LOCAL SITE EFFECTS ON EARTHQUAKE EARLY WARNING

A DISSERTATION

Submitted in partial fulfillment of the

requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

EARTHQUAKE ENGINEERING

(With Specialization in Structural Dynamics)

by

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CANDIDATE’S DECLARATION

I hereby declare that the study which is being presented in this Dissertation entitled “LOCAL SITE EFFECTS ON EARTHQUAKE EARLY WARNING”, submitted in the partial fulfillment of the requirements for the award of the degree of Master of Technology in Earthquake Engineering with specialization in Structural Dynamics, Indian Institute of Technology Roorkee, is an authentic record of my own work carried out for a period from June 2017 to June 2018, under the supervision of Dr. Ravi S Jakaa, Associate Professor, Department of Earthquake Engineering, Indian Institute of Technology, Roorkee and Dr Ashok Mathur, Retired Associate Professor, Department of Earthquake Engineering, Indian Institute of Technology Roorkee The matter embodied in this dissertation work has not been submitted by me for the award of any other degree or diploma.

Date:

Place: Roorkee.

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

Earthquake Early Warning System (EEW) is a standout amongst the most helpful instruments to effectively reduce seismic risk. EEW approaches have just been created around the world. The issues of improving the accuracy and applicability are still controversial. On the basis of the existing measurable parameters related to the magnitude, method is developed here in this dissertation in terms of cubic equation between various parameters and magnitude for different site classes. Parameters comprise of Peak Displacement and average period of the P- wave and they are calculated using initial 3-sec of P-wave. Different equations for different site classes between displacement and magnitude, and also between average period of P-wave and magnitude are obtained, so that magnitude can be calculated for Earthquake Early warning after accounting site effects. Site amplification at the surface of different site classes is also analyzed. Results from different site classes for different magnitude and epicentral distances are compared and discussed.

Chapter 1

INTRODUCTION

1.1 GENERAL

Earthquake Early Warning is considered as one of the real time earthquake damage mitigation measures which detects, analyzes and transmits information of the impending ground shaking prior to the arrival of seismic waves at potential user site. The basic requirement of an EEW system is the development of a real time algorithm for fast calculation of earthquake source parameters and estimation of reliability.

The reliable issuance of the warning depends on the accuracy of the estimated parameters which depends on the initial 3 –sec of the P- onset wave. As P- waves are faster than shear waves, parameters are calculated on the basis of initial 3 –sec of the P-waves. Earthquake early warning is issued when at least 3 stations exceed the pre threshold value of the Early warning parameter alarm is issued.

Parameters that are used for the calculation of earthquake Early Warning are (τ_c) and Peak Displacement. These are calculated from the initial time period of P- wave.

Local site conditions can profoundly influence all of the important characteristics i.e. amplitude, frequency and duration of strong ground motion. The extent of their influence depends on the properties of the sub surface material, on site topography and on the characteristics of the input motion. The nature of the local site effects can be illustrated in several ways by simple theoretical ground response analysis. It affects the spectral acceleration of the soil. It gets increased at the surface of the soil.

NEED FOR STUDY

Even a few sec of warning can help in reducing damages that are caused due to earthquake. Earthquake Early Warning is helpful in reducing damage caused by earthquake such as rapid transit vehicles and high speed trains can reduce their speed in order to avoid accident; it will be useful for orderly shutoff gas pipelines to minimize fire hazards and shut down of high technological manufacturing operation to reduce potential losses.

1.2 OBJECTIVES

Objective of the dissertation is to investigate the influence of local site conditions on the earthquake early warning parameters and their estimation. Various tasks involved in the study are:

- Initially to study effect of soil condition on surface ground motion parameters
- To study how local site effects are influenced by different earthquake motions
- To obtain EEW parameters for different earthquake motions and soil conditions
- To estimate magnitude from EEW parameters.

Chapter 2

LITERATURE REVIEW

Earthquake Early Warning is relatively new concept to mitigate seismic risk. EEW system has been in place in different countries. Here, a brief summary of literature on EEW is initially presented. After wards, literature on local site effects on ground motion characteristics is presented

Hauksson et al. (2007) investigated a reasonable way to deal with Earthquake early warning in southern California by deciding a ground-movement period parameter τc and a high-pass filtered uprooting sufficiency parameter τc from the underlying 3sec of the P wave shapes recorded at the Southern California Seismic Network stations for tremors with M >4.At a given site, we assess the size of an occasion from τc and the pinnacle ground-movement speed (PGV) from Pd. The approaching three segment signals are recursively changed over to ground increasing speed, speed and relocation. The relocations are recursively filtered with a restricted Butterworth high-pass filter with a cut-off recurrence of 0.075 Hz, and a P-wave trigger is always observed. At the point when a trigger happens, τc and Pd are registered. We found the connection amongst τc and greatness (M) for southern California, and amongst Pd and PGV for both southern California and Taiwan. These two connections can be utilized to recognize the event of a noteworthy seismic tremor and give nearby cautioning in the region around the station where beginning of solid ground movement is normal inside seconds after the landing of the P wave. At the point when the station thickness is high, the strategies can be connected to multi station information to build the power of on location early warning and to include the area a notice approach. In a perfect circumstance, such admonitions would be accessible inside 10s of the root time of a huge quake whose ensuing ground movement may keep going for several seconds.

Kanamori et al. (2008): As urbanization advances around the world, seismic tremor posture genuine danger to lives and properties for urban regions close significant dynamic blames ashore or subduction zone seaward. seismic earhquake early warning (eew) can be helpful apparatus for diminishing earthquake dangers, if the spatial connection amongst urban communities and quake sources is good for such warning and their residents are appropriately prepared to react to earthquake warning messages. An earthquake early warning framework cautions a urban zone of inevitable solid shaking, typically with a couple of sec to couple of several sec of warning time, i.e., before the entry of the dangerous s wave some portion of the solid ground movement. indeed, even a couple of second of guidance ahead of time will be valuable for pre-modified crisis measures for different basic offices, for example, quick travel vehicles and fast prepares to maintain a strategic distance from potential crash; it will be additionally helpful for precise shutoff gas pipelines to limit fire perils, controlled shutdown of high-innovative assembling tasks to decrease potential misfortunes, and safe-guarding of pc offices to keep away from loss of imperative databases. we investigated a handy way to deal with EEW with the utilization of a ground-movement period parameter τc and a high-pass sifted vertical dislodging abundancy parameter pd from the underlying 3 sec of the p waveforms. at a given site, a quake extent could be resolved from τc and the Peak ground velocity(PGV) could be evaluated from pd. in this strategy, approaching solid movement speeding up signals are recursively changed over to ground speed and uprooting. a p wave trigger is continually checked. at the point when a trigger happens, τc and pd are figured. the seismic tremor greatness and the on location ground-movement force could be assessed and the notice could be issued. in a perfect circumstance, such admonitions would be accessible inside 10 sec of the birthplace time of a vast seismic tremor whose resulting ground movement may keep going for several seconds.

Shen Et al. (2012): For over 10 years, the Central Weather Bureau of Taiwan has worked a Earthquake early cautioning (EEW) framework and has issued alerts for particular organizations. For as far back as two years, the Earthworm stage has been utilized to coordinate constant seismic information streams from various kinds of seismic stations and to screen seismicity in Taiwan. Utilizing the Earthworm stage, the Earthworm Based Earthquake Alarm Reporting (eBEAR) framework is as of now being developed for shortening detailing times and enhancing the exactness of admonitions for EEW purposes. The eBEAR framework comprises of new Earth worm modules for overseeing P-wave stage picking, trigger affiliations, hypocenter areas, extent estimations, and caution sifting preceding telecom. Here, we diagram the procedure and execution of the eBEAR framework. To adjust the eBEAR framework, a disconnected test was executed utilizing 154 seismic tremors with extents extending from ML 4.0 to 6.5. In a correlation of online execution utilizing the current EEW framework, the eBEAR framework lessened detailing times and enhanced the exactness of seaward seismic tremor areas and sizes. Online execution of the eBEAR framework showed that the normal revealing circumstances managed by the framework are around 15 and 26 s for inland and seaward tremors, individually. The eBEAR framework currently conveys alerts to rudimentary and middle schools in Taiwan**.**

Bhardwaj (2013): Earthquake Early Warning (EEW) framework is considered as one of the ongoing quake harm relief measures, which recognizes, investigations and transmits data of the approaching ground shaking before the entry of seismic waves at the potential client destinations. The notice time is utilized to limit property harm, loss of lives and to help crisis reaction. Such frameworks can be comprehensively delegated local and on location cautioning frameworks. While Regional cautioning approach is organize based, the Onsite cautioning approach utilizes single station perceptions for parameter estimation to give speedy cautioning.

The solid issuance of caution by EEW framework relies on the precision and dependability of anticipated parameters used to characterize the measure of the approaching occasion progressively. Such parameters are assessed utilizing the investigations of beginning part of seismic tremor records. In the present examination, not just the individual parameters, for example, Maximum Predominant Period (τp max), Average Period (τc), Peak Displacement (Pd), Cumulative Absolute Velocity (CAV) and RSSCV (Root Sum of Squares total speed) have been utilized to build up a calculation yet in addition different mixes have been endeavored to issue alert and gauge size with dependable exactness in insignificant time window. The evaluated parameters are observationally relapsed with the an earlier known index extent of the occasion at variable time windows beginning from 1 sec to 5 sec to decide edge esteems for the considered parameters to issue cautioning for occasion having $M \geq 6$. For instance, for a period window of 4 sec the edge estimations of parameters are observed to be 1.1 sec for τp max, 1.42 sec for τc, 0.95 cm for Pd, 23 cm/sec for CAV and 5.2 cm/sec for RSSCV, separately. The edge esteems figured for issuing cautioning at various time windows have been contrasted and the edge esteems recommended by different analysts and a nearby match has been taken note. The model for issuing cautioning depends on the alert status of closest four stations inside chosen epicentral separation of the occasion. Out of these four when three stations exceed the preset value estimation of an EEW parameter warning is issued.

Fahjan et al. (2004): One hundred in number movement accelerometers have been set in populated regions of Istanbul, inside a zone of around 50x30km, to constitute a system that will empower quick shake guide and harm evaluation after a harming tremor. After activated by a quake, each station will process the spilling solid movement to yield the phantom increasing velocities at particular periods and will send these parameters as SMS messages to the primary server farm, through accessible GSM organize administrations. A shake guide and harm conveyance will be consequently produced. The shake and harm maps will be accessible on the Internet and will likewise be pushed to a few end clients. For seismic tremor early cautioning data ten in number movement stations were situated as close as conceivable to the Marmara Fault. The consistent on-line information from these stations will be utilized to give close continuous cautioning to rising conceivably sad tremors.

Chiang et al. (2012): Taiwan is situated at the intersection of the Eurasian and Philippine Sea Plates, which is a piece of the circum-Pacific seismic belt with high quake exercises. By and large, in excess of 4,000 seismic tremors happen every year in the encompassing zone of Taiwan; in any case, current human innovation isn't yet able to do precisely estimating quake events in a viable way (helpful data including size, area, time, and so on.) to alarm influenced individuals before a harming seismic tremor really hits. For the most part, the tremor source is arranged somewhere inside the earth with the end goal that its seismic wave prepares dependably travel through muddled soil/shake stratum, and subsequently the wave speed differs along its movement way. The seismic waves can be quickly arranged into two noteworthy composes, P-and S-waves. The speed of P-wave is around 5-7 km/sec, while the more ruinous S-wave goes at around 3-4 km/sec. This investigation builds up an on location Earthquake Early Warning System (EEWS) using the physical mark that P-wave ventures quicker than S-wave. The proposed EEWS machine utilizes the flag from the on location sensors, requires just a genuinely negligible computational time, and is reasonable for giving seismic tremor early cautioning to the site that is near the epicenter. Likewise, the proposed nearby EEWS is incorporated with a fiasco decrease control framework utilizing a showing house that has been tried on NCREE's shaking table. The coordinated nearby EEWS can give the early seismic tremor cautioning through communicate, TV and LED content show. Additionally, it can naturally stop the lift, close down the gas, turn off the power control, open the crisis entryway, and turn on the lights along the escape course. Consolidating the on location

EEWS and calamity diminishment control framework, the life and financial misfortune can be extraordinarily lessened. As indicated by the approval tests directed in the field and lab, the proposed nearby EEWS has achieved a 80% effective rate of precisely foreseeing the seismic tremor power levels, and can consequently send an alert message no less than eight seconds previously the pinnacle S-wave trains come notwithstanding when the site is in the nearness of the quake epicenter.

LOCAL SITE EFFECTS

Ground surface movements are impacted by nearby site condition this is said based on couple of hypothetical reasons. At most destinations the thickness and S-wave speed of materials close to the surface are littler than at more noteworthy profundity. In the event that the impact of dissipating and material damping are disregarded, the protection of versatile wave vitality requires that stream of vitality from profundity to ground surface must be steady thusly, ρ and Vs diminishes as wave approach the ground surface. The attributes of neighborhood soil store can likewise impact the degree to which ground movement intensification will happen when particular impedance is consistent.

The site comprise of different soils of generally uniform shear wave speed overlying bed shake, thus, the recurrence reliance of the genuine intensification work is subjectively like that anticipated by basic ground reaction investigation for destinations with more convoluted sub surface condition, or for more grounded tremor in which soil non linearity wind up noteworthy, capacity of straightforward ground reaction examination to foresee sporadic pinnacles and valleys of real enhancement diminishes.

This can be examined by considering two cases of huge seismic tremors having nearby site condition: Michoacán Earthquake and California.

Mexico city 1985

September 19, 1985 (M=8.1) quake caused just direct harm in the region of its epicenter yet caused broad harm somewhere in the range of 350km away in Mexico city. Mexico city is partitioned into three zones lower region zone, lake zone, and change zone The best harm happened in those bit of lake zone which are underlain by 38 to 50 m softsoil. Most working in the 5-10 story run were fell or gravely damaged.It appears like that harmed structures were subjected to numerous cycles of huge dynamic powers at periods close to their principal period This "twofold reverberation condition" (intensification of bedrock motion by the soil deposit and amplification of the soil motion by the structure) combined with structural design and construction deficiency to cause locally devastating damage.

San Francisco Bay Area,1989

On October 19,1989 M=7.1 tremor happened close Mt. Loma Prieta situated around 100 km south of san Francisco and oak arrive, California. The reaction of two instruments, the reverberation condition situated at yerba Buena island and Treasure Island amidst San Francisco narrows mud. In spite of the fact that both are situated at same separation from the source however crest quickening recorded at Treasure Island is more when contrasted with yerba Buena island.

Chapter 3

METHODOLOGY

To analyse the effect of local site conditions on soil, earthquake data from KIKNET at different soil conditions have been downloaded. Motions are initially applied the baseline correction and butter worth filter of frequency of 0.10 Hz. Calculated spectral acceleration for input and output motions. Motion obtained at the surface is used to calculate the peak displacement and average period of P- wave using initial 3 sec of P-wave and calculate magnitude for the earthquake early warning.

Download the data from KIKNET and use the vertical motion data of the earthquake data.

1. Download earthquake data of different magnitude and epicentral distances.
2. Apply baseline correction and butter worth filter of frequency 0.1 Hz using seismosignal software.
3. Calculate spectral acceleration using ground response analysis using deepsoilv6.1software
4. Consider soil profile having different shear wave velocity and lying in different site class.
5. Calculation of different early warning parameters such as peak displacement and average period of P-wave.
6. Developing the relation between average period of the P-wave and magnitude and also between peak displacement and magnitude.
7. Calculate the magnitude using the relation.
8. Amplification of soil at the surface using spectral acceleration.

3.1 GROUND RESPONSE ANALYSIS

Ground Response Analysis are used:

- To predict ground surface motion for development of design response spectra.
- To evaluate dynamic stress and strain for evaluation of liquefaction hazard.
- To determine the earthquake induced forces that can lead to instability of earth and earth retaining structures.

A complete ground response analysis would model the rupture mechanism at the source of an earthquake, the propagation of stress waves through the earth to the top of the bed rock beneath a particular site and would then determine the how the ground surface motion is influenced by soils that lie above the bed rock.

One dimensional ground response analysis are based on the assumption that all boundaries are horizontal and response of soil deposit is caused by the SH – waves propagating vertically from the underlying bedrock soil and bed rock are extended infinitely in horizontal direction.

3.1.1 EQUVALENT LINEAR MODEL

A soil subjected to symmetric cyclic loading as would be expected beneath a level ground surface might exhibit a hysteresis loop. The hysteresis loop can be describe in two ways: first by actual path of loop itself and second by parameter that describe its shape. The two important characteristics of the loop are its inclination and its breadth. The inclination depends on the stiffness of the soil,which can be described at any point during the loading processby the tangent shear modulus,G_{tan} varies throughout a cycle of loading but its average value over the entire loop can be approximated by secant shear modulus.

$$Gsec = \frac{\tau c}{\Upsilon c} \quad \text{....3.1}$$

Where and τ_c and Υ_c are the shear stress and shear strain amplitudes respectively.

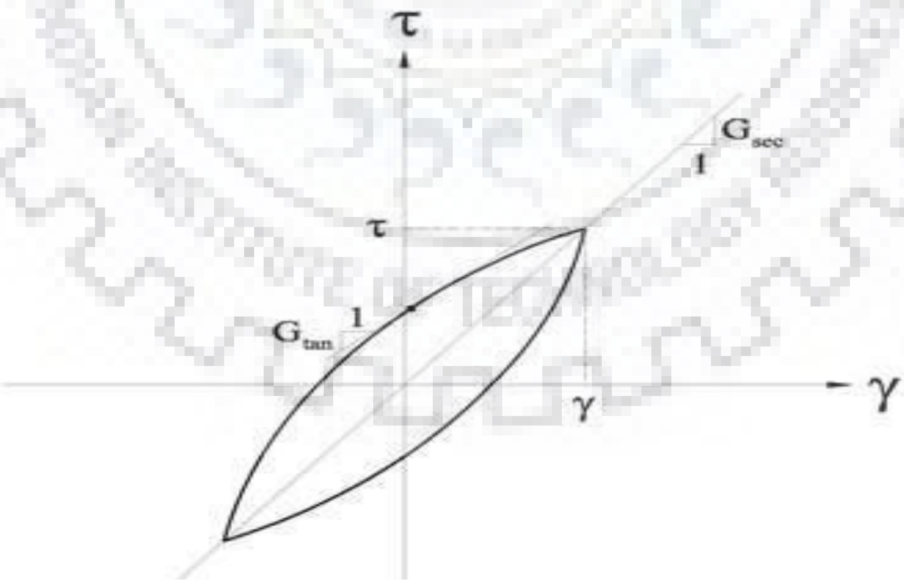

Figure 3.1: Hysteresis loop.

