ASSAM ENGINEERING COLLEGE

A Dissertation on

AI BASED ATTENUATION OF SPECTRAL ACCELERATION IN NORTH-EAST INDIA

Submitted in partial fulfillment of the requirements for the Degree of Master of Technology

in

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I do hereby declare that the work presented in this thesis entitled **"AI based Attenuation of Spectral Acceleration in North-East India"** was carried out by me under guidance & supervision of Dr. Jayanta Pathak, Professor & HOD and Dr. Sasanka Borah , Assistant Professor, Department of Civil Engineering, Assam Engineering College**.**

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ABSTRACT

Northeast India, lying on the converging plate boundary between the Indian Plate and the Eurasian Plate is particularly susceptible to seismic activities due to the complex interactions of these tectonic plates. This region has witnessed some of the most devastating earthquakes in history, notably the 1897 Assam earthquake and the 1950 Assam-Tibet earthquake. These events highlight the region's high seismic risk, underscoring the importance of rigorous seismic hazard assessments to inform effective planning, construction, and disaster management strategies. The attenuation of spectral acceleration in the North-East India involves studying how seismic waves lose their energy as they travel through the Earth's crust in this specific geographical area. It examines the decrease in the amplitude of ground shaking over distance and frequency. Factors like geological conditions, soil characteristics, and seismic activity impact how much the shaking diminishes. Understanding attenuation is crucial for seismic hazard assessment, construction of resilient infrastructure, and implementing effective disaster mitigation strategies in this seismically active region.

In this study, a brief discussion about ground motion attenuation relations is given, which are developed by different investigators for various regions around the globe. It has been observed that ANN based attenuation model may be adopted for prediction of Spectral Acceleration with high accuracy and efficiency.

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CHAPTER 1

INTRODUCTION

1.1 General

Seismic hazard estimation has emerged into a pivotal component in the field of engineering, playing a critical role in shaping infrastructure, architectural design, and risk management strategies at a global scale. The assessment of seismic hazards by anticipating earthquake occurrences and their potential impact on specific regions, enabling engineers to devise structures and systems that can withstand these forces and minimizing potential harm.

The understanding of seismic hazards has undergone significantly over the years, driven by advancements in seismology, geology, and engineering sciences. Past seismic events have provided invaluable data, yielding insights into the characteristics and frequency of earthquakes. Technological innovations, such as advanced sensors, improved data collection methods, and advanced computational models, have enhanced our ability to scrutinize seismic activity, allowing for more accurate hazard assessments.

The incorporation of seismic hazard estimation into engineering practices has instigated to fundamental changes in infrastructure planning and design criteria. Engineers now can integrate seismic considerations into the planning and construction of buildings, bridges, dams, and other vital infrastructure.

In this project, Artificial Neural Network (ANN) is also used as an alternative to traditional regression methods. The ANN has the advantage that no prior function form is used, but rather, is established through the ground motion data. The ANN technique is particularly useful for regions where a limited amount of strong motion data is available. ANN has the capability to formulate an attenuation relationship that is consistent with the theory of ground motion attenuation and also incorporates region-specific characteristics of earthquakes. With the incorporation of input parameters due to availability of more data, ANN performance can be enhanced.

1.2 Ground Motion Prediction

The North-East region of India is seismically active due to its location near the convergence of the Indian Plate with the Eurasian Plate. This tectonic setting makes the region prone to earthquakes and ground motion prediction in this area is of utmost importance for ensuring the safety and resilience of infrastructure and communities.

Predicting ground motion in this region involves considering various factors specific to this area including the geological complexities, fault systems and historical seismicity.

Given the unique geological makeup of the region, seismic hazard estimation requires specialized approaches tailored to these conditions.

Local site effects play a significant role in ground motion prediction. The diverse topography and soil conditions can significantly amplify or attenuate seismic waves as they travel through different types of geological formations. Understanding these side effects is crucial for accurate ground motion estimation and engineering design. The different types of ground motion records are discussed later.

1.3 General Terminology Associated with Earthquakes

a) **Hypocentre or focus** – It is defined as the point within the earth where earthquake originates.

b) **Epicentre** - The point on the ground surface vertically above the hypocentre. The epicentre of an earthquake is typically expressed in terms of its geographical coordinates: latitude and longitude.

c) **Magnitude-** The magnitude of an earthquake is a measurement of the size or strength of the seismic event. It quantifies the amount of energy released at the earthquake's source. It is a single value measured on the Richter Scale or moment -magnitude scale.

d) **Intensity** – The intensity of an earthquake refers to the effects of consequences of the seismic waves as they are felt at a specific location on the Earth's surface. Unlike magnitude, which quantifies the energy released at the earthquake's source, intensity assesses the impact of earthquake on people, buildings, and the environment.

Intensity is typically measured using various scales like the Modified Mercalli Intensity (MMI) scale or the European Macro seismic Scale

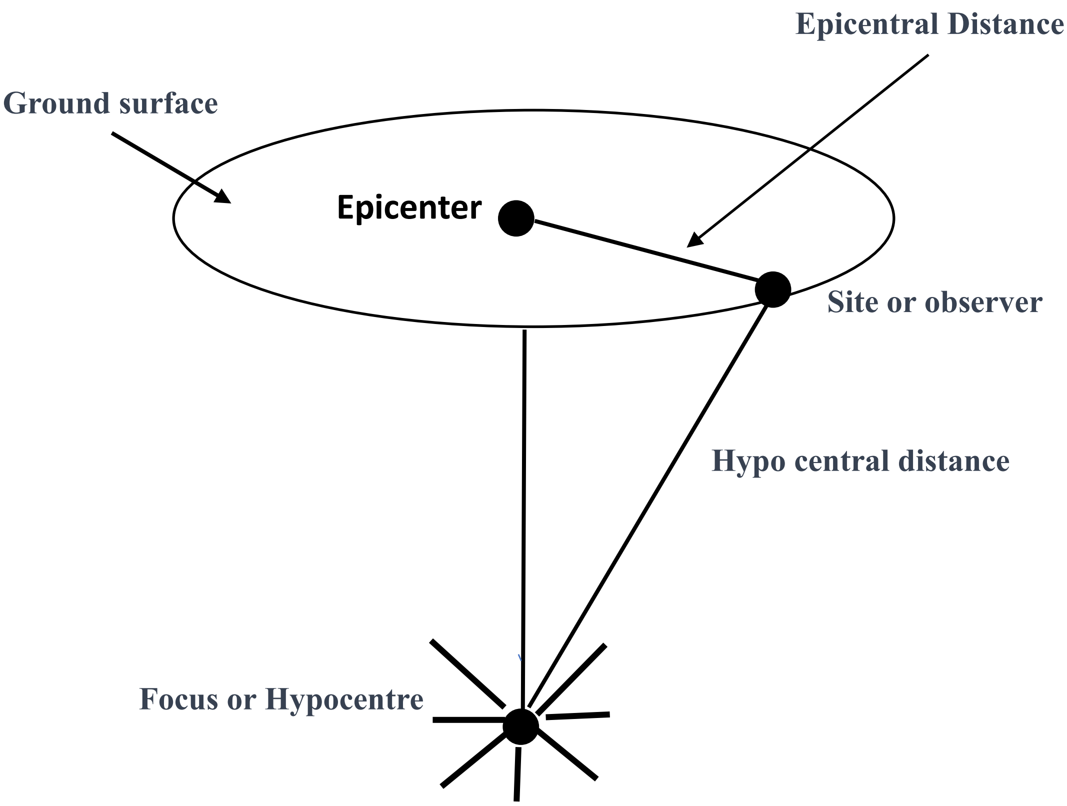


Figure 1 : Notation for description of earthquake (Kramer 1996)

e) **Epicentral Distance:** The distance on the ground surface between an observer or site and the epicentre is known as the epicentral distance.

f) **Hypo-central Distance:** The distance between the observer and the focus is called the focal distance or hypo central distance.

1.4 Sources of Seismic Activity:

Main Sources of Seismic Activity includes –

(a) **Tectonic Plate Boundaries**: They comprise of Divergent boundaries, Convergent boundaries and Transform boundaries.

(b) **Volcanic Activity**: Shallow volcanic earthquakes may result from sudden shifting or movement of magma.

(c) **Nuclear explosions:** Seismic waves may be produced by underground detonation of chemical explosives or nuclear devices.

(d) **Fault along Slippage lines:** Gradual accumulation of stress within the Earth's crust eventually reaches a critical point leading to a sudden release of energy that triggers seismic shaking resulting in an earthquake event. Other sources of seismic activity may also be present.

1.5 Locating the Epicentre of an Earthquake: Triangulation Method:

During the movement of plates, seismic energy is released resulting to earthquake. The seismic data are then collected by stations which are used to determine the origin of the earthquake, namely three stations. The data from these stations will tell us their distance from the epicentre.

This is done by finding the difference in the arrival time of P-Wave and S-wave. It should be kept in mind that the arrival time of P-wave and S-wave will tell us how far the station is from the source. Since P-waves travel faster than S-waves, high value between these two tells that the station is far from the source. In contrast smaller value means it is closer from the epicentre. The intersection point of three distances is said to be the earthquakes' epicentre.

The distance of the epicentre for each seismic station is calculated by:

$$\mathbf{d} = \frac{\textbf{Time difference of arrival of P and S waves}}{\textbf{8 secs}} \text{ x } 100 \text{ km} \qquad \text{... (1)}$$

In bed rock, P-wave velocities are generally 3-8 km/sec (1.9 to 5 miles) and S wave velocities range from 2 – 5 km /sec (1.2 to 3.1 miles per second)

Next a line is drawn from each seismic station using proper scaling for the map. A circle is drawn around each seismic station using the distance as its radius in order to avoid confusion because direction is not accurately available. Thus, the intersection point of three distances is said to be the earthquakes' epicentre.

1.6 Types of Ground Motion Records

Earthquake engineers are interested primarily in strong -ground motion which has motion of sufficient strength to affect human beings and their environment. The ground motion records are quite complicated so at a given point it can be described by three orthogonal components of translational motion that are most commonly measured.

They are basically acceleration, velocity and displacement time -histories.

For Engineering purposes, three characteristics of earthquake ground - motion are of primarily significance namely amplitude, frequency content and duration of motion.

1.7 Summary

This chapter summarizes the significance of predicting ground motion and maintaining earthquake records in the North-East Part of India as it plays a crucial role in risk reduction, safeguarding lives and enhance the durability of infrastructure and communities. Accurate ground motion models help engineers and architects in designing structures such as buildings, bridges and dams that can endure seismic forces, thus diminishing the likelihood of disastrous failures and casualties during an earthquake. Particularly in regions like North-East India with high population density and ongoing infrastructure growth, these models are indispensable to ensure that progress does not compromise safety.

Through the examination of earthquake records, researchers can detect patterns and trends in seismic behaviors enhancing the accuracy of future earthquake predictions. Given the region's high seismic activity, therefore these studies are essential for nurturing a resilient society capable of confronting the challenges posed by future earthquakes.

CHAPTER 2

ATTENUATION RELATIONSHIP

2.1 Definition of Attenuation

Attenuation refers to the gradual decrease or weakening of something, often with distance or as it passes through a medium. In various fields such as physics, electronics, signal processing and acoustics, attenuation describes the reduction in intensity, strength or magnitude of a phenomenon as it travels through or interacts with a medium. Similarly, seismic waves also become attenuated as they move from the earthquake source.

2.2 Definition of Attenuation Relation

Attenuation relations in seismology describe the way seismic waves lose energy as they travel through the Earth. An attenuation relation is expressed as a mathematical function relating a strong motion parameter (peak ground acceleration, spectral acceleration, velocity, displacement) to parameters characterizing the earthquake, propagation medium, local site condition and structure.

They are usually expressed as a function of magnitude, distance and in some cases other variables such as soil (Lang et al). The general form of an attenuation relation is shown below.

$$\mathbf{Y = f\,(M, R, P_i)}$$

Where

Y - Ground motion parameter

M- Magnitude parameter

R - Distance parameter

P_i - Other parameter such as focal depth

2.3 Types of Ground Motion Parameters

(a) Amplitude Parameters:

These include Peak Horizontal Acceleration, Peak Horizontal Velocity and Peak Displacement.

(b) Frequency Content parameters:

(i)- Ground Motion Spectra – Comprise Fourier spectra , Power Spectra Power spectra and Response spectra.

(c) **Spectral parameters:** parameters like Predominant period, Bandwidth, Central Frequency and Shape factor. The Shape Factor lies between 0 and 1 with higher values corresponding to larger bandwidths.

(d) **Duration:** It influences the amount of damage, especially to structures with longer periods.

(e) **Other Ground motion parameters:** these include Root Mean Square Acceleration (RMSA), Effective Peak Acceleration, Arias Intensity etc.

2.4 What is Peak Ground Acceleration?

Peak ground acceleration (PGA) refers to the maximum acceleration experienced by a particular location on the ground during an earthquake. It's a measure of the intensity of seismic shaking at a specific site. PGA is typically measured in units of gravity (g), where 1 g is equivalent to the acceleration due to gravity at the Earth's surface.

PGA can be estimated by attenuation relationships using magnitude, distance and source type etc. of a ground motion as it varies in respect to these parameters. In the past, several researchers have developed various attenuation relationships for predicting PGA for a specific region. Some of those empirical attenuation relationships are discussed in the next chapter.

2.5 Definition of Spectral Acceleration

Spectral acceleration refers to a measure used in earthquake engineering to quantify the intensity of ground shaking at different frequencies during an earthquake. It represents the maximum acceleration that a structure or site is expected to experience at a specific range of frequencies. Engineers use Sa to assess the potential impact of seismic activity on buildings infrastructure, helping in the design and evaluation of structures to ensure they can with-stand seismic forces effectively.

During an earthquake, the ground shaking can have different amplitudes at different frequencies. Spectral acceleration is plotted on a graph shows how the acceleration (typically in units of gravity, 'g') varies with different frequencies of the shaking. This graph is known as a response spectrum.

In the past, several researchers have developed various attenuation relationships for predicting PGA for a specific region but with coming up Spectral acceleration, things have changed dramatically. Some of those empirical attenuation relationships are discussed in the next chapter and are compared with compared with PGA.

2.5.1 Concept of Response to an Earthquake

If we push a structure horizontally, we remove the acting force to allow the structure to vibrate freely, the time needed by the structure to make a complete free vibration cycle is called the natural time period. The value of the natural time – period depends on the properties of the structure, mainly depends on the Mass of the structure (M) and the Stiffness of the Structure (k).

When the mass increases, the time period also increases. Heavy building vibrate slower than light buildings. On the other hand, when the stiffness increases, the time period decreases. Short buildings are stiffer than tall buildings, therefore short buildings vibrate faster than tall buildings.

If we have a very light building with negligible mass subjected to earthquake motion at the base, the building as a whole will move back and forth following exact motion of the earthquake but no force will be generated in the building i.e. the building will not be affected structural by the earthquake as long as its mass is very small as depicted below.

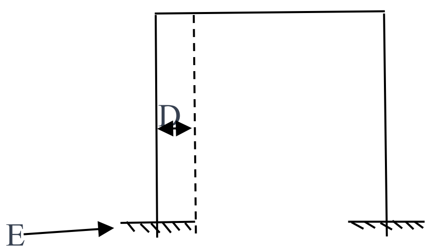


Figure 2.1 - Building with no mass (moves back and forth with no force generated)

However, on adding a considerable **mass** at the top of the building, the building will not move as one unit as before. There will be the difference in motion between the top of the building and its base known as relative displacement which causes forces to be generated in the building. So, the effect of the earthquake on the structure is mainly dependent on the relative displacement '**U**' and not the displacement of the base '**D** 'as shown below.

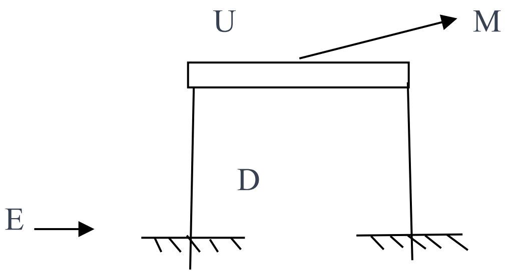


Figure 2.2 – Understanding the concept of relative displacement

Therefore, the response of the structure to earthquake is measured by the relative displacement. The force which is used for the design of the building is called shear force which is obtained as –

Shear force (V) = Relative displacement (U) * Stiffness (k)

However, in seismic design we prefer to use acceleration instead of relative displacement because we can directly obtain the design force by multiplying the acceleration with the mass of the building.

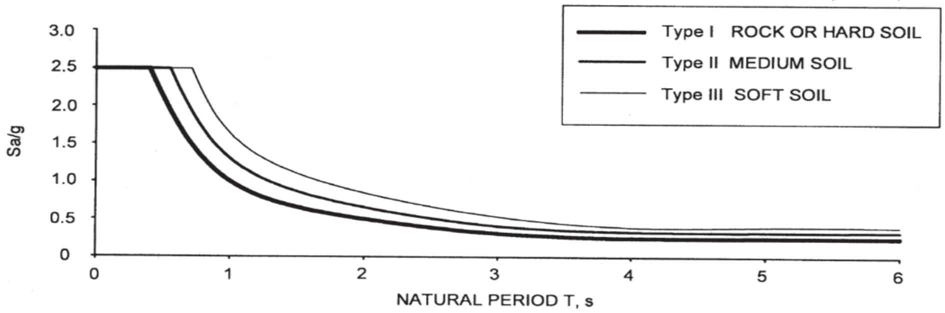
Shear force (V) = Acceleration (a) * Mass (M)

In structural design we are mainly interested in the maximum value of the force that occurs in the building. We are not concerned about the direction of the force or when does it happen.

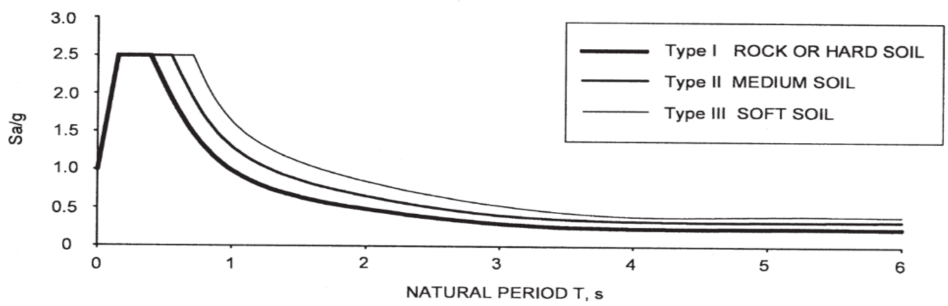
2.5.2 Response Spectrum Analysis (A brief Understanding)

In this analysis, the seismic input is represented by a response spectrum, which is a plot showing the maximum responses (displacements, velocities, or accelerations) of a single-degree-of-freedom system subjected to a range of natural frequencies and damping ratios. It provides a quick way to estimate the maximum response of a structure at various frequencies without solving the complex equations of motion.

IS 1893 Part 1 (2016)



2A SPECTRA FOR EQUIVALENT STATIC METHOD



2B SPECTRA FOR RESPONSE SPECTRUM METHOD

Figure 2.3: Design Acceleration Coefficients (S_a/g) (Corresponding to 5% Damping)

The above figure is taken from Indian Standard code IS 1893 Part 1 (2016). It shows the variation of response acceleration with natural time period for three different types of soil. In this standard Equivalent Static Method, Response Spectrum Method and Time History Method are adopted. Equivalent Static method may be used for analysis of regular structures with approximate natural period T less than 0.4 secs.

Key **differences** in Application: The primary distinction is evident in the complexity and nature of structures for which they are utilized; the **Equivalent Static Method** is employed for uncomplicated, uniform structures, whereas **the Response Spectrum Method** is appropriate for intricate, irregular, or taller structures. The Equivalent Static Method furnishes a simplified and cautious approximation of seismic forces, whereas the Response Spectrum Method presents a more detailed and accurate evaluation by considering the dynamic attributes and structural response tendencies.

The design horizontal seismic coefficient $\boldsymbol{A}_{\mathrm{h}}$ for a structure shall be determined by

$$\boldsymbol{A}_{\mathrm{h}} = \frac{\left(\frac{Z}{2}\right)Sa/g}{\frac{R}{I}}$$

Where

Z = seismic zone factor

I = importance factor given in IS 1893 (Parts 1 to 5) for the corresponding structures; when not specified, the minimum values of *I* shall be ,

(a) 1.5 for critical and lifeline structures;

(b) 1.2 for business continuity structures; and

(c) 1.0 for the rest

R = response reduction factor given in IS 1893 (Parts 1 to 5) for the corresponding structures and $\left(\frac{S_a}{g}\right)$ = design acceleration coefficient for different soil types, normalized with PGA, corresponding to natural period $\boldsymbol{T}$ of structure (considering soil – structure interaction, if required).

It shall be taken as that corresponding to 5 percent damping, given by expressions like :

- For use in Response Spectrum method:

(a) For rocky or hard soil sites:

$\frac{S_a}{g}$ =

1+15T	T < 0.10 s
2.5	0.10 s < T < 0.40 s
1/T	0.40 s < T < 4.00 s
0.25	T > 4.00 s

(b) For medium stiff soil sites

$\frac{S_a}{g}$ =

2.5	0.10 s < T < 0.55 s
1.36/T	0.55 s < T < 4.00 s
0.34	T > 4.00 s

(c) For soft soil sites

$\frac{S_a}{g}$ =

2.5	0.10 s < T < 0.67 s
1.67 / T	0.67 s < T < 4.00 s
0.42	T > 4.00 s

Seismo-Signal, a software used in earthquake engineering, employs Response Spectrum Analysis to denote the **maximum response** of a structure across different frequencies due to seismic loading. This helps engineers understand how the structure might behave during an earthquake at various frequencies and design or modify the structure to improve its seismic performance.

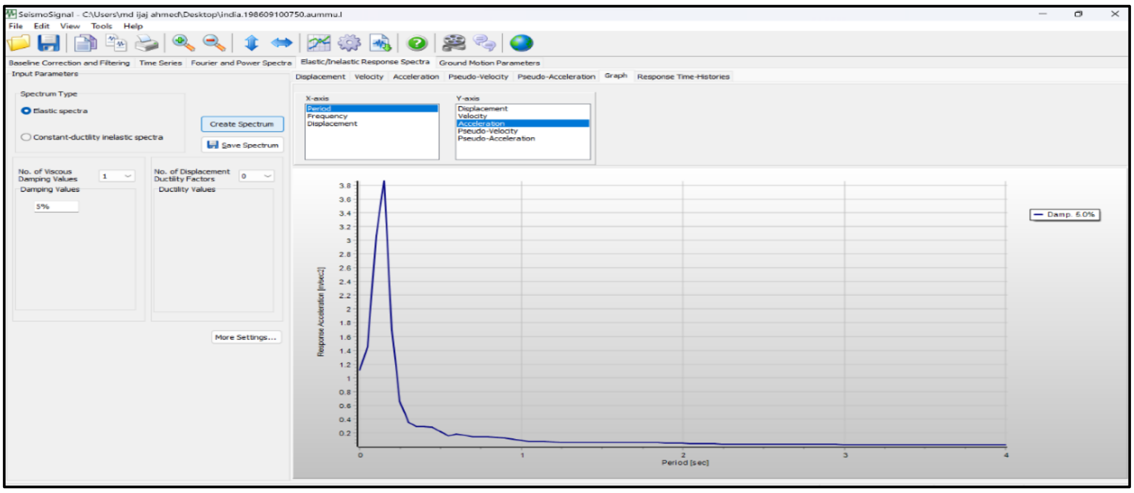


Figure 2.4 : Representation of Time period Vs Response acceleration ($^{m}/_{s^2}$) for earthquake occurring in 10 Sept 1986 in NE-India (Ummu long station) analysed in Seismo-Signal

2.6 Regression Analysis

Regression analysis is a collection of statistical procedures utilized to estimate connections between variables. It encompasses various methodologies for modelling and examining numerous variables, with a particular emphasis on the association between a dependent variable and one or more independent variables (also known as 'predictors').

Within the MATLAB environment, users can easily apply linear regression, Nonlinear regression, and other intricate data fitting techniques using built functions tailored through implementations.

The significance of regression analysis is evident in the development of Ground Motion Prediction Equations (GMPEs), which are empirical models forecasting the intensity of earthquake ground movements like peak ground acceleration (PGA), Sa or peak ground velocity (PGV) . GMPE' s utilize regression analysis to establish connections between ground motion parameters and earthquake attributes (such as magnitude, depth), source-to-site distance and local site effect among other factors.

Important criteria for successful Artificial Neural Network (**ANN)** training is The **Regression** Curve. If **Regression R =1**, its training is successful i.e. ANN has successfully trained up to 100 % otherwise it needs to be trained again. We must try to train the ANN and get the regression curve up to 1 as much as possible.

However, if due to any reasons, it is not achieved then at least Regression must be greater than 0.9 (satisfactory) but this is the last point.

2.7 Fast Fourier Transform

Engineers commonly perform a vibration analysis in relation to frequency. The fast Fourier transform (FFT) is utilized as a computational method that converts time-domain data into the frequency domain by decomposing the signal into its fundamental components, notably sine and cosine waves.

The Fast Fourier Transform (FFT) holds great significance in earthquake engineering, especially in the examination of Response Spectra. It enables the effective transformation of seismic data from the time domain to the frequency domain, allowing for the determination of essential parameters such as natural frequencies and damping ratios of structures. By employing FFT, precise assessment of seismic reactions becomes feasible, aiding in tasks like restoring seismometer responses, calculating source spectra, and assessing frequency-dependent attenuation.

2.8 Summary

Studying the attenuation relationships for spectral acceleration in the North-Eastern region of India holds great significance for engineers owing to the heightened seismic activity prevalent in the area. These relationships delineate the decay of ground motion induced by earthquakes concerning distance and play a pivotal role in the estimation of shaking intensity at various sites. Response spectrum facilitates the comprehension of how distinct structures will react to seismic events and assists in the development of buildings that can better withstand earthquakes through the consideration of the structural dynamics.

The Equivalent Static Method, while less complex, remains inferior to the Response Spectrum Method due to its assumption of the structure behaving in a purely static manner during seismic events, imposing a uniform later force based on the structure's mass and seismic coefficients.

Finally, his chapter ends with how the Fast Fourier Transform (FFT) acts as a crucial tool for the conversion of earthquake signals in the time domain into spectral representations in the frequency domain in the creation of precise response spectra. Utilization of regression analysis is prominent in the process of deriving empirical correlations from spectral information, facilitating the establishment of prognostic frameworks for structural reactions to seismic events.

CHAPTER 3

LITERATURE REVIEW

Ground Motion Prediction Equations (GMPEs) play a pivotal role in seismic hazard assessment by providing estimates of the expected ground motion parameters, such as Peak ground acceleration (PGA), Peak ground velocity (PGV), and Spectral acceleration (Sa) resulting from earthquakes at a specific site. In Japan, **Kanai et al. (1966**) were the first group of researchers to propose an acceleration attenuation curve as a function of **magnitude** and **distance.** Over time the dataset of strong motion available for the development of these relations has increased tremendously in quality and quantity, particularly in the last 30 years

Singh et al. (1996) utilized a robust motion database in the context of Northeast India to formulate attenuation relationships concerning peak acceleration and velocity for the horizontal component. Sharma (1998) conducted a study focusing on the Himalayan region, establishing an attenuation relationship for peak horizontal accelerations which exhibited lower values at shorter distances when compared to other regions.

Sharma (2000) further investigated the Himalayan region, developing an attenuation relation specifically for peak vertical accelerations. **Gupta (2010)** observed that in-slab earthquakes occurring along the subduction zone of Indo-Burma displayed significantly larger ground motion amplitudes in terms of response spectral attenuation. **Baruah et al. (2011a, 2011b**) illustrated empirical relations between ground motions and various seismic parameters, such as earthquake magnitude, source depth, fault type, medium velocity characteristics, and distance, while establishing correlations between Ground Motion Parameters (GMPs) and seismogenic zone characteristics.

In a parallel effort, **Singh et al. (2016**) conducted simulations of 30,000 ground motions to create a horizontal ground-motion prediction model tailored to Northeast India. Gupta (2018) estimated wave attenuation of strong motion resulting from deep earthquakes in the Burmese subduction zone by analysing strong ground motion data from Northeast India, presenting empirical scaling equations (Gupta and Trifunac, 2018).

Ramkrishna et al. (2020) formulated Ground Motion Prediction Equations (GMPEs) for acceleration based on established models capable of predicting ground acceleration across wider ranges of hypo central distance and magnitudes.

In essence, GMPEs serve as the cornerstone of seismic hazard assessments, providing crucial estimates of expected ground motion parameters essential for informed engineering and policy decisions to mitigate seismic risks and ensure the safety and resilience of communities in earthquake-prone regions. In this section, brief **reviews** of some the earlier published **attenuation relationships** of Peak Ground Acceleration and Spectral Acceleration is discussed.

