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Effect of Containment Reinforcement on the Seismic Performance ofUn-Reinforced MasonryBuildings

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Abstract -Un-Reinforced Masonry (URM) construction is the most common type of construction in rural as well as urban areas due to its lower cost and ease of construction.However, these are weak in resisting lateral loads. The main objective of this study was to investigate the effectiveness of vertical containment reinforcement in mitigating seismic vulnerability of URM buildings using finite element method. URM building of dimensions 6×3×3m with openings in the buildings have been considered.All the walls were assumed to be fixed at their bases along their length. 12mm diameter steel bars were used as vertical containment reinforcement and it was laid on the surface of the walls on both the faces at a spacing of 1m. In this study, time history analysis of the building was carried out forBhuj ground motion. The responses such as base shear and storey deflection of URM buildings were evaluated. The study was concluded that on providing the vertical containment reinforcement along with roof slab and lintel band, the deflection gets reduced by 96 % from that of the building without roof slab, lintel band and reinforcement.

Keywords -Laterite masonry, Containment reinforcement, Time history analysis

I. INTRODUCTION

Masonryis generally a highly durable form of construction throughout the world. The common materials of masonry construction are brick, limestone, laterite stone, concrete block etc. Among them laterite is the most favoured masonry material in south-west coastal areas of India due to its availability in abundance. Un-Reinforced Masonry (URM) construction is the most common type of construction in rural as well as urban areas due to its lower cost, ease of constructionand good aesthetics.

Fig.1. Failure of an URM building during 2010 Haiti earthquake [1]

When such a masonry structure is subjected to lateral inertial loads during an earthquake, the walls develop shear and flexural stresses. A masonry wall can also undergo in-plane shear stresses if the lateral forces are in the plane of the wall. Shear failure in the form of diagonal cracks is observed due to this. However, catastrophic collapses take place when the wall experiences out-of-plane flexure. This can bring down a roof and cause more damage. Fig1 shows typical failure of an URM building during 2010 Haiti earthquake [1]. Masonry buildings with light roof such as tiled roof is more susceptible to out-of-plane vibrations, since the top edge can undergo large deformations due to lack of lateral restraint. Damage to masonry buildings in earthquakes may be influenced by four general categories namely quality of materials and construction, connections between structural elements, structural layout and soil structure interaction.

II. BACKGROUND OF STUDY

Numerous experimental investigations were carried out on URM walls which shows the seismic behaviour of brick masonry walls [2,3]. While considering the influence of flanges on the in-plane behaviour of URM walls it is observed that for a diagonal tension-controlled wall, once a stair stepped crack is opened up, sliding can be expected to occur along the bed joints and deformation can be expected [4]. The seismic performance of URM with different types of failures such as lack of anchorage between floor and walls, anchor failure when joists are anchored to walls, in-plane failure [5], out-of- plane failure, a combined in-plane and out of plane effects showed that in-plane failure may not lead to collapse since the load carrying capacity of a wall is not completely lost by diagonal cracking, whereas, out-of-plane failure leads to unstable and explosive collapse [6].In containment reinforcement, vertical reinforcement is wrapped around the masonry unit at the foundation and tied at the top in lintel band. Such vertical reinforcement is to be provided at an appropriate spacing along the length of the wall. The reinforcements on the two faces are tied together through links or ties provided at a definite vertical spacing. Fig 2 displays masonry with containment reinforcement and links connecting them through bed joints. As the masonry wall bends, one face of masonry would be subjected to tension and the reinforcement on that side would bend to its profile while the reinforcement on the compression side would tend to become slack and the reverse happens as the wall bends the other way.

Here the reinforcement is ntended to prevent the growth of flexural tensile cracks that lead to failure.