The breadth of the hysteresis loop is related to the area which as a measure of energy dissipation can be described by the damping ratio.

$$\varsigma = W_D / 4\pi W_S \qquad \ldots 3.2$$

$$= A_{loop} / 2\pi G_{Sec.\gamma c}{}^2 \qquad \ldots 3.3$$

Where W_D is the dissipated energy and W_S the maximum strain energy and A_{loop} the area of hysteresis loop.

The parameters G_{sec} and ς are often referred as equivalent linear material parameters.it is only an approximation of the actual non-linear behavior of the soil.it cannot be used for problems involving permanent deformation or failure.

3.1.1.1 SHEAR MODULUS

Laboratory test have shown that soil stiffness is influenced by cyclic strain amplitude, void ratio, mean principle effective stress, plasticity index, over consolidation ratio, and number of loading cycles.

The secant shear modulus varies with the cyclic shear strain amplitude. At low strain amplitudes, secant shear modulus is high, but it decreases as as the strain amplitude increases. The locus of points corresponding to the tips of hysteresis loop of various strain amplitudes is called a backbone curve (or skeleton).its slope at the origin represents the largest value of the shear modulus, G_{max} at greater cyclic strain amplitude, the modulus ration G_{sec}/G_{max} drops to value of less than 1 therefore, characterization of the stiffness of an element of soil requires consideration of both $G_{max}$and the manner in which the modulus ratio G/G_{max} varies with cyclic strain amplitude and other parameters.

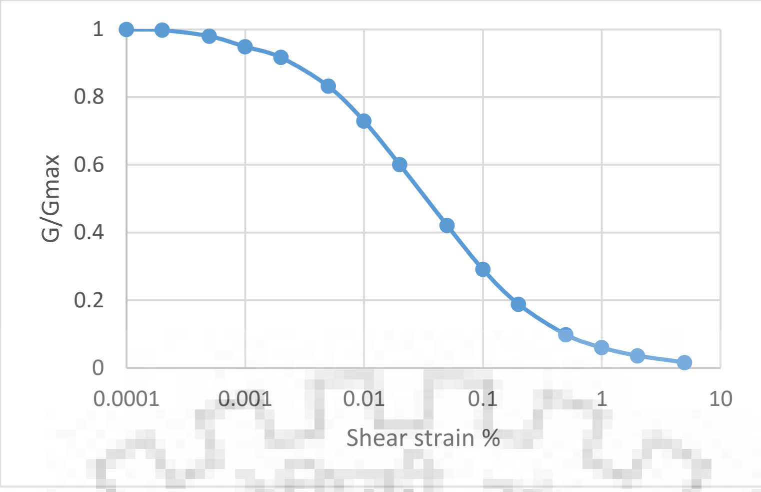

Figure 3.2: Modulus reduction curve.

3.1.1.2 MAXIMUM SHEAR MODULUS, G_{MAX}

Since most geo physical test induce shear strain lower than about 3x 10^-4%measured shear wave velocity can be used to compute G_{max}

$$G_{max}= \rho V_s\text{\^{}}2 \qquad \ldots 3.4$$

It is generally the most reliable means of evaluating the in –situ value of G_{max} for a particular soil deposit.laboratory test have suggested that maximum shear modulus can be expressed as

$$G_{max} = 625F(E)(e)\ (OCR)^k \rho_a^{1-n}(\sigma_m)^n \qquad \ldots 3.5$$

Where F(e) is a function of void ratio, OCR the over consolidation ratio exponenetσ_m the mean principal effective stress (σ_m'= σ_1 + σ_2 + σ_3 /3, n a stress component and ρ_a is atmospheric pressure in same units as σ_m' and G_{max} F(e) = 1/(0.3+.7e^2)the stress component is often taken as n-=.5.

3.2 DEEPSOIL SOFTWARE

DEEPSOIL is a one dimensional site response analysis program that can perform:

1) 1-D non-linear time domain analysis with and without pore water pressure generation, and

2) 1-D equivalent linear frequency domain analysis including convolution and deconvolution

Ground response spectrum is used for the amplification of the soil. Few steps that are used for the ground response analysis are listed below:

1) Earthquake motions of 3-sec of different magnitude and epicentral distance are added in the deep soil software.

Figure 3.3: Figure representing how motions to be added in the deeepsoil software.

2) Equivalent Linear Method of discrete points is used for spectral acceleration.

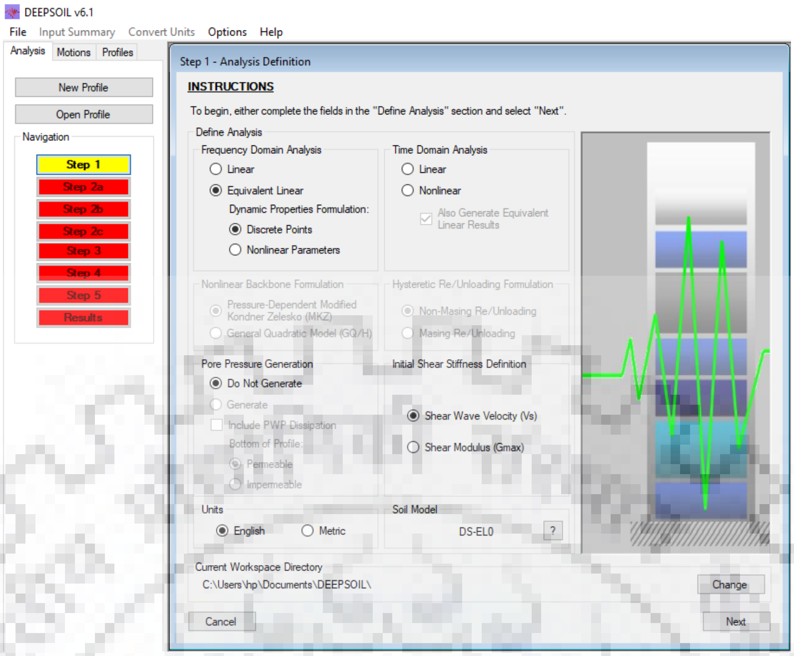

Figure 3.4: Steps for selecting equivalent linear method.

3) Consider a soil profile of depth 30m coming under different site classes and apply seed and iddris shear strain % and G/Gmax values

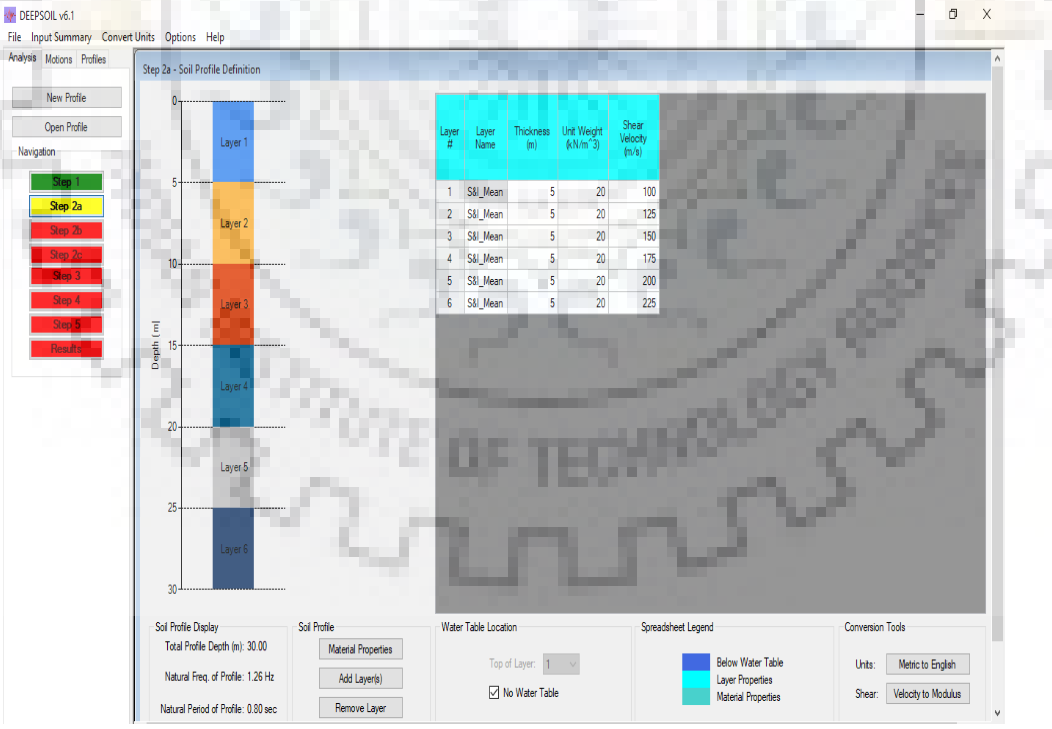

Figure 3.5: Assumption of soil layers for different site classes.

4) Analyse the result using the frequency domain analysis and we will get the spectral acceleration.

Chapter 4
PARAMETRIC STUDY

According to National Earthquake Hazard Reduction Program (NEHRP), soil is classified as:

Table 4.1: Classification of soil according to NEHRP.

Site Class	Type	Shear wave velocity (m/sec)
A	Hard rock	$V_s > 1500$
B	Rock	$760 < V_s \leq 1500$
C	Very dense soil or soft rock	$360 < V_s \leq 760$
D	Stiff soil	$180 < V_s \leq 360$
E	Soft soil	$V_s \leq 180$

Average shear wave velocity for a depth of height 30m is computed as:

$$Vs_{30} = \Sigma d / (\Sigma d_i / V_i) \qquad 3.6$$

1) Consider a soil profile having different shear wave velocity and lying in different site class according to NEHRP soil classification

Site class A

Average shear wave velocity for 30m depth is 2195.943 m/sec.

Table 4.2: Soil layers representing soil class A.

Layers	Depth (m)	Shear wave velocity (m/sec)
1	5	1900
2	5	2000
3	5	2200
4	5	2300

5	5	2400
6	5	2500

Site class B

Average shear wave for site class B is 932.130 m/sec

Table 4.3: Soil class representing soil class B.

Layers	Depth(m)	Shear wave velocity (m/sec)
1	5	750
2	5	800
3	5	900
4	5	1000
5	5	1100
6	5	1200

Site class C

Average shear wave velocity for very dense soil or soft rock is 534.09 m/sec

Table 4.4: Soil class representing soil class C.

Layers	Depth (m)	Shear wave velocity(m/sec)
1	5	475
2	5	500
3	5	525
4	5	550
5	5	575
6	5	600

Site class D

Average shear wave velocity for stiff soil is 255.416 m/sec.

Table 4.5: Soil class representing soil class D.

Layers	Depth(m)	Shear wave velocity(m/sec)
1	5	200
2	5	225
3	5	250
4	5	275
5	5	300
6	5	325

Site class E

Average shear wave velocity for soft soil is 150.65 m/sec.

Table 4.6: Soil class representing soil class E.

Layers	Depth(m)	Shear wave velocity(m/sec)
1	5	100
2	5	125
3	5	150
4	5	175
5	5	200
6	5	225

2) Download the earthquake data and apply baseline correction of .075Hz.
3) Filter the earthquake data to 3 sec using seismosignal.
4) Assume a soil profile of 30 m depth coming under different site classaccording to NEHRP classification

5) Apply earthquake data at the base of the soil.

6) Calculate peak displacement at the surface of the soil using initial portion of the P – wave.

7) Calculate average period (τ_c) of the P- wave using the relation

$$\tau_c = \frac{2\pi}{\sqrt{\gamma}} \qquad \text{...3.7}$$

$$\gamma = \frac{\int_0^{to} |\dot{u}|^2}{\int_0^{to} |u|^2} \qquad \text{...3.8}$$

Where ü, u̇, u is the acceleration, velocity and displacement of the earthquake history.

8) Draw the response spectrum comparing different site class.

RESULTS AND DISCUSSIONS

5.1 Response Spectrum for different Magnitude and Epicentral distances

A response spectrum is a plot of the peak or steady state (acceleration, velocity or displacement) of a series of oscillators of varying frequency that are forced into motion by the Earthquake.

From the graph we can conclude that when damping and density are constant and only shear wave velocity is varying. Amplification increases with increase in shear wave velocity. In site class A and B we have highest amplification as compared to other site classes.

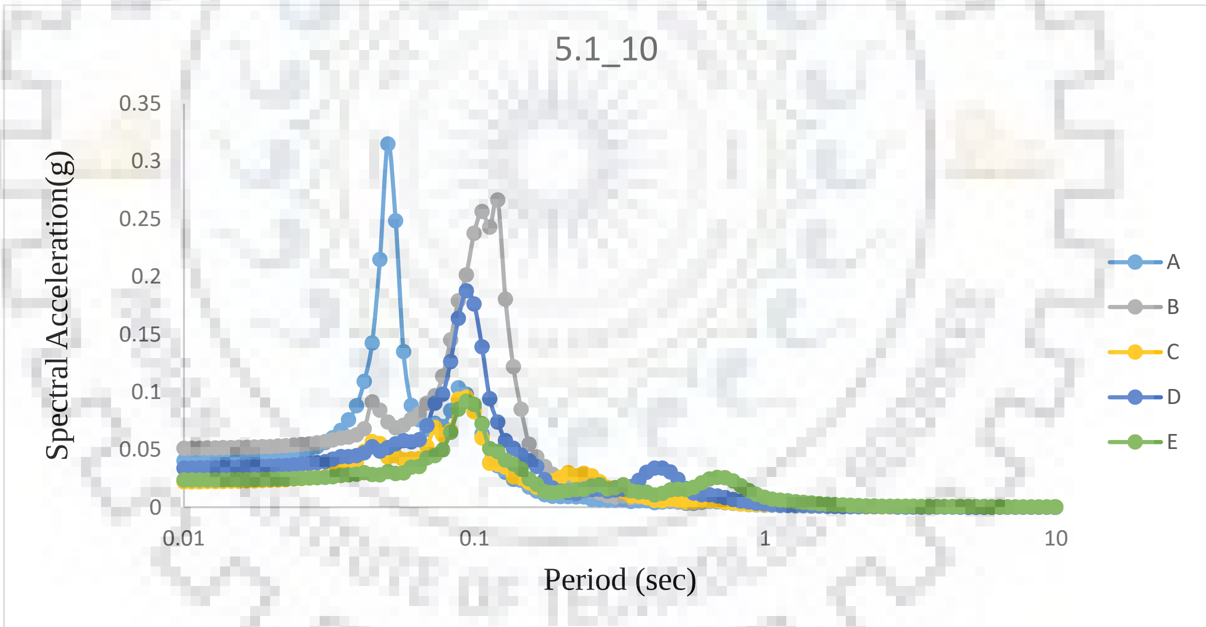

Figure 5.1: Response spectrum for different site class of 5.1 $M_w$and 10km epicentral distance.

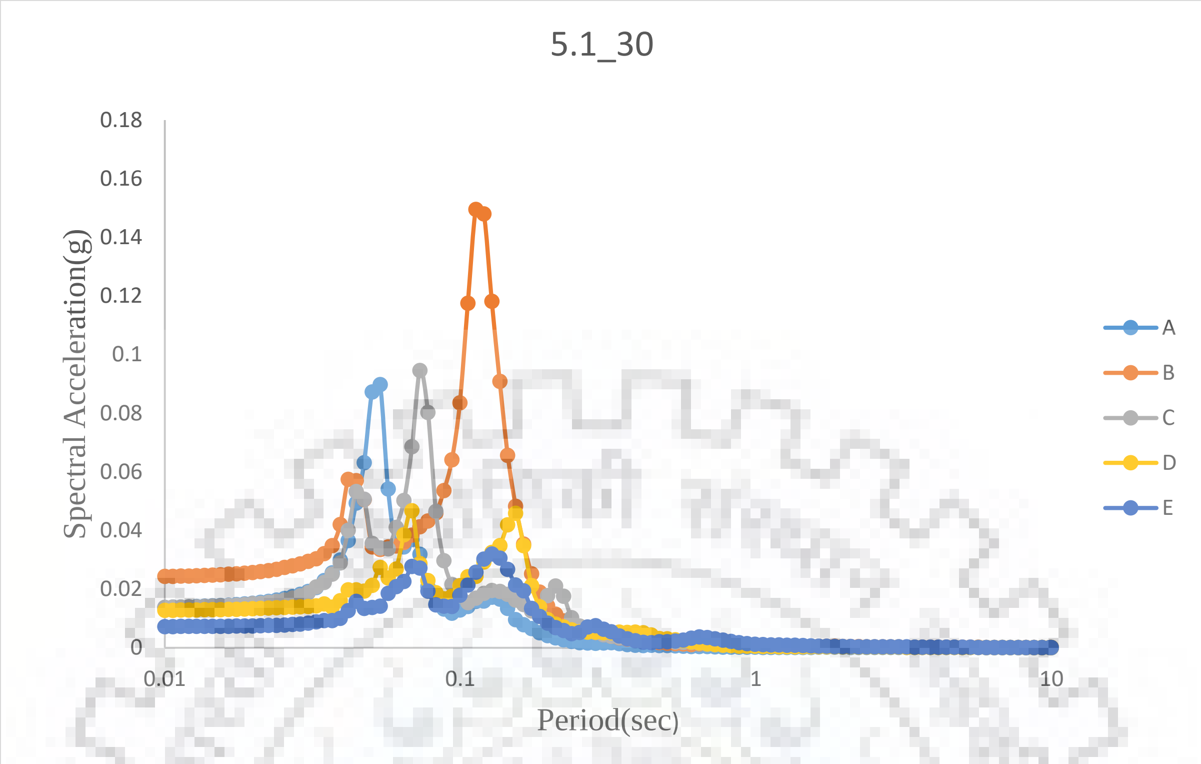

Figure 5.2: Response spectrum for different site class of 5.1 M_w and 30km epicentral distance.

