International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 10 | October - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

Methodology for Evaluating Seismic Analysis and Performance of Reinforced Concrete Buildings in Seismic Zones III and V

Mr. Nirav Patel[1], Mr. Arjun Khatri[2]

[1] Department of Civil Engineering & Parul University, Gujarat, India

[2] M.tech. Structural Engineering, Department of Civil Engineering & Parul University, Gujarat, India

Abstract:

Reinforced concrete buildings are widely used in contemporary construction practices, particularly in India, where design standards such as IS 875 and IS 1983:2016 are adhered to. This research delves into the seismic performance of reinforced concrete (RC) frames, employing both linear and nonlinear analyses. A seven-story building, designed in accordance with Indian standards, is modeled using Finite Element Software ETABS v21.0.0. The study evaluates the response of these buildings, focusing on parameters like base shear and story displacement, for structures located in seismic Zones III and V. The capacity of the building is assessed through displacement-controlled nonlinear static analysis, known as pushover analysis. Time history loading is applied to the structure to ascertain the seismic demand at varying Peak Ground Acceleration (PGA) levels. Fragility curves are developed to quantify hazard levels and determine the probability of exceeding different PGA levels for both Zone III and Zone V, employing the First Order Second Order Method (FOSM). The study reveals that buildings in Zone V are more vulnerable to seismic events compared to their counterparts in Zone III.

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

INTRODUCTION

According to a study of the area's seismic history, large earthquakes that produce shaking levels of IX or higher on the modified Mercalli Intensity (MMI) scale only happen around once every 75 years, whereas smaller ones happen more frequently. Similarly, the pastearthquake history of India shows that India is most vulnerable zone in terms of seismic hazard.As it is impossible to construct earthquake proof structure however efforts should be done to make structures earthquake resistant. Damage on the port of Oakland, Oakland airport facilities caused by the 1989 Loma Prieta Earthquake [1]. Non-structural damage occurred at the control tower (window damage) and international terminal (ceiling damage and sprinkler damage) of San-fransisco airport. The Toussaint L'Ouverture international airport was badly damaged due to the earthquake that hit Haiti in January 2010.This damage resulted in the reductionof humanitarian supplies to Haiti from international society [2]. Therefore, seismic vulnerability of buildings has to be carried out and suitable interventions have to be done to so as to ensure their safety during future earthquake.

Weak buildings are structures that lack the necessary structural integrity and strength to withstand various stresses and loads, including those from natural disasters such as earthquakes, hurricanes, or even strong winds. These buildings are often characterized by design, construction, or material deficiencies that make them vulnerable to damage or collapse, particularly when subjected to external forces. Weak buildings can pose significant risks to the safety of their occupants and contribute to increased casualties and damage during disasters.

Here are some of the common factors that could make the building weak,

Poor Construction Materials: The use of substandard or low-quality construction materials can weaken a building's structural elements. Weak materials may lack the strength and durability needed to withstand the test of time and environmental stressors.

Inadequate Design: Flawed architectural and structural design can result in buildings that are unable to support the loads they are meant to bear. Inadequate structural calculations, improper placement of load-bearing elements, or lack of reinforcements can make a building structurally unsound.

Lack of Maintenance: Neglecting regular maintenance and repairs can lead to the deterioration of a building's structural components. Cracks, corrosion, or other forms of degradation can weaken the building over time.

Non-Compliance with Building Codes: Ignoring or not following local building codes and regulations can result in buildings that lack the necessary standards for structural safety and integrity.

Overcrowding and Modifications: When buildings are modified or overcrowded beyond their original design capacity, it can strain the structural elements, potentially making the building weak and unstable.

Following procedures are performed to obtain the results of this thesis work.

Review of relevant literature.

Select the building for the study and collect data related to it.

Model building in ETABS V21.0.0.

Determine the capacity of structure performing pushover analysis.

Determine the demand of structure at different scale of PGA performing Nonlinear Time history analysis for Zone III and Zone V.

Develop fragility functions for analysis of both zones the structures using HAZUS methodology.

Result discussion and draw conclusion.

A building capacity curve represents structure's lateral load resistance as a function of a specific lateral displacement (i.e., a force deflection plot). It is produced from a plot of static-equivalent base shear vs. building displacement (e.g., roof). The building capability is outlined by capacity curve with three control points i.e., design capacity, yield capacity and ultimate capacity. Design capacity is the nominal building strength needed according to seismic code requirements. Yield capacity measures the real lateral strength of the building, taking into account design redundancy, regulatory restrictions, and true (rather than nominal) material strength. When the global structural system has achieved a fully plastic condition, the maximum strength of the building indicates the ultimate capacity [14].