3.1 Attenuation Relation for Peak Ground Acceleration

- **Milne and Davenport (1969)** proposed a relation for obtaining peak acceleration relating to magnitude and epicentral distance which was applicable to the Western region of Canada. The relationship is as follows:

$$A = \frac{0.69e^{1.64M}}{1.1e^{1.10M} + \Delta^2} \qquad (1.1)$$

Were,

A= Peak ground acceleration in the percentage of g

M= Earthquake magnitude

Δ = Epicentral distance (in km)

- **Esteva** in 1970 presented a modified version of their earlier relation **[Esteva and Rosenbluth (1963)]** to predict peak ground acceleration and velocity for firm ground relating to magnitude and hypo-central distance [Esteva (1970)] as

$$\mathbf{a = 1230\ e^{0.8m}(R+25)^{-2}} \qquad (1.2)$$

Where,

a = Peak ground acceleration (in gals)

m = Instrumental magnitude

R = Distance to the source (in km)

- **Esteva and Villaverde (1973)** proposed a relationship for calculating peak horizontal acceleration and velocity on 'firm ground'. They used hypo-central distance as the distance parameter and no specific reference was made regarding the scale and range of magnitude. The peak values of two recorded horizontal components were used as two distinct data points. The relationship is as follows:

$$\mathbf{a_c = 5600\ e^{0.8M}(R+40)^{-2}} \qquad (1.3)$$

Where,

a = Peak ground Acceleration at the centre (in gals)

M= Earthquake magnitude

R = Hypo-central Distance (in km)

- **Blume (1965)** presented an attenuation relation for peak ground acceleration relating to epicentral distance and focal depth on all types of ground as

$$\mathbf{a} = \frac{a_0}{1+\frac{\Delta^2}{h^2}} \qquad (1.4)$$

Where,

A = Peak ground acceleration (in g)
a_0 = Peak ground acceleration at the epicentre (in g)
Δ = Epicentral distance (in miles)
H = Focal depth (in miles)

- **Campbell (1989)** developed an attenuation relation to study the dependence of peak horizontal acceleration on magnitude, distance and side effects for small magnitude earthquakes in California and Eastern North America. The data recorded from 91 earthquakes having local magnitude (M_L) ranging from 2.5 to 5.0 were used. The mean of the two components of horizontal peak acceleration was considered. The distance measure was epicentral distance. All the data points of the data set were recorded on deep soil having a depth of more than 10 m. The relationship is as follows:

$$\ln PHA_b = -2.501 + 0.623\, M_L - 1.0 \ln [R + 7.28] \quad [\sigma = 0.296] \qquad (1.5)$$

Where,

PHA_b = Peak Horizontal Acceleration (in g) considering both horizontal components
M_L = Local Magnitude
R = Epicentral Distance (in km)

- **Kanai (1966)** predicted peak acceleration using the predominant period of ground as one of the independent parameters using data from Hitachi mine and the source region of the Matsu-Shiro earthquake swarm in Japan. The relationship is as follows;

$$A = \frac{5}{\sqrt{Tg}}\, 10^{\,0.61\, M - \left(1.66 + \frac{3.6}{R}\right) \log R + 0.167 - \frac{1.83}{R}} \qquad (1.6)$$

Where,

A = Peak ground acceleration (in gal)
T_g = Time domain period (in sec)
M = Magnitude (in Richter)
R = Hypo-central distance (in km)

3.2 Attenuation Relation for Spectral Acceleration

Attenuation relationships for **Spectral Acceleration** usually involve response spectra which show the acceleration response of a structure to different frequencies of ground motion. These relationships provide estimates of **Spectral Acceleration** at different periods (or frequencies) and at various levels of seismic intensity (usually expressed in terms of earthquake magnitude and distance from the source). Some of the published relationships about Spectral Acceleration -

- **Idriss (2007):** presented a model constructed for estimating the average peak horizontal acceleration and the average horizontal values of pseudo-spectral acceleration (PAA) for periods of 0.02, 0.03, 0.04, 0.2, 1 and 3 seconds.

  The approach taken in this model was the use of “bins” of average shear wave velocity, Vs30 and only the parameters for the model pertaining to the range of Vs30 = 450 to 900 m/s were considered. The equation was given as below:

  $$\ln [PAA(T)] = \alpha_1(T) + \alpha_2(T)M - [\beta_1(T) + \beta_2(T)M] \ln(R_{rup} + 10) + \gamma(T)R_{rup} + \varphi(T)F \quad (1.7)$$

  Where,

  PAA(T) = Pseudo Absolute Acceleration for period T at spectral damping ratio of 5%
  M = Moment Magnitude
  R_{rup} = Closest distance to rupture surface in km
  $\gamma(T)$ = Distance Adjustment Factor
  F = Source mechanism designator
  = 0 for strike slip
  = 1 for reverse slip
  $\varphi(T)$ = Source mechanism (or style of faulting)
  & α_1(T), α_2(T), β_1 and β_2 are the parameter obtained from regression process

- **Boore and Atkinson (2007*) :*** developed a model for ground motion prediction equations (GMPEs) for a particular measure of horizontal -component ground motions as a function of earthquake mechanism, distance from source to site, local average shear -wave velocity and fault type. The equation are for peak ground acceleration (PGA), peak ground velocity (PGV) and 5% -damped pseudo-absolute acceleration spectra (PSA) at periods between 0.01 s and 10 sec. The equations were derived by empirical regression of the PEER NGA strong motion database. For periods of less than 1s , the analysis used 1574 records from 58 mainshocks in the distance range from 0 km to 400 km (the number of available data decreased as the period increased).

  The equation is as follows:

  $$\ln Y = F_M(M) + F_D(R_{JB}, M) + F_S(V_{S30}, R_{JB}, M) + \varepsilon\, \sigma_\tau \quad (1.8)$$

Where,

F_M = magnitude scaling

F_D = distance function

F_S = site amplification

M = moment magnitude

R_{JB}, = Joyner -Boore distance

= closest distance to the surface projection of the fault, which is approximately equal to the epicentral distance for events of M<6

V_{S30} = time -averaged shear -wave velocity over the top 30 m of the site

ε = fractional number of standard deviations of a single predicted value of ln Y away from the mean value of ln Y

$$\sigma_\tau = \sqrt{\sigma^2} + \sqrt{\tau^2}$$

Where,

σ = Intra-event (within -earthquake) aleatory uncertainty

And $\tau =$ Inter -event (between -earthquake) aleatory uncertainty

- **Ghosh and Kushwaha (2004):** The best relation for Spectral Acceleration in India is the one developed by Ghosh and Kushwaha titled "Development of Uniform Motion Response Spectra for a site. "It uses 144 horizontal acceleration records from rock sites to develop an attenuation relation for response spectral acceleration is assumed to be

$$\mathbf{S = S(M, R, \zeta, T) = b1 \exp(b_2M)(R+D)^{-b_3}} \qquad (1.9)$$

where M is the magnitude and R is the hypo-central distance. D is a distance correction factor, ζ is the value of damping and T is the period for which the response spectrum is being evaluated. The constants, b1, b2, b3 depend on ζ and T. The results determine the seismic hazard at the given site and the associated uncertainties. The attenuation relations thus developed were used for the development of uniform hazard response spectra i.e. spectra having the same MRI (mean recurrence interval at all frequencies for that particular site.

- **S. Raghukanth and R.N Iyengar (2007**): This paper analytically simulates ground motion in **Peninsular India** to arrive at an empirical relation for estimating 5%

damped response spectra as a function of magnitude and source to site distance, covering bedrock and soil conditions. The attenuation equation chosen for Peninsular India is similar to the one used in the literature for other intra-plate regions (Atkinson and Boore 1995). The attenuation relation is of the form -

$$\ln(y_{br}) = c_1 + c_2(M - 6) + c_3(M - 6)^2 - \ln(r) - c_4 r + \ln(\varepsilon_{br}) \qquad \textbf{(2.1)}$$

In the above equation, ***ybr* = (*Sa/g*)** stands for the ratio of spectral acceleration at Bedrock level to acceleration due to gravity . *M* and *r* refer to moment magnitude and hypocentral distance respectively. The study reports the coefficients for including local site conditions in the analysis.

Key **contributions** of this paper –

- Provides empirical relationships to estimate seismic spectral acceleration in Peninsular India, thereby assisting in the rational formulation of design response spectra for construction sites and urban areas within the region

- Improves comprehension of seismic risk in Peninsular India through the incorporation of factors such as earthquake magnitude, source-to-site distance, and local site characteristics in the analytical framework.

- **I.D Gupta (2010**) observed that in-slab earthquakes occurring along the subduction zone of Indo-Burma displayed significantly larger ground motion amplitudes in terms of response spectral attenuation. It developed empirical attenuation relations by modifying the Atkinson and Boore model to suit North-east conditions.

Certain **reasons** can be highlighted for **higher amplitudes in North-East India** after reviewing this paper. They are-

- In-slab earthquakes along the Indo-Burmese subduction zone exhibit larger ground motion amplitudes due to specific source characteristics, propagation path, and site geologic condition

- The application of an adjusted attenuation model specific to northeast India yields a more accurate prediction of spectral amplitudes generated by seismic

- activities within the subduction zone, underscoring a notable influence on the seismic hazard profile of the area.

- This revised model accounts for consistent scaling of both horizontal and vertical ground motions concerning magnitude and distance, thereby enhancing the precision of forecasting response spectral amplitudes within northeast India.

The functional form of this AB- 2003 model can be stated as –

$$\log Y = C_1 + C_2M + C_3h + C_4R - g\log R + C_5 slS_C + C_6 slS_D + C_7 slS_E \quad - \qquad (2.2)$$

This equation represents the mathematical equation used to calculate the response spectral attenuation relations for in slab earthquakes in the Indo-Burmese Subduction zone.

Components of the Equation:
The variable **Y** represents the Response spectral amplitude. Coefficients C_1 to C_7 are specific to the equation . **M** stands for the Magnitude of the earthquake, h denotes the Focal depth of the earthquake in km, **R** indicates the Distance from the earthquake source to the recording station. The term g represents the Acceleration due to gravity. Factors S_C, S_D, S_E are site -specific in nature.

3.3 Next Generation Attenuation NGA Relation

The Next Generation Attenuation (NGA) models are a set of ground motion prediction equations (GMPEs) developed by a collaborative effort within the seismological and earthquake engineering communities. NGA relations are not different from previous attenuation relations; however, they are considered as significant updated versions & improvements over the existing ones. They were developed over several years with extensive discussions between many participants under a program called “Next Generation of Ground Motion Attenuation Models “for the western United States (NGA West). It was coordinated by the Lifelines Program of the Pacific Earthquake Engineering Research Centre (PEER) as a multidisciplinary research program in partnership with the U.S. Geological Survey and the Southern California Earthquake Centre.

The NGA models consider factors such as earthquake magnitude, distance from the seismic source, site conditions (such as soil type and site class) and sometimes additional parameters to estimate ground motion levels accurately.

Some sets of ground -motion attenuation models were developed by teams working independently but also interacting with one another throughout the development process. They are discussed below:

- **Campbell and Bozorgnia (2014)** used expanded PEER NGA -West2 database to develop a new ground motion prediction equation (GMPE) for the average horizontal components of PGA, PGV and 5% damped linear pseudo – absolute acceleration response spectra at 21 periods ranging from 0.01 s to 10 s.

  This new GMPE is considered to be valid for estimating horizontal ground motion from shallow crustal continental earthquakes in an active tectonic domain for rupture distances ranging from 0 km to 300 km and magnitudes ranging from 3.3 to 7.5 -8.5, depending on the source mechanism.

The NGA -West2 database provides better constraints on magnitude scaling and attenuation of small -magnitude earthquakes, where their 2008 GMPE was known to be biased.

- **Stewart et al. (2016)** presented ground motion prediction equations (GMPEs) for computing natural log means and standard deviations of vertical -component intensity measures (IMs) for shallow crustal earthquakes in active tectonic regions.

  The equations were derived from a global database with events of magnitude range 3.0-7.9 for the primary magnitude and distance -dependence of peak acceleration, peak velocity and 5% damped pseudo -spectral accelerations at oscillator periods between 0.01 -10 s.

3.4 Limitations of Peak Ground Attenuation Relationships

While Peak Ground Acceleration (PGA) attenuation relationships have been historically used and still hold significance in seismic analysis, they do have certain disadvantages compared to other metrics like Spectral Acceleration (Sa). Here are a few drawbacks associated with PGA attenuation relationships from previous study:

1. **Sensitivity to Local site conditions**: PGA may not account adequately for the effects of local site conditions on ground shaking. Different soil types and geological formations can significantly amplify or attenuate ground motion at a specific site. PGA alone might not capture these variations effectively compared to SA-based relationships, which consider frequency-dependent amplification due to site conditions.

2. **Limited Frequency Information:** PGA represents the maximum amplitude of ground motion regardless of frequency. It doesn't offer insight into how different frequencies of shaking affect structures. Spectral Acceleration on the other hand, provides a spectrum of ground motion amplitudes across various frequencies, offering a more detailed understanding of how structures will respond to different parts of the seismic spectrum.

3. **Applicability to Tall Structures:** For tall or flexible structures, understanding how ground motions vary across different frequencies becomes crucial for accurate design and assessment. PGA, being a single value, might not evaluate the dynamic response of these structures, which are sensitive to different frequency components of the seismic waves.

4. **Seismic Hazard Assessment Limitations:** While PGA is valuable for assessing ground shaking intensity, SA provides more comprehensive information needed for seismic hazard assessments, especially when considering the potential impact of a range of structures and their vulnerabilities to different frequencies of shaking.

By analysing spectral accelerations at different frequencies, researchers can create hazard maps that provide a more detailed representation of seismic risks in specific regions.

3.5 Research Gap

- Given the diverse geological features and tectonic complexities in the **North-East Region**, there's a unique seismic behavior that necessitates region-specific attenuation relationships.

- The **lack of comprehensive studies and data** in this area poses challenges in accurately predicting ground motion parameters during earthquakes.

  Bridging this gap in research is essential to develop reliable models that account for the geological intricacies of the region. It requires collaborative efforts among seismologists, geologists and engineers to conduct thorough investigations, gather seismic data and analyze ground motion patterns.

- Therefore, this project aims in developing an **attenuation relationship** specifically for **North-East India** which can effectively predict the ground motion parameters which in turn will help in effective seismic design of structures.

3.6 Summary

In recent literature, there has been a growing preference for Spectral Acceleration (SA) over Peak Ground Acceleration (PGA) in the field of earthquake engineering Due to its enhanced reliability. SA provides a thorough depiction of the seismic demands of structures by taking into account the spectral content of ground motion & the dynamic response of structures over different time periods.

In contrast to PGA, which solely records the peak ground acceleration without regard for frequency characteristics, SA offers valuable insights into the expected responses of various structures to different shaking frequencies . This feature makes SA particularly advantageous for the design and assessment buildings and infrastructures infrastructure with diverse natural periods.

In order to fill the gaps in the research concerning Spectral Acceleration (SA), it is imperative to adopt a comprehensive approach. Utilizing sophisticated computational techniques, such as Artificial Neural Networks (ANNs), may be employed to enhance the accuracy of predicting the decrease in SA.

CHAPTER 4

ARTIFICIAL NEURAL NETWORK

4.1 General

Artificial Intelligence (AI) refers to the simulation of human intelligence in machines that are programmed to think and learn like humans. One prominent subset of AI is Neural Networks, inspired by the structure of the human brain. In Geo-technical Engineering, Neural Networks prove efficient due to their ability to recognize complex patterns and relationships within large sets of data. They excel in tasks such as soil classification, landslide prediction, and subsurface modelling by analysing vast amounts of geological and geotechnical data.

Neural Networks in Geo-technical Engineering can predict soil behaviour, assess risks, and optimize designs, contributing to more accurate and efficient solutions in construction and infrastructure development. Their adaptability and learning capability make them a powerful tool for tackling intricate problems in this field.

Various similar AI techniques were proposed and used such as **Neural networks, Fuzzy logic systems, Genetic Algorithms, Support Vector Machines (SVM) and Genetic Programming**. These techniques demonstrate the diverse applications of AI in Geotechnical Engineering, offering solutions to complex problems and enhancing decision-making processes within the field.

Over the years, the combination of their learning capabilities, adaptability, and success in addressing complex problems has positioned ANNs as a powerful and widely adopted paradigm of artificial intelligence, particularly in the domain of geotechnical engineering.

Artificial Neural Networks (ANNs) serve as a powerful computational mechanism in Geotechnical Engineering due to their ability to process large volumes of complex geotechnical data, recognize intricate patterns, and model nonlinear relationships between various soil parameters and geological factors. They excel in tasks such as soil classification, slope stability analysis, and prediction of ground behaviour, offering a computational framework that learns from data, adapts to new information, and enhances the accuracy of predictions and assessments.

ANN's computational prowess lies in their capacity to handle the multidimensional and nonlinear nature of geotechnical problems, providing engineers with valuable insights and predictive capabilities crucial for designing robust and safe structures and infrastructures.

4.2 Background of ANN Research

The groundwork for ANNs was laid with the introduction of simple models mimicking the human brain's neuron interactions. Researchers such as **Warren McCulloch (neuroscientist) and Walter Pitts (logician) (1943)** proposed the first computational mathematical models of artificial neurons, laying the foundation for neural network theory.

This model paved the way for research to split into two approaches. One approach focused on biological processes while the other focused on the application of neural networks to artificial intelligence i.e.

A summation over- weighted input.

An output function of the sum.

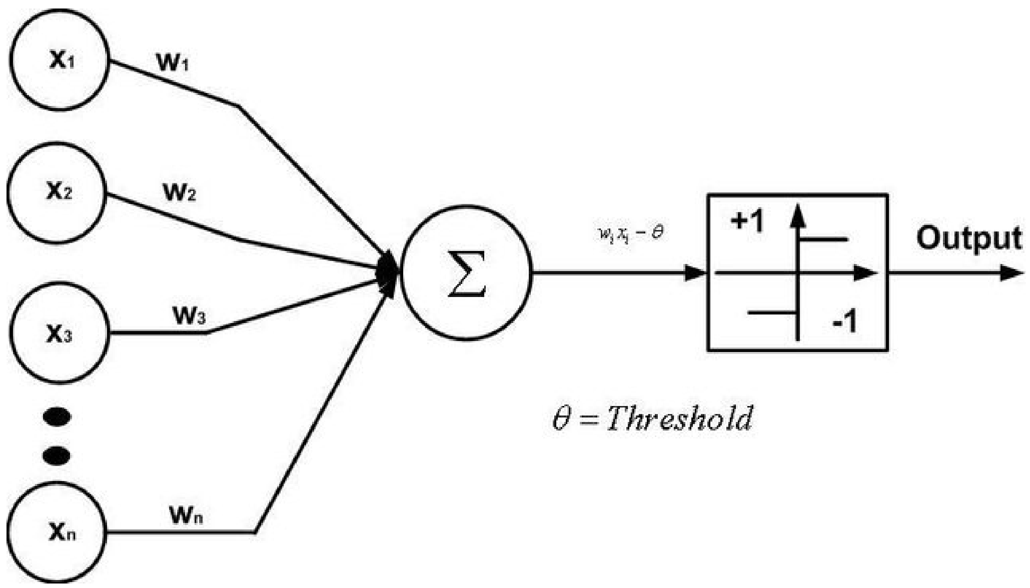


Figure 4.1: Schematic diagram of McCulloh-Pitts neuron

The model neuron computes the weighted sum of incoming signals x_i and produces an output of one or zero depending upon whether this sum is above or below a given threshold value θ. This can be mathematically expressed as:

$$\textbf{Output} = f(\sum w_i x_i - \theta_i)$$

Where $f(x)$ is a Heaviside step function:

$$f(x) = \begin{Bmatrix} 0 \;\; if \;\; x \leq 0 \\ 1 \; otherwise \end{Bmatrix}$$

The weight w_i represents the excitatory or inhibitory effect of the synapse attached to connection i . McCulloh and Pitts (1943) showed how a synchronous assembly of these model neurons could compute any logical function for a suitable selection of the weights w_i.

The ability of these artificial neurons to compute, however, was only a first step towards emulating the functionality of the human brain. The next effort was to emulate learning from example, which is one of the most fundamental properties of the human brain.

During the 1950s the first neurocomputers were built and tested **[Minsky (1954)]** with adaptive connections. During this time **Rosenblatt (1958)** invented neuron-like elements called perceptron, which was a trainable machine, capable of learning to classify certain patterns by modifying connections to the threshold elements.

Minsky (1967) proved that McCulloch and Pitt's neuron models were able to construct a general computing machine despite the simpleness of this idealized learning model and the actual complex behaviour of neurons.

However, after precise mathematical analysis, **Minsky and Papert (1969)** pointed out that the perceptron was not able to solve some nonlinear separable problems, including the computation of the parity function typified by the XOR function, due to architectural limitation and lack of a powerful learning scheme for the general feed-forward multi-layer system. This critical analysis by itself almost ended research in neural networks in the 1970s. It wasn't until Hopefield's associative memory and energy approach in 1982 that research partially started again in the neural network field. The introduction of back propagation neural networks using a sigmoidal activation function and the development of the generalized delta rule defined the beginning of a new generation of multi-layer neural networks.

4.3 Application of ANN Based Models

Artificial Neural Network (ANN) models serve a multitude of applications across industries. They power advancements in image and pattern - recognition, enabling tasks like facial recognition and medical image analysis. In natural language processing, ANNs excel in sentiment analysis, machine translation, and chatbot development, revolutionizing how we interact with technology. These models are instrumental in forecasting, used for predicting stock prices, weather patterns, and trends in various fields. In healthcare, ANNs aid in disease diagnosis, patient outcome prediction, and drug discovery by analysing complex medical data. They're also vital in autonomous vehicles, powering decision-making processes for self-driving cars. From financial services to energy optimization, manufacturing, and cybersecurity, ANNs adapt and learn from data, driving innovations and solutions in diverse domains. Their versatility and ability to discern intricate patterns make them a cornerstone of modern technological advancements. A representative overview of the wide range of ANN based models, that have been implemented is presented here.

An ANN based model for material behaviour prediction was presented by **Ghaboussi et.al** ***(1991)*** where material behaviour was represented in a unified environment of a neural network directly trained from experimental data using the self-organizing capabilities of ANN.

Ahmed et al. (2008) modelled Ground Motion Prediction Equations for three peak ground motion parameters namely, **PGA, PGV and PGD** using ANN. The dataset comprised of 358 records (two horizontal components at each station) from 42 shallow earthquakes in Europe with Magnitude (Ms) from 5.5 to 7.9. The model was trained using 75 percent data and the remaining data of 25 percent was used to test the performance of the trained ANN.

The input variables consisted of magnitude, a distance parameter and a classification based on soil type.

Wong et al. (1992) trained a network to map a vector of inputs describing an earthquake event, local geology and location data onto an output providing a forecast of its intensity at the position denoted.

Khanduri et al. (1995) used a back-propagation neural network to infer wind pressure on buildings.

Hammal et al. (2018) used neural network approach for prediction of influence of seismological parameters on PGA.

Moreover, artificial neural networks (ANNs), in conjunction with other sophisticated algorithms such as Fuzzy Logic and Genetic Programming, are utilized for the purpose of forecasting geotechnical and geo-environmental challenges, offering accurate solutions and minimizing carbon emissions in geotechnical operations. The incorporation of ANNs with seismic wave velocity data has demonstrated enhanced predictive capability in anticipating factors like water content and dry density, surpassing conventional multilinear regression techniques.

Chao et al. (2018) reviewed the principles of ANN algorithms and their application in Geotechnical Engineering. This review suggested that ANN can classify soil accurately and is able to group rock mass, predict the stability of slopes exactly which could be used for risk assessment.

Shahin et al. (2000) recently conducted a study that involved similar methodologies aimed at predicting the settlement of shallow foundations on cohesionless soils. The research utilized 272 data records for the purpose of modelling. The primary input variables deemed to exert the most substantial influence on settlement prediction were the width and length of the footing, the pressure applied on the footing, and the compressibility of the soil. A comparison was made between the results obtained from Artificial Neural Networks (ANN) and three widely recognized traditional techniques, namely Meyerhof (1965), Schultze and Sherif (1973), and Schmertmann et al. (1978). The outcomes of the investigation validated those reported by Sivakugan et al. (1998), demonstrating the superior predictive capabilities of ANNs over conventional methods.

The ANN model exhibited notably high correlation coefficients (r), minimal root mean squared errors (RMSE), and low mean absolute errors (MAE) in contrast to the alternative methodologies, as illustrated in Table.

Category	**ANN**	**Meyerhof (1965)**	**Schultze & Sherif (1973)**	**Schectman et al. (1978)**
Correlation	0.99	0.33	0.86	0.70
RMSE (mm)	3.9	27.0	23.8	45.2
MAE (mm)	2.6	20.8	11.1	29.5

Table - 4.2 Comparison of predicted vs measured settlements (Shahin et al. 2000)

It is apparent that Artificial Neural Networks (ANNs) outperform, or perform equally well as, the traditional methods utilized as a reference point in numerous scenarios, although they exhibit inadequacy in some cases.

Several problems encountered in geotechnical engineering are highly intricate and not fully comprehended. The majority of mathematical models aiming to address such issues compensate for the lack of physical insight by either simplifying the problem integrating multiple assumptions into the models.

These models also depend on presupposing the model's structure in advance, which could be suboptimal. Consequently, numerous mathematical models struggle to replicate the intricate behaviour of most geotechnical engineering problems.

Conversely, ANNs are solely based on data, allowing the model to be trained on input-output data pairs to ascertain the model's structure and parameters. In this scenario, there is no necessity to simplify the problem or incorporate any Despite excelling in numerous scenarios, ANNs are afflicted by various limitations, notably the absence of a theoretical foundation to aid in their advancement, uncertainty in achieving a satisfactory solution, and their restricted capacity to elucidate how they leverage available information to reach a solution. Hence, there is a requirement to establish guidelines to assist in the development of ANNs.

4.4 Summary

The utilization of Artificial Neural Network (ANN) based models for predicting the attenuation of Spectral Acceleration (SA) shows great potential within the realm of earthquake engineering. Through training on extensive datasets containing seismic event characteristics, geological data and recorded SA values, ANNs can effectively forecast the decrease in SA as the distance from the earthquake source increases.

Literature reviews indicate that ANN-based models outperform traditional regression models in terms of accuracy and reliability for predicting SA Attenuation. Studies have shown that ANNs can significantly minimize prediction inaccuracies and offer more reliable insights into seismic risks.

Ultimately, the integration of these models in seismic inquiries cultivates a proactive Approach towards earthquake readiness, potentially lessening the likelihood of structural collapses and enhancing public safety,

CHAPTER 5

OBJECTIVE

5.1 Objective

The prime objective of the whole project-

1) To study the attenuation of ground motion parameters for some selected earthquakes and understand the concept of Response Spectrum in seismic design of structures.

2) To develop an attenuation relationship using Artificial Neural Network for North-East India which can predict the ground motion parameters for an earthquake and compare it with some of the earthquakes that have already occurred

CHAPTER 6

METHODOLOGY

6.1 What is ANN Prediction Model?

An Artificial Neural Network (ANN) prediction model is a computational model inspired by the human brain's neural structure. It comprises interconnected nodes(neurons) organized in layers: an input layer receives data, hidden layers process information and an output layer generates predictions or classifications.

Through a process called training, where the network learns from labelled data ANN adjusts its connections (weights) between neurons to minimize prediction errors. Once trained, the model can make predictions or classify new, unseen data based on the patterns it has learned during training.

6.2 ANN Based model for prediction of Spectral Acceleration

The model developed in this study is based on artificial neural networks and is created using the ANN Toolbox within MATLAB. This software enables users construct shallow neural networks efficiently for the purposes of predicts and curve fitting. Spectral Acceleration holds significant importance in the field of earthquake engineering, as it signifies the peak acceleration experienced by a structure while vibrating at specific natural frequencies and damping ratios.

For analysis of seismic data, an artificial neural network has the capability to learn and forecast Spectral Acceleration values for various earthquake layout which could potentially enhance methodologies for designing earthquake resistant structures.

However, work on developing attenuation relations for Spectral Acceleration (Sa) is still very limited. The most suitable attenuation relation for Sa in India can vary depending on the specific geographical area.

A statistically simulated empirical relation has been suggested for Peninsular India (PI) below 24°N latitude to estimate 5% damped response spectra based on magnitude and source-to-site distance, taking into account the geological conditions of bedrock and soil. In the North-East -Himalayan region, a relationship for empirical attenuation of peak horizontal ground accelerations has been formulated using data from strong-motion arrays and the Strong Motion Network project, offering valuable insights for site- specific studies and hazard assessment.

Furthermore, a proposed attenuation relationship for peak horizontal ground accelerations in the Himalayan region highlights the importance of further research with a larger dataset to enhance the accuracy as more data become accessible.

Therefore, in this study an attempt has been made to develop an attenuation relation for Spectral Acceleration specially for North-East India using artificial neural network as an alternative to regression methods.

