EVALUATION OF THE SEISMIC ANALYSIS AND PERFORMANCE OF BUILDING IN ZONE III AND ZONE V

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ABSTRACT

Reinforced Concrete buildings are very popular practice in today's context. The Reinforced concrete buildings in India are designed considering the IS 875 and IS 1983:2016 code guidelines. In this research, the seismic performance of reinforced concrete RC frame has been studied using linear and nonlinear analysis. The seven-story building has been modelled according to Indian standard code with the help of Finite Element Software ETABS v21.0.0. The response of the buildings in terms of Base shear, story displacement was studied for both building in zone III and V. The capacity of building is evaluated using displacement controlled nonlinear static analysis (Pushover). The time history load is applied to the structure to determine the seismic demand of the building at different PGA levels. The hazard levels have been quantified by plotting fragility curve for both Zone III and Zone V. For different damage state, the capacity and demand value are used to obtain the probability of exceeding at different PGA levels. The fragility curve is developed using First Order Second Order Method (FOSM). From the study, it is found, the buildings of Zone V are more vulnerable than compared to buildings of Zone III.

Keywords: Reinforced concrete, Response spectrum, Pushover analysis, Story displacement, Base shear, ETABS.

Chapter1: Introduction

1.1 Background

India lies in high seismic zone. India sits on the Indian Plate, which is a major tectonic plate in the Earth's lithosphere. The first documented earthquake in India is difficult to pinpoint with precision due to the lack of historical records that date back thousands of years. India has a long history of earthquakes, and many of them likely went unrecorded in ancient times. However, there are some historical accounts and inscriptions that provide information about early earthquakes in India. Looking into the historyof earthquake India has experienced damaging earthquakes, Assam earthquake - magnitude of 8.6 (1950), Gujarat earthquake – magnitude of 7.7 (2001), Kashmir earthquake – magnitude of 7.6 (2005), Latur earthquake – magnitude of 6.2 (1993), Sikkim earthquake – magnitude of 6.9 (2011), Bhuj earthquake – magnitude of 7.5 (1819), Kangra earthquake – magnitude of 7.8 (1905), Andaman-Sumatra earthquake – magnitude of 9.2 (2004).

1.2Vulnerability Assessment

The ability of a structure to sustain damage from ground shaking of a specific intensity is referred to as seismic vulnerability. An earthquake-related vulnerability assessment seeks to assess the probability that a specific building type will suffer a certain amount of damage. Vulnerability assessment is the methodology for determining the vulnerability of an asset or assets at risk of being damaged or destroyed. There are wide variety of threats; one is the natural threats which includes flood, earthquake, hurricanes, etc. whereas other are fires, breakdown of equipment. A vulnerability analysis must be performed for a specific ground motion characterization that will represent the earthquake's seismic demand on the structure [3]. The chosen parameter must be able to relate ground motion to structural damage to buildings. Macro seismic intensity and peak ground acceleration (PGA) have traditionally been utilized, but more recent approaches have connected the seismic vulnerability of the buildings to response spectra obtained from the ground motions.

1.3Need of Study

IS 1893 is the Indian Standard code for earthquake-resistant design and construction. It categorizes different regions of India into various seismic zones based on their susceptibility to seismic activity. The two zones as per research interest, Zone III and Zone V, represent different levels of seismic risk. Zone III represents areas with moderate seismic activity, while Zone V includes regions with the highest seismic risk. Buildings in Zone V need to adhere to stricter seismic design and construction standards to ensure they can withstand more powerful earthquakes. It's essential for engineers, architects, and builders to consider the seismic zone classification when designing and constructing structures to mitigate earthquake risks.

Although the building has been analyzed and designed by the designer; for a research purpose nonlinear analysis of building to assess seismic building responses and perform seismic vulnerability by developing the fragility curves for different damage states shall be carried out.

1.4. Objectives

Major objective is to determine the structural vulnerability of a building considering Zone III and Zone V. Specific objectives are as follows:

a) To determine seismic capacity of structure using nonlinear push over analysis

b) To determine the demand of structure using time history analysis for Zone III and Zone V

c) To differentiate the vulnerability of the building for zone III and Zone IV using fragility curves.

1.5. Scope and limitation of study

This thesis on Evaluation of the seismic analysis and performance of building in Zone III and Zone V is a commercial building located in one of the cities of India. This building is been designed according to the guidelines of municipal office of India. This building must be serviceable during and after earthquake so vulnerability assessment on terminal building is very important. If the building was designed for Zone III, will it be safe for Zone V? Under such condition, the building's vulnerability response has been carried out and quantified in terms of numeric values. In general, this study also highlights the vulnerabilities of the building through a more detailed nonlinear push-over analysis and time history analysis.

