Seismic Fragility Estimates for RC Buildings using Reliability Analysis

Kruthika N V
VTU

***Abstract*—The project focuses on fragility analysįs ōf a RC structure with respect to six different earthquakes with different magnitude. The main aim of the study is to evaluate the behavior of low rise, mid rise and high rise structures considering nōn-lįnear time hįstory analysįs and to evaluate seismįc desįgn parameter such as story drift, story shear, story displacement and base shear. Building analysis is performed in e-tabs software and fragility curve is plotted with seismic parameter and python is a tool used to plot fragility curve. By considering the fragility curve percent of safety can be determine with a different damages states like slight, moderate, extensive and complete damage with the probabilities of exceedance for seismic design along with limit capacity addressing uncertainties in hazard damages and loss analysis using fragility curve.**

***Index Terms*—fragility curve, low rise building, mid rise building and high-rise building.**

I. INTRODUCTION

Reliability-based analysis of fragility curve with RC framed buildings involves assessing the failure under seismic events of varying intensities (Bakalis & Vamvatsikos, 2018). Initially develop fragility curves that deducts the ratio of exceeding certain damage states i.e slight, modarate, extensive and complete collapse. This involves collecting data on past earthquakes, structural properties of RC buildings, and damage observations (Baker, 2015). Buildings with different heights i.e low rise, mid rise and high-rise buildings separately by determining the structural responses to earthquakes which differs significantly due to differences in stiffness, damping, and resonance characteristics (Bassam et al., n.d.).

Utilize probabilistic methods such as Monte Carlo simulation or response surface methods to assess the reliability of the buildings against seismic events (Efraín et al., 2013) (Lagaros, n.d.). This involves considering uncertainties in ground motion, structural parameters, and modeling assumptions. Ensure that the fragility analysis aligns with performance-based design criteria, such as specific damage states or performance objectives defined by building codes or standards (M et al., 2023). Perform sensitivity analysis to identify influential factors affecting the reliability of RC framed buildings, such as soil conditions, structural detailing, and material properties (Patel et al., 2016).

Validate the fragility analysis results by comparing them with observed details for past seismic action or by experimental studies on similar building types. Assess the potential consequences of structural damage or failure in terms of human safety, economic losses, and societal impacts to inform risk management and mitigation strategies (Martins et al., n.d.). By considering these, you can conduct a comprehensive reliability-based fragility analysis of RC framed low rise, mid rise and high rise structures under the different seismic scenarios (Baker, 2015).
The aįm of thįs work įs to evaluate behavior of low, mid and high rise building considering non-linear time history analysis. By evaluating seismic design parameter such as story drįft, story shear, story displacement. And to study the probabilities exceedance for seismic design along with limit capacity addressing uncertainties in hazard, structural damages and loss analysis using fragility curve.

II. MATERIALS AND METHODS

E-Tabs is a software used to analyze the buildings of different height ie low rise, mid rise and high rise. Post seismic data is assigned usįng Non lįnear tįme hįstory method, earthquakes with six different magnitude is considered. Live load, dead load and earthquake loads are assigned to three different buildings. By considering the base shear value of action fragility curve and percentage of damages are calculated (Bakalis & Vamvatsikos, 2018). Python is a tool used to plot fragility curve. The damage states are considered with reference to HAZUZ manual, the HAZUZ manual states that if the damage index is between 0.15 to 0.3 denotes slight damage, the damage index is between 0.3 to 0.6 denotes moderate damage, the damage index is between 0.6 to 0.9 denotes extreme damage and damage index greater than 0.9 leads to complete collapse. Standard deviation and mean values for damage states are also referred by hazuz consideration. The results are also derived by the above concept and consideration (Patel et al., 2016).

