PLOTTING OF HAZARD CURVE FOR A CITY

A DISSERTATION

SUBMITTED IN PARTIAL FULFILMENT

OF THE REQUIREMENTS FOR THE AWARD

OF DEGREE

OF MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

Submitted By

GAURAV FULARA

(2K20/STE/08)

Under the Supervision of

Associate Prof. G.P. Awadhiya

DEPARTMENT OF CIVIL ENGINEERING

(Formerly Delhi College of Engineering)

DELHI TECHNOLOGICAL UNIVERSITY

Bawana Road, Delhi-110042

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CANDIDATE'S DECLARATION

I, Gaurav Fulara, Roll No. 2K20/STE/08 student of M.Tech (Structural Engineering), hereby declare that the project dissertation titled "PLOTTING OF HAZARD CURVE FOR A CITY" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi GAURAV FULARA

Date:

CERTIFICATE

I hereby certify that the Project Dissertation titled “PLOTTING OF HAZARD CURVE FOR A CITY” which is submitted by GAURAV FULARA, Roll No. 2K20/STE/08, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this university or elsewhere.

Place: Delhi

Date:

Associate Professor

G.P. Awadhiya

ACKNOWLEDGEMENT

I sincerely take this opportunity to acknowledge the debt of gratitude, that I owe to my supervisor Associate Prof. G.P. Awadhiya for her consistent guidance throughout the journey. He has helped me by means of his vast knowledge and expertise of the course content.

He provided the desired impetus when things were not turning in the favour, which really helped me to achieve the anticipated goals within a given time frame. It is my fortune that, I got an opportunity to work under her guidance for both of my Major Projects. I wish that my learning under his guidance continues forever.

At the last, I would like to extend a token of thanks to my parents, whose uninterrupted efforts have been a constant motivation throughout the journey.

GAURAV FULARA

ABSTRACT

In the present era, earthquake has become a serious disaster. Proper designing of a building for earthquake must be done, otherwise it would to serious loss of life and property. Although complete safety from earthquake cannot be ensured, as it would become highly uneconomical. But we can assure safety from earthquake up to some degree. It is highly uncertain to predict the occurrence of future earthquakes. Because occurrence of some earthquakes might be unexpected. Various methods like Probabilistic Seismic Hazard Analysis and Deterministic Seismic Hazard Analysis are developed but they both have their own merits and demerits. In this Thesis, Hazard is plotted for a city using USGS (United States Geological Survey) method. USGS method plots the hazard curve for given edition, location, spectral period and site class. After that Fragility curve is being plot for a Reinforced Concrete 4-Storey building using Lognormal distribution.Lognormal function is a two parameter function i.e. mean and standard deviation. For plotting the fragility curve, incremental dynamic analysis was carried out in ETABS Software for 12 Ground Motions. Corresponding to the ground motions, IDA(Incremental Dynamic Analysis) curves are plotted. From the IDA curves, Fragility curves were plotted corresponding to Immediate occupancy, Life Safety and Collapse Prevention damage states. After that I found the point of intersection of Hazard curve and Fragility Curve to predict the vulnerability of the Building under the earthquake.

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CHAPTER 1

INTRODUCTION

Any incident that has the potential to inflict death or property harm is considered a hazard. Hazard may be of many types like natural and anthropogenic. Natural Hazards include flood, cyclone, earthquake, tsunami etc. Anthropogenic Hazards include blasting etc. Hazards like earthquake are rare but highly dangerous. India has witnessed various disastrous earthquakes like Kashmir(2005),Gujarat(2001),Kangra(1905) which caused serious damage to life and property. This shows that designing a building earthquake resistant is of utmost importance. Although we can't fully safeguard the building from earthquake, we can safeguard the building upto some degree. We can't prevent the possible ground displacement during an earthquake but we can construct various man made structures which can mitigate the damage to buildings or any other structures. As a result of growing population various man made structures are needed like houses, dams, reservoirs, roads etc. Unless these structures are properly engineered and maintained, there could be serious loss of life and property during an earthquake. Hence the need of Hazard and Fragility Curves came into picture.

There is a serious concern about the safety of man-made structures during an earthquake. Engineers shall not only be concerned about the safety of new structures but they should also be concerned about the safety of old and existing structures. Hence adequate Seismic Hazard Analysis should be performed in order to safeguard the buildings from future earthquakes. This damage can be predicted using the past data. For this, Time Period, Site Condition and Peak ground acceleration data is a must.

1.1 Organisation of Thesis

The Dissertation titled **“PLOTTING OF HAZARD CURVE FOR A CITY”** is composed of six chapters, Bibliography and list of Publications. Following are the chapters

Chapter 1 consists of Introduction, objectives.

Chapter 2 Consists of Literature Review

Chapter 3 consists of introduction to Hazard and Fragility Curve.

Chapter 4 explains the different methods for seismic Hazard analysis.

Chapter 5 contains methodology to plot Hazard and Fragility curve.

Chapter 6 contains Results, Discussions and Conclusions.

References of the literatures which have been referred in the study is also provided

1.2 Preliminaries

1.2.1 Recurrence Interval

In general, Return Period or Recurrence interval means Time period on an average after which an event is expected to occur at least once. Suppose return period of an event is 100 years, this means that on an average this event will occur at least once in 100 years. Generally buildings have a design life of 100 years while monuments may last up to 150 years or more. We try to design the building considering the return period of the occurrence of earthquake. In this report, Hazard curve is plotted for 2% probability of exceedance in 50 years.

Return period is a must for constructing the Hazard curve and accordingly the building may be designed.

1.2.2 Site Class

Site class is an important factor to be considered for constructing the Hazard curve. Here, site class denotes the ground conditions i.e. whether it is hard rock, medium hard rock, soft soil or very soft soil. Site class is classified on the basis of average shear wave velocity. When shear wave velocity cannot be observed, adequate generalised relationships between shear wave velocity and standard penetration test (SPT) blow counts, Cone Penetration Test (CPT) tip resistance, shear strength, or other geotechnical parameters must be employed to estimate shear wave velocity.

Following Table shows the site class corresponding to different shear velocities.

Site Class	Shear wave velocity Profile
A. Hard Rock	>1524m/s
B. Medium Hard Rock	>915 to 1524m/s
BC. Soft Rock	>640 to 915m/s
C. Very dense sand or hard clay	>442 to 915m/s
CD. Dense sand or very stiff clay	>305 to 442m/s
D. Medium dense sand or stiff clay	>213 to 305m/s

DE. Loose sand or medium stiff clay	>152 to 213m/s
E. Very loose sand or soft clay	<152m/s
F. Soils requiring site response analysis	See FEMA P-2082-1

Table 1.1 Site class corresponding to different shear velocities

1.2.3 Spectral Acceleration

Spectral Acceleration is measured in units of g(acceleration due to gravity). It is the acceleration that a structure experiences during an earthquake.The acceleration that is experience by the ground is called Peak ground acceleration. Generally we consider Peak Ground acceleration for constructing a Hazard Curve because it is more accurate, as it is independent of the type of building and depends only on the magnitude of earthquake and ground conditions.

CHAPTER 2

2.1 Literature Review

India is divided into four seismic zones (II, III, IV, and V) corresponding to zone factors of 0.1,0.16,0.24 and 0.36 respectively. Here zone II is least severe to earthquake while zone V is most severe to earthquake.

R.N. Iyengar (2004) Here, Seismic Hazard Curve was plotted for Delhi city considering 40kmX30km region using Probabilistic Seismic Hazard Analysis. Here attenuation relationship was developed to predict seismicity of earthquake.

Anbazhagan(2007) In this paper Probabilistic Hazard assessment of Bangalore was carried out as a part of project national level microzonation programme. Here maximum considered earthquake has been determined considering a radius of 350km around Bangalore city. Here PGA is calculated for different source and moment magnitude by calculating shortest distance from Bangalore.

Ravikant Singh(2018) Here the author has plotted fragility curve for Reinforced Concrete building and increased the number of storeys to study the changes in fragility curve due to change in storeys. Time history method is used in ETABS Software. Fragility curve is plotted for four damage states.

Nirav K. Patel(2020) Here the author has plotted fragility curve using HAZUS Technical Manual. Here the fragility curve is plotted for Reinforced Concrete three storey(for short period), six storey(medium period) and 12 storey(high period). SAP 2000 Software is used to plot the curve.

Koktong Tan(2014) Here the fragility curve is plotted for 3 storey moment resisting frame. Here the building is subjected to a small number of ground motions. After that the fragility curve is plotted corresponding to each ground motions. Here the fragility curve is plotted for slight, moderate and extreme damage states.

K.A. Korkmaz(2008) Here the fragility curve for Reinforced concrete buildings is plotted using Monte Carlo simulations. Here the behaviour of structures using probabilistic seismic assessment has been evaluated. Also, here the comparison is done between monte carlo simulation and analytical analysis.

Aslan S. Hokmabadi(2012) In this paper a G+14 concrete moment resisting building is designed using Time-History functions. Then accuracy of each method in predicting inter-storey drifts under three earthquakes 1995 Kole, 1994 Northridge and 1940 El Centro are checked. The results indicate that the absolute maximum drift over time should be calculated. Other methods results in unconservative design.

Amin Gholizad(2014) Here the fragility curve is plotted for mid rise reinforced concrete frames according to Iranian design seismic code. Here the four, six and eight storey buildings were designed. Incremental dynamic analysis was carried out for these buildings to determine maximum interstorey drifts. Based on the above results fragility curve was plotted for immediate occupancy and life safety damage states using lognormal distribution.

Jahangir Alam(2017) Here the fragility curve is plotted for Reinforced concrete buildings using Pushover analysis. After that seismic fragility parameters is calculated using results from pushover analysis. Now the seismic hazard and seismic fragility curve for a site are integrated to assess the seismic risk of structure.

Megha Vasavada(2016) Here the fragility curve for a building is developed for reinforced concrete building using analytical approach. Guidelines from Hazus Technical manual was used and performance of two ten storey reinforced concrete buildings were compared.

Pratima Patel(2018) Here the fragility curve is plotted for asymmetric reinforced concrete buildings. Here two building models were selected. Buildings were modelled using SAP 2000 software. Incremental dynamic analysis was carried out was fifteen ground motions and they were scaled to give comparable IDA results. Fragility curves were developed for immediate occupancy, life safety and collapse prevention limit states for buildings in both X and Y directions. It was observed that presence of infill increases the capacity of building.

Fadzli Mohamed Nazri(2015) In this paper the fragility curves for steel and concrete frames were plotted from near and far field ground motion records. Incremental dynamic analysis was used. The five performance levels were taken from FEMA 273.

Chu Mai(2017) Using Monte Carlo simulation and Kernel density estimation, the fragility curve is displayed. Using a large number of synthetic ground motions, a fragility curve for a three-story steel frame is plotted. Non-parametric curves were also compared to lognormal distribution curves.

Jack W. Baker(2015) In this paper the applicability of statical interference concepts for fragility function estimation is discussed. This paper also approaches to provide alternative analysis procedure that may arise in future.

Fadzli Mohamed Nazri(2016) The fragility curves for various building geometries were obtained here. For Incremental Dynamic analysis and Pushover analysis, far field ground motions were used. Operational phase, immediate occupancy, damage control, life safety, and collapse avoidance are the five building performance levels extracted from FEMA 273.

CHAPTER 3

USGS HAZARD MAPS

3.1 Introduction

In June 1996 the USGS completed new national seismic hazard maps for the conterminous United States.

Seismic Hazard Curve is a tool which is used to predict the possible damage of a region during an earthquake. Hazard Curve is a graph between Probability of exceedance and Peak Ground Acceleration.

Figure shown below shows a Sample Hazard Curve which is a plot between probability of exceedance on Y-axis and Peak Ground Acceleration on X-axis.

