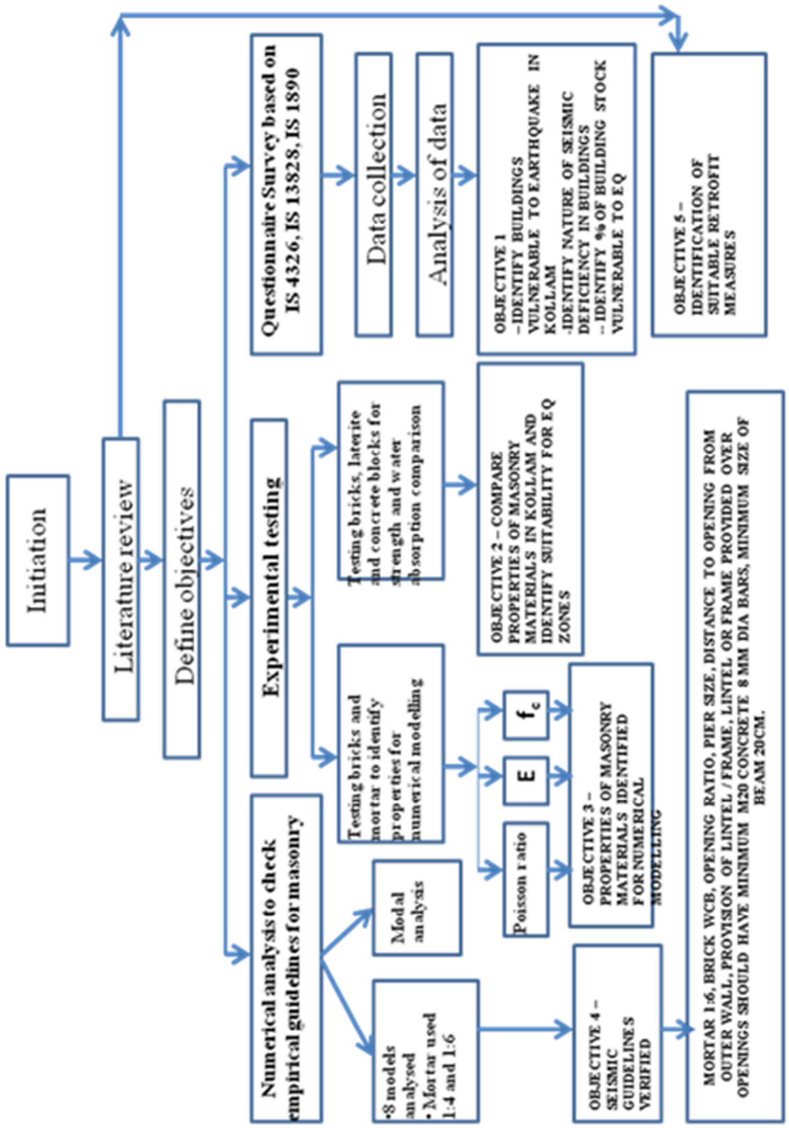


Fig. 2. Flow Chart of Methodology for Questionnaire Survey and Experimental Work.

(a) Sub- stage 1: Model 1 was subjected to only in-plane ground motion for mortar 1:4, 1:6 and 1:8. The purpose is to assess the impact of mortar type on the stresses.

(b) Sub – stage 2: Models 2, 3, 4 and 5 subject to in-plane and out of plane ground motions for mortars 1:4 and 1:6 only. The aim was to identify the effect of openings and pier size.

(c) Sub – stage 3: Model 6, 7 and 8 subject to in-plane and out-of-plane ground motions for mortar mix 1:6 only. The aim was to identify the effect of providing frames/ lintels around and over openings and to evaluate the stress change due to the frame/ lintel.

The wall used for study having size 3.6 m length×2.7 m height was modelled using Solid 65 element.