Table 1 Different damage states (hazuz manual considerations)

States of damage	Slight	Moderate	Extensive	Complete collapse
Status of structure	Minor cracks at infill walls	Extensive cracks at walls, shear at beams and columns	Lateral deformation, structural damage	Total failure
Damage index	0.15-3	0.3-0.6	0.6-0.9	>0.9
Standard deviation	0.18	0.24	0.31	0.15
Mean	0.2	0.5	1.5	2.5

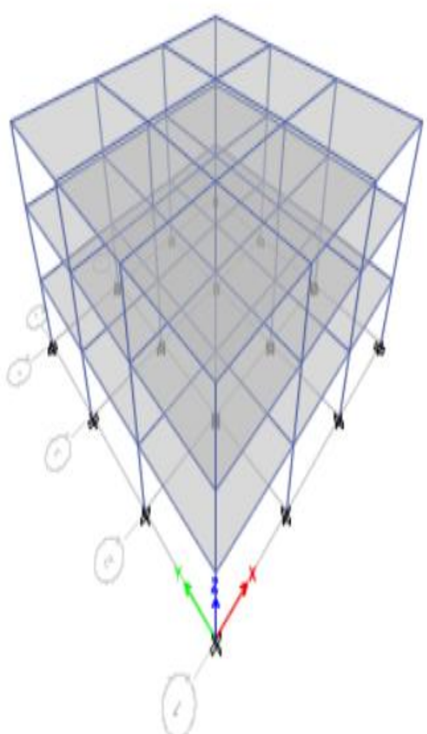

Figure 1: Three dimension view for Low rise building

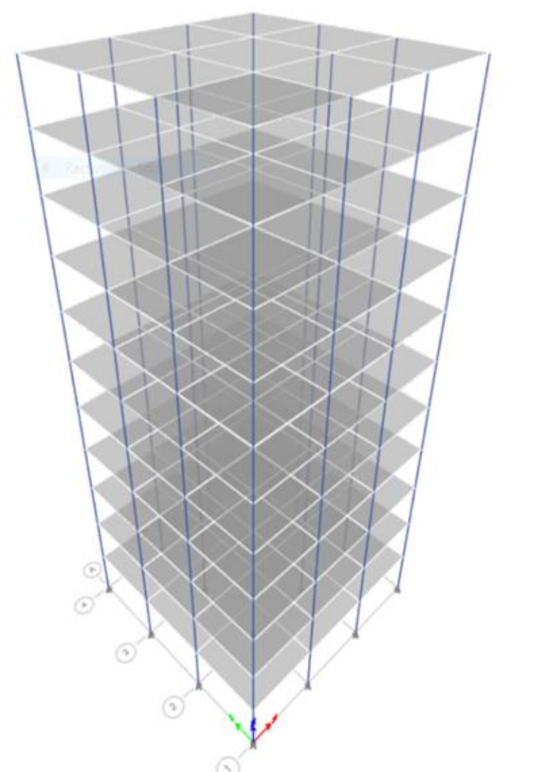

Figure 2: Three dimension view for Mid rise building

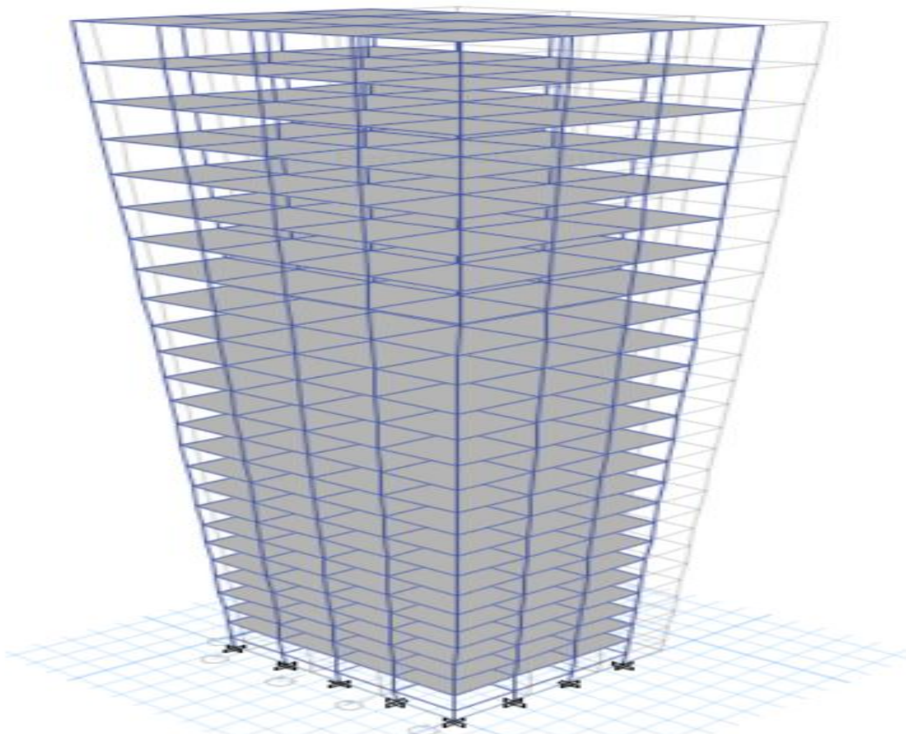

Figure 3: Three dimension view for High rise building

Table 2 Material property and other details

Type of buildings	Low rise building, Mid rise building, High rise building
Type of building	Multi-purpose commercial building
Total area of building	15m*15m (low rise, mid rise), 12m*16m (high rise)
Considered loads	Live load, Static load and earthquake load
Type of structure	SMRF (Special Moment Resisting Frame)
Seismic zone: Zone 5 [Z=0.36]	Soil condition: Medium stiff
Grade of cement: M30	Grade of steel: Fe500

Table:3 Earthquake details

Sl No	Considered Earthquakes	Magnitude of earthquake	Location
1	Bhuj earthquake	7.7	Gujarat, India
2	Chamolli earthquake	6.8	Uttarkhand, India
3	El Centro earthquake	6.9	Imperial Country California
4	Newhall earthquake	6.6	Santa Clarita, California
5	Petrolia earthquake	7.2	Humboldt, California
6	Yermo earthquake	7.3	San Bernardino, California

Table:4 Structural details of a buildings

Description	Low rise building	Mid rise building	High rise building
Total no of stories	G+3	G+11	G+24
Total height of Structure	12m	36m	75m

Beam size	250*300mm	400*450mm	450*550mm (Main beams) 250*350mm (secondary beam)
Column size	300*300mm	450*450mm	350*350mm (from 12th floor) 450*450mm (from base to 11th floor) 250mm*250mm(interior column)
Building area	15*15m	15*15m	16*12m
Slab thickness	150mm	150mm	150mm