The effect of soil structure interaction on dynamic behavior of building is not incorporated in this study. Temperature, Creep and fatigue effects are not considered in the analysis. In this paper, only one method is used to analyze the vulnerability curve, which is lack of comparative test.

1.6 Report Organization

The report is organized into five chapters.

Chapter 1: describes about the introductory parts of the study with background, methodology flowchart, objective, scope and limitations.

Chapter 2: describes about literature review for the present study. It includes literature review related to the pushover analysis, Time history analysis-δ effects, capacity curve, vulnerability assessment of RC building.

Chapter 3: describes about methodology of the thesis work.

Chapter 4: describes about the results of analysis and discussion.

Chapter 5: describes about the conclusion drawn from the thesis work and recommendation for future works.

Chapter 2: Literature Review

2.1. Seismic Vulnerability Analysis

Based on the damage seen after earthquakes, there are two main types of empirical methodologies that can be referred to as "damage-motion relationships" for assessing the seismic susceptibility of buildings:

1) Damage probability matrices (DPM) are discrete expressions of the conditional likelihood of obtaining a damage level j as a result of a ground motion intensity i, P[D=j/i].

2) Vulnerability functions are continuous functions that express the probability of exceeding a given damage state as a function of earthquake intensity. [4]

2.2 Review of Past work

Referenced literature investigates the possible hazard and direct economic damage of earthquakes using airport transportation systems as the primary research focus. The framework and theoretical model of HAZUS disaster assessment and direct economic loss created by FEMA are introduced based on the response of the structure and damage characteristics of buildings under earthquake action. This research focuses on the usage of the vulnerability curve and capacity curve in the risk assessment and economic loss evaluation of buildings [3].

Performance based method is used to quantify the structural and non-structural systems of buildings. There is a chance of great damages to the non-structural systems due to lower magnitude earthquake. Such systems are more vulnerable to the low magnitude seismic events. This paper has described about performance-based approach to define the vulnerability of buildings. Six classification criteria such as structural concerns, non-structural concern, Life safety issues, cost, construction time and fragility are developed to access the vulnerability of each system. There is a three-classification level namely A, B, C where Classification level A consists of systems that is important to occupy during and after earthquake. Level B and Level C consists of the system that are important during and after earthquake for storage and other life safety purpose. Overall vulnerability for each component depending on classification level A, B or C is obtained by adding the points assigned for each classification criteria. The higher is the value, the more will be vulnerable. The study was done to the Mid-America airports due to New Madrid Seismic Zone and found that five systems such as baggage systems, fire sprinkler systems, electrical equipment. Backup power generators and unreinforced masonry walls were found vulnerable [6].

The building under consideration is a reinforced concrete structure which is made up of four symmetric flexural flanges joined by floor slabs at twelve levels. The structure's dynamic analysis is performed by using ANSYS finite element program. The Response spectrum method is used to estimates the lateral forces on the structure and the ultimate strength of the structure as well as the cracking patterns were revealed through a nonlinear static push-over analysis. The study concluded that floor diaphragms doesn't have adequate stiffness to connect the wings together and also showed that slabs loses integrity due to large rotations at the corner [7].

Seismic vulnerability of reinforced concrete beam column connection designed for gravity loads only. The experimental results outlined the significant vulnerability of the connection and found using smooth bars and inadequate anchorage length is the main reasons for slippage failure. The concrete wedge failure is results of interaction between shear cracking and stress concentration at hook anchorage location [10].

Fragility functions are currently being generated for a 10-story reinforced concrete building with and without infill walls using the HAZUS methodology. This paper currently describes the application of the HAZUS methodology to create fragility curves. Yield and ultimate displacements are currently being derived from the building's capacity curve, while the variability in damage states is currently being sourced from the HAZUS Technical manual for various damage states. The conclusion currently drawn is that there is a high probability of damage occurring to the bare frame when compared to the infill frame, due to the added strength and stiffness provided by infill walls. [9].

Displacement coefficient method is used to assess the non-linearity of ten storied reinforced concrete building. Modelling of plastic hinge were done using moment curvature relationship for both column (interactive P-M hinges) and beam sections (Moment hinges). The pushover curve is formed after giving displacement to roof node up to target displacement. This paper concludes that maximum base shear capacity exceeds the design base shear and plastic hinges were formed first at beam before column [10].

FEMA273 has explained the structural performance levels based on Drift % as 1% for Immediate Occupancy, 1-2% for Life safety and 4% for collapse prevention. Also, explained about the different types of damage in three different structural performance levels with primary and secondary type [13].

