Enhancement of the Seismic Performance of Open Ground Storeyed Building using X-bracings

Shemin T John1, Deepak Kumar Sahu1*, S Sujeesh2 and Pradip Sarkar3

1 Ph.D. Scholar, National Institute of Technology Rourkela, India, 769008
2 M Tech Scholar, Mar Baselios College of Engg and Technology, Trivandrum, India, 695015
3 Associate Professor, National Institute of Technology Rourkela, India, 769008
*deepaksahu3269@gmail.com

Abstract. High rise buildings are rapidly increasing in India, and the reason is the unavailability of land. The latest developments in the construction industry improved the utility of available space in productive ways. Perhaps the most recent pattern in the development field is Open Ground Story (OGS) encircled structures, where the ground story is kept open without infill dividers mostly because of points of interest on parking facilities. The ground storey of these buildings are considered as soft and weak, making it most vulnerable to earthquakes, and incorrect structural designing of these buildings will result in catastrophic failure. It is found that the addition of steel bracings significantly improves the seismic performance of OGS buildings in recent years. The motivation of the present study is to focus on the OGS framed buildings with and without steel bracings. In this work, a combination of conservative lateral load resisting systems such as X-bracings and multiplication factor is employed along with moment resisting frame to develop a hybrid system thus by improving the seismic performance of OGS structures.

1. Introduction
Structures nowadays are constructed with the bottom storey made vacant for increasing the parking space, i.e. there is no partition wall (RCC or masonry) between columns, and such type of buildings are called as OGS buildings. The characteristics of OGS buildings are relative flexibility in the ground floor having a more significant relative horizontal displacement of the upper storey compared to the ground storey, also known as Soft Storey condition [1]. This condition results in a relatively weaker ground storey. A large variety of OGS buildings can be found in Ahmedabad city in India. The Bhuj earthquake in 2001 caused severe damage, resulting in huge losses, have proved that these buildings can be extremely vulnerable under seismic ground motion. After the Bhuj earthquake, significant revisions have been implemented in Indian Standard IS 1893 (Part1) 2002 regarding OGS buildings [2]. It suggests to calculate the design forces of bare frame building without considering the effect of infill wall under earthquake loading and then to redesign the columns of the ground storey of an OGS building by applying a factor, 2.5 times the forces calculated from the previous analysis. The factor is termed as multiplication factor (MF) [1]. Several studies suggested for providing walls in the ground storey made up of either masonry or reinforced concrete wall (shear wall) to avoid the unfair and irregular distribution of stiffness and strength in any storey of the building [3,4,5]. The present study efforts to calculate the seismic performance of OGS frame braced with X-bracing system. It is found that the addition of steel bracings considerably improves the performance of OGS buildings [6,7,8]. In this work, a combination of conservative lateral load resisting systems such as X-bracings and multiplication factor is employed along with moment resisting frame to develop a hybrid system thus by improving the seismic performance of OGS structures.
linear static method to the forefront[9]. Pushover analysis is a static non-linear technique in which the magnitude of the structural loading is increased in the lateral direction of the structure according to a pre-defined pattern [10].

2. Modelling
The building used for analysis is a four-storied RC building with a floor height of 3.2 m. The building is assumed to be located in seismic zone IV. The structure is designed as a frame model with masonry infill and constraints as fixed for the ground storey columns. The load combinations specified by Indian seismic code [1] has been considered.

![Frames considered for analysis](image_url)
Figure 1 shows 12 models considered for non-linear static pushover analysis. The figure shows OGS buildings with and without X-bracing with different magnification factor [11]. The column dimensions near the supports are increased with increasing magnification factor as per IS 1893 [1].

3. Results and discussions
Four storied OGS frames were analysed by non-linear static (pushover) analysis. The structure was modelled and analysed using the software SAP2000 v18. Pushover analysis is then carried out by vertical loading (gravity load) followed by a gradually increasing displacement controlled lateral load [12].

3.1. Pushover curve
The capacity curve, also known as pushover curve is a plot of base shear versus roof displacement of the structure. The pushover load case was defined as the earthquake load pattern assigned to the nodes, and the displacement was controlled with the maximum monitored value as 4% of the height of the building, which is equal to 0.512 m. The capacity curve is a good indicator of the inelastic behaviour of the building beyond the elastic stage [13,14]. The pushover curve of all 12 models is plotted in figure 2 and figure 3.