III. RESULTS AND DISCUSSION

- Bhuj earthquake

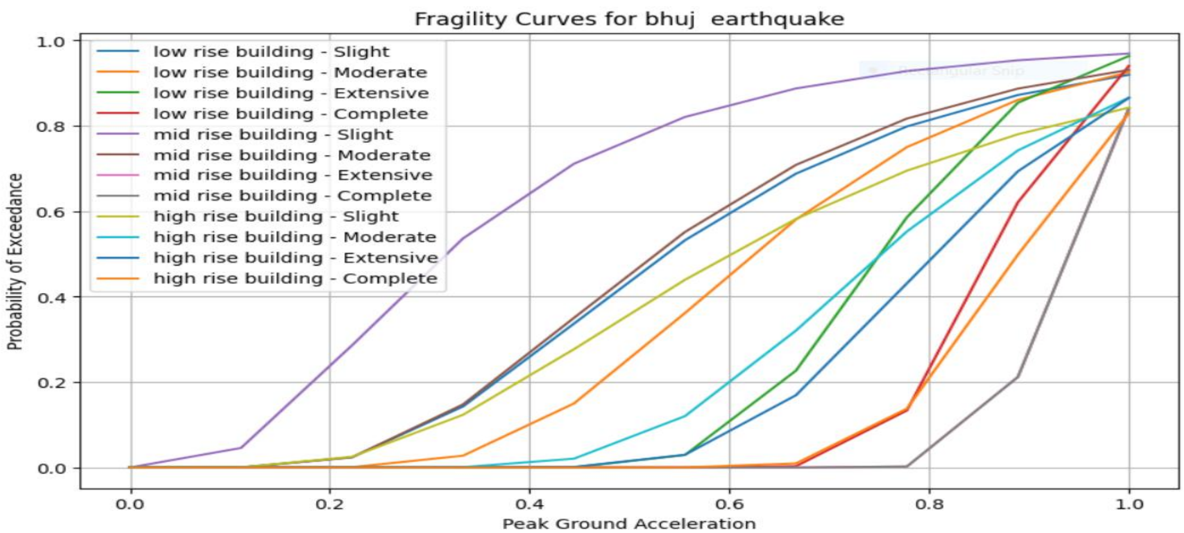

Figure 4: Fragility curve for bhuj earthquake

Figure 4 explains that Low rise building experience 92% slight damage, 73% moderate damage, 55% of extensive damage and 31% of complete collapse. Mid rise building experience 96% slight damage, 92% moderate damage and 29% of complete collapse. High rise building experience 92% slight damage, 62% moderate damage,50% of extensive damage and 28% of complete collapse.

- Chamolli earthquake

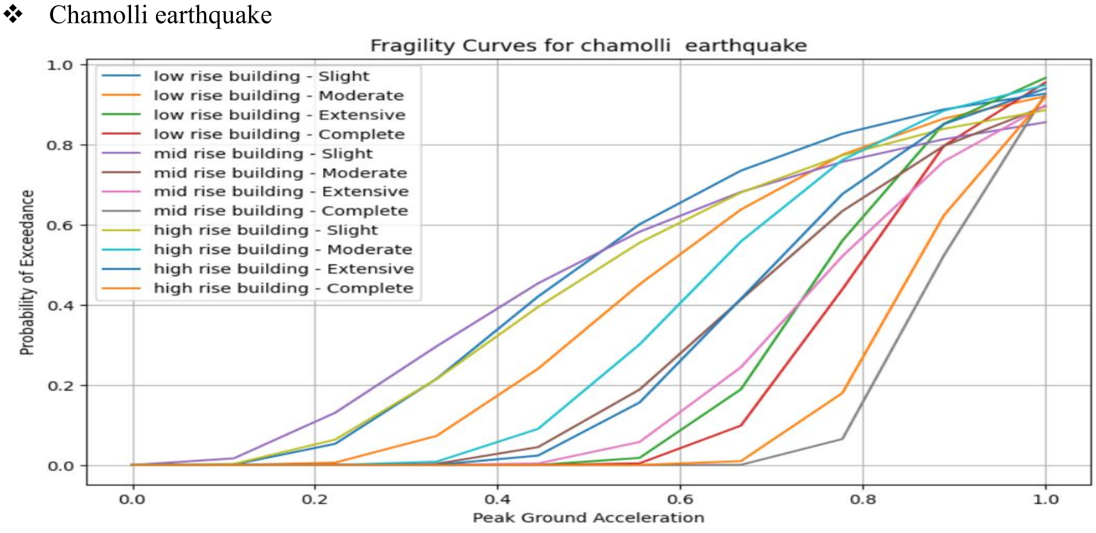

Figure 5: Fragility curve for chamolli earthquake

Figure 5 explains that Low rise building experience 95% slight damage, 70% moderate damage, 59% of extensive damage and 33% of complete collapse. Mid rise building experience 96% slight damage, 63% moderate damage, 58% of extensive damage and 31% of complete collapse. High rise building experience 90% slight damage, 78% moderate damage, 50% of extensive damage and 41% of complete collapse.