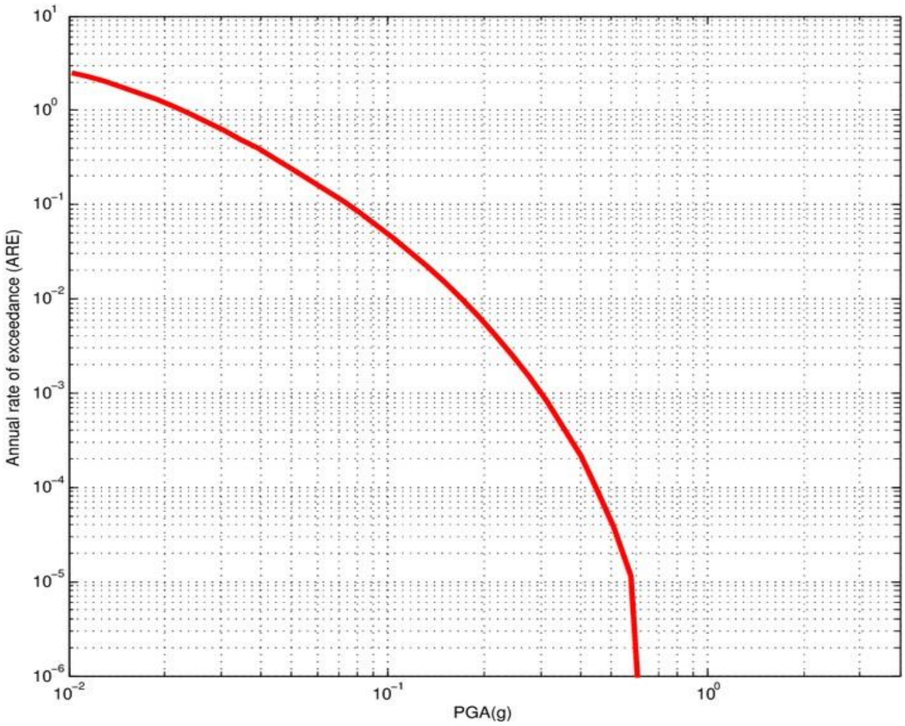


Figure 3.1 Sample Hazard Curve

Each set of the Hazard map includes maps of peak ground acceleration and spectral responses at 0.2,0.3 and 1 seconds for 10%, 5% and 2% probability of exceedance in 50years. These probabilities of exceedance correspond to return times of about 500, 1000, and 2500 years, respectively.

3.2 Response Spectra

Response Spectra is a graph between Spectral acceleration versus time period where spectral acceleration is plotted on Y-axis and Time Period on X-axis. The response spectra can be used to assess the peak response of buildings to earthquake and the buildings can be designed accordingly.

The figure given below represents a sample response spectra corresponding to any earthquake.

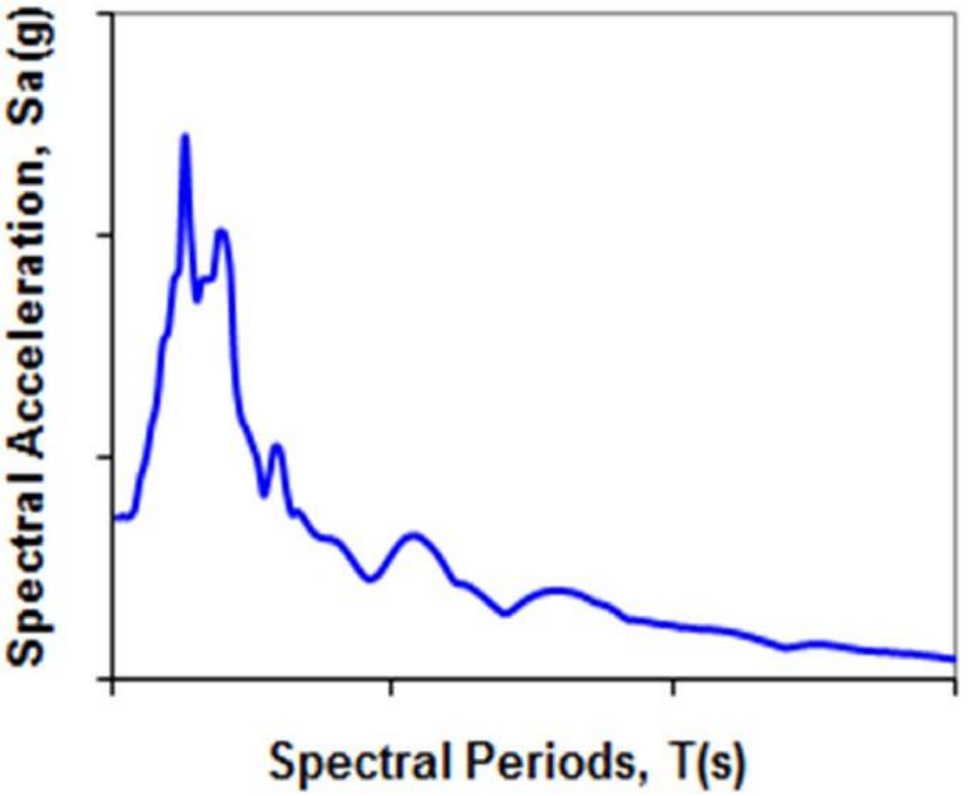


Figure 3.2 Response Spectra

3.3 Fragility Curve

Fragility curve is plotted for a particular building. It is a plot between probability of exceedance and peak ground acceleration. It is used to estimate the potential damage to a building during an earthquake. Here Fragility curve is plotted corresponding to Immediate occupancy, Life Safety and Collapse Prevention damage levels. In immediate occupancy the structure experiences very little or no damage. In Life safety significant damage is observed whereas Collapse Prevention leads to complete damage.

Figure given below shows a Fragility curve corresponding to slight, moderate, extensive and complete damage.

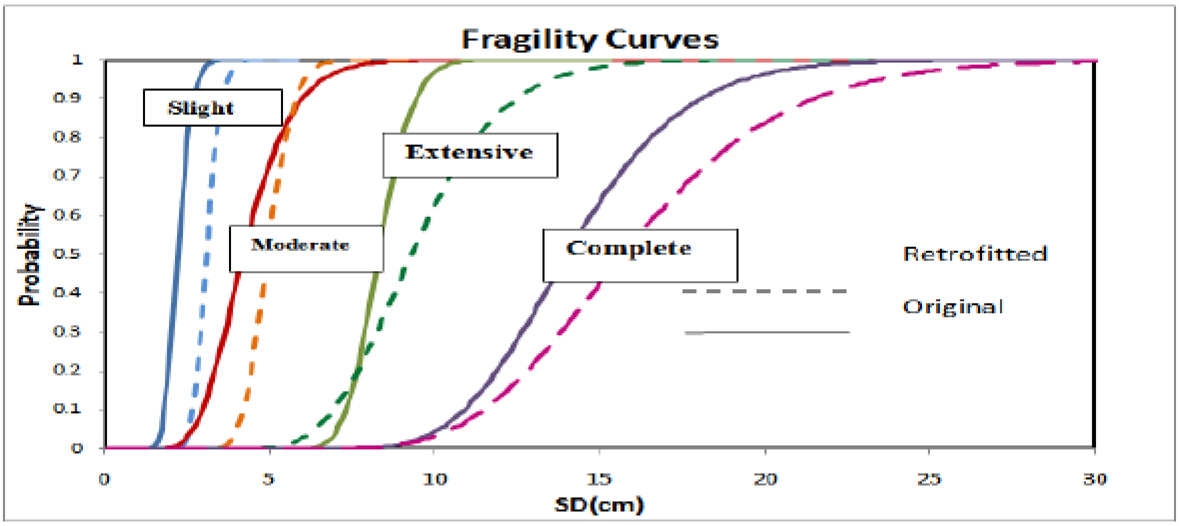


Figure 3.3 Sample Fragility Curve

CHAPTER 4

4.1 Seismic Hazard Analysis

The figure given below shows Global Seismic Hazard Map (GSHAP).

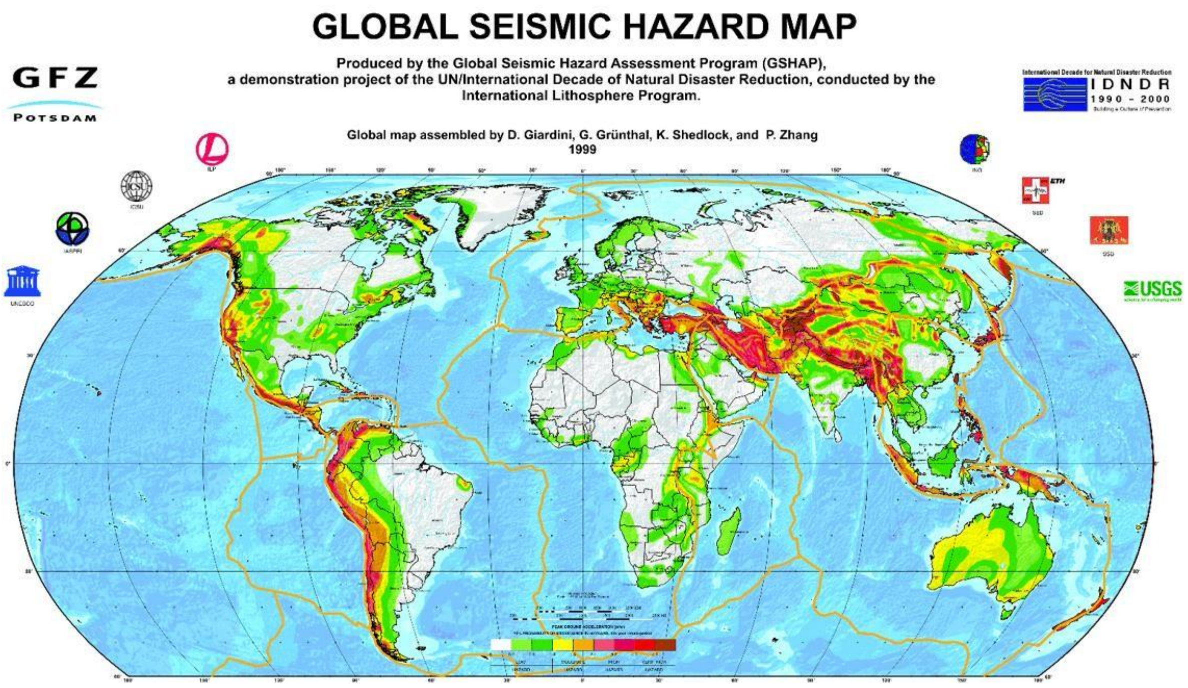


Figure 4.1 Global Seismic Hazard Map

This map was prepared using Probabilistic Seismic Hazard Analysis. This map helps to prepare earthquake catalogue, earthquake sources, seismic ground motion and computation of seismic hazard. GSHAP depicts seismic hazard as Peak ground acceleration with 10% probability of exceedance in 50 years, corresponding to a return period of 475 years.

4.2 Deterministic Seismic Hazard Analysis

Steps of Deterministic Seismic Hazard Analysis include:

1. Identification of sources of earthquake like line sources, area source etc.
2. Developing magnitude recurrence relationship, which is a plot of magnitude of earthquake versus distance from source. It is used to check the seismicity of earthquake.
3. Plotting graph between ground motion and distance.
4. Developing Seismic Hazard curve which is a relation between probability of exceedance and peak ground acceleration.

Figure given below shows step by step methods in deterministic seismic hazard analysis.

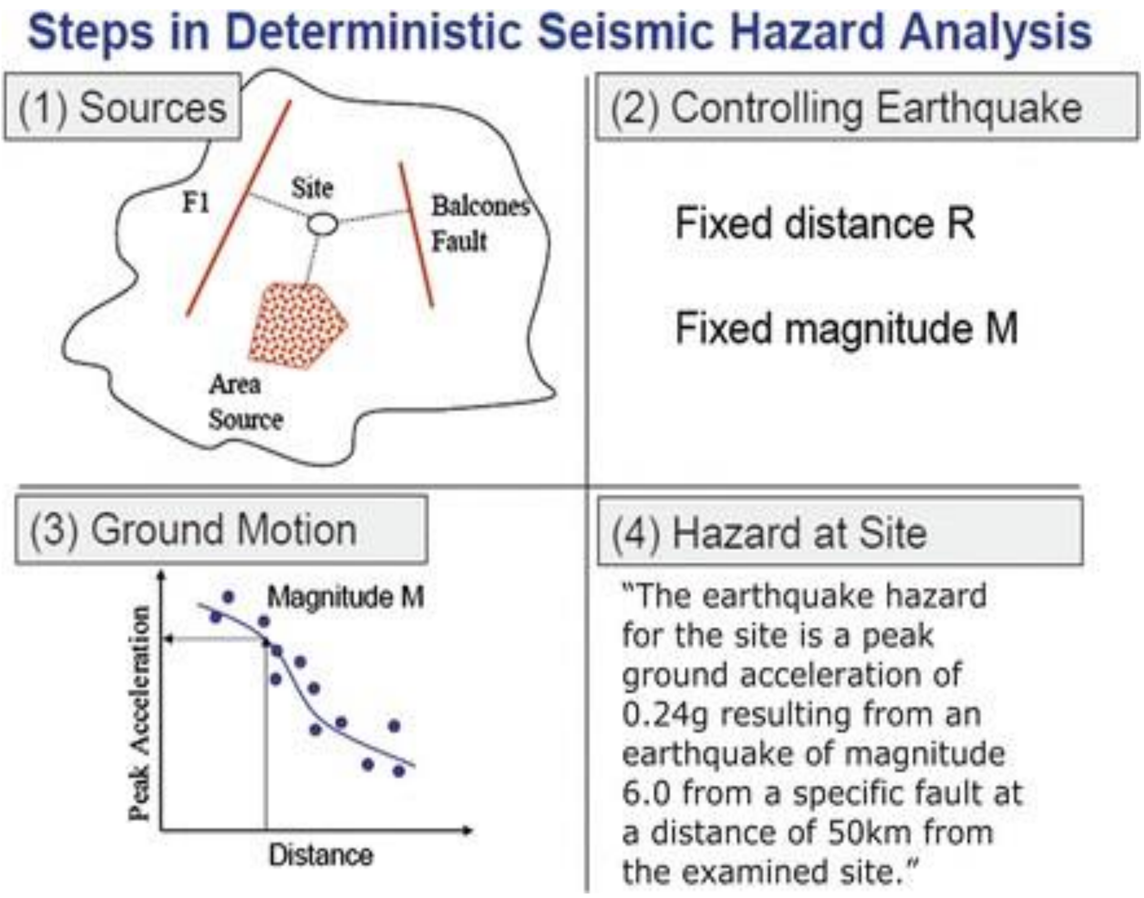


Figure 4.2 Steps in DSHA

4.3 Probabilistic Seismic Hazard Analysis

Basic steps are same in both deterministic and probabilistic seismic hazard analysis. But in probabilistic hazard analysis we take elements of uncertainty into consideration whereas in deterministic hazard analysis we select a controlling earthquake and proceed accordingly.

