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Effect of Poor Soil Condition on Seismic Vulnerability of Overcrowded Building

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Abstract. Every building has its own defined loading and they are designed accordingly. All buildings are designed for designated dead loads, live loads and loads due to natural disasters like earthquake, wind etc. Earthquakes are most destructive and unpredictable, creating serious damage to structures founded on ground. Seismic performance assessment of building is very important to civil engineers from disaster management and emergency preparedness points of view. The performance of structures on poor soil during earthquake may be completely different from those on hard soil strata. A structure may be over crowded during festivals or special occasions or when used as store, perhaps over a small duration of time. Earthquake may strike when the structure is over-crowded. The question is how the structure performs during earthquake when it is over-crowded and loaded beyond its design capacity and when it rests on soft soil. This paper attempts to simulate the conditions of a normal structure being over crowded, resting on soft soil and establish the performance of such structures under dynamic loading of earthquake type. Gazetas approach (1991) has been used to model the ground with varying stiffness. Overloaded reinforced concrete frame on flexible ground is considered in analysis. Overloading is idealized by increasing live load on structure. For this purpose, ETABS, a finite element software that performs non-linear pushover analysis is used and three-dimensional analysis is performed. Frames subjected to increased live load leads the structures to more vulnerable than the normally loaded structures and over loaded structures resting on weak soil are even more vulnerable.

Keywords: Seismic performance, over-crowded structure, soft soil, vulnerability index, fragility, Pushover analysis.

1 INTRODUCTION

Earthquakes can create serious damage to structures due to their randomness and unpredictability. The performance of structures on poor soil during earthquake may be completely different from those on hard soil strata. The characteristics of soil change from place to place and hence similar structures in different locations may perform differently during earthquakes. Buildings that rest on loose strata may show greater vulnerability than those resting on dense strata. Hence, seismic performance assessment at different locations plays an important role for the civil engineers. 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 vulnerability assessment is to obtain the probability of a given level of damage to a given building type due to a scenario of earthquake.

It has been understood that overloading on building has phenomenal influence on seismic behaviour of structures. Overloading on building increases mass on building, building attracts more shear hence increases vulnerability to the earthquakes. The objective of this paper is to identify the vulnerability of buildings with overloading condition and the building resting on different soil strata. Gazetas approach (1991) has been used to model the ground with varying stiffness.