The containment reinforcement will prevent brittle failure due to tension cracks and permit larger deflections and hence a much higher absorption of energy without a substantial increase in strength.The behaviour of brick masonry structures during the Bhuj earthquake of January 2001 reported that higher bond strength improves the earthquake resistance of masonry, use of lintel band, seems to introduce a rigid box-like behaviour in the upper portion of the buildings while the portions below the lintel bands cracked badly suggesting the need for more horizontal bands at different levels and provision of corner reinforcement in corners and junctions, as suggested by IS 4326-1993, has to be properly bonded with the surrounding masonry possibly with dowels or keys to prevent separation [8]. Containment reinforcement is intended to control post-cracking deflections, stresses and impart flexural ductility to masonry buildings [9]. From shock table test results on 1/6th of the buildings, it is observed that reserve energy capacity of the masonry building is vastly enhanced due to the presence of ductile containment reinforcement [10]. In some studies, the seismic strengthening of URM elements such as walls with glass fibre reinforced polymers [11] and piers with steel elements [12] were carried out. The strengthening system showed significant improvement in stiffness and ductility.

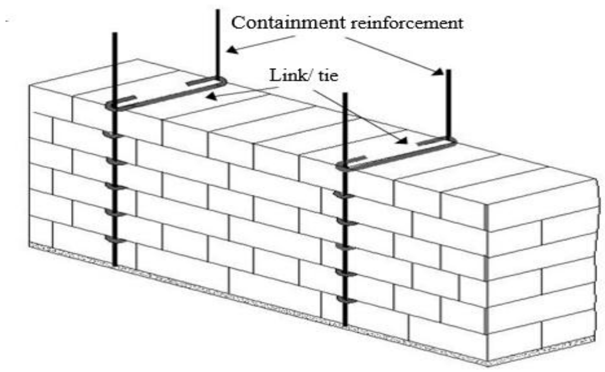

Fig. 2. Masonry with containment reinforcement and links [7]

Consideration of ductility for earthquake resistant design is important for buildings, structures and building materials. When a structure undergoes lateral forces, the structure could not remain elastic anymore and the next stage is damage. It can go through plastic stage or fracture or damage, where stiffness will decrease significantly and deformations will be drastically increasing even for a small load. So, there is a need for providing reinforcement for making the structure ductile. These reinforcements are called containment reinforcement. The effect of containment reinforcement on the seismic response of a single storeyed URM buildings was investigated and is being outlined here.

IDEALISATION OF THE BUILDING

A URM building with plan dimensions of 6m x 3m x 3m have been considered for the analysis. Provisions of openings in the buildings have been considered with one door opening (of size 1m x 2m) and one window opening (of size 1m x 1m) on both the longer walls. Each of the short walls was assumed to be provided with one central window opening. All the walls of the building were assumed to be fixed at their bases, all along their lengths. The top nodes were free in structures without roof, and merged to roof nodes, in structures with roof. The different types of single storeyed laterite masonry structures used for the analysis are given in Table 1. Vertical containment reinforcement made of 12mm diameter steel bars was provided on the surface of the walls on both the faces at a spacing of 1m. M25 grade concrete and Fe250 grade steel reinforcementwas used. Table 2 provides the properties of masonry, RCC and vertical containment reinforcement bars used in the finite element analysis.

TABLE 1. TYPES OF SINGLE STOREYED LATERITE MASONRY STRUCTURES ANALYSED

Designation	Building description
U	URM building without roof slab and lintel band
UL	URM building without roof slab and with lintel band
ULR	URM building with roof slab and lintel band
ULRC	URM building with roof slab, lintel band and containment Reinforcement

TABLE 2. MATERIAL PROPERTIES [10]

Property	Laterite masonry in 1:6 cement mortar	Reinforced concrete	Vertical reinforcement (steel)
Modulusof Elasticity (GPa)	1.20	25	200
Poisson'sRatio (assumed)	0.15	0.15	0.30
Mass Density (kg/m^3)	2500	2500	7850

III. SEISMIC FORCES

Non-linear time history analysis was conducted for URM buildings for Bhuj ground motion.The responses of a structure to any earthquake can be computed by time history analysis. A part of the Bhuj ground motion acceleration recorded at Ahmedabad during earthquake of January 26, 2001 which lasted over 2 minutes is shown in Fig 3. This was considered for the analysis. The peak ground acceleration is 0.11g at time 46.94 s for Bhuj ground motion. The earthquake reached a magnitude of 7.7 on the moment magnitude scale. The Fourier amplitude spectrum of Bhuj earthquake is revealed in Fig 4.