Figure given below shows step by step procedure in Probabilistic Hazard Analysis.

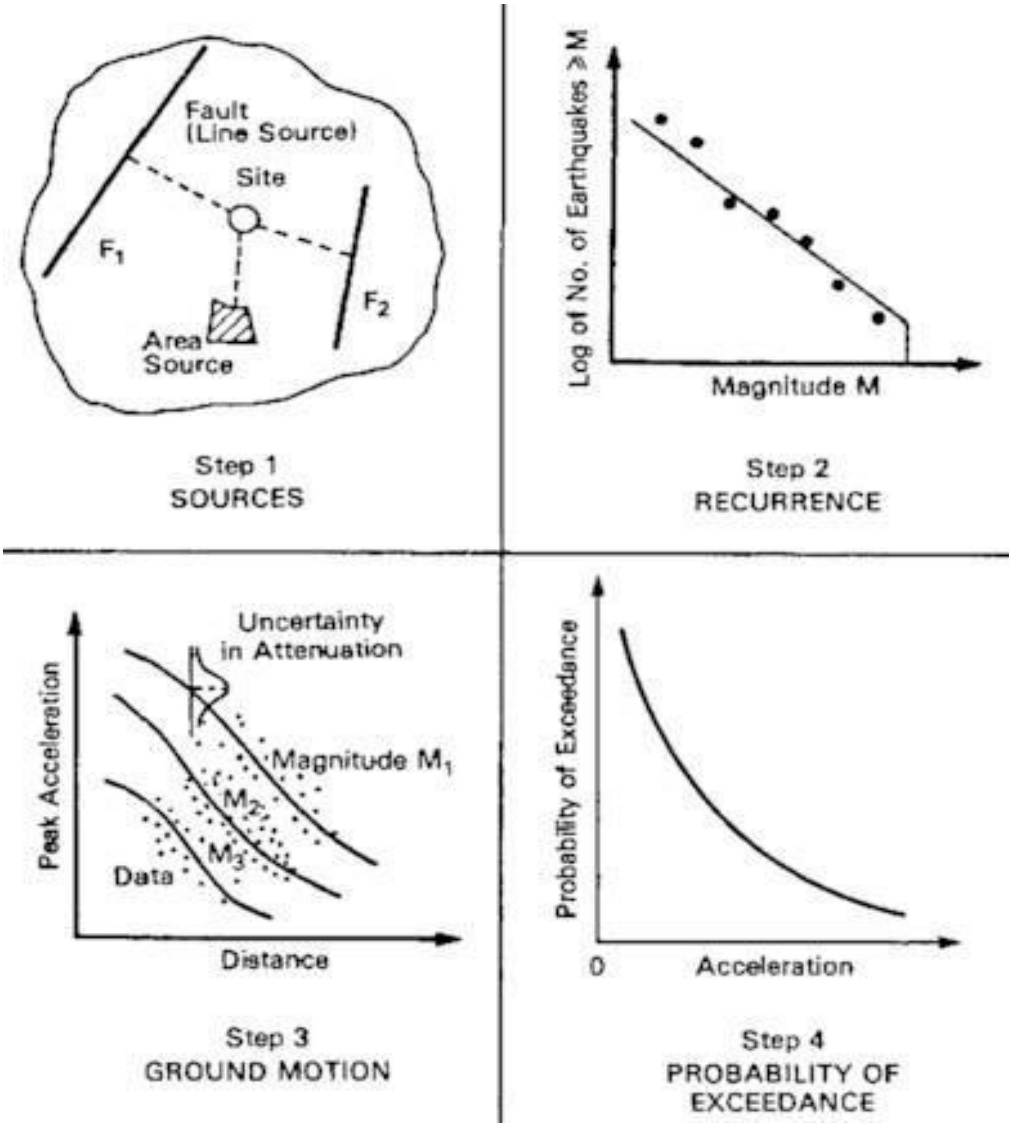


Figure 4.3 Steps in PSHA

CHAPTER 5

METHODOLOGY

We have to input the following variables to get Hazard Curve.

5.1 Edition

There are various editions present in USGS website, like Conterminous U.S. 2014, Dynamic: Conterminous U.S. 2008, Alaska 2007, Hawaii 1998, Puerto Rico and U.S. Virgin Islands, etc. These editions are developed for various places in United States to compute Hazard Curve.

5.2 Spectral Period

Here, we have to input the Spectral Period like Peak Ground acceleration, 0.1 second spectral acceleration, 0.2 second spectral acceleration etc. Generally we consider peak ground acceleration, as it better indicates the ground motions.

5.3 Location

We have to input the location to indicate that for which location we have to plot the Hazard Curve.

We can either pinpoint the location on the map or we can input the coordinates(latitude and longitude) of that place.

5.4 Time Period

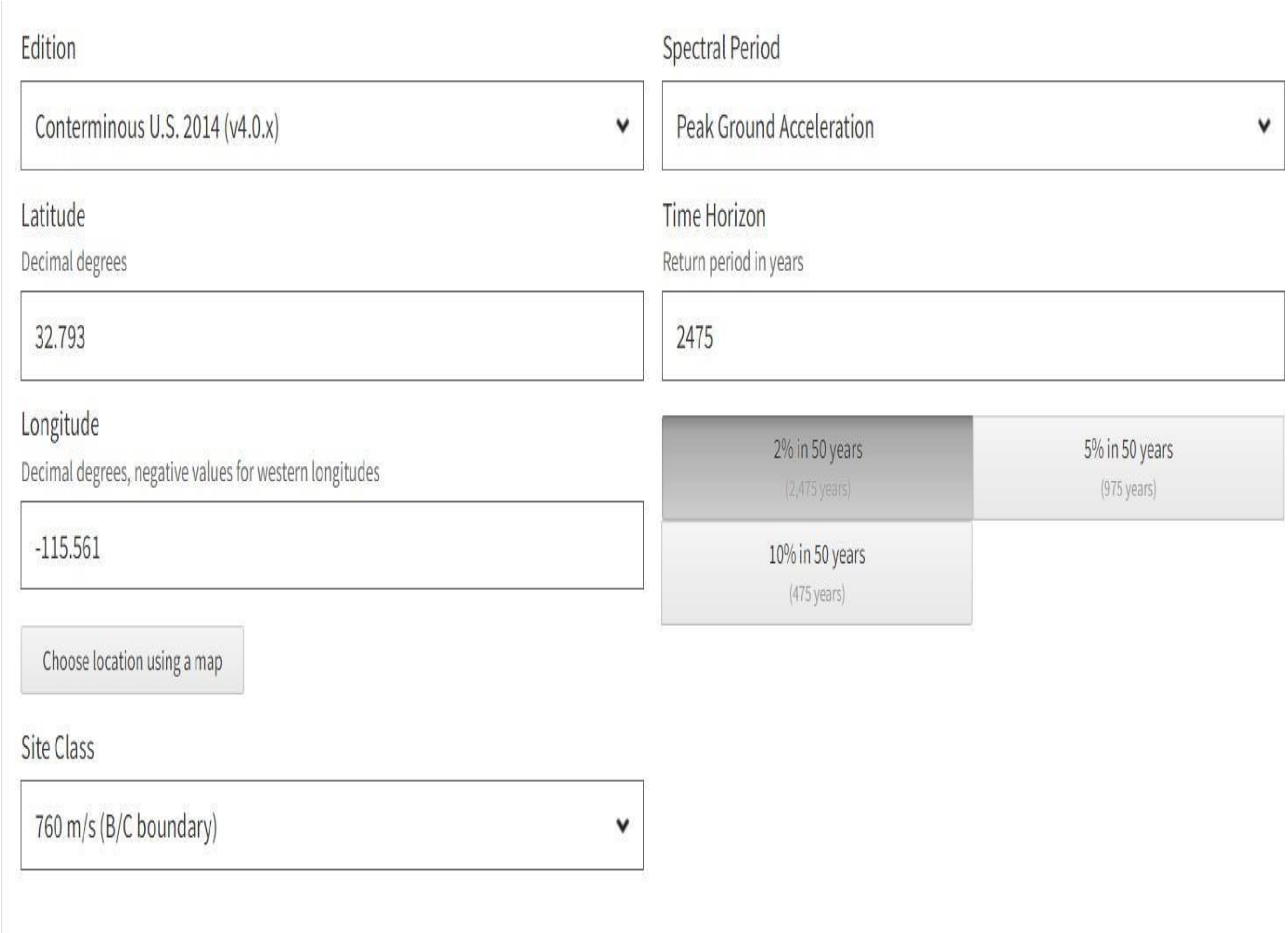
Here we have to input the Time Period. Time period is the period on an average after which an event is expected to occur at least once. We have to specify that for which time period we have to plot the curve.

5.5 Site Class

Here we have to indicate that for which site class we have to plot the curve. Site class may be Hard rock,

Medium hard rock or soft rock. Accordingly we will get the Hazard Curve.

Figure given below shows the whole methodology to plot the hazard curve and uniform hazard spectrum which can be plotted from the USGS website.



<u>Figure 5.1 Steps to plot Hazard Curve</u>

5.6 Methodology to plot Fragility Curve

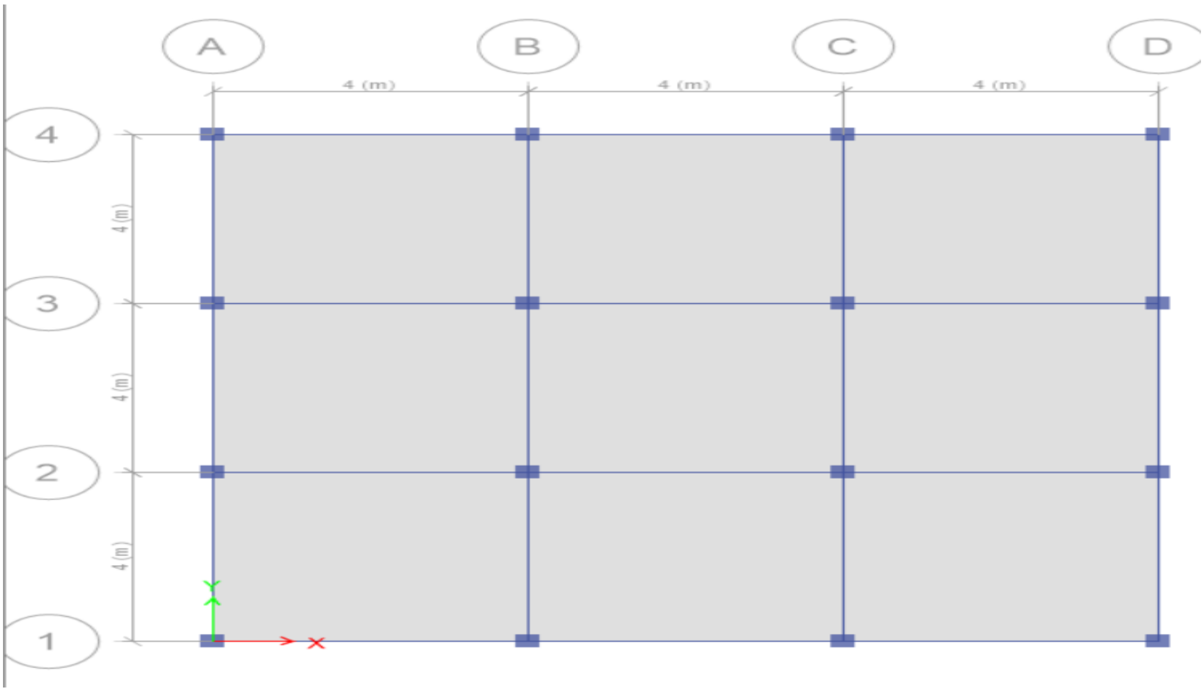
Here, for plotting the Fragility curve, Incremental dynamic analysis is used. In incremental dynamic analysis, we apply different ground motions and corresponding to these ground motions we record the storey drift of the roof of top storey. For performing incremental dynamic analysis we define Time History Functions and apply different ground motions to record the top storey drift. We apply the ground motions till the collapse of the building. After that we plot the incremental dynamic analysis curves. Incremental dynamic analysis curves are the plot between peak ground acceleration and storey drift. From these IDA Curves we note the peak ground acceleration corresponding to 1%, 2% and 2.5% drift ratio which correspond to immediate occupancy, life safety and collapse prevention damage levels. After this we plot the Fragility curves corresponding to these damage states using lognormal distribution.

