INFLUENCE OF CONTAINMENT REINFORCEMENT ON THE SEISMIC RESPONSE OF URM BUILDINGS CONSIDERING THE EFFECT OF FLEXIBILITY OF SOIL MEDIUM

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Abstract: *Un-Reinforced Masonry (URM) buildings represent one of the most seismically vulnerable building types, which are weak in resisting lateral loads. In most of the studies the seismic response of conventional URM buildings are evaluated without considering the effect of soil strata. The main objective of this study is to investigate the effectiveness of vertical containment in mitigating seismic vulnerability of URM buildings incorporating the effect of flexibility of underlying soil strata. Four URM buildings with dimension 6×3×3m are considered namely, (i)buildings without roof slab and lintel band (ii) building without roof slab and with lintel band (iii) buildings with roof slab and lintel band and (iv) buildings with roof slab, lintel band and containment reinforcement. Vertical containment reinforcement of 12mm diameter steel bars of Fe250 grade is provided on the surface of the walls on both faces with a spacing of 1m. Time history analysis is carried out by considering Bhuj (2001) ground motion. The effect of Soil-Structure Interaction (SSI) is evaluated by considering three different types of soil strata such as soft clayey sand strata, medium clayey sand strata and rock. Three-dimensional building-foundation-soil system is analysed using finite element method on the basis of direct method of SSI. Non-linear material behavior of underlying soil medium and linear behaviour of buildings is considered. The responses such as storey deflection and base shear of URM buildings with and without considering the effect of SSI are evaluated. It is found that responses such as storey deflection and base shear of the buildings increased by two times and nine times respectively for buildings with containment reinforcement than building without it due to the effect of SSI. Also, with lintel band, roof slab and containment reinforcement the deflection decreased by four times compared to building without it in mitigating seismic vulnerability in terms of deflection.*

Keywords*: Un-Reinforced Masonry buildings, Containment reinforcement, Time history analysis, Soil-Structure-Interaction*

1. INTRODUCTION

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 construction and good aesthetics. The damages observed in these structures depend on quality of materials and construction, structural layout and connections between structural elements.

Numerous experimental investigations were carried out on URM walls which shows the seismic behaviour of brick masonry walls [1-3]. 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 in-plane failure [5], out-of- plane failure, lack of anchorage between floor and walls, anchor failure when joists are anchored to walls were studied. 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]. The structural performance of URM buildings are improved by using containment reinforcement. This containment reinforcement is provided around masonry walls at an appropriate spacing. The reinforcements on the two faces are tied together through links or ties provided at a definite vertical spacing as shown in Fig.1.

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. The reinforcement on the compression side would tend to become slack. The reverse happens as the wall bends the other way [7,8]. Here the reinforcement is intended 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.

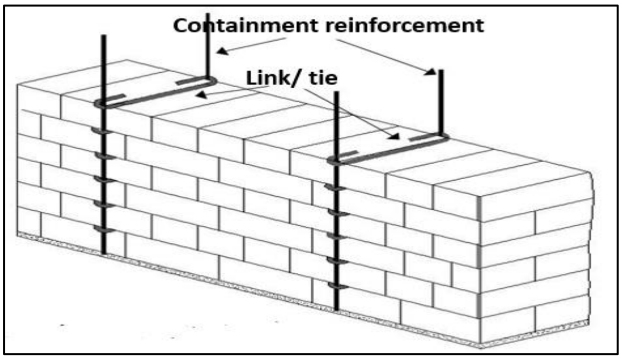

Fig. 1. Masonry with containment reinforcement and links [9]

From the studies it is understood that response of buildings depends on the response of the underlying soil medium and vice versa especially when considering the dynamic loads. The soil-structure interaction model can be used for a complete probabilistic study of the response of a corner section of a single storey masonry veneer house founded on an expansive soil [10]. The model has the potential for widespread applications for similar such studies [11-12]. The responses of various buildings on soft clay and hard rock have been performed by introducing the theory of SSI [13]. There are two different approaches for interaction effects namely, direct approach and indirect approach. In the direct approach, structure is modelled explicitly with soil strata and a complete solution is obtained in a single analysis. In the substructure method, the soil-structure system is analysed separately as two substructures; a structure which may include a portion of non-linear soil strata and the unbounded soil. If the structural foundations were perfectly rigid, the solution arrived by substructure approach and direct-method will be identical. The influence of SSI on elastic and inelastic range responses of low-rise building frames resting on shallow foundations shows that the base shear increases due to the effect of SSI. The seismic response of medium to high rise buildings generally decreases due to the influence of SSI [14,15].
Many of the previous researches focus on the numerical, analytical and experimental study on masonry building. Very few studies emphasis in the seismic behaviour of masonry buildings subjected to earthquake ground motion considering the effect of underlying soil medium. This study enumerates the effects of SSI on URM buildings using an integrated three-dimensional soil-structure system considering nonlinear behaviour of soil stratum.

