Comparative vulnerability analysis of structure with sand and soft soil

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Abstract: World frequently faces the seismic activities at different locations with varying intensities causing heavy damage to the property. Here we are doing Comparative vulnerability study between two soil type which is sand and soft soil. We will analyze two building having same dimensions, beam column sections. This paper represents the comparative vulnerability analysis which have been resulted using pushover analysis. Also the plastic hinge properties have been utilized for calculating the seismic vulnerability index to examine the performance stages of the selected building, complete used software is SAP 2000.

Keywords: Pushover curve, Performance stages, Plastic hinges, Pushover analysis, Seismic Vulnerability, monitored displacement.

List of symbols

| Symbol | Description                          |
|--------|--------------------------------------|
| Z      | Zone factors                         |
| POA    | Push over Analysis                   |
| I      | Importance Factor                    |
| $V_b$  | Base Shear                           |
| $D$    | Displacement                         |
| $S_a/g$| Design Acceleration Coefficient,     |
| $g$    | Acceleration due to Gravity          |
| $h$    | Height, Total Height of the Structure|
| $X_i$  | Weighting Factor                     |
| $SVI$  | Seismic Vulnerability Index          |
| $M_3$  | Hinges for Beam (ATC-40)             |
| $P(M2-M3)$ | Hinges for Column (ATC-40)         |
| $R$    | Response reduction                   |
| $K$    | Stiffness                            |
| $SBC$  | Safe bearing capacity                |
| $\nu$  | Poisson’s ration                     |
| $G$    | Shear Modulus                        |
| $I$    | Moment of Inertia                    |
| $A_b$  | Area of foundation                   |
| $L$    | Half-length of Foundation             |
| $B$    | Half width of Foundation              |
| $KN$   | Kilo Newton                          |
| $MM$   | Mile meter                           |
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\( K_x \) Stiffness at Horizontal lateral direction

\( K_Y \) Stiffness at Horizontal longitudinal direction

\( K_z \) Stiffness at Vertical direction

\( K_{rx} \) Stiffness at around lateral direction

\( K_{ry} \) Stiffness at around longitudinal direction

\( K_{rz} \) Stiffness at around Vertical direction (Torsion)

1. Introduction

For Structural analysis, Seismic analysis is very essential and it is computation of behaviour of structure for earthquake. Here in this paper done with comparative vulnerability study of two structures which is built on two different soil type. Determining the vulnerability by using overall study, decided to proceeding Pushover analysis.

Pushover analysis (POA) is the method for determining the capacity for a building.[11, 12, 13] The Pushover analysis is a nonlinear static analysis, which structure is provided by gravity assigned loadings. While attending the Push over analysis (POA), some information is essential such as material property, section property, mass source, response spectrum, diaphragm, gravity loading, defined the push-X load case and push-Y load case as non-linear static type of earthquake loading, plastic hinged property etc.

The performances stages at ATC-40 is as follow [12]:

Immediate accuracy (IO): immaterial/restricted harm, structure stays the initial firmness.

Life safety (LS): extensive harm has occurred to the construction, and it may have lost a significant amount of its firmness. A huge edge stays for additional parallel deformity before absolute disappointment.

Collapse prevention (CP): the design has encountered serious harm, if misshaping proceeds forward of this point; the construction can be moved to fall.

![Damage States](image)

**Figure 1.** Performance stages defined by pushover curve
2. Methodology

2.1 Modelling of building

The properties considered for both model are M20 grade of concrete, Fe415 grade of rebar, height as 3m. Although plans with the grid spacing of 3 m has been shown in the figure 2. The two basic frame structure has been modeled. Number of floor is 4, the size of columns are floor (1-2) and floor (3-4) is (450 X 450) mm and (350 X 350) mm respectively. The size of beams (350 X 350) mm. both models have been assigned dead, dead wall, dead slab, live and live slab loads as per IS-875-1987 Part I and IS-875-1987 Part II. The models has been analyzed and designed only for load combination as 1.5(Dead Load + Live Load) according to IS-456-2000.