Here, for plotting the fragility curves for using lognormal distribution, Ms-Excel is used.

5.7 Building Data

- Height of Building = 12m
- Type of Building is G+3 Building.
- Beam Size= 230X300mm
- Column Size= 300X300mm
- Slab Thickness= 150mm
- Concrete Grade= M30
- Steel Grade= Fe415
- Dead Load= 2.5kN/m2
- Live load= 3kN/m2

5.8 Building Modelling



<u>Figure 5.2 Plan of Building</u>

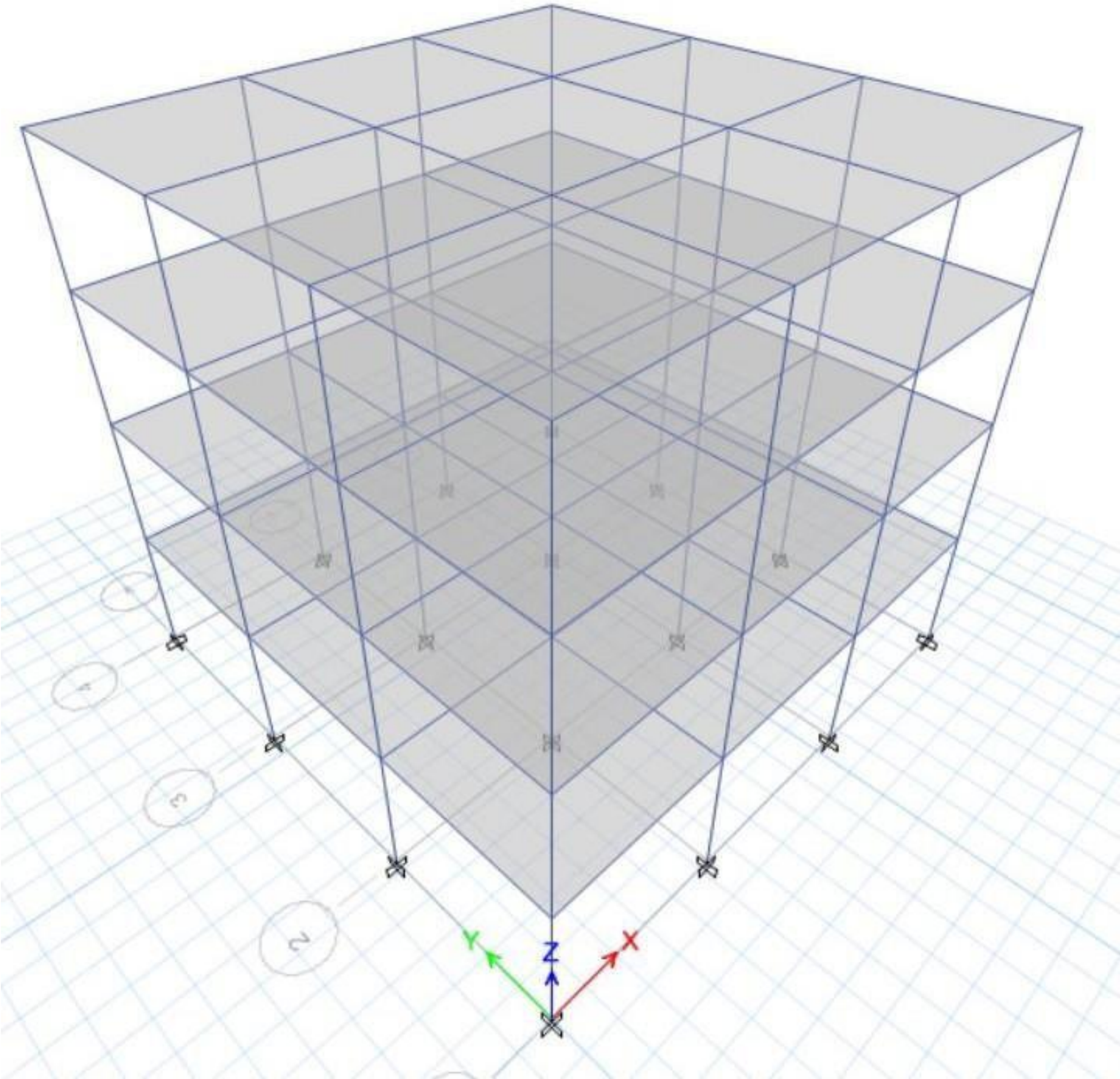
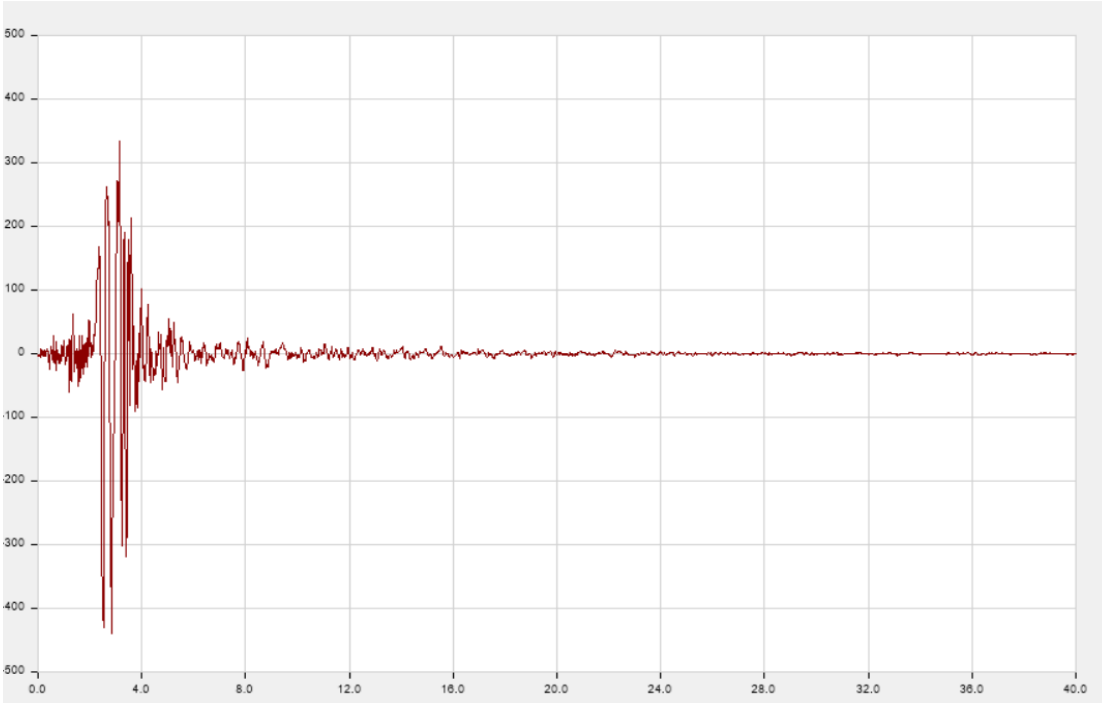


Figure 5.3 3D View of Building

5.9 Ground Motion Data

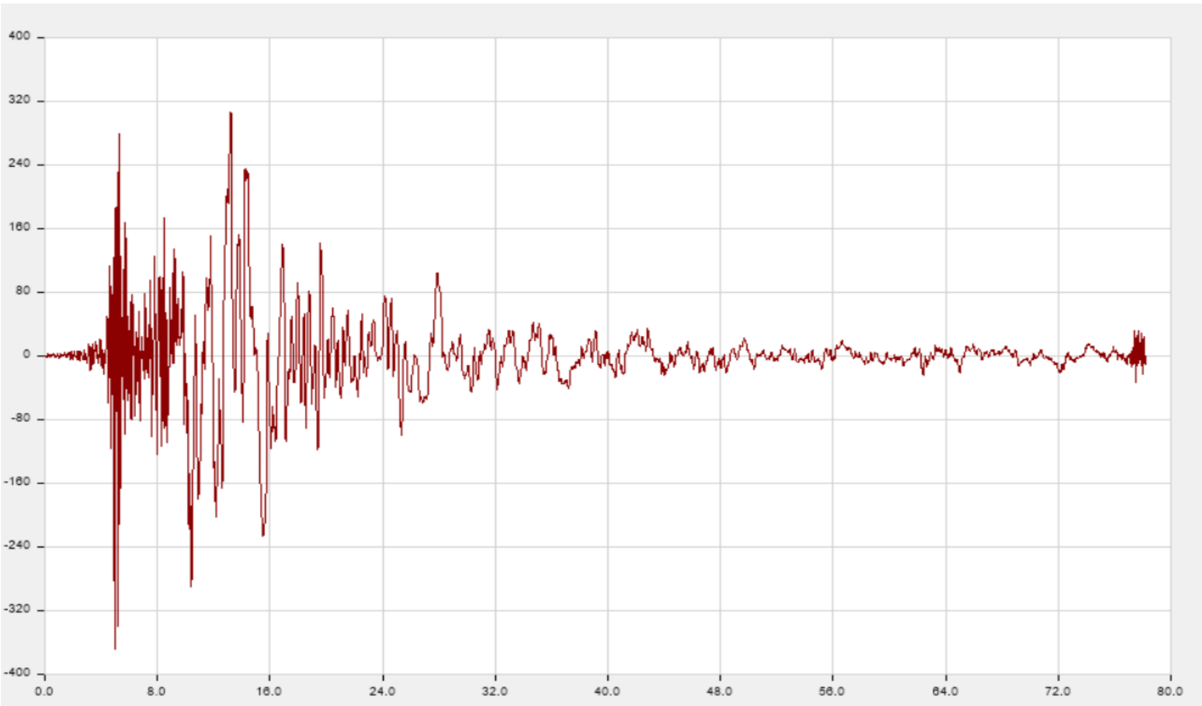
Following Ground Motion Data was considered for performing the analysis