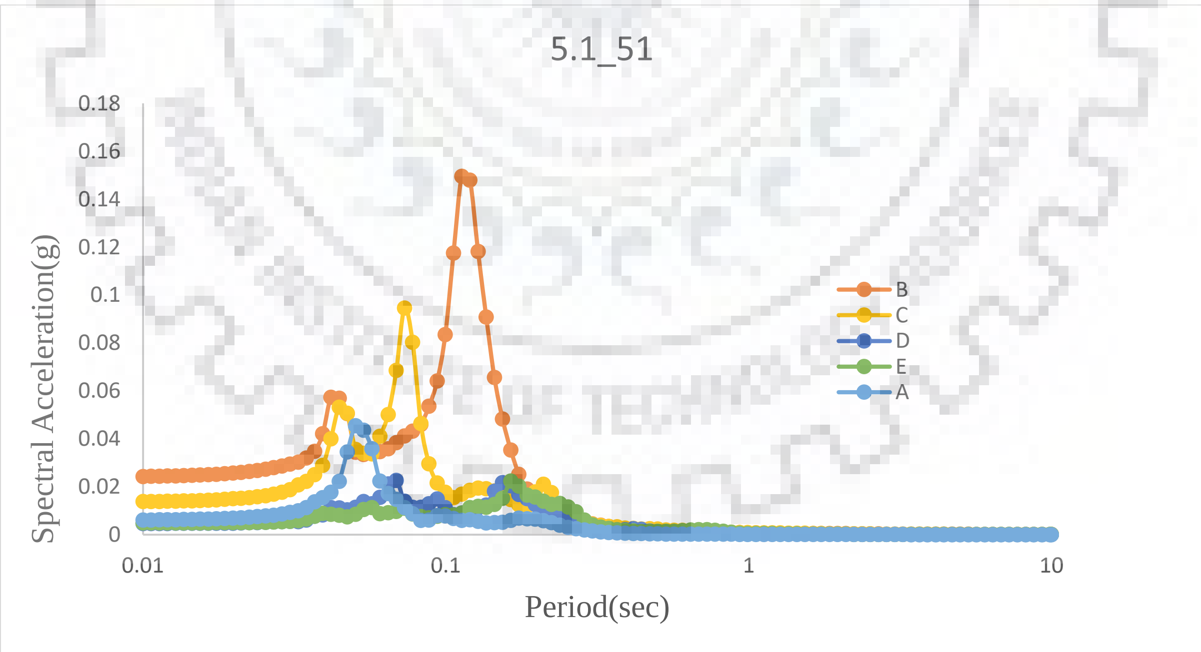

Figure 5.3: Response spectrum for different site class of 5.1 M_w and 51km epicentral distance.

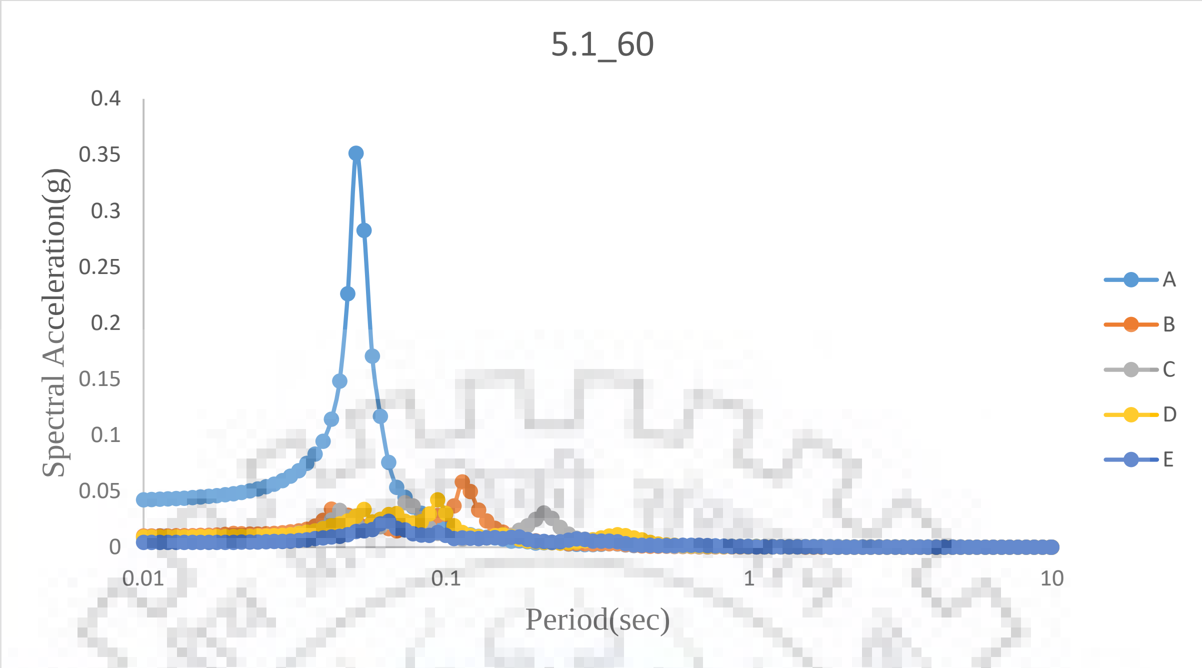

Figure 5.4: Response spectrum for different site class of 5.1 M_w and 60km epicentral distance.

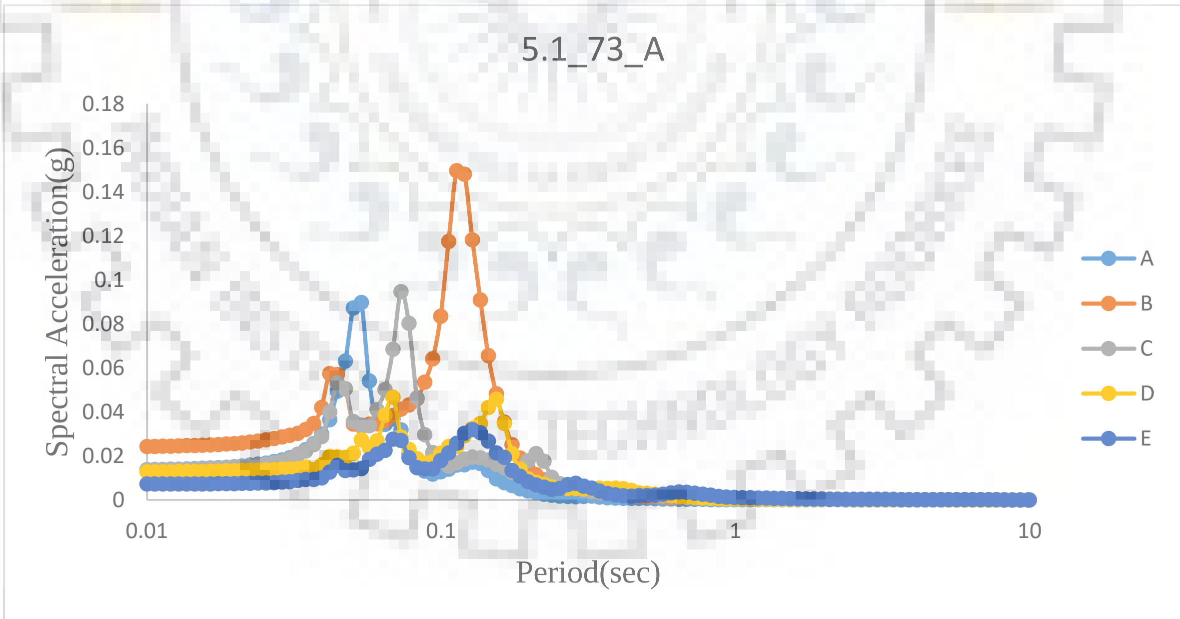

Figure 5.5: Response spectrum for different site class of 5.1 M_w and 73km epicentral distance.

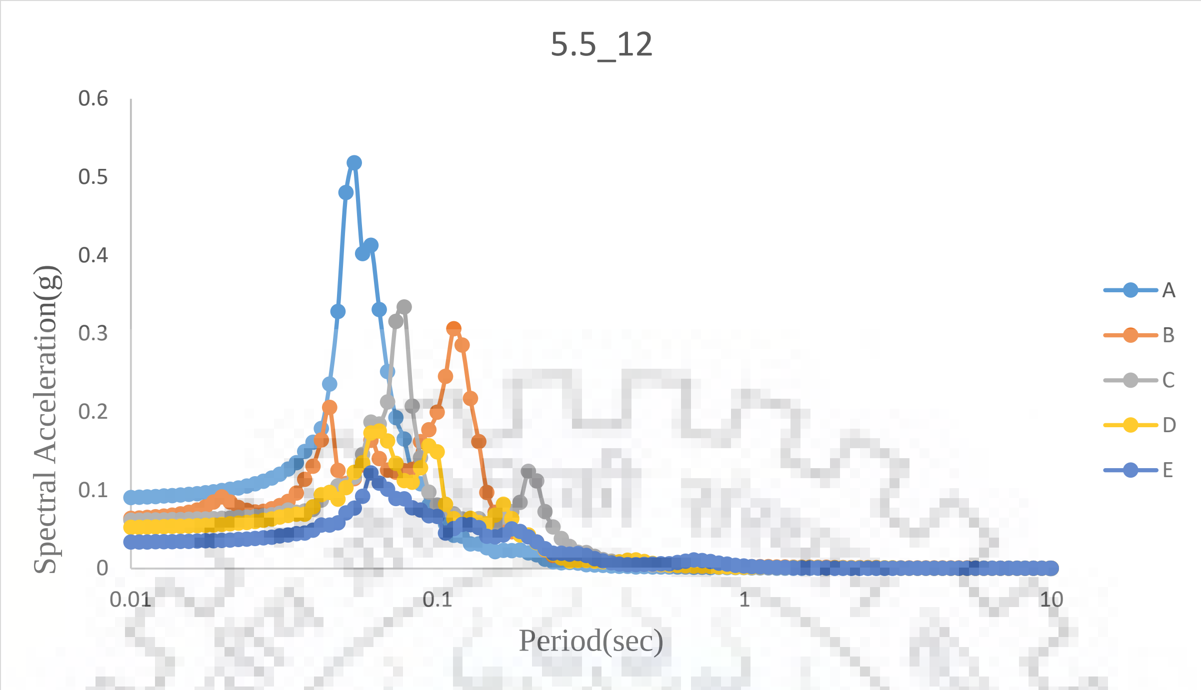

Figure 5.6: Response spectrum for different site class of 5.5 M_w and 12km epicentral distance.

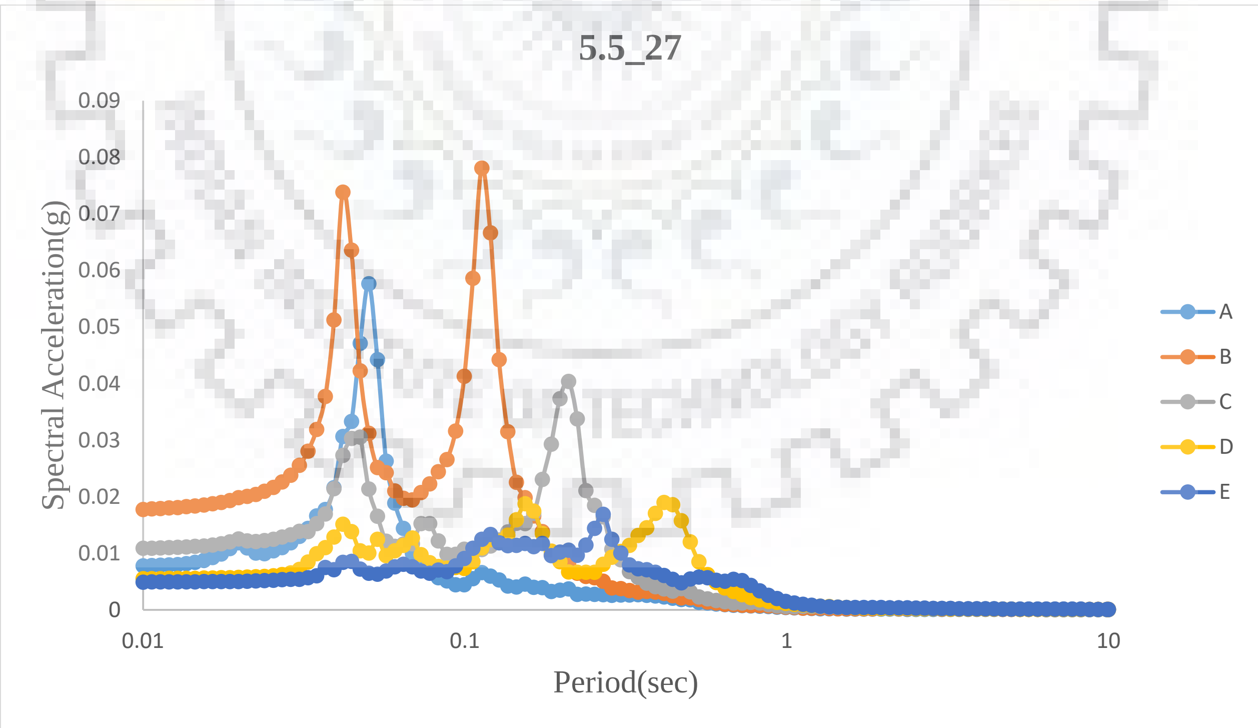

Figure 5.7: Response spectrum for different site class of 5.5 M_w and 27km epicentral distance.

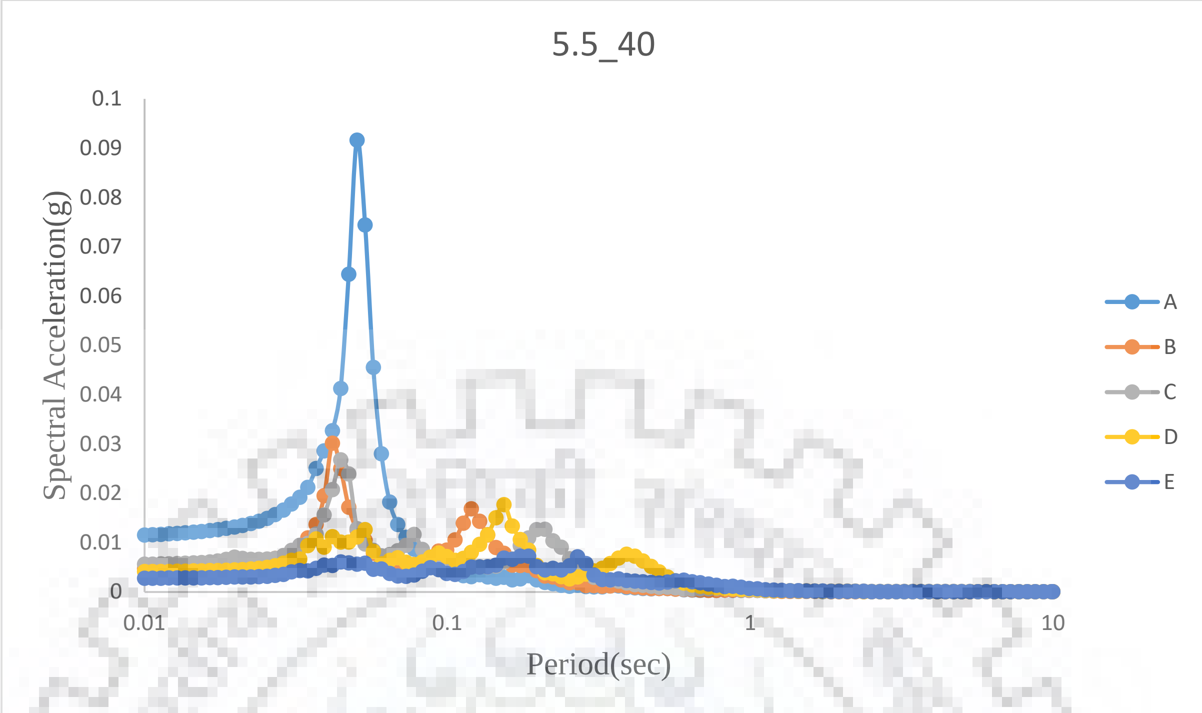

Figure 5.8: Response spectrum for different site class of 5.5 M_w and 40km epicentral distance.

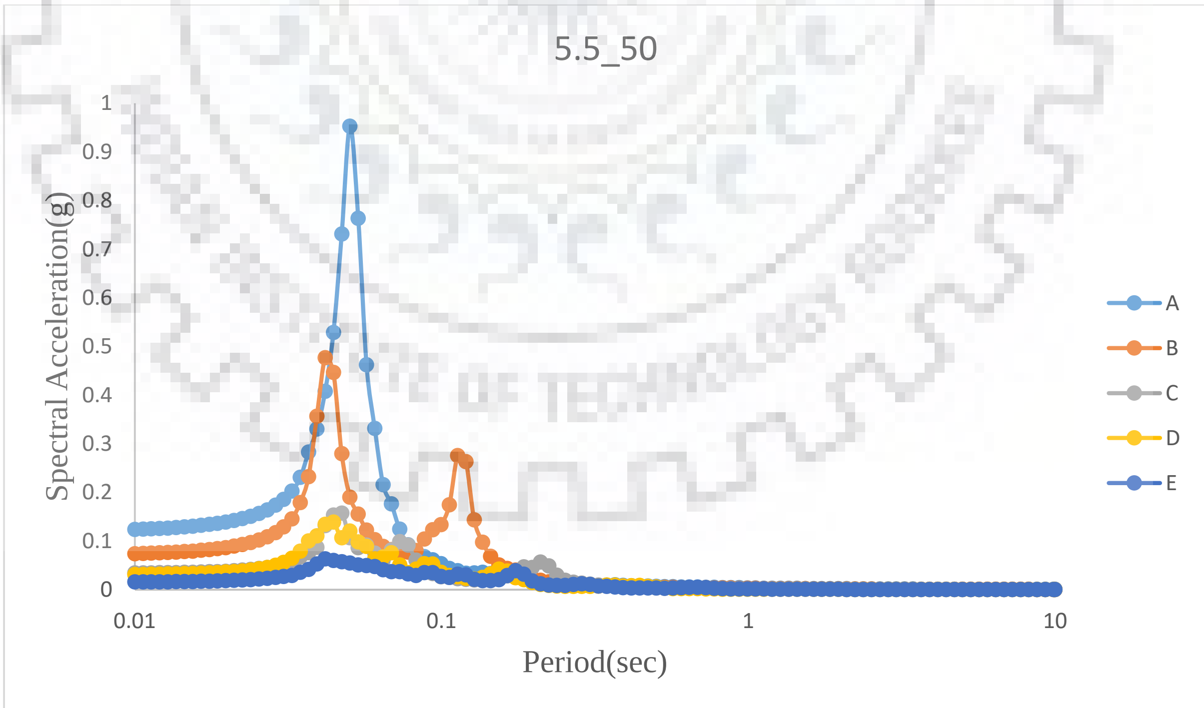

Figure 5.9: Response spectrum for different site class of 5.5 M_w and 50km epicentral distance.

