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Stimulus of Soil Stiffness on Seismic Vulnerability of Asymmetrical Buildings

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ABSTRACT

Seismic performance of building is a challenge to civil engineers, especially in India. The uncertainties of earthquakes, complexity in construction, deviations from rules, and regulations during construction have made many structures vulnerable during earthquakes. Complex soil conditions make the situation further worse. There are many urban areas in seismically active zones with poor soil conditions having soft and thick overburden. It has been well established that local site conditions can enhance the vulnerability of structures. This paper attempts to show that irregular buildings that are generally vulnerable during earthquake will become even more vulnerable due to poor soil conditions. For this purpose, ETABS, a finite element software that performs nonlinear pushover analysis is used, and three dimensional analysis is performed. Two types of reinforced concrete frames, one regular and symmetric in elevation and the other unsymmetric resting on three types of soil as per IS1893 (Part-1) 2002, namely hard soil, medium soil, and soft soil are considered in the analysis. Unsymmetric structural frame on soft ground was found to be most vulnerable indicating that extra care is necessary when buildings are built on soft soil in seismically active zones.

Key words: Seismic vulnerability, Pushover analysis, Site effect, Structure on soft ground, ETABS.

1. INTRODUCTION

Earthquakes can create serious damage to structures due to their randomness and unpredictability. The past earthquakes have revealed that the irregularity either in plan or in elevation of buildings is of vital importance on seismic performance of structures. The irregularity may be in terms of soft storey, long and short column, unsymmetric plan or elevation, heavy inertial force, etc., among many leading to earthquake risk. Earthquake risk is associated with seismic hazard, seismic vulnerability of buildings and exposure. Seismic vulnerability of building indicates risk caused to life. The seismic vulnerability of a structure can be described as its susceptibility to damage by ground shaking of a given intensity. The aim of a vulnerability assessment is to obtain the probability of a given level of damage to a given building type due to a scenario earthquake. It has been well understood that site effect has phenomenal influence on seismic behavior of structures. Thickness and stiffness of overburden soil are likely to influence the seismic behavior of structure. IS 1893 (Part-1) 2002 identifies three types of soil namely hard soil, medium soil, and soft soil. Soft soil is one which has very low stiffness and sufficiently thick overburden. It is quite likely that most buildings will be more vulnerable on these soils. The objective of this paper is to identify the vulnerability of irregular frames resting on soft soil.

2. PUSH OVER ANALYSIS

Pushover analysis captures the nonlinear behavior of the building 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 [3-5]. The response spectrum corresponding to the seismic zone, soil type and damping level of the structure forms the "demand curve." Intersection of these two curves is the performance point of the structure (Figure 1). Vulnerability index is obtained by multiplying the probability of excedence of damage state developed by the fragility curves with the cost fraction associated with the damage states [6]. **3. PROBLEM DEFINITION**

This paper presents the performance of regular and irregular buildings during earthquake from pushover analysis. For this purpose, one regular and two irregular frames as shown in Figure 2 are considered with three dimensional idealizations. The properties of reinforced concrete frames considered in the analysis are detailed in Table 1. Care has been taken to maintain the total volume, floor heights, column spacing, number of columns and beams, and properties of structural members same for all three frames for the purpose of comparison. The frames are considered to be in Zone IV and the analysis is made for the frame on all three types of soil, namely hard, medium, and soft soils.