1. ALTADENA - EATON CANYON PARK



<u>Figure 5.4 ALTADENA - EATON CANYON PARK</u>

2. EL CENTRO,ARRAY 6,HUSTON RD



<u>Figure 5.5 EL CENTRO,ARRAY 6,HUSTON RD</u>

3. CORRALITOS - EUREKA CANYON RD

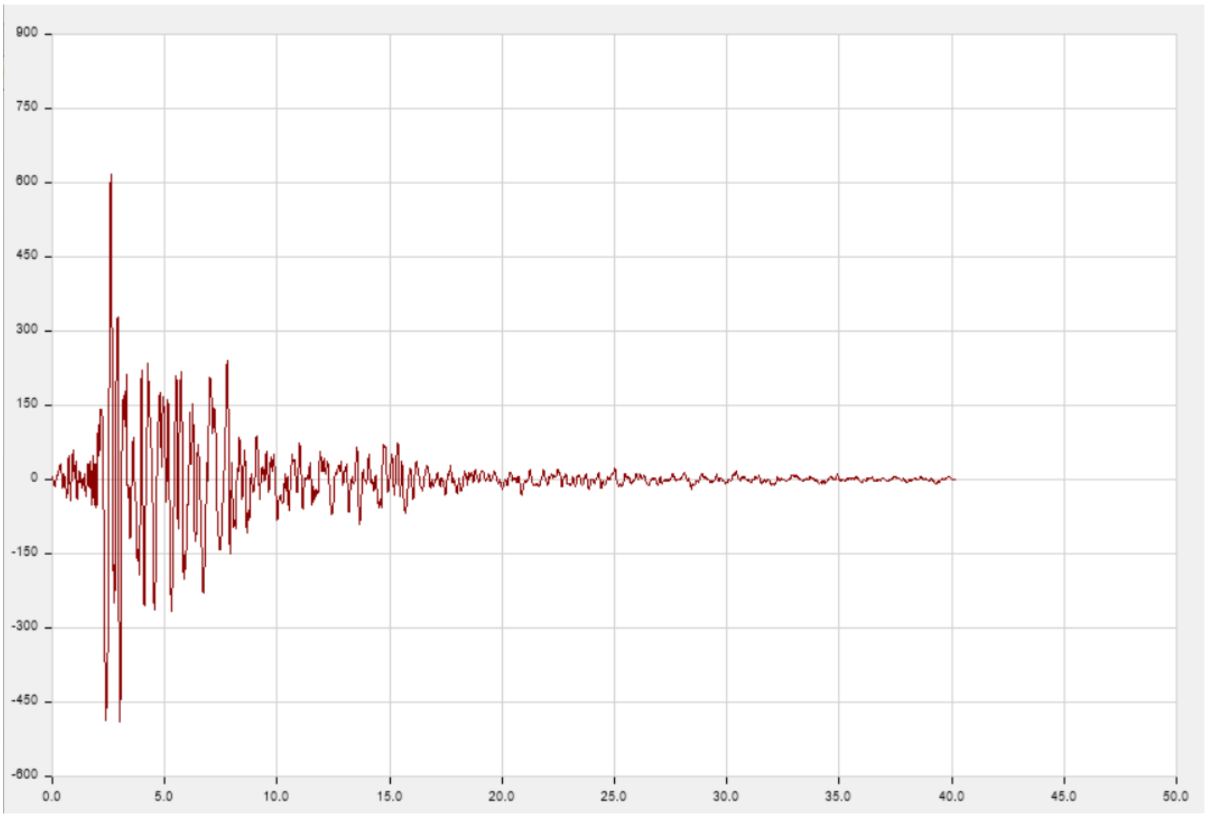


Figure 5.6 CORRALITOS - EUREKA CANYON RD

4. HOLLISTER - SOUTH STREET AND PINE DRIVE

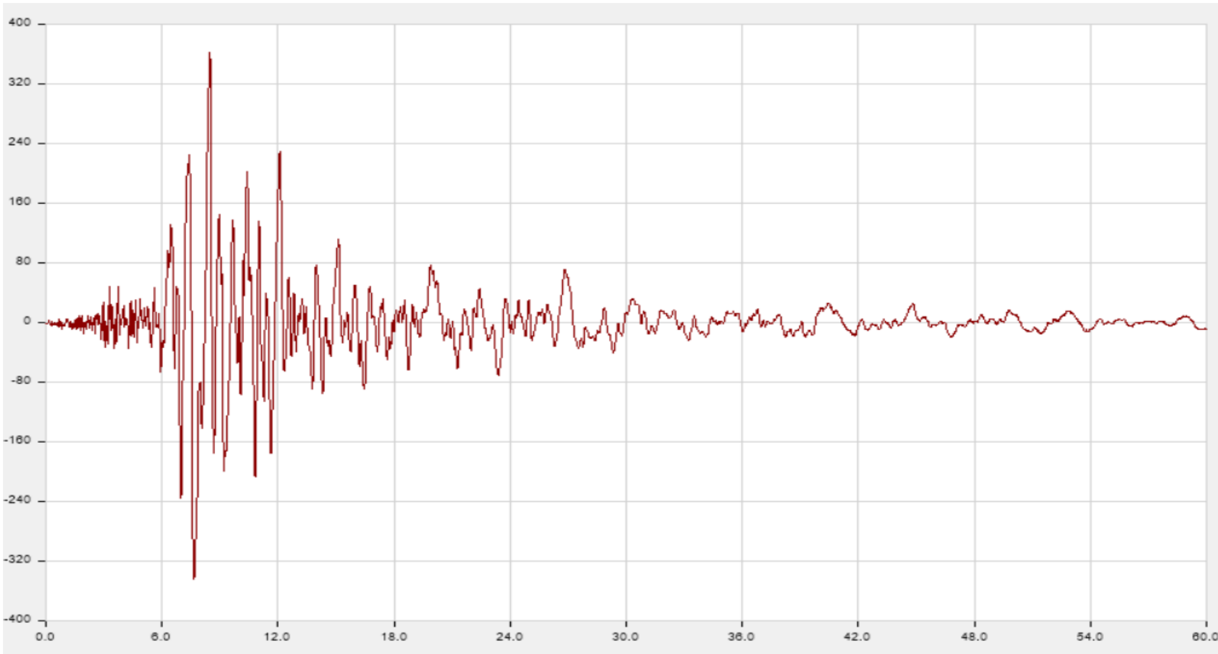


Figure 5.7 HOLLISTER - SOUTH STREET AND PINE DRIVE

5. CENTURY CITY - LACC NORTH