2. METHODOLOGY

Idealisation of the building and foundation

In this study, single storeyed masonry buildings having masonry walls made of laterite blocks of 1:6 cement mortar is considered. For improving the seismic performance of URM buildings lintel bands, roof slabs and containment reinforcement are used. Four types of masonry buildings such as (i) building without roof slab and with lintel band (ii) building without roof slab and with lintel band (iii) building with roof slab and lintel band (iv) building with roof slab, lintel band and containment reinforcement are used. The designation used for the above four types of buildings are given in Table 1. Fig.2 shows the various building configurations used for the analysis. URM buildings 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 of size 1 m x 2 m on front longer wall. The considered plan has one window in the front longer wall and two windows in the longer wall of backside. Each of the short walls is assumed to be provided with one central opening of dimension 1m ×1m for window. Fig.3 illustrates the plan dimension of the URM building with vertical containment reinforcement. Vertical containment reinforcement made of 12mm diameter steel bars of Fe250 grade is provided on the surface of the walls on both the faces at a spacing of 1 m. Roof slab of thickness 0.12m and lintel band of thickness 0.2m and width 0.2m with M25 grade concrete and Fe250 grade steel reinforcement is used.

Table 1. Types of single storeyed masonry structures

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

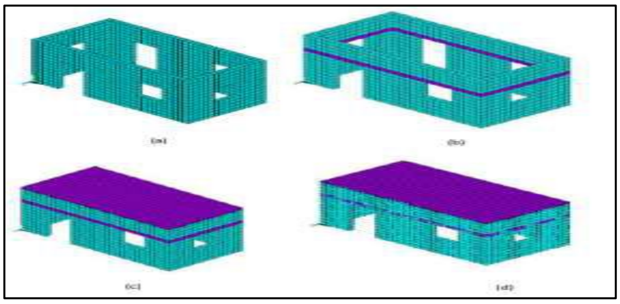

Fig.2. Configurations of URM buildings (a) U (b) UL (c)ULR (d) ULRC type [8]

Table 2. Material properties

Property	Masonry	RC (used in lintel band, Roof Slab)	Vertical Containment reinforcement
Modulus of Elasticity (kN/m^2)	1.20×10^6	2.50×10^7	2×10^8
Poisson's Ratio (assume)	0.15	0.15	0.30
Mass Density (kg/m^3)	2100	2500	7850

Strip footing of random rubble masonry having width of 0.6 m and depth of 0.6m is provided. Table 2. provides the properties of masonry, RCC and vertical containment reinforcement bars. Fig.4 gives the sectional elevation of URM building giving the details of foundation.

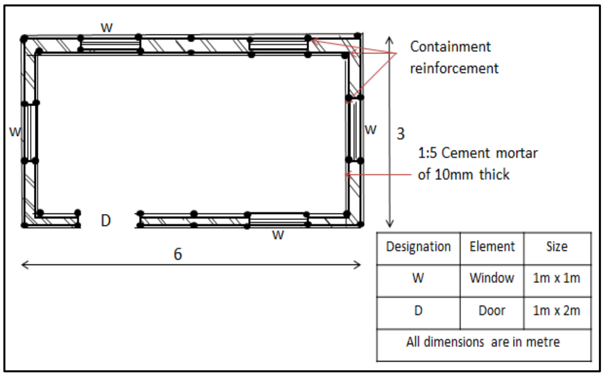

Fig.3. Plan of ULRC building [8]

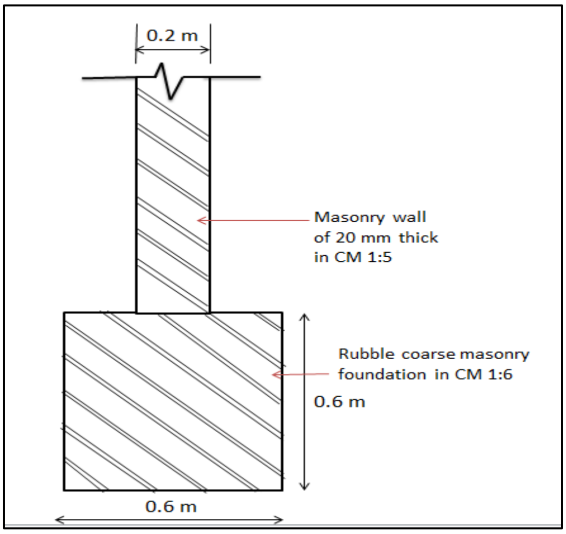

Fig.4. Sectional elevation of U building

Idealisation of soil strata

Three different soil strata considered in this analysis are Soft clayey sand strata (S), Medium clayey sand strata (M) and Rock (R) in which the flexibility decreases from rock to soft strata. Bedrock was assumed at a depth of 30m below the soil stratum. The lateral dimension of the soil stratum was taken as four times the lateral dimension of foundation [16]. The properties of soil strata are defined by its mass density, modulus of elasticity, poisson's ratio and angle of internal friction [17] as shown in Table 3. There are various types of soil models used to represent soil media. Here, Drucker-Prager (DP) model is used to define the non-linear soil stratum. DP model represents non-linear plastic failure of the soil and is simple as well as easy for numerical analysis. The DP yield criterion is a pressure-dependent model for determining whether a material has failed or undergone plastic yielding. The criterion was introduced to deal with the plastic deformation of soils and have been applied to rock, concrete, polymers, foams, and other pressure-dependent materials.