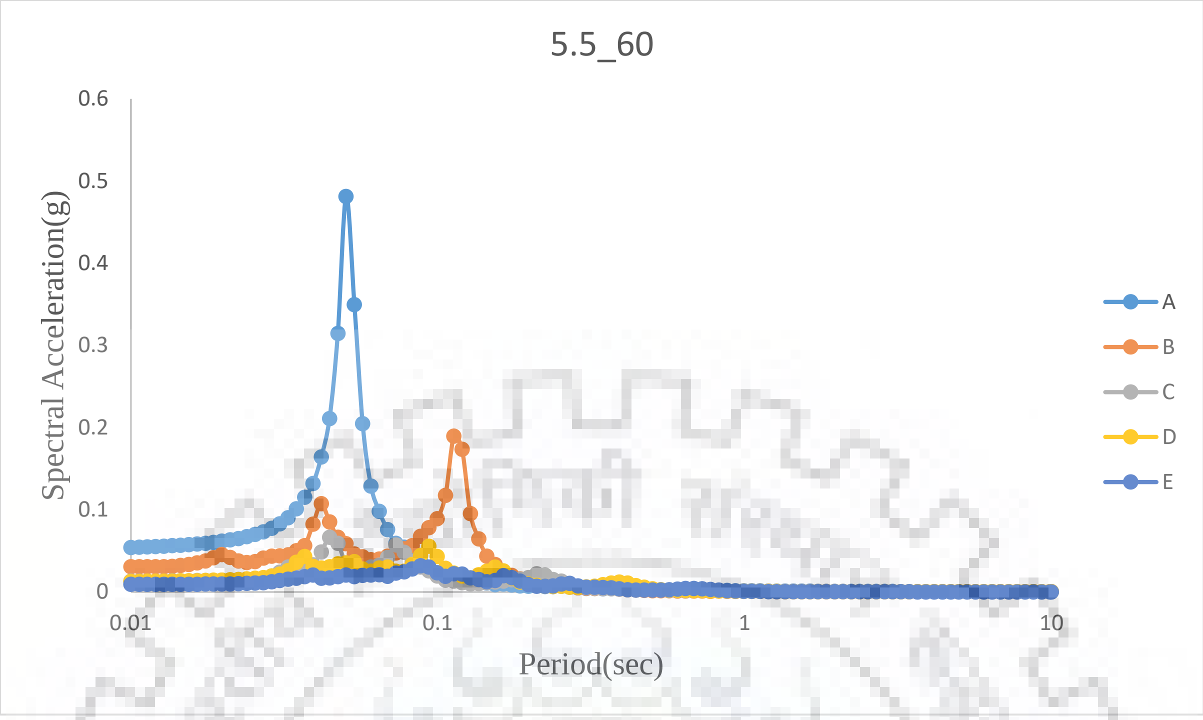

Figure 5.10: Response spectrum for different site class of 5.5 M_w and 60km epicentral distance.

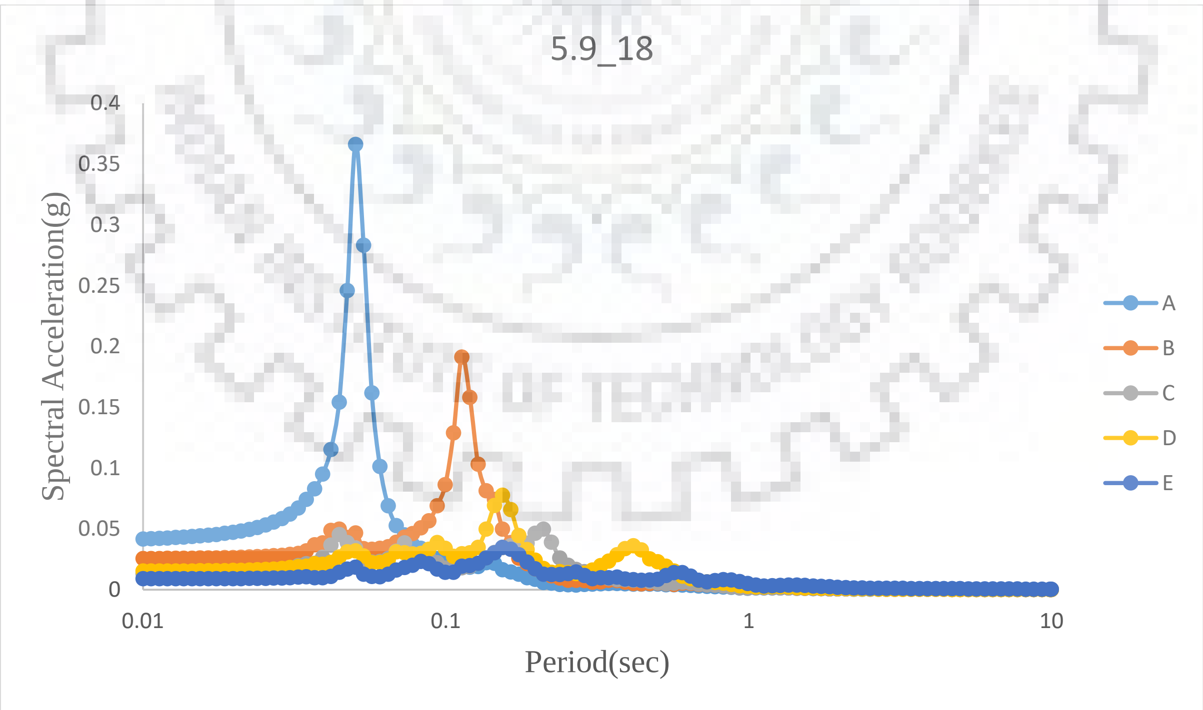

Figure 5.11: Response spectrum for different site class of 5.9 M_w and 18km epicentral distance.

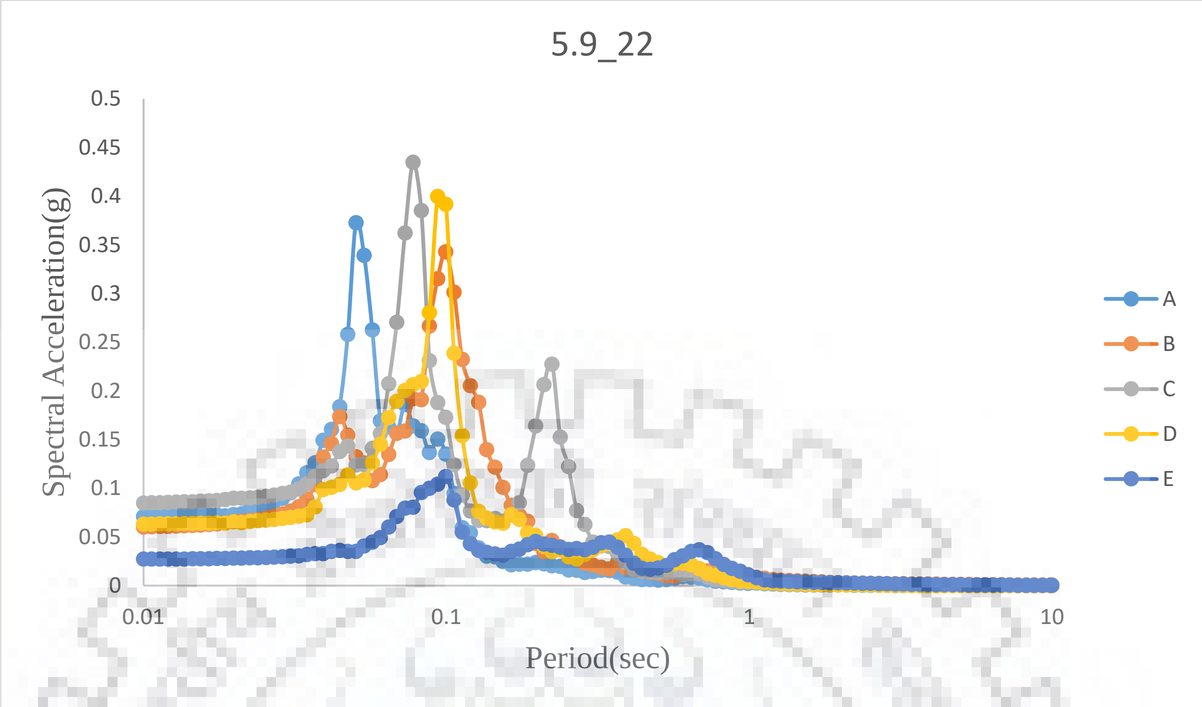

Figure 5.12: Response spectrum for different site class of 5.9 M_w and 22km epicentral distance.

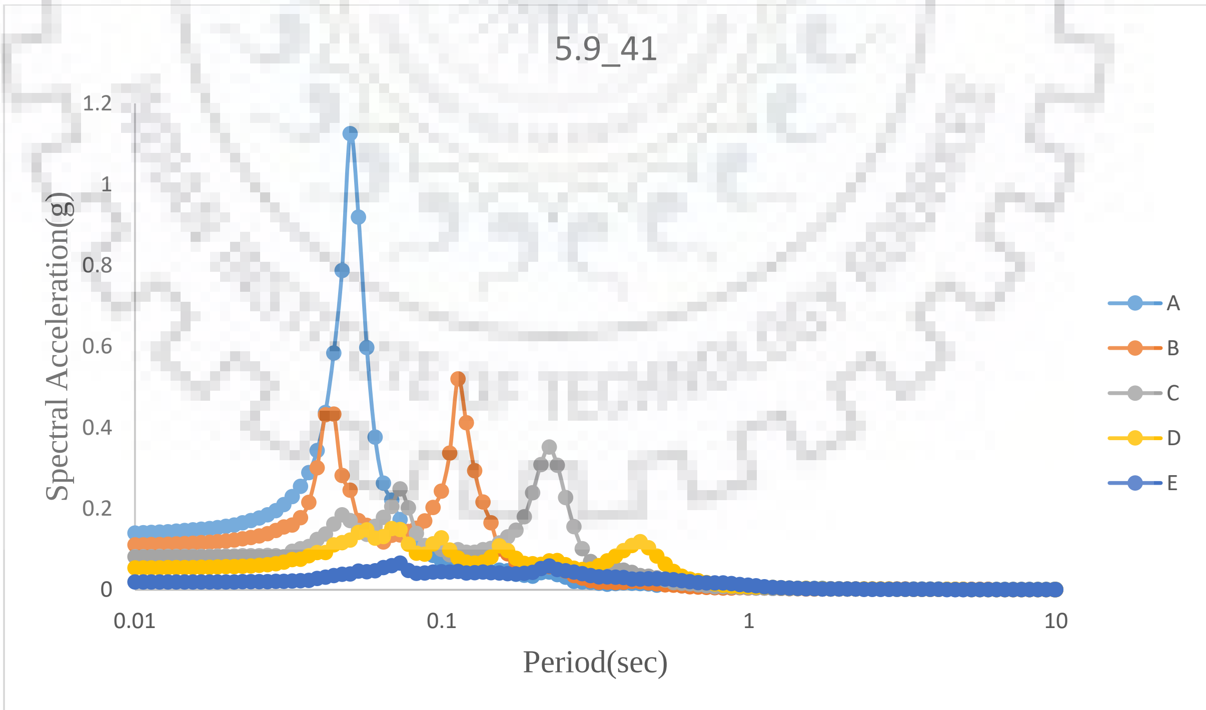

Figure 5.13: Response spectrum for different site class of 5.9 M_w and 41km epicentral distance.

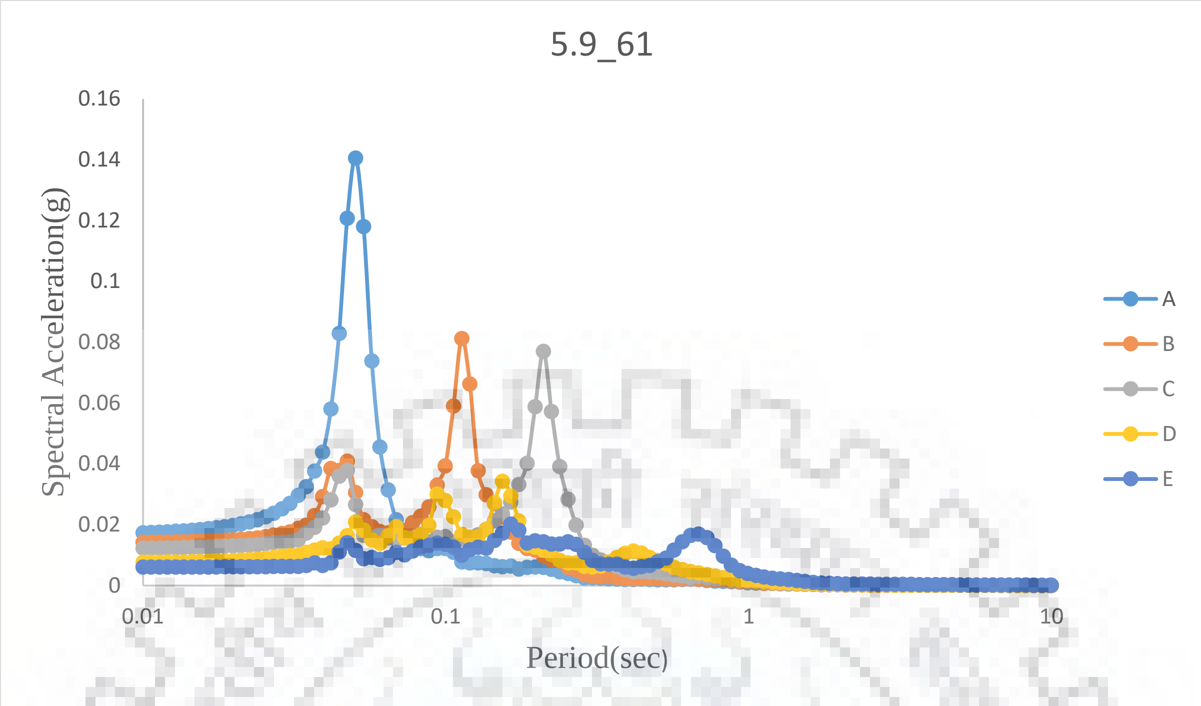

Figure 5.14: Response spectrum for different site class of 5.9 M_w and 61km epicentral distance.

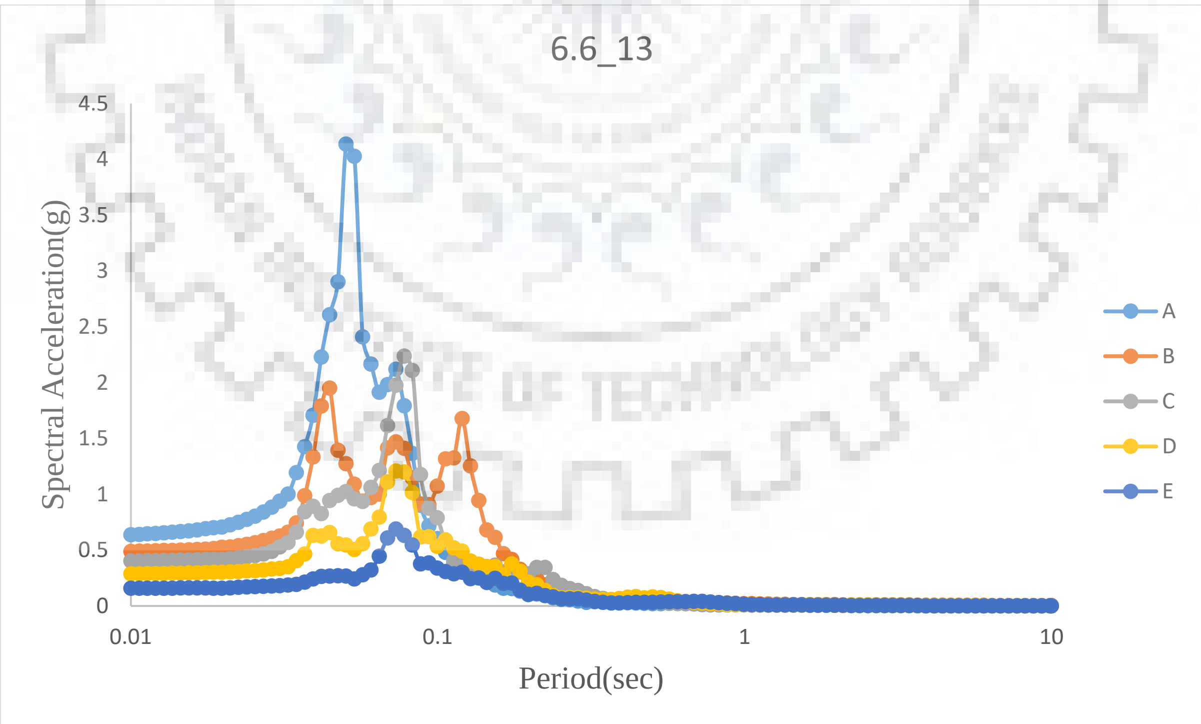

Figure 5.15: Response spectrum for different site class of 6.6 M_w and 13km epicentral distance.

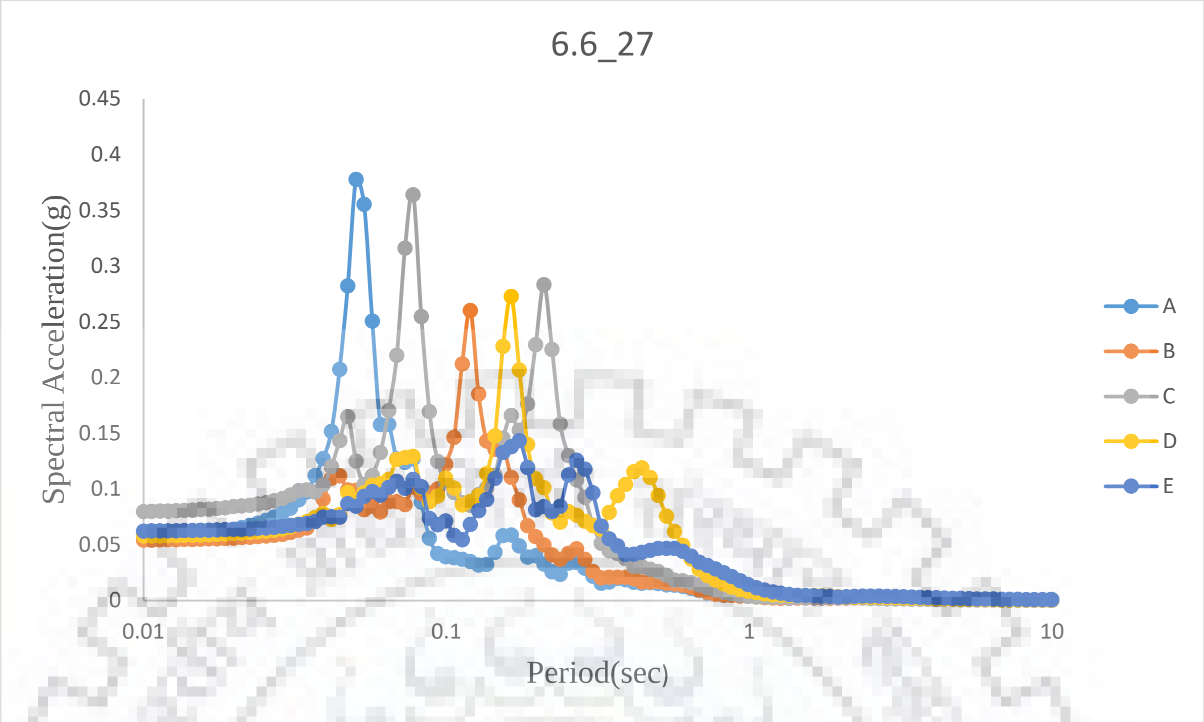

Figure 5.16: Response spectrum for different site class of 6.6 M_w and 27km epicentral distance.