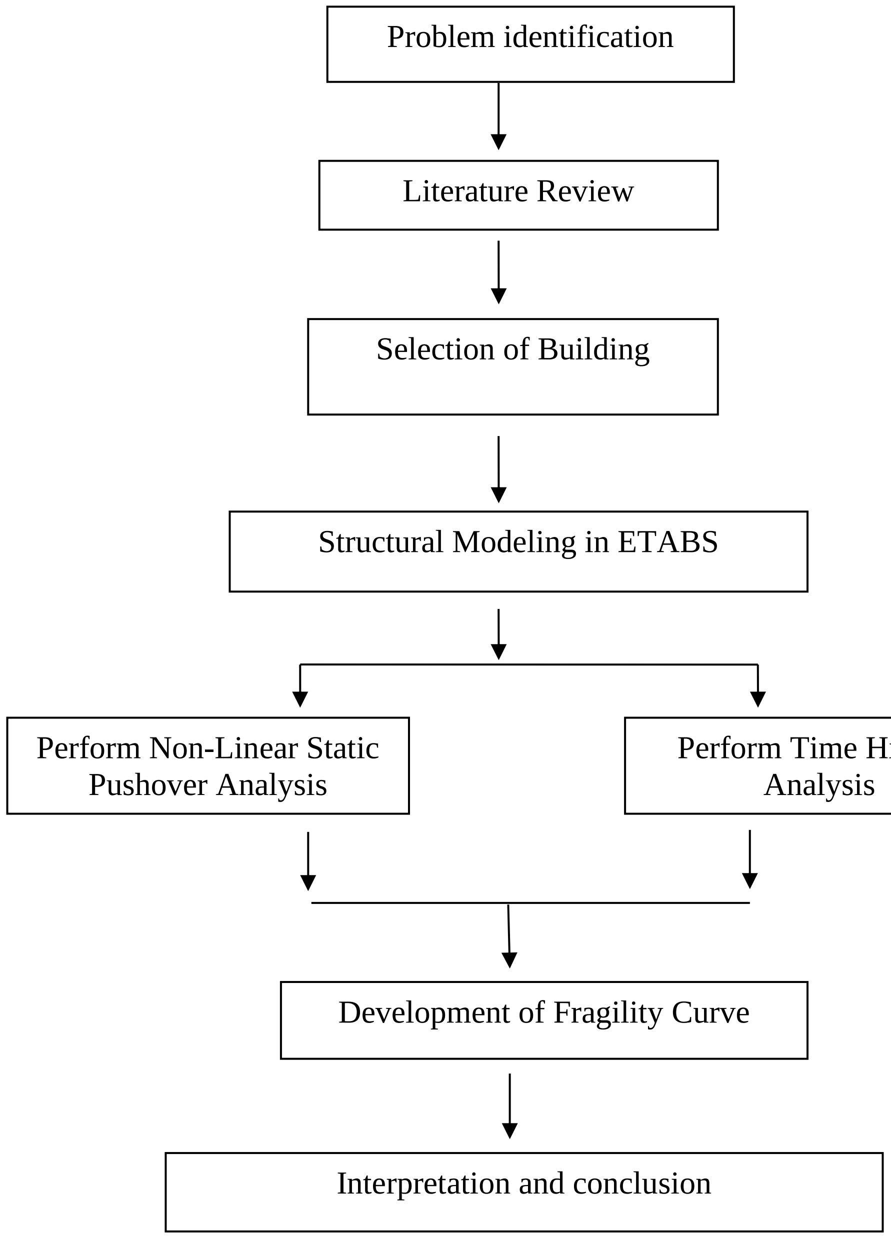
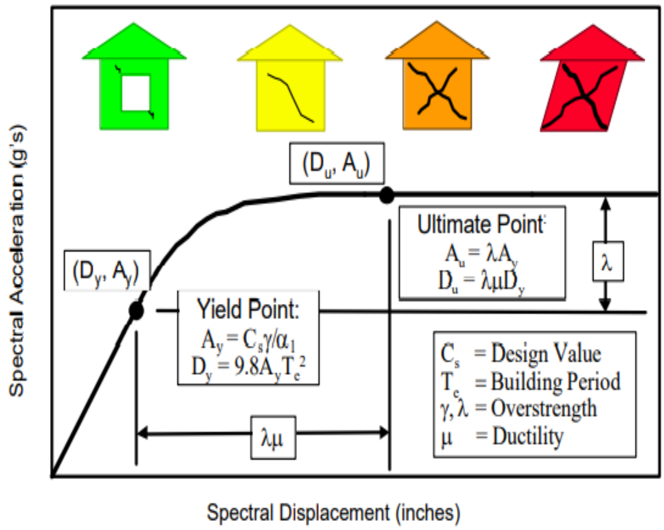


Figure 1 General Methodology flowchart adopted for study

Figure 2 Building Capacity Curve and Control



Points (HAZUS MH-MR1)

Where,

Cs point of significant yielding of design strength coefficient (fraction of building's weight),

T_e is expected "elastic" fundamental-mode period of building (seconds),

α_1 is fraction of building weight effective in the pushover mode,

α_2 is fraction of building height at the elevation where pushover-mode displacement is equal to spectral displacement,

γ is over strength factor relating "true" yield strength to design strength,

λ is over strength factor relating ultimate strength to yield strength, and

υ is ductility ratio.