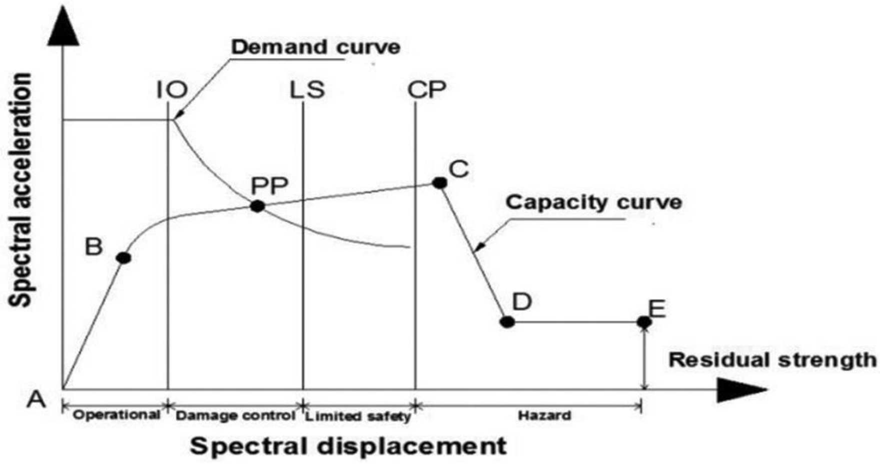
2 PUSHOVER ANALYSIS

Pushover analysis is a nonlinear static analysis in which the structure is subjected to gravity loads and monotonically increasing lateral load until the target displacement is reached or the collapse state of the structure is reached. It is used to obtain a pushover or capacity curve and hence the relationship between Base shear and roof displacement under increasing lateral load is arrived at. From this relation, it is possible to determine the deformation capacity of the structure. The pushover describes behavior of structure beyond its elastic state. It is a procedure in which it is possible to estimate the seismic performance or seismic deformation of a structure under different levels of earthquake shaking. It is possible to provide graphical comparison between the structure capacity and the seismic demand from Pushover analysis. Earthquakes can create serious damage to structures due to their randomness and unpredictability. The performance of structures on poor soil during earthquake may be completely different from those on hard soil strata. The characteristics of soil change from place to place and hence similar structures in different locations may perform differently during earthquakes. Hence, seismic performance assessment at different locations plays an important role for the civil engineers. 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 seismic vulnerability of a structure represents the degree of weakness the structure experiences during a design earthquake. It can be measured by vulnerability index, which is obtained by analysing the fragility curves. Fragility curve helps in identifying the different damage states (namely. Slight damage state, Moderate damage state, Extensive damage state and Collapse or complete damage state) of the structure for a given level of earthquake intensity.

3 PROBLEM DEFINITION

This paper presents the vulnerability assessment of overloaded structures in comparison with normally loaded structures resting on ground with varying soil stiffness. For this purpose, RC framed structures are modelled as in Fig.2 and analyzed considering displacement controlled non-linear pushover analysis. The properties of reinforced concrete frames considered in the analysis are detailed in Table 1. Live load is increased on the structure to obtain overloading condition in to three stages, namely, 5 kN/m2, 15 kN/m2 and 25 kN/m2 with varying soil stiffness of Soft ground with Es = 20 MPa, Medium stiff ground with Es = 200 MPa and Stiff ground with Es = 20000 MPa and the pushover analysis is carried out. Fig.3 and Fig.4 represent the situations when the building is either overcrowded with people or overloaded with material as in a warehouse.



IO: Immediate Occupancy, LS: Life Safety, CP: Collapse Prevention, C: Collapse, PP: Performance Point.

Fig. 1. Capacity and demand curves along with Performance Point in a typical Pushover Analysis.

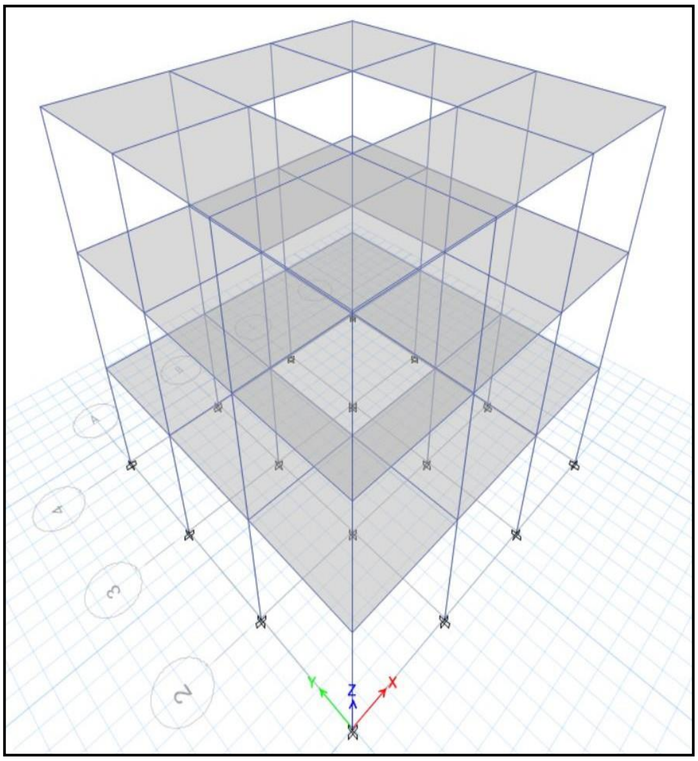


Fig. 2. Three storeyed three bay (both directions) structural frame considered in present study.

Table 1. Design details of structural frame along with soil spring considered in the present study.

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	Soft (Es = 20 MPa) Medium (Es = 200 MPa) Stiff (Es = 20000 MPa)
Floor finish	1 kN/m^2
Live load	5 kN/m^2, 15 kN/m^2, 25 kN/m^2

Fig. 3. Overcrowded roof top, present loading condition may be beyond the design load

Fig. 4. Overloaded warehouse, present loading condition may be beyond the design load

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. In the present study is focus has been on identifying the effect of increase in live load and the effect of decrease in stiffness of ground. Three different live loads, namely, 5 kN/ sq m, 15 kN/sq m and 25 kN/sq m and three different stiffness of ground with soil moduli of 20MPa, 200MPa and 20000MPa are considered in the present work. 20 MPa represents soft soil, 200Mpa represents medium stiff soil and 20000MPa represents stiff soil. Base shear carrying capacity and displacements at the roof level of the structures are considered for the comparison.