2.3 Push over analysis

Nonlinear static analysis is presently conducted to assess a structure's strength capacity, extending beyond its limit state and approaching its ultimate strength. This method aids in pinpointing vulnerable areas within the structure by monitoring the sequence of damages occurring in each structural component. Nonlinear static analysis serves to highlight those members that are prone to reaching critical states during an earthquake, emphasizing the need for specific design and detailing considerations. The pushover analysis of a structure currently involves static nonlinear analysis under constant vertical loads while incrementally applying lateral loads to simulate equivalent conditions.

According to Displacement Coefficient Method (DCM) adopted by (NEHRP) in their Pre-standard for Seismic Rehabilitation of Buildings (FEMA-356), the expected maximum Displacement (or target displacement) for the nonlinear static analysis procedure is determined. The target displacement (δt) is given by

$$\delta_t = C_0 C_1 C_2 C_3 S_a \frac{T_e^2}{4\pi^2}$$

Where, factors C0, C1, C2, and C3 are modification factors that account for spectral displacement, inelasticity, hysteresis shape, and P-Δ effects, respectively.

$$T_e = T_i \sqrt{\frac{K_i}{K_e}}$$

Where, Ti= elastic fundamental period

Ki = initial elastic stiffness

Ke = stiffness at base shear strength equal to 60% of the yield strength of the structure.

Static lateral loads approximately represent earthquake induced forces. Push over analysis is generally used to strengthened the existing structure or part of structure which are deficient in seismic resisting capacity. Pushover analysis is a nonlinear static procedure in which the magnitude of the structural loading is incrementally increased in accordance with a certain predefined pattern and is an effective tool for performance-based design. Base reaction and roof displacement is obtained for each increment of load and corresponding structural failure mode at each step. Finally, base shear and roof displacement at each step is converted into the spectral acceleration and spectral displacement using modal properties which is known as capacity curve. Push over analysis can be done using commonly available analysis & design software such as SAP 2000, ETABS, and etc. POA is done by assigning the hinges in the nonlinear computer model. Hinges are the point in the structure where cracking and yielding is expected to occur with high intensity. Generally, these hinges are located at either ends of beams and columns.

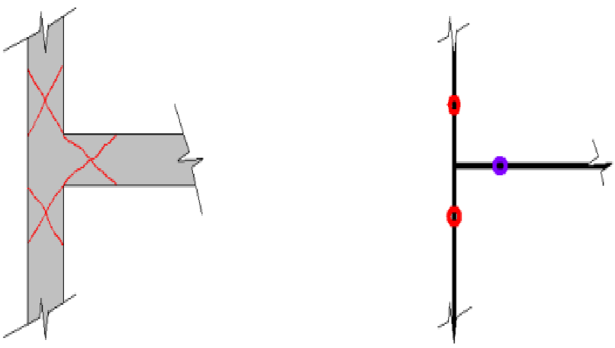

Figure 1 Location of hinges in column & beam

Flexural and shear hinges are inserted into the ends of beams and column. The seismic behavior of the structure is greatly influenced by the infill wall .so infill wall can be modeled using diagonal strut and hence the axial hinges are inserted at either ends of the diagonal struts.

Chapter3: Methodology

Building used for the study purpose is made of Reinforced concrete structure seven stories. ETABS V21.0.0.is used for modeling and analysis of building. Frame structure with thin slab member model is constructed on ETABS software. Fe500 Rebar and M30 Grade concrete material is defined on it. Material and section properties are taken as presented in Table 1 and 2. Foundation is restrained in all direction; live load values are taken from IS 875 (part 2:1987). Nonlinear Static (Push over) analysis is done to determine the seismic capacity of the structure. The response of the building in different earthquakes with different PGA value is determined using nonlinear dynamic analysis which is taken as demand for building. Building capacity curve is obtained from the Pushover curve by FEMA equivalent linearization. Median value of spectral displacement for each damage state is obtained from the Capacity curve. Fragility curve is developed with help of spectral median value obtained from capacity curve and demand obtained from the time history analysis. Fragility curve provides probability of failure for give PGA. Overall Methodology is divided into four major parts as

1. Model Selection
2. Pushover Analysis
3. Nonlinear Time history analysis
4. Fragility curve development

3.1 General description of building

The study building has dimension of 30 m X 15 m in X-axis and Y-axis having the elevation of 3.6 m per story. The total height of the building is 25.20 m. The building is going to be constructed in India. The building has one blocks rectangular in shape. This building is been designed for commercial purpose.

3.2 Spectral Analysis

The building is analyzed and designed using Response spectrum method. The relevant code for earthquake-resistant design and construction is known as IS 1893:2016, which is titled "Criteria for Earthquake Resistant Design of Structures." This code provides guidelines and requirements for designing buildings and structures to withstand the seismic forces generated during an earthquake. Here are some key factors inculed and explained in the code.

