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Seismic Performance of Open Ground Floor Tall Buildings on Flexible Ground

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Abstract. Seismic performance assessment of building is challenge to civil engineers. The complexity of earthquakes, unpredictable soil and uncertainties in construction lead many structures to be vulnerable during earthquakes. Generally in urban area, buildings have open ground floor to accommodate parking, reception, lobbies with reduced infill etc. It has been well established that open ground floor buildings can enhance the vulnerability of structures. This paper attempts to show that tall open ground floor buildings on soft soil will become even more vulnerable during earthquakes, due to flexibility of ground. For this purpose, ETABS, a finite element software that performs non-linear pushover analysis is used and three dimensional analysis is performed. Gazetas approach (1991) has been used to model the ground with varying stiffness. Open ground floor reinforced concrete frame on flexible ground is considered in analysis. Unsymmetrical structural frame was found to be more vulnerable indicating that extra care is necessary while handling unsymmetrical structures.

Keywords: Soft Storey collapse, Seismic performance, Flexible base, Gazetas solution, Pushover analysis, Stiffness of ground.

1 Introduction

Earthquakes are the most destructive calamities causing huge casualties, injuries and economic loss. Earthquake risk assessment is needed for disaster management, and emergency preparedness. Many urban tall buildings in India have open ground floor as an unavoidable feature. This is primarily being adopted to accommodate parking or reception lobbies with reduced infill in the ground floor, and hence the lateral stiffness of this floor is less than 70% of upper floors or less than 80% of the average lateral stiffness of the three floors above (IS: 1893 Part1 2016). Soft storey collapse during earthquakes is certainly one of the most significant failures. It has been found that the soft storey at ground level is the most vulnerable location from seismic performance view point. Acute shortage of land in urban areas, the economic considerations, functional requirements and the necessity of vertical growth have forced the construction of tall buildings with soft storey on relatively poor ground.

It has been well understood that open ground storey has phenomenal influence on seismic behavior of structures. Thickness and stiffness of overburden soil are likely to influence the seismic behavior of structure. Soft soil is one which has very low stiffness, hence most buildings will be more vulnerable on these soils. For the purpose of presenting performance of soft storey building, a three storey (tall) building has been considered in which the ground storey is made soft storey. Pushover analysis has been effectively used in the past to study the performance of irregular structure under lateral loading (Madhusudhan et.al. (2014), Rajesh (2014)). The primary objective of this paper has been to study the vulnerability of soft storey (open ground storey) resting on soft ground, which is attained by using ATC40 and FEMA356. For this purpose, ETABS (2016) has been used. However, recent guidelines such as ASCE41 are expected to give similar results.

2 Push Over Analysis

Pushover analysis captures the nonlinear behavior of the building subjected to lateral load effectively and hence can trace the behavior of the structure progressively up to failure. Pushover analysis can provide the most effective measure of global behavior of structures in terms of base shear capacity and displacement ductility of the structure. Pushover analysis can also define the performance of the structure for a given level of earthquake intensity. One of the challenging tasks associated with seismic analysis of buildings is the quantification of the relative influence of various parameters on the seismic performance of structures. In this study, this challenge is accomplished by analytical vulnerability assessment of the structure. This method is an effective way to quantify the seismic risk associated with the structure with due considerations to the uncertainties associated with structural behavior as well as ground motion characteristics. By subjecting a structure to a monotonically increasing load (or deformation) and monitoring the base shear and roof top displacement at each step, the pushover curve is plotted to represent the seismic capacity of the structure. The response spectrum corresponding to the seismic zone, soil type and damping level of the structure forms the demand curve. The intersection of these two curves is the performance point of the structure (see Fig. 1).

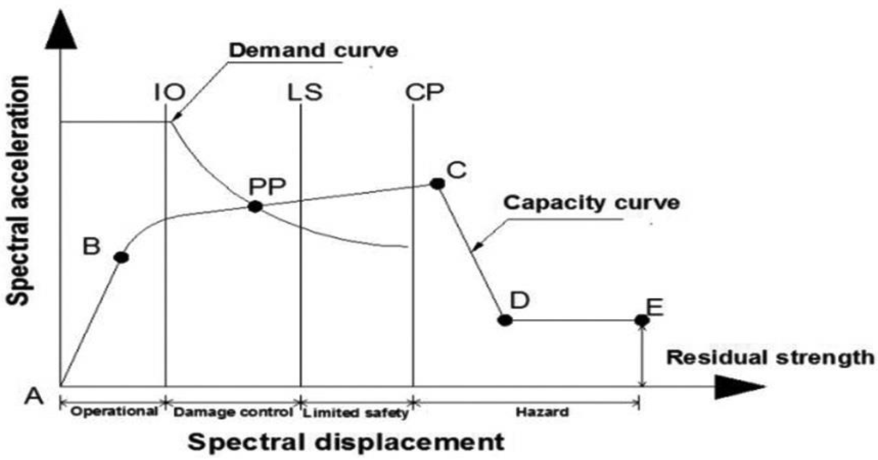

Fig. 1. Capacity and demand curves during a pushover analysis. IO: Immediate occupancy, LS: Life safety, CP: Collapse prevention, C: Collapse.