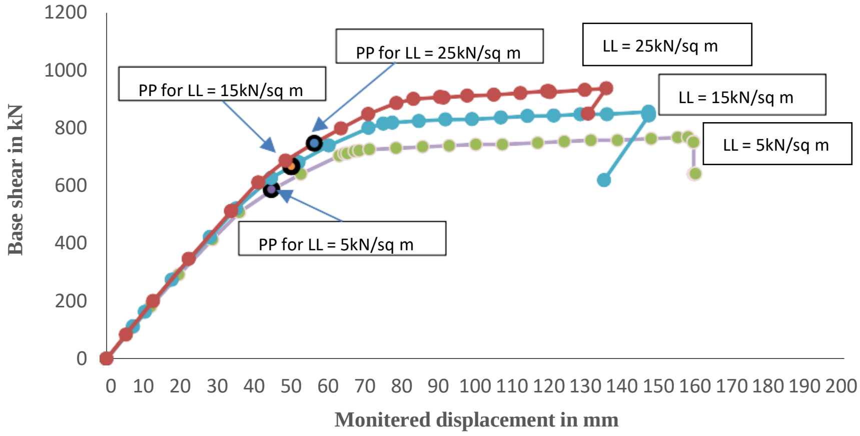


Fig. 5. Pushover curves and performance points with varying live loads for soil stiffness Es = 20MPa.

Fig. 5 presents the variation of base shear with roof top displacement of frame considered with different live load. It can be seen that base shear increases with increase in live load and roof top displacement decreases with increase in live load. Performance point moves towards higher damage state of pushover curve as there is an increase in live load.

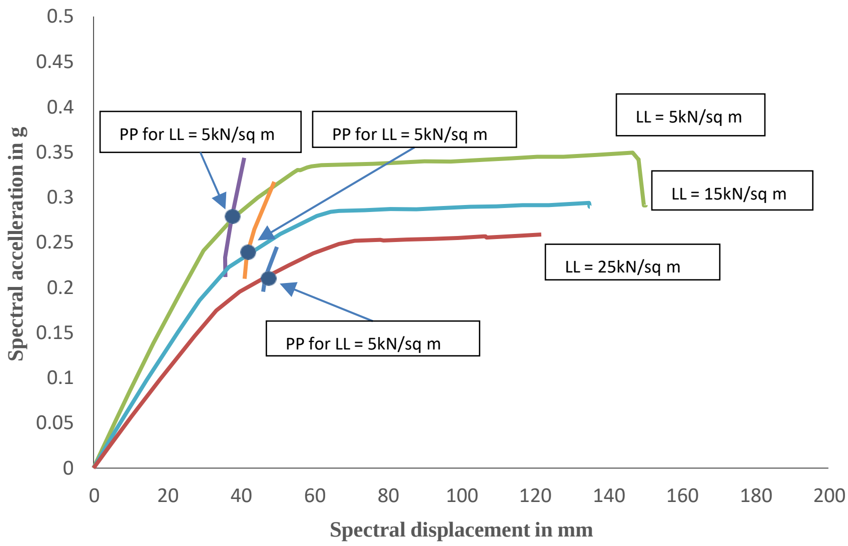


Fig. 6. Pushover curves and performance points with varying live loads in ADRS format for soil stiffness Es= 20MPa.

Fig. 6 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 for the structure on ground with soil stiffness Es = 20 MPa and varying live load. It suggests that 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 live load on the frame increases, indicating the increased vulnerability of the building.