Table 3. Properties of soil strata [17]

Soil type	Poisson's ratio	Density (kg/m^3)	Elastic modulus (kN/m^2)	Angle of friction (ø)	Cohesion (kN/m^2)
S	0.20	16	50000	30	50
M	0.25	18	100000	34	100
R	0.30	20	250000	38	200

3. FINITE ELEMENT ANALYSIS

Finite element analyses of 3D integrated soil-structure system were carried out by using the finite element software. Different building components of a URM building under consideration are masonry, roof band, lintel band and vertical containment reinforcement. The URM building, foundation and underlying soil strata were modeled using eight noded brick element having three translation degrees of freedom at each node. Roof slab is modeled by using four noded elastic shell element. The element has six degrees of freedom at each node and has both bending and membrane capabilities. The vertical reinforcements were modeled using truss elements which is a uniaxial tension-compression element, also with three translational degrees of freedom at each node. All the masonry walls, lintel band, roof slab, vertical containment reinforcement and foundation were discretized with mesh size 0.2m. The soil strata were discretized with mesh size of 1m upto a depth of 20m and with mesh size 2m for the remaining depth along the vertical direction. Along the lateral direction soil stratum is discretized with mesh size 1m. The finite element structure of building with and without soil medium is depicted in Fig.6 and Fig.7 respectively. The total discretized system, consisting of the structure and the soil was then analyzed. This system was analyzed based on direct method of SSI by assuming the linear behaviour of building and foundation and nonlinear behaviour of underlying soil strata.

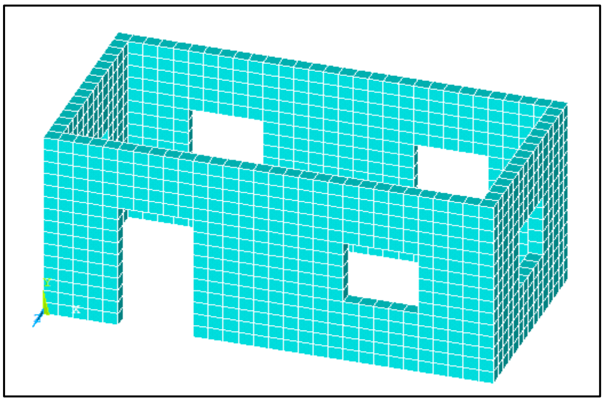

Fig.6. Finite element URM building

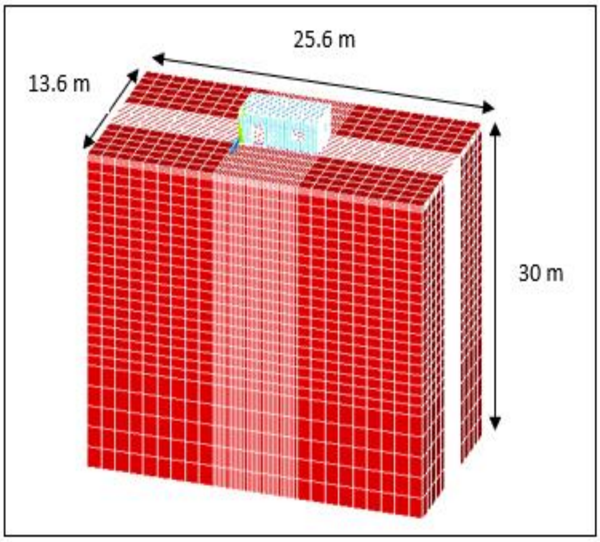

Fig.7. Finite element Soil-Structure system

4. GROUND MOTION

Time history analysis was conducted for URM buildings for Bhuj ground motion (2001). A part of the Bhuj ground motion acceleration recorded at Ahmedabad during earthquake which lasted over 135s is revealed in Fig.8 [18]. The peak ground acceleration is 0.11g at time 46.94s for Bhuj ground motion. The earthquake reached a magnitude of 7.7 M_w on the moment magnitude scale. The Fourier amplitude spectrum of Bhuj earthquake is revealed in Fig.9. Free vibration analysis is carried out to find the frequency and mode shapes of the U, UL, ULR and ULRC buildings with and without considering SSI. The responses such as storey deflection and base shear is also found out from the time history analysis considering their base fixity and base flexibility.

