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Retrofitting Solutions for Existing Open Ground Storey RC Buildings

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Abstract

In the last few decades with the increase in population and decrease in usable land, there has been an enormous rise in the construction of residential buildings with open ground storey (OGS) to facilitate vehicle parking. Such OGS are created by removing the infill walls in the first storey. However, during the past earthquakes many of such OGS buildings have suffered severe damage and sometimes complete collapse of the structure. This is because OGS buildings, in general, exhibit soft story irregularity. Although the design codes have recommended provisions to enhance the seismic capacity of the OGS buildings, such provisions are barely implemented during construction. In order to avoid casualties and economic losses, it is necessary to retrofit the existing OGS structures. In this work, an attempt is made to strengthen the OGS buildings using masonry infill walls and braces as the retrofitting solutions. The models are developed in Seismostruct and analysed using suitable analytical methods. The behaviour of OGS buildings with masonry and braces at selected locations is evaluated. Retrofitting solutions that provide enhanced seismic performance and maximum parking space are proposed.

Keywords: open ground storey, soft storey, retrofitting, seismostruct

1. Introduction

A study of the damages during the past earthquakes shows that Open Ground Storey (OGS) failure is one of the most common types of failure. These OGS buildings are constructed by eliminating the infill walls in the ground storey to facilitate vehicle parking. However, the removal of infill walls in the ground storey usually results in drastic decrease of the lateral stiffness of the ground storey with respect to that of the upper storeys. Due to the soft storey irregularity this type of buildings show high tendency to collapse during earthquakes. Design codes have special provisions for the construction of OGS buildings. Nevertheless, it is observed that such provisions are rarely implemented. In order to prevent casualties and economic loss in future strong earthquakes, the existing OGS buildings need to be analysed and if required retrofitted. Several researchers have adopted different measures for vibration control of buildings [1-4].

In the present study, the behavior of OGS is analyzed by nonlinear static pushover analysis. Two retrofitting schemes viz. masonry infill walls and steel braces are implemented to enhance the performance capacity of OGS buildings.

2. Nonlinear static analysis

In pushover analysis, the capacity curve is determined by statically loading the structure with realistic gravity loads combined with a set of lateral forces to calculate the roof displacement and base shear that defines first significant yielding of structural elements. The yielding elements are then relaxed to form plastic hinges and incremental lateral loading is applied until a nonlinear static capacity curve is created [9]. For structures that vibrate primarily in the fundamental period, the pushover analysis will very likely provide good estimates of global as well as local inelastic deformation demands. Also exposes design weaknesses such as story mechanisms, excessive deformation demands, strength irregularities and overloads on potentially brittle elements, which may remain hidden in an elastic analysis [5].

3. Model parameters

The study evaluates the behavior of OGS building subjected to lateral loads. The following model parameters are considered.

3.1 Material model

A G+5 storeyed 3D RC building is modeled in SeismoStruct academic version [17]. SeismoStruct is a fibre based FE package capable of predicting the large displacement behavior of space frames under static and dynamic loading, considering both geometric nonlinearity and material inelasticity [15]. Currently fourteen material types are available for material modeling in SeismoStruct. In this study, Mander et. al nonlinear concrete model is chosen to model concrete material. This is a uniaxial nonlinear constant confinement model, initially programmed by

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Madas [1993] [14], that follows the constitutive relationship proposed by Mander et al. [1988] [6] and the cyclic rules proposed by Martinez-Rueda and Elnashai [1997] [7]. The mean compressive strength of concrete considered is 20 MPa. The reinforcements are modeled following Menegotto and Pinto steel model with a yield strength of 415 MPa. This is a uniaxial steel model initially programmed by Yassin [1994] [16] based on a simple, yet efficient, stress-strain relationship proposed by Menegotto and Pinto [1973] [10], coupled with the isotropic hardening rules proposed by Filippou et al. [1983] [13].