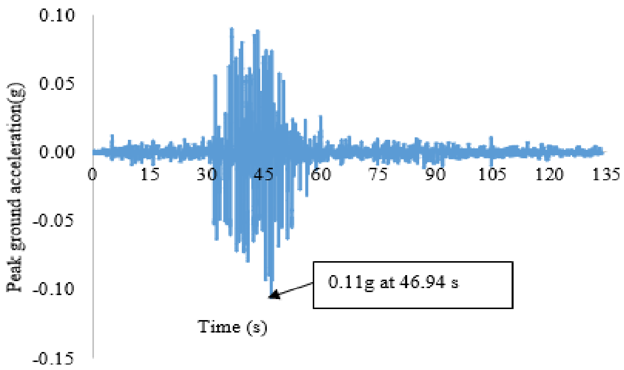

Fig.3. Acceleration time history of Bhuj earthquake [13]

Damping in a structure increases with displacement amplitude since with increasing displacement more elements may crack or become slightly non-linear. For linear seismic analysis, viscous damping is usually taken as 5% of critical as the structural response to earthquakes are usually close to or greater than the yield displacement [9]. Hence, damping ratio of the building was chosen as 5%. The time history analysis was performed by applying each acceleration value to the building step by step in time domain.

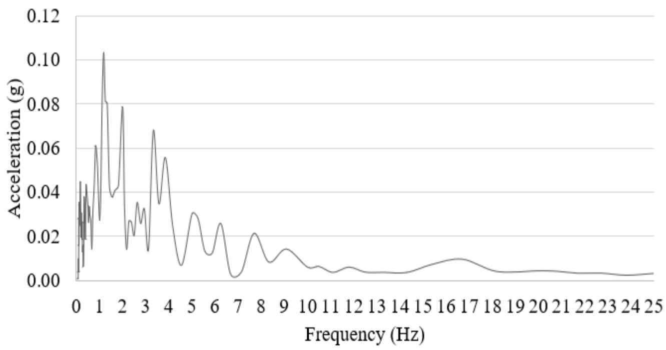

Fig.4. Fourier amplitude spectrum of Bhuj earthquake [13]

IV. FINITE ELEMENT ANALYSIS

The URM building with lintel band, roof slab and containment reinforcement was analysed by finite element method. Eight nodded brick (SOILD185) elements was used for the masonry of URM building. It is having three translation degrees of freedom at each node. For roof slab, four nodded elastic SHELL181 element was used. The element has six degrees of freedom at each node and has both bending and membrane capabilities. Truss elements (LINK180) were used for the vertical reinforcements which is a uniaxial tension-compression element, also with three translational degrees of freedom at each node. The discrete modelling was used for the bars of steel reinforcement. In the discrete model, for the reinforcement, bar element was used to connect concrete mesh nodes. Therefore, the concrete and the reinforcement mesh share the same nodes and concrete occupies the same regions occupied by the reinforcement.

Vertical reinforcements called containment reinforcement were provided at a horizontal spacing of 1m on both the faces of the walls, as shown in Fig 5. The whole building was discretised with element of 0.2m size. Four types of building are chosen for analysis. Configurations of the four types of buildings analysed are illustrated in Fig 6.