Vulnerability index is obtained by multiplying the probability of exceedance of damage state developed by the fragility curves with the cost fraction associated with the damage states (Comartin et.al. (2000), Council (1997)).

3 Problem Definition

This paper presents the vulnerability of open ground floor tall structures on soft ground to seismic loading. For this purpose, RC framed structures are modelled (see Fig. 2). The lateral loading distribution is taken as triangular variation and analyzed considering displacement controlled non-linear pushover analysis and properties of reinforced concrete frames considered in the analysis are detailed in Table 1. Gazetas approach (1991) has been used to model the ground with varying stiffness as detailed in Table 2.

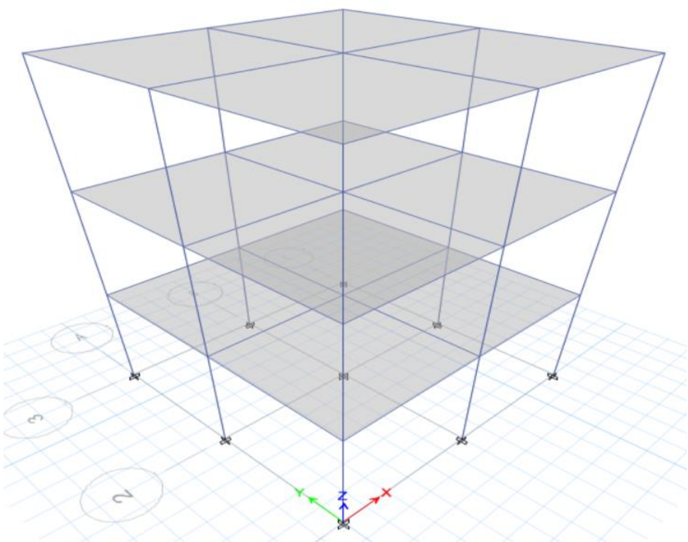

Fig. 2. Frame considered for analysis

Table 1. Design details of frame considered.

Type of Structure	Special RC Moment Resisting Frame
Grade of materials	M20 and Fe415
Beam section	230 mm X 300 mm
Thickness of slab	150 mm
Column section	300 mm X 300 mm
Storey height	3 m
Bay width	3 m

Earthquake zone	III
Soil type	Medium
Floor finish	1 kN/m^2

Table 2. Ground stiffness's for different Ground types

Ground Type	Ground stiffness in MPa
1	1
2	10
3	1000
4	10000
5	100000
6	Fix support

4 Results and Discussion

Pushover curves resulting from the analysis of RC framed elements are compared to study the effect of analytical parameters on the pushover analysis. Base shear carrying capacity and displacements of the structures are considered for the comparison.

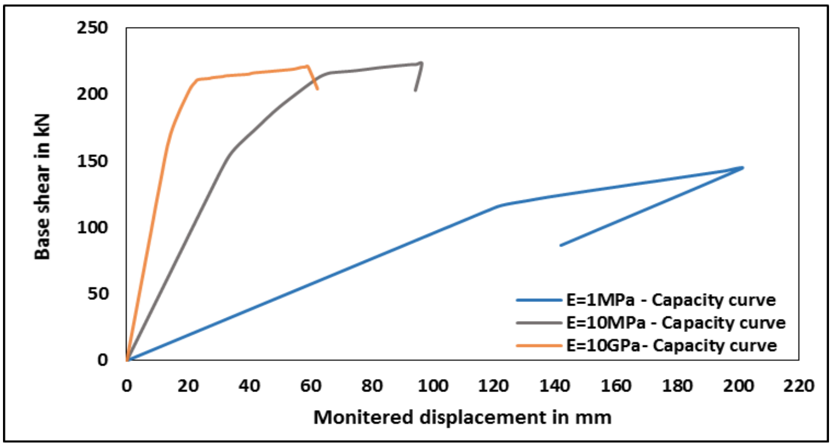

Fig. 3. Base shear versus roof top displacement for building on different soil types.