6.3 Neural Attenuation Model for this Research Study

The utilization of the trial-and-error method is essential when it comes to the selection of the most optimal configuration for neural network models in the prediction of earthquake data. This is primarily attributed to the intricate nature and non-linear characteristics that are inherent in earthquake data. This particular strategy enables the empirical examination necessary to pinpoint a network framework that can effectively encompass the diverse relationships present within the data. The complexities within earthquake data, such as magnitude and focal depth, interact in intricate, non-linear manners that pose challenges in terms of theoretical modelling.

Here, Neural Network Tool (nntool) from MATLAB (R2016a) is used and the algorithm considered is Feed Forward back propagation (FFBP) algorithm in which output nodes are back -propagated through the connections to re-configure the network. This feature makes FFBP popular for predicting complex non-linear systems.

6.4 ANN Optimization Method

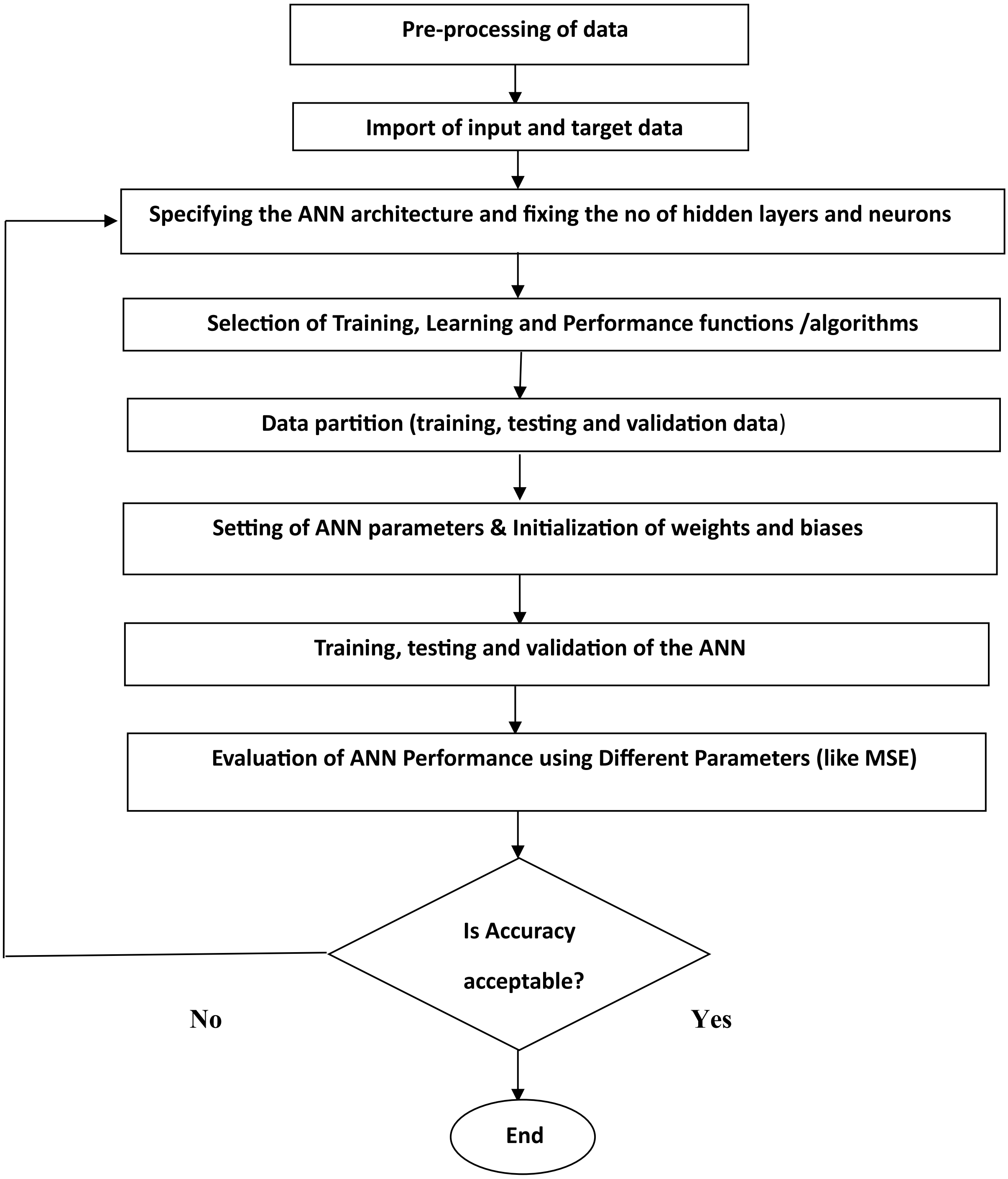


Figure 6.1 : Flowchart of ANN Optimization Method

6.4.1 Schematic Representation of ANN Model

The general architecture of an Artificial Neural Network (ANN) comprises three main layers: **input layer, hidden layer(s), and output layer** connected via neurons. The data flows from the input layer to the output layer via the hidden layer(s). The intensity of the connection of these neurons is represented by their weights. All neurons in one layer are connected to all other neurons in the next layer. The neurons within a layer are not connected.

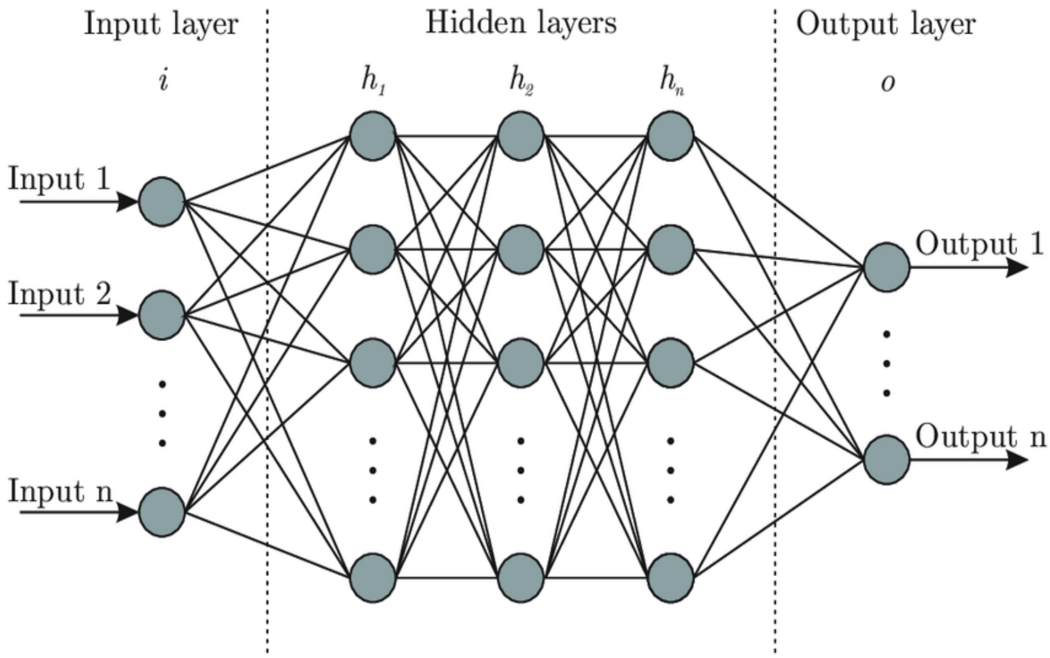


Figure 6.2: Schematic diagram of typical neural network topology

The propagation of the signal in the network is done by the neurons. In the input layer, input nodes are available, the number of which is decide by the number of independent variables considered in the ANN. The number of neurons required in the output layer is decided by the number of dependent variables. In between, the number of hidden layers and the number of hidden neurons in each hidden layer is decided based on the required complexity of the network model.

An ANN model is built based on examples of data with known outputs. Building an Artificial Neural Network (ANN) involves several key steps. First, the problem should be defined what we want the ANN to solve—whether **it's classification, regression, pattern recognition,** etc. Then, the data is gathered and pre -processed for **training, validation and testing**. The ANN is trained to minimize the error between the computed value from the network and the targeted value. The errors obtained are fed back to the network and the weights are adjusted accordingly to minimize the error. This ensures that the future response of the model is comparatively more accurate.

The value fed to a hidden neuron of the hidden layer is determined by the summation of each input value fed at the input nodes multiplied by its respective weight connecting to that particular hidden neuron. This is done by the **combination function.** Small random numbers are used to initialize the weights. After this step, the transfer function transforms the value of the combination function to give a transformed value which is then fed into the output layer. In the last step, the output neurons repeat the same process as was done by the hidden neurons using their respective weights and transfer functions to produce the final response of the network which are the estimated target values.

6.4.2 Training, Validation and Testing of ANN Model

Training an Artificial Neural Network (ANN) involves multiple iterations where data is fed forward through the network, generating predictions. These predictions are compared to the actual targets using a loss function, quantifying the error.

The first step involves gathering a dataset relevant to the problem the ANN aims to solve. This dataset is then divided into **training, validation, and test sets**. The training set is used to teach the network, the validation set helps in tuning hyperparameters, and the test set assesses the model's performance. The network's architecture (number of layers, neurons, etc.) is defined, and the weights and biases of the neurons are **initialized** randomly.

During training, data from the training set is fed into the network, and the input values pass through the network's layers via a process called **forward propagation**. Each neuron computes a weighted sum of its inputs, applies an activation function, and passes the result to the next layer.

The **outpu**t of the network is compared to the actual target values from the training set. The difference between the **predicted output and the actual output** is measured using a loss or cost function, which quantifies the network's performance. There are many transfer functions that can be used such as threshold functions, Linear functions and sigmoid functions. Together the combination function with the transfer function is known as the activation function. Sigmoid functions are more popular transfer functions due to their non-linearity. These are "S-Shaped "functions. When the weighted sum of the inputs is near zero the sigmoid function approximates a linear function. As the value of the weighted sum gets larger, the transfer function gradually saturates and transforms itself from a linear model to a non-linear model. The network adjusts its weights and biases to minimize the error calculated in the previous step. This process involves propagating the error **backward** through the network, using techniques like **gradient descent** to update the weights and biases in a direction that reduces the error.

The testing phase manifests in two steps, namely testing and validation. Here an appropriate model has to be selected amongst all other competitor models. The best -performing model is chosen based on the evaluation from the validation dataset and its accuracy is tested. Hence, the dataset is grouped into three parts: training, validation and testing. If the dataset is not large enough to ensure proper splitting of the dataset into representative subsets, other methods such as cross-validation may be used.

The iterative process of **forward and backward propagation** continues for multiple epochs (iterations), gradually improving the network's ability to make accurate predictions by minimizing the loss function.

The model's performance is evaluated using the validation set to tune parameters and prevent **overfitting.** The phenomenon of over-fitting is generally caused by having too many hidden layers in the network or too many neurons in the hidden layers. Also, the number of iterations may also be responsible for causing over-fitting of the network. To avoid over-fitting, determining the parameters of the network by trail and error is most convenient.

Another problem may arise where the network works fine on then training data but performs poorly on the testing dataset. Here, the network is unable to learn the desired function. This is referred to as under-fitting which occurs when the network is too simple or when the training data contains noise . Finally, the performance is assessed on the test set to gauge how well the model generalizes to new, unseen data.

The process of "**ANN database calculation**" isn't a specific step; instead, it involves training the network on a dataset by adjusting weights and biases iteratively to learn patterns and relationships within the data, enabling the network to make accurate predictions or classifications.

6.5 Possible method that can be applied for Prediction of Attenuation of Spectral Acceleration in North-East India

Seismic data must be gathered specific to the North-East region, including Earthquake records, ground motion data, geological information and distances from seismic sources.

The collected data should be cleaned and pre-processed ensuring consistency and compatibility. Preparing features such as earthquake magnitude, distance from seismic sources, soil type, and other geological parameters that influence attenuation.

A dataset should be created combining seismic features (like earthquake magnitude, epicentral distance) with corresponding spectral acceleration values observed in the region.

MATLAB's Neural Network Toolbox should be used to **design** and create an ANN. The network architecture must be defined specifying the number of layers, neurons, activation functions, and other parameters suitable for regression tasks. The dataset must be divided into training, validation, and test sets using MATLAB's built-in functions for data partitioning. The ANN should be used using the training dataset. Utilizing MATLAB's neural network training functions (e.g., train Network, fit net) along with optimization algorithms like stochastic gradient descent to minimize errors and adjust network parameters.

The trained model's performance should be validated using the validation dataset. Fine-tune the ANN's hyperparameters (e.g., learning rate, number of neurons) to optimize the model's accuracy without overfitting.

The trained ANN's performance must be assessed using the test dataset. Utilizing MATLAB's evaluation functions to measure the model's accuracy, such **as mean squared error (MSE)** or **root mean squared error (RMSE).**

The trained ANN should be deployed to predict spectral acceleration attenuation for new seismic events or locations within the North-Eastern Region by inputting relevant seismic features into the trained network.
MATLAB provides a comprehensive environment with its Neural Network Toolbox that includes functions for **data manipulation, model creation, training, validation, and evaluation.**

6.6 Summary

The methodology of an Artificial Neural Network (ANN) prediction model comprises a series of steps: data collection, preprocessing, model selection, training, validation and testing. Initially, data is gathered and standardized before being divided into training and testing datasets. The selection of the model's architecture is determined by the complexity of the issue at hand, often involving multiple layers of interconnected neurons. Throughout the training process, the model adjusts weights through backpropagation in order to minimize errors. A regression score of 1, which indicates a perfect match with the training data, means that the training is successful.

CHAPTER 7

AREA OF STUDY

7.1 Introduction

The North -East region of India stands as a seismically active zone experiencing numerous earthquakes owing to its complex tectonic setting. A strong motion data curated from earthquakes in this region serves as a critical foundation for developing Ground Motion Prediction Equations (GMPEs).

These equations are instrumental in estimating the ground motion characteristics during seismic events, enabling accurate seismic hazard assessment and facilitating robust engineering designs for infrastructure resilience

7.2 Area of Study

The Indian Standard code **IS 1893 (Part 1) :2016** divides the country into four Seismic zones: **II, III, IV and V** with **Zone V** being the most vulnerable zone. The primary focus of studying earthquakes in Zone V of India, particularly in the North-East region, revolves around comprehensive seismic hazard assessment. This helps Understanding fault characteristics, seismicity patterns and ground motion features or characteristics specific to this region. The goal is to develop tailored engineering design criteria, assess structural vulnerabilities, and formulate effective mitigation strategies to enhance infrastructure resilience and minimize the socio-economic impact of seismic events.

In this study, all the earthquakes considered had occurred in either Zone IV or Zone V, while a handful had also occurred outside India in the neighboring countries of Nepal and Bhutan which will be mentioned in next session of the project. Some of the great historically significant earthquakes that occurred here are-

1. The Assam -Tibet Earthquake of 1950 (Magnitude of approx. 8.67)
2. The Sikkim Earthquake of 2011 (Magnitude of 6.9)
3. The Bihar-Nepal Earthquake of 1934 (Magnitude around 8)
4. The 1897 Shillong Earthquake

The northeastern region (NER) of India lies in seismic zone V as per IS 1893 (2002) in country and is considered one of the most seismically active zones in the world. It has very complex tectonics and geological setup.

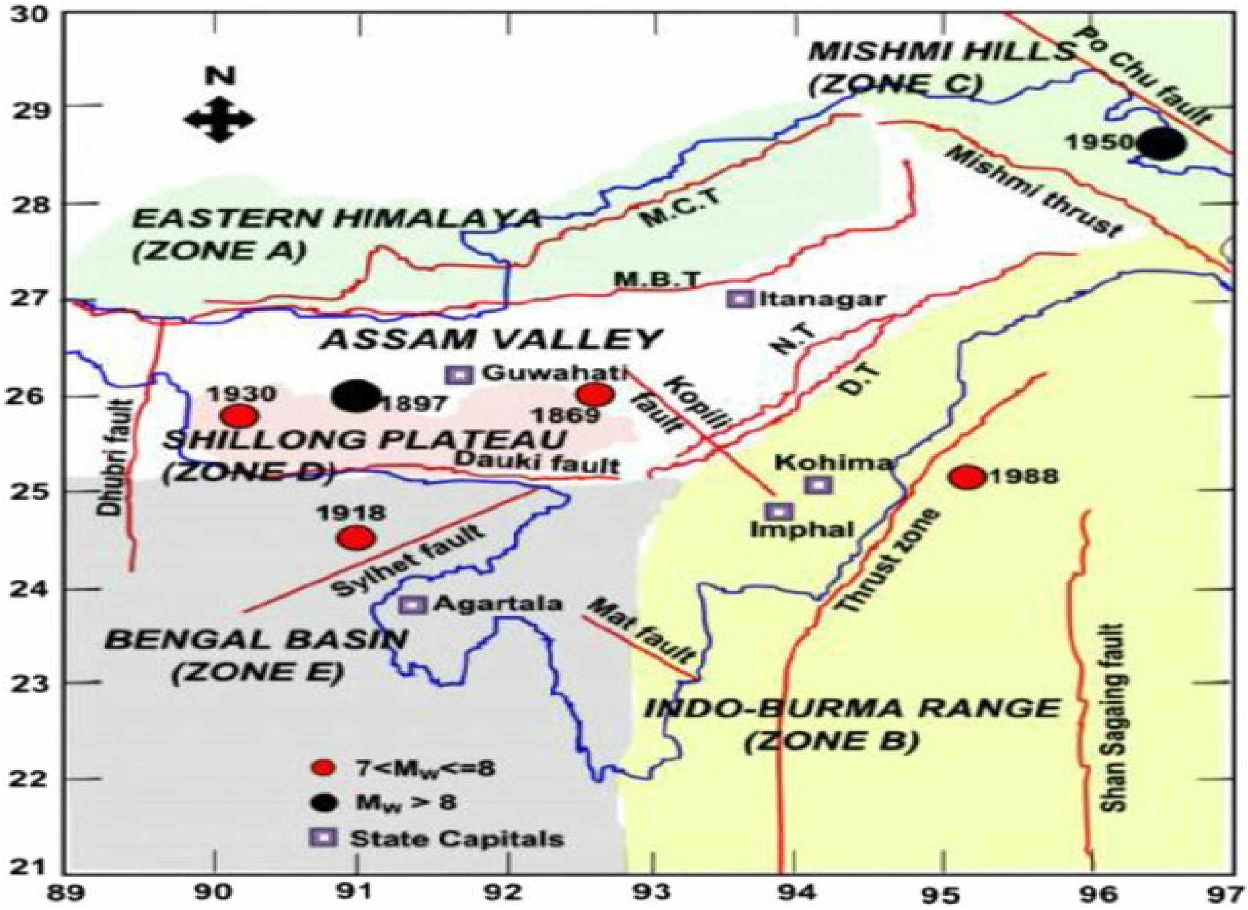


Figure 7.1 - Seismo-tectonic map of North East India showing epicentres of damaging earthquakes

1. Tectonic zones (zones A, B, C, D and E) and major thrusts (MBT-Main Boundary Thrust; MCT-Main Central Thrust; NT-Naga Thrust; DT-Disang Thrust) are also shown.

2. Thick blue line represents the international boundary of North Eastern part of India bordering Myanmar and Bangladesh (not to scale) and red lines represents faults and thrusts.

$7 < M_W <= 8$ where $\boldsymbol{M_w}$ represents **Moment Magnitude**

$M_W > 8$

7.3 Strong-Motion Dataset

India has relatively strong ground motion records compared to other seismically active countries like Japan, USA and China. Hence, the records for the study are obtained from two sources, namely, the Consortium of Organizations for Strong-Motion Observations Systems (COSMOS) and the Program for Excellence in Strong – Motion Studies (PESMOS).

The records composed of earthquakes records of local as well as regional earthquakes occurred in and around the North-Eastern Region from the year 1980 to 2013.

Nath et al. (2009) proposed a GMPE for Guwahati City using local earthquake records recorded by the Indian Institute of Technology**,** Guwahati strong motion network to simulate historical events such as the 1897 Shillong Earthquake, the 1934Nepal -Bihar, the 1950 Assam and the 1988 Manipur Earthquakes.

The authors used geotechnical data acquired by Assam Engineering College, Guwahati at 200 borehole locations in and around Guwahati to corroborate site amplification values with those calculated from strong motion -data. The GMPE thus, developed is valid for the magnitude (Mw) range of 4.8-8.1 and up to 100 km hypo-central distance only.

7.3.1 Consortium of Organization for Strong -Motion Observation System (COSMOS)

COSMOS brings together various organizations, including research institutions, government agencies, and engineering firms, to collaborate on the development and maintenance of strong-motion databases. Earthquake records can be searched region wise across the world.

COSMOS Strong- Motion Virtual Data Centre (VDC) consists of a list of of earthquakes that occurred in India between 1986 and 2001 which were recorded on instruments installed by the Department of Earthquake Engineering, IIT-R.
In 1982, the National Science Foundation, USA funded by department of Earthquake Engineering, IIT-R for the installation of 50 analog accelerographs in the Shillong -region of North-East India.

7.3.2 Program for Excellence in Strong -Motion Studies (PESMOS)

PESMOS is the strong motion instrumentation network operated by IIT-R. A total of 298 strong motion accelerographs were installed from Jammu & Kashmir in the western part to Assam and Meghalaya in the east which lie in the seismic zone V, IV and III of the Indian seismic zoning maps, in a project sanctioned by the Department of Science and Technology (DST), Government of India. The average spacing of recording stations was kept at 40-50 km in plain areas and less than 25-35 km in hilly terrains. Most of the stations were connected to Roorkee for health monitoring of instruments and data downloading using tele-communication links.

7.3.3 Pacific Earthquake Research Centre (PEER): PEER provides access to seismic hazard databases and models, including ground motion prediction equations and spectral acceleration values for seismic risk assessment.

7.4 EARTHQUAKE DATA FOR ANALYSIS

Here some earthquakes are taken which have occurred in North-East part of India and few adjoining areas of West- Bengal, Myanmar and Tibet.

The time period of three buildings are taken for each station and their corresponding Spectral Acceleration values are noted.

T_1 = Time period of 1^{ST} building
T_2 = Time period of 2^{nd} building
T_3 = Time period of 3^{rd} building

A plot between Time period and Sa/g values is done for each station in order to have a clear picture how different structures responds to same earthquake motion. The trend of how acceleration values decrease with increase in time period having different site classes is the prime scenario to look out for.

Earthquake Datasets

DATASET -1:

Station Name = Boko, Region = Bhutan

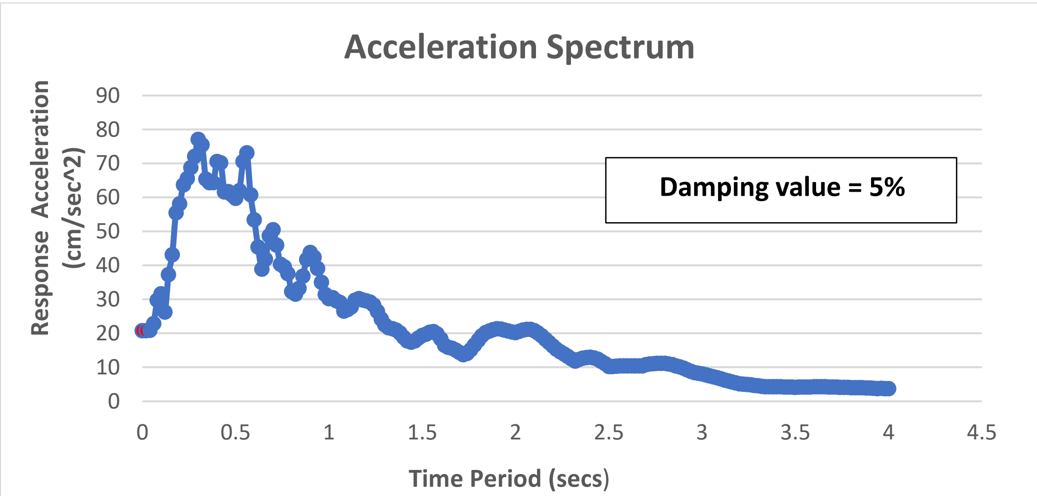
Site class **C:** Soft soil site

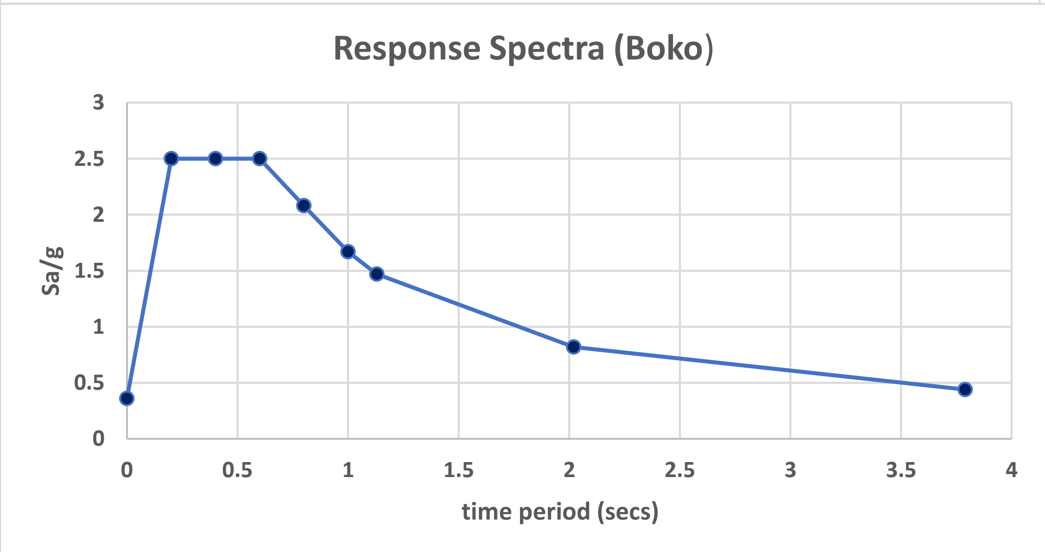
Earthquake date and Time = 21-Sep 2009 Org. Time= 8:53:04 (Dir: EW)
T_1 = 1.13 secs Sa/g = 1.47

Magnitude (M) = 6.2
T_2 = 2.02 secs Sa/g = 0.82

Focal Depth (d) = 8.0 Km
T_3 = 3.79 secs Sa/g = 0.44

Epicentral Distance (ED) = 148 km





Station Name = Goalpara, Region = Bhutan

Site class **C**: Soft soil site

Earthquake date and time = 21 Sep 2009 Org. Time = 8:53:04 (Dir: EW)

T_1 = 1.19 secs Sa/g = 1.40

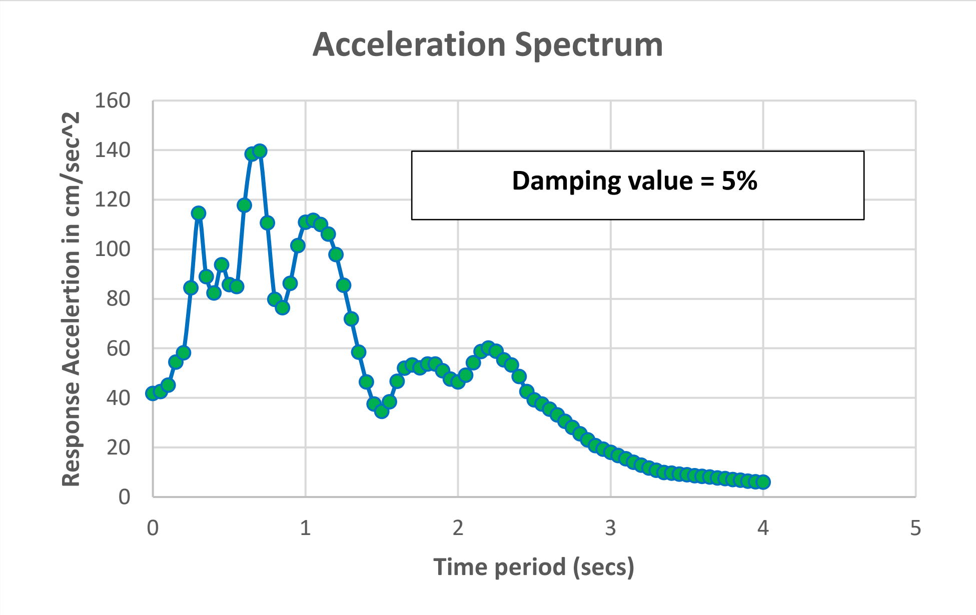
Magnitude (M) = 6.2

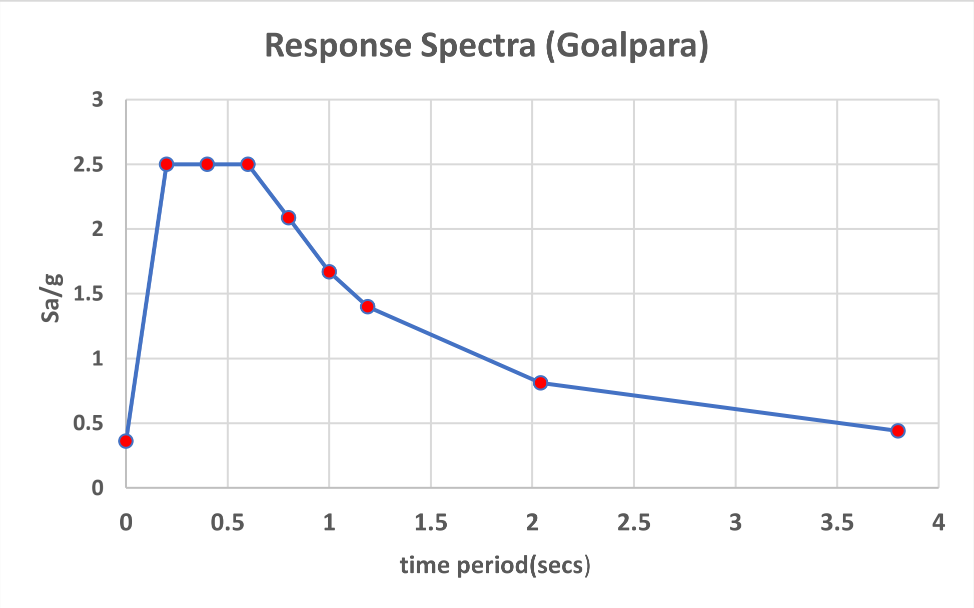
T_2 = 2.04 secs Sa/g = 0.81

Focal Depth (d) = 8.0 km

T_3 = 3.80 secs Sa/g = 0.43

Epicentral Distance (ED) = 153 km





Station Name = Guwahati, Region = Bhutan

Site Class **C**: Soft soil

Earthquake date and Time = 21 Sep 2009 Org. Time = 8:53:04 (EW)