The details of the 8 models are: (1)Wall without opening, (2) Wall with window of size 1.5 m×1.0 m, (3) Wall with door (0.9 m×2.0 m) and window of size (1.2 m×1.0 m) located at the centre of wall keeping pier distance as 0.6 m, (4) Wall with door (0.9 m×2.0 m) and window of size (1.2 m×1.0 m) located at the centre of wall keeping pier distance as 0.34 m, (5) Wall with door (1.0 m×2.0 m) and window of size (1.35 m×1.2 m) located at the centre of wall keeping pier distance as 0.60 m. Edge distance was 0.325 m, (6) Wall with door (0.9 m×2.0 m) and window of size (1.0 m×1.2 m) located at the centre of wall keeping pier distance as 0.34 m. A concrete frame of thickness 0.12 m provided around the opening (7) Wall with window of size (1.5 m×1.0 m) located at the centre of wall. A concrete frame of thickness 0.12 m provided around the opening (8) Wall with door of size (1.0 m×2.0 m) and window opening of size 1.35 m×1.2 m located at the centre of wall by keeping pier distance as 0.6 m. A concrete frame of thickness 0.12 m is provided around the opening. The models are compared in Table 2. Models 5 and 8 did not comply with the requirement that opening width should be less than or equal to L/3.

The mortar mix proportions of 1:4 and 1:6 were used since 1:8 mix proportion is not recommended for earthquake prone areas. The base of each model is assumed as "fixed". Each model was subjected to uniform distributed vertical load of intensity of 6kN/m. In this study, acceleration time data of Bhuj earthquake was normalised by multiplying with a factor 0.7326 to make it equivalent to that of the ground motion of Kerala region for a period of 20 seconds. The multiplying factor is obtained by dividing the maximum expected PGA value of Kerala 0.278g with the PGA value of Bhuj EQ 0.36g (0.278g\0.36g=0.7326). The normalised acceleration time data of Bhuj earthquake was adopted for the study. The ground motion equivalent to that of the Bhuj earthquake was applied on the models, both in - plane and out - of - plane to the masonry wall and the stresses on the walls were evaluated.

4. Results and Discussion

The first four natural frequencies of vibration of the modelled brick wall for three different mortar proportions fall in the range of 1-13 Hz. The results of Rao [18] are having higher natural frequencies namely 6-20 Hz for the whole structure since the whole structure is more rigid. The results of Lam et al. [19] fall in the range 5-10 Hz where walls were modelled. Amrheim [35] noted that URM buildings are stiff structures with natural frequencies in the range 2 - 10 Hz. Hence the current micro finite element modelling of the masonry wall is also verified.

Table 2. Summary of Parameters of Models Tested for its Influence on Seismic Resistance.

Model	L (m)	H (m)	Window size (m)	Door size (m)	%	Opening width not greater than L/3	CM	Pier size (m)
1	3.6	2.7	-	-	-	OK	1:4, 1:6, 1:8	-
2	3.6	2.7	1.5×1.0	-	15.42	OK	1:4, 1:6,	-
3	3.6	2.7	1.2×1.0	0.9×2.0	30.86	OK	1:4, 1:6	0.6
4	3.6	2.7	1.2×1.0	0.9×2.0	30.86	OK	1:4, 1:6	0.34
5	3.6	2.7	1.35×1.2	1.0×2.0	37.24	Not OK	1:4, 1:6	0.6 Edge distance =0.325
6^{+}	3.6	2.7	1.0×1.2	0.9×2.0	30.86	OK	1:4, 1:6	0.34
7$^{\Phi}$	3.6	2.7	1.5×1.0	-	15.43	OK	1:6	-
8$^{\beta}$	3.6	2.7	1.35×1.2	1.0×2.0	37.24	Not OK		0.6

\+ Concrete frame of thickness 0.12 m provided around the openings
Φ Concrete beam around the openings
β concrete frame of 0.12 m thickness

4.1. Questionnaire survey results

A total of 6800 data was used for the analysis. The statistics of the buildings analysed consisted of residential buildings (64.2%), commercial buildings (19.2%), industrial buildings (1%), government buildings (3.5%), hospitals and public buildings, and educational buildings (5.1%). The detailed analysis of the buildings on their compliance with the seismic resistant provisions was presented in Potty and Sirajuddin [36, 37].