Seismic Zones: India is divided into several seismic zones based on the level of seismic activity. These zones range from Zone II (low seismicity) to Zone V (high seismicity). The code provides design parameters for each of these zones.

Seismic Zone II: Peak Ground Acceleration (PGA): 0.10 g

Seismic Zone III: Peak Ground Acceleration (PGA): 0.16 g

Seismic Zone IV: Peak Ground Acceleration (PGA): 0.30 g

Seismic Zone V: Peak Ground Acceleration (PGA): 0.36 g

Where,

(g = acceleration due to gravity, approximately 9.81 m/s²)

Importance of Structures: The code categorizes structures into various importance levels, such as essential, important, and ordinary. The seismic design and detailing requirements are more stringent for structures of higher importance.

Response Spectrum: The code provides response spectra that represent the acceleration response of structures to ground motion. Designers use these spectra to calculate the forces and displacements that structures should be able to withstand during an earthquake.

Load Combinations: The code specifies different load combinations for earthquake-resistant design, including combinations with dead loads, live loads, and seismic forces.

Ductility Requirements: The code emphasizes the importance of designing structures to be ductile, which means that they should be able to undergo substantial deformations without losing their stability. This helps in dissipating seismic energy.

Foundation Design: It provides guidelines for the design of foundations, considering factors like soil type and ground motion.

Retrofitting: The code also includes provisions for the retrofitting of existing buildings to enhance their earthquake resistance.

Materials and Construction Practices: It provides guidance on the use of appropriate construction materials and techniques to ensure the seismic performance of buildings.

The response spectrum curves for seismic Zone III and Zone V in India, as defined by IS 1893:2016, differ significantly due to the varying levels of seismic hazard in these zones. The response spectrum is a graphical representation of how a structure responds to ground motion at different periods or frequencies. Here are the key differences between the response spectrum curves for Zone III and Zone V:

Peak Acceleration (PGA): The peak ground acceleration (PGA) is higher in Zone V than in Zone III. This means that the maximum acceleration experienced by a structure during an earthquake is greater in Zone V, indicating a more severe seismic hazard.

Short-Period Response: The response spectrum curve for Zone V typically exhibits higher accelerations for short periods (high-frequency ground motion) compared to Zone III. This reflects the higher energy release associated with stronger earthquakes in Zone V.

Long-Period Response: In Zone III, the response spectrum curve may have lower accelerations for longer periods (low-frequency ground motion) compared to Zone V. This is because the seismic hazard in Zone III is generally lower, leading to reduced long-period ground motion.

Damping Ratio: The damping ratio used in the response spectrum calculations may differ between Zone III and Zone V. Damping is a measure of energy dissipation within a structure, and it is typically higher in Zone V to account for the greater seismic energy.

Shape of the Spectrum: The overall shape of the response spectrum curves for the two zones is distinct. Zone V's curve is characterized by higher and more sustained acceleration values across a broader range of periods, reflecting a greater seismic threat.

The response spectrum is a fundamental tool for seismic design and helps engineers assess how structures will respond to different earthquake frequencies. The differences in response spectrum curves between seismic zones highlight the need for structures in higher seismic zones (such as Zone V) to be designed with more robust earthquake-resistant features to withstand the increased seismic forces and ground motion associated with those areas.

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Figure 2 Response spectrum used in spectral analysis

The time period calculated using empirical formula as per IS is 0.881 s. The spectral shape value $C_h(T)=2.5$ is obtained from graph of Response spectrum of soil type C for time period of 0.881s.

Zone III

Importance factor I=1.5, Zoning factor Z=0.16 (zone III)

Elastic site spectra for horizontal loading $C(T)= C_h(T)*Z*I$

=2.5*0.16*1.5

=0.6

Zone V

Importance factor I=1.5, Zoning factor Z=0.36 (zone V)

Elastic site spectra for horizontal loading C(T)= C_h(T)*Z*I

=2.5*0.36*1.5

=1.35

3.3 Pushover analysis

The Pushover analysis determines the strength capacity of structure up to the ultimate State. This method helps to determine the potential failure area of the structural elements. Plastic hinges are assigned to beam (autoM3 hinge) and column (auto P-M2-M3 hinge) as per ASCE 41-13 [16] at relative location of 10% from the ends of length of structural elements.