![Pushover curve of OGS models including bare frame and fully infilled.](image)

**Figure 2.** Pushover curve of OGS models including bare frame and fully infilled.

**Table 1.** Maximum base shear and corresponding displacement.

| Frame model | Base Shear(kN) | Base Shear Increase (%) | Roof Displacement(m) |
|-------------|----------------|-------------------------|----------------------|
| BF 1.0      | 969            | 0.32                    |                      |
| FI          | 28607          | 0.07                    |                      |
| O 1.0       | 4394           | -                       | 0.17                 |
| O 1.5       | 4826           | 8.94                    | 0.13                 |
| O 2.0       | 5495           | 20                      | 0.12                 |
| O 2.5       | 8966           | 50.99                   | 0.11                 |
| O 3.0       | 13180          | 66.66                   | 0.10                 |

From the pushover curves obtained as in figure 2, the maximum base shear and corresponding roof displacement of various buildings are tabulated in Table 1. It can be concluded that by applying different multiplication factors to the ground storey of the OGS building, ranging from 1.5 to 3.0 at an interval of 0.5, the base shear capacity is increased from 8.94% to 66.66%. The base shear is comparatively more for MF 2.5 and MF 3.0; this is mainly due to the increase in the area of cross-section causing an increase in total base shear, which makes the overall weight of these buildings more than ordinary OGS. Now the OGS building with various MF is provided with X bracing throughout the centre of the building and corresponding pushover curves are being plotted in figure 3 and the base shear capacity is tabulated in table 2. It can be seen that by applying different multiplication factors to the ground storey of the OGS with X bracing ranging from 1.5 to 3.0 at an interval of 0.5 the base shear capacity is increased from 10.49% to 68.11% with a total increase of 57.62%.
Figure 3. Pushover curve for OGS with X-bracings.

Table 2. Maximum base shear capacity of OGS with X bracing.

| Frame model | Base Shear (kN) | % increase in Base Shear Capacity | Roof Displacement (m) |
|-------------|-----------------|----------------------------------|-----------------------|
| OX 1.0      | 5260.85         | -                                | 0.16                  |
| OX 1.5      | 5812.90         | 10.49                            | 0.14                  |
| OX 2.0      | 6416.43         | 21.96                            | 0.12                  |
| OX 2.5      | 9999.58         | 52.02                            | 0.11                  |
| OX 3.0      | 14528.21        | 68.11                            | 0.09                  |

The base shear capacity of the OGS building with X bracing is relatively higher than the OGS buildings without X bracing. This indicates that the seismic ability of the building is enhanced with a redesign of OGS building with MF and with the X bracing.

3.2. Performance level

Three performance level namely performance level 1 (PL1), performance level 2 (PL2), performance level 3 (PL3) are the limits defined to assess the performance of a structure. Performance level 1 (PL1) indicates only a very limited structural damage, performance level 2 (PL2) shows significant damage to some structural elements and performance level 3 (PL3) shows severe damage to some structural elements. All the performance level of the OGS building with various MF (1 to 3) with and without X-bracing are plotted in figures 4 and 5. The performance points of the corresponding building are marked on the graph and are plotted below.

Figure 4. Performance points of OGS without X-bracings.
From figure 4, it can be seen that the OGS building with MF 1.0 is having the performance point between the PL 2 and PL 3 that means spalling of concrete is occurring at this stage. For OGS building with MF 1.5, the point lies just at the PL 2, which shows that the spalling of concrete has been started. For the OGS building with MF 2.0 and MF 2.5, the performance point lies between PL 1 and PL 2, which shows that the yielding of steel is taking place, which enables the occupants to get to a safer place before the collapse. For the OGS building with MF 3.0, the point lies below PL 1, which shows that the building is on much safer side but approaching to the yielding of steel.

![Graph showing performance point of OGS buildings](image)

Figure 5. Performance point of OGS with X-bracings.

Figure 5, shows that the OGS building with MF 1.0 and X bracing is having the performance point between the PL 1 and PL 2 indicating yielding of reinforcement steel. For the OGS building with MF 1.5, including X bracing, the performance point lies just at the PL 1, which show that the yielding of steel has just been started. For the OGS building with MF 2.0 with X bracing, the performance point lies just below the PL 1, which indicates that the yielding of steel is only going to happen. For OGS building with MF 2.5 and MF 3.0 with X bracing, the performance point lies just below PL 1, this shows that the building is on much safer side but approaching to the yielding of steel.

By comparing the above plots, the addition of X bracing to OGS building with various MF, the performance of the building is improved to some extent, thus enhancing the seismic performance of the building. From the nonlinear analysis, it is clear that OGS building with X bracing is somewhat a suitable replacement for the RC shear wall and designing the OGS building with MF 2.5 and 3.0 enhances the seismic performance. Like-wise the OGS frame with MF 1.5 has lower base shear capacity than frame with MF 1. From the analysis, OGS building with MF 2.0 has a better performance and a comparable stiffness when compared to the MF 1.0. And the addition of X bracing to the OGS building with MF 2.0 increases the seismic performance due to larger base shear capacity.

IS 1893(part 1) 2002 suggests that the building with soft storey should be redesigned with an MF 2.5 for the ground storey columns. However, from the present study, it is clear that MF 2.5 is an overestimated value. OGS building with MF 2.0 has higher base shear capacity and lower roof displacement with or without X-bracings. Thus, MF 2.0 is observed to be an optimum value for the redesign of the ground storey columns of OGS building.

4. Conclusions
   - The introduction of X-bracing increases the seismic performance of the OGS buildings considered in the present study.
   - With the addition of the X-bracing to the OGS building with MF (1.5 to 3) the total base shear capacity is increased by 57.62%.
   - With the addition of X- bracing, the performance level (PL 3) shifted to PL 2 for OGS buildings indicating increase in base shear capacity as well as safety.
5. References

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