❖ El centro earthquake

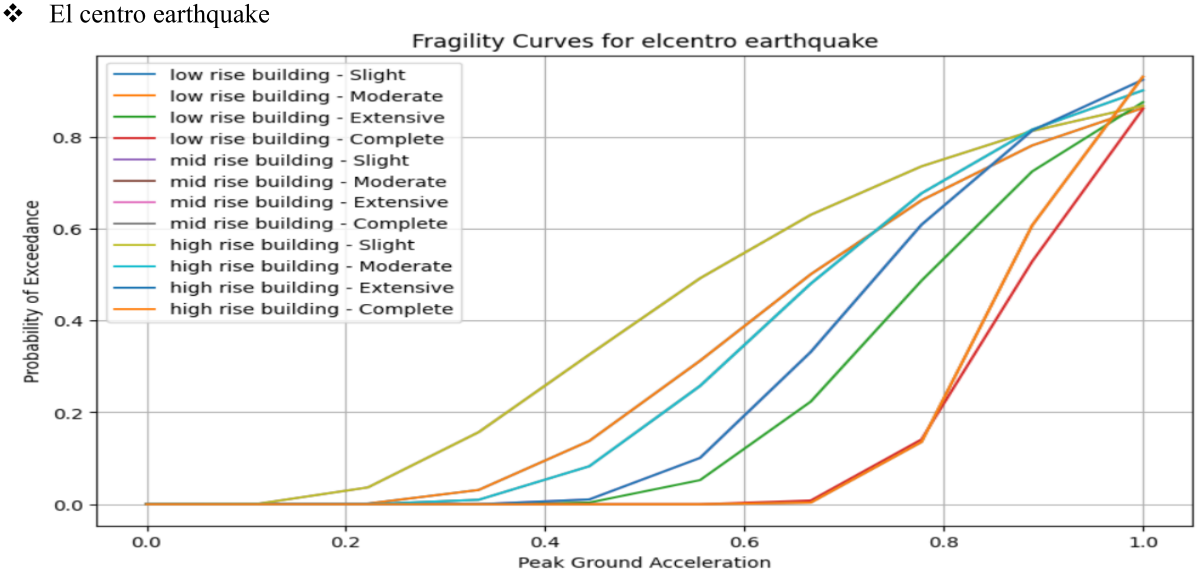

Figure 6: Fragility curve for elcentro earthquake

Figure 6 explains Low rise building experience 88 % slight damage, 70% moderate damage, 60% of extensive damage and 32% of complete collapse. Mid rise building experience 90% slight damage, 78% moderate damage, 50% of extensive damage and 31% of complete collapse. High rise building experience 95% slight damage, 86% moderate damage, 58% of extensive damage and 35% of complete collapse.

❖ Newhall earthquake

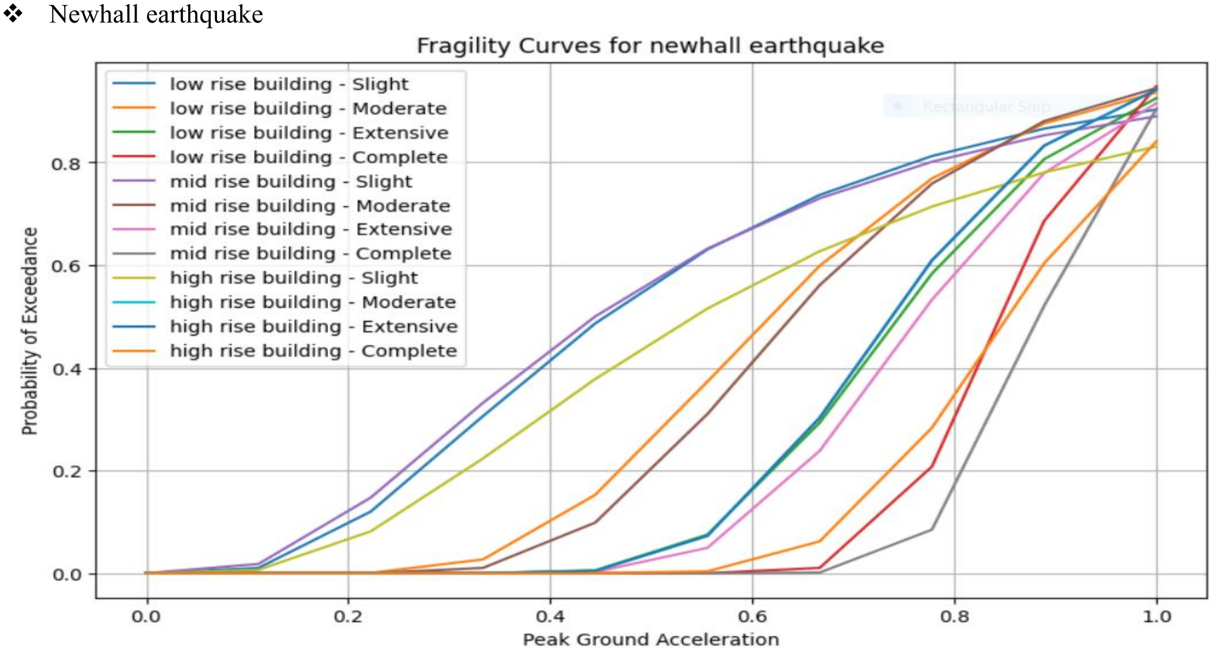

Figure 7: Fragility curve for newhall earthquake

Figure 7 explains Low rise building experience 95% slight damage, 73% moderate damage, 58% of extensive damage and 33% of complete collapse. Mid rise building experience 92% slight damage, 70% moderate damage, 56% of extensive damage, and 30% of complete collapse. High rise building experience 90% slight damage, 50% of extensive damage, and 41% of complete collapse.