3.3.1. Hinge Modeling

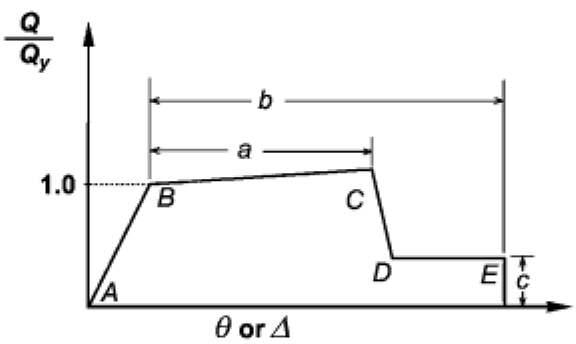

Figure 3 Generalized force deformation relations for concrete elements or components (ASCE 41-13)

where, A-B denotes the Linear response, point A is the unloading stage and point B is the effective yield point. B-C represents linear response at reduced stiffness, C-D is sudden reduction in seismic force resistance and D-E is response at reduced resistance. And a, b, c is modeling parameters in which 'a' and 'b' are plastic rotation angle (radians) and 'c' is the Residual strength ratio.

The modeling of hinge for the column is done using interaction of P-M2-M3 with modeling parameters and acceptance criteria as explained in ASCE 41-13, table 10-8 in ETABS considering the flexure and shear failure of concrete. Similarly, for beam M3 auto hinges with modeling parameters and acceptance criteria as explained in ASCE41-13, table 10-7; provided at relative location of 10% and 90%.

3.3.2Procedure for pushover analysis

The procedure follows following steps:

a) Create three-dimensional model of building

b) Implementation and application of gravity loads, live loads, etc.

c) Define properties and acceptance criteria for the pushover hinges. The ETABS program includes several built-in default hinge properties as per ASCE 41-13.

d) Locate the pushover hinges on the model by selecting one or more frame members and assigning them one or more hinge properties

e) Define the pushover load cases

f) Push the structure using the load patterns of static lateral loads, to displacements larger than those associated with target displacement using static pushover analysis

g) The numbers of hinges in Beam and columns with performance objectives; immediate occupancy, life safety, collapse prevention to define the force deflection behavior of the hinge

h) The result of the push over analysis gives the relation between base shear and Roof displacement known as pushover curve

i) Developing of capacity curve in ADRS format using FEMA 440 equivalent Linearization.

Chapter 4: RESULTS AND DISCUSSIONS

4.1Modal analysis

The modal analysis is carried out to the study of dynamic properties of structures under the excitation force. The fundamental period and modal participating mass ratios are 0.881s and 82.71 % respectively for the 1st mode. Similarly, different modal time period and corresponding modal participation ratio is presented in the table which is summarized in the Annex.

The section of the structural elements determined after designing as per IS 875 (II) is presented in the Table 5.

Table 1 Section Property of Commercial Building

Section	Size (mm)	Grade of Rebar	Grade of Concrete
Column	Square of 650 X 650	HYSD Fe500	M30
Beam	MB-450 X 650	HYSD Fe500	M30
Slab	125	HYSD Fe 500	M30

4.2. Pushover Analysis

Pushover analysis is performed using vertical gravity loading followed by a progressively rising displacement controlled lateral load in both the x and y directions. The figure 15 and 16 represents the result of Pushover analysis. The structure is displaced for 39.767mm at base shear of 7748.2787 KN in the first step of pushover. The curve shows that it tends to bend down as it reaches ultimate roof displacement of 405.677 mm at Base shear of 34240.3756 KN. Similarly in y direction, the roof displacement is also 43.539 mm at the Base shear of the 7666.0424 KN in the first step of push over. The ultimate roof displacement is 419.118 mm at the base shear of 33301.1525 KN.

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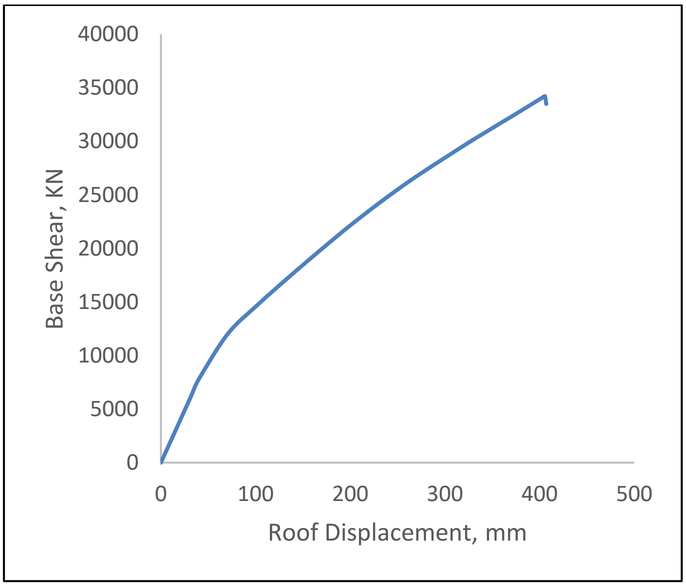