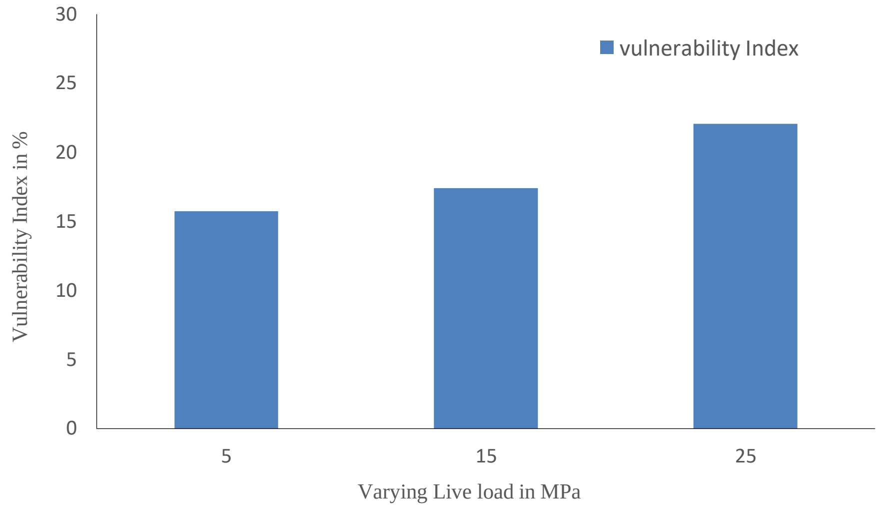


Fig. 7. Vulnerability Index with Varying Live Load for soil modulus Es= 20MPa.

Fig. 7 indicates variation of vulnerability index of frame with varying live load from less to more. It can be seen that the vulnerability index is more for frame with more live load compared to that with less live load.

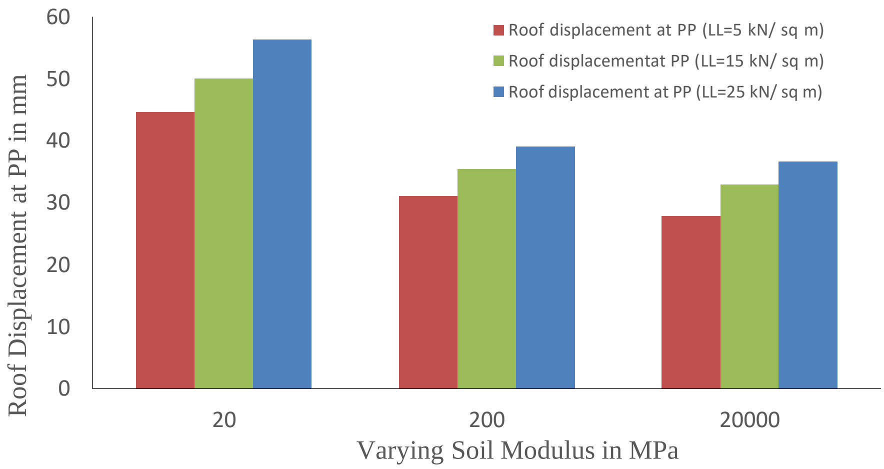


Fig. 8. Roof Displacement at Performance points with Varying Live Loads for soil moduli of Es= 20MPa, Es= 200MPa and Es= 20000MPa.

Fig. 8 indicates variation of Roof Displacement at Performance point of frame with varying live load from 5 kN/sq.m to 25 kN/sq.m for the structures founded on ground with low (20MPa) to high stiffness (20000MPa). It can be seen that the roof displacement increases with increase in live load and decreases with increase in stiffness of the ground. Hence, the most vulnerable situation is when the live load is high and when the ground is least stiff.

Further, Table 2 to Table 7 present various data in the form of Roof displacement, Base shear capacity, Bending moment, Shear force, Hinge status factor and Vulnerability Index for various live loads and structure resting on soil with different stiffness. All these data will indicate the overall seismic performance of the structure. The inference can be made that the performance is the best when the live load is the least and soil on which the structure rests is sufficiently stiff. On the other hand, seismic performance is most vulnerable for structures resting on less stiff. Ground and subjected to maximum live load.

Table 2. VARIATION OF SEISMIC ASSESMENT PARAMETERS WITH VARYING LIVE LOADS FOR SOIL MODULUS Es = 20 MPa.