P-Delta Effect

It is a type of geometric nonlinearity that includes the equilibrium compatibility relationships of a structural system loaded around its deflected configuration. The application of gravity stress on laterally displaced multi-story building constructions is particularly concerning. This state amplifies story drift and certain mechanical characteristics while lowering deformation capacity.

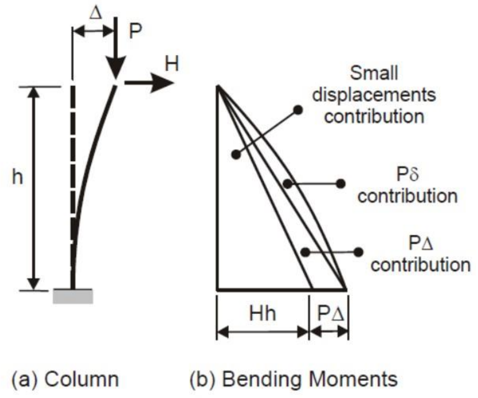


Figure 3 P-Delta about Column (CSI America)

Time History Analysis

Time history analysis is the analysis technique to evaluate the dynamic structural response of a structure under loading which varies with times. In the time history analysis structural response is calculated for each time step. Modal and direct integration methods are the two different type of time history analysis.

Fast Nonlinear Analysis (FNA), also known as nonlinear modal time-history analysis, is more accurate and efficient than direct-integration time-history analysis. The accuracy of FNA depends upon the sufficiency of suitable mode shapes, similar to how direct integration requires small enough time steps to accurately characterize dynamic behavior [15].Time history analysis is an important approach for structural seismic analysis, especially when the analyzed structural response is nonlinear. To conduct such a study, a representative earthquake time history for the building under consideration is necessary. Time history analysis is a step-by-step examination of a structure's dynamic response to a specific loading that may vary over time. The seismic response of a structure under dynamic loading of a representative earthquake is determined using time history analysis. [16].

The dynamic equilibrium equation is second order differential equation as given by

$[M]\{\ddot{X}(t)\}+[C]\{\dot{X}(t)\}+[K]\{X(t)\}=\{F(t)\}$……… ……….. 1

Where, [M] is mass matrix, [C] is damping matrix, [K]is stiffness matrix.

Direct integration method and Modal Time history method with linear and nonlinear considerations are the methods of nonlinear dynamic time history analysis. Direct integration is step by step numerical integration which doesn't involve use of mode shapes or modal properties. It solves coupled equation of motion directly and gives combined dynamic response of structure. There are various solution techniques such as Newmark, Wilson, Hilber-Hughe-Taylors for direct integration technique. Modal Time history analysis uses mode shape or modal properties provide highly efficient and accurate procedure.

Fragility curves

In recent days fragility curve is used in vulnerability assessment of building structures. Fragility curves of building are obtained as lognormal distribution function that provides the probability of reaching or exceeding the particular damage state for given spectral displacement or PGA. Damages in the building vary from none to complete as a continuous function of building response. The lognormal standard deviation value governs the slope of the fragility curve (Beta). The lower the Beta value, the less changeable the damage state and the steeper the fragility curve. A higher Beta value indicates a more changeable damage state and a flatter fragility curve.

Four damage states namely slight, Moderate, Extensive and complete has been described in the [17] .

Reinforced Concrete Moment Resisting Frames (C1):

Slight Structural Damage: Flexural or shear type hairline cracks in some beams and columns near joints or within joints.

Moderate Structural Damage: Most beams and columns exhibit hairline cracks. In ductile frames some of the frame elements have reached yield capacity indicated by larger flexural cracks and some concrete spalling. Nonductile frames may exhibit larger shear cracks and spalling.

Extensive Structural Damage: Some of the frame elements have reached their ultimate capacity indicated in ductile frames by large flexural cracks, spalled concrete and buckled main reinforcement; nonductile frame elements may have suffered shear failures or bond failures at reinforcement splices, or broken ties or buckled main reinforcement in columns which may result in partial collapse.

