Seismic Vulnerability of Code Compliant RC Frame Building with Unreinforced Masonry Infill Walls

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Abstract

Unreinforced masonry (URM) infill walls in Reinforced concrete (RC) buildings are normally designed as non-structural elements. However, in the past, the post-earthquake response of the RC frame building showed that URM infill walls increase the strength and stiffness of the RC frame buildings. Further, it is also observed that URM helped to prevent the disastrous destruction by acting as a structural member in RC frame. In the present study, the performance assessment of a four-storey URM infill RC frame with different infill configurations, namely bare and Open Ground Storey (OGS) is done using fragility analyses. Nonlinear masonry material is modelled as the equitant three strut model in ETABS. Nonlinear static pushover analysis is applied for the analysis of the configured RC frames. The probability of damage states is determined by firstly converting pushover curves into capacity curves and accordingly, performance-point values of Spectral acceleration and Spectral displacement for seismic demand Zone-V (Elastic Response Spectra as per IS 1893:2016) using the capacity-spectrum method (ATC-40) are determined. The fragility function used is an approximation of the continuous to discrete distribution. Fragility curves and mean damage matrix are derived to compare performance with each other. From the vulnerability analyses, it is observed that the OGS framed RC building performs better as compared to the bare frame.

Keywords: RC frame, Fragility analysis, Unreinforced-Masonry Infill wall, Pushover analysis

1. Introduction

Bhuj's (2001) earthquake not only questioned the quality of building structures in the Gujarat region, but also leads to the revision of the seismic Indian standards. In India, most RC frame buildings do not consider the influence of infill walls, however, the post-earthquake study showed that the unreinforced masonry wall is also resisting the lateral force and effectively acts as a structural member in the RC frame buildings [1, 2]. In the last two decades, a large number of works have been done on the mathematical modelling approach of the Unreinforced Masonry (URM) infill wall. The equivalent/single strut method is the widely accepted method and is given in the Indian seismic code i.e., IS 1893 (2016) [3]. However, many researchers have suggested to use more advance method known as the three-strut method [4].

In metro cities, a most common tendency is to leave the ground floor area without infill walls to serve different purposes like social gatherings and parking spaces. Structural designers are designing buildings without considering the lateral stiffness of the masonry walls. Previous studies found that when the URM lateral stiffness is taken into consideration, the over-strength of the RC frame increases, but the ductility decreases dramatically [5]. The capacity spectrum method (CSM) method is convenient for local and regional seismic vulnerability and risk assessment of RC frame buildings' seismic behaviour [6-8].

In the present study, the seismic vulnerability of a four-storey RC frame building is calculated considering the lateral stiffness of the URM infill walls for bare and OGS configurations. The procedure of estimation of the seismic vulnerability for RC buildings for the current study is summarized below

- Design the sample structural members of RC frame buildings with an effective moment of inertia as per IS 1893:2016 (Part-1) [3].
- Nonlinear Static Pushover Analysis (NSPA) was conducted to derive the pushover curve for the Bare and OGS URM infill wall RC building frame considering lateral structural stiffness of unreinforced infill walls. •
- Seismic Vulnerability analysis of RC frame buildings is done to determine the most likelihood of damage using the CSM and Fragility curves.

2. Fragility analysis of RC frame

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Fig. 1 shows details of the four-storey OGS and bare RC frame building designed as per IS 456 (2000) [9]. The buildings are assumed to be built on medium-strength soil in Surat (zone-III, PGA= 0.16-g). Floor finish and live load on the slab are taken as 1 and 3 kN/m2, respectively. Diaphragm action is used to simulate the effect of a 150 mm thick slab. The basic time-period of these frames on a 5% damped design spectrum for a medium-stiff soil and seismic zone-III is 0.543 seconds. Nonlinear static pushover analysis is performed as per the FEMA 356 (2000) [10]. Performance criteria and default hinges are taken for the structural components like beam and column from ASCE 41 (2012) [11]. The derived Pushover curve is later converted into the capacity curve as per the ATC-40 (1996) [12] and HAZUS (2003) [13]. This converted spectral displacement is used in the derivation of a fragility curve for various damage states. The likelihood of reaching or exceeding a particular damage state as a function of a parameter defining the seismic action to which the building is subjected to a certain damage state is described by a fragility curve.

