DIFFERENCE IN SITE RESPONSE OF NEAR-FIELD AND FAR-FIELD EXCITATIONS

A DISSERTATION

Submitted in partial fulfilment 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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MAY, 2016

CANDIDATE'S DECLARATION

I hereby certify that the work that is being presented in this **PROJECT REPORT**, entitled "**Difference in Site Response of Near-Field and Far-field Excitations**" in partial fulfillment of the requirements for the award of the Master of Technology in Structural Dynamics, submitted to the Department of Earthquake Engineering of the Indian Institute of Technology Roorkee, India, is an authentic record of my work carried out under the guidance of **Dr. H.R. Wason**, Professor, Earthquake Engineering Department, IIT Roorkee. The matter embodied in this has not been submitted for the award of any other degree.

Place: Roorkee
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CERTIFICATE

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

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I thank all well-wishers who in any manner directly or indirectly have put hands in any part of this work.

Place: Roorkee **Piyush Ranjan**

Date: May 2016

ABSTRACT

The recent advancement in technology has brought about a huge amount of change in the method of design of structures. Now, apart from the gravity load carrying capacity the engineers are also concerned about the vulnerability of the structures on account of seismic loads. Ultimately, the structure has to be erected on the ground only. Hence, the ground response to various earthquake loads becomes highly important. In this report, two ground motions (near-field and far-field) are applied at a station in Delhi. The same is done for a station in Guwahati and the difference in ground response to both the applied motions is obtained and discussed.

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Chapter 1

INTRODUCTION

In recent times, the traditional methods of design of structures have undergone huge amount of change. Now the engineers are not only interested in the gravity loading but also in capacity of structures to withstand the seismic loads. So the importance of earthquake loads and the corresponding ground response has become immense.

Occurrence of an earthquake triggers seismic waves of various frequencies. These waves travel through a medium having complicated properties which are also variable. Some waves having higher frequencies get attenuated and only those having lower frequencies propagate for large distances. So, the sites at different distances from the source receive waves of different frequencies. For example, at a site near the fault, only higher frequency waves are received and for the same site waves of lower frequency arrive from a far-field source.

Ultimately the structures are to be erected at site only. So, the response of site to various ground motions gains utmost importance. The aim of this report is to study the **Difference in Site Response produced by Near-field and Far-field Excitations.** The ground response analysis of site at Delhi is done for a near field as well a far field excitation.

Chapter 2

SITE RESPONSE

One of the most commonly encountered problems in earthquake engineering is the evaluation of ground response. *Ground response analyses* are used for the following purposes:-

- For development of **design response spectra** by the evaluation of surface motions at a site.
- To evaluate dynamic stresses and strains for evaluation of liquefaction hazards.
- To determine the earthquake –induced forces that can lead to instability of earth and earth-retaining structures.

The ideal procedure for ground response analysis involves the following steps:-

- The mechanism of rupture at the source of an earthquake is modeled.
- The path through which stress waves propagate to reach the top of bedrock is modeled at a particular site
- Finally the motion obtained at the top of bedrock is transferred to the surface by the evaluation of suitable transfer function.

In practice however the mechanism of fault rupture is not simple enough to be modeled mathematically. Also there is a high degree of uncertainty involved in the way energy is transferred through the soil media from source to site. So, this approach is not feasible for most engineering applications. In practice, empirical methods based on the characteristics of recorded earthquakes are used to develop relationships for predicting PGA, PGV and PGD (at the bedrock level). Once the value of any ground motion parameter is obtained at the top of bedrock, ground response analysis just transfers the motion parameter to the surface.

The techniques are broadly divided into one, two and three dimensional ground response analysis. Two and three dimensional analyses are more of an extension of the one dimensional approach. This report uses the one dimensional approach.

Chapter 3

ONE-DIMENSIONAL GROUND RESPONSE ANALYSIS

The one-dimensional wave equation by modeling the soil as an infinite long rod is given as:-

$$\frac{\partial^2 u}{\partial t^2} = v_p^2 \frac{\partial^2 u}{\partial x^2}$$

where v_p is the wave propagation velocity given by:

$$v_p = \sqrt{\frac{M}{\rho}}$$

Where, M - Constrained shear modulus

u - Particle velocity

ρ - Material density

From this equation we can say that v_p is less for surface layers as compared to the layers beneath. Also by the time waves reach the surface multiple refractions bend them to a nearly vertical direction. One dimensional approach proceeds with two assumptions:-

- All the boundaries are horizontal.
- For the evaluation of response of a soil deposit, it is assumed that the S-H waves propagate vertically from the top of bedrock.

The last assumption can be explained as follows. The body waves travel from the source in all directions. The wave velocity decreases as it goes towards the surface. So, the refracted wave becomes almost vertical by the time it reaches the surface (Snell's Law) as illustrated in Figure 3.1.