T_1 = 1.23 secs Sa/g = 1.35

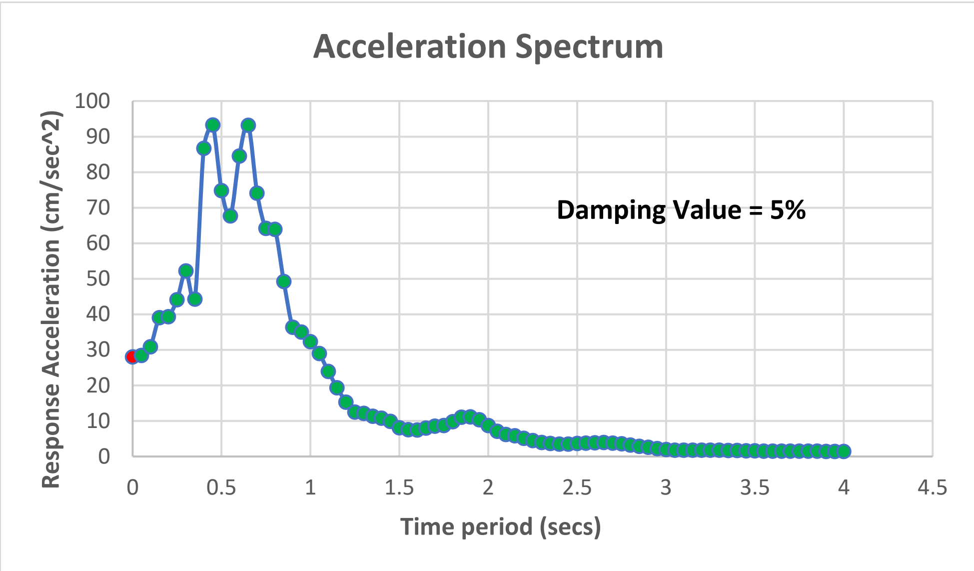
Magnitude (M) = 6.2

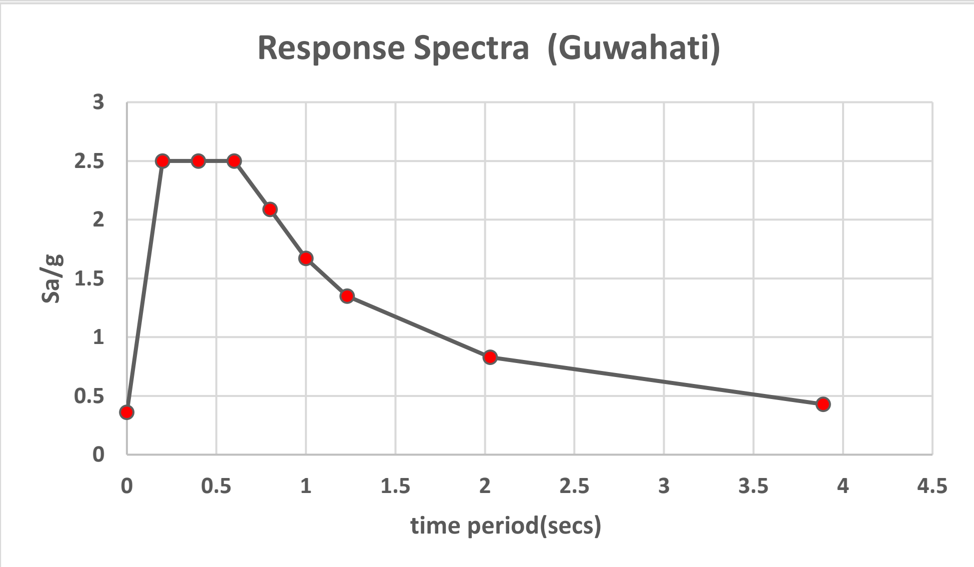
T_2 = 2.03 secs Sa/g = 0.83

Focal Depth (d) = 8.0 km

T_3 = 3.89 secs Sa/g = 0.42

Epicentral Distance (ED) = 125 km





Station Name = Nongstoin, Region = Bhutan

Site Class **A: rocky/hard soil**

Earthquake date and Time = 21 Sep 2009 Org. Time = 8:53:04 (EW)