❖ Petrolia earthquake

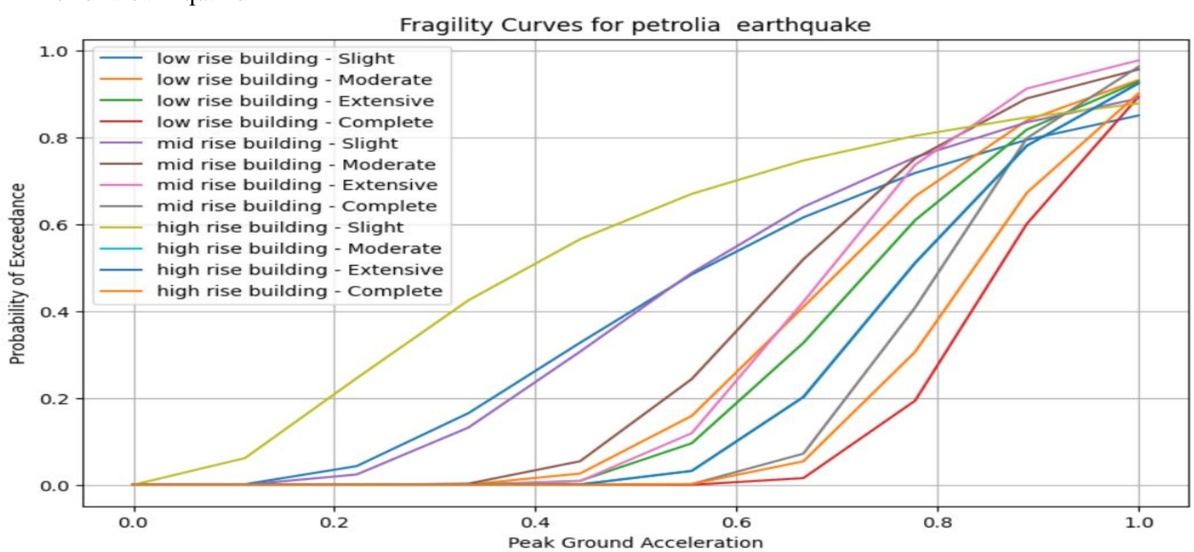

Figure 8: Fragility curve for petrolia earthquake

Figure 8 explains Low rise building experience 89% slight damage, 61% moderate damage, 59% of extensive damage. Mid rise building experience 88% slight damage, 66% moderate damage, 58% of extensive and 41% of complete collapse. High rise building experience 96% slight damage, 58% of extensive and 31% of complete collapse.