Complete Structural Damage: Structure is collapsed or in imminent danger of collapse due to brittle failure of nonductile frame elements or loss of frame stability. Approximately 13%(low-rise), 10%(mid-rise) or 5%(high-rise) of the total area of C1 buildings with Complete damage is expected to be collapsed. The Probability of occurrence of particular damage state for given spectral displacement is given by

$$P[ds|S_d] = \Phi\left[\frac{1}{\boldsymbol{\beta ds}}\ln\left(\frac{\mathbf{Sd}}{\overline{\mathbf{S}}\,\mathbf{d,ds}}\right)\right]$$

……………….. 2

Where;

$\overline{S}\,d,ds$ is the median value of spectral displacement at which the building reaches the threshold of damage state,

Bdis the standard deviation of the natural logarithm of spectral displacement for damage state, ds,

Φ is the standard normal cumulative distribution function.

The total variability of each equivalent-PGA structural damage state, β_{SPGA}, is modeled by the combination of following two contributors to damage variability:

Uncertainty in the damage-state threshold of the structural system ($\beta_{M(SPGA)}$) = 0.4 for all building

Volume: 07 Issue: 10 | October - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

types and damage states),

Variability in response due to the spatial variability of ground motion demand ($\beta_{D(V)} = 0.5$ for long-period spectral response).

The two contributors to damage state variability are assumed to be lognormally distributed, independent random variables and the total variability is simply the square root-sum-of-the-squares combination of individual variability terms (i.e., $\beta_{SPGA} = 0.64$).

The fragility curves categorize damage as Slight, Moderate, Extensive, or Complete. Discrete damage-state probabilities are determined for each given value of spectral response as the difference between the cumulative probability of attaining and exceeding consecutive damage states. Discrete damage-state probabilities are utilized as inputs to several forms of building-related loss calculations.

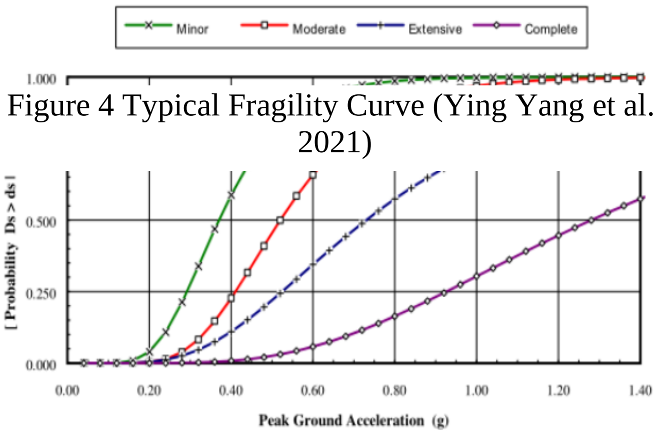


Figure 4 Typical Fragility Curve (Ying Yang et al., 2021)

METHODOLOGY:

Data Collection and Building Modeling:

Gather necessary data for the study, including seismic codes (IS 875 and IS 1983:2016), architectural and structural details of the seven-story RC building.

Utilize Finite Element Software ETABS v21.0.0 to create a 3D model of the building in accordance with Indian standard codes.

Linear and Nonlinear Analysis:

Conduct both linear and nonlinear analyses to assess the seismic performance of the RC frame.

Perform linear analysis to evaluate the building's response to seismic forces within the elastic range.

Execute nonlinear analysis to investigate the behavior of the building under inelastic deformations, including yielding of structural elements.

Response Evaluation:

Assess the response of the building in terms of critical parameters, including base shear and story displacement.

Conduct this assessment for buildings located in seismic Zones III and V, as defined by IS 1983:2016.

Pushover Analysis:

Utilize displacement-controlled nonlinear static analysis, commonly known as pushover analysis, to determine the capacity of the building.

Analyze the building's response to lateral forces and displacements applied incrementally, reaching the point of structural failure.

Time History Analysis:

Apply time history loads to the structural model to simulate the seismic demand on the building.

Analyze the behavior of the structure in terms of displacement and base shear under various levels of earthquake input.

Fragility Curve Development:

Quantify hazard levels by plotting fragility curves for both Zone III and Zone V.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 10 | October - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

Utilize the First Order Second Order Method (FOSM) to develop fragility curves based on different damage states.

Conclusion (Summarized): The seismic performance and susceptibility of commercial buildings in seismic Zones III and IV were studied in this research. A case study involving a seven-story RC building was conducted using Finite Element Software ETABS V21.0.0. Linear and nonlinear analyses were performed to evaluate the building's response to seismic forces. Through time history analysis, the building's behavior in terms of displacement and base shear under varying earthquake intensities was examined. This study presented fragility curves, which quantify the likelihood of structures sustaining minor, moderate, substantial, and complete damage in accordance with the IS1983:2016 code for Zone III and Zone IV.