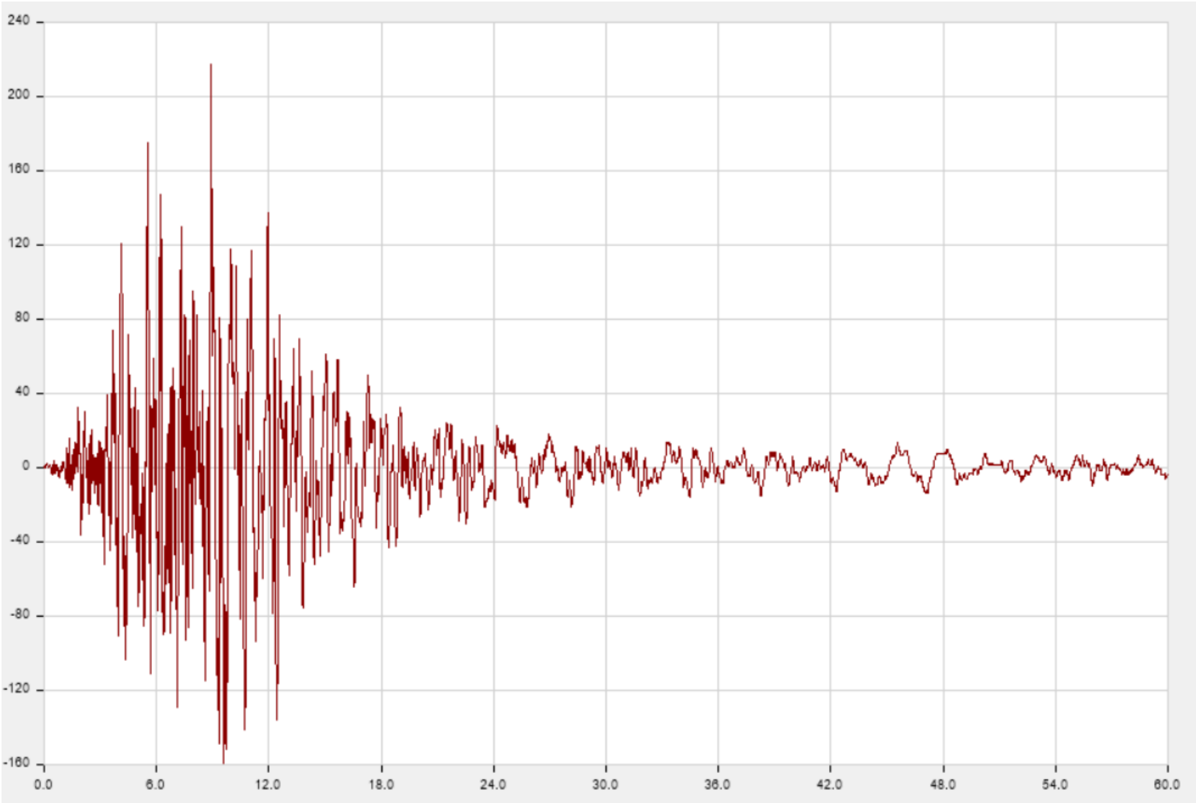


Figure 5.8 CENTURY CITY - LACC NORTH

6. LEXINGTON DAM

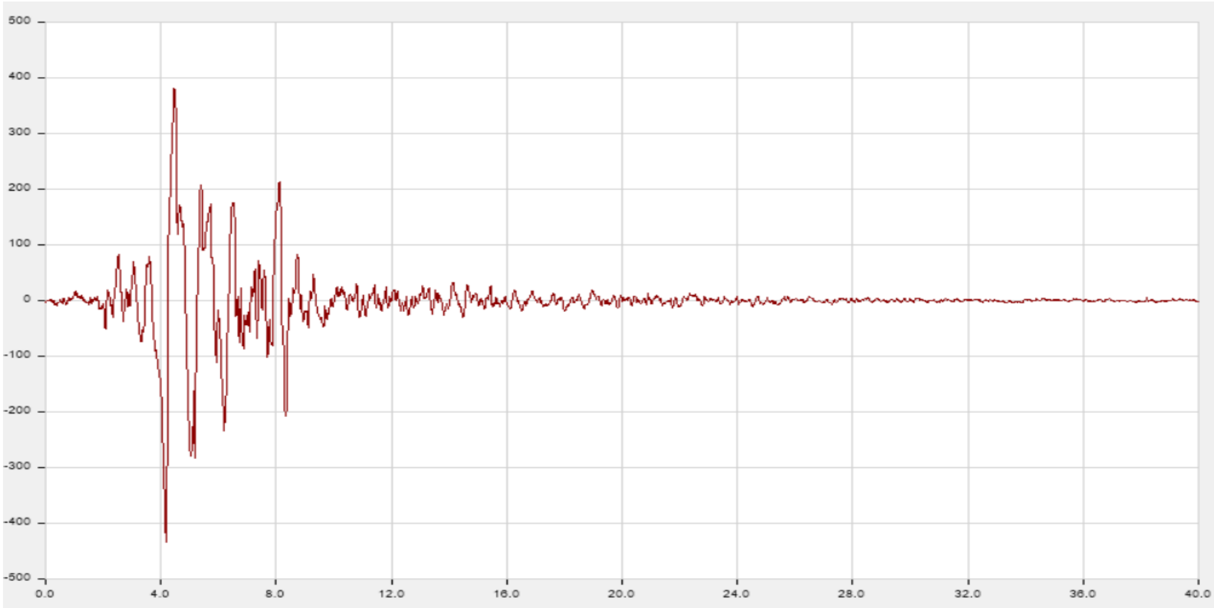


Figure 5.9 LEXINGTON DAM

7. LUCERNE VALLEY

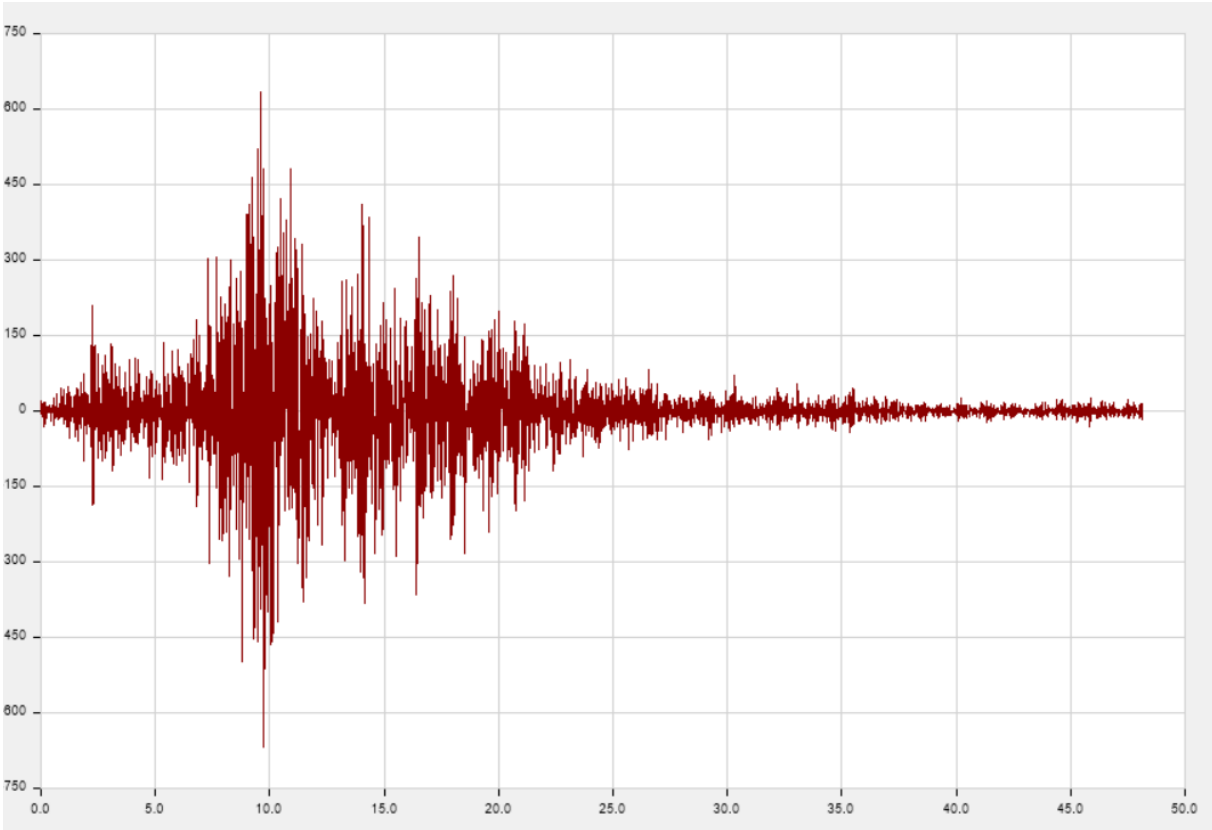


Figure 5.10 LUCERNE VALLEY

8. NEWHALL - LA COUNTY FIRE STATION

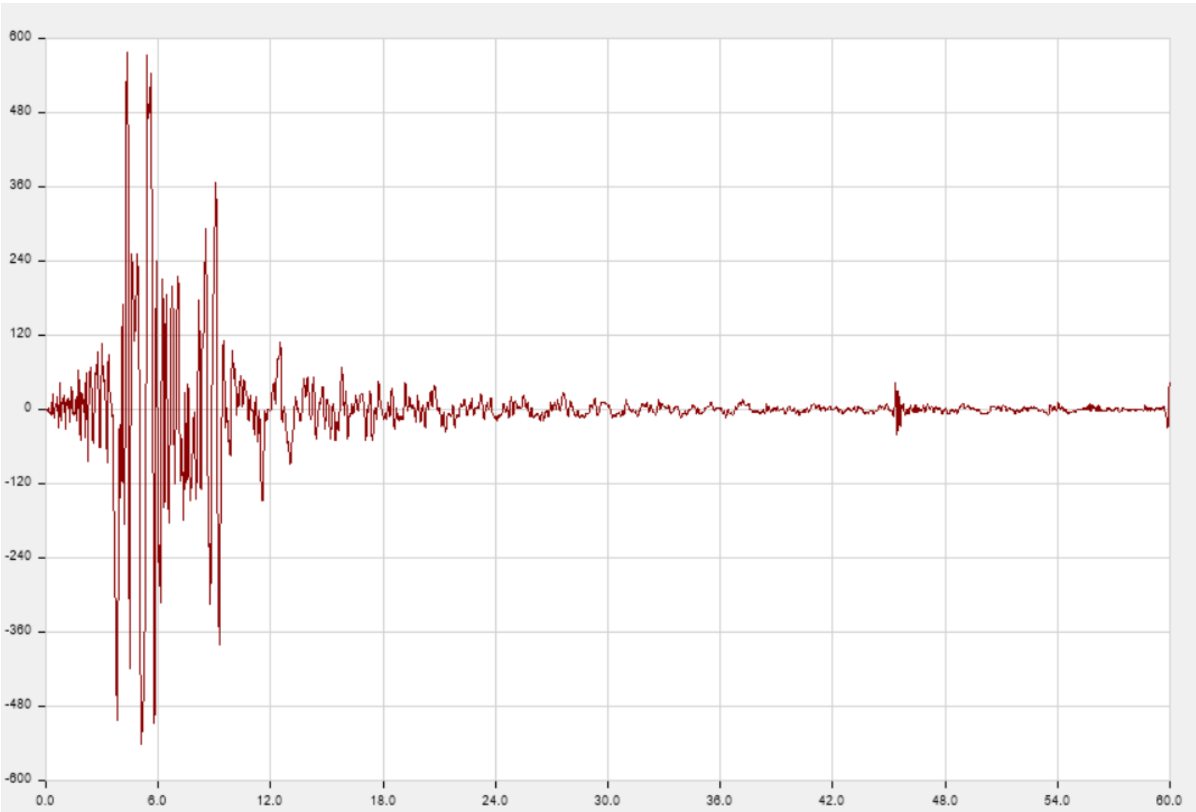
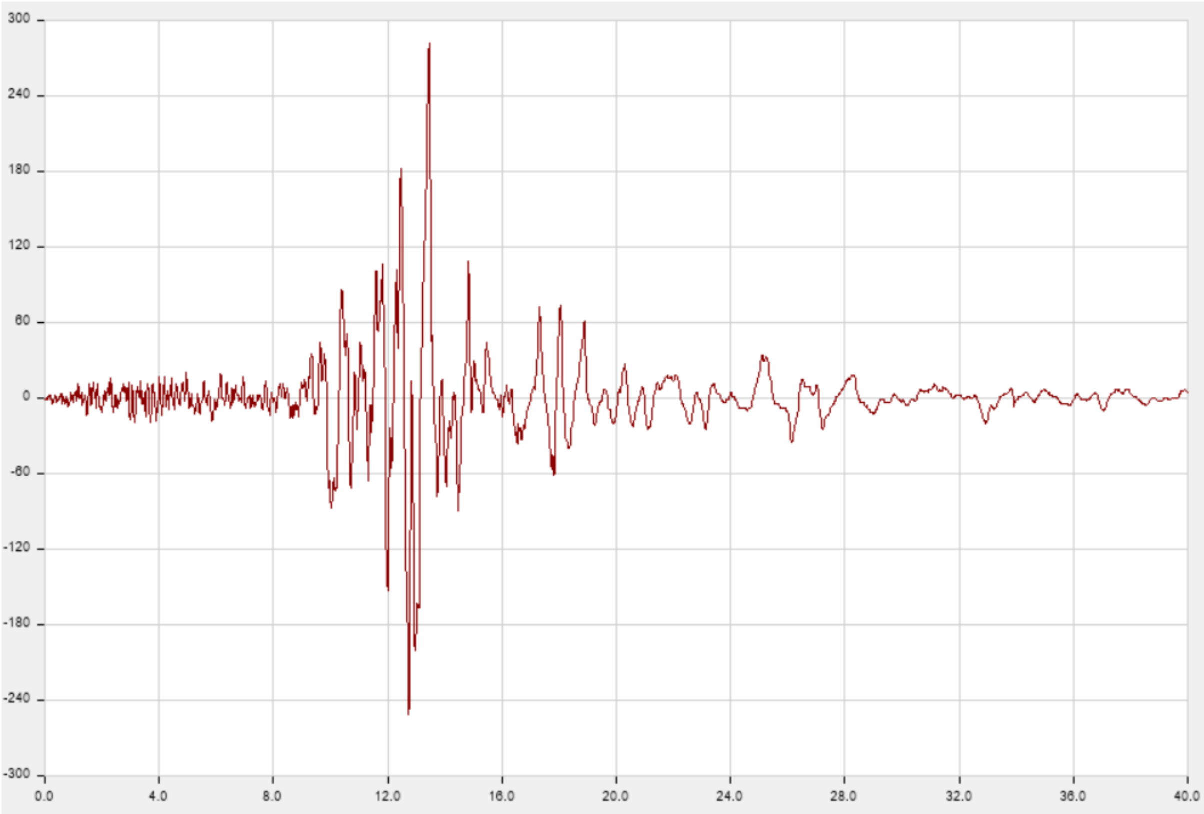


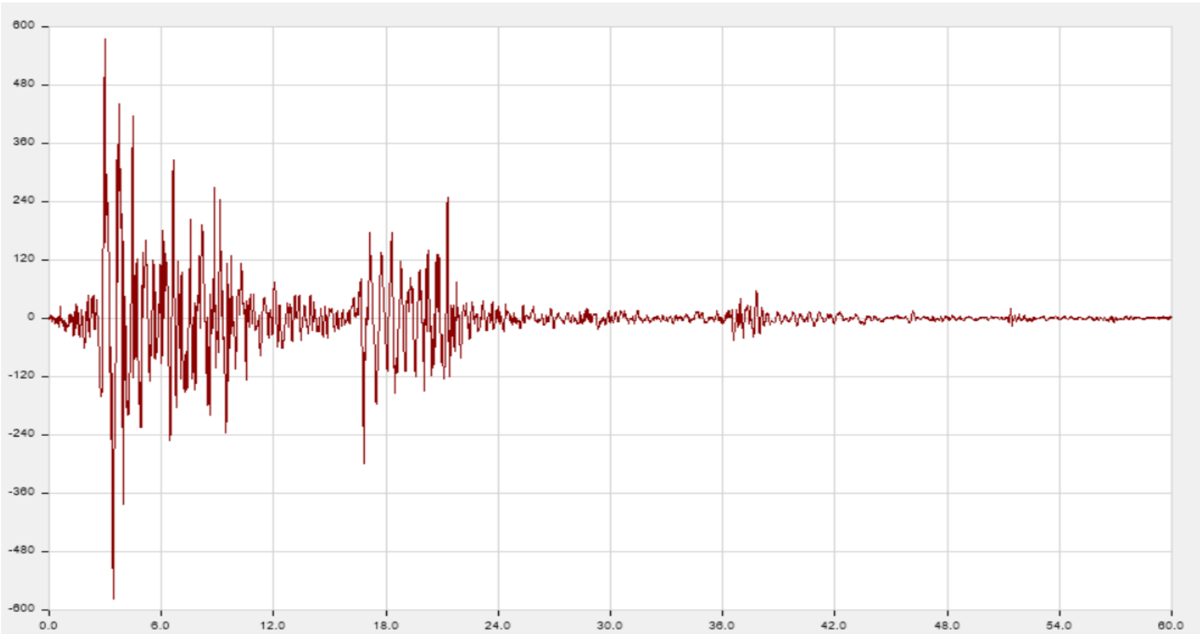
Figure 5.11 NEWHALL - LA COUNTY FIRE STATION