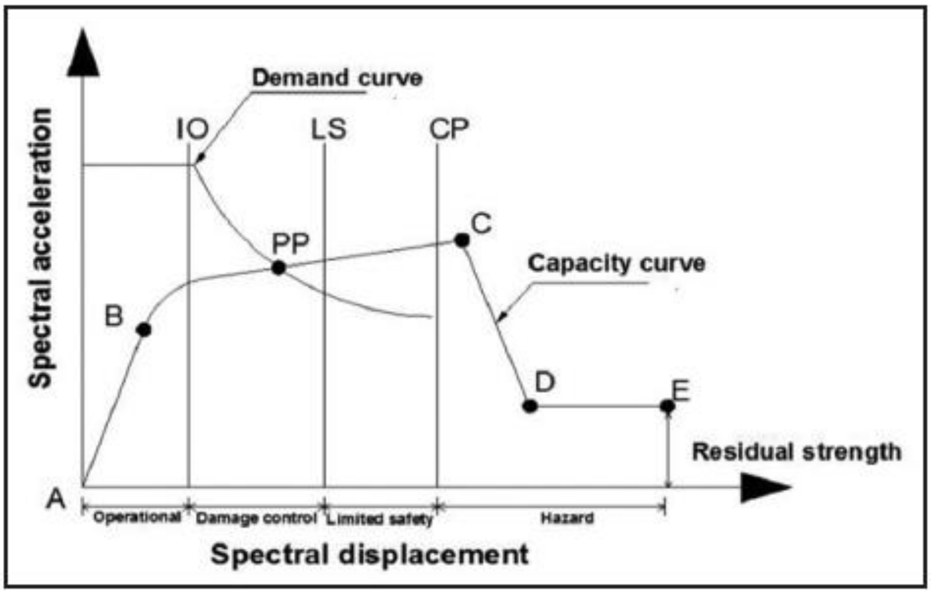

Figure 1: Capacity and demand curves during a pushover analysis. IO: Immediate occupancy, LS: Life safety, CP: Collapse prevention, C: Collapse.

Table 1: Design details of frames considered.

Type of structure	**Special RC moment resisting frame**
Seismic zone	IV
Imposed load	3 kN/m2
Floor finish	1 kN/m2
Grades of materials	M30 and Fe 415
Size of beam	230 mm×300 mm
Size of columns	300 mm×300 mm
Thickness of slab	130 mm

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 of the structure and displacements capacity of the structures are considered for the comparison. Figure 3 presents the variation of base shear with roof top displacement for the three types of frames considered in medium soil. It can be seen that base shear increases with roof top displacement till a stage is reached beyond which increase is marginal. Further, base shear carrying capacity of regular frame is much higher than those of irregular frames. Besides, ductility of regular frame is found to be marginally higher than those of irregular frames. Figure 4 is plotted to identify the performance point. Performance point locates the intersection of capacity curve with demand (displacement) curve in spectral acceleration and spectral displacement space. This point indicates the overall status of the building under earthquake shaking of Zone IV. It suggests the base shear carrying capacity, ductility, and region in which the building lies (such as elastic, immediate occupancy,

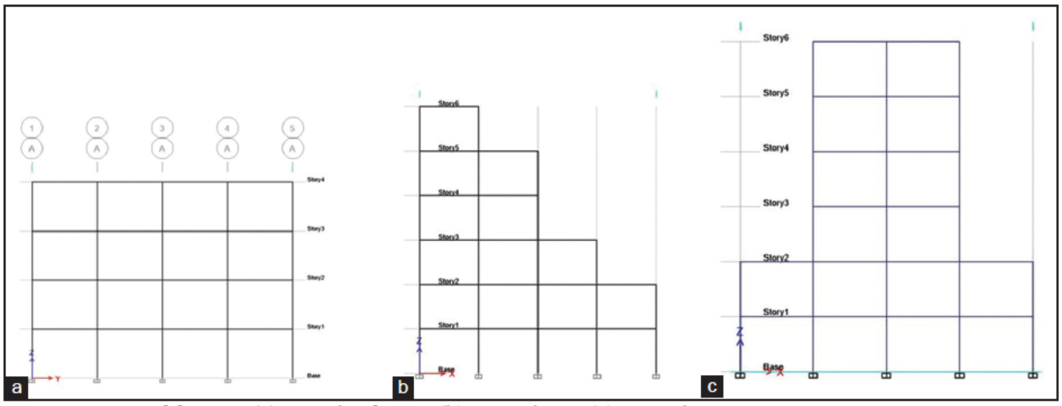

Figure 2: Types of frames. (a) Regular frame, (b) Irregular 1, (c) Irregular 2.