The infill panel is modeled as a four-node masonry panel element, developed and initially programmed by Crisafulli [1997] [12] and implemented in SeismoStruct by Blandon [2005] [11] and the same has been implemented in the present work. Each panel is represented by six strut members; each diagonal direction features two parallel struts to carry axial loads across two opposite diagonal corners and a third one to carry the shear from the top to the bottom of the panel. The axial load struts use the masonry strut hysteresis model, while the shear strut uses a dedicated bilinear hysteresis rule [17].

3.2 Section specifications

The sectional parameters are described in table 1.

3.3 Prototype structure

Fig. 1. shows a plan view of the G+5 storeyed building considered in the present study. Number of bays are four and five in X and Y directions respectively with average bay width of 4m. Height of the ground storey is 3m and all other storeys are 3.3m.

4. Behavior of OGS building

In order to analyse the behavior of OGS structure, two models are prepared: fully infilled, with infill walls in all the storeys, and OGS, infill walls in all storeys except the ground storey. A nonlinear static analysis is carried out to evaluate the performance of OGS with respect to fully infilled.

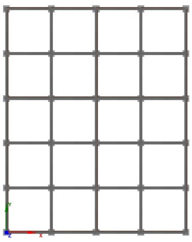


Fig. 1. Building plan

Table-1. Sectional parameters

Element	beam	column
Dimensions (mm×mm)	250×500	300×450
Longitudinal reinforcement	Corner 4@20 Top_bottom_sides (2@16)	Corner 4@20 Top_bottom_sides (2@20) left_right_sides (2@20)
Transverse reinforcement	8mm@100mm	8mm@100mm

Table 2. Roof displacements and base shear for fully infilled and OGS

Parameters →	**Roof displacement(m)**		**Base shear (kN)**	
Model →	Fully infilled	OGS	Fully infilled	OGS
concrete strain < 0.002	0.036	0.012	14354.252	3352.185
concrete strain < 0.0035	0.060	0.024	15495.271	4829.464

The lateral loading is applied in the X direction only. The lateral load pattern for the model is calculated based on the base shear and eigen solutions of the model. Figure 2 shows the pushover curves of fully infilled and OGS. It is observed that in case of OGS there is considerable decrease of base shear capacity as compared to a fully infilled structure. To understand the performance behavior further, two relevant stages are considered: concrete strain < 0.002 and concrete strain < 0.0035.

It is observed from table 2 and figure 2 that in case of OGS the elements reach limiting condition of concrete strains at a much lower base shear capacity than that of the fully infilled model. This shows that the OGS buildings are more vulnerable to lateral loading than the fully infilled structures.

5. Retrofitting of OGS buildings

From the above result, it is seen that the OGS buildings are seismically vulnerable. However, the functional requirement of such buildings cannot be neglected. Therefore, it is necessary to retrofit such OGS buildings. Various retrofitting schemes are analyzed in several literatures. In this study, two retrofitting schemes are considered viz. infill walls and steel braces. Three cases of infill wall locations is analyzed to evaluate the most suitable location that causes minimum intervention in vehicle parking as well as enhance the performance capacity. Similar cases are also considered for the steel braces.

5.1 Retrofitting scheme 1- infill walls

The three cases of infill wall locations analyzed are as described below

Case 1 _ outer infilled: In this case the infill walls are provided in all the perimeter bays with a central opening in the longer direction as shown in figure 3 (a).

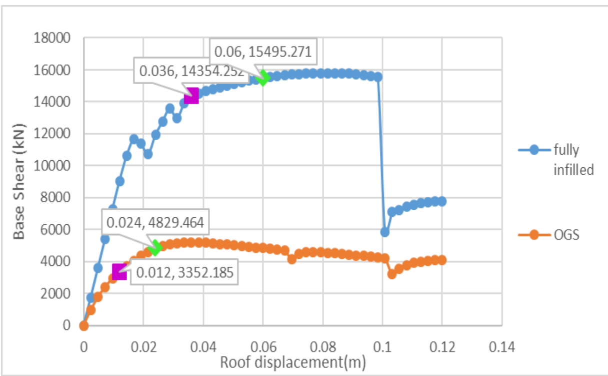
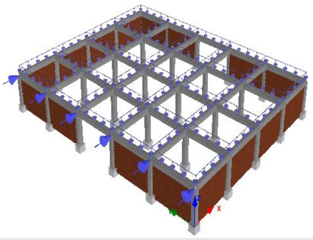