The lognormal probability density function, as shown in equation (1), is widely used to appropriately depict fragility curves.

$$\rho_k(S_d) = P[DS \geq DS_k \mid S_d] = \Phi\left[\frac{1}{\beta_k} \ln\left(\frac{S_d}{S_{d,ds}}\right)\right] \quad (1)$$
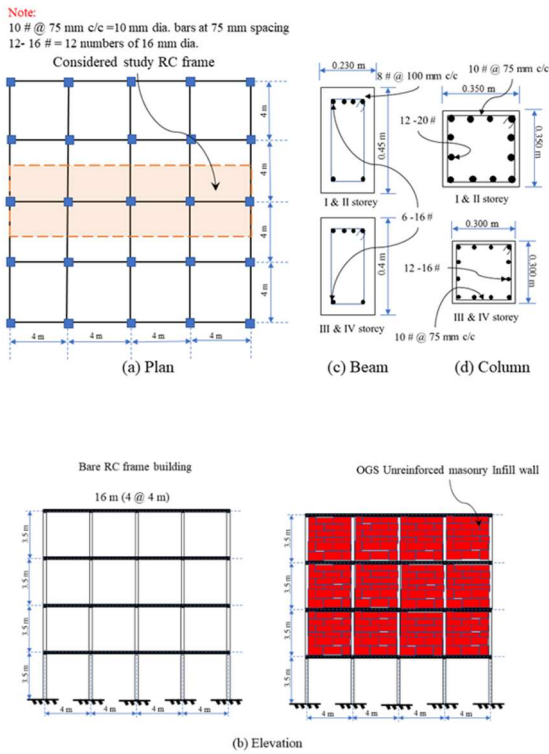
$$S_{d,k} = \begin{cases} 0.7D_y & Slight \\ D_y & Moderate \\ D_y + 0.25\left(D_u - D_y\right) & Severe \\ D_u & Complete \end{cases} \quad (2)$$

where, S_d is the spectral displacement, Sd, ds is the mean spectral displacement; βk is the standard deviation of a natural logarithm of spectral displacement for damage grades, and Φ is the standard normal cumulative distribution function.

The damage grade threshold based on the yielding and ultimate spectral changes of the building structure is given in the following equation. D_y and D_u are the displacements at yield and ultimate level. Damage likelihood matrices (DPM) are defined as the weighted average damage index (DS_m) for the maximum likelihood of the RC frame building damage state, which can be derived from the following equation.

$$DS_m = \sum_{i=1}^{4} k\, p_k[N, d] \quad (3)$$

For the damage grades considered in the study, the value of k is taken from 1 to 4, and $p_k[N, d]$ demonstrates the equivalent likelihood of occurrence of damage. The most likely damage state is the mean damage index for individual RC frame buildings. According to Barbat [14], the range of DS_m values for different damage levels is as follows: No-damage (0-0.5), Slight (0.5-1.5), Moderate (1.5-2.5), Severe (2.5-3.5), and Complete (3.5-4).
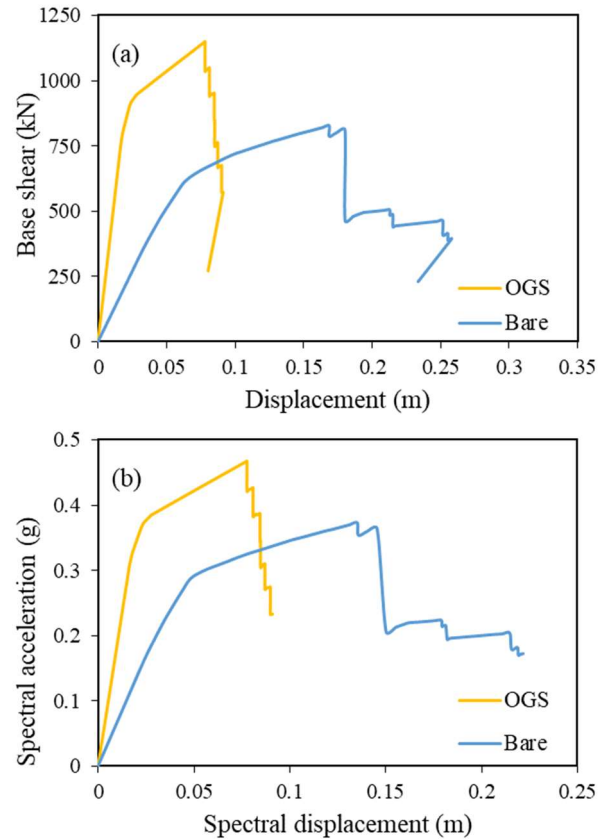

Fig. 1. a) Plan, b) Elevation, Reinforcement detailing of (c) beam, and d) column for OGS and bare RC frame building

Fig. 2. Derived (a) pushover and (b) capacity curve for the 4-storey OGS and bare RC frame building.