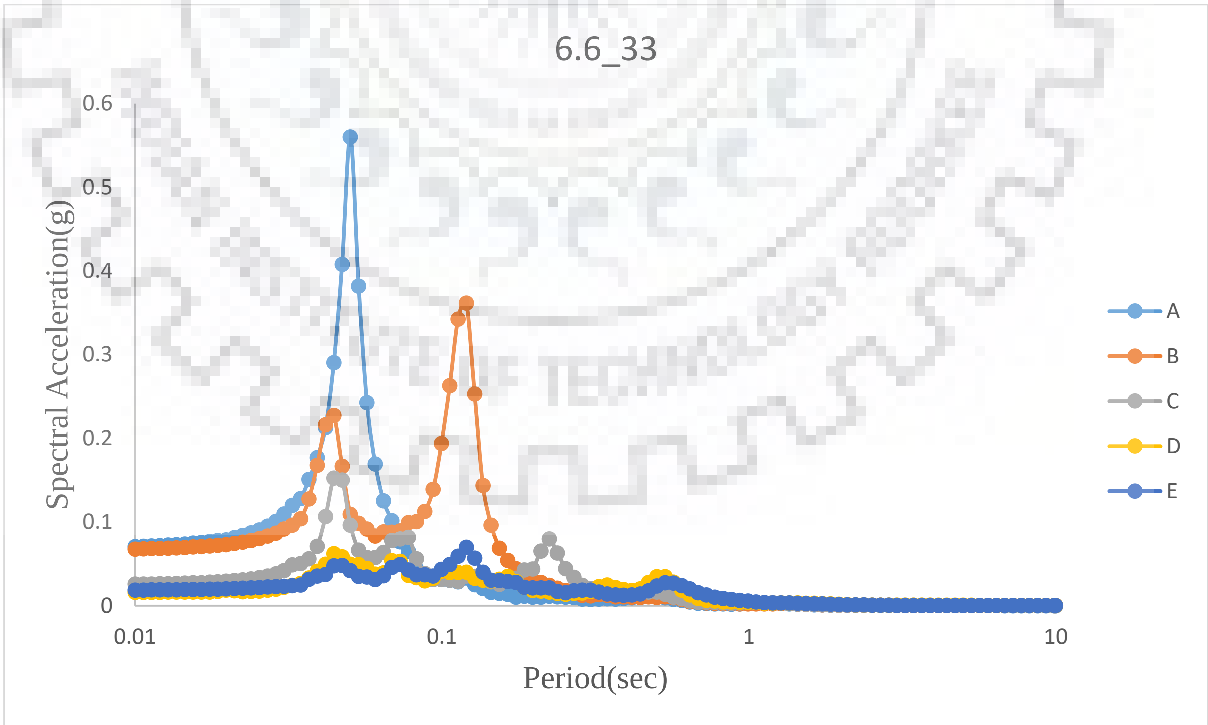

Figure 5.17: Response spectrum for different site class of 6.6 M_w and 33km epicentral distance.

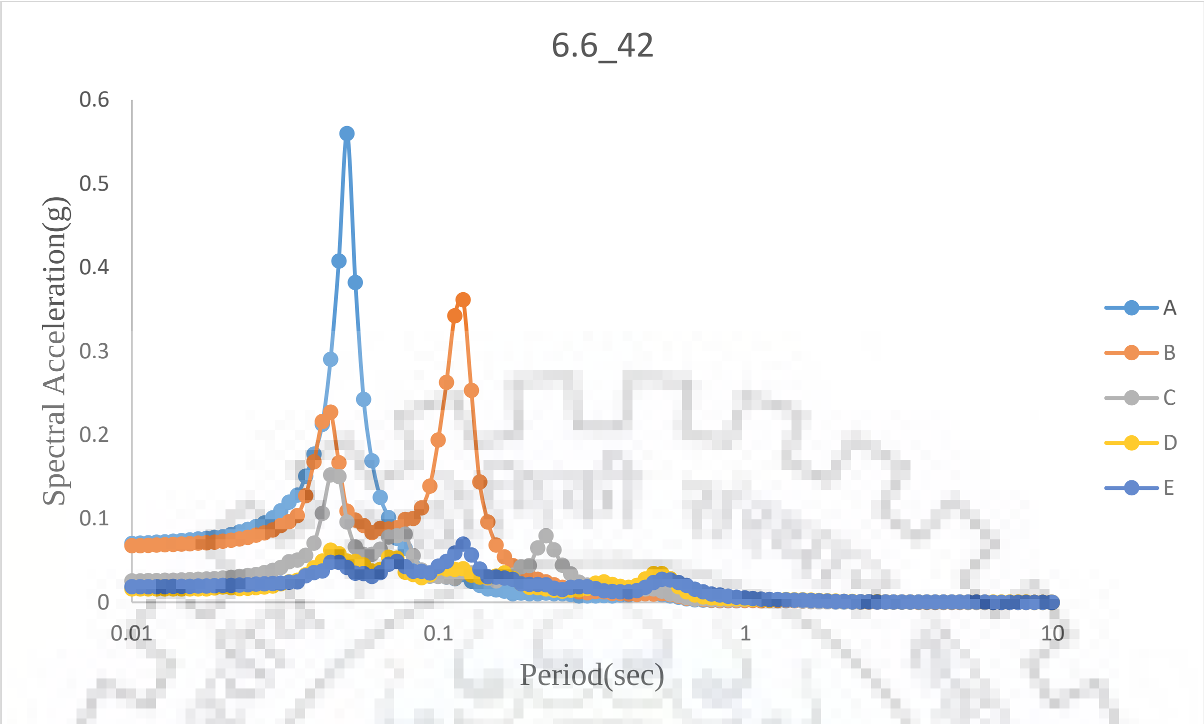

Figure 5.18: Response spectrum for different site class of 6.6 M_w and 42km epicentral distance.

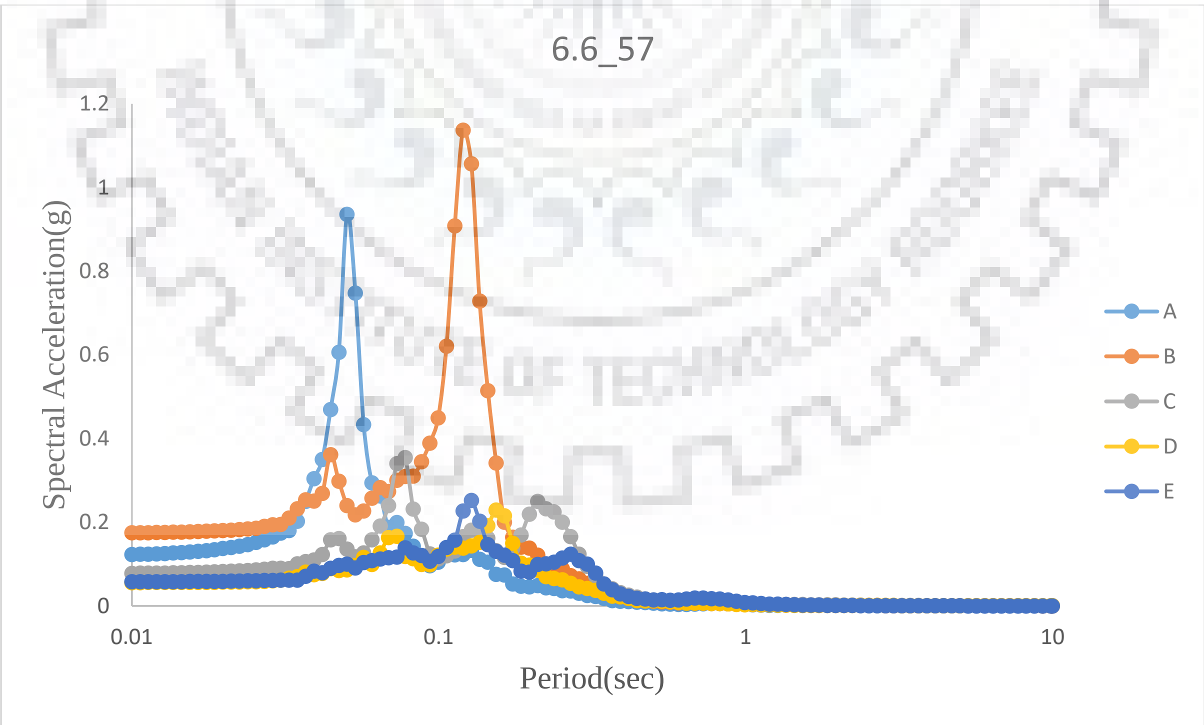

Figure 5.19:Response spectrum for different site class of 6.6 M_w and 57km epicentral distance.

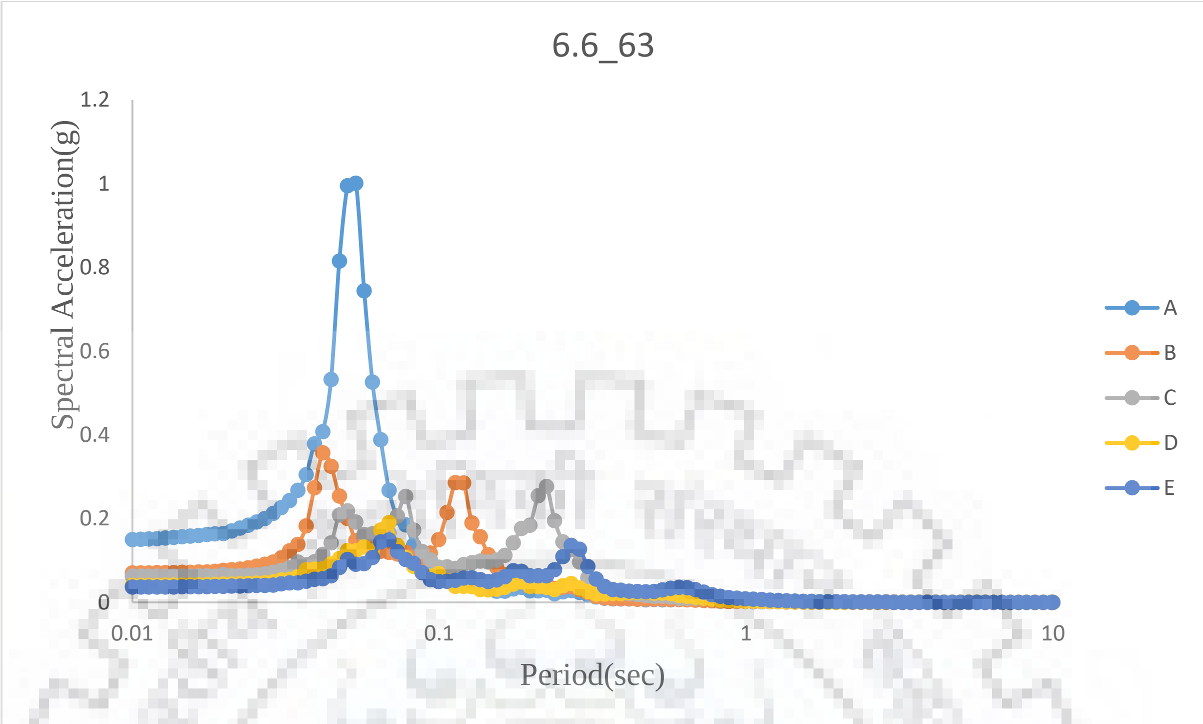

Figure 5.20: Response spectrum for different site class of 6.6 M_w and 63km epicentral distance.

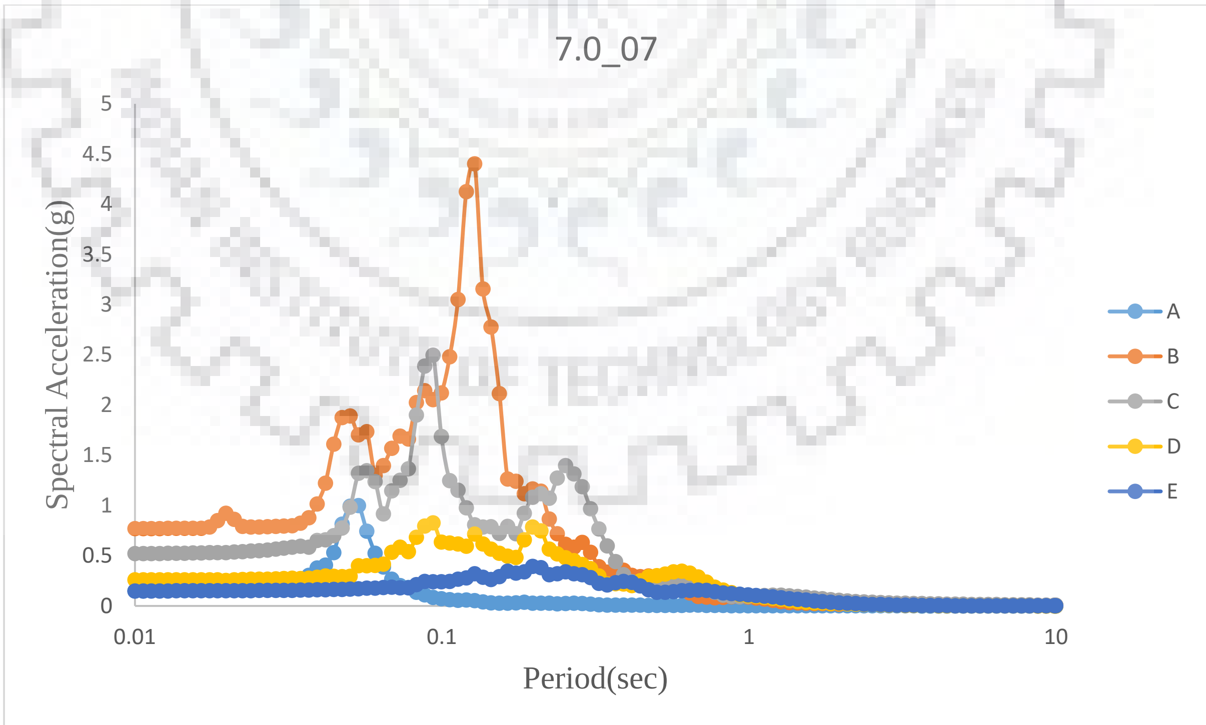

Figure 5.21:Response spectrum for different site class of 7.0 M_w and 07km epicentral distance.

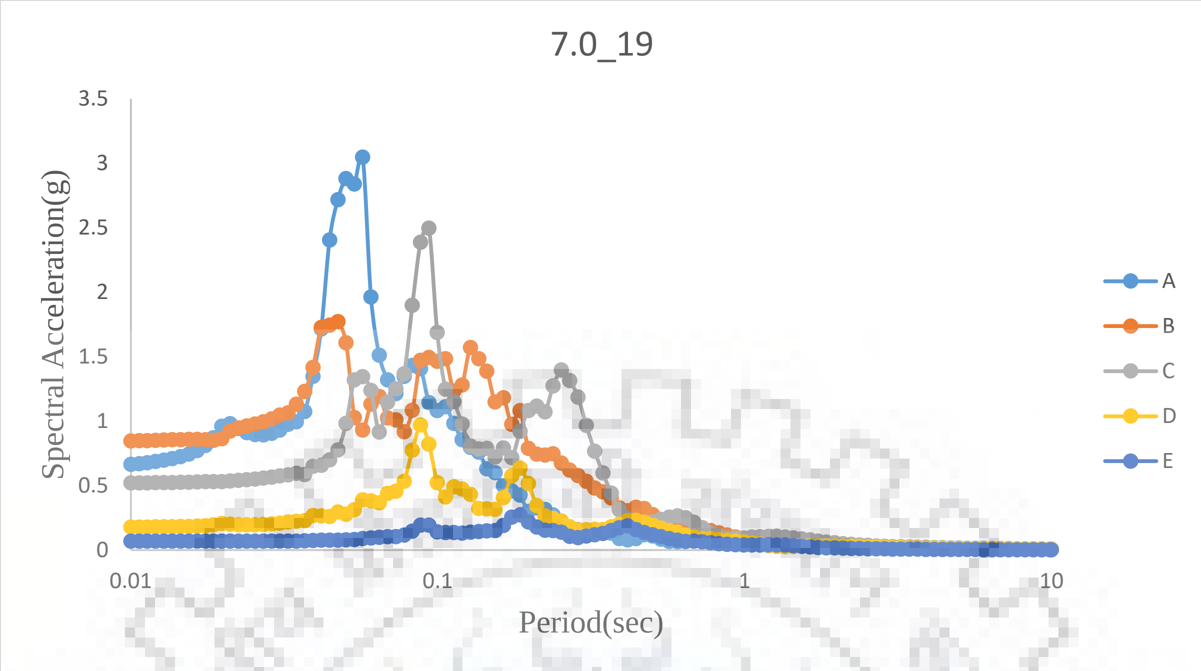

Figure 5.22: Response spectrum for different site class of 7.0 M_w and 19km epicentral distance