9. OAKLAND - OUTER HARBOR WHARF



<u>Figure 5.12 OAKLAND - OUTER HARBOR WHARF</u>

10. PETROLIA



<u>Figure 5.13 PETROLIA</u>

11. POMONA - 4TH & LOCUST

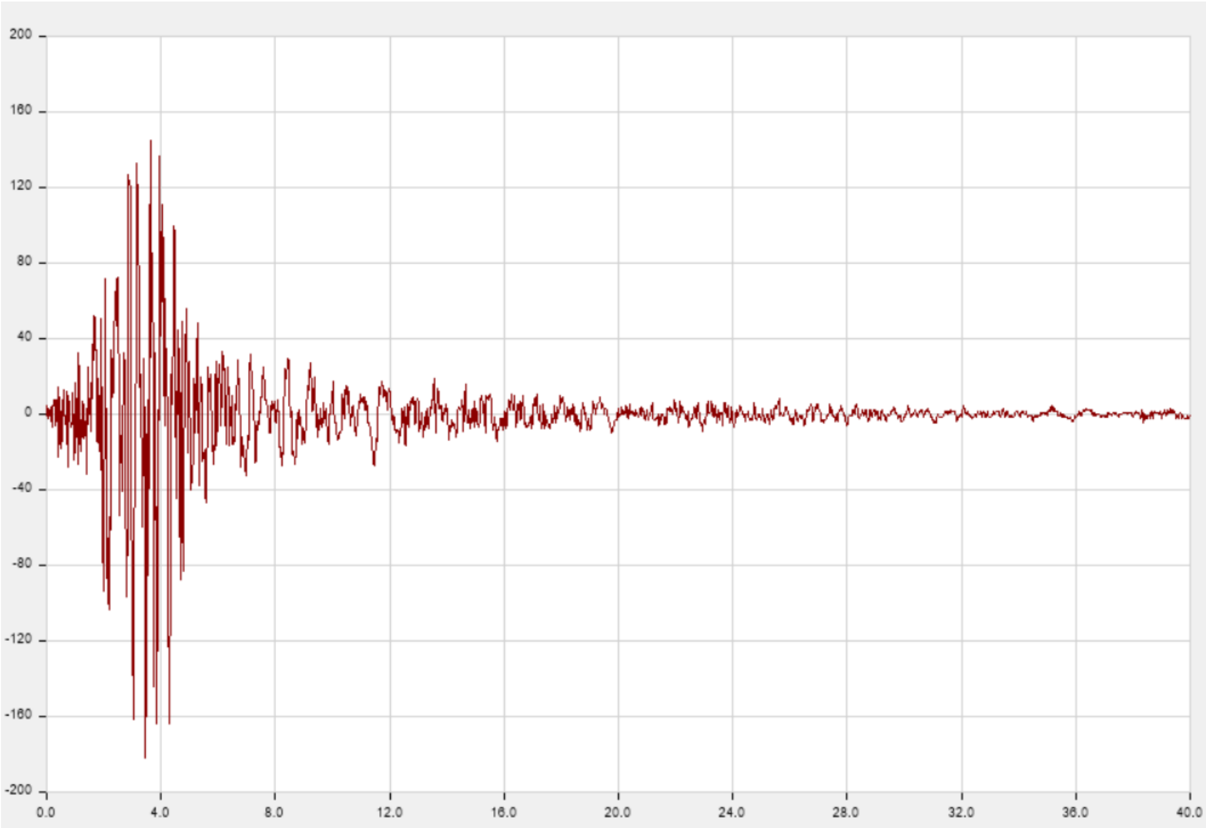


Figure 5.14 POMONA - 4TH & LOCUST

12. SANTA MONICA - CITY HALL

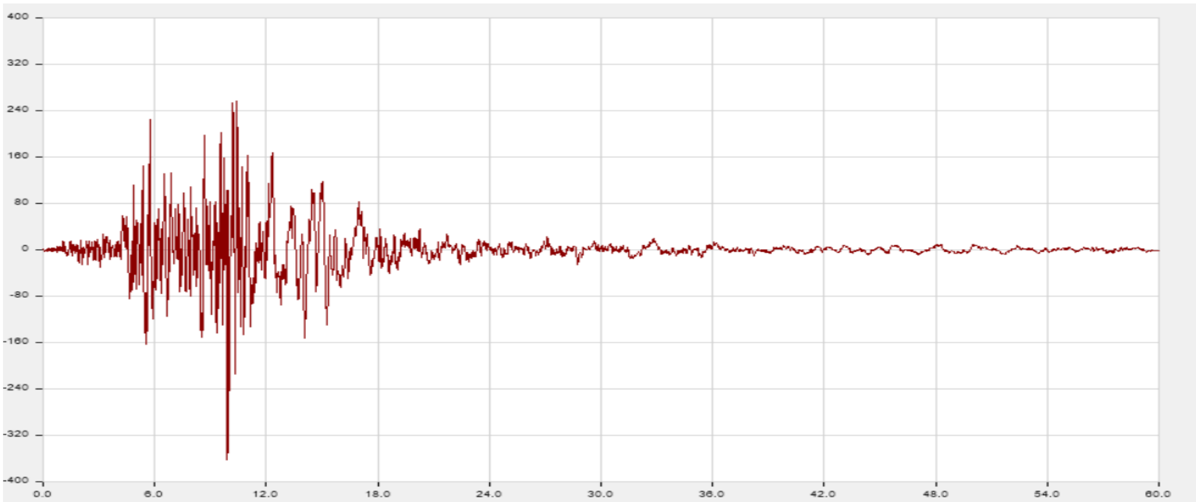
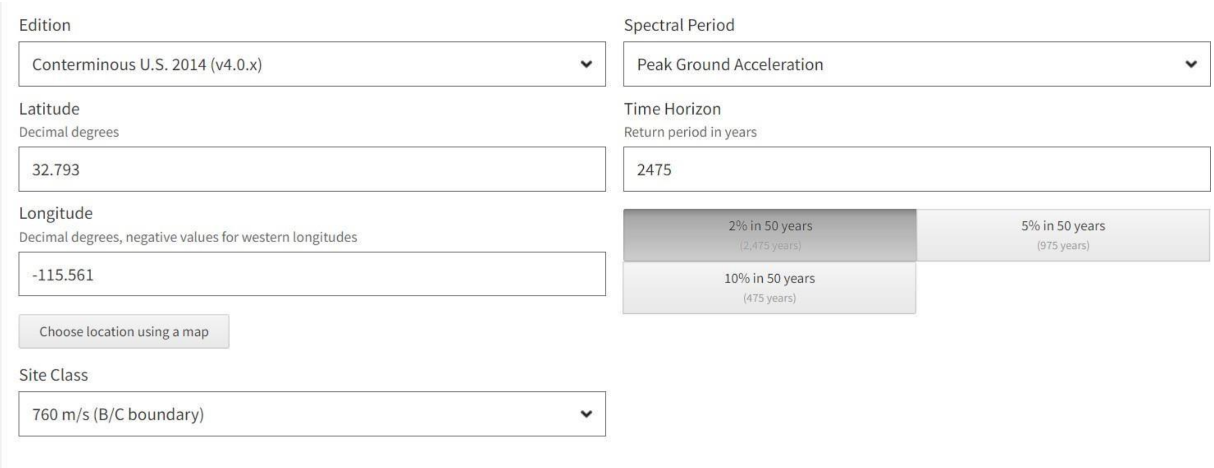


Figure 5.15 SANTA MONICA - CITY HALL

CHAPTER 6

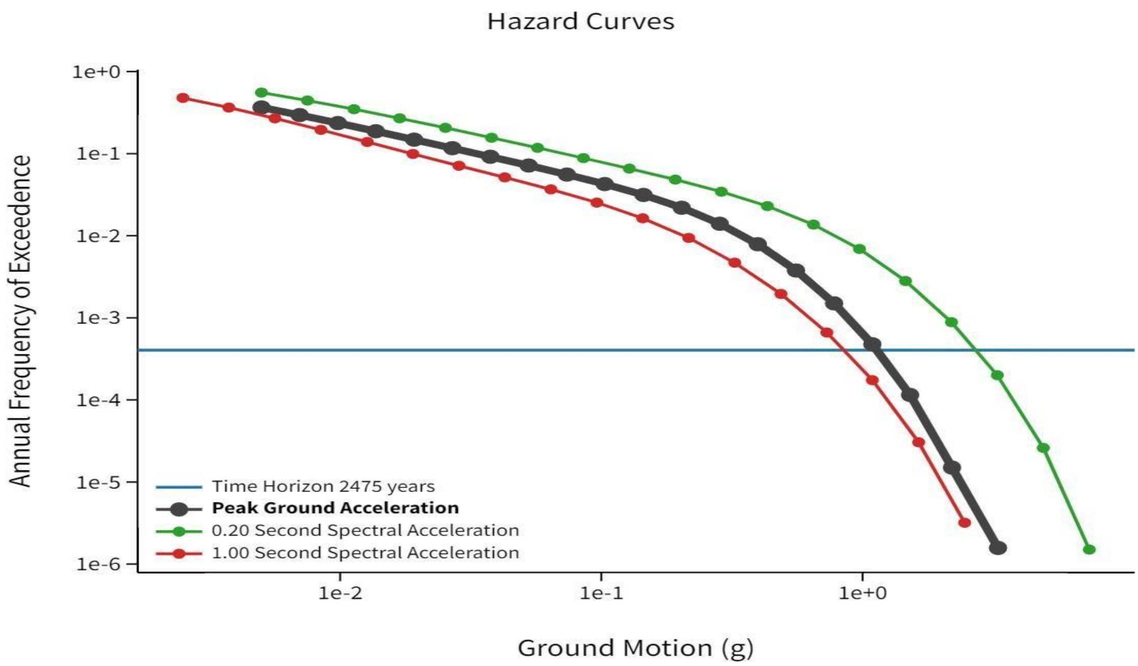
6.1 Plotting Hazard Curve

Figure given below shows the input parameters for Plotting Hazard Curve.



<u>Figure 6.1 Data to plot Hazard Curve</u>

Figure given below shows the Hazard Curve for the city for Peak Ground Acceleration considering Time Horizon of 2475 years and site class B/C.



<u>Figure 6.2 Hazard Curve</u>

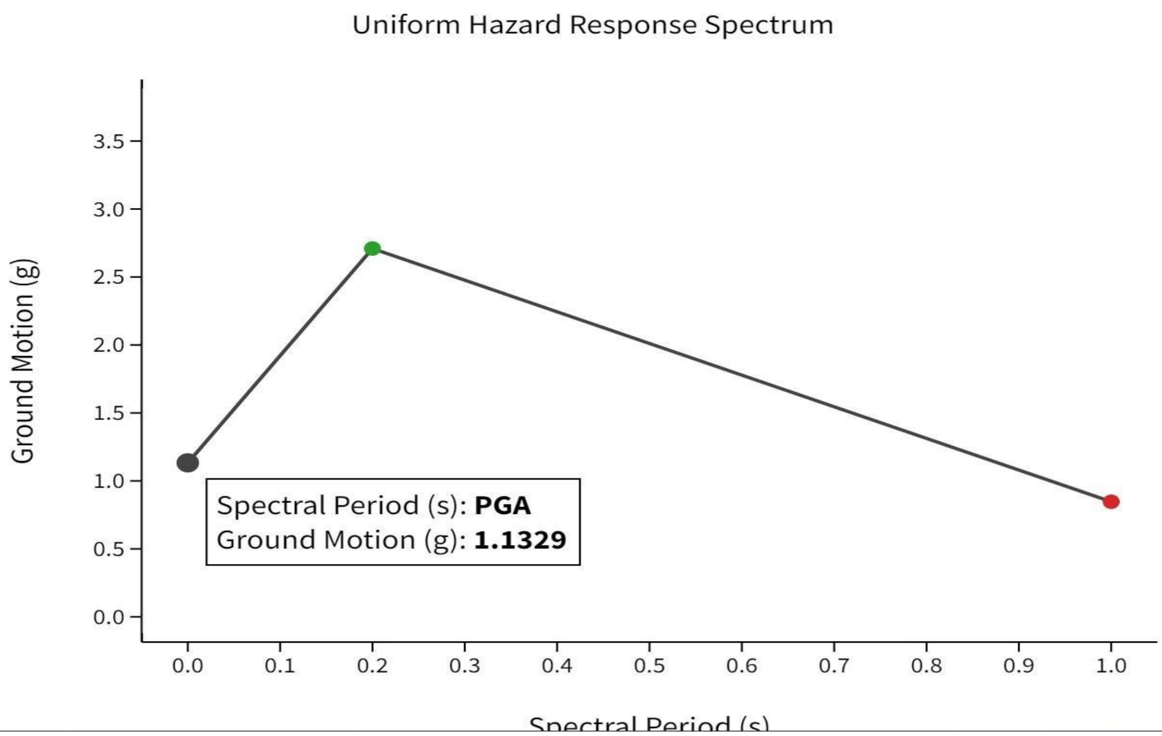


Figure 6.3 Uniform Hazard Response Spectrum

Figure given above shows the Uniform Hazard Response Spectrum which is a plot between Peak ground acceleration and Spectral Period.