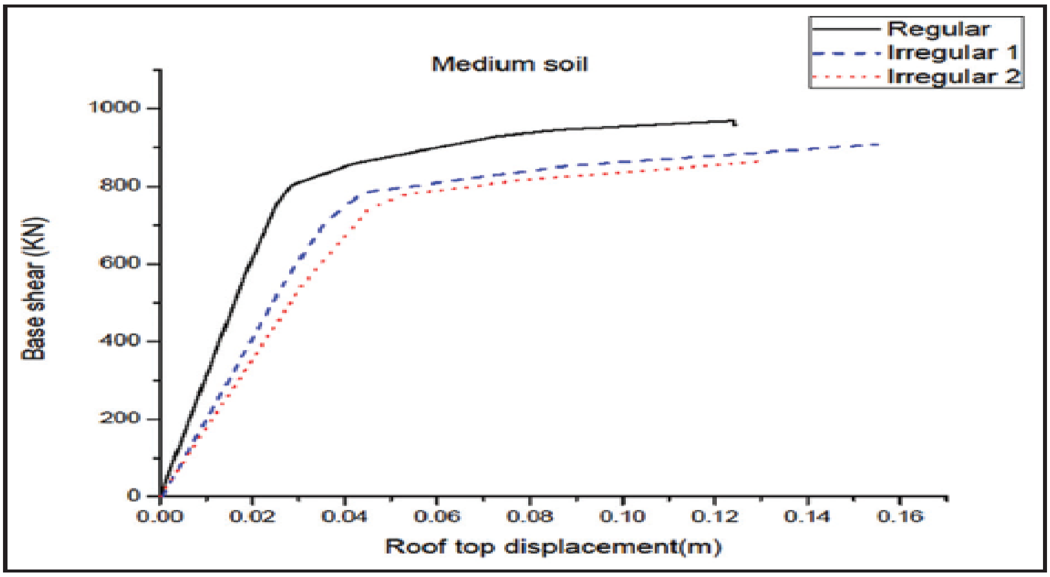

Figure 3: Base shear versus roof top displacement.

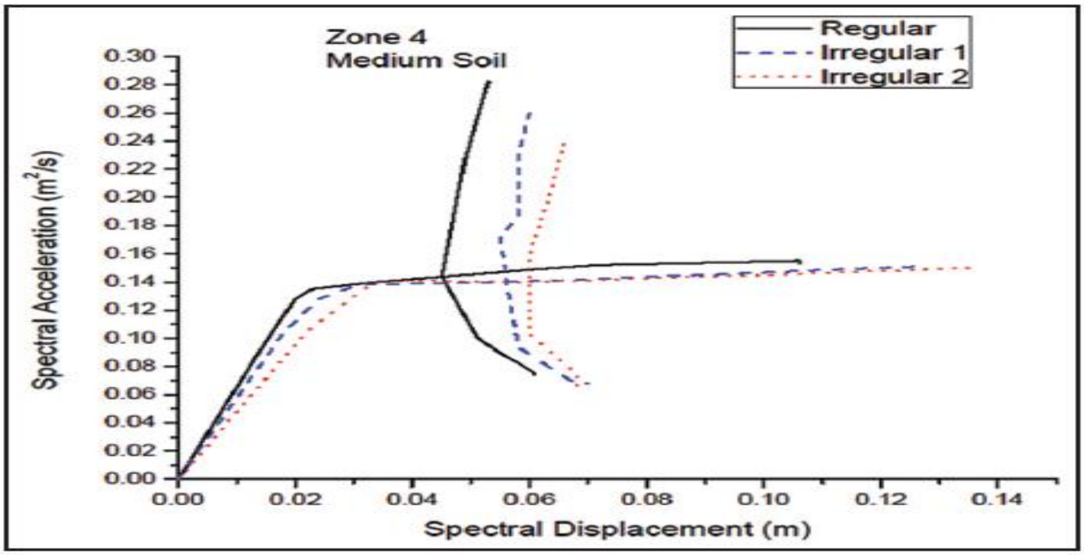

Figure 4: Push over curves and performance points.