Figure 4 Pushover curve in x direction

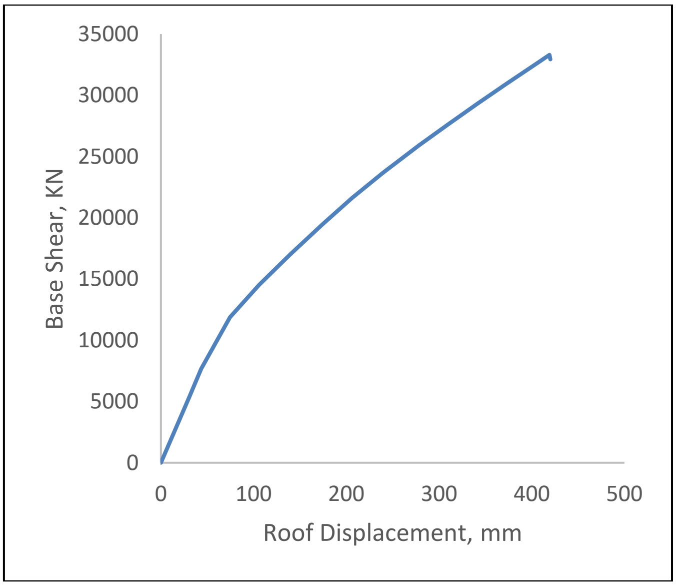

Figure 5 Pushover curve in y direction.

The pushover curve obtained from the Push Over analysis is converted into ADRS format using FEMA 440 equivalent linearization using modal properties. Figure 17 and 18 shows plot of capacity curve of building. Yield Spectral Displacement is the displacement at which yielding starts to occur and Ultimate Spectral Displacement is taken corresponding to the maximum spectral acceleration. This two-displacement value is obtained from the Plot of Spectral acceleration and Spectral displacement of the structure from push over analysis. The curve shows the nonlinear relation between spectral acceleration and Spectral displacement.