![Figure 2. Grid Spacing](image)

Grid spacing of structure,

2.2 Modelling of Soil

The Stiffness of foundation is infinite and stiffness of soil is something in corresponding value, Therefore for balancing the stiffness of soil, foundation and to determine the vulnerability assessment between two different soil we have to need modelling of soil. Very first we have to know vertical reaction of each column for that modelled consider building analysis in Software using 1.5(D.L.+L.L.) Load combination, using the value of analysed vertical reaction and safe bearing capacity from table 1. Calculate the size of foundation from safe bearing capacity of soil using properties are given in table 2 considered [10]. Soil can model using three directional spring (kx , ky and kz) and three radial springs (krx, kry and krz). The expressions for such spring stiffness, as stated in literature [8], are given in Table 2. The empirical values such as shear modulus and Poisson’s ratio is assumed for soil conditions given in table 3. Considered from [9]. After calculate the value of stiffness, assigned at every base joint as shown in figure 3.
Table 1. Safe bearing capacity of soil

| Soil Type | Safe bearing Capacity of Soil |
|-----------|--------------------------------|
| Soft soil | 150 KN/sq. m.                 |
| Sand      | 245 KN/sq. m.                 |

Table 2. Equations for spring stiffness as Available in literature [8].

| Degree of Freedom | Stiffness of equivalent soil spring |
|-------------------|------------------------------------|
| Vertical          | \[ 2GL/(1-\nu) \left(0.73+1.54 \times \chi 0.75 \right) \] where \( \chi = \frac{Ab}{4L^2} \] |
| Horizontal        | \[ 2GL/(2-\nu) \left[2+2.50(\chi)0.85\right] \] (Lateral) where \( \chi = \frac{Ab}{4L^2} \] Direction |
| Rocking (Longitudinal) | \[ G/(1-\nu) \frac{Ibx^0.75}{(L/B)^{0.25}} \] |
| Rocking (Around the Longitudinal) | \[ [2.4+0.5(B/L)] \] |
| Rocking (Around the Longitudinal) | \[ 3G/(1-\nu) \frac{Iby^0.75}{(L/B)^{0.15}} \] Lateral |
| Torsion           | \[ 3.5G \cdot \frac{Ibz^0.75}{(L/B)^{0.4}} \left(1+\frac{B^4}{B^4}\right)^{0.2} \] |

\( Ab \)- Calculated area of foundation, \( L,B \)- Half Length and Width of foundation; \( Ix, Iy, I_z \)- Moment of inertia of foundation Area

Table 3. Soil parameter (Empirical values) [9].

| Type of Soil | Shear Modulus | Poisson’s ratio |
|--------------|---------------|----------------|
| Soft Soil    | 10,000        | 0.3            |
| Sand         | 20,000        | 0.25           |
2.3. Pushover Analysis

2.3.1. Hinges assignment.

The plastic hinges is a graph shows the strength and deformation of each member (i.e. Beam and Column) in the form of moment and rotation. The auto hinge properties have been assigned to the sections in SAP 2000 including the guidelines of ATC-40. The hinges are set to column and beam at the ends [4].

2.3.2. Pushover load case.

Non-linear static Load cases has been assigned for both model is as follows:
Gravity load- This load case consisting of 0.25 load factor of live load and fully dead load.
Push-X- Horizontal Lateral direction.
Push-Y- Horizontal Longitudinal direction.

2.3.3. Monitored Displacement.

In the pushover analysis consist of load case of push X and Y. In this load case consist of Monitored displacement which is up to the 2 percent of height of building. U1 and U2 are the direction of analysis which will target by Monitored displacement.

3. Result and Discussion

3.1. Pushover Curve

In all graphs, units of displacement is in ‘mm’ and unit of base shear is in ‘KN’. Pushover analysis for Push-X in sand model, total performance steps are 296. Pushover analysis for Push-Y in sand model, total performance Steps are 98. Pushover analysis for Push-X in soft soil model, total performance steps are 767. Pushover analysis for Push-Y in sand model, total performance steps are 11. The pushover results showing the relation of displacement and base shear figure 4 and figure 5.
Figure 4. Pushover curves for Push-X
3.2. Hinges formation

In system model of SAP2000 has been allotted the section property of column, beam after estimated using section designer. The twisted hinges (M3) and the interrelating coupled hinges (P-M2-M3) allotted to Beam and Column at every end. Deflection and force is defined by the used of five point labeled (A, B, C, D and E) for showing figure 6.
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Figure 6. Showing Deformation curve Vs Force

Behavior of the hinge and these points labeled as:

1) As the load get increases from point A to B, it is in Elastic states. Here, point A indicate without any loading and point B indicate limit of elastic behavior & beginning of plastic Behavior.

2) As further load increase from B to IO, it is below the sudden residence.

3) From point IO to LS, it is between sudden Residence living welfare.