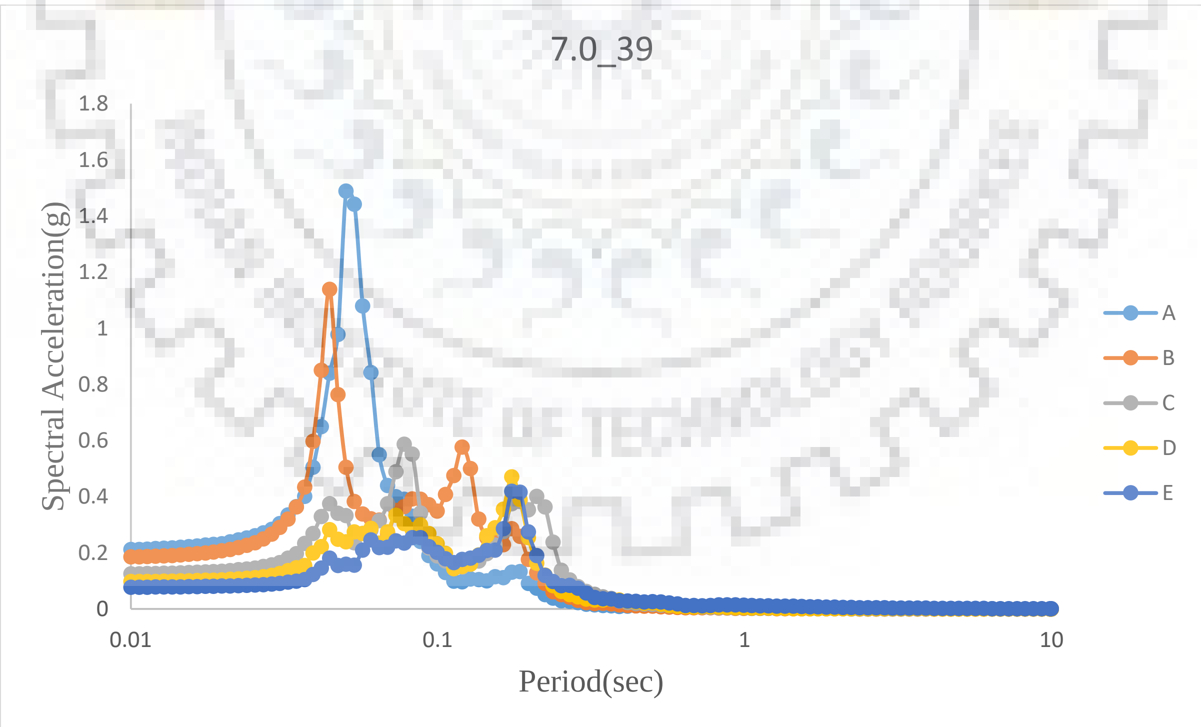

Figure 5.23: :Response spectrum for different site class of 7.0 M_w and 39 km epicentral distance

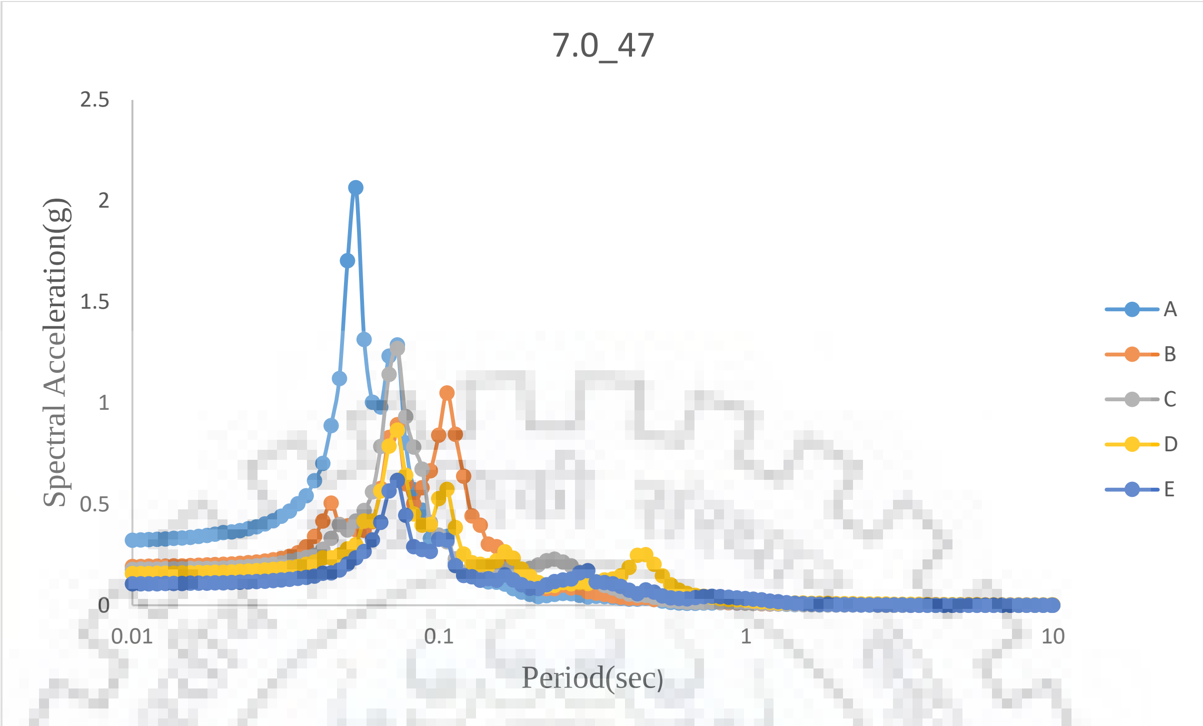

Figure 5.24: Response spectrum for different site class of 7.0 M_w and 47km epicentral distance

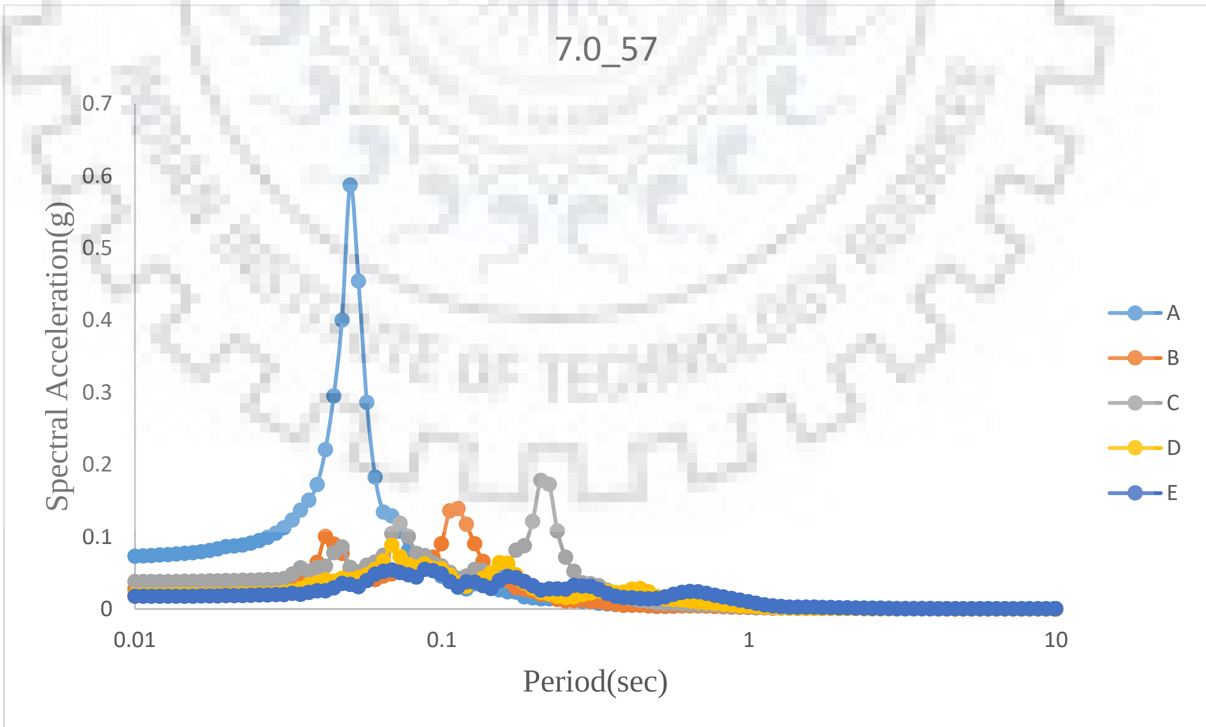

Figure 5.25:Response spectrum for different site class of 7.0 M_w and 57km epicentral distance

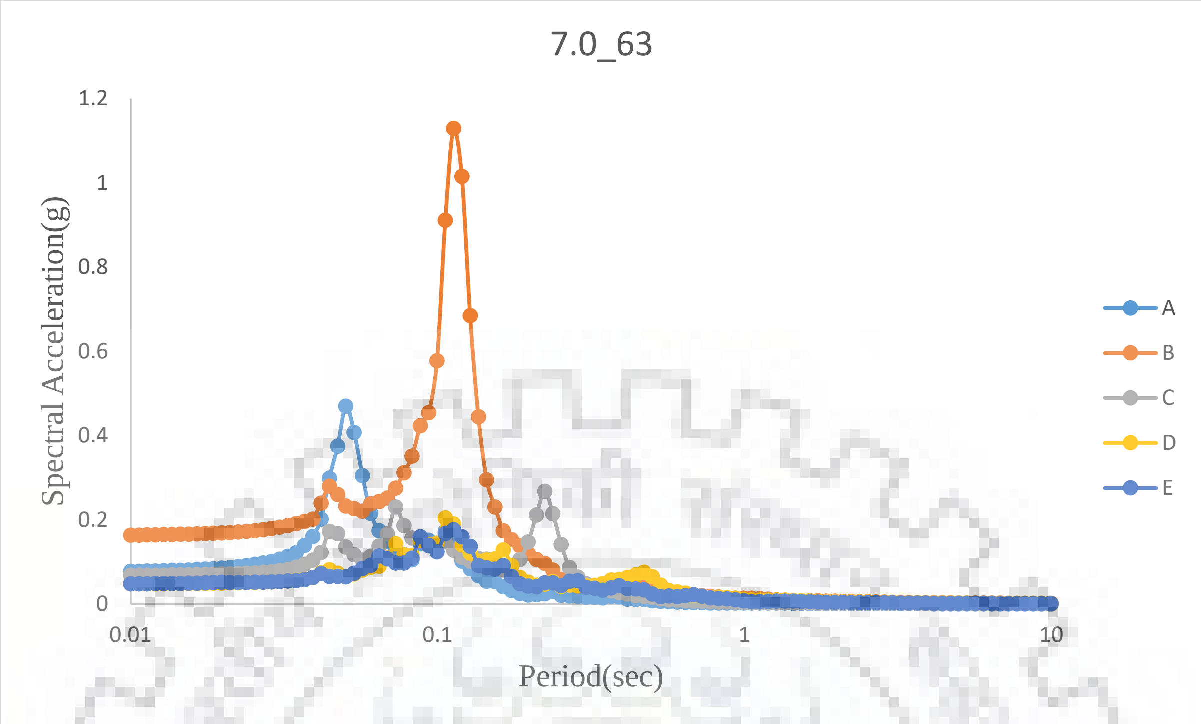

Figure 5.26:Response spectrum for different site class of 7.0 M_w and 63km epicentral distance

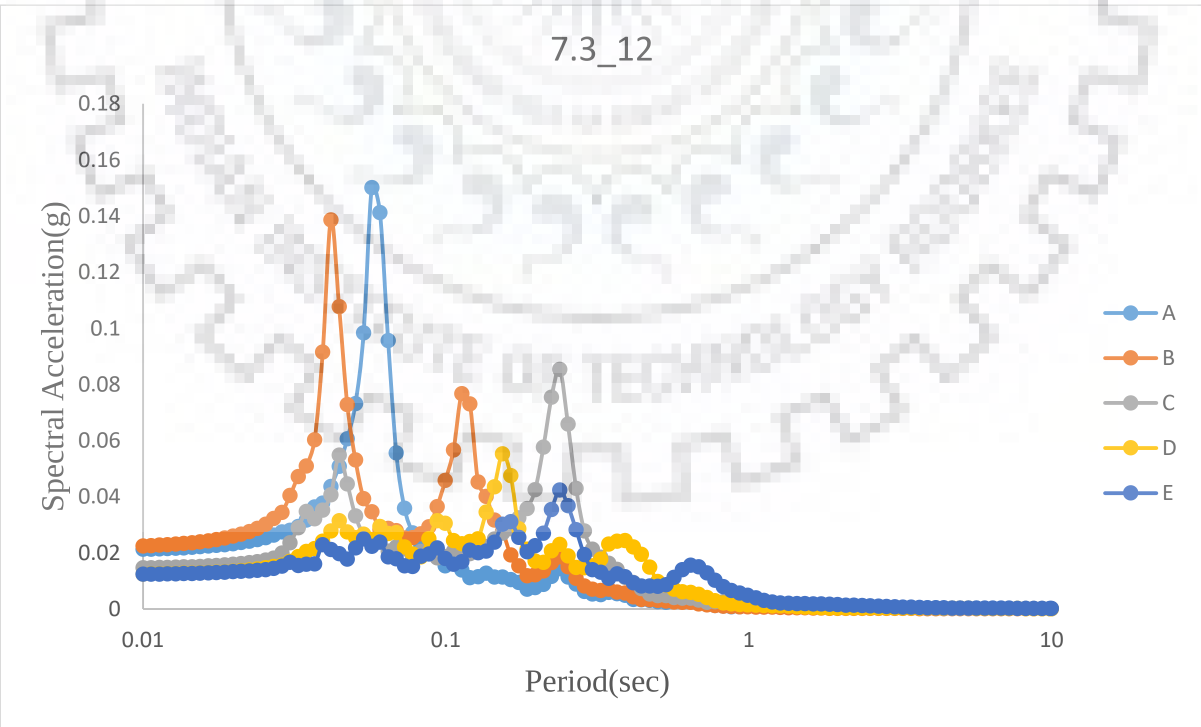

Figure 5.27:Response spectrum for different site class of 7.3 M_w and 12km epicentral distance

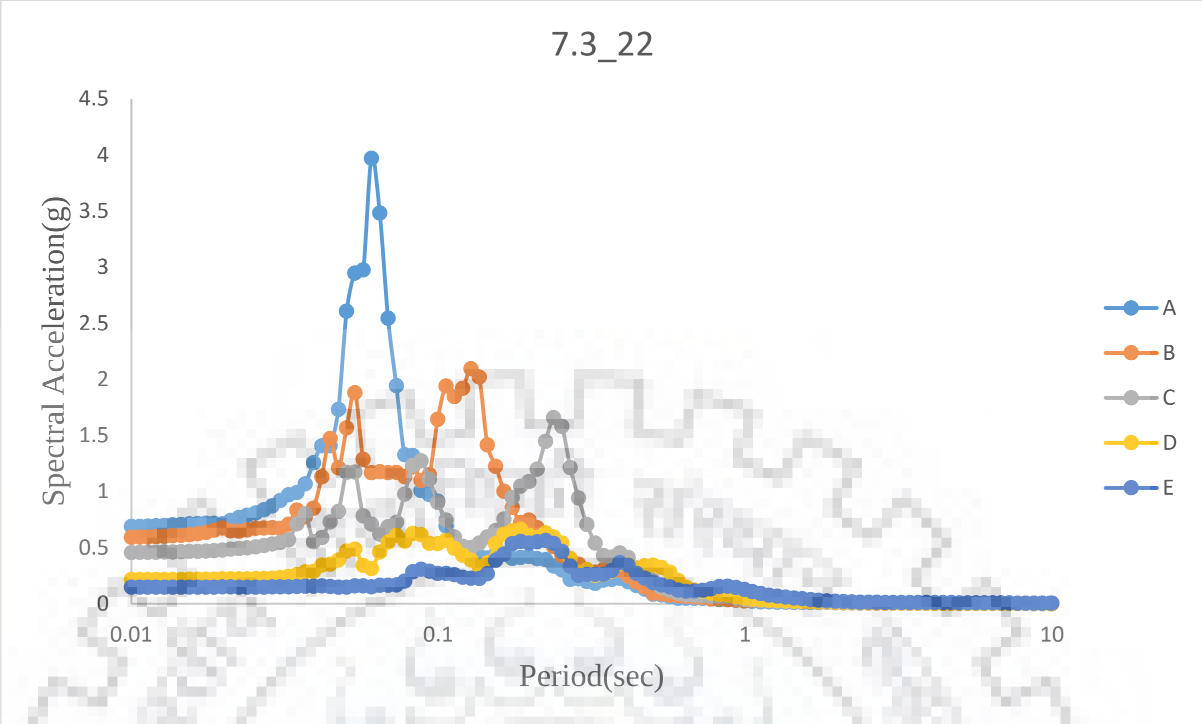

Figure 5.28Response spectrum for different site class of 7.3 M_w and 22km epicentral distance

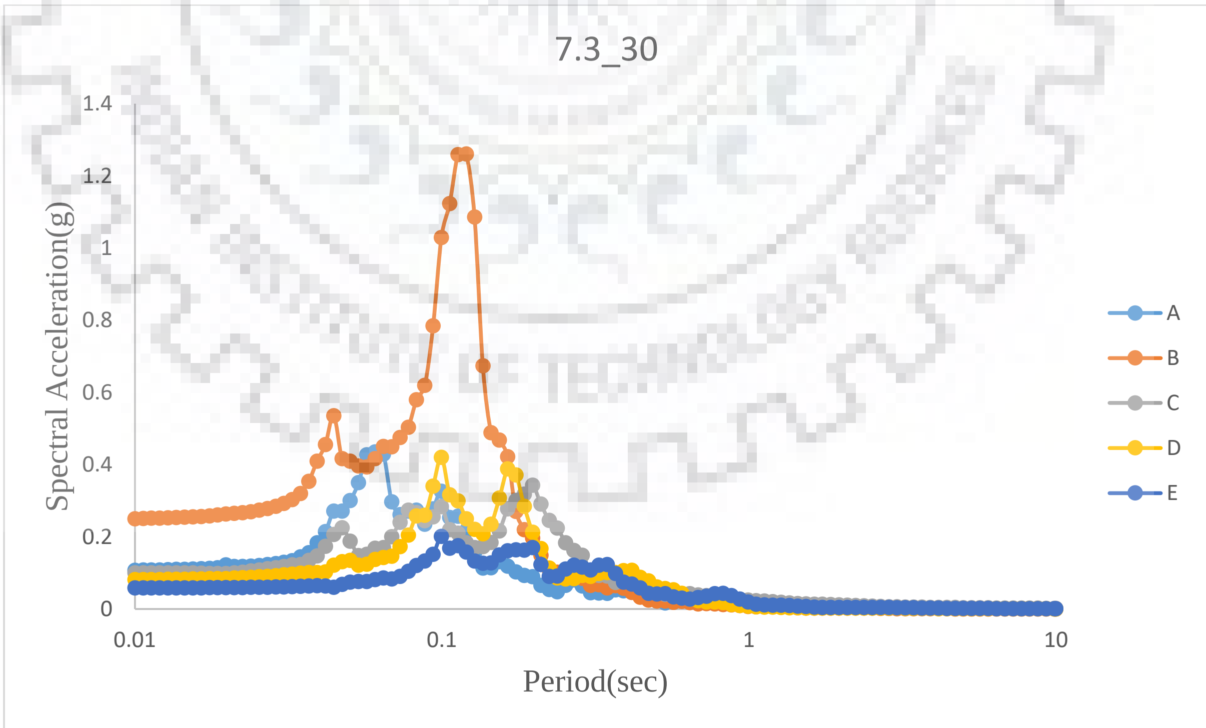

Figure 5.29Response spectrum for different site class of 7.3 M_w and 30km epicentral distance