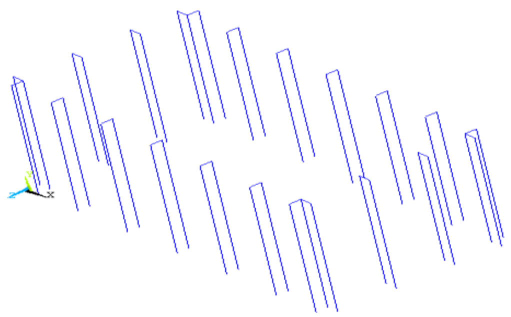

Fig.5. Configurations of containment reinforcement in URM buildings[9]

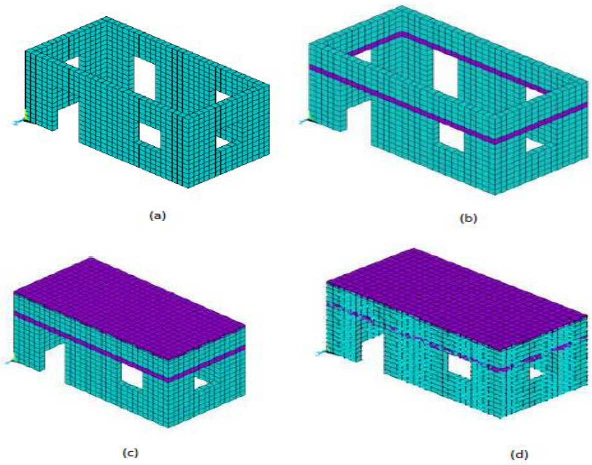

Fig.6. Configurations of URM buildings (a) U (b) UL (c)ULR (d)ULRC type[9]

V. RESULTS AND DISCUSSION

Different configurations of URM building with lintel band, roof slab and containment reinforcement were selected for the study. Analysis was carried out by considering the base of the building as fixed. From the free vibration analysis, the frequency and mode shape of the buildings were obtained. Structural response in terms of storey deflection of building and base shear were evaluated.

A. Natural Frequencies

Free vibration studies were conducted to find the natural frequencies and mode shapes of all the four types of buildings, the results of which are tabulated in Table 3.

TABLE 3. NATURAL FREQUENCIES

Mode No.	Natural Frequencies (Hz)			
	Designation			
	U	UL	ULR	ULRC
1	4.950	6.904	11.058	12.397
2	5.303	7.550	11.356	17.649
3	10.232	15.800	15.588	18.528
4	11.585	15.965	16.794	21.021
5	14.124	20.519	18.063	22.192

In the above table, there is an increase of 37% and 45% in frequency from U type building to UL type building and ULR type building respectively. But while considering ULRC type building there is an increase of 81.45% in frequency than U type building. Therefore, it is clear that for URM buildings with lintel band, roof slab and containment reinforcement, there is an increase in the natural frequencies of the structure. This is due to the increase in the stiffness of the building.

B. Time History Responses

1) Storey Deflection

All the four types of URM buildings discussed earlier were analysed to findtheir responses to Bhuj acceleration. In URM building without roof (U), the maximum deformation wasobserved above the openings. Table 4 gives the maximum storey deflections ofdifferent type of URM buildings.

TABLE 4. MAXIMUM DEFLECTION

Designation	Deflection (mm)
U	3.717
UL	2.109
ULR	0.160
ULRC	0.150

For the buildings of Type UL, Type ULR and Type ULRC respectively, a reduction of 43.26%, 95.69% and 95.96% from Type U. Thus, in single-storeyed URM building, vertical containment reinforcement seems to help in controlling the total deformation significantly. Again, the displacements in the various URM buildings with roof are quite small as compared to structures without roof.

2) Base shear

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. Table 5 conveys the base shear values of URM buildings. In the above table, there is an increase of 35% of base shear in ULRC type building than U type building. Therefore, base shear of a building with lintel band, roof slab and containment reinforcement are much higher than that of building without these.

TABLE 5. BASE SHEAR

Designation	Base Shear (kN)
U	179.98
UL	194.10
ULR	236.31
ULRC	243.06

VI. CONCLUSIONS

The effect of strengthening factors like lintel band, roof slab and containment reinforcement on the natural frequencies were analysed. Response of URM buildings, to Bhuj acceleration was obtained using time-history analysis. From the above results, it is concluded that URM buildings with lintel band, roof slab and containment reinforcement are more effective in mitigating seismic vulnerability as they reduced storey deflection and base shear.

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