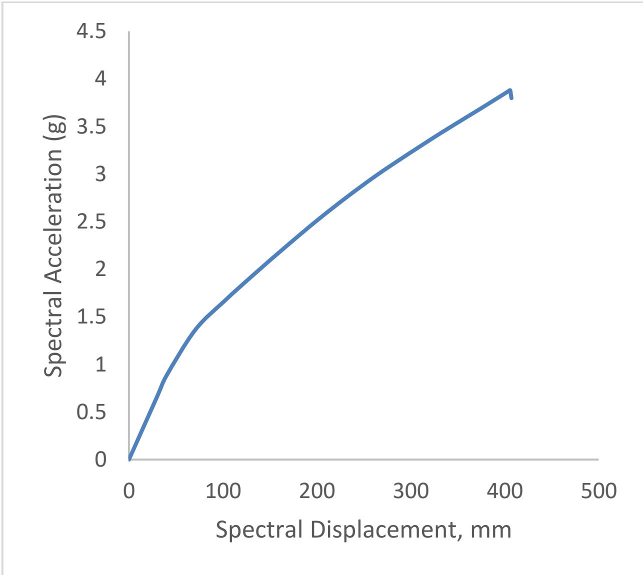

Figure 6 Capacity Curve in x direction

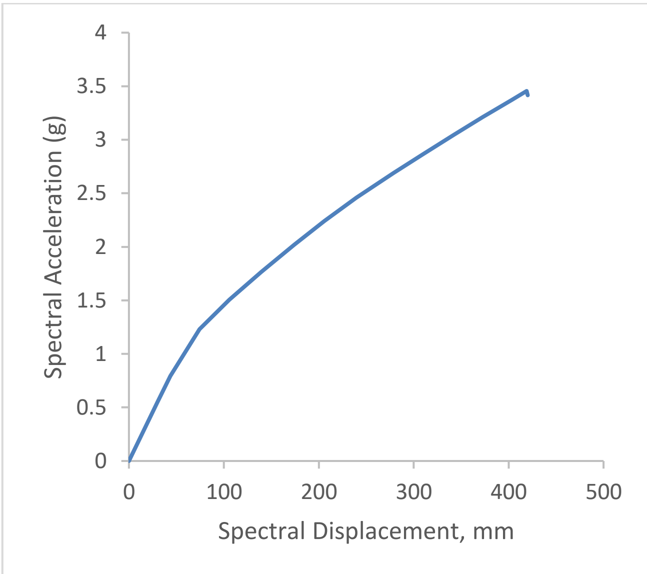

Figure 7 Capacity Curve in y direction

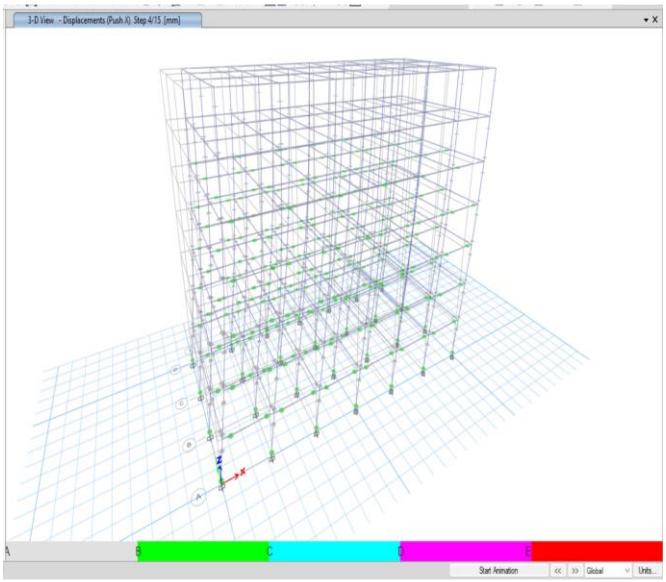

Figure 8 Plastic hinges at various performance level at 400mm roof displacement

The result shows that hinges in the beam and column are in various Performance levels. Figure 19 shows that more than 75% of the hinges are within the immediate occupancy level and remaining hinges are in Life safety and collapse prevention performance level at 400mm roof displacement. Most of the hinges are in immediate occupancy level within the target displacement is due to stiffness of the frame is sufficiently high. Stiffness is reduced beyond the elastic limit in the Pushover curve which is due to the formation of cracks in the structural elements. Similarly, slope of the curve is decreased and finally the ultimate strength of the structure is reached.

4.3 Time history Analysis

The time series data for roof displacement is obtained by performing nonlinear time history analysis and the maximum roof displacement is noted. Similarly, table 6 shows that the result of roof displacement is different for different earthquake at their original hazard level for both Zone III and Zone V models. The line of best fit is drawn from the data obtained from the time history analysis.

Table 2 Roof Displacement for different Earthquake at respective PGA for Zone III and Zone V

Earthquake	PGA_{max}	Maximum Roof Displacement (mm)	
		Zone III	Zone V
Landers	0.164g	91.127	105.369
Kobe Earthquake	0.483g	240.154	280.846
Kern County Earthquake	0.0533g	45.775	65.287
Northridge-01 Earthquake	0.067g	53.084	69.879
Loma Prieta Earthquake	0.443g	208.065	246.028
Chi-Chi Earthquake	0.091g	70.128	83.198
Imperial Valley Earthquake	0.281g	150.028	170.125

4.4 Fragility curve

The value for yield spectral displacement and ultimate spectral displacement obtained from capacity curve are 30.24 mm and 407.11 mm.

Damage State	**Damage State Threshold**
Slight Damage	21.168 mm
Moderate damage	80.209 mm
Extensive damage	273.18 mm
Complete damage	407.11 mm