T_1 = 1.28 secs Sa/g = 0.78

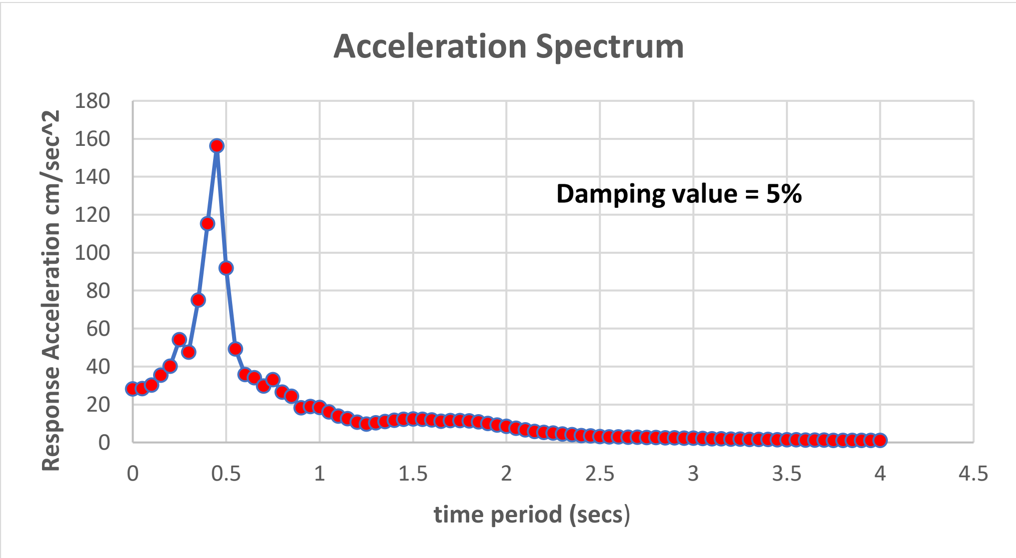
Magnitude (M) = 6.2

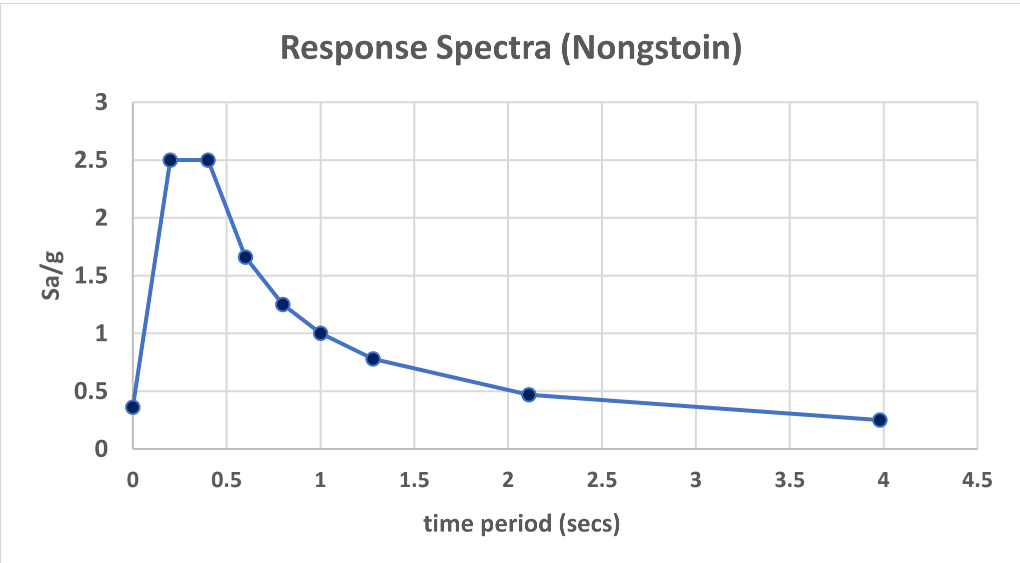
T_2 = 2.11 secs Sa/g = 0.47

Focal Depth (d) = 8.0 km

T_3 = 3.98 secs Sa/g = 0.25

Epicentral Distance (ED) = 197 km





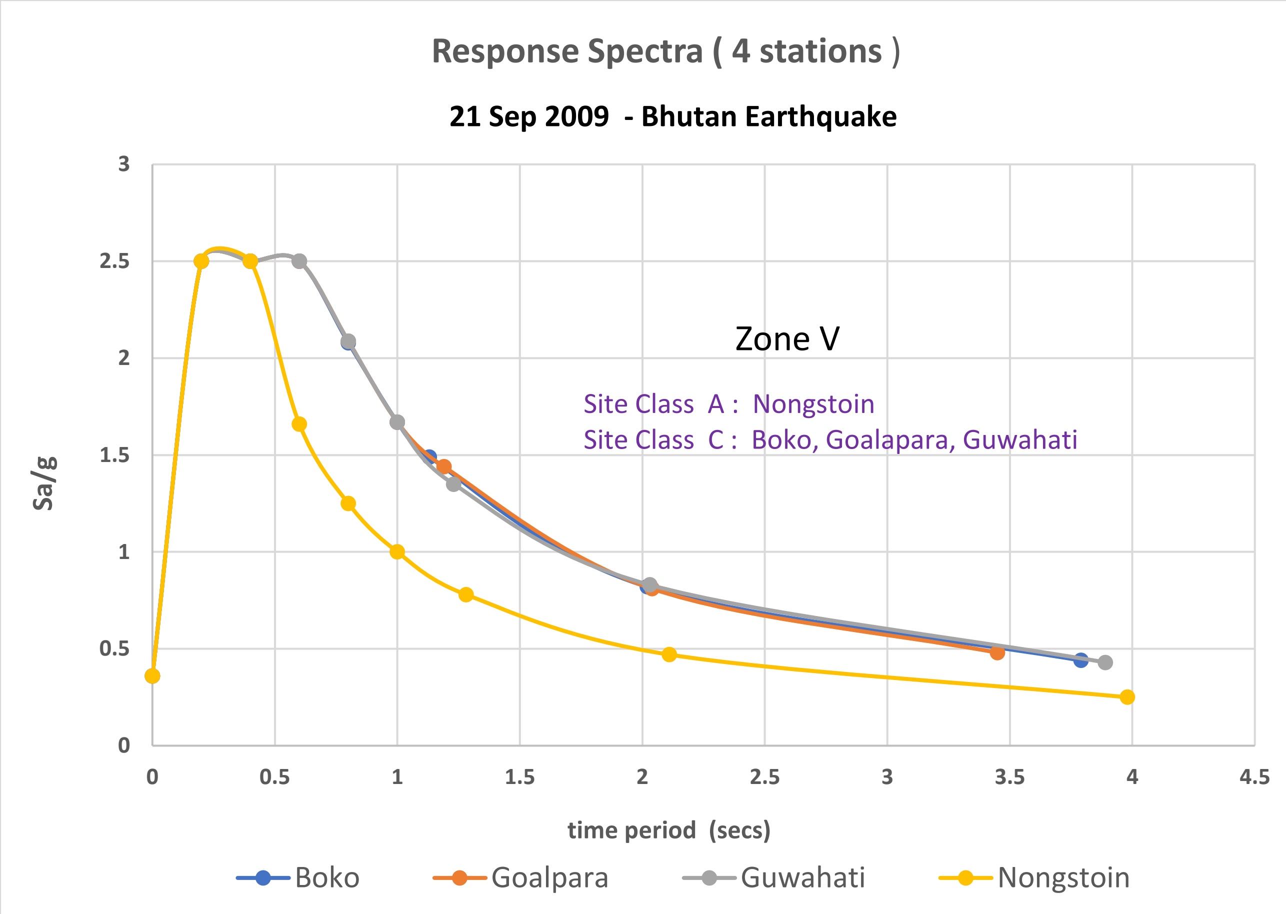


Figure 7.1 : Plot between time period vs Sa/g of 21 Sep 2009 Bhutan Earthquake

DATASET 2

Station Name = Barpeta Region = Assam – Meghalaya border

Site Class **C**: Soft soil site

Earthquake date and Time = 15 Feb 2009 Org. Time = 07:35:55 (N-S) direction

T_1 = 1.15 secs Sa/g = 1.45

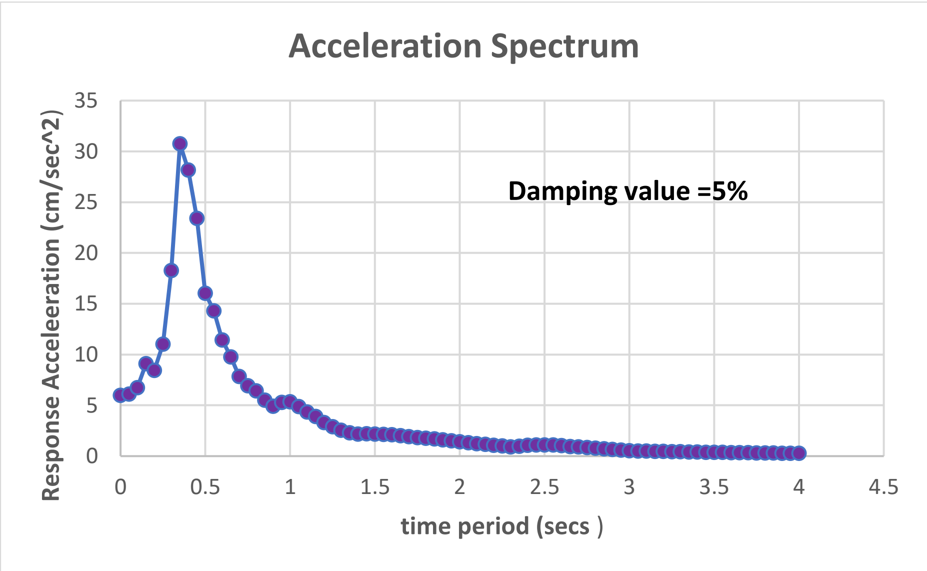
Magnitude (M) = 4.4

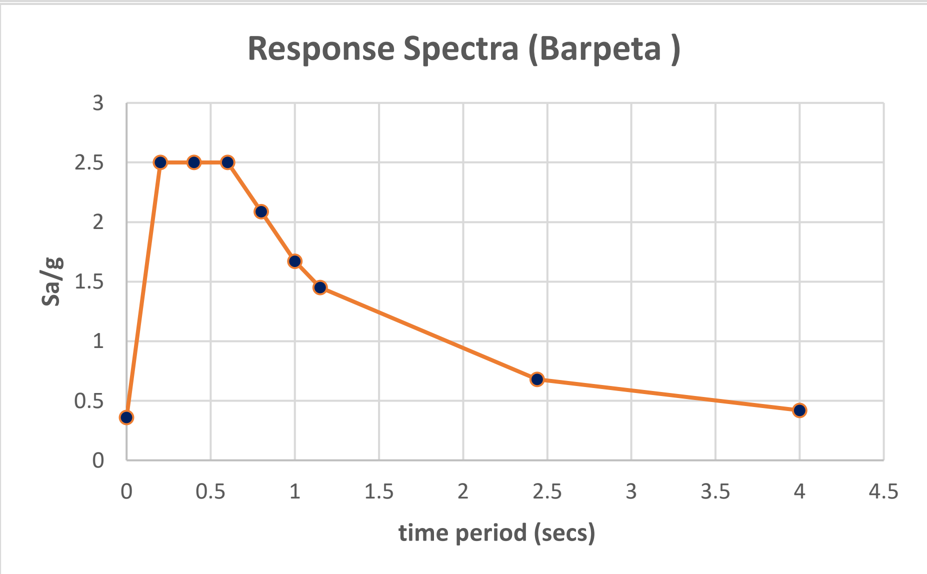
T_2 = 2.44 secs Sa/g = 0.68

Focal Depth (d) = 39.3 km

T_3 = 3.99 secs Sa/g = 0.42

Epicentral Distance (ED) = 88 km





Station Name = Bongaigaon Region = Assam – Meghalaya border

Site Class **C**: Soft soil site

Earthquake date and Time = 15 Feb 2009 Org. Time = 07:35:55 (N-S) direction

T_1 = 1.55 secs Sa/g = 1.07

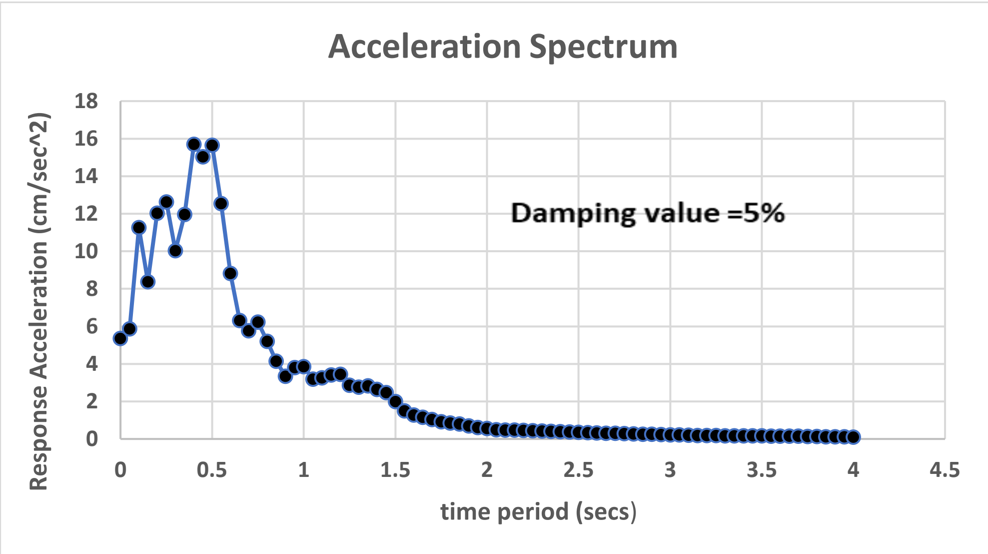
Magnitude (M) = 4.4

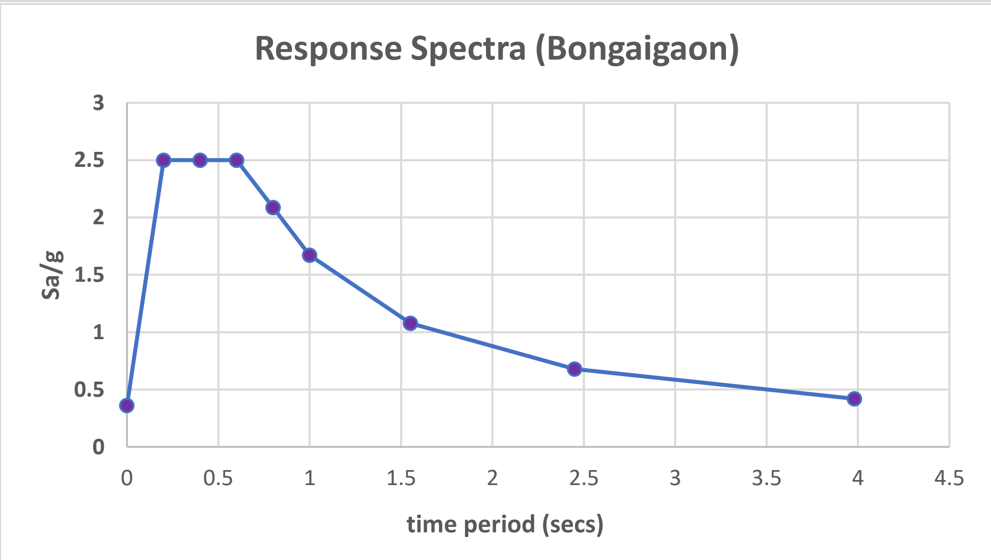
T_2 = 2.45 secs Sa/g = 0.68

Focal Depth (d) = 39.3 km

T_3 = 3.98 secs Sa/g = 0.42

Epicentral Distance (ED) = 64 km





Station Name = Dhubri Region = Assam – Meghalaya border

Site Class **C**: Soft soil site

Earthquake date and Time = 15 Feb 2009 Org. Time = 07:35:55 (N-S) direction

T_1 = 1.12 secs Sa/g = 1.49

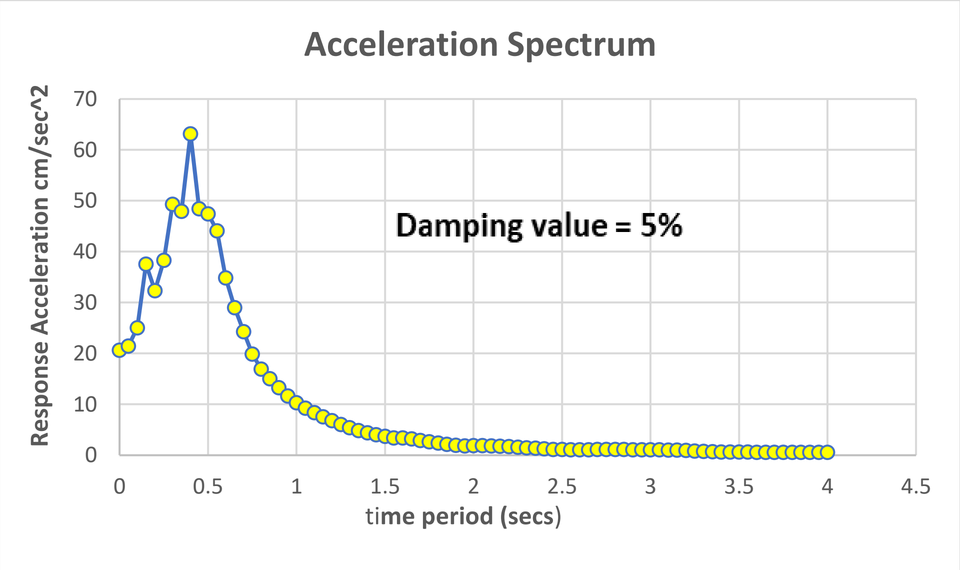
Magnitude (M) = 4.4

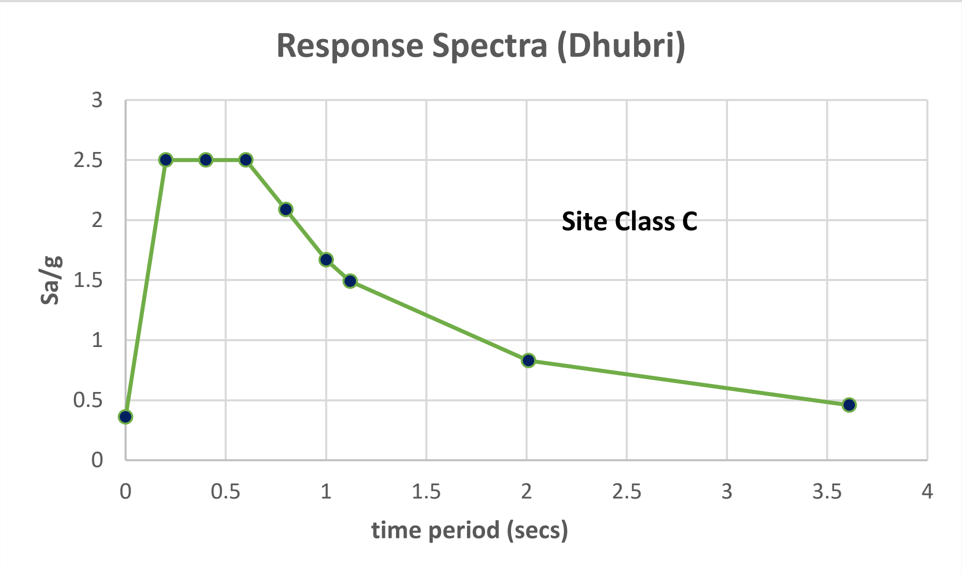
T_2 = 2 .01 secs Sa/g = 0.83

Focal Depth (d) = 39.3 km

T_3 = 3.61 secs Sa/g = 0.46

Epicentral Distance (ED) = 21 km





Station Name = Kokrajhar Region = Assam – Meghalaya border

Site Class **C**: Soft soil site

Earthquake date and Time = 15 Feb 2009 Org. Time = 07:35:55 (N-S) direction

T_1 = 1.01 secs Sa/g = 1.65

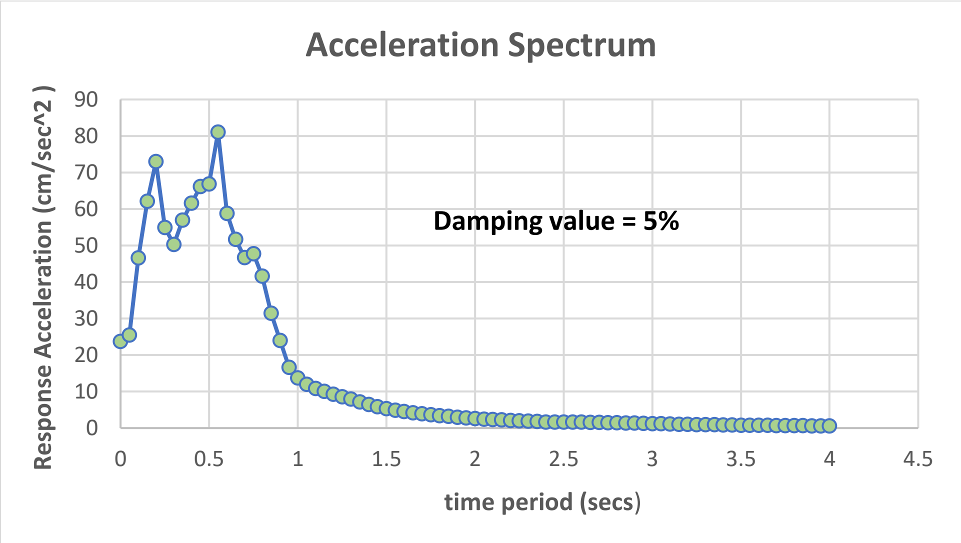
Magnitude (M) = 4.4

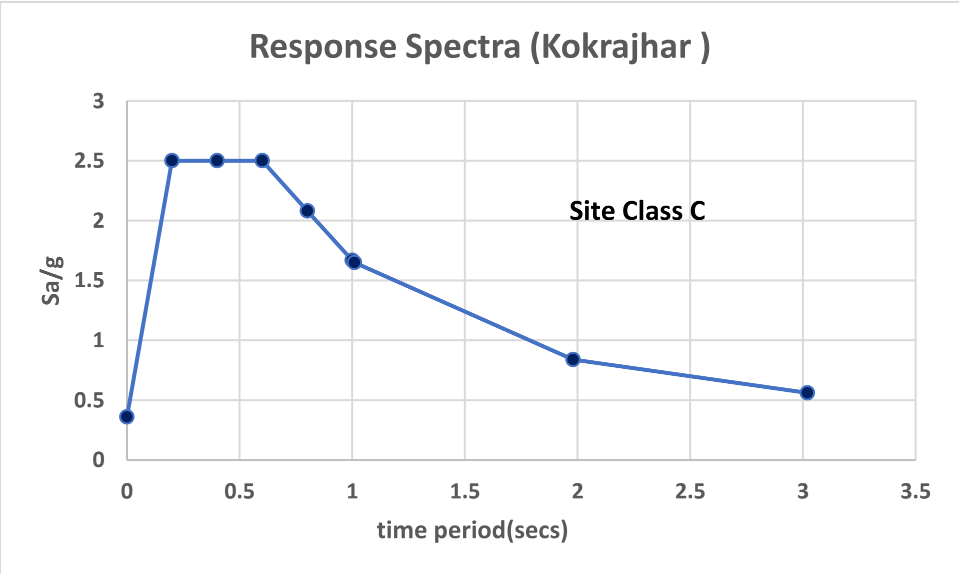
T_2 = 1.98 secs Sa/g = 0.84

Focal Depth (d) = 39.3 km

T_3 = 3.02 secs Sa/g = 0.56

Epicentral Distance (ED) = 45 km





Station Name = Tura Region = Assam – Meghalaya border

Site Class **B**: **Medium Stiff soil sites**

Earthquake date and Time = 15 Feb 2009 Org. Time = 07:35:55 (N-S) direction

T_1 = 1.07 secs Sa/g = 1.27

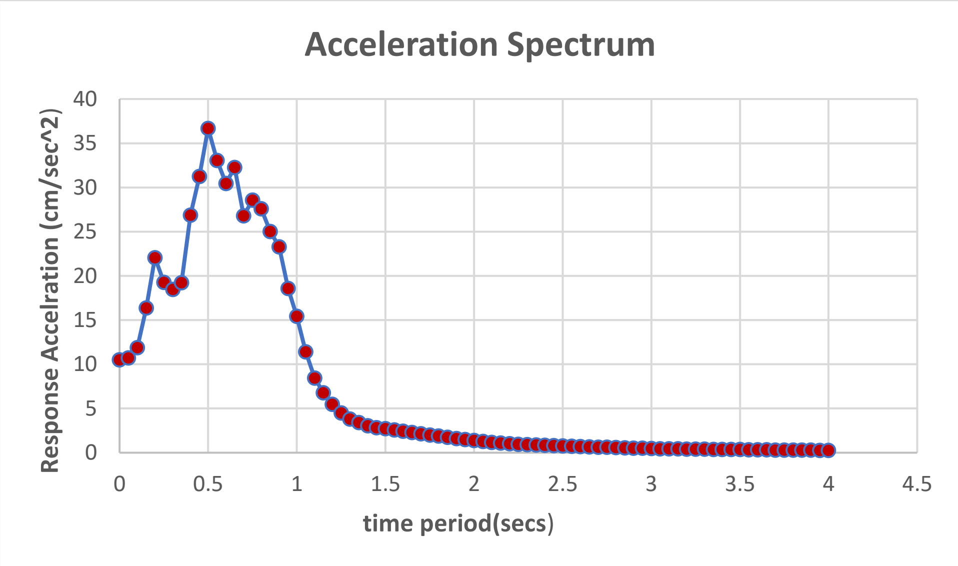
Magnitude (M) = 4.4

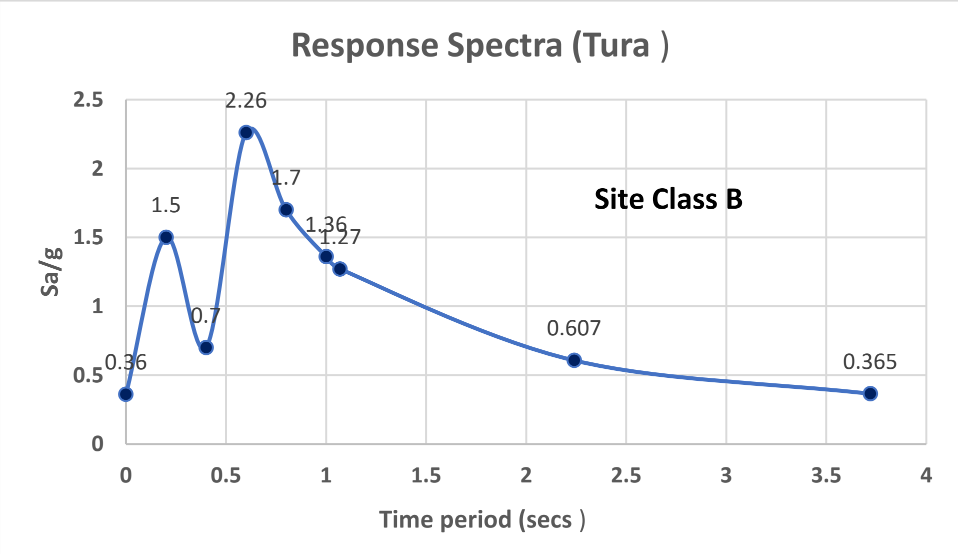
T_2 = 2.24 secs Sa/g = 0.607

Focal Depth (d) = 39.3 km

T_3 = 3.72 secs Sa/g = 0.365

Epicentral Distance (ED) = 55 km





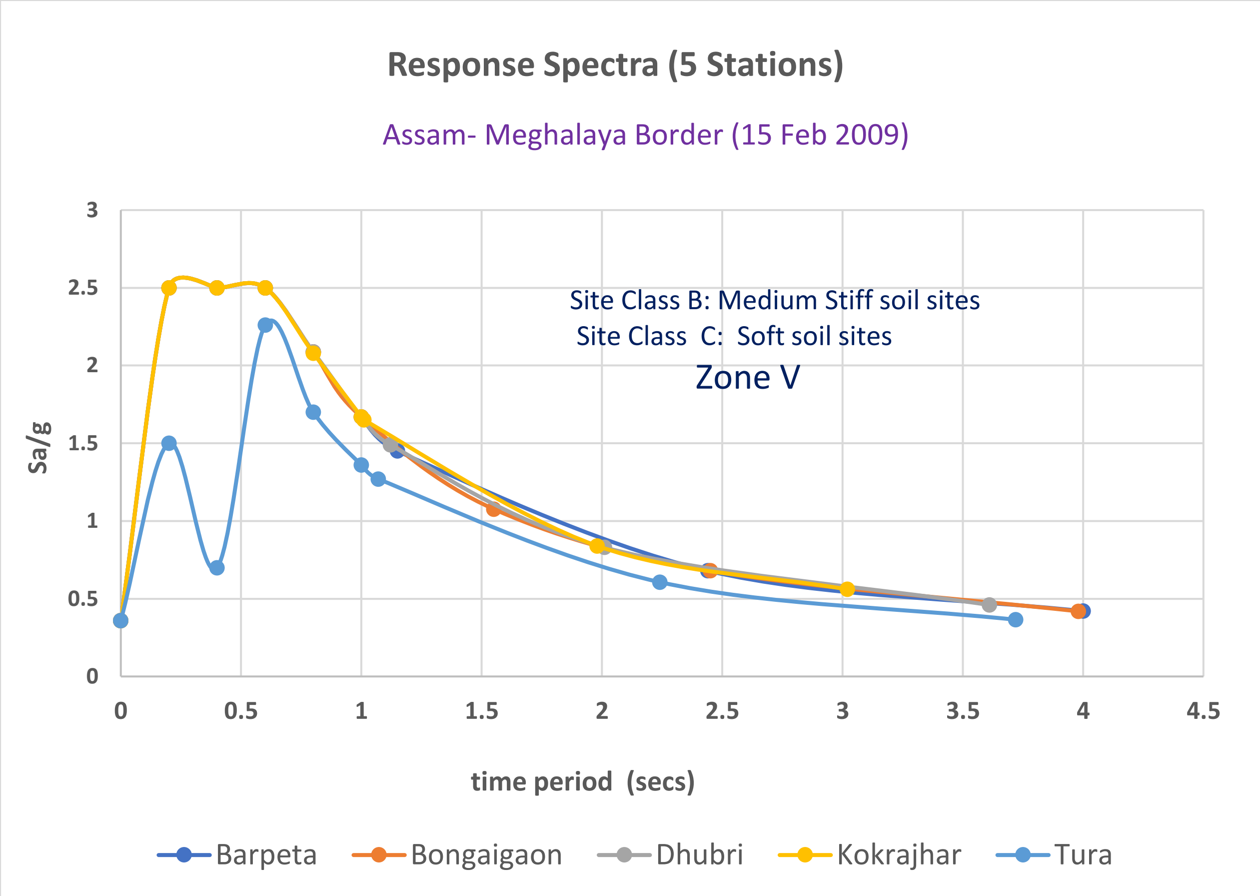


Figure 7.2 : Plot of time period vs Sa/g of 15 Feb 2009 Earthquake

DATASET - 3

Station Name = Bongaigaon Region = Tibet

Site Class **C**: Soft soil site

Earthquake date and Time = 26 Feb 2010 Org. Time = 4:42:33 (N-S direction)

T_1 = 1.22 secs Sa/g = 1.37

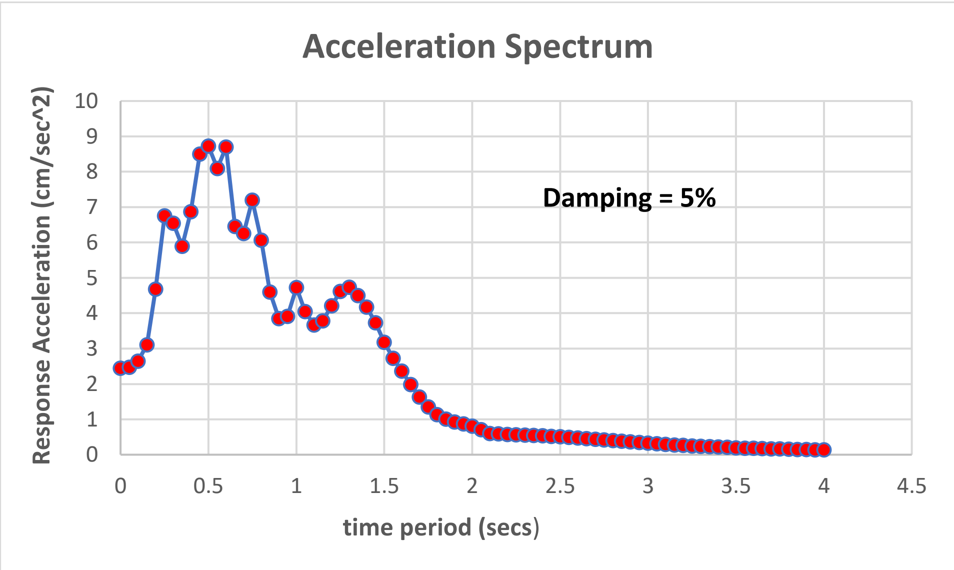
Magnitude (M) = 5.4

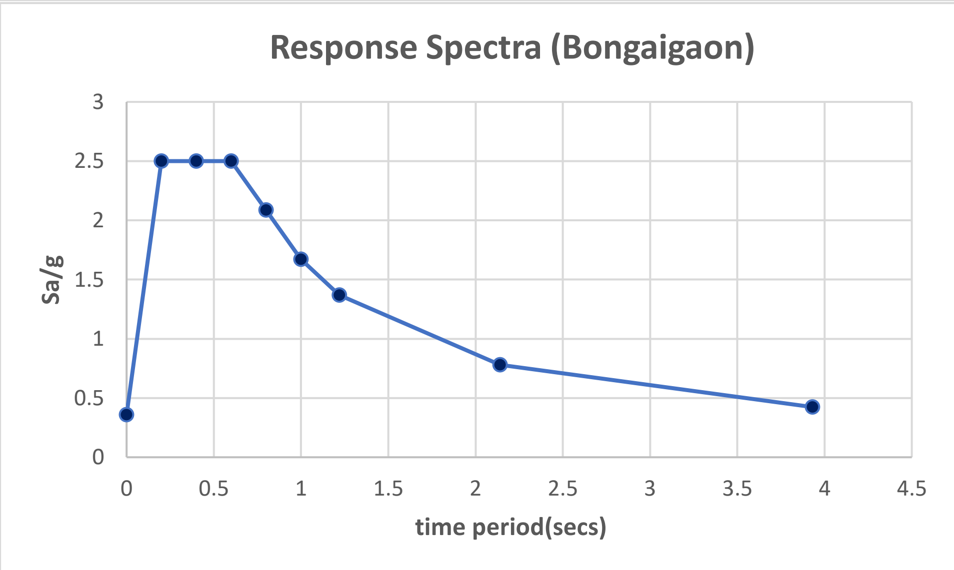
T_2 = 2.14 secs Sa/g = 0.78

Focal Depth (d) = 28 km

T_3 = 3.93 secs Sa/g =0.424

Epicentral Distance (ED) = 443 km





Station Name = Darjeeling Region = Tibet

Site Class **A**: Rocky/hard soil site

Earthquake date and Time = 26 Feb 2010 Org. Time = 4:42:33 (N-S direction)

T_1 = 1.08 secs Sa/g = 0.93

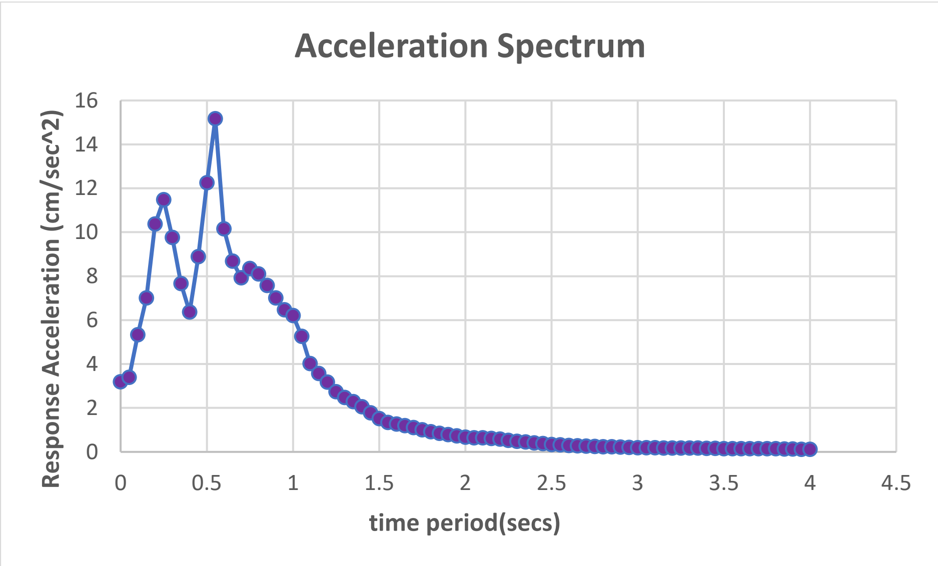
Magnitude (M) = 5.4

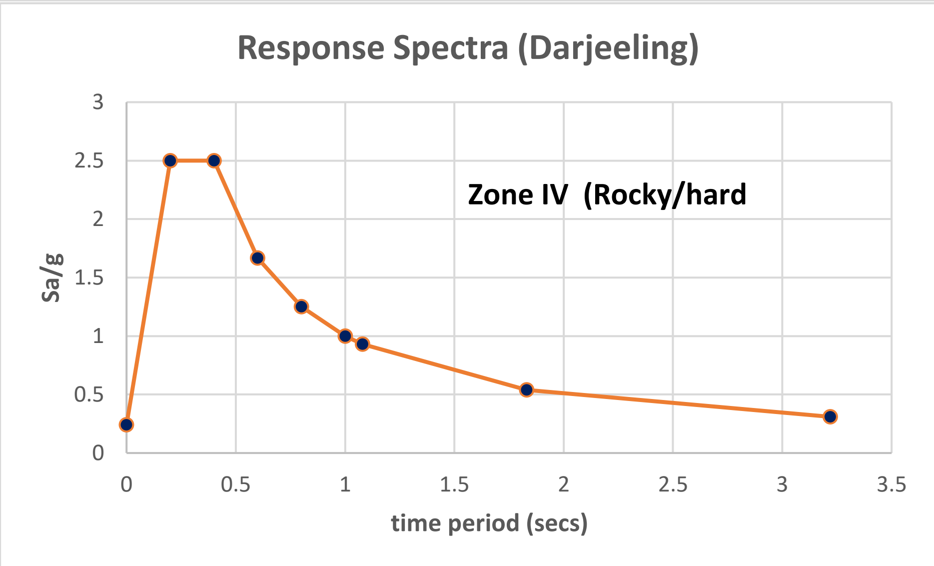
T_2 = 1.83 secs Sa/g = 0.54

Focal Depth (d) = 28 km

T_3 = 3.22 secs Sa/g = 0.31

Epicentral Distance (ED) = 222 km





Station Name = Gangtok Region = Tibet

Site Class **A**: **Rocky/hard soil sites**

Earthquake date and Time = 26 Feb 2010 Org. Time = 4:42:33 (N-S direction)

T_1 = 1.1 secs Sa/g = 0.90

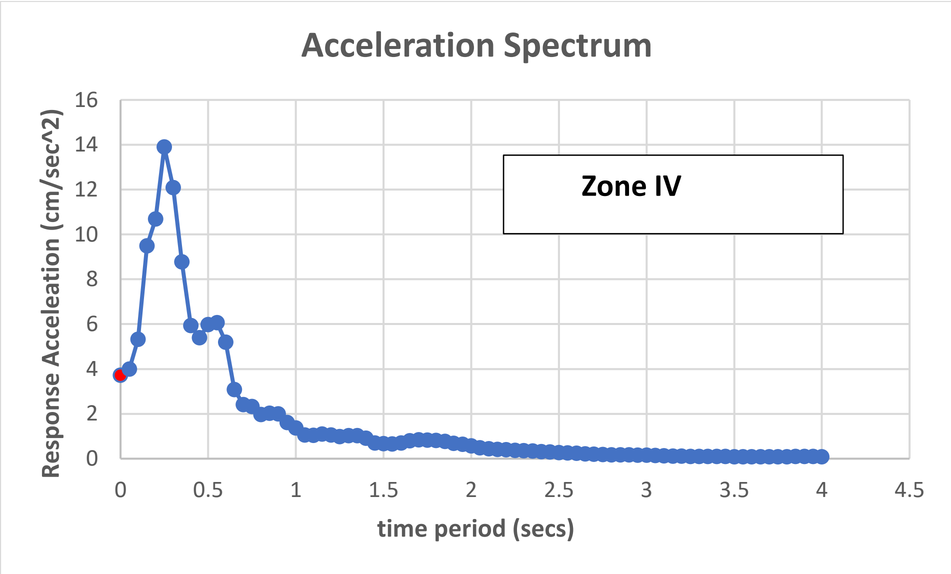
Magnitude (M) = 5.4

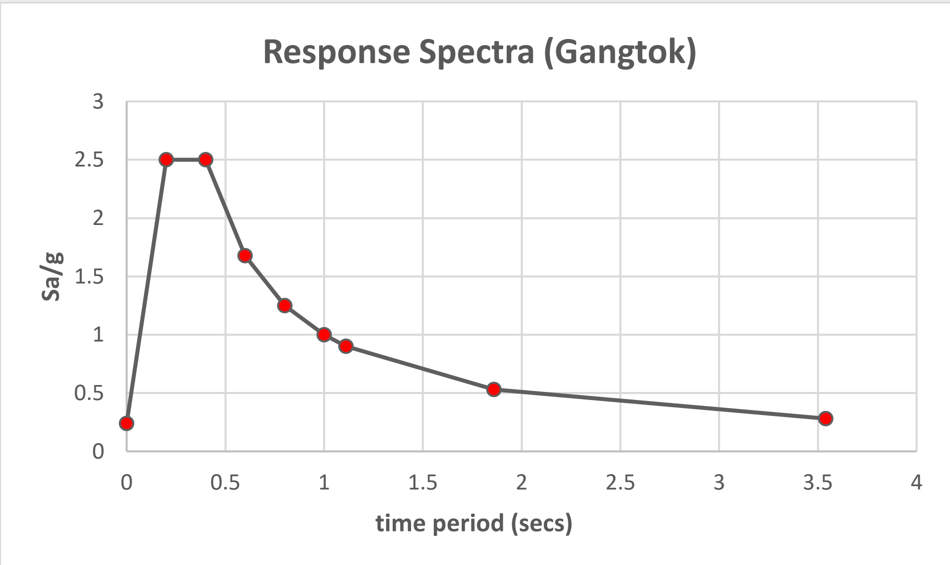
T_2 = 1.86 secs Sa/g = 0.53

Focal Depth (d) = 28 km

T_3 = 3.54 secs Sa/g = 0.28

Epicentral Distance (ED) = 228 km





Station Name = Goalpara Region = Tibet

Site Class **C**: **Soft Soil**

Earthquake date and Time = 26 Feb 2010 Org. Time = 4:42:33 (N-S direction)

T_1 = 1.09 secs Sa/g = 1.53

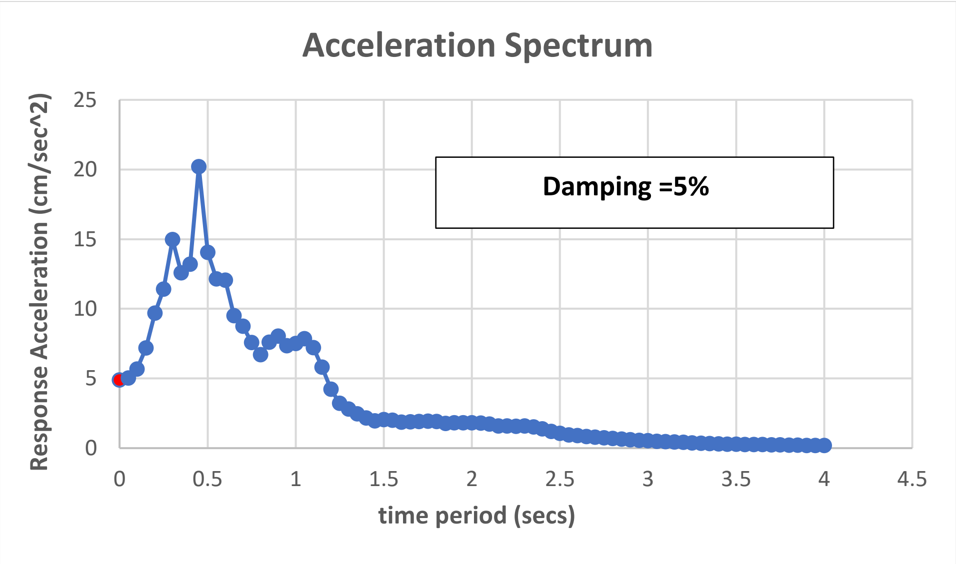
Magnitude (M) = 5.4

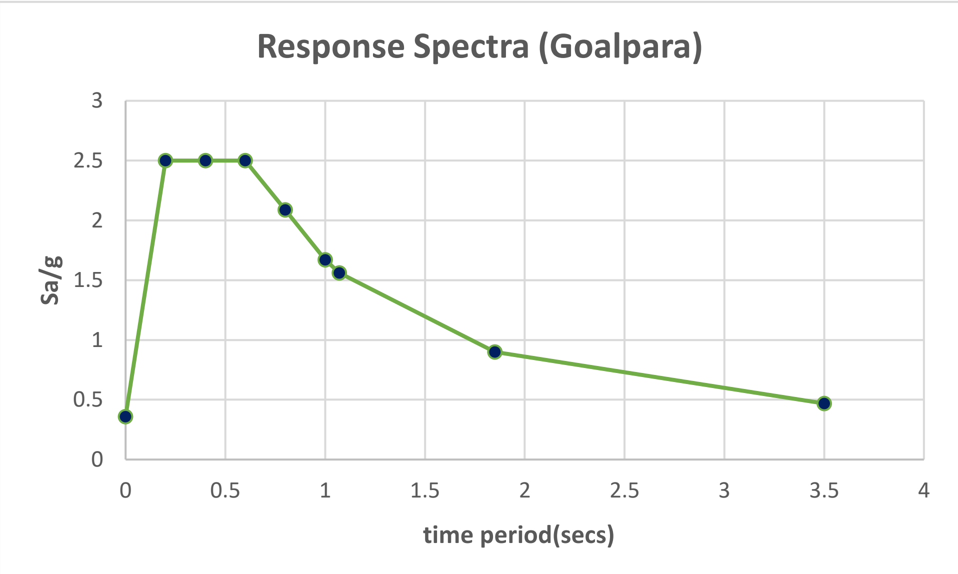
T_2 = 1.85 secs Sa/g = 0.90

Focal Depth (d) = 28 km

T_3 = 3.50 secs Sa/g = 0.47

Epicentral Distance (ED) = 468 km





Station Name = Guwahati Region = Tibet

Site Class **C**: **Soft Soil**

Earthquake date and Time = 26 Feb 2010 Org. Time = 4:42:33 (N-S direction)

T_1 = 1.15 secs Sa/g = 1.45

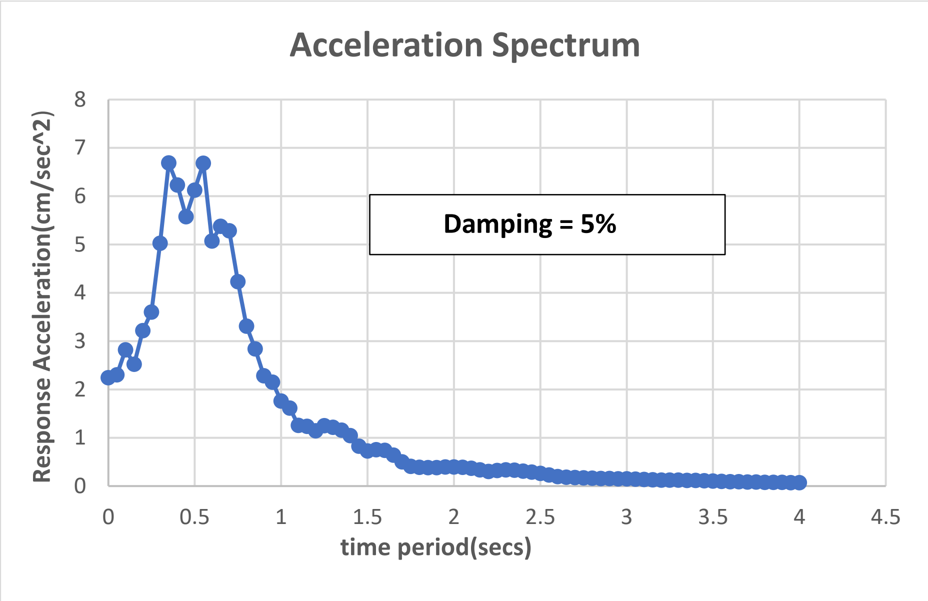
Magnitude (M) = 5.4

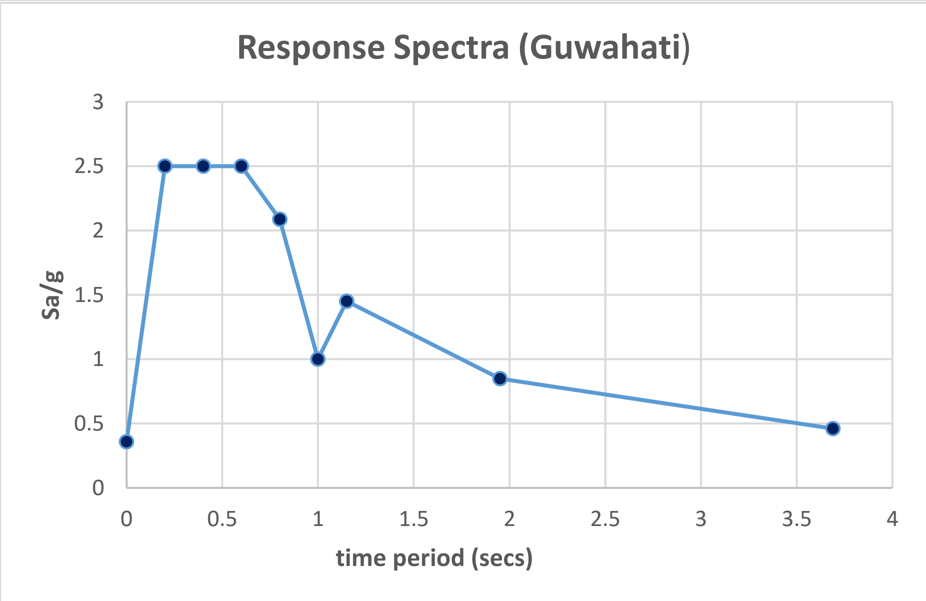
T_2 = 1.95 secs Sa/g = 0.85

Focal Depth (d) = 28 km

T_3 = 3.69 secs Sa/g =0.46

Epicentral Distance (ED) = 561 km





Station Name = Kokrajhar Region = Tibet

Site Class **C**: **Soft Soil**

Earthquake date and Time = 26 Feb 2010 Org. Time = 4:42:33 (N-S direction)