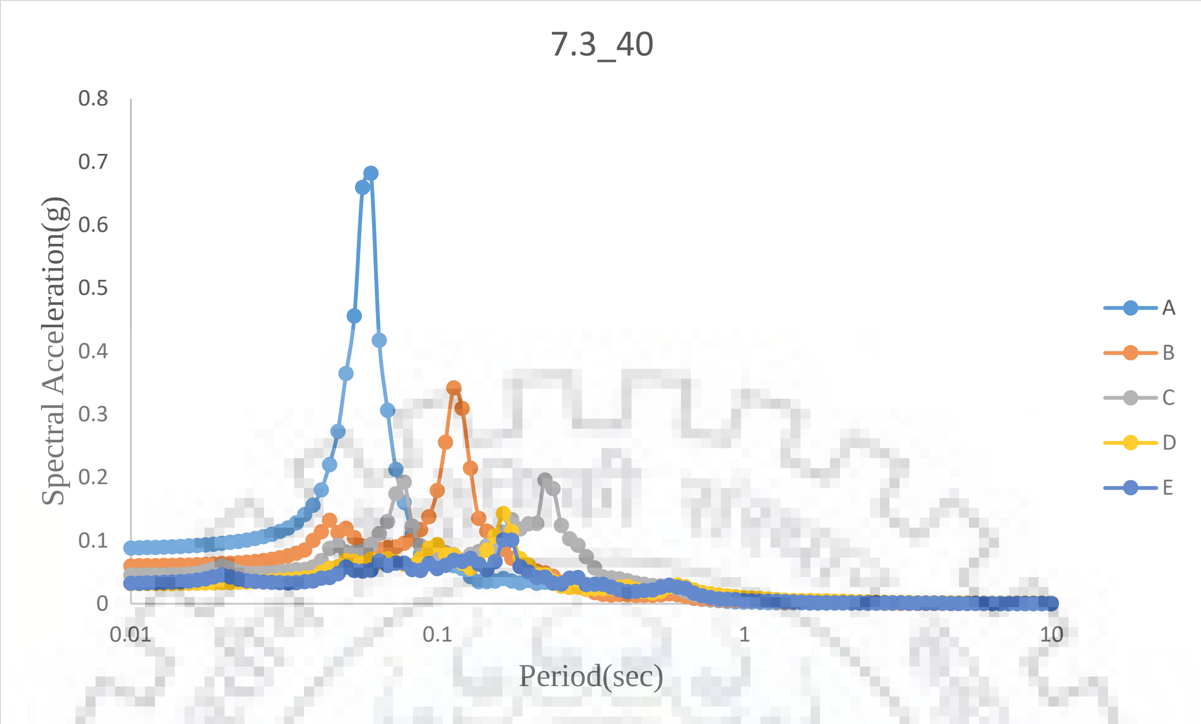

Figure 5.30Response spectrum for different site class of 7.3 M_w and 40km epicentral distance

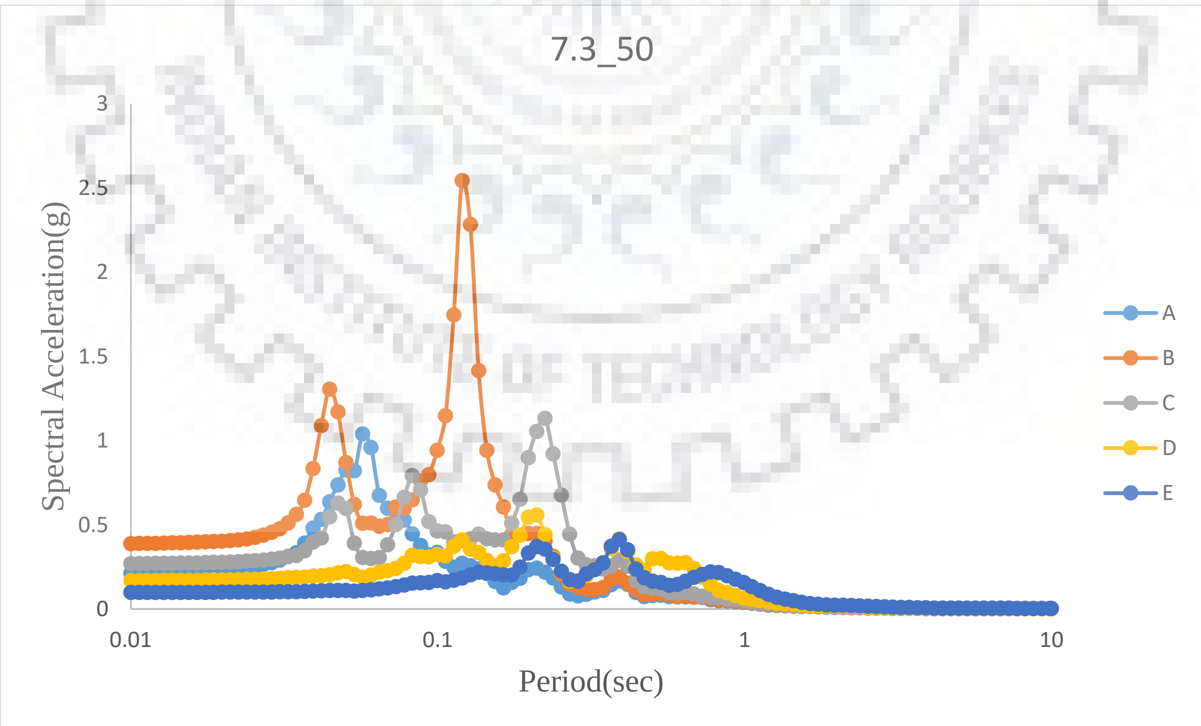

Figure 5.31Response spectrum for different site class of 7.3 M_w and 50km epicentral distance

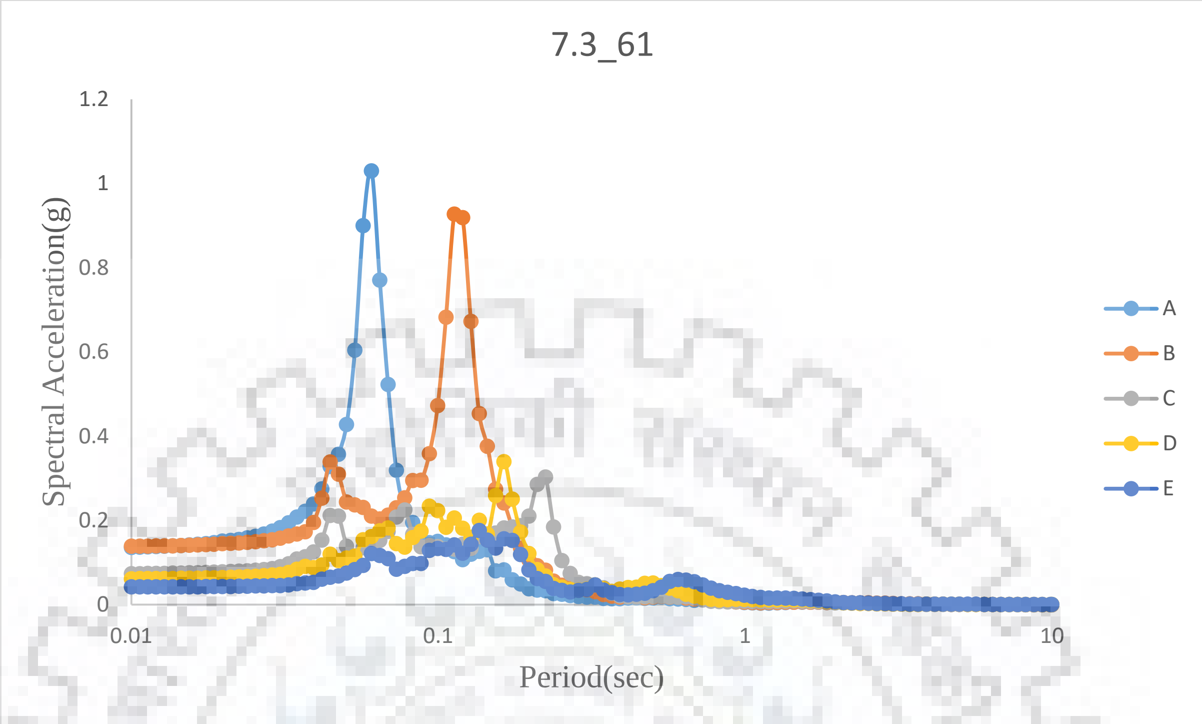

Figure 5.32 Response spectrum for different site class of 7.3 M_w and 61km epicentral distance

5.2 Estimation of Early Warning Parameters

Earthquake early warning parameters are estimated using initial 3 sec of the earthquake data. Early warning parameters that are calculated are peak displacement and average period of the P-wave. They are estimated using initial 3-sec of the P-wave as mostly damage is caused due to S-wave.

5.2.1.1 Calculation of Peak Displacement

Peak displacement is the maximum amplitude at the surface of the soil and it is calculated with the help of p-wave. As shear wave are the most damaging wave and mostly destruction is due to shear wave. It is the maximum value of the displacement Due to this parameters are estimated on the basis of primary wave. Table below shows the value of peak displacement for different epicentral distances and magnitudes.

Table 5.1: Peak displacement values for different magnitude and epicentral distance.

	Epic	A	B	C	D	E
Mag 5.1	10	0.2382	0.2418	0.2417	0.2999	0.4345
	30	0.0011	0.0157	0.0048	0.0026	0.0016
	51	0.0519	0.0597	0.0651	0.0549	0.0592
	60	0.0193	0.0167	0.0265	0.0345	0.0265
	73	0.0046	0.0148	0.0173	0.0084	0.0090
Mag 5.5	12	0.0369	0.0566	0.0757	0.0630	0.0949
	27	0.0242	0.0260	0.0368	0.0488	0.0574
	40	0.0010	0.0017	0.0019	0.0021	0.0023
	50	0.0052	0.0171	0.0070	0.0099	0.0176
	60	0.0506	0.0651	0.0487	0.0586	0.0703
Mag 5.9	18	0.0423	0.0479	0.0441	0.0646	0.0846
	22	0.0358	0.0660	0.1010	0.1500	0.2650
	41	0.8665	0.8410	0.8410	0.9689	0.8780
	61	0.0300	0.0354	0.0610	0.0487	0.1420
Mag 6.6	13	0.3782	0.3110	0.4290	0.2940	0.4800
	27	0.4360	0.4520	0.5410	0.5270	0.5940
	33	0.3098	0.3220	0.3340	0.4580	0.3530
	42	0.3098	0.3220	0.3340	0.4580	0.3530
	57	0.3866	0.4590	0.4160	0.4180	0.5970
	63	0.1008	0.1041	0.1714	0.1170	0.2300
Mag 7	7	1.1604	1.1505	1.0703	2.1992	2.2187
	19	1.8360	1.9544	2.2147	2.6383	2.9097
	39	0.1243	0.1598	0.2467	0.1956	0.2996
	47	0.0069	0.0173	0.0029	0.0004	0.0006

	57	0.2286	0.2321	0.2510	0.2720	0.3384
	63	0.0032	0.0052	0.0052	0.0054	0.0052
Mag 7.3	12	0.7132	0.7154	0.7491	0.7850	0.7604
	22	0.5959	0.6359	0.7433	0.8503	1.1581
	30	0.0237	0.0329	0.0423	0.0465	0.0481
	40	0.0015	0.0010	0.0461	0.0009	0.0007
	50	1.1807	1.2100	1.3900	1.9100	2.3000
	61	0.1333	0.1703	0.1910	0.2220	0.2560

5.2.1.2 Peak Displacement for complete data

Peak displacement is also calculated using the complete data of earthquake and it is seen for particular epicentral distance, its value is getting increased from site class a to site class e. It is shown in table below:

Table 5.2 Peak displacement values for different magnitude and epicentral distance for complete data of earthquake

		A	B	C	D	E
Mag 5.1	10	0.268652	0.294955	0.288755	0.356181	0.585574
	30	0.097525	0.103733	0.176437	0.24329	0.277984
	51	0.071566	0.071428	0.07669	0.10389	0.096149
	60	0.053771	0.064746	0.073361	0.13921	0.115202
	73	0.039151	0.041117	0.079912	0.06897	0.08387
mag 5.5	12	0.094072	0.164591	0.349137	0.338566	0.196335
	27	3.88276	4.11244	5.04264	11.5847	9.47736
	40	0.024246	0.025234	0.043157	0.101381	0.096745
	50	0.070607	0.213403	0.181857	0.268817	0.213543
	60	7.95815	16.793	10.8331	11.2117	8.30166

mag 5.9	18	45.4827	48.7464	75.8136	86.0553	100.857
	22	0.711532	0.758615	0.803646	1.6103	2.0167
	41	0.463079	0.52702	0.874768	1.03112	1.42014
	61	0.125426	0.136427	0.17399	0.275837	0.373962
mag 6.6	13	174921	174919	174917	174914	174915
	27	2.61707	2.64174	2.71956	3.42743	3.26744
	33	0.886518	0.904507	0.904337	1.14063	1.20608
	42	88.5034	89.5071	94.2123	157.365	144.852
	57	0.886518	0.904507	0.904337	1.14063	1.20608
	63	0.685022	0.711284	0.720196	0.802352	1.26938
mag 7	7	68.1675	69.2451	78.1856	73.4026	106.668
	19	11.6176	11.6048	11.9169	13.2161	24.3773
	39	8.10708	8.10304	8.09982	8.09836	8.09691
	47	9.09082	9.20878	9.42248	10.31	10.5006
	57	7.81271	7.86238	8.22552	8.28567	10.0151
	63	2.33937	2.81479	2.88843	2.68059	3.74205
mag 7.3	12	1.01073	1.04133	1.04661	1.21746	1.3437
	22	20.3383	20.9754	22.046	22.7656	24.9683
	30	0.085079	0.098047	0.092737	0.104752	0.137152
	40	153200	153199	153197	153194	153194
	50	21.5413	21.6785	22.1696	22.2452	28.5345
	61	4.96394	4.97711	5.05472	5.21246	6.21991

5.2.3 Empirical Relation between Magnitude and Peak Displacement

A relationship between magnitude and peak displacement is estimated on the basis of non-linear regression analysis and it is developed for different site classes.

- For site class A

$$\mathbf{M = (0.671\, P_d^3) + (-2.391{*}P_d^2) + (2.738{*}P_d) + (5.925)} \quad ..5.1$$

Table 5.3 Calculation of magnitude for site class A using peak displacement

Magnitude	A	Calculated M	Error
5.1	0.238214	6.450620818	0.2648276
5.1	0.00114	5.928116847	0.1623759
5.1	0.051942	6.060860878	0.1884041
5.1	0.019253	5.976833476	0.1719281
5.1	0.004597	5.937536042	0.1642228
5.5	0.036907	6.022828254	0.0950597
5.5	0.024229	5.989945447	0.089081
5.5	0.000982	5.92768716	0.0777613
5.5	0.005233	5.939263144	0.079866
5.5	0.050607	6.057525919	0.1013683
5.9	0.042264	6.036499591	0.0231355
5.9	0.035779	6.019931543	0.0203274
5.9	0.866534	6.938808796	0.1760693
5.9	0.030004	6.005016343	0.0177994
6.6	0.378214	6.654829752	0.0083075

6.6	0.436025	6.719888081	0.0181649
6.6	0.309812	6.563722181	0.0054966
6.6	0.309812	6.563722181	0.0054966
6.6	0.386628	6.66495741	0.009842
6.6	0.100788	6.177356225	0.0640369
7	1.16044	6.931067417	0.0098475
7	1.83598	7.04493634	0.0064195
7	0.124336	6.229758218	0.1100345
7	0.006936	5.94387629	0.1508748
7	0.228591	6.433958147	0.0808631
7	0.003226	5.933808363	0.1523131
7.3	0.713192	6.90496665	0.0541142
7.3	0.595859	6.849498062	0.0617126
7.3	0.023733	5.988642393	0.179638
7.3	0.001491	5.929076417	0.1877978
7.3	1.18069	6.929015782	0.0508198
7.3	0.133333	6.249149806	0.1439521
			2.9319579
(Error %)			9.1623685

- For site class B

$$\mathbf{M = 0.540 * P_d^{3} + (-2.110) * P_d^{2} + 2.641 * P_d + 5.903} \qquad \ldots 5.2$$

Table 5.4 Calculation of magnitude for site class B using peak displacement.

Magnitude	B	Calculated M	Error
5.1	0.241833	6.425918712	0.2599841
5.1	0.015651	5.943819509	0.1654548
5.1	0.059656	6.053156513	0.1868934
5.1	0.016688	5.94648662	0.1659778
5.1	0.014805	5.941638497	0.1650272
5.5	0.05656	6.045721742	0.0992221
5.5	0.025998	5.970245079	0.0854991
5.5	0.001673	5.907412147	0.0740749
5.5	0.017077	5.947486692	0.0813612
5.5	0.065121	6.066185717	0.1029429
5.9	0.047884	6.024681739	0.0211325
5.9	0.065953	6.06815753	0.0285013
5.9	0.840507	6.952805278	0.1784416
5.9	0.035379	5.993819569	0.0159016
6.6	0.311175	6.536772887	0.0095799
6.6	0.45188	6.715389317	0.0174832
6.6	0.322216	6.552970487	0.0071257
6.6	0.322216	6.552970487	0.0071257
6.6	0.4593	6.723214957	0.0186689
6.6	0.104094	6.155658296	0.0673245
7	1.15052	6.970911267	0.0041555
7	1.95436	7.036221624	0.0051745
7	0.15981	6.273374392	0.1038037
7	0.017254	5.947941926	0.150294

7	0.232125	6.409105048	0.0844136
7	0.005164	5.916580726	0.1547742
7.3	0.715368	6.910180387	0.0533999
7.3	0.635948	6.8680777	0.0591674
7.3	0.032931	5.987702115	0.1797668
7.3	0.001021	5.905694895	0.1910007
7.3	1.2093	6.966067217	0.0457442
7.3	0.170335	6.294303904	0.1377666
			2.9271835
Error (%)			9.1474485

- For site class C

$$M = (0.444P_d^{\ 3}) + (-1.937*P_d^2) + (2.647*P_d) + 5.856 \quad \text{…..5.3}$$

Table 5.5 Calculation of magnitude for site class C using peak displacement.