3. Results and discussion

Fig. 2 shows the pushover and capacity curve obtained for the bare and OGS RC frame. For the bare RC frame, the yield and ultimate spectral displacements are 43 and 149 mm, respectively. Similarly, for the OGS RC frame, the yield and ultimate spectral displacements are 22 and 77 mm, respectively. The initial or elastic stiffness of the bare frame is about 9684 kN/m, while the initial stiffness of the OGS infill wall type configuration is 45000 kN/m.

The intersection of the capacity spectrum with the relevant demand spectrum is determined using the A-type iterative procedure of equal displacement approximation according to ATC-40 in the capacity spectrum method. For a particular lateral seismic force, it describes the inelastic or nonlinear response that the structure will experience. The accompanying damage state for the structure can be analyzed and compared for different earthquakes using the performance point. For RC frame buildings with bare and OGS infill walls for Indian seismic zone-V with PGA of 0.36g and 5% damped elastic response spectra, the performance point is shown in Fig. 2(b). From this capacity curve, it is observed that the performance point in bare type RC frame is coming in the nonlinear range, i.e., beyond the yield point.

The different parameters relating to the fragility function for Bare and OGS RC frame buildings are shown in Table-I. From Table-I, it is observed that the spectral displacement for the bare frame is larger than that of the OGS frame. As a result, it can be concluded that the mid-rise OGS RC frame performs better than the bare RC frame. The median spectral displacement for slight, moderate, substantial, and total damage states of mid-rise RC buildings, as determined by damage states thresholds is given in Table-I. Fig. 3 shows fragility curves for both bare and OGS RC buildings. These curves can be used to determine whether a structure can withstand a specific degree of seismic load or not and how it will behave in the nonlinear or inelastic region. It is shown that for a bare type RC frame model with 54 mm spectral displacement (S_d), the estimated chance of little damage is roughly 93 %, moderate damage is 66%, severe damage is 29%, and full damage is 5%, respectively. Similarly, for the OGS RC frame for a 141 mm spectral displacement (S_d), the estimated likelihood of damage is increased to 83 % for minor damage, 45 % for moderate damage, 13 % for severe damage, and 2 % for total damage, respectively. This shows that the 4-storey OGS RC frame building shows fewer damages, as compared to the bare RC frame.

Damage probability matrices (DPM) greatly depend on the spectrum displacement of the performance point and the stiffness of the building for each case earthquake hazard level. The damage probability matrices of the investigated building for both bare and OGS in Indian seismic zone-V (PGA=0.36g) are shown in Table-II. DS_m is the weighted average damage state determined using equation 3, and is assumed to be close to the structure's most likely damage condition. Finally, a comparison of fragility curves of bare and OGS RC frame for each damage state has been shown in Fig. 4. The comparison plot also confirms that the probability of damage in bare frame for each damage level is higher than that of OGS frame.

Table-1. Fragility function parameter of 4-storey RC frame building with bare and OGS configuration.

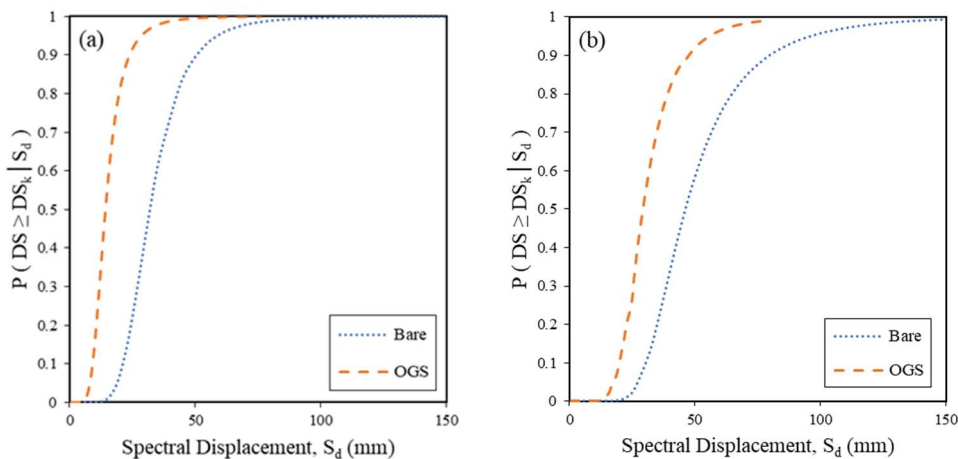| Damage States	d	DS_1	DS_2	DS_3	DS_4	Mean, $S_{d,ds}$ (mm)		Uncertainty, β	
						Bare	OGS	Bare	OGS
Slight	0.19	0.50	0.17	0.07	0.01	33.60	15.40	0.33	0.36
Moderate	0.39	0.86	0.50	0.22	0.05	48.00	22.00	0.37	0.43
Severe	0.63	0.99	0.84	0.50	0.14	69.75	35.75	0.49	0.57
Complete	0.85	1.00	1.00	0.91	0.50	135.00	77.00	0.62	0.74