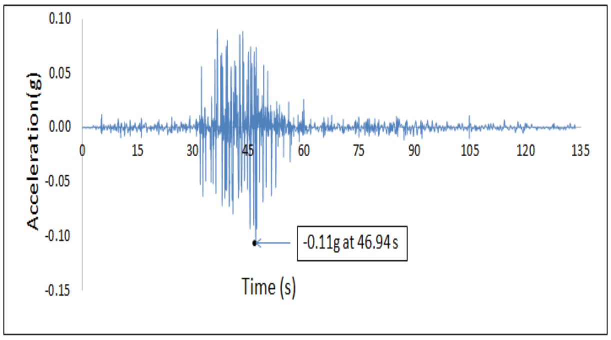

Fig.8. Acceleration time history of Bhuj earthquake [18]

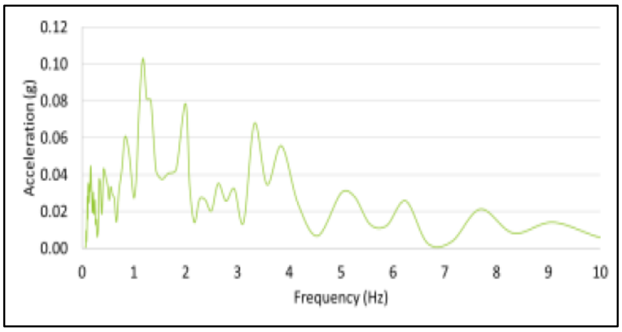

Fig.9. Fourier-amplitude spectrum Bhuj earthquake [18]

5. RESULTS AND DISCUSSIONS

All the four types of URM buildings were analysed to find their responses under Bhuj ground excitation. Frequencies were calculated. The absolute maximum responses such as deflection and base shear corresponding to fixed base buildings were evaluated.

Variation of Natural frequency

The natural frequency determined for URM building with and without the soil stratum is tabulated in Table 4. Fundamental natural frequency obtained from buildings with fixed base is higher than that obtained from SSI analysis. Increase in frequency of the buildings is due to the increase in stiffness of the building. Variation of fundamental frequency of building with flexible base from that of building with fixed base is more for U type building resting on soil type S and the maximum variation is about 47%.

Table 4. Comparison of natural frequency of building

	Fundamental Natural Frequency (Hz)			
	U	UL	ULR	ULRC
S	2.859	4.394	4.575	4.583
M	2.860	4.408	5.002	5.182
H	2.862	4.411	5.071	5.339
Fixed	4.950	6.904	11.058	12.397

Variation of deflection

The percentage variation of displacement of buildings with flexible base compared to fixed base is given in Table 5. The percentage variation of deflection for UL, ULR and ULRC buildings decreased by 43%, 95% and 96% respectively with respect to U building without considering the flexibility of soil strata. The percentage variation of deflection is 60% for U building supported on soft soil strata when compared with the same type of building with base fixed. The variation reduced to 40% and 20% for the same building supported on medium strata and rock respectively. The same is observed in UL, ULR and ULRC buildings. It is found that the deflection of the UL, ULR and ULRC building increases with decrease in stiffness of soil compared to U type building.

Table 5. Percentage variation in displacement

Designation	Displacement (Without SSI) (mm)	% variation of displacement (with SSI)		
		S	M	R
U	3.717	60.10	40.70	20.42
UL	2.109	78.97	73.37	40.25
ULR	0.160	96.47	93.31	87.40
ULRC	0.150	96.45	92.80	87.20

Variation of Base shear

Variation in base shear of low-rise buildings with flexible base is higher than buildings with fixed base. Table 6. displays percentage variation in the base shear of buildings. In the table given, 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. The building with more seismic weight has high base shear. Also, base shear got increased approximately about 94% for URM buildings due to the effect of SSI compared to masonry buildings without SSI.

Table 6. Variation in base shear of buildings

Designation	Base Shear (without SSI) (kN)	Variation of base shear of buildings (%)		
		S	M	R
U	179.98	87.78	92.17	93.49
UL	194.10	88.95	92.19	94.27
ULR	236.31	89.11	92.20	94.35
ULRC	243.06	89.75	93.57	94.85

6. CONCLUSIONS

The analysis of URM buildings considering the SSI effect is compared with buildings with fixed base. The major findings are shown below:
(i) With lintel band, roof slab and containment reinforcement the deflection decreased by four times compared to building without it in mitigating seismic vulnerability in terms of deflection.
(ii) The effect of SSI is significant while considering vertical containment reinforcement. The shear is increased by nine times and deflections increased by two times for buildings with vertical containment reinforcement than building without it when soft clayey sand stratum is account for.

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