T_1 = 1.07 secs Sa/g = 1.56

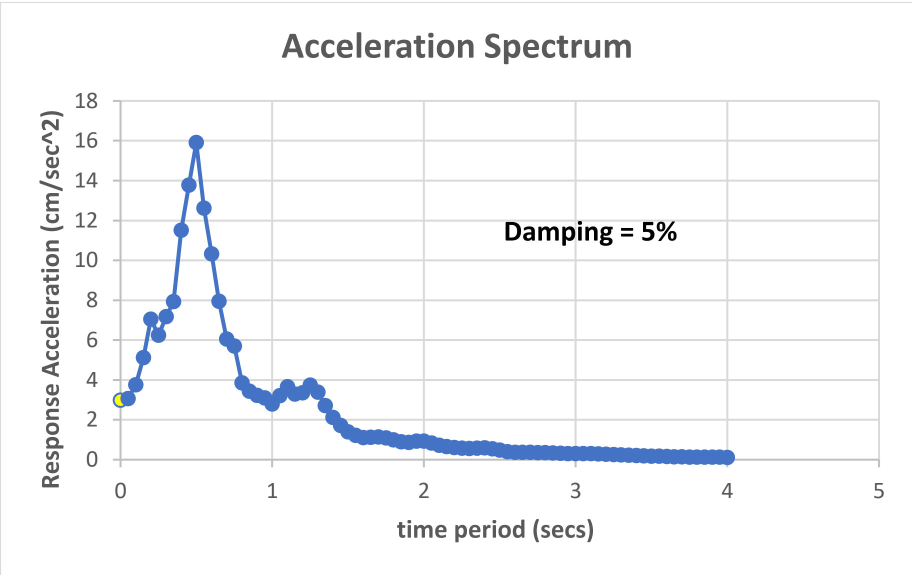
Magnitude (M) = 5.4

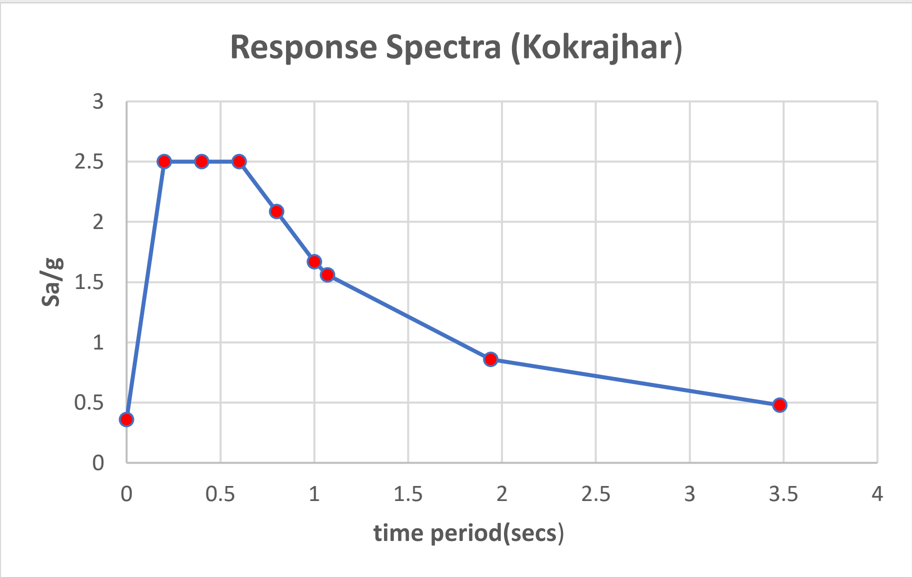
T_2 = 1.94 secs Sa/g = 0.92

Focal Depth (d) = 28 km

T_3 = 3.48 secs Sa/g = 0.48

Epicentral Distance (ED) = 422 km





Station Name = Siliguri Region = Tibet

Site Class **C**: **Soft Soil**

Earthquake date and Time = 26 Feb 2010 Org. Time = 4:42:33 (N-S direction)

$T_1 = 1.22$ secs $Sa/g = 1.36$

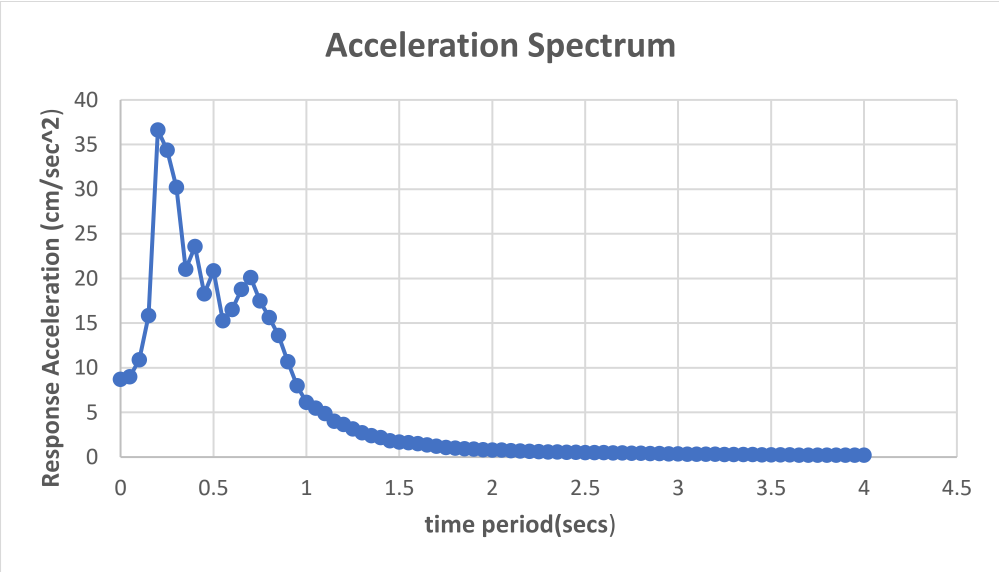
Magnitude (M) = 5.4

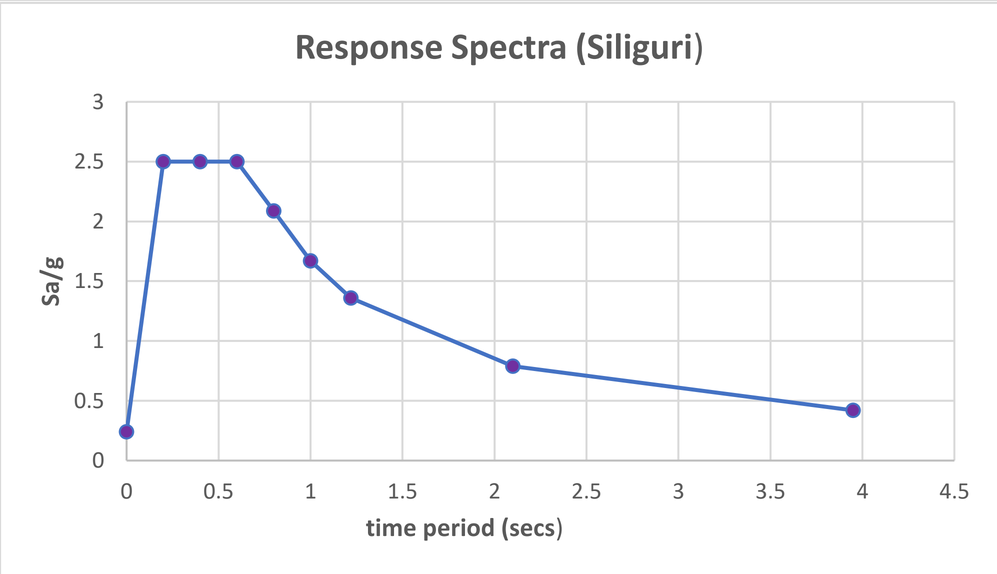
$T_2 = 2.10$ secs $Sa/g = 0.79$

Focal Depth (d) = 28 km

$T_3 = 3.95$ secs $Sa/g = 0.42$

Epicentral Distance (ED) = 261 km





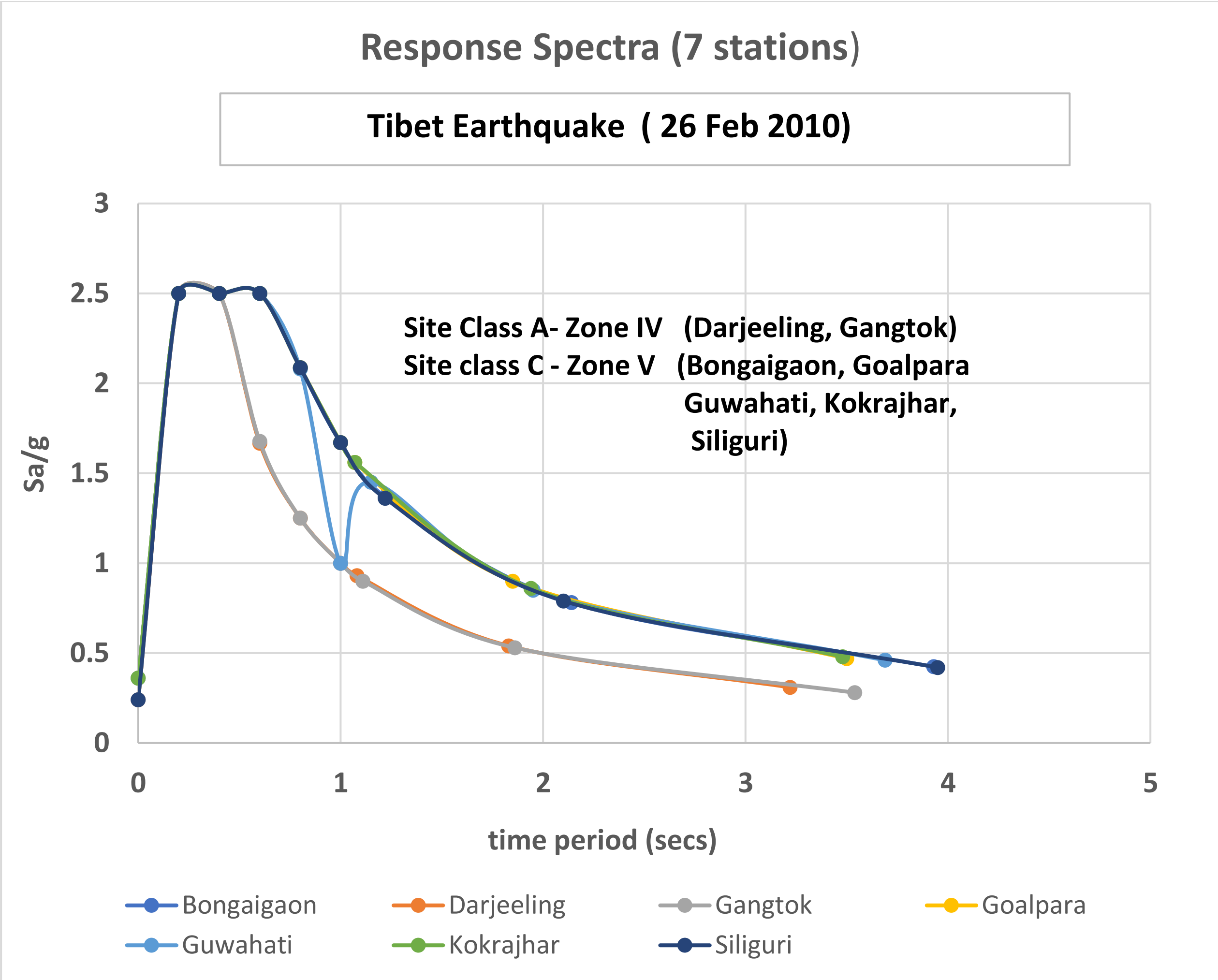


Figure 7.3 Plot between time period vs Sa/g of 26 Feb 2010 Earthquake

DATASET - 4

Station Name = Diphu Region = India (Nagaland)-Myanmar -Border

Site Class **B**: **Medium /Stiff soils**

Earthquake date and Time = 24 Feb 2009 Org. Time = 17:46:13 UTC (N-S Direction)

T_1 = 1.1 secs Sa/g =1.23

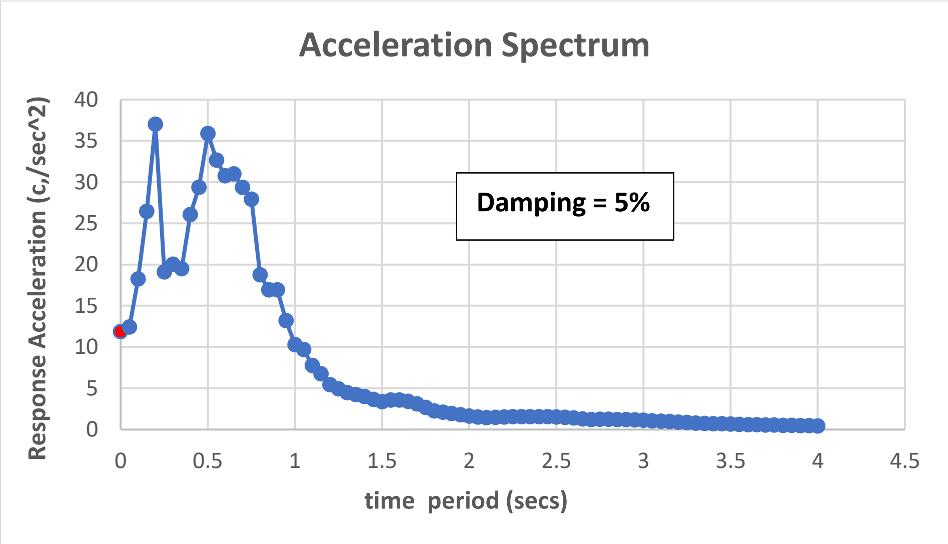
Magnitude (M) = 4.8

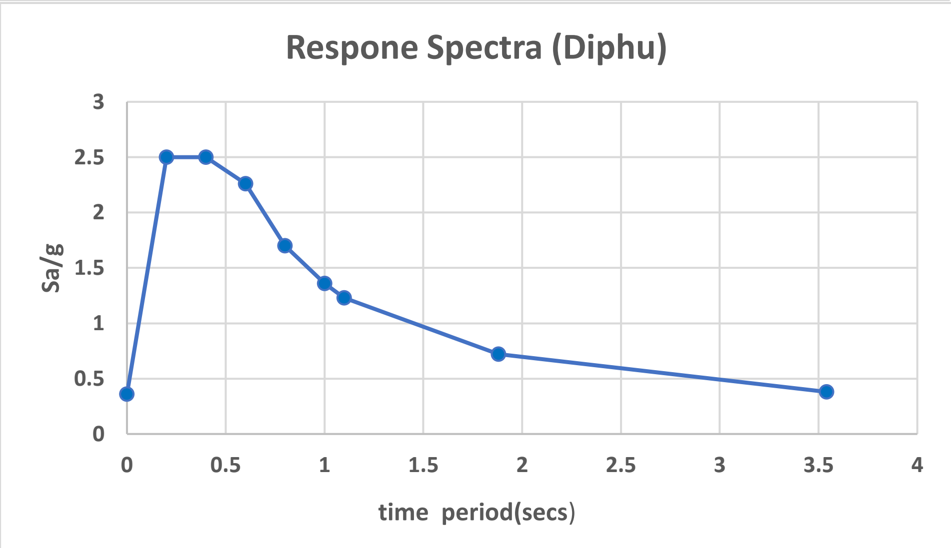
T_2 = 1.88 secs Sa/g = 0.72

Focal Depth (d) = 10.0 km

T_3 = 3.54 secs Sa/g = 0.38

Epicentral Distance (ED) = 87 km





Station Name = Golaghat Region = India (Nagaland)-Myanmar -Border

Site Class **B**: **Medium /Stiff soils**

Earthquake date and Time = 24 Feb 2009 Org. Time = 17:46:13 UTC (N-S Direction)

T_1 =1.13 secs Sa/g = 1.20

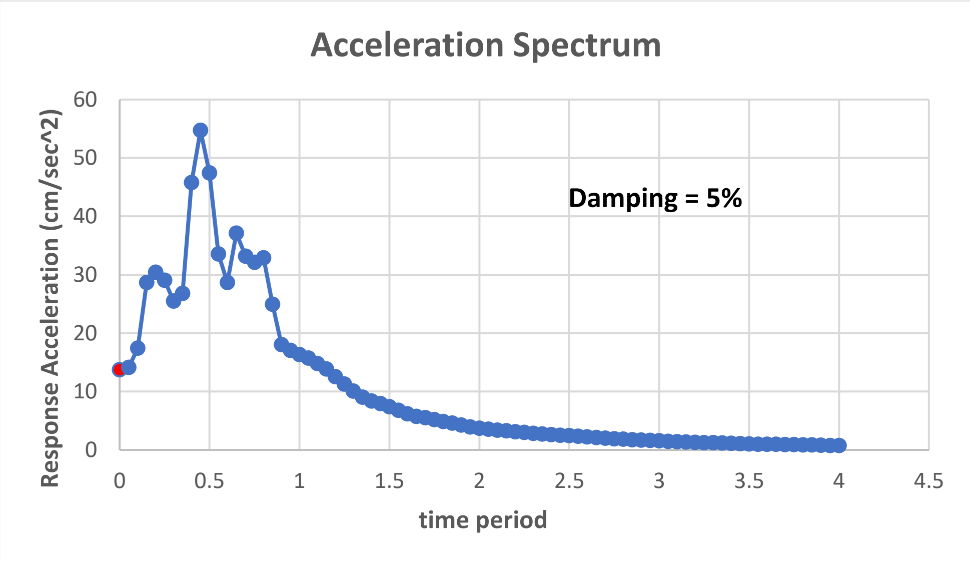
Magnitude (M) = 4.8

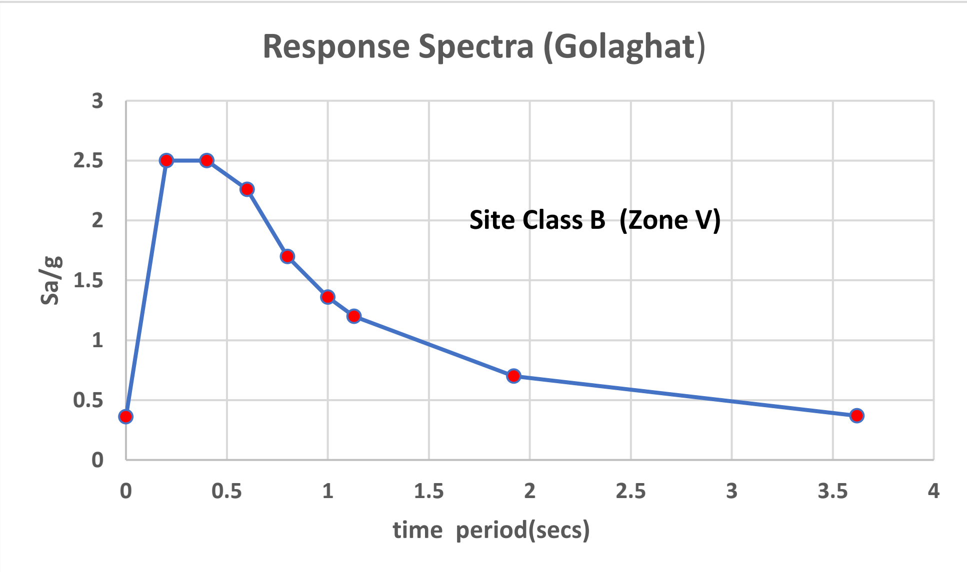
T_2 = 1.92 secs Sa/g = 0.70

Focal Depth (d) = 10.0 km

T_3 = 3.62 secs Sa/g = 0.37

Epicentral Distance (ED) = 75km





Station Name = Lakhimpur Region = India (Nagaland)-Myanmar -Border

Site Class **C**: **Soft soil**

Earthquake date and Time = 24 Feb 2009 Org. Time = 17:46:13 UTC (N-S Direction)

T_1 = 1.06 secs Sa/g = 1.57

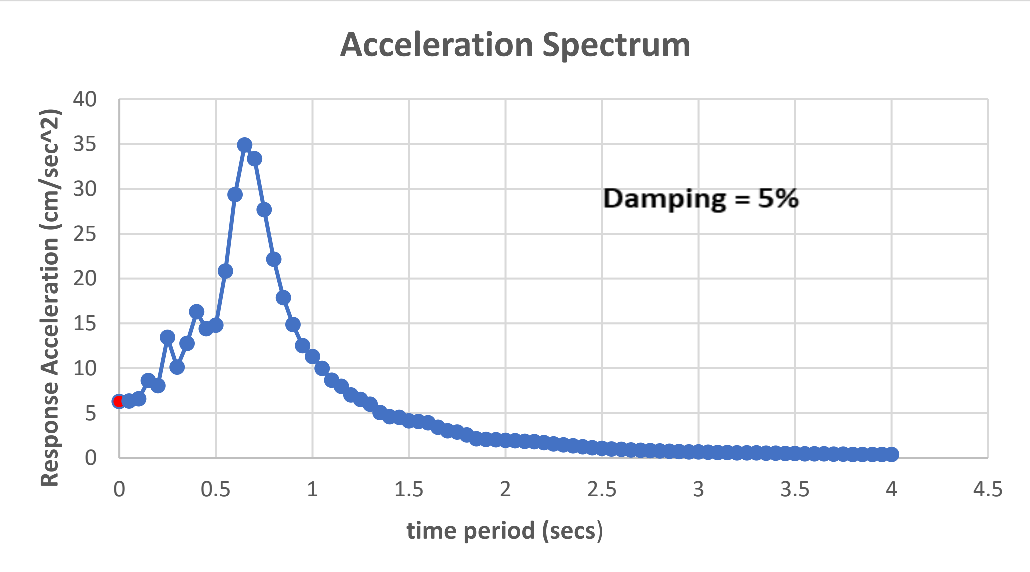
Magnitude (M) = 4.8

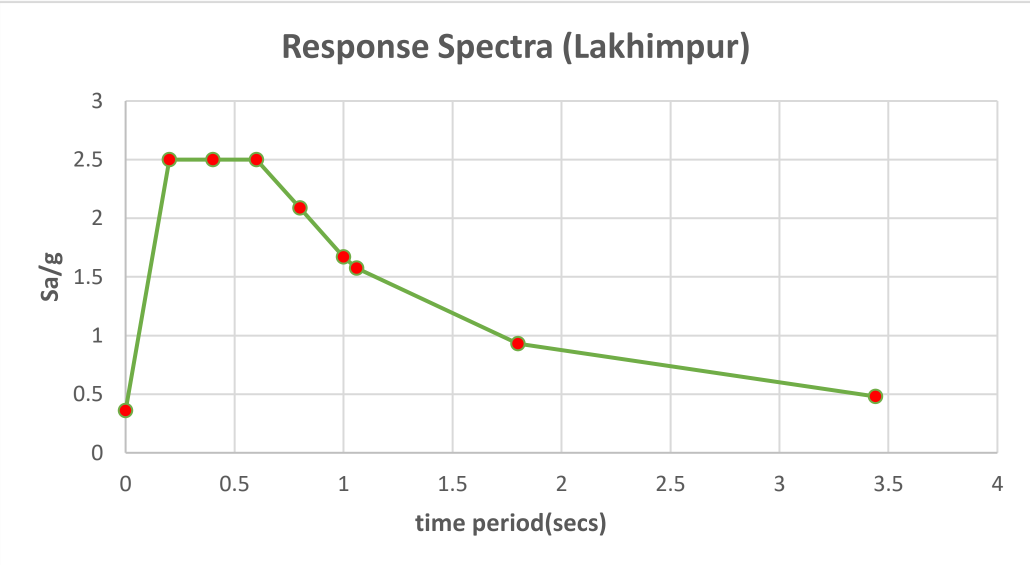
T_2 = 1.80 secs Sa/g = 0.92

Focal Depth (d) = 10.0 km

T_3 = 3.4 secs Sa/g = 0.49

Epicentral Distance (ED) = 150 km





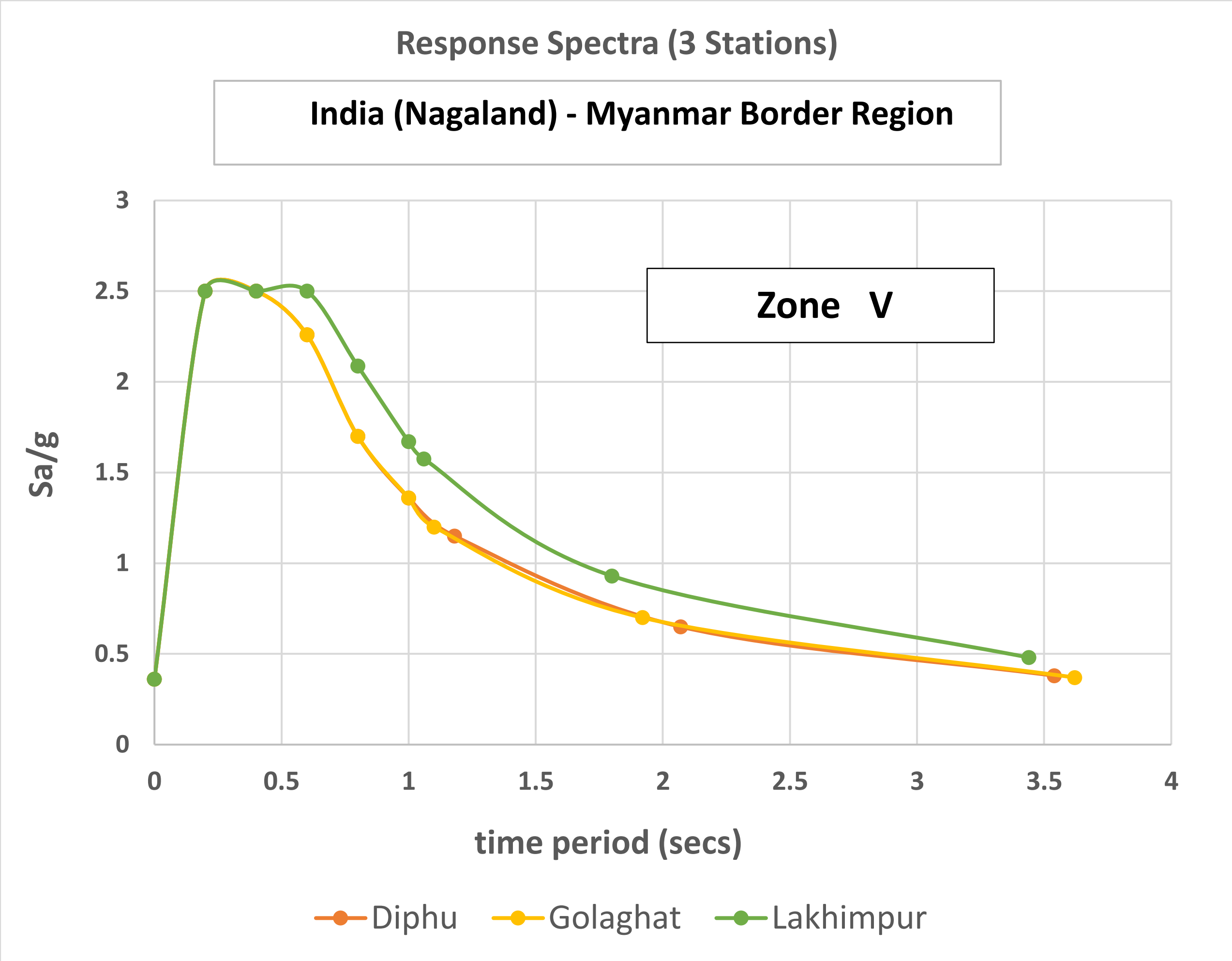


Figure 7.4 Plot of time period vs Sa/g of 24 Feb 2009 Earthquake

7.5 Types of Spectral Regions in Response Spectrum

In a Response Spectrum diagram, earthquake engineers consider three primary in regions. The **Acceleration-sensitive region** affects structures with short natural periods (high frequency) usually less than about 0.3 seconds. The **Velocity – Sensitive region** typically affect structures with natural periods ranging from about 0.3 to 1.0 seconds whereas the **Displacement -Sensitive region** primarily affects structures usually greater than 1.0 seconds.

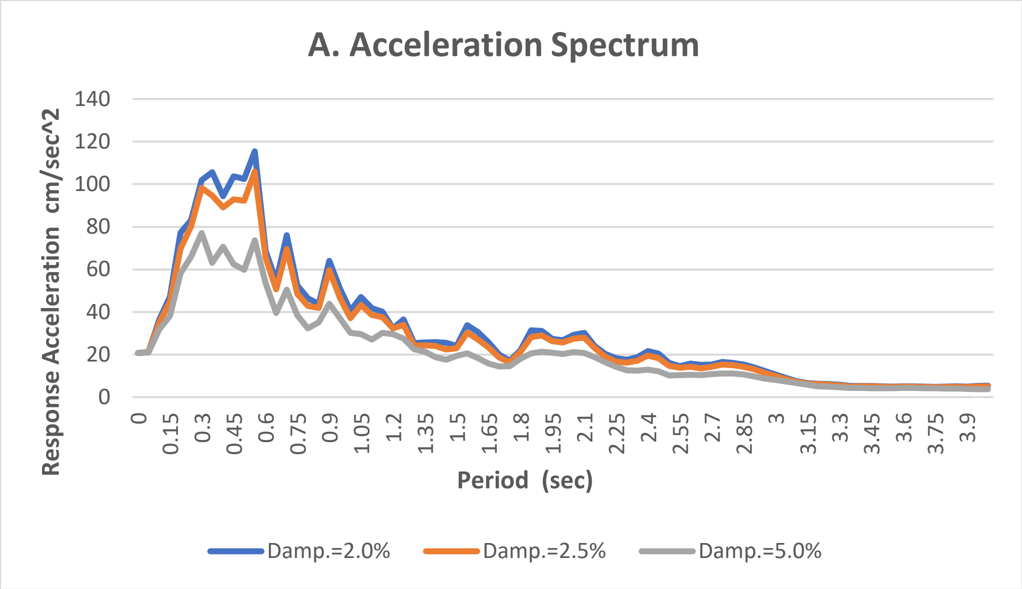
In the context of **North-East India,** the **acceleration -sensitive region** is the most critical part of the Spectral response considered by earthquake engineers This part of India demands careful consideration in the design and construction of structures to ensure they can withstand peak forces. While displacement sensitive region is necessary for the design of tall structures and bridges, it is less critical for the majority of common structures in North-East India. The design forces for buildings and infrastructure are typically derived from the accelerations they might experience during an earthquake. These forces are significant and must be accounted for to prevent structural failure. Short -period structures like residential buildings are highly sensitive to peak accelerations which dominate the seismic response in high frequency regions. Guidelines mentioned in IS 1893 ensures that the buildings are designed to withstand the forces produced by high accelerations and can handle the most violent shaking thereby ensuring safety of inhabitants and structural integrity in highly seismic zones.