Life safety (LS), collapse prevention, collapse as per ATC-40 and FEMA-273) [1,2]. Here, the graphs are plotted for the three types of frames on medium soil in Zone IV. It can be seen that the performance point shifts toward right when the frames are irregular indicating that the status is beyond elastic limit and in the region of immediate occupancy to LS and that status is more vulnerable in irregular frames.

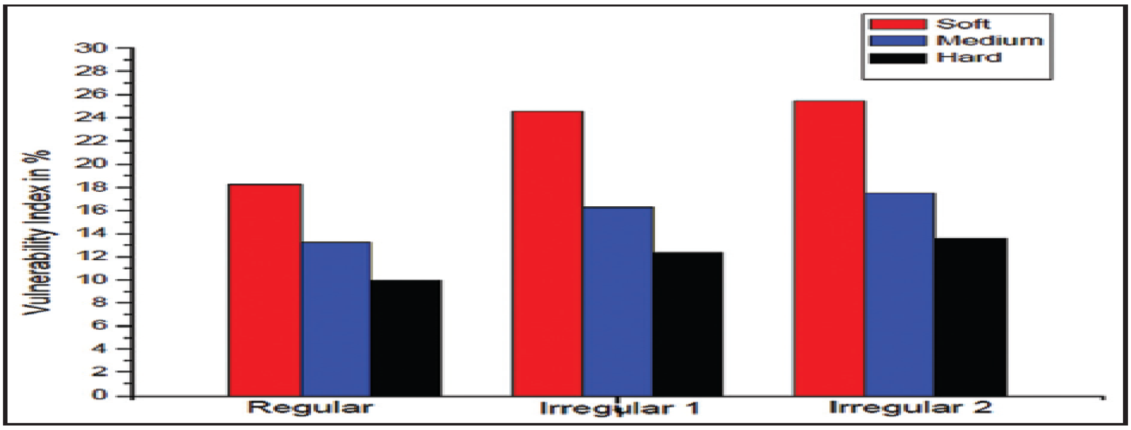

Figure 5 Vulnerability index.

Figure 5 indicates that the vulnerability index for different types of frames on different types of soils.

It can be seen that the vulnerability index is more for frame on soft soil compared to that on hard soil. It can also be seen that vulnerability index is more for irregular frames than regular frame. Further, it is interesting that the percentage increase in vulnerability for regular building on soft soil compared to hard soil is around 85%. Whereas, the percentage increase in vulnerability for irregular building on soft soil compared to hard soil is more than 105% indicating that the effects are more significant.

Table 2 indicates that the vulnerability is much more for irregular buildings on soft soils than those on hard soils. It can be seen that spectral displacement for irregular building on soft soil is one and a half times that of irregular building on hard soil.

Table 3 gives the status of hinges for frames of different types on three different soils. The table clearly indicates that the status of hinges in irregular frames on soft soil is more vulnerable than those of regular frames on hard soil.

5. CONCLUDING REMARKS

The following are the major inferences from this study:

1. Frames that are irregular in elevation are more vulnerable than those which are regular in elevation. The vulnerability is identified based on the base shear carrying capacity, ductility characteristics, status of hinges, and vulnerability index.

Table 2: Performance points from pushover curves.

Types of soil	Frame type	Performance points (Sa, Sd)
Soft soil	Regular	(0.148, 0.056)
	Irregular 1	(0.139, 0.065)
	Irregular 2	(0.140, 0.067)
Medium soil	Regular	(0.140, 0.045)
	Irregular 1	(0.132, 0.055)
	Irregular 2	(0.134, 0.059)
Hard soil	Regular	(0.139, 0.034)
	Irregular 1	(0.136, 0.042)
	Irregular 2	(0.134, 0.043)

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