4) From point LS to CP, it is indicating the living welfare to collapse interception, range, Here, Point C is Relative to the final strength.

5) From CP to C, it is indicating the collapse interception and final range, Here, Point C is Relative to the final strength.

6) From C to Do it is indicated final strength to extra capacity, Here, Point D is Relative to the extra capacity.

7) From D to E is specify the extra capacity to collapse, Here, Point E is Relative to the collapse.

3.3. Seismic Vulnerability Index (SVI)

When the POA is completed, Quantity of hinges will create at various performance levels for structure element (i.e., beam and column) is to be added from the output hinge results. The weighting factors (xi) allotted for each performance stage are given in Table 4.[11] The Seismic Vulnerability index (SVI) is defined as there is classification of Weight factor of various performance level and created plastic hinges. The number of hinges added for the different performance steps for both the push direction for both models has been organized in Table 5.
Table 4: Distribution of weighting factors

| Sr. No. | Performance Level (i<sup>th</sup>) | Weighting factor (x) |
|---------|-----------------------------------|----------------------|
| I       | < B                               | 0                    |
| II      | B – IO                            | 0.125                |
| III     | IO – LS                           | 0.375                |
| IV      | LS – CP                           | 0.625                |
| V       | CP – C                            | 0.875                |
| VI      | C-D, D-E                          | 1                    |

Table 5: Hinges count at each performance stage for beam & column

| Model  | Performance stages | Beam | Column | Beam | Column | Beam | Column | Beam | Column | Beam | Column |
|--------|--------------------|------|--------|------|--------|------|--------|------|--------|------|--------|
|        | B-IO               | 52   | 4      | 32   | 16     | 0    | 0      | 0    | 0      | 0    | 0      |
|        | IO-LS              | 52   | 5      | 32   | 15     | 0    | 0      | 0    | 0      | 0    | 0      |
| Soft Soil |                 | 92   | 26     | 0    | 0      | 0    | 0      | 0    | 0      | 0    | 0      |
| Sand   | LS-CP              | 91   | 30     | 3    | 30     | 0    | 0      | 0    | 0      | 0    | 2      |
|        | CP-C               |      |        |      |        |      |        |      |        |      |        |
|        | C-D, D-E, > E     |      |        |      |        |      |        |      |        |      |        |

3.4. Formation of Hinges

In figure 7. showing of hinges at each performance stages of pushover analysis. All these hinges are counted and written in table 5.

(a) Sand PA-X

(b) Sand PA-Y
3.5. Vulnerability Classification for RC buildings

Classification have been suggested of vulnerability for integrating the SVI calculation and it is shown in Table 7 [11, 12]. However, the classifications had been associated with the observed damage. The calculated SVI and vulnerability class for the RC building models considered in this paper for both the push direction independently is illustrated in Table 8.

| Damage Levels       | SVI Range | Damage Description                                      |
|---------------------|-----------|--------------------------------------------------------|
| Negligible          | 0.1-0.2   | Very minor damage                                      |
| Minor               | 0.2-0.4   | Minor damage for structural member, moderate for non-structural member |
| Moderate            | 0.4-0.55  | Moderate for structural member, heavy for non-structural member |
| Sever Collapse      | 0.55-0.70 | Heavy for both the type of members                     |
| Total Collapse      | 0.7-1.0   | Total collapse                                          |

Table 6: Vulnerability classification for RC buildings as per SVI

| Model No. | Push Direction | Seismic Vulnerability Index (SVI) | Damage Level |
|-----------|----------------|----------------------------------|--------------|
| Soft soil | X              | 0.27163                          | Negligible   |
|           | Y              | 0.26802                          | Minor        |
| Sand      | X              | 0.13877                          | Negligible   |
|           | Y              | 0.24358                          | Negligible   |
4. Conclusion

Sandy soil structure falls under Very minor damage for structural member by push X and Y direction. Soft soil structure falls under very minor damage by push X direction and minor damage by push Y direction. Result showing soft soil structure more vulnerable than sandy soil structure. Vulnerability assessment depends on Safe bearing capacity of soil. Graphs of pushover analysis are showing for X-direction, Soft soil structure more displace and base share than sandy structure. For Y-direction, Soft soil structure more displace and base share than sandy structure. Actually vulnerability is mainly depend on bearing capacity of soil. A so many terms have been used in this project such as Safe bearing capacity of soil, stiffness, size of foundation.

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