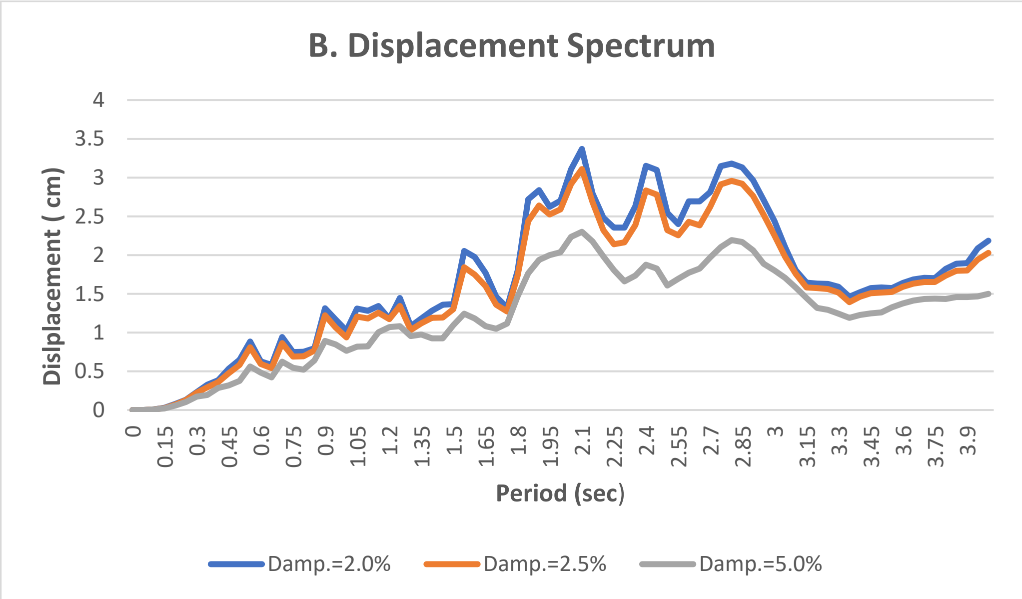
However, the effect of damping tends to be greatest in the velocity -sensitive region of spectrum. Damping helps a structure dissipate its vibrational energy during an earthquake. The ground motion velocity in this region has the greatest influence on the structure’s response. Effective damping can significantly reduce the amplitude of oscillations by converting kinetic energy into heat or other forms of energy. Also, the structure remains stable and safe by mitigating the potential for resonance and movements which could lead to failure of structure. If the ground motion is nearly harmonic over many cycles, the effect of damping would be especially large for systems near resonance.

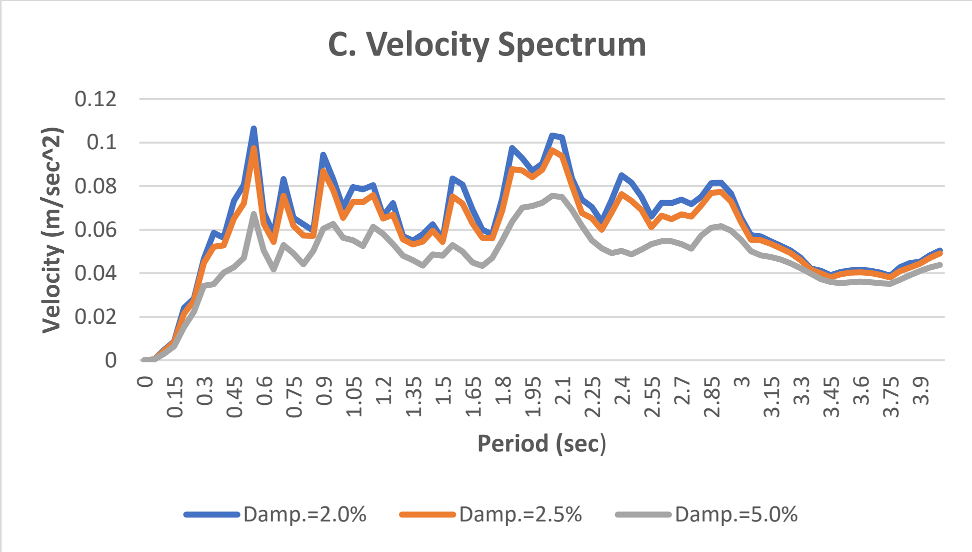
7.6 Comparison of Different Spectrums with different damping ratios

(A) Graphs representing trends of

Graph 7.5 (A), (B), (C) **Earthquake 21-Sep 2021** (**Bhutan- Boko station-**EW Direction showing Acceleration Vs Displacement vs Velocity Spectrum







From the graphs, it can be concluded that –

For Shorter periods, acceleration is very high for the building compared to longer periods where displacement stays very high compared to acceleration. It is quite important to understand fundamentally if we are designing the building for any earthquake.

What happens is that shorter the building, the more violently kind of it accelerates because its natural period being very low and is closer to earth's what could be the natural period of the earthquake that's coming in and its natural tendency of the building. For example, in case of inverted pendulum, we have to shake it violently back and forth and the response is also violent due to short time period.

When we look at longer time period buildings, they go very slow back and forth but they displace so much that they demand a lot of ductility from system.

Response Acceleration spectrum shows that it may not experience significant accelerations but they do experience a lot of displacements in general. So, we have to focus on ductility and how much can our building drift. Therefore, a lot of tall buildings are designed to drift like 2-2.5 percent while shorter 2 storey building it's not even 0.5-0.6.

We can see that on lowering the damping value in an acceleration response spectrum, the spectral acceleration at shorter periods (high frequencies) increases while those at longer periods (lower frequencies) decrease due to greater oscillations offered by lower damping values.

According to earthquake data to get the required elastic response spectra for 5% damping, we plot the Sa(g) values with time period in secs for Site Class C.

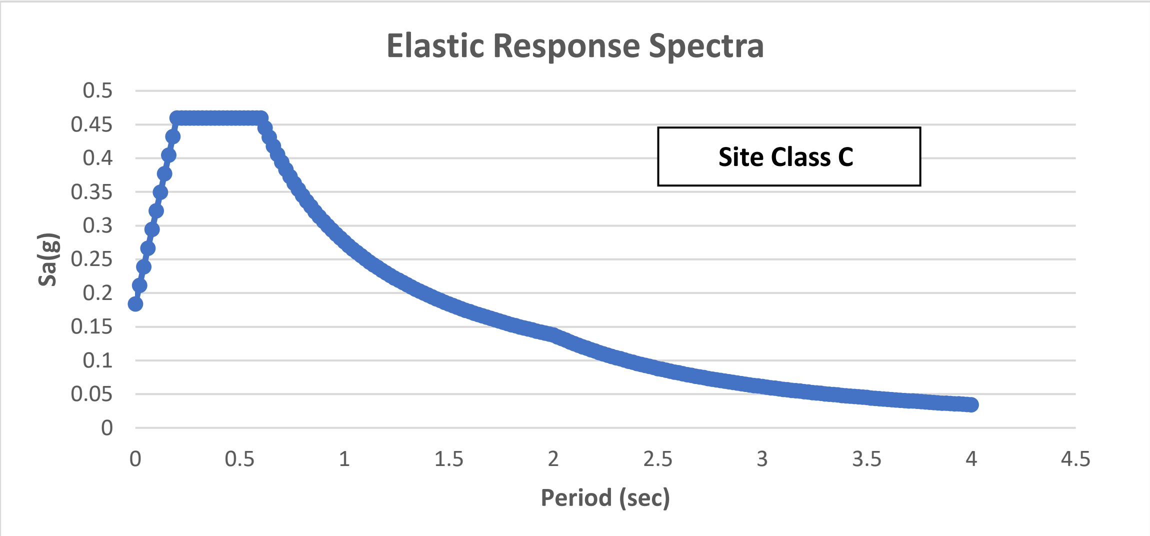


Figure 7.6 Representing elastic Response Spectra of Boko Station

For site Class C

Elastic Spectra can be depicted in various forms, contingent upon the requirements of the engineer and the type of information being conveyed. Some of the most prevalent formats encompass -

- Spectral velocity vs period
- Spectral acceleration vs period
- Spectral Displacement vs period
- Tripartite plots (Sa, Sv and Sd vs period)
- Spectral acceleration vs Spectral displacement (capacity design spectra)
- Also, any of the above (except the capacity design spectrum) can be plotted versus frequency rather than period

Factors which effect elastic spectra include the damping ratio, site conditions and near fault ground motion effects such as rupture directivity.

(B) Earthquake – 21 Sep 2021 (Bhutan -Goalpara station)

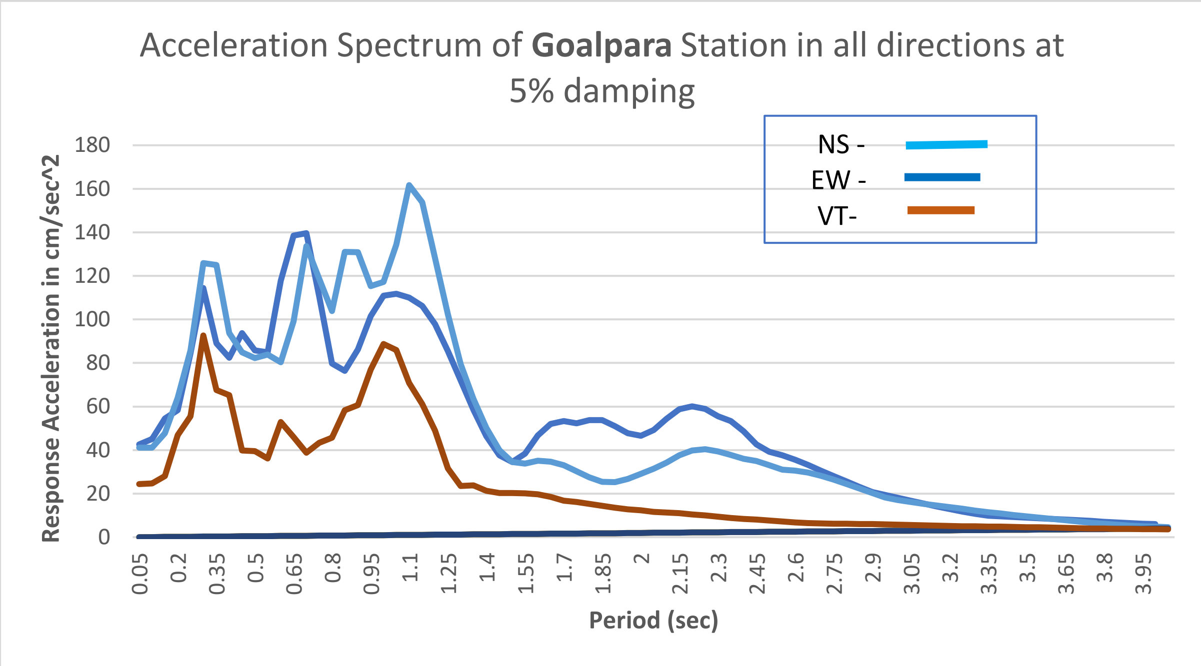


Figure 7.7 **Trends of rates of acceleration in all directions**

Now how to estimate 'natural period 'for different buildings by looking at the spectrum and tell which building will experience higher acceleration during this particular earthquake. Well, let us select two buildings –

(a) 2-storey building: W (Weight of the building) = 2.5 MN, K (stiffness) = 350 MN/m
(b) 900 m tall tower: W (Weight of the tower) = 6000 MN, K (Stiffness) = 250 MN/m

Because we are using weights and not mass, we are going to divide weights which is 2.5 /9.81 where g= acceleration due to gravity.

To calculate **Natural Period (T=sec) for a Single degree of Freedom System**, we us the formula

$$\mathbf{T = 2}\pi\sqrt{\frac{w/g}{k}}$$

Step 1 - For 2 -Storey building

$$\mathbf{T = 2*3.14}\ \sqrt{\frac{2.5}{9.81}}\ \mathbf{/350 = 0.169\ secs}$$

Step 2 – For 900 m tall tower,

$$T = 2*3.14\sqrt{\frac{6000}{9.81}/250} = 9.83 \text{ sec}$$

Therefore, we see that for smaller buildings 1 storey, 2 storey the building will be subjected to much **greater acceleration** compared to high rise tower buildings.

Shorter buildings exhibit greater **stiffness** in comparison to taller buildings, resulting in higher natural frequencies. The elevated natural frequencies of shorter buildings increase the likelihood of resonance with higher frequency seismic waves generated by earthquakes, consequently causing greater acceleration. The distribution of mass in taller buildings spans a greater height, impacting the building's response to seismic forces. The larger mass distribution requires more energy to overcome damping mechanisms, leading to reduced relative acceleration at higher levels of the building. Taller buildings are often equipped with advanced damping mechanisms to mitigate seismic energy, decreasing acceleration. Conversely, smaller buildings may lack such systems due to financial limitations or design choices. The seismic wave characteristics, including longer periods of surface waves and higher frequencies of body waves, also significantly influence the response of buildings based on their height

It can be seen that in the North-South direction, it was subjected to higher rate of acceleration. After plotting **Sa(g)/time period** values, we get the required design spectrum curve.

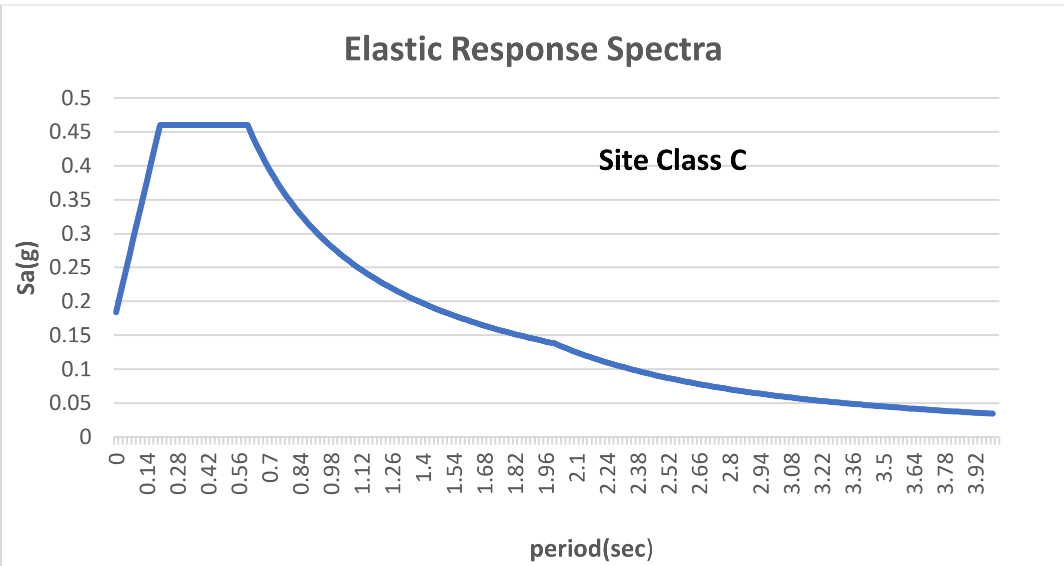


Figure 7.8 - Representing Design Spectrum for Goalpara Station

7.7 Summary

When analysing the relationship between time period and Sa/g values for various buildings, the decrease in Sa/g values as time period increases is attributed to the natural frequency of the structures. Shorter buildings generally exhibit higher natural frequencies, leading to elevated Sa/g values at shorter time periods. Conversely, taller buildings have lower natural frequencies, resulting in decreased Sa/g values at longer time periods. This trend elucidates the response of buildings to seismic forces, with stiff structures experiencing higher accelerations during short periods and flexible structures undergoing lower accelerations but larger displacements.

The classification of site classes plays a significant role in determining Sa/g values, given that local soil conditions have the potential to amplify or attenuate seismic waves. Various site classes, ranging from hard rock to soft soil, impact the spectral characteristics of ground motion. Soft soils have a tendency to amplify long-period waves, affecting taller structures to a greater extent, whereas hard rock amplifies short-period waves, affecting shorter buildings more profoundly. Thus, a thorough comprehension of site class is imperative for precise seismic design and analysis, ensuring that structures are resilient to local ground motion attributes.

Engineers in North-East India exhibit a particular interest in the spectral sensitive region associated with acceleration and velocity. This region holds paramount importance due to the seismic activity prevalent in North-East India, situated in close proximity to the convergent boundary of the Indian and Eurasian plates. The heightened seismicity underscores the necessity of understanding how buildings and infrastructure react to ground accelerations and velocities to avert disastrous consequences. It is essential to guarantee that structures can endure significant accelerations and velocities for the safety and durability of the constructed environment in this region. Consequently, incorporating design considerations for these spectral regions is crucial in mitigating the potential impact of earthquakes.

CHAPTER 8

RESULTS AND DISCUSSION

8.1 Introduction

Estimation of seismic ground motion parameters can be achieved through the utilization of diverse analytical approaches. Depending on the accessibility and suitability of strong-motion data these methods can be adopted for a study. This report work adopted Artificial Neural Network as the machine learning method to obtain results using different parameters and approaches. Table 8.1 gives the list of Indian Earthquakes considered for the ANN Model.

8.2 Input and Output Parameters

In this study, ANN based toolbox has been used for the prediction of Spectral Acceleration (Sa) from multiple predictor variables. Both Sa and PGA are seismic ground motion metrics each influenced by unique factors and serving distinct purposes in earthquake engineering.

While Sa is affected by similar factors as PGA such as earthquake magnitude, Epicentral distance and site conditions, it heavily relies on the dynamic properties inherent to the structure itself making it crucial for designing and evaluating the seismic resilience of building and other structures.

Using ANN Toolbox input parameters taken were magnitude, focal depth, epicentral distance and time period and output parameters were Sa/g values. The model was trained using Levenberg-Marquardt function. All the recording stations in the study area have been grouped into three categories namely Rock, stiff soil and soft soil which have been inferred from the information gathered on the site geology of the respective places from various sources such as COSMOS and PESMOS.

Table 8.1: Details of Indian Earthquake considered for the ANN Model

Sl No.	Station name & Earthquake date	Epicentral Distance (km)	Focal Depth(km)	Magnitude (Mb)
1	Ummulong - 10/9/1986	13	43	5.2
2	Dauki - 06/02/1988	79	15	5.8
3	Berlongfer- 06/08/1988	201	91	6.8
4	Diphu - 10/01/1990	223	119	6.1
5	Nongpoh- 08/05/1997	119	35	5.7
6	Kokrajhar- 15/02/2009	75	39.3	4.4
7	Lakhimpur -24/02/2009	150	10	4.8
8	Tura -30/08/2009	460	85	5.3
9	Silchar -03/09/2009	191	100	5.9
10	Boko -21/09/2009	148	8	6.2
11	Goalpara -29/10/2009	80	10	4.2
12	Gangtok -26/02/2010	228	28	5.4
13	Guwahati - 11/09/2010	158	20	5.0
14	Tezpur - 09/01/2013	250	89	5.9
15	Dibrugarh - 16/04/2013	317	16	4.6

The range of magnitude and epicentral distances of earthquakes taken is plotted as shown in Fig 8.1. Therefore, the network which will be developed using these earthquakes will only be applicable to predict the value of Spectral Acceleration for earthquakes having the same range of magnitude and epicentral distance.

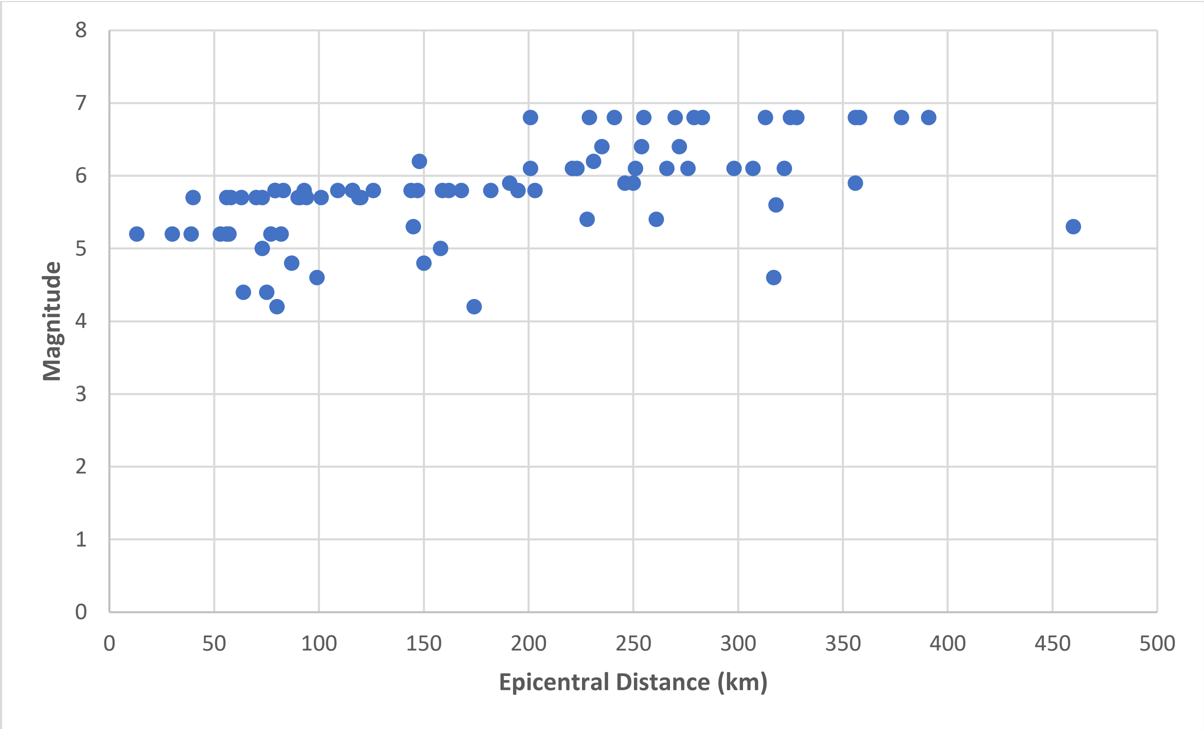


Figure 8.1 - Range of magnitude and Epicentral Distance of Earthquakes.

To develop the network, values of the above earthquakes has been divided into two sets. The training set, which is about 70% of the complete database has been used to train the network. The testing set about 30% has been used to judge the performance of the trained network and for validation, data within the training set has been used by the software automatically for the purpose of monitoring the training process and to guard against overfitting.

8.3 Influence of Number of Neurons on the Network

The particular network is configured on the basis of number of neurons in the hidden layer so that the error in the Log- sigmoid -linear network (taken in this study) can be reduced i.e. RMS error becomes minimum. So at first, the network was started with 3 neurons and then the number of neurons were increased until an optimum number is reached. Table 8.2 lists the influence of numbers of neurons in the hidden layer on the Log-sigmoid -Linear Network.

Table 8.2: Influence of number of neurons on the network

Neuron	R_{train}	R_{valid}	R_{test}	R_{All}	RMS Error
3	0.9425	0.8934	0.8989	0.9324	0.0123
4	0.9243	0.9843	0.9822	0.9233	0.0104
5	0.9959	0.9992	1.00	0.9799	0.0076
6	0.9367	0.8634	0.9327	0.9276	0.0134
7	0.9826	0.9023	0.9673	0.9235	0.0174
10	0.983	1.00	1.00	0.9885	0.0023

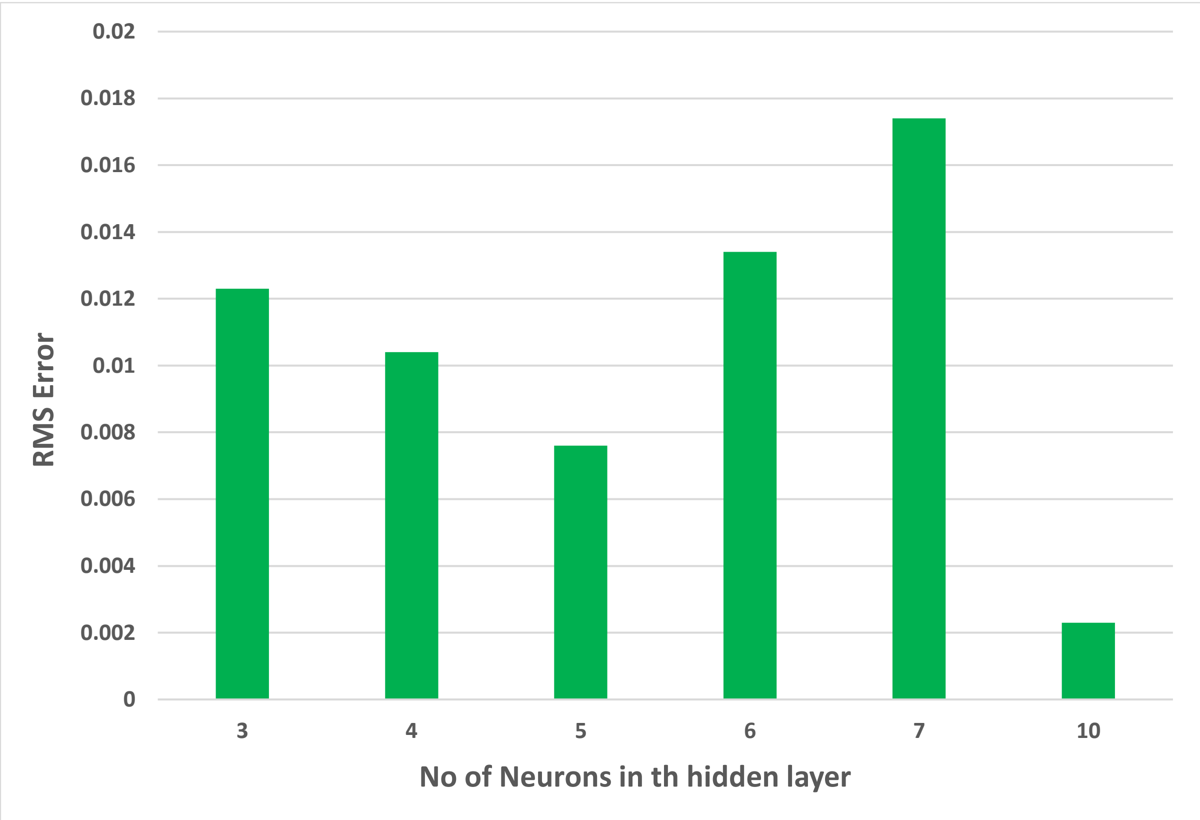


Figure 8. 1: Optimization of numbers of neurons in the hidden layer

From the above diagram, it is seen that the network having 10 neurons in the hidden layer gives minimum RMS Error. Therefore, the network considered is developed by using Log-

Sigmoid function in the hidden layer and Purelin function in the output layer with 10 numbers of neurons in the hidden layer.