Fig. 3 presents the variation of base shear with roof top displacement of frame considered with different soil stiffness. The range of stiffness of soil considered is from E = 1 MPa to E = 10 GPa to cover wide range of soils. When E = 10 GPa, it indicates solid rock, on the other hand E = 1 MPa is for extremely soft soil, either when cohesionless soil is in the process of liquefaction during earthquake or when there is an extremely soft clay close to its liquid limit encountered. It can be seen that base shear increases with increase in soil stiffness and roof top displacement decreases with increase in soil stiffness. Further, base shear carrying capacity of frame on stiff soil is much higher than that on softer soil. The decrease in soil stiffness results in bearing capacity failure or excessive settlement or uneven settlement. All these are responsible for additional pressure on the structure and results in the failure of structure.

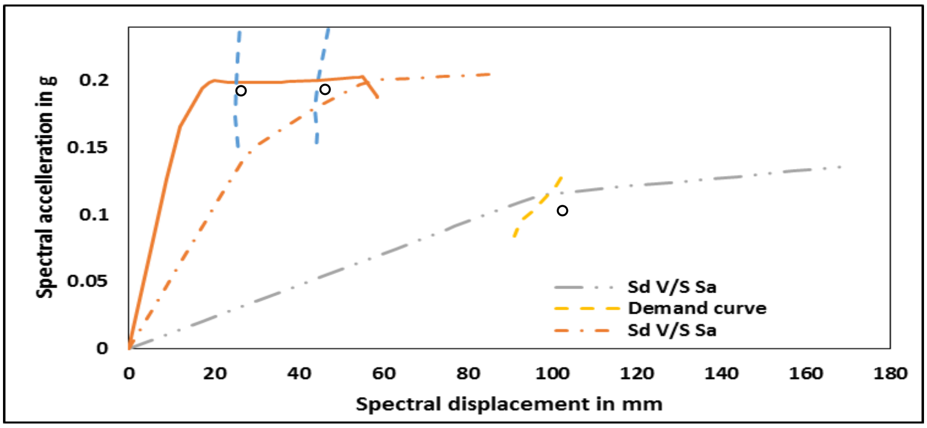

Fig. 4. Pushover curves and performance points for building on different soi types.

Fig. 4 is plotted to identify the performance point. Performance point locates the intersection of capacity curve with demand curve in spectral acceleration and spectral displacement space. This point indicates the overall status of the building under earthquake shaking of Zone III. It suggests the base shear carrying capacity, ductility, and region in which the building lies (such as elastic, immediate occupancy (IO), life safety (LS), collapse prevention(CP), collapse(C) as per ATC-40 and FEMA-273) [1, 2]. It can be seen that the performance point shifts toward right when the frame is located on less stiff soil, indicating the increased vulnerability of the building.

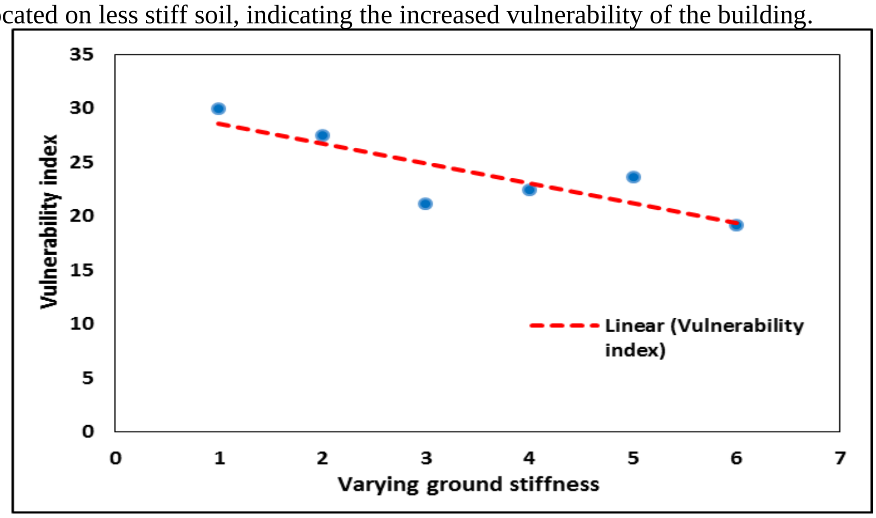

Fig. 5. Vulnerability index Vs varying ground stiffness.

Fig. 5 indicates variation of vulnerability index of frame with varying soil stiffness from less stiff to very stiff conditions. It can be seen that the vulnerability index is more for frame on soft soil compared to that on hard soil.

5 Conclusions

The major inference from this study is that frames with open ground floor are vulnerable during earthquakes and frames with open ground floor resting on soft soil are even more vulnerable to the earthquakes of same intensity. In the present paper, the vulnerability is identified based on the base shear carrying capacity, ductility characteristics and vulnerability index.

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