❖ Yermo earthquake

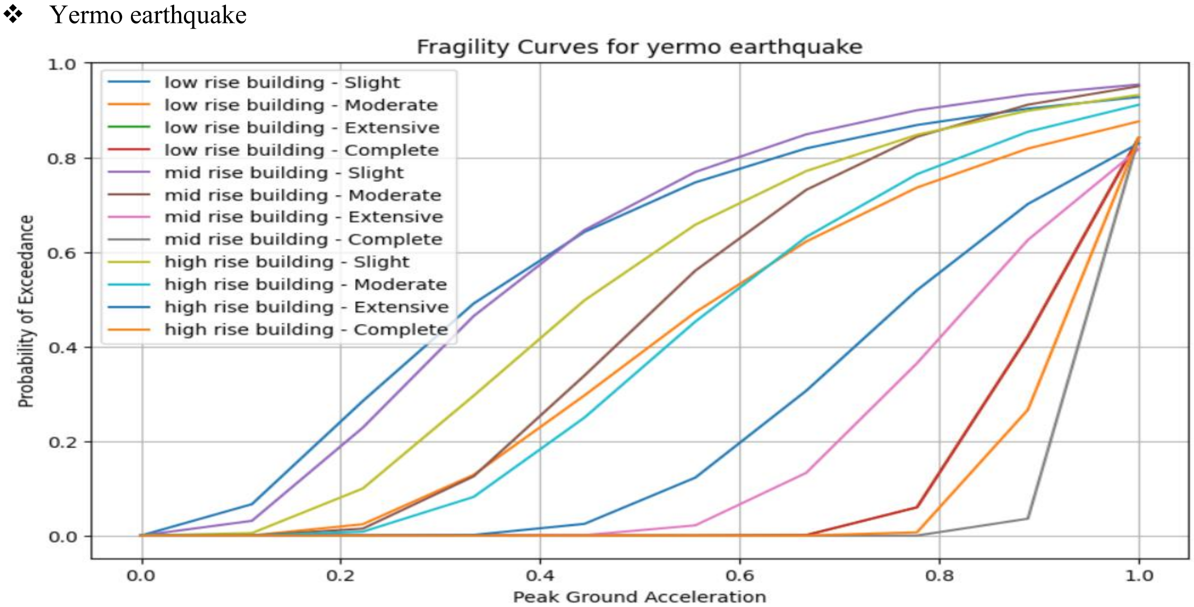

Figure 9: Fragility curves for yermo earthquake

Figure 9 explains Low rise building experience 98% slight damage, 82% moderate damage and 31% of complete collapse. Mid rise building experience 90% slight damage, 78% moderate, 56% of extensive damage and 38% of complete collapse. High rise building experience 90% slight damage, 80% moderate, 62% of extensive damage and 26% of complete collapse.

IV. CONCLUSIONS

A regular Special Moment-Resisting Frame (SMRF) structure was analyzed, and fragįlįty curves were generąted fōr six different earthquakes of varying magnitudes. The analysis was conducted using Python, executed on Google Colab, to produce the fragility curves. The percentage ōf structurąl damąge increased based on the quality of construction materials and other factors beyond seismic action. The fragility graph was plotted using base shear values, a critical measure of a building's seismic demand. Key findings from the analysis are as follows:

- A comparison of damage probabilities for earthquakes of different magnitudes reveals that as ground motion and acceleration increase, the probability of damage also rises. Higher base shear can lead to building collapse.
- Story displacement, story drift, and story shear values across buildings of different heights exhibit approximately 5% variation when subjected to earthquakes of varying magnitudes.
- Based on fragility curves, the study concludes that the Bhuj earthquake (magnitude 7.7) offers 58% safety, Chamoli earthquake (magnitude 6.8) offers 64% safety, El Centro earthquake (magnitude 6.9) provides 65% safety, Newhall earthquake (magnitude 6.6) offers 58% safety, Petrolia earthquake (magnitude 7.2) provides 64% safety, and Yermo earthquake (magnitude 7.3) offers 61% safety.
- Despite its higher magnitude, the Bhuj earthquake presents lower safety levels, similar to the Newhall earthquake, which has a lower magnitude.
- The probability of slight damage is more prevalent in low-rise, mid-rise, and high-rise structures, while the probability of extensive damage is significantly higher in high-rise buildings, with lower occurrences in low-rise structures.

ACKNOWLEDGMENTS

- I express my gratitude to our Guide Dr. C M RAVI KUMAR for giving me constant encouragement, support and valuable guidance throughout the course of the DISSERTATION WORK without whose stable guidance this presentation would not have been achieved.
- I also express my gratitude to our Co-Guide PRUTHVIRAJ S R for giving me constant encouragement, support and valuable guidance throughout the course of the DISSERTATION WORK without whose stable guidance this presentation would not have been achieved.
- I express whole-hearted gratitude to Dr. K. MANJUNATHA who is our respectable Head of the Department of Civil Engineering. I wish to acknowledge his help who made my task easy by providing with her valuable help and encouragement.
- I would like to extend my gratitude to all staff and non-teaching staff of the Department of Civil Engineering for the help and support rendered to me. I have benefited a lot from the feedback, and suggestions given by them.