Fig. 2. Comparison of pushover curves of fully infilled and OGS

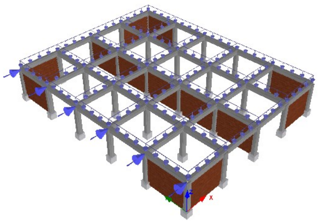
Case II_ outer corner + central infilled: In this case, the infill walls are provided in the outer adjacent walls of the four corners and in the central bay along the longer direction as shown in figure 3 (b).

Case III_ inner corner + central infilled: In this case, the infill walls are provided in the inner adjacent walls of the four corners and also in the central bay along the longer direction as shown in figure 3 (c).

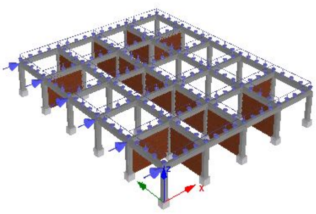
The pushover curves of the three cases of infill wall locations are shown in Figure 4. Case II and III shows similar results with increase of base shear capacity than the OGS. Maximum performance enhancement is observed in case I. A comparison of performance capacities at concrete strain < 0.002 and concrete strain < 0.0035 are tabulated in table 3.



(a) Case I



(b) Case II



(c) Case III

Fig. 3. Perspective view of the ground storey with infill walls at different locations

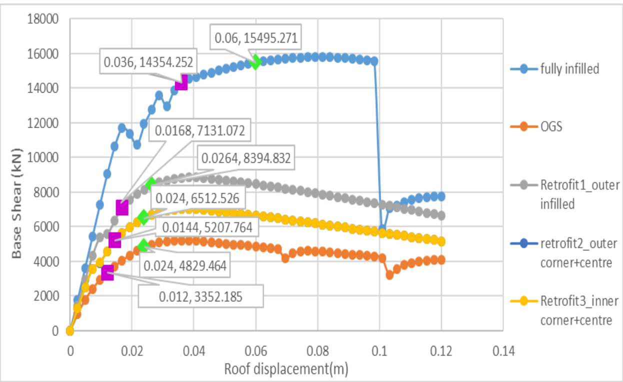


Fig. 4. Pushover curves of the three cases of infill wall locations

Table 3. Performance capacities of the three cases of infill wall locations

concrete strain →	<0.002		< 0.0035	
Parameters →	**Roof displacement(m)**	**Base shear (kN)**	**Roof displacement(m)**	**Base shear (kN)**
Case 1 _ outer infilled	0.0168	7131.07	0.0264	8394.83
Case II_ outer corner + central infilled	0.0144	5203.37	0.0240	6516.14
Case III_ inner corner + central infilled	0.0144	5207.76	0.0240	6512.53

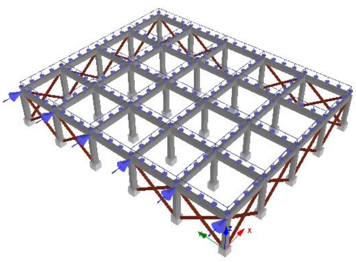
5.2 Retrofitting scheme 2- steel braces

Retrofitting of existing structure with steel bracings could improve the seismic performance of the structure since the braced frame will resist higher lateral loads than the moment resisting frame and it provides adequate ductility [8]. In this study W6×25 steel section, available in SeismoStruct, is used as X- braced pattern in the ground storey. Similar to the infill wall locations, steel braces are also analysed for three cases.