Magnitude	C	Calculated M	Error
5.1	0.241679	6.388854163	0.2527165
5.1	0.004813	5.868696399	0.1507248
5.1	0.065077	6.020178921	0.1804272
5.1	0.026534	5.924880042	0.1617412
5.1	0.017284	5.901174388	0.157093
5.5	0.075656	6.045367116	0.0991577
5.5	0.036829	5.950879991	0.0819782
5.5	0.001868	5.860938737	0.0656252
5.5	0.00699	5.874407123	0.068074
5.5	0.048674	5.980301973	0.0873276

5.9	0.044149	5.969125633	0.0117162
5.9	0.100674	6.103305129	0.0344585
5.9	0.840872	6.976182868	0.1824039
5.9	0.061027	6.010424216	0.018716
6.6	0.428931	6.670046086	0.010613
6.6	0.540731	6.791153828	0.0289627
6.6	0.334381	6.541129259	0.0089198
6.6	0.334381	6.541129259	0.0089198
6.6	0.415925	6.653811711	0.0081533
6.6	0.171429	6.255085042	0.0522598
7	1.07026	7.014544732	0.0020778
7	2.21465	7.040612924	0.0058018
7	0.246747	6.397877038	0.0860176
7	0.002895	5.863645629	0.1623363
7	0.250967	6.405327113	0.0849533
7	0.00525	5.869843242	0.161451
7.3	0.749067	6.938541313	0.0495149
7.3	0.743264	6.935651612	0.0499107
7.3	0.042325	5.964598235	0.1829317
7.3	0.04614	5.974051279	0.1816368
7.3	1.39382	6.984638276	0.0432002
7.3	0.190876	6.29376451	0.1378405
			2.8176612
Error (%)			8.8051912

- For Site class D

$$M = (0.189*P_d^{3}) + (-1.068*P_d^{2}) + (1.936*P_d) + 5.920 \quad .....5.4$$

Table 5.6 Calculation of magnitude for site class D using peak displacement.

Magnitude	D	Calculated M	Error
5.1	0.299915	6.409668564	0.2567978
5.1	0.00259	5.925006249	0.1617659
5.1	0.054909	6.023115823	0.1810031
5.1	0.034516	5.985557636	0.1736388
5.1	0.008415	5.936215235	0.1639638
5.5	0.06295	6.037686721	0.0977612
5.5	0.048801	6.011957586	0.0930832
5.5	0.002105	5.924069835	0.0771036
5.5	0.009853	5.938971159	0.0798129
5.5	0.058612	6.02984101	0.0963347
5.9	0.06464	6.040732171	0.0238529
5.9	0.149577	6.186318904	0.0485286
5.9	0.968863	6.96508129	0.1805223
5.9	0.048735	6.01183623	0.0189553
6.6	0.293646	6.401192755	0.0301223
6.6	0.527368	6.671676116	0.01086
6.6	0.458211	6.601044776	0.0001583
6.6	0.458211	6.601044776	0.0001583
6.6	0.417753	6.556164134	0.0066418
6.6	0.116987	6.132172833	0.0708829
7	2.19919	7.022567443	0.0032239

7	2.63828	7.06463228	0.0092332
7	0.195568	6.259185713	0.1058306
7	0.000371	5.920718899	0.154183
7	0.27204	6.371436334	0.0897948
7	0.00541	5.930442955	0.1527939
7.3	0.784958	6.873032358	0.0584887
7.3	0.850336	6.910217658	0.0533948
7.3	0.046538	6.007803191	0.1770133
7.3	0.000948	5.921834598	0.1887898
7.3	1.91342	7.038259519	0.0358549
7.3	0.221798	6.298923578	0.1371338
			2.9376823
Error (%)			9.1802573

- For Site Class E

$$\mathbf{M = (0.074*P_d^{\,3}) + (-0.615*P_d^2) + (1.547 * P_d) + 5.912} \quad \text{…..5.5}$$

Table 5.7 Calculation of magnitude for site class E using peak displacement.

Magnitude	E	Calculated M	Error
5.1	0.434546	6.474184174	0.2694479
5.1	0.001629	5.914519049	0.1597096
5.1	0.059246	6.001509509	0.1767666
5.1	0.026501	5.952566962	0.16717
5.1	0.009004	5.925878907	0.161937
5.5	0.094857	6.053273834	0.1005952

5.5	0.057434	5.998835001	0.0906973
5.5	0.002258	5.915489235	0.0755435
5.5	0.017608	5.939049304	0.0798271
5.5	0.070259	6.017679912	0.0941236
5.9	0.084609	6.038531776	0.02348
5.9	0.265384	6.280618525	0.0645116
5.9	0.877668	6.846046288	0.1603468
5.9	0.141781	6.119183473	0.0371497
6.6	0.479738	6.520783743	0.0120025
6.6	0.593994	6.629427751	0.0044588
6.6	0.353197	6.384936154	0.0325854
6.6	0.353197	6.384936154	0.0325854
6.6	0.597248	6.632334042	0.0048991
6.6	0.230045	6.23623427	0.055116
7	2.21866	7.125131256	0.0178759
7	2.90973	7.029450299	0.0042072
7	0.29962	6.322292688	0.0968153
7	0.000556	5.912859316	0.1553058
7	0.338415	6.367963316	0.090291
7	0.005154	5.919957374	0.1542918
7.3	0.760397	6.765274103	0.0732501
7.3	1.1581	6.993685059	0.041961
7.3	0.048081	5.984968381	0.1801413
7.3	0.000714	5.913104201	0.1899857
7.3	2.29548	7.117592303	0.0249874
7.3	0.256286	6.269325376	0.1411883

			2.973254
Error (%)			9.2914187

5.2.1.3 Estimation of average period of P-wave

Another parameter average period of the p-wave tau (τ_c) is estimated using the relation E velocity and displacement

$$\tau_c = \frac{2\pi}{\sqrt{\gamma}}$$

$$\gamma = \frac{\int_0^{to} |\dot{u}|^2}{\int_0^{to} |u|^2}$$

Where ü, u̇, u is the acceleration, velocity and displacement of the earthquake history.

5.3 Empirical relation between magnitude and average period of P-wave

Relation between magnitude and average period of the p-wave is also estimated ant it is also calculated for different site classes.

- Site class A

$$\mathbf{M = 0.576*log_{10} (\tau) + 6.295} \quad ...5.6$$

Table 5.8 Calculation of magnitude for site class A using average period of P-wave.

tau(A)	M	Calculated M	Error(%)
1.93265	5.1	6.459824244	0.266632
2.683585	5.1	6.541940008	0.282733
2.037031	5.1	6.47298264	0.269212
0.101447	5.1	5.722594544	0.122077
0.557166	5.1	6.148686912	0.205625
0.103655	5.5	5.72798019	0.041451
0.517818	5.5	6.130365929	0.114612
3.96866	5.5	6.639818887	0.20724

0.117815	5.5	5.760010678	0.047275
0.324364	5.5	6.013354796	0.093337
2.362886	5.9	6.510103012	0.103407
0.829574	5.9	6.248260455	0.059027
2.718219	5.9	6.545147879	0.109347
0.725203	5.9	6.21462465	0.053326
0.342564	6.6	6.027011077	0.086817
3.049879	6.6	6.573946797	0.003947
1.148806	6.6	6.329702075	0.040954
1.148806	6.6	6.329702075	0.040954
0.964021	6.6	6.285833804	0.047601
0.528138	6.6	6.135302594	0.070409
0.82675	7	6.247407682	0.107513
0.811264	7	6.242677306	0.108189
0.130918	7	5.786391934	0.173373
2.735388	7	6.546722918	0.064754
1.336366	7	6.367533069	0.090352
3.532468	7	6.610693084	0.055615
6.637305	7.3	6.768467251	0.072813
1.975725	7.3	6.46533846	0.114337
1.934742	7.3	6.46009492	0.115055
1.284481	7.3	6.357627238	0.129092
5.115051	7.3	6.703297594	0.08174
3.772753	7.3	6.627155231	0.092171
			3.470989
			10.84684

- Site class B

$$\mathbf{M = (0.770 * \log_{10}(\tau)) + 6.411} \quad ...5.7$$

Table 5.9 Calculation of magnitude for site class B using average period of P-wave.

tau(A)	M	Calculated M	Error(%)
0.944567	5.1	6.391929392	0.253319
0.674427	5.1	6.279279757	0.231231
0.959476	5.1	6.397166241	0.254346
0.213102	5.1	5.894012766	0.155689
0.143653	5.1	5.762132485	0.12983
0.127072	5.5	5.721117709	0.040203
0.22555	5.5	5.912997499	0.07509
5.088878	5.5	6.955098989	0.264563
0.169583	5.5	5.817624976	0.05775
0.262945	5.5	5.964295463	0.084417
1.656438	5.9	6.579764837	0.115214
0.510995	5.9	6.186480887	0.048556
1.883847	5.9	6.622785218	0.122506
0.519317	5.9	6.191882962	0.049472
0.334216	6.6	6.044500517	0.084167
2.508059	6.6	6.718490127	0.017953
0.562295	6.6	6.218472471	0.057807
0.562295	6.6	6.218472471	0.057807
0.334849	6.6	6.045133321	0.084071
0.553332	6.6	6.213098942	0.058621

0.620917	7	6.251635801	0.106909
0.68544	7	6.284696287	0.102186
0.150352	7	5.77737458	0.174661
2.285146	7	6.687363702	0.044662
1.796428	7	6.606895566	0.056158
1.059184	7	6.430227914	0.081396
6.170438	7.3	7.019543292	0.038419
1.789768	7.3	6.605653463	0.095116
0.842955	7.3	6.353869446	0.129607
1.209181	7.3	6.474518287	0.11308
3.335885	7.3	6.813872494	0.066593
1.628219	7.3	6.57401888	0.099449
			3.35085
			10.47141

- For site class C

$$\mathbf{M = 0.789*log_{10}(\tau) + 6.382} \quad ...5.8$$

Table 5.10 Calculation of magnitude for site class C using average period of P-wave.

tau(A)	M	Calculated M	Error (%)
2.110897	5.1	6.638004536	0.30157
1.189546	5.1	6.441475733	0.263034
0.324296	5.1	5.996132444	0.175712
0.281072	5.1	5.94711693	0.166101
0.236844	5.1	5.888450977	0.154598
0.171184	5.5	5.777202372	0.0504

0.275015	5.5	5.939652473	0.079937
3.324719	5.5	6.793664611	0.235212
0.362507	5.5	6.03430099	0.097146
0.815139	5.5	6.311961769	0.147629
2.428302	5.9	6.686003852	0.133221
0.399332	5.9	6.067452361	0.028382
1.358923	5.9	6.487090714	0.099507
0.337249	5.9	6.009552748	0.018568
0.401362	6.6	6.069189677	0.080426
1.432805	6.6	6.505231599	0.014359
1.081289	6.6	6.408780004	0.028973
1.081289	6.6	6.408780004	0.028973
0.588227	6.6	6.200170984	0.06058
0.370284	6.6	6.041574172	0.08461
0.652633	7	6.235773655	0.109175
0.620589	7	6.218522492	0.11164
0.201555	7	5.833166704	0.16669
2.40166	7	6.682223644	0.045397
0.800151	7	6.305602531	0.0992
1.610141	7	6.545215699	0.064969
4.020698	7.3	6.858793836	0.060439
1.21199	7.3	6.447880839	0.116729
1.271921	7.3	6.464419124	0.114463
0.894811	7.3	6.343915836	0.13097
3.167045	7.3	6.77701623	0.071642
2.145826	7.3	6.643628082	0.089914

			3.430166
			10.71927

- Site class D

M = (.044*τ^3) + (-0.367*τ^2) + (1.168*τ) + 5.463 …5.9

Table 5.11 Calculation of magnitude for site class D using average period of P-wave.

tau(A)	M	Calculated M	Error(%)
1.116868	5.1	6.371007773	0.249217
1.315789	5.1	6.464687491	0.267586
1.285132	5.1	6.451299293	0.264961
0.369804	5.1	5.846967027	0.146464
0.32985	5.1	5.80991387	0.139199
0.203605	5.5	5.685967749	0.033812
0.443581	5.5	5.912730496	0.075042
2.508541	5.5	6.778096738	0.232381
0.522675	5.5	5.97950702	0.087183
0.697096	5.5	6.113772351	0.111595
1.389162	5.9	6.495268759	0.100893
0.51348	5.9	5.971937463	0.012193
1.443189	5.9	6.516517139	0.104494
0.601572	5.9	6.042401912	0.024136
0.593617	6.6	6.03622487	0.08542
1.289558	6.6	6.453254961	0.022234
0.857002	6.6	6.222129294	0.057253
0.857002	6.6	6.222129294	0.057253
0.976934	6.6	6.294818973	0.04624

0.773463	6.6	6.167208857	0.065574
0.947394	7	6.277568322	0.103205
0.855615	7	6.2212466	0.11125
0.200052	7	5.682325726	0.188239
1.62029	7	6.57916681	0.060119
1.405494	7	6.501803293	0.071171
1.860558	7	6.649085068	0.050131
4.568054	7.3	7.33442797	0.004716
1.663432	7.3	6.592917482	0.096861
1.133733	7.3	6.379595183	0.126083
1.223875	7.3	6.423428883	0.120078
2.821892	7.3	6.825242735	0.065035
2.393133	7.3	6.759388738	0.074056
			3.254075
			10.16899

- Site class E

$$\mathbf{M = (.103*\tau^3) + (-0.786*\tau^2) + (1.920*\tau) + 5.073} \quad ....5.10$$

CONCLUSIONS

From the study carried out in this dissertation, the following conclusions are drawn.

- Amplification will be more where frequency of the earthquake matches with the frequency of the soil.
- Calculated magnitude depends up on the peak displacement and average period of the P-wave as compared to shear wave velocity.
- For different site classes, amplification increases with the increase in shear wave velocity under the considered ground motion scenario.
- Relation is developed between magnitude and peak displacement for different site classes.
- Peak displacement and average period of the P-wave is calculated using initial 3-sec of P-wave.
- When peak displacement is calculated using complete data of earthquake its value is getting decreased with increased epicentral distance and getting increased from site class A to E. This is not seen with all the cases as it also depends on other parameters also such as frequency, PGA, Topography etc.
- Magnitude is estimated using equation developed and error is calculated.
- Cubic equation is developed between peak displacement and magnitude. Logarithmic equation is developed between average period of the P-wave and magnitude.
- Magnitude is calculated with the help of non-linear regression analysis, which can be used for the estimation of expected seismic hazard at the target city or location.

REFERENCES

- Allen, R.M., Brown, H., Hellweg, M., Khainovski, O., Lombard, P. and Neuhauser, D., 2009. Real-time earthquake detection and hazard assessment by ElarmS across California. Geophysical Research Letters, 36(5).
- Allen, R.M. and Kanamori, H., 2003. The potential for earthquake early warning in southern California. Science, 300(5620), pp.786-789.
- Bhardwaj, R. 2013 Algorithm for earthquake early warning system. PhD Thesis, IIT Roorkee
- Cooper, J. D., 1868. Letter to editor, San Francisco Daily Evening Bulletin.
- Dunn, P.T., Ahn, A.Y., Bostrom, A. and Vidale, J.E., 2016. Perceptions of earthquake early warnings on the US West Coast. International Journal of Disaster Risk Reduction, 20, pp.112-122.
- Hashash, Y.M.A., Musgrove, M.I., Harmon, J.A., Groholski, D.R., Phillips, C.A. and Park, D., 2015. DEEPSOIL 6.1, user manual. Board of Trustees of University of Illinois at Urbana-Champaign, Urbana Google Scholar.
- Hsiao, N.C., Wu, Y.M., Zhao, L., Chen, D.Y., Huang, W.T., Kuo, K.H., Shin, T.C. and Leu, P.L., 2011. A new prototype system for earthquake early warning in Taiwan. Soil Dynamics and Earthquake Engineering, 31(2), pp.201-208.
- Kanamori, H., 2005. Real-time seismology and earthquake damage mitigation. Annu. Rev. Earth Planet. Sci., 33, pp.195-214.
- Lin, C.C.J., Lin, P.Y., Chang, T.M., Lin, T.K., Weng, Y.T., Chang, K.C. and Tsai, K.C., 2012. Development of on-site earthquake early warning system for Taiwan. In Earthquake Research and Analysis-New Frontiers in Seismology. InTech.
- Mert, A., Alçık, H., ErdiK, M., Gül, M., Özel, O. and Fahjan, Y., 2004, August. Istanbul Earthquake Rapid Response And The Early Warning System. In 13th World Conference on Earthquake Engineering Vancouver, BC, Canada.
- Nakamura, Y., 1988, August. On the urgent earthquake detection and alarm system (UrEDAS). In Proc. of the 9th World Conference on Earthquake Engineering (Vol. 7, pp. 673-678). Japan: Tokyo-Kyoto.
- Nakamura, Y., Saita, J. and Sato, T., 2011. On an earthquake early warning system (EEW) and its applications. Soil Dynamics and Earthquake Engineering, 31(2), pp.127-136.

- Satriano, C., Wu, Y.M., Zollo, A. and Kanamori, H., 2011. Earthquake early warning: Concepts, methods and physical grounds. Soil Dynamics and Earthquake Engineering, 31(2), pp.106-118.
- Wang, J.P., Wu, Y.M., Lin, T.L. and Brant, L., 2012. The uncertainties of a Pd3–PGV onsite earthquake early warning system. Soil dynamics and earthquake engineering, 36, pp.32-37.
- Wang, Z. and Zhao, B., 2018. Method of accurate-fast magnitude estimation for earthquake early warning-----Trial and application for the 2008 Wenchuan earthquake. Soil Dynamics and Earthquake Engineering, 109, pp.227-234.
- Xu, Y., Wang, J.P., Wu, Y.M. and Kuo-Chen, H., 2017. Reliability assessment on earthquake early warning: A case study from Taiwan. Soil Dynamics and Earthquake Engineering, 92, pp.397-407.
- Yih-Min, W., Kanamori, H., Allen, R.M. and Hauksson, E., 2007. Determination of earthquake early warning parameters, τ c and Pd, for southern California. Geophysical Journal International, 170(2), pp.711-717.
- Zambrano, A.M., Perez, I., Palau, C. and Esteve, M., 2017. Technologies of internet of things applied to an earthquake early warning system. Future Generation Computer Systems, 75, pp.206-215.