6.2 Plotting Fragility Curve

Following IDA Curve was obtained using Incremental Dynamic Analysis

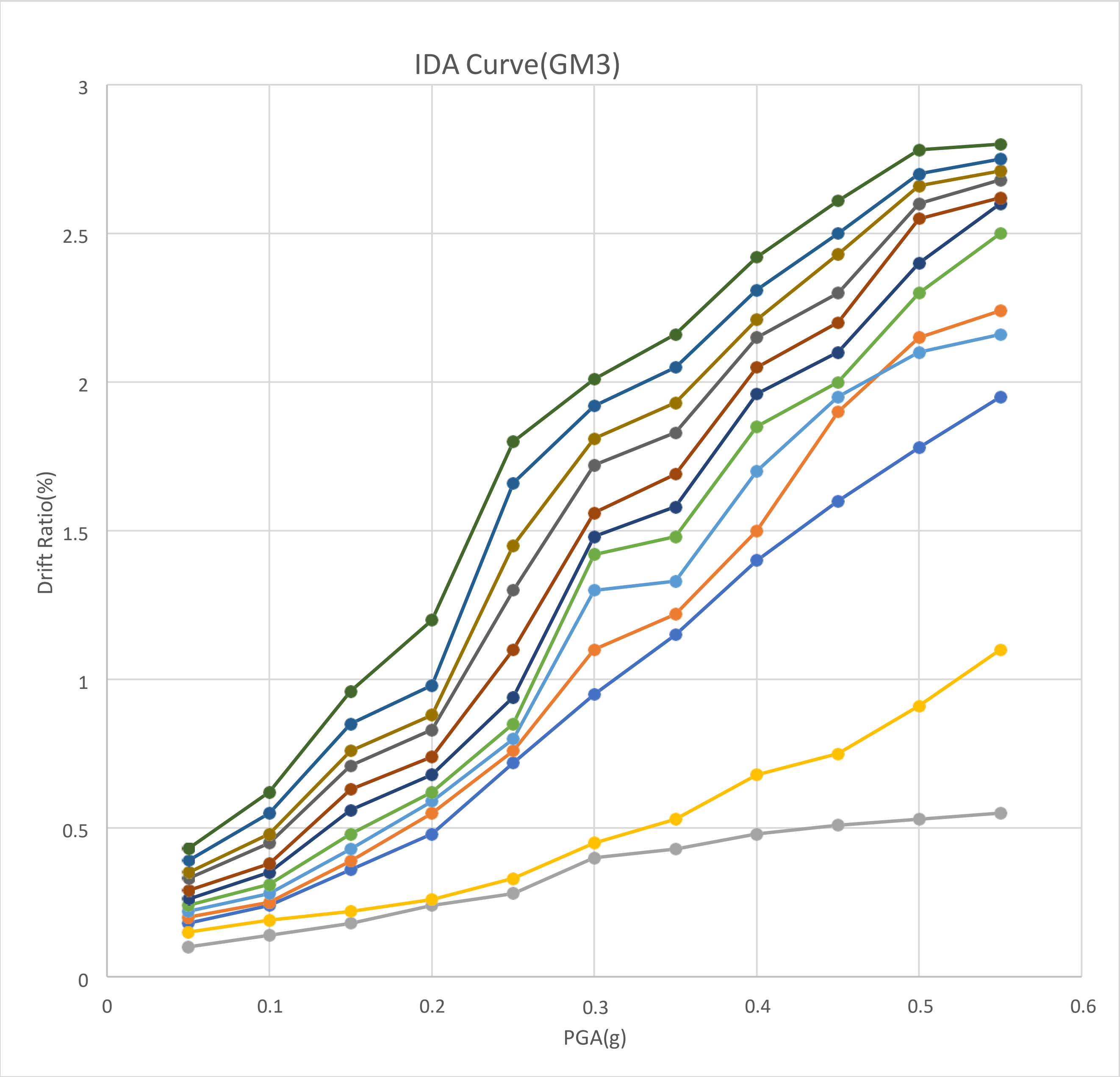


Figure 6.4 IDA Curves for different Ground Motions

From the above IDA curve we found the following mean and standard deviation for different damage states

Damage State	Mean	Standard Deviation
Immediate Occupancy	0.239	0.12
Life Safety	0.295	0.185
Collapse Prevention	0.281	0.251

Table 6.1 Mean and SD for different building performance levels

Now we will find the Probability of exceedance from the following expression

$$P[D/PGA] = \Phi((\ln(PGA) - \mu)/\sigma)$$

Where,

PGA denotes Peak Ground Acceleration

D denotes the damage state

μ denotes mean

σ denotes standard deviation

Fragility curve data for Immediate Occupancy is given below

Table 6.2 PGA and Probability for IO

PGA(g)	Probability of exceedance
0.05	0.00285
0.1	0.3567
0.15	0.8546
0.2	0.9658
0.25	0.9912
0.3	0.9956
0.35	0.9979
0.4	0.9988
0.45	0.9991
0.5	0.9994
0.55	0.9996

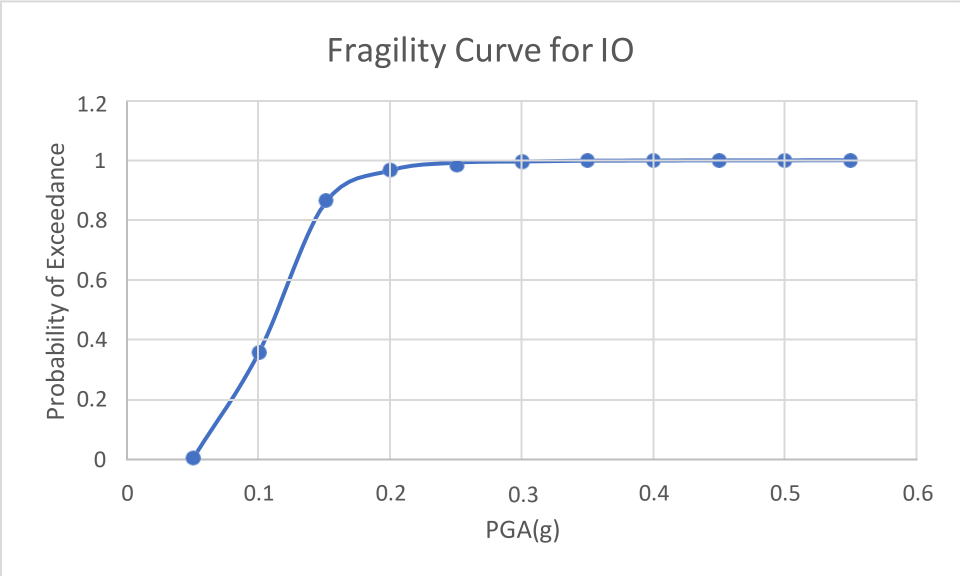


Figure 6.5 Fragility curve for IO

Fragility curve data for Life Safety is given below

PGA(g)	Probability of exceedance
0.05	0
0.1	0
0.15	0.0398
0.2	0.3966
0.25	0.7318
0.3	0.8866
0.35	0.9399
0.4	0.9741
0.45	0.9855
0.5	0.9921
0.55	0.9953

Table 6.3 PGA and Probability for LS

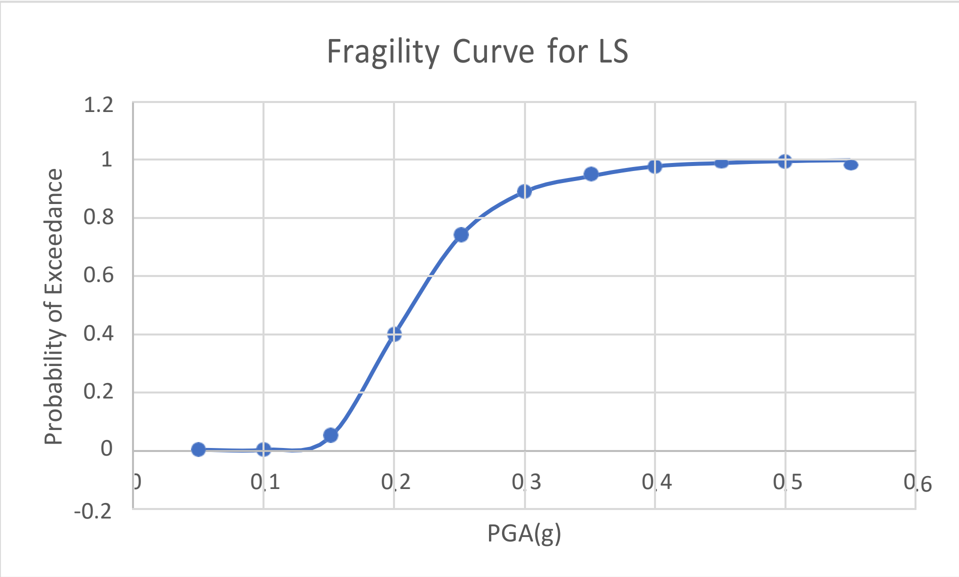


Figure 6.6 Fragility curve for LS

Fragility curve data for Collapse Prevention is given below

PGA(g)	Probability of Exceedance
0.05	0
0.1	0
0.15	0
0.2	0
0.25	0.0015
0.3	0.0398
0.35	0.1862
0.4	0.3966
0.45	0.591
0.5	0.7312
0.55	0.8279

Table 6.4 Probability and PGA for CP

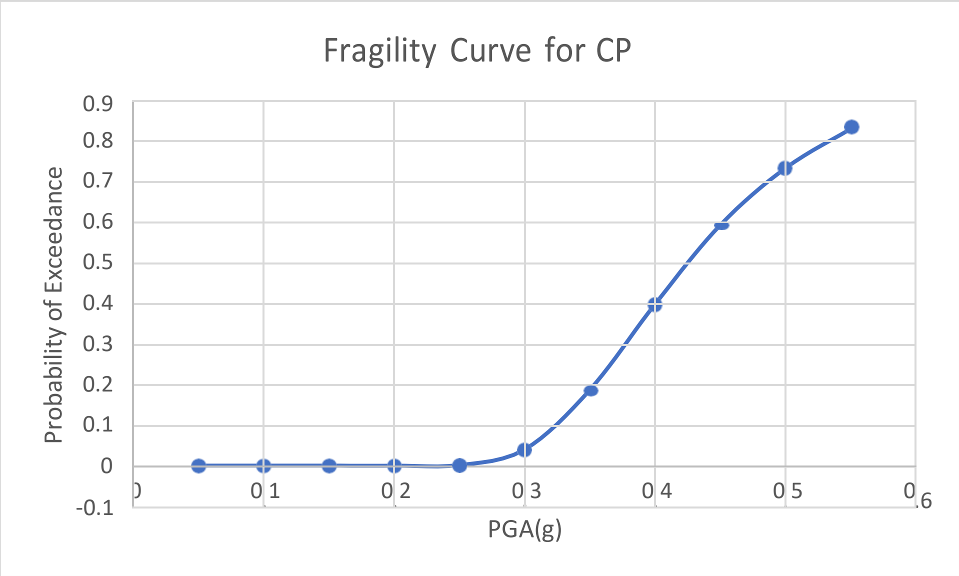


Figure 6.7 Fragility curve for CP

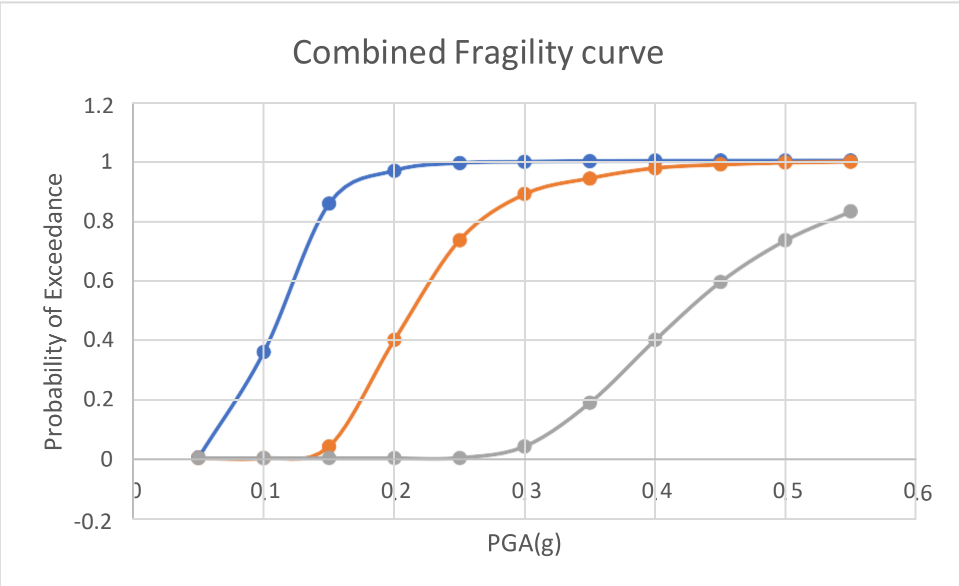


Figure 6.8 Combined Fragility Curve

6.3 Discussion and Conclusion

Here, Hazard Curve is plotted for 2% Probability of exceedance in 50 years, which means that the annual probability of exceedance comes out to be 0.0004. Also, Hazard curve is plotted considering Peak ground acceleration, 0.2 second spectral acceleration and 1 second spectral acceleration as ground motion parameters. Also, Uniform Hazard Response Spectrum is plotted which has peak value of 1.1329g for PGA, 2.7095g for 0.2 second SA and 0.8466g for 1 second SA.

Fragility curve is plotted for a G+3 Building for Immediate occupancy, Life Safety and Collapse Prevention damage states corresponding to the drift ratio of 1%, 2% and 2.5% respectively. From the combined fragility curve it is observed that the curve for Collapse Prevention state lies below the curve for Immediate occupancy and Life Safety damage states.

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