REFERENCES

[1] Bakalis, K., & Vamvatsikos, D. (2018). Seismic fragility functions via nonlinear response history analysis. Journal of Structural Engineering, 144(10).doi:10.1061/(asec)st.1943-541x.0002141

[2] Baker, J. W. (2015). Efficient analytical fragility function fitting using dynamic structural analysis. Earthquake Spectra, 31(1), 579–599. www.doi.org/10.1193/021113EQS025M

[3] Bassam, A., Kosbab, B., Tehrani, P., & Ebrahimian, H. A CASE STUDY ON THE STRUCTURAL ANALYSIS AND FRAGILITY CALCULATION DUE TO SEISMIC IMPACT BETWEEN ADJACENT STRUCTURES.

[4] Efraín, J., Zamora, M., Van De Lindt, J. W., Atadero, R., & Strong, K. (2013). THESIS SEISMIC FRAGILITY ANALYSIS OF

REINFORCED MASONRY BUILDINGS Submitted.

[5] Feng, R., Wang, X., Yuan, W., & Yu, J. (2018). Impact of seismic excitation direction on the fragility analysis of horizontally curved concrete bridges. Bulletin of Earthquake Engineering, 16(10), 4705–4733. www.doi.org/10.1007/s10518-018-0400-2

[6] Hariri-Ardebili, M. A., & Saouma, V. E. (2016a). Seismic fragility analysis of concrete dams: A state-of-the-art review. Engineering Structures, 128, 374–399. www.doi.org/10.1016/j.engstruct.2016.09.034

[7] Hariri-Ardebili, M. A., & Saouma, V. E. (2016b). Seismic fragility analysis of concrete dams: A state-of-the-art review. Engineering Structures, 128, 374–399. www.doi.org/10.1016/j.engstruct.2016.09.034

[8] Kim, K., & Lee, J. (2020a). fragility of bridge columns under vehicle impact using risk analysis. Advances in Civil Engineering, 2020(1),7193919.doi:10.1155/2020/7193910

[9] Kumar C. M. R. (2016). FRAGILITY ESTIMATES FOR RC BUILDINGS.

[10] Lagaros, N. D. (n.d.). PROBABILISTIC FRAGILITY ANALYSIS: A TOOL FOR ASSESSING DESIGNED RULES OF RC BUILDINGS.

[11] Martins, L., Silva, V., Crowley, H., & Bazzurro, P. (n.d.). Investigation of Structural Fragility for Risk-targeted Hazard Assessment.

[12] Ramesh B M., Manjunatha, K., & Ravikumar, C.M. (2023). Seismic Fragility Estimates of Regular and Irregular Structures with Different Soil Conditions Using Time History Analysis. IUP Journal of Structural Engineering, 16(3), 24-56.

[13] B of Indian Standards, B. (n.d.-a). IS 456 (2000): Plain and Reinforced Concrete - Code of Practice.

[14] B of Indian Standards, B. (n.d.-b). IS 875-1 (1987): Code of Practice For Design Loads (Other Than Earthquake) For Buildings And Structures, Part 1: Dead Loads - Unit Weights of Building Material And Stored Materials (Incorporating IS 1911 : 1967).

[15] Patel, S. A., Darji, A. R., Parikh, K. B., & Patel, R. (2016). FRAGILITY ANALYSIS OF HIGH-RISE BUILDING STRUCTURE. In JETIR1607027 Journal of Emerging Technologies and Innovative Research (Vol. 3, Issue 7). JETIR. www.jetir.org

[16] Rajkumari, S., Thakkar, K., & Goyal, H. (2022). Fragility analysis of structures subjected to seismic excitation: A state-of-the-art review. In Structures (Vol. 40, pp. 303–316). Elsevier Ltd. doi.org/10.1016/j.istruc.2022.04.023

[17] Zakeri, B., Padgett, J. E., & Amiri, G. G. (2014). Fragility Analysis of Skewed Single-Frame Concrete Box-Girder Bridges. Journal of Performance of Constructed Facilities, 28(3), 571–582. https://doi.org/10.1061/(asce)cf.1943-5509.0000435