The major conclusions of this study are as follows: a. At a PGA of 0.5g, buildings in Zone III have a 99.994% probability of SLIGHT failure, whereas buildings in Zone V have a 99.998% probability of SLIGHT failure, highlighting the heightened vulnerability of Zone V buildings. b. At a PGA of 0.5g, buildings in Zone III have a 95.921% probability of MODERATE failure, while buildings in Zone V have a 97.604% probability of MODERATE failure, emphasizing the greater vulnerability of Zone V buildings. c. Similarly, at a PGA of 0.5g, buildings in Zone III have a 43.069% probability of EXTENSIVE failure, compared to 52.523% probability in Zone V, indicating the increased vulnerability of buildings in Zone V. d. At a PGA of 0.5g, buildings in Zone III have a 21.248% probability of COLLAPSE failure, whereas buildings in Zone V have a 28.771% probability of COLLAPSE failure, further highlighting the heightened vulnerability of Zone V buildings. e. The developed fragility curve provides a valuable tool for determining damage probabilities and aiding in loss estimation. f. The buildings constructed in Zone V are more vulnerable than those in Zone III due to differing hazard levels, underscoring the importance of considering zone factors in structural design.

ETABS Model

3-D modeling, analysis and design of the building have been done using ETABS V21.0.0. Model is done as beam column slab frame structure with rigid diaphragm. Beam column joint is rigid connection and base of column is restrained in all direction. Following figure 6 is a show the 3D Model of study commercial building. The proposed structure of the building has been designed using IS 875 codal provision.

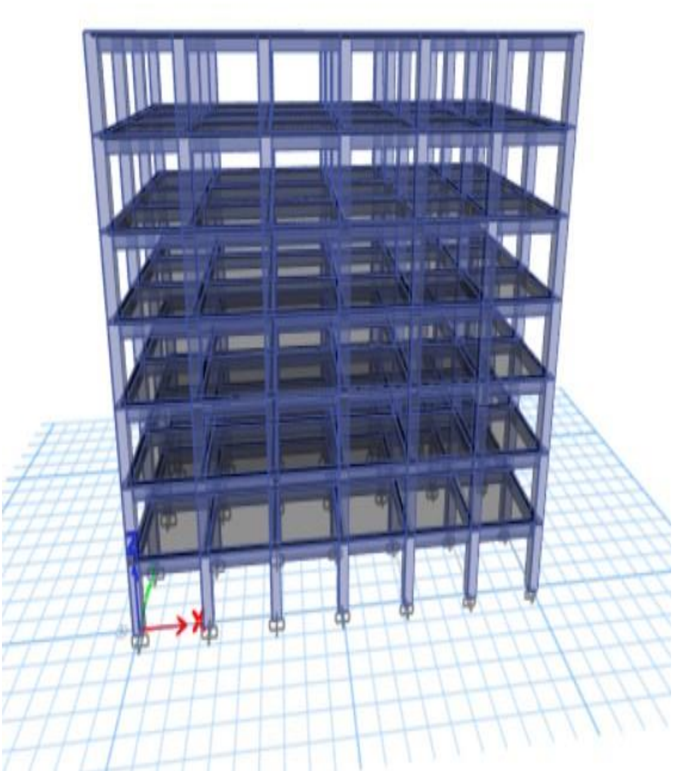


Figure 5 3-D model of study Building modelled in ETABS

3.2.1 Material Properties

3.2.1.1 Concrete Properties

Concrete used for the analysis of the building has following properties as shown in following Table

Table 1 Material Properties

Concrete M30	
Density of Concrete (Kg/m3)	2548.538
Weight per unit Volume (KN/m3)	24.9926
Compressive Strength (MPa)	30
Modulus of Elasticity (E) (MPa)	27386.13
Poisson Ratio (U)	0.2
Coefficient of Thermal Expansion (1/C)	0.000013
Shear Modulus (MPa)	11410.89

3.2.1 Rebar Properties

Rebar with following properties has been used for the analysis of building as shown in table 2.

Table 2 Material Property of Rebar

Rebar HYSD Fe500	
Density (kg/m3)	7849.047
Modulus of Elasticity (MPa)	200000
Coefficient of Thermal Expansion (1/C)	0.0000117

Loads

The Dead loads and Live loads are applied on the floor as per IS: 875-1987 Part 1 and Part 2 respectively.

Live load on the floors: 3KN/m^2, 4 KN/m^2

Live load on terrace: 0.75 KN/m^2

Floor finish: 1.5 KN/m^2

Glass load: 0.167 KN/m

Main wall load: 19.64 KN/m

Partion wall load: 9.82KN/m

3.5. Non-Linear Time history Analysis

The time history analysis gives the dynamic response of the structures subjected to loading which varies with time. This method requires the accelerogram data for the analysis to determine the demand of structure. Nonlinear time history analysis has been performed using three earthquake accelerogram data as per IS1983:2016 to find the response of the structure during particular earthquake. The selection of earthquake data has been done considering amplitude, frequency content and duration of events. The selected ground motions must be scaled to match the target spectrum (for both the response spectrum, Zone III and Zone IV) between periods T_n and $\sqrt{R_\mu}$xT_1, where T_1 is the fundamental period of vibration of the structure, Tn is the period of the highest vibration mode to ensure 90% mass participation, and R_μ is the ductility factor. The accelerograms data mentioned below are used in this time history analysis.