Many buildings in Kollam city seem to have sufficient resistance against moderate earthquakes as per Indian standard specifications and general criteria. Immediate and important attention is required for the residential structures. The growth rate of residential structures is very high and just a few have got seismic resistance of its own. Government should impose new rules regarding seismic resistance regulations and should educate the public about the possible damages due to earthquakes. The tendency of providing large openings and asymmetric designs are to be curbed. Economic retrofits in the form of wire meshed concrete on the corners of masonry walls in tiled roof structures and division of longer walls to shorter ones can be done for structures greater than 30 years of age. In commercial structures strict rules must be imposed to avoid huge capacity overhead water tanks. Also the provision of open cellar area for parking must be avoided. Tie beams at regular intervals should be provided for structures having floor height higher than 4 m. Alternate technology must be developed to remove the mobile service towers from highly occupied areas due to danger of collapse. Schools should be of single storey as far as possible. The water tanks must be kept away from the buildings in the school campus. The structural support between roof and walls of old tiled buildings should be improved by using cleat and angles connection. Long and big construction in a single stretch must be avoided. Smaller structure must be placed well apart [36-38].

4.2. Experimental tests on masonry units and mortar

The experimental testing was structured to identify the properties of the masonry units and mortars prepared locally. The properties of the bricks and blocks were compared with the limits proposed in the codes namely IS 2185 [39] and IS 1077 [40]. The experimental study on materials for wall construction revealed that, most of them failed to meet the standard specified by IS. It is mainly due to poor quality control and use of inferior quality raw materials. It was found that wire cut bricks were the most ideal material available for construction of walls. It meets strength requirements and it is economical.

Basic material properties such as Compressive Strength, Modulus of Elasticity and Poisson's ratio of the three varieties of brick and the Compressive Strength, Modulus of Elasticity and Poisson's ratio of the three different mix proportions of mortar were experimentally determined. The choice of wire cut and fired brick and three mortars (1:4, 1:6 and 1:8) were identified for numerical analysis.

4.3. Evaluation of efficiency of the empirical seismic guidelines for masonry buildings

The results of modal analysis of masonry wall of three different mortar mixes and without opening were compared. The masonry walls with richer mortar mixes have higher frequencies because they are stiffer, as expected. The frequencies also agree well with frequencies of models of masonry walls and whole houses, which verifies the micro finite element models.

Table 3 shows the results of the nonlinear dynamic analysis of masonry walls with door and window opening conforming to different provisions of the Indian seismic codes for 1:4, 1:6 and 1:8 mortars and subject to both in-plane and out-of-plane accelerations using the Bhuj ground motion records. Column 3 shows the different features recommended by the codes which were used in the model. Table 3 indicates which all cases are safe or unsafe. The case of 1:8 mortar has not been investigated for out-of-plane earthquake since it is not recommended for use by the Seismic codes.

Table 3. Summary of Results of Analysis of Wall Subject to Earthquake Accelerations.

Masonry wall Models		Features	In plane Earthquake			Out of plane Earthquake	
Mortar mixes			**1:4**	**1:6**	**1:8**	**1:4**	**1:6**
Sub-stage 1	1	Plane wall (MW)	S	S	S	U	U
Sub-stage 2	2	MW+W	S	S	ND	U	U
	3	MW+W+D Pier = 0.6 m	S	S	ND	U	U
	4	MW+W+D Pier=0.34 m	U	U	ND	U	U
	5	MW+W+D Pier=0.6 m Edge=0.6 m	U	U	ND	U	U
Sub-stage 3	6	MW+W Frame provided for W	ND	S	ND	ND	S
	7	MW+W+D Frame provided for D+W	ND	S	ND	ND	S
	8	Same as 5 ; with Frame	ND	U	ND	ND	ND

S, U and ND denote "SAFE", "UNSAFE" and "analysis not done" respectively.