Sl No.	Soil Modulus (MPa)	Live Load (kN/Sq m)	Displacement (mm)	Base Shear (kN)	Bending Moment (kN-m)	Shear Force (kN)	Vulnerability Index	Hinge Status Factor
1	20	5	159.8	766.3	68.4	49.8	15.7	89.83
2	20	15	146.8	855.7	78.1	57.0	17.3	90.66
3	20	25	135.3	936.5	86.4	63.3	22.0	90.33

Table 3. VARIATION OF SEISMIC ASSESMENT PARAMETERS WITH VARYING LIVE LOADS FOR SOIL MODULUS Es = 200 MPa

Sl No.	Soil Modulus (MPa)	Live Load (kN/Sq m)	Displacement (mm)	Base Shear (kN)	Bending Moment (kN-m)	Shear Force (kN)	Vulnerability Index	Hinge Status Factor
1	200	5	134.01	699.2	69.08	49.00	10.13	91.54
2	200	15	116.20	790.9	79.89	57.99	15.62	93.16
3	200	25	47.45	836.9	86.74	62.82	18.72	93.16

Table 4. VARIATION OF SEISMIC ASSESMENT PARAMETERS WITH VARYING LIVE LOADS FOR SOIL MODULUS Es = 20000 MPa.

Sl No.	Soil Modulus (MPa)	Live Load (kN/Sq m)	Displacement (mm)	Base Shear (kN)	Bending Moment (kN-m)	Shear Force (kN)	Vulnerability Index	Hinge Status Factor
1	20000	5	129.72	684.3	68.33	49.37	23.76	94.16
2	20000	15	60.60	766	79.61	57.50	31.42	94.10
3	20000	25	63.29	846.7	89.42	64.86	32.84	93.16

Table 5. VARIATION OF SEISMIC EVALUATION PARAMETERS WITH VARYING SOIL MODULI FOR LIVE LOAD = 5 kN/Sq m.

Sl No.	Soil Modulus (MPa)	Live Load (kN/Sq m)	Displacement (mm)	Base Shear (kN)	Bending Moment (kN-m)	Shear Force (kN)	Hinge Status Factor
1	20	5	159.83	766.35	68.40	49.86	89.83
2	200	5	134.01	699.20	69.08	49.00	91.54
3	20000	5	129.72	684.31	68.33	49.37	94.16

Table 6. VARIATION OF SEISMIC EVALUATION PARAMETERS WITH VARYING SOIL MODULI FOR LIVE LOAD = 15 kN/Sq m.

Sl No.	Soil Modulus (MPa)	Live Load (kN/Sq m)	Displacement (mm)	Base Shear (kN)	Bending Moment (kN-m)	Shear Force (kN)	Hinge Status Factor
1	20	5	146.84	855.74	78.12	57.05	90.66
2	200	5	116.20	790.96	79.89	57.99	93.16
3	20000	5	60.60	766.00	79.61	57.50	94.10

Table 7. VARIATION OF SEISMIC EVALUATION PARAMETERS WITH VARYING SOIL MODULI FOR LIVE LOAD = 25 kN/Sq m.

Sl No.	Soil Modulus (MPa)	Live Load (kN/Sq m)	Displacement (mm)	Base Shear (kN)	Bending Moment (kN-m)	Shear Force (kN)	Hinge Status Factor
1	20	5	135.35	936.56	86.41	63.39	90.33
2	200	5	47.45	836.98	86.74	62.82	93.16
3	20000	5	63.29	846.73	89.42	64.86	93.16

5 CONCLUDING REMARKS

The focus of the present paper was to show the effects of overloading a building and reduction in stiffness of ground on the seismic performance of building. For this purpose, pushover analysis using ETABS was performed. The performance was assessed through Base Shear carried, corresponding roof displacement, location of Performance Point, number of plastic hinges formed fragility curves, Vulnerability Index, Bending moment and shear force induced etc. The following were the major inferences made.

- With the increase in live load from 5kN/m^2 to 25 kN/m^2, the structure became more vulnerable at any soil condition. The vulnerability was assessed through increased vulnerability index, increased number of plastic hinges and increased roof displacement at performance point.
- With the reduction in stiffness of ground from soil modulus of 20000 MPa to 20 MPa, the structure became more vulnerable.

Hence, the soil which is likely to undergo degradation in strength and stiffness during earthquake (such as liquefiable soil) is extremely dangerous in earthquake prone areas. Ground improvement is essential, when any structure is proposed in such situations. It is always advisable not to load any structure beyond the design load. A load higher than design load can make the structure more vulnerable during earthquake. Care has to be taken not to overload structures beyond limits in earthquake prone areas.

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