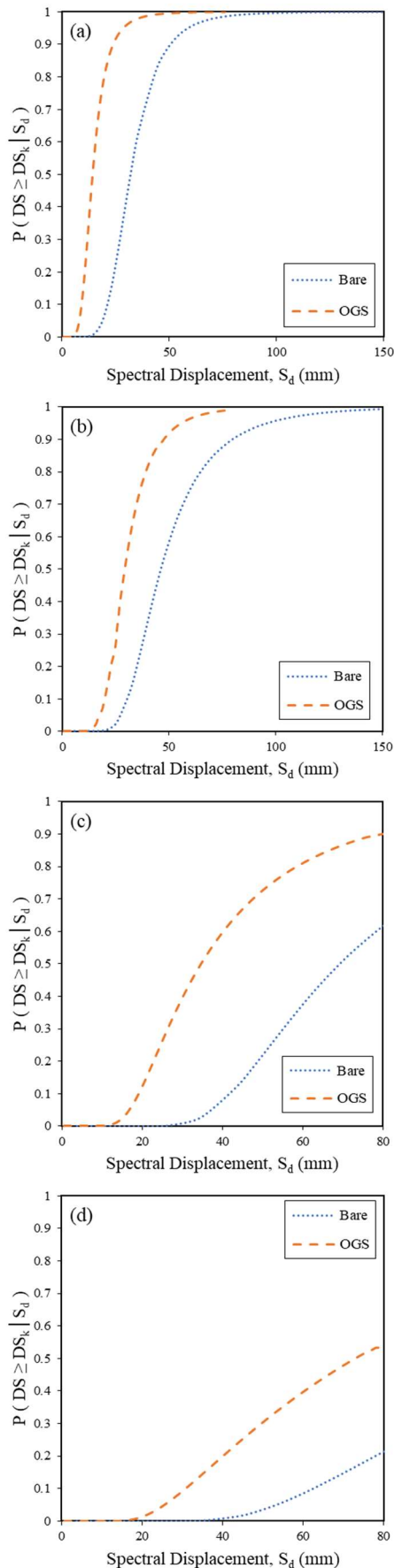Fig. 3. Fragility curves for the four storeys (a) bare and (b) OGS RC frame buildings with infill walls.

Fig. 4. Fragility curves comparison of bare and OGS 4-storey RC frame building for all damage states.

Table-2. Comparison of mean damage grade (DS_m) considering 4-storey RC frame building with bare and OGS configuration.

Model type	Probability of occurrence					DS_m
	No-damage	Slight	Moderate	Severe	Complete	
Bare	7.2%	26.7%	37.4%	23.3%	5.4%	1.94
OGS	17.3%	38.1%	31.4%	11.5%	1.6%	1.46

4. Conclusions

Nonlinear static pushover analysis was used to analyse the seismic performance of four-storey, four-bay bare, and OGS RC frame building. Further, a fragility study was conducted to produce probabilistic fragility curves that reflect the expected structural deformation. For determining the damage state of a building, damage probability matrices are devised. It is found that for zone-V earthquake loading (as per IS 1893:2016) [3], bare frames are more susceptible to damage as compared to OGS frame according to the fragility curves. Further, the numerical results show that the bare framed RC building may receive moderate damage for zone-V earthquake, while the projected damage in the OGS RC frame building is slight damage according to damage probability matrices and mean damage index intervals.

Acknowledgement

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