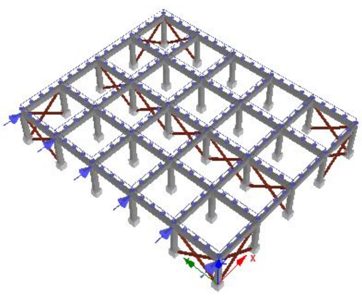
Case 1 _ outer braced: In this case the steel braces are provided in all the perimeter bays with a central opening in the longer direction as shown in figure 5 (a).

Case II_ outer corner + central braced: In this case, the steel braces are provided in the outer adjacent walls of the four corners and in the central bay along the longer direction as shown in figure 5 (b).

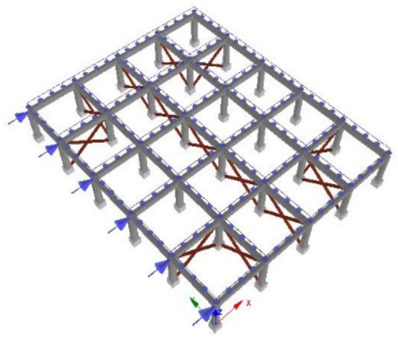
Case III_ inner corner + central braced: In this case, the steel braces are provided in the inner adjacent walls of the four corners and also in the central bay along the longer direction as shown in figure 5 (c).



(a) Case I



(b) Case II



(c) Case III

Fig. 5. Perspective view of the ground storey with steel braces at different locations

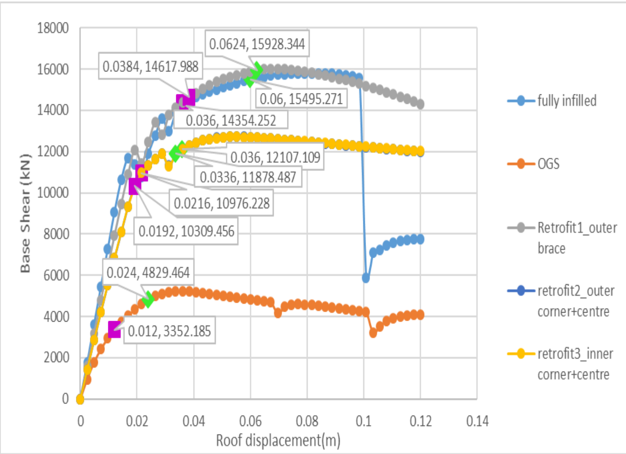


Fig. 6. Pushover curves of the three cases of steel braces locations

The pushover curves of the three cases of steel brace locations are shown in Figure 6. Case II and III shows similar results with increase of performance capacity than the OGS. Maximum performance enhancement is observed in case I and is equivalent to that of fully infilled building. A comparison of performance capacities at concrete strain < 0.002 and concrete strain < 0.0035 are tabulated in table 4.

Table 4. Performance capacities of the three cases of infill wall locations

concrete strain →	**<0.002**		**< 0.0035**	
Parameters	**Roof displacement(m)**	**Base shear (kN)**	**Roof displacement(m)**	**Base shear (kN)**
Case 1 _ outer infilled	0.0384	14617.98	0.0624	15928.34
Case II_ outer corner + central infilled	0.0216	10976.23	0.0360	12107.11
Case III_ inner corner + central infilled	0.0192	10309.46	0.0336	11878.49

6. Conclusion

With the increase of population and decrease of usable land, the demand for multistoreyed buildings have increased tremendously. In order to facilitate vehicle parking, a large number of these buildings are constructed with Open Ground Storey (OGS) that, in general, contributes to soft storey irregularity. Consequently, the OGS buildings have high tendency to collapse during strong earthquakes. In this study, the behavior of the OGS buildings is evaluate by nonlinear static pushover analysis and two retrofitting measures viz. masonry infill walls and steel braces are proposed. It is observed that both the retrofitting measures results in significant enhancement of performance capacity of the OGS buildings.

Disclosures

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