5. Conclusions

From the questionnaire survey analysis, the following general conclusions can be made.

- In general, many buildings in Kollam city seem to have sufficient resistance against moderate earthquakes as per Indian standard specifications and general criteria.
- The rapid growth of residential structures and lack of seismic resistance requires attention of authorities. Government should impose new rules regarding seismic resistance regulations and should educate the public about the possible damages due to earthquakes.
- The tendency of providing large openings and asymmetric designs are to be curbed.
- Economic retrofits in the form of wire meshed concrete on the corners of masonry walls in tiled roof structures and division of longer walls to shorter ones can be done for structures greater than 30 years of age.
- In commercial structures strict rules must be imposed to avoid huge capacity overhead water tanks. Also the provision of open cellar area for parking must be avoided. Tie beams at regular intervals should be provided for structures having floor height higher than 4 m.
- Alternate technology must be developed to remove the mobile service towers from highly occupied areas due to danger of collapse.
- Schools should be of single storey as far as possible. The water tanks must be kept away from the buildings in the school campus.
- The structural support between roof and walls of old tiled buildings should be improved by using cleat and angles connection.
- Long and big construction in a single stretch must be avoided. Smaller structure must be placed well apart.

From the nonlinear analysis on the eight wall models structures to examine the seismic provisions of the code, the conclusions are

- In the masonry wall with rich mortar mix proportion, the magnitude of maximum stresses developed was found to be small under the nonlinear dynamic analysis.
- Wall was more vulnerable to earthquake in out-of-plane direction than to earthquake in in-plane direction. When the wave hit in the out-of-plane direction of wall, the stiffness offered by the wall was less, or the height to thickness ratio was much greater.
- The wall was safe in in-plane dynamic loading when the pier distance was kept at 0.6 m for mortar mix proportion of 1:4 and 1:6. But it was not safe against out-of-plane loading.
- When the pier distance was reduced to 0.34 m, the equivalent stress developed on the wall was more than the stress developed in the case of pier distance of 0.6 m, for mortar mix proportion 1:4 and 1:6. In this case, the maximum stress developed was more than the permissible crushing or compressive strength (0.35 N/mm^2) of masonry, for both mortar mix proportions. So masonry wall was not safe in both in-plane and out-of-plane dynamic loading for a pier distance of 0.34 m. So in this case, the IS code recommendation is not being satisfied, even in the in-plane loading.

- When sizes of openings were increased and the positions of openings were kept near the edge of the wall, the maximum equivalent stress was found to be developed at the bottom corner of the opening. Here the opening from the edge of the wall is at a distance of 0.325 m, which is more than the thickness of the wall. Even in this case, the wall is not safe in in-plane and out-of-plane dynamic loading and it does not satisfy the code recommendation for minimum edge distance.
- It was found that providing a concrete frame around the openings of the wall with a pier distance of 0.34 m will make the existing unreinforced brick masonry structure safe against collapse. In this case, concrete frame takes the stresses acting on the wall. The maximum equivalent stress (1.69 N/mm^2 in in-plane and 1.7 N/mm^2 in out-of-plane loading) developed in the model was less than the permissible stress of concrete (20 N/mm^2).
- It is to be noted that the concrete frame consisted of M20 concrete and reinforcement bars as per seismic guidelines (10 cm thick beam and 8 mm diameter reinforcement bar).
- When the size of opening was increased and the position of opening was kept near the edge of the wall, the structure was not safe even in the in-plane loading. So the opening near the edge of the wall should be avoided.

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