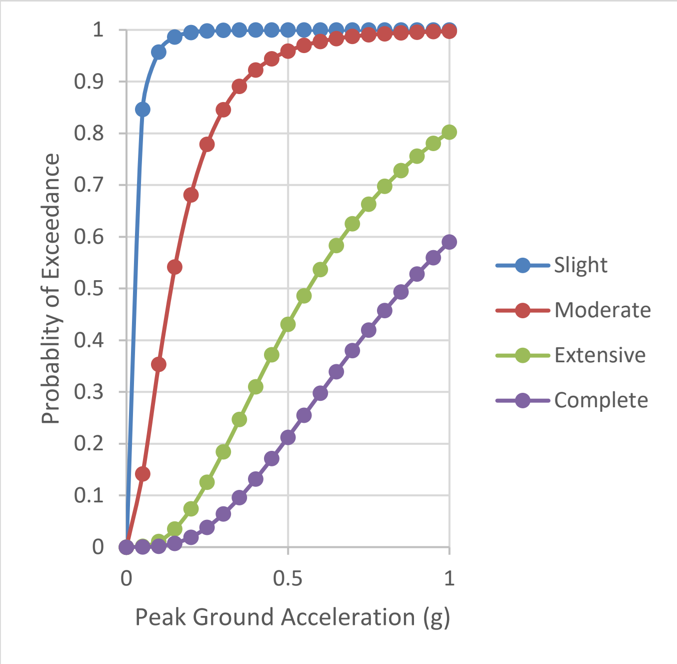

Figure 9 Fragility curve for a building considering Zone III

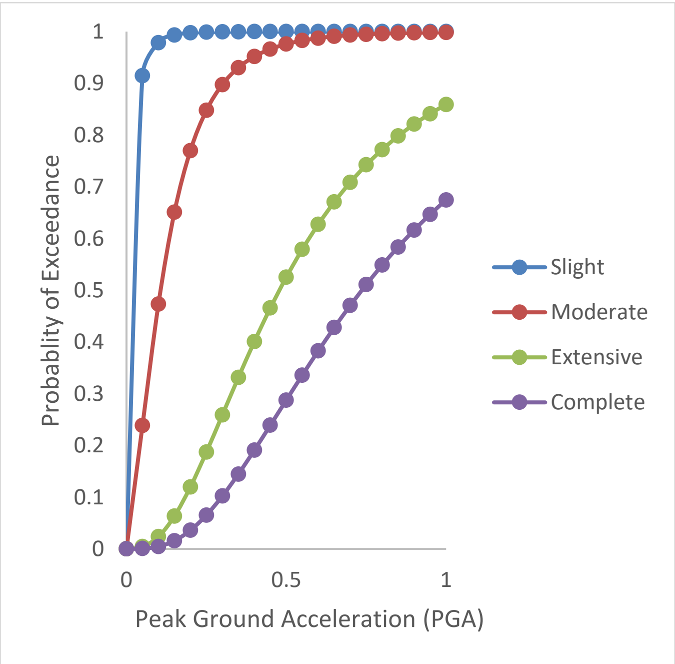

Figure 10 Fragility curve for a building considering Zone V

The probability of being or exceeding the different damages states for given 0.5g hazard level is obtained from the fragility curves of Commercial building and presented in the table 7.

Table 3 Probability of occurrence of particular damage state at 0.5g

	Probability of failure at 0.5g			
	Slight	Moderate	Extensive	Complete
Zone III	99.994 %	95.921 %	43.069 %	21.248 %
Zone V	99.998 %	97.604 %	52.523 %	28.771 %

At 0.5g PGA for Zone III the building has 99.994%, 95.921%, 43.069% and 21.248% of slight, moderate, extensive and complete probabilities of failure. At 0.5g for zone V the building has 99.998%, 97.604%, 52.523% and 28.771% of slight, moderate, extensive and complete probabilities of failure. The analysis was done taking seven different real time earthquake date. From the result in table 7 we can clearly observe that the same building is vulnerable in Zone V compared to that in Zone III.

Chapter five Conclusion and recommendation

5.1 Conclusion

The seismic susceptibility of commercial buildings for zone III and IV is investigated in this study. A case study on the RC building was conducted in order to achieve the result. The finite element program ETABS V21.0.0 was used to perform both nonlinear static and dynamic analysis. During time history analysis, the seismic behavior of a structure is understood in terms of displacement and base shear at various levels of earthquake input. This thesis presents a fragility curve that quantifies the chance of a structure sustaining minor, moderate, substantial, and complete damage considering the two different seismic zones according to the IS1983:2016 code i.e., Zone III and Zone IV.

Major Conclusion of this study is

a. At 0.5g PGA the building has 99.994% probability of SLIGHT failure for the building in Zone III and at same PGA level the same building has 99.998% probability of SLIGHT failure in Zone V. The building is more Vulnerable to earthquake in Zone V compared to the same building at Zone III.

b. At 0.5g PGA the building has 95.921% probability of MODERATE failure for the building in Zone III and at same PGA level the same building has 97.604% probability of MODERATE failure in Zone V. The building is more Vulnerable to earthquake in Zone V compared to the same building at Zone III.

c. Similarly, at 0.5g PGA the building has 43.069% probability of EXTENSIVE failure for the building in Zone III and at same PGA level the same building has 52.523% probability of EXTENSIVE failure in Zone V. The building is more Vulnerable to earthquake in Zone V compared to the same building at Zone III.

d. At 0.5g PGA the building has 21.248% probability of COLLAPSE failure for the building in Zone III and at same PGA level the same building has 28.771% probability of COLLAPSE failure in Zone V. The building is more Vulnerable to earthquake in Zone V compared to the same building at Zone III.

e. Fragility curve developed can be used to determine probability of damages and also useful for loss estimation.

f. The buildings constructed in zone V are more vulnerable than the buildings being constructed in zone III. As the zones are defined according to the different hazard levels. The zone V is more susceptible for higher amplitude earthquake compared to zone III. So, the zone factor value for designing of structure should not be neglected.

5.2 Recommendation for future works

- The future study can incorporate the effect of soil structure interaction on dynamic behavior of building.
- Vulnerability assessment is done for only one building. Thus this assessment can carried out to the other considering many buildings.
- The present work used Modal time history analysis is used to determine the demand of structure and is recommended to perform direct integration Time history analysis and check the variation in demand.

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