Table 3 Earthquake Accelerogram data

S. N.	Description of Earthquake	Magnitude	Station	PGA
1.	Landers Earthquake	7.28	Lucerene	0.164 g
2.	Kobe Earthquake	6.9	Nishi-Akashi	0.483 g
3.	Kern County Earthquake	7.36	Pasadena - CIT Athenaeum	0.0533g
4.	Northridge-01 Earthquake	6.69	Anacapa Island	0.067 g
5.	Loma Prieta Earthqua	6.93	Los Gatos - Lexingto	0.443 g

S. N.	Description of Earthquake	Magnitude	Station	PGA
	ke		n Dam	
6.	Chi-Chi Earthquake	7.62	HWA002	0.091 g
7.	Imperial Valley Earthquake	6.95	El centro Array #9	0.281 g

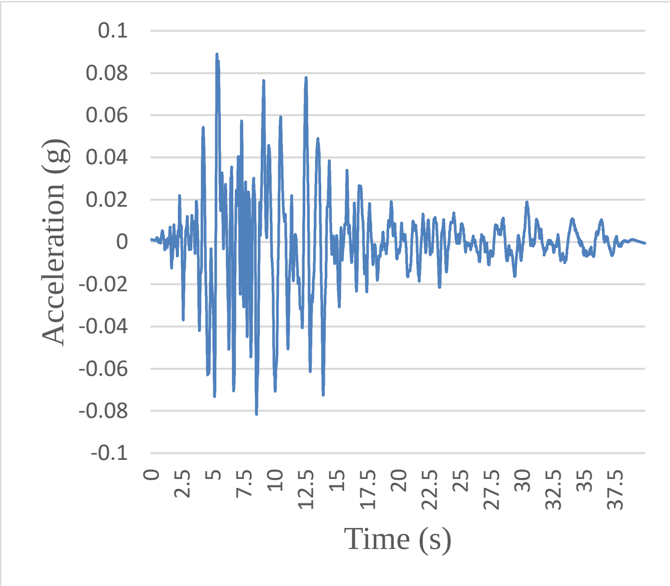


Figure 6 Accelerogram of Loma Prieta

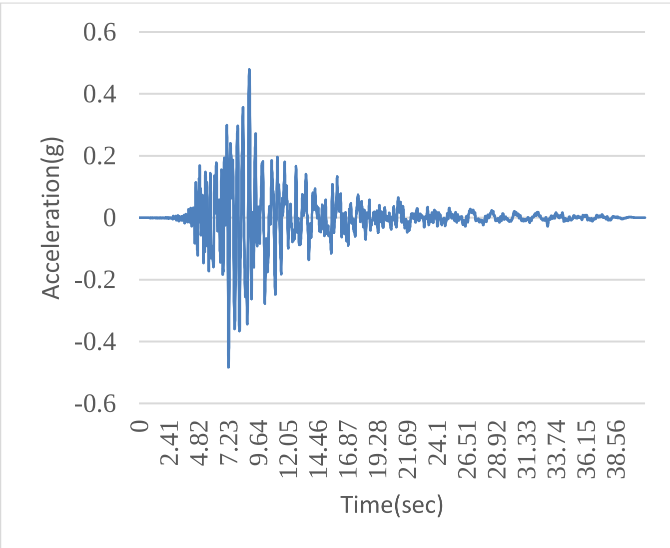


Figure 7 Accelerogram of Kobe Earthquake 1995

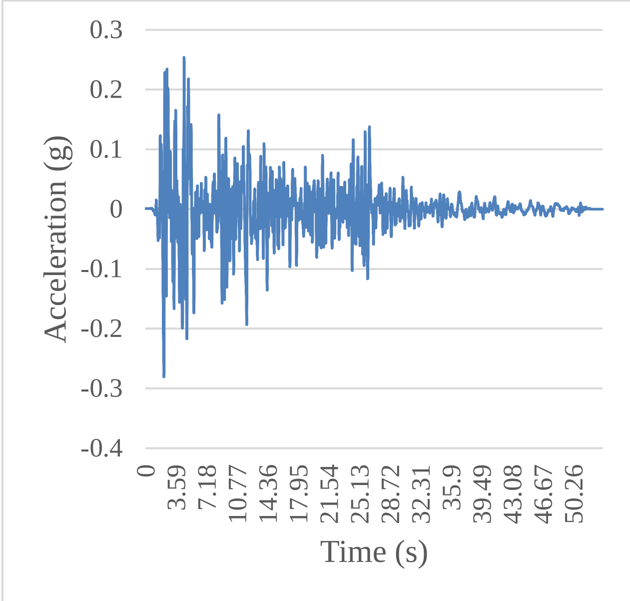


Figure 8 Accelerogram of Imperial Valley Earthquake 1940

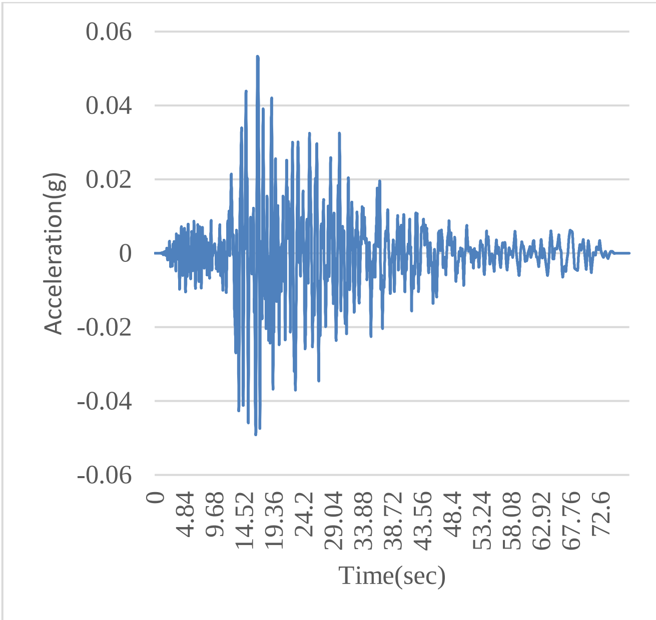


Figure 9 Accelerogram of Kern Country Earthquake

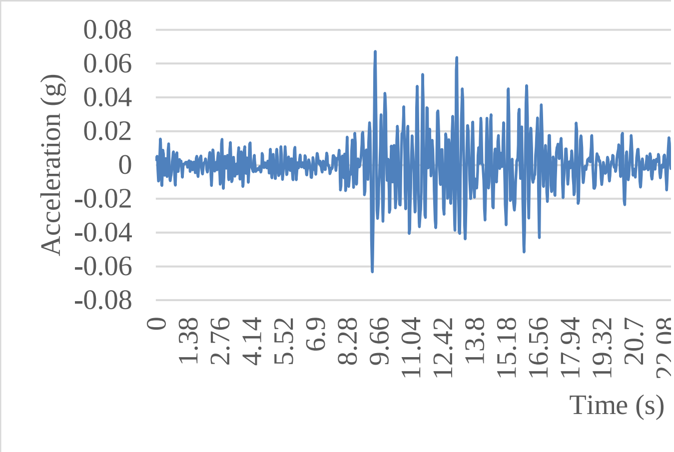


Figure 10 Accelerogram of Northridge -01 Earthquake

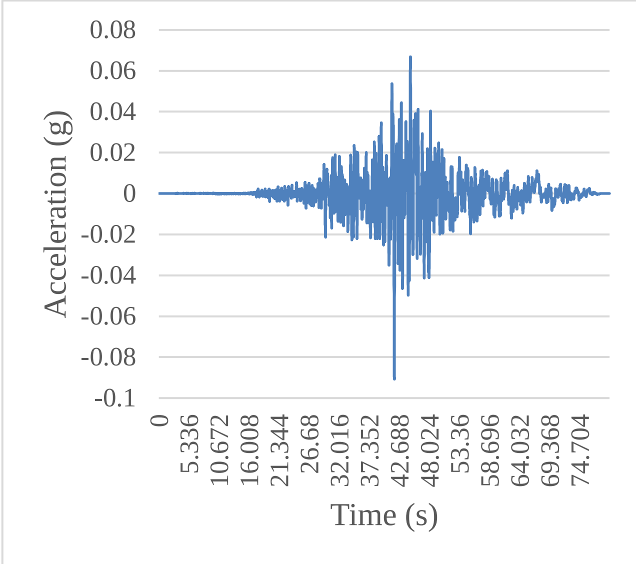


Figure 11 Accelerogram of Chi-Chi Taiwan Earthquake

Table 4 Damage state threshold values described on [20]

Damage State	Damage State Threshold
Slight Damage	$\overline{Sd1}=0.7S_{dy}$
Moderate damage	$\overline{Sd2}=S_{dy}$
Extensive damage	$\overline{Sd3}=S_{dy}+0.25(S_{du}+S_{dy})$
Complete damage	$\overline{Sd4}=S_{du}$

3.6 Fragility Function

Fragility curve is obtained as the lognormal distribution function of probability of failure for given PGA or spectral displacement. The fragility curve is plotted with median value of spectral displacement as a capacity and spectral displacement as the demand for each earthquake. The conditional probability of failure with respect to spectral displacement is given by

$$\mathbf{P[ds|S_d] = \Phi\left[\frac{1}{\beta ds}\ln\left(\frac{Sd}{\bar{S}_{d,ds}}\right)\right].}$$

The yield spectral displacement and ultimate spectral displacement value derived from the capacity curve are used to calculate the median value of spectral displacement, which is the important parameter for calculating the fragility curve for four distinct damage states of the structure.