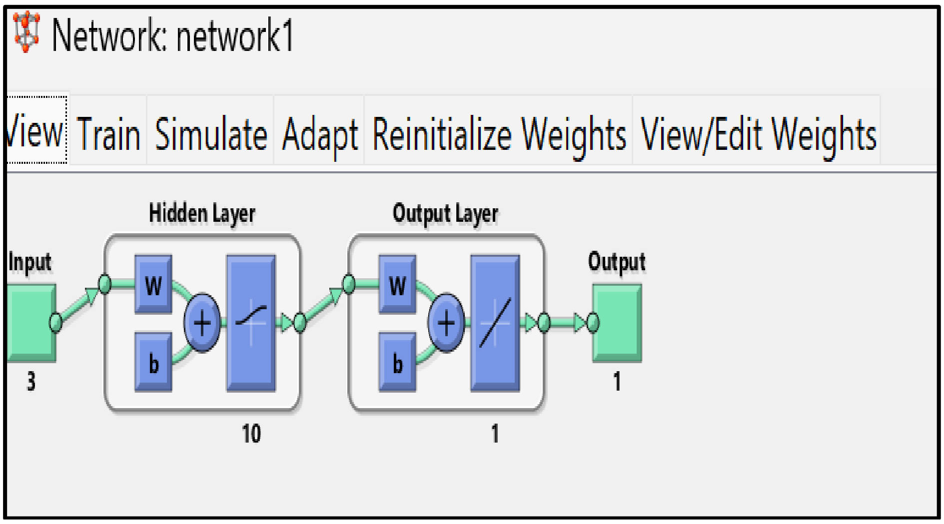


Figure 8.2 (a) : ANN Model with 10 hidden neurons

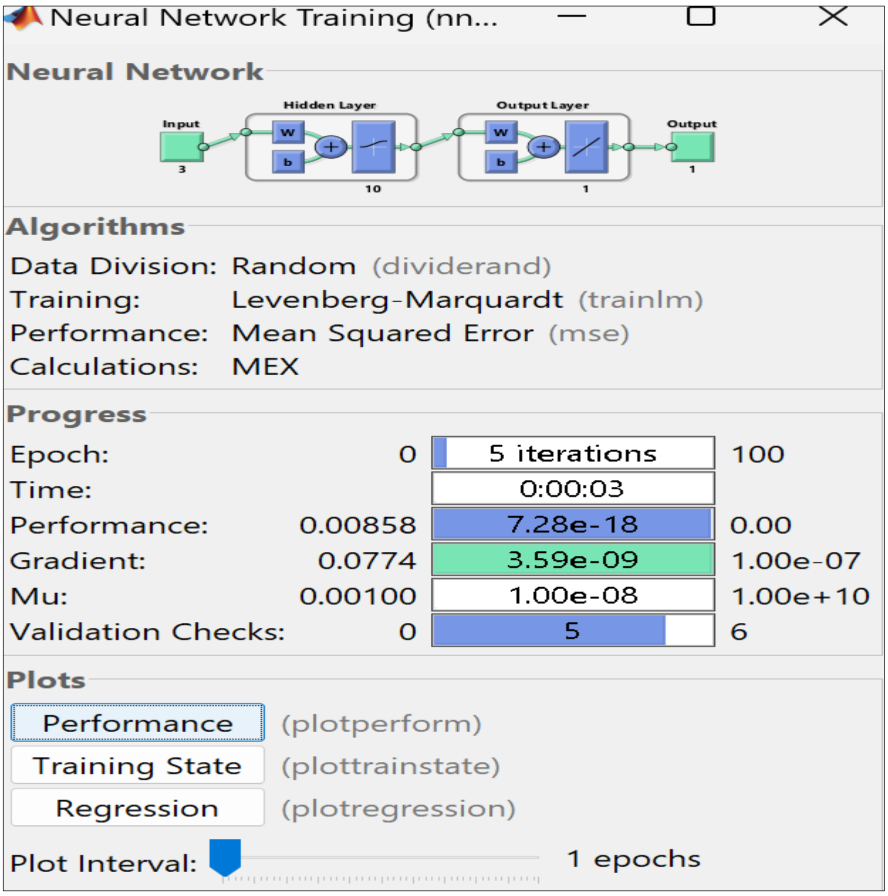


Figure 8.2 (b) : Training completion of ANN Model

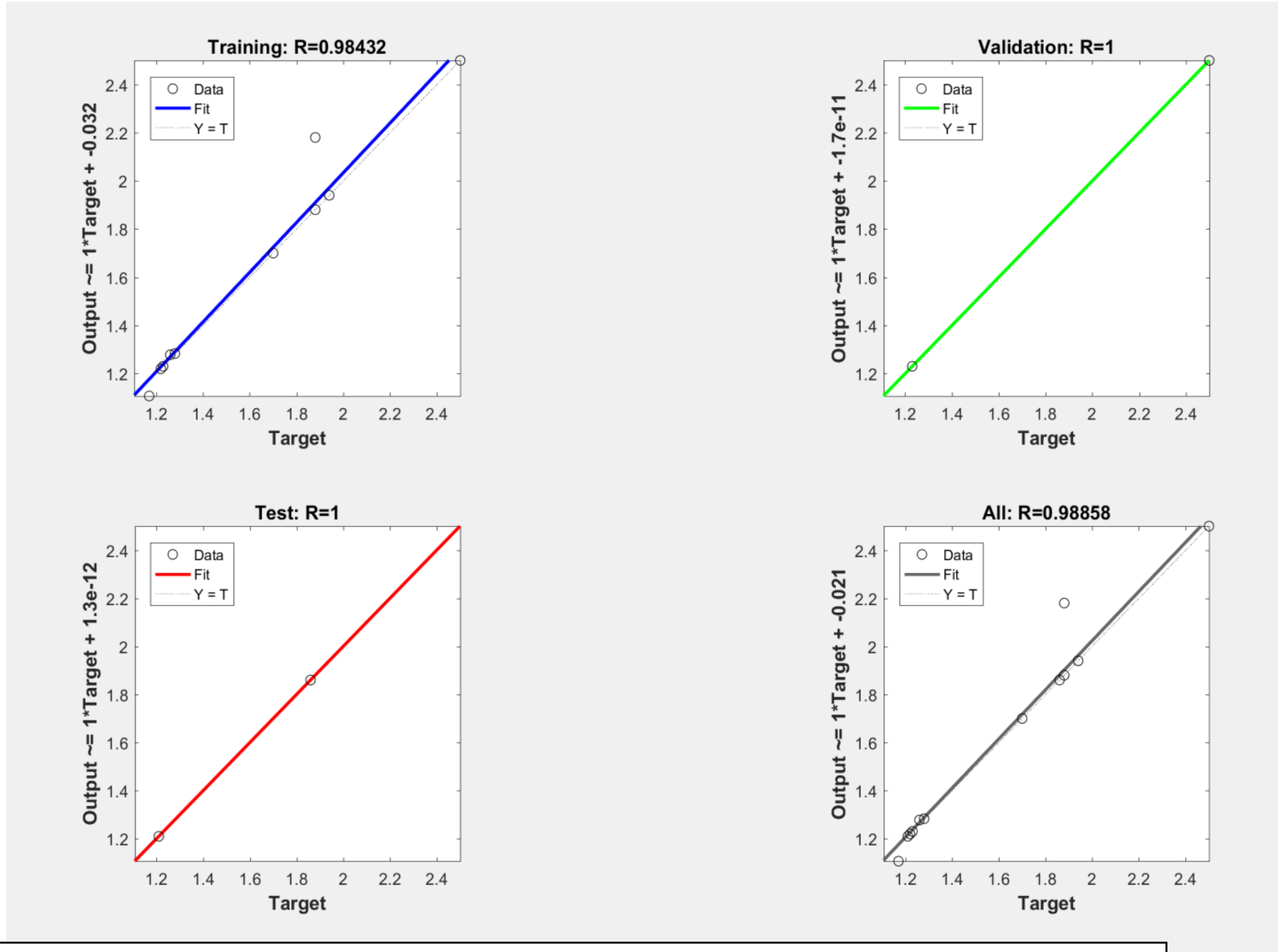


Figure 8.2 © **Training, Testing and Validation and Validation plots of ANN Model**

This ANN Model is used to predict the value of Sa/g at different locations for different earthquakes and a comparison between the predicted Sa/g and the actual observed Sa/g in those locations is discussed next.

8.4 Sa/g Predicted by ANN Model for the Testing Data

The ANN Model developed in study is used to test against the testing data (around 30% of the complete data set) randomly selected from the earthquakes listed before. The epicentral distance wise records of predicted Sa/g and the actual Sa/g of the testing data is given.

Table 8.3: **Epicentral distance wise comparison of observed Sa/g and Predicted Sa/g values**

Epicentral Distance (km)	Observed Sa/g	Predicted Sa/g	Error (E)
13	2.5	2.19	0.31
79	1.94	2.03	-0.09
201	1.88	1.83	0.05
223	1.86	1.77	0.09
119	2.5	2.11	0.39
75	1.23	2.24	-1.01
150	1.26	2.25	-0.99
460	1.88	1.71	0.17
191	1.22	1.86	-0.64
148	1.21	1.94	-0.73
80	1.23	2.28	-1.05
228	2.5	2.09	0.41
158	1.17	2.23	-1.06
250	1.7	1.84	-0.14
317	1.28	2.04	-0.76

8.5 Comparison of Observed Sa/g VS ANN Predicted Sa/g

For all the datasets, Sa/g at each location for each earthquake station is predicted by the ANN model and a plot between observed Sa/g and ANN Predicted Sa/g with epicentral distance is made to compare the two values.

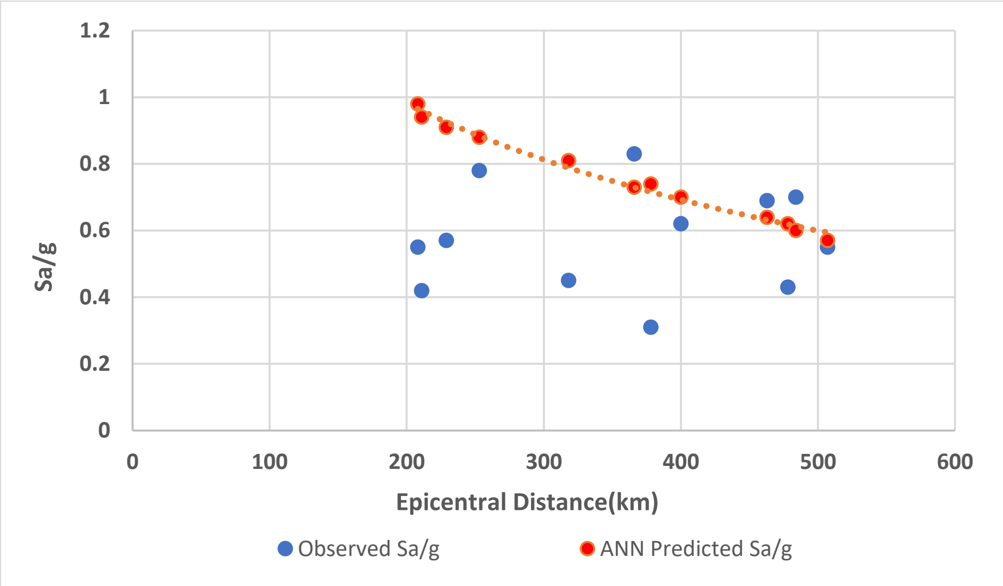


Figure – 8.2: Observed Sa/g Vs ANN Predicted Sa/g of 11 Aug 2009 Earthquake

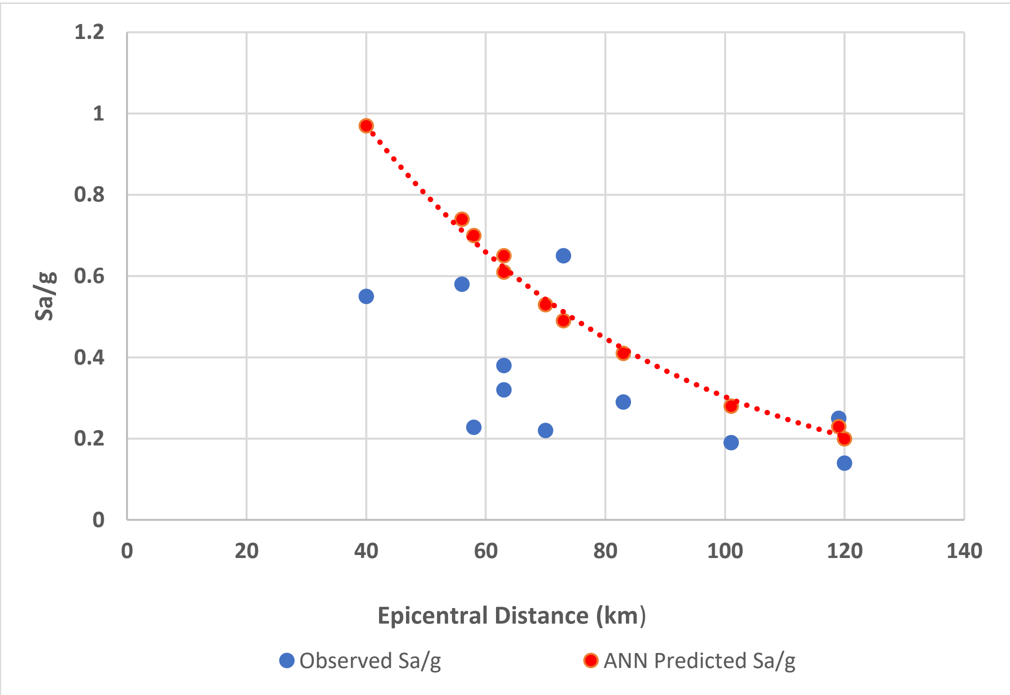


Figure - 8. 3: Observed Sa/g Vs ANN Predicted Sa/g of 8 May 1997 Earthquake

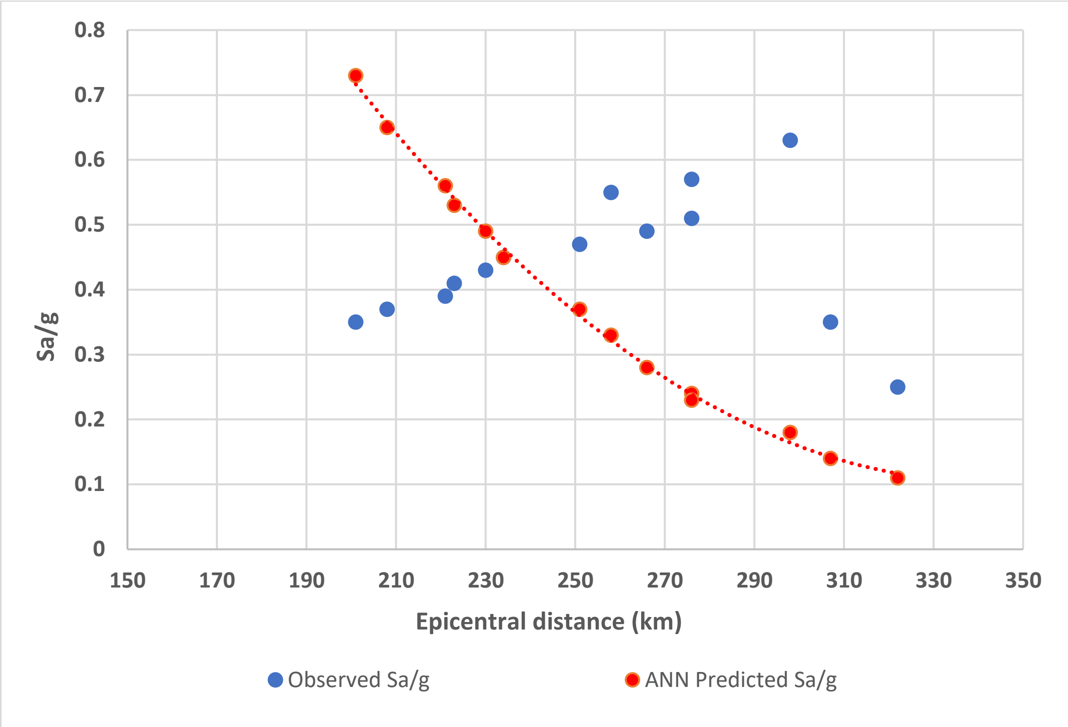


Figure - 8. 4: Observed Sa/g Vs ANN Predicted Sa/g of 10 Jan 1990 Earthquake

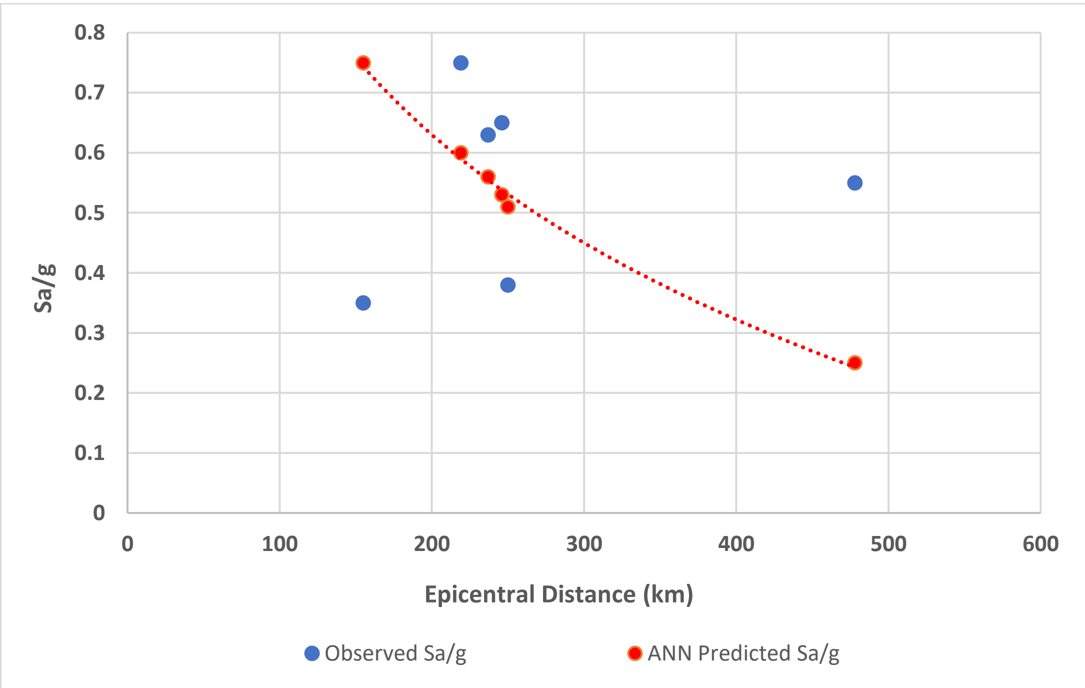


Figure 8.5: Observed Sa/g Vs ANN Predicted Sa/g of 09- Jan 2013 Earthquake

8.6 Site Amplification

From the time period vs Sa/g plots, it is seen that most of the calculated Sa/g values decrease with increase in time period. But some of them increases with epicentral distance. The prime reason may be due to the amplification of the seismic wave because of the local site conditions. The amplification of the seismic waves at specific sites have a notable impact on the ground motion obs served particularly concerning spectral acceleration (Sa/g). When constructing graphs correlating Epicentral distance with both actual Sa/g and ANN Predicted Sa/g for various sites, site amplification become key factor in discrepancies and patterns seen in the data.

Soft soil sites exhibit greater amplification of seismic waves compared to hard rock or firm soil sites, resulting in higher observed Sa/g values than those predicted by ANN which may not fully consider local soil conditions. Hence the disparities between observed and predicted values are clearly visible in soft soil sites, especially at shorter epicentral distances where amplification effects are stronger.

In contrast sites characterized by hard rock or firm soil display minimal amplification of seismic waves. Here, the observed Sa/g values tend to align more closely with ANN predictions. The limited amplification means that the ANN Model 's predictions are generally, more accurate for these sites.

Consequently, the graph representing these sites demonstrate a consistent trend with minimal fluctuation in observed Sa/g values across epicentral distances. This consistency suggests that the ANN model is better at predicting ground motion in areas with less complex site conditions.

In areas with intermediate soil characteristics, the observed behaviour falls between the extremes observed in soft soil and hard rock sites. These sites encounter moderate amplification effects, resulting in observed Sa/g values that are slightly high er than ANN predictions, albeit not as significantly disparate as in soft soil - sites. The graph depicting these sites illustrate a gradual rise in observed Sa/g values with some variability showcasing the mixed impact of soil conditions. This implies that while the ANN model incorporates certain site-specific elements, further enhancements may be necessary to accurately predict ground motion across all types of sites.

Overall, comprehending the role of site amplification is essential for enhancing the dependability of seismic hazard evaluations and the predictive capabilities of ANN Models.

8.7 Summary

When examining the relationship between observed Sa/g and Sa/g predicted by (ANN) based on epicentral distance, it is common practice to assess the alignment of the model's predictions with actual data. Ideally, a linear trendline should closely follow a 1:1 correlation, indicating high level of prediction accuracy.

However, as the epicentral distance increases, it is common to observe that depicts a decrease in Sa/g due to the natural attenuation of seismic waves. In cases where the ANN model is precise, the predicted values should also exhibit corresponding decrease. Also, the discrepancies between observed and predicted values at different distances can pinpoint areas where the model requires refinement particularly accounting for wave attenuation and local geological factors.

The analysis of site amplification holds significant importance in this context. Variations in site conditions including soil composition and rock properties can lead to the amplification of seismic waves to different extents thus influencing the observed Sa/g values. In the North- East region of India notable for its seismic activity and diverse geological features, the impacts of site amplification are particularly pronounced. Softer soil types for instance may result in higher observed Sa/g values when compared to sites with harder rock formations. For an ANN model to be effective in this scenario, it must accurately integrate these local site amplification aspects This ensures that the model delivers dependable predictions across various sites, a crucial aspect for the development of earthquake -resistant structures and the formations of effective mitigation strategies.

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CHAPTER 9

SUMMARY AND CONCLUSION

Earthquakes are a great phenomenon of the earth resulting from the sudden release of energy in the Earth's Crust causing seismic waves which propagate throughout the Earth as they move. Ground shaking is the main reason of damage during an earthquake.

Attenuation relationships are vital for estimating ground motions at various distances from the epicentre. It considers various factors like seismic wave propagation through different geological structures, soil types, and tectonic settings unique to North-east India. The result is a set of equations, termed ground motion prediction equations (GMPEs), that quantify the expected level of ground shaking at specific locations given earthquake characteristics, like magnitude and distance.

Firstly, analysing earthquake signals through Seismo-Signal provides data on the magnitude, depth and frequency of seismic events. This information is crucial for seismic hazard assessment and risk mitigation strategies. By studying these signals, scientists can identify patterns, such as clustering of earthquakes or the recurrence intervals between major seismic events. This aids in predicting potential future earthquakes and assessing the vulnerability of infrastructure and communities in the area.

Secondly, the analysis of earthquake signals of North-East India helps in understanding the local geological structures and fault systems. Differentiating between various types of seismic waves and their propagation paths offers insights into the complexities of the Earth's crust in this region. It assists geologists in mapping fault lines, determining stress accumulations, and assessing the potential for future seismic activity along specific fault segments.

By training ANNs with regional seismic data, engineers can develop models that provide accurate predictions of ground shaking and spectral acceleration. This helps in designing structures that are better equipped to withstand local seismic hazards, enhancing safety and resilience.

From an engineering viewpoint, the consideration of site amplification and epicentral distance in North-East India holds paramount importance. Precise modelling of these elements aids in the anticipation of the seismic forces that structures may encounter. Engineers can leverage these predictions to devise buildings and infrastructure that exhibit resilience to earthquakes, while factoring in the specific local site conditions. Moreover, a comprehension of the trend depicting a reduction in Sa/g concerning distance can support regional seismic hazard evaluations, thereby guiding construction methodologies and safety protocols tailored to the unique seismic attributes of North-East India.

Therefore, Spectral attenuation relationships are crucial in seismic hazard analysis as they help predict ground motion at different frequencies, which is vital for engineering designs, especially for structures sensitive to specific frequency ranges.

CHAPTER 10

SCOPE FOR FUTURE STUDY

Studying the attenuation of spectral acceleration in North-east India holds immense significance for seismic risk assessment, infrastructure design, and disaster mitigation strategies in the region. Understanding how seismic waves attenuate as they travel through the region's geology is crucial for predicting ground motions during earthquakes.

By analysing how seismic waves lose energy as they propagate through the diverse geological structures of North-east India, scientists and engineers can develop more accurate GMPEs tailored to this specific region. These equations are pivotal for seismic hazard assessments, influencing building codes, infrastructure design and risk mitigation strategies.

Moreover, North-east India's complex geological setting, including varying rock types, soil conditions, and tectonic features, presents a unique challenge and opportunity for seismic research. Understanding how seismic waves interact with this diverse geological environment can offer insights into the attenuation characteristics specific to these conditions.

This knowledge not only aids in predicting ground motions but also helps in identifying vulnerable areas and improving the resilience of infrastructure, such as buildings, bridges, and lifeline systems, against potential seismic events.

Furthermore, the study of attenuation in North-east India contributes to broader seismic research and global seismic risk assessment models. The data collected and the models developed can serve as valuable inputs for international seismic hazard assessments, benefiting neighbouring regions with similar geological settings. Collaborative efforts in studying attenuation in this region could potentially contribute to advancements in seismic science and engineering practices worldwide.

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APPENDIX - I

(A) Dataset – 1: Indian National Strong Motion Instrumentation Network (PESMOS)

1. Earthquake data of **11 Aug 2009** – (Myanmar **- India-Manipur border)**
Focal depth = 22 Km, Mb = 5.6

Stations	**Epic. Distance (km)**	**Latitude (◦N)**	**Longitude (◦E)**	**Site Class**
Silchar	208	24.830	92.801	C
Diphu	211	25.839	93.435	B
Hailakandi	229	24.682	92.563	C
KarimGanj	253	24.870	92.354	C
Tezpur	318	26.619	92.797	B
Guwahati	366	26.190	91.746	C
Nongstoin	378	24.400	94.800	A
Boko	400	25.976	91.230	C
Goalpara	463	26.152	90.627	C
Tura	478	25.511	90.220	B
Bongaigaon	484	26.473	90.561	C
Kokrajhar	507	26.400	90.261	C

2. Earthquake data of **03 Sep 2009** – (**Myanmar -India-Manipur Border**)
Focal Depth = 100 Km, Mb= 5.9

Stations	**Epic. Distance (km)**	**Latitude (◦N)**	**Longitude (◦E)**	**Site Class**
Silchar	191	24.830	92.801	C
Diphu	208	25.839	93.435	B
Hailakandi	210	24.682	92.563	C
Guwahati	356	26.190	91.746	C
Nongstoin	363	25.522	91.264	A
Boko	388	25.976	91.230	C
Goalpara	450	26.152	90.627	C
Tura	462	25.511	90.220	B
Bongaigaon	472	26.473	90.561	C

3. Earthquake data of **29 Oct 2009 – (Bhutan region)**

Focal Depth = 10 Km, Mb = 4.2

Stations	**Epicentral.Dist (Km)**	**Latitude (◦N)**	**Longitude (◦E)**	**Site Class**
Kokrajhar	34	26.400	90.261	C
Bongaigaon	58	26.473	90.561	C
Goalpara	80	26.152	90.627	C
Tura	123	25.511	90.220	B
Nongstoin	174	25.522	91.264	A

4. Earthquake data of **26 Feb 2010 – (Tibet region**)

Focal Depth = 28 Km, Mb = 5.4

Stations	**Epi. Distance (km)**	**Latitude (◦N)**	**Longitude (◦E)**	**Site Class**
Darjeeling	222	27.050	88.262	A
Gangtok	228	27.352	88.627	A
Siliguri	261	26.712	88.428	C
Kokrajhar	422	26.400	90.261	C
Bongaigaon	443	26.473	90.561	C
Goalpara	468	26.152	90.627	C
Guwahati	561	26.190	91.746	C

5. Earthquake data of **11 Sep 2010 – (Meghalaya – Assam border)**

Focal Depth = 20 km, Mb = 5

Stations	**Epi. Distance (Km)**	**Latitude (◦N)**	**Longitude (◦E)**	**Site Class**
Kokrajhar	56	26.400	90.261	C
Bongaigaon	73	26.473	90.561	C
Guwahati	158	26.190	91.746	C

6. **Assam** Earthquake data of 16 April 2013

Focal Depth = 16 Km, Mb = 4.6

Stations	**Epicentral.Dist(km)**	**Latitude (◦N)**	**Longitude (◦E)**	**Site Class**
Nagaon	68	26.349	92.690	C
Tezpur	87	26.619	92.797	B
Barpeta	99	26.332	91.006	C
Dibrugarh	317	27.467	94.912	C

APPENDIX-II

Dataset -2: Source - COSMOS Virtual Data Centre

(A) Earthquake data of 10 Jan Sept 1986 (North-East India region)

Focal depth = 43 Km, Mb = 5.2

Stations	Epicentral Dist. (Km)	Latitude (◦N)	Longitude (◦E)	Site Class
Baithalangso	80	25.970	92.600	B
Dauki	27	25.190	92.030	B
Khliehriat	30	25.360	92.370	A
Nongkhlaw	53	25.690	91.640	A
Nongpoh	57	25.910	91.880	A
Nongstoin	82	25.510	91.270	A
Panimur	77	25.660	92.800	B
Pynursla	22	25.310	91.910	A
Saitsama	45	25.720	92.390	B
Ummulong	13	25.520	92.160	A
Umrongso	56	25.510	92.630	A
Umsning	39	25.740	91.890	A

(B) Earthquake data of 6 May 1995 (India-Burma Border region)

Focal Depth = 117 Km, Mb = 6.4

Stations	Epicentral Dist. (Km)	Latitude (◦N)	Longitude (◦E)	Site Class
Khliehriat	302	25.360	92.370	A
Umrongso	279	25.510	92.630	B
Baigao	254	25.410	92.860	B
Bamungao	237	25.890	93.010	B
Berlongfer	227	25.770	93.250	B
Diphu	216	25.920	93.440	B
Halflong	235	25.170	93.020	B
Hatikhali	235	25.650	93.110	B
Hojai	272	26.000	92.860	B