Conclusion:

This research investigates the seismic susceptibility of commercial buildings in seismic Zones III and IV. A case study of an RC building was conducted, employing both nonlinear static and dynamic analyses through the finite element program ETABS V21.0.0. The seismic behavior of structures in terms of displacement and base shear under various levels of earthquake input was assessed during time history analysis. The study presents fragility curves that quantify the likelihood of structures incurring minor, moderate, substantial, and complete damage in accordance with the IS1983:2016 code for Zone III and Zone IV.

The major conclusions of this study are as follows: a. At a PGA of 0.5g, buildings in Zone III have a 99.994% probability of SLIGHT failure, whereas buildings in Zone V have a 99.998% probability of SLIGHT failure. This demonstrates the increased vulnerability of buildings in Zone V to earthquakes compared to those in Zone III. b. At a PGA of 0.5g, buildings in Zone III have a 95.921% probability of MODERATE failure, while buildings in Zone V have a 97.604% probability of MODERATE failure, again highlighting the greater vulnerability of Zone V buildings. c. Similarly, at a PGA of 0.5g, buildings in Zone III have a 43.069% probability of EXTENSIVE failure, compared to 52.523% probability in Zone V, indicating the increased vulnerability of buildings in Zone V. d. At a PGA of 0.5g, buildings in Zone III have a 21.248% probability of COLLAPSE failure, whereas buildings in Zone V have a 28.771% probability of COLLAPSE failure, further emphasizing the heightened vulnerability of buildings in Zone V. e. The developed fragility curve provides a valuable tool for determining damage probabilities and aiding in loss estimation. f. Buildings constructed in Zone V are more vulnerable due to the higher seismic hazard levels compared to Zone III, highlighting the significance of considering the zone factor in structural design.

This research offers insights into seismic vulnerability and performance that can inform structural design and safety practices, particularly in areas with varying seismic hazards.

References:

"Preliminary Evaluation of Methods for Defining Performance," *ATC-58-2*, pp. 1-99, 2003.

Multi-hazard Loss Estimation Methodology Earthquake Model HAZUS®MH MR4 Technical Manual..

wiki.csiamerica.com.

A. S. Patil and P. D. Kumbhar, "TIME HISTORY ANALYSIS OF MULTISTORIED RCC BUILDINGS FOR DIFFERENT SEISMIC INTENSITIES," *International Journal of Structural and Civil Engineering Research*, vol. 2, no. 3-Aug, pp. 194-201, 2013.

Multi-hazard Loss Estimation Methodology Earthquake Model Hazus®-MH2.1..

ASCE, seismic evaluation and retrofit of existing buildings ASCE 41-13, American Society of Civil Engineers, 2014.

S. Lagomarsino and S.G, "Macroseismic and mechanical models for vulnerability and damage assessment of current building," *Bull earthquake engineering*, 30 Sept 2006.

GoN, "National Earthquake Monitoring and Research Center," 2022. [Online]. Available: http://seismonepal.gov.np/historical-events. [Accessed 24 04 2022].

DPNet-Nepal, "Disaster Preparedness Network-Nepal," 12 04 2022. [Online]. Available: https://www.dpnet.org.np/public/. [Accessed 24 4 2022].

S. b. KJ Sriranjani, "PUSHOVER ANALYSIS

AND DESIGN OF MULTI STOREY BUILDING USING ETABS," *International Journal of Engineering and Techniques,* vol. 7, no. 2, 2021.

M. O. U. D. GoN, N E P A L N A T I O N A L B U I L D I N G C O D E NBC:105:2020, singdurbar,Kathmandu, 2077.

ATC-40, Seimic evaluation and retrofit of concrete buildings, Redwood city,california: APPLIED TECHNOLOGY COUNCIL, 1996.

S. Eshghi and H. Farroki, "Seismic Vulnerability Analysis of Airport Traffic Control Towers," *Journal of seismology & Earthquake Engineering,* vol. 5, no. 1, pp. 31-40, 2003.

Pierepiekarz, M.R. , Ballantyne, D.B. and Hambutrger, R.O. “Damage Report from Seattle”, Civil Engineering Magazine., 2001.

ATC58-2, Preliminary evaluation of methods for defining performance, Redwood City, 2003.