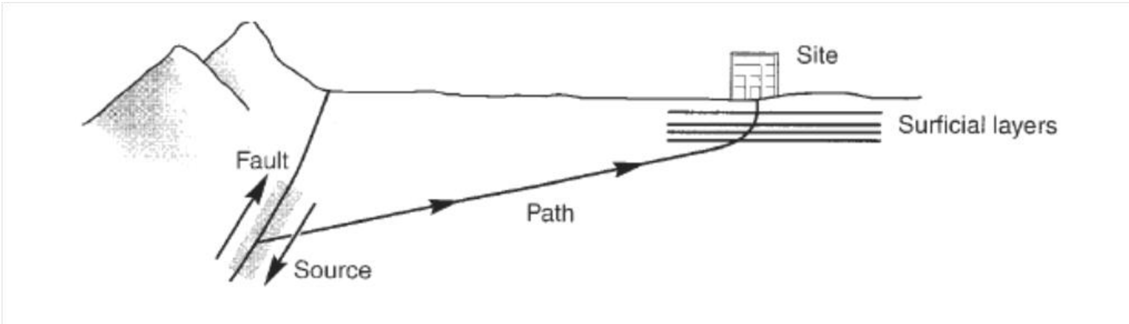


Fig 3.1 Refraction process that produces nearly vertical wave propagation near the ground surface

The soil properties at the site affect the analysis of the ground response in a major way. So the method for analysis depends on the Stress-Strain curve of soil under cyclic loading. Based on the stress-strain curve of soil the analysis can be done by the following three methods:-

- **Linear Approach**
- **Equivalent Linear Approach**
- **Non-Linear Approach**

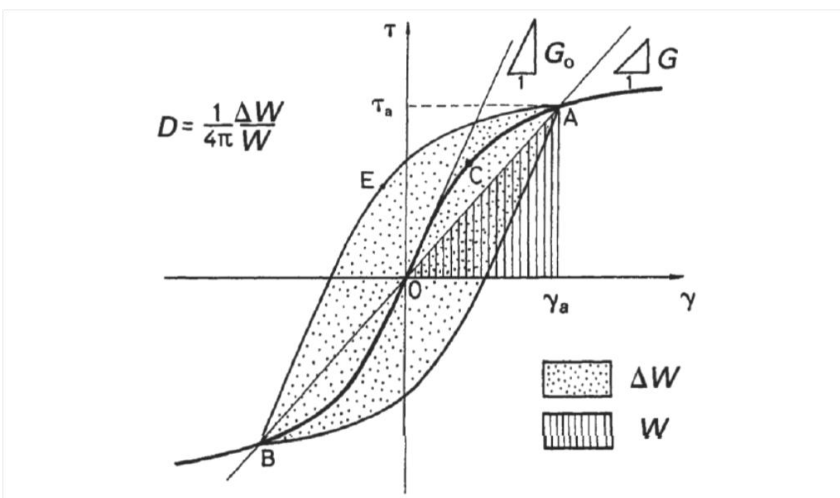


Fig 3.2 Stress-Strain diagram for cyclic loading of soil

Now we decide the method of analysis based on the portion of the diagram our site conditions belong to. For instance for low strain values the linear approach can be used effectively to get correct results. However as the behavior tends to be non-linear the equivalent-linear or the non-linear approach should be used.

3.1 LINEAR APPROACH

This approach is used for analysis when the strains are relatively low in magnitude. For higher values of strains this method may give error in results. The key to this approach is the evaluation of the transfer functions for various classes of soil and bedrock combination and for various magnitudes of damping. The transfer function then can be used to express the surface response parameters like displacement, velocity and acceleration in terms of the bedrock motion (input) parameters. The value of transfer functions for various combinations of soil, bedrock and damping ratios are given below as explained by Kramer (1996).

(a) Uniform Undamped Soil on Rigid Rock

The transfer function for the bedrock to surface motion is given as:-

$$F_1(\omega) = \frac{u_{\max}(0,t)}{u_{\max}(H,t)}$$

$$F_1(\omega) = \frac{2Ae^{i\omega t}}{2A\cos kHe^{i\omega t}}$$

$$F_1(\omega) = \frac{1}{\cos kH}$$

$$F_1(\omega) = \frac{1}{\cos\left(\frac{\omega H}{v_s}\right)}$$

From the above equation we can see that $F_1(\omega)$ becomes infinite for zero value of the denominator i.e. $\frac{\omega H}{v_s} = \frac{\pi}{2} + n\pi$.

However, practically the ground response parameter never gets amplified infinitely from the top of bedrock to the surface. So, we go for a more feasible approach i.e. Uniform Damped soil on Rigid Rock.

(b) Uniform Damped Soil on Rigid Rock

We use the Kelvin-Voigt wave propagation equation given as:-

$$\rho \frac{\partial^2 u}{\partial t^2} = G \frac{\partial^2 u}{\partial z^2} + \eta \frac{\partial^3 u}{\partial z^2 \partial t}$$

The transfer function obtained is:-

$$F_2(\omega) = \frac{1}{\cos k^* H}, \; F_2(\omega) = \frac{1}{\cos\left(\frac{\omega H}{v_s^*}\right)}$$

where v_s^* - complex shear wave velocity is given by the equation :-

$$v_s^* = \sqrt{\frac{G^*}{\rho}}$$
$$v_s^* = \sqrt{\frac{G(1+i2\xi)}{\rho}}$$
$$v_s^* \approx \sqrt{\frac{G}{\rho}}(1+i\xi)$$
$$v_s^* \approx v_s(1+i\xi)$$

On substituting the value of v_s^* we get the final transfer function as :-

$$|F_2(\omega)| \approx \frac{1}{\sqrt{\cos^2 kH + (\xi kH)^2}}$$

$$|F_2(\omega)| \approx \frac{1}{\sqrt{\cos^2\left(\frac{\omega H}{v_s}\right) + \left[\xi\left(\frac{\omega H}{v_s}\right)\right]^2}}$$

Now the denominator can't be zero as ξ can't be zero (since there has to be some damping at the site).The figure below shows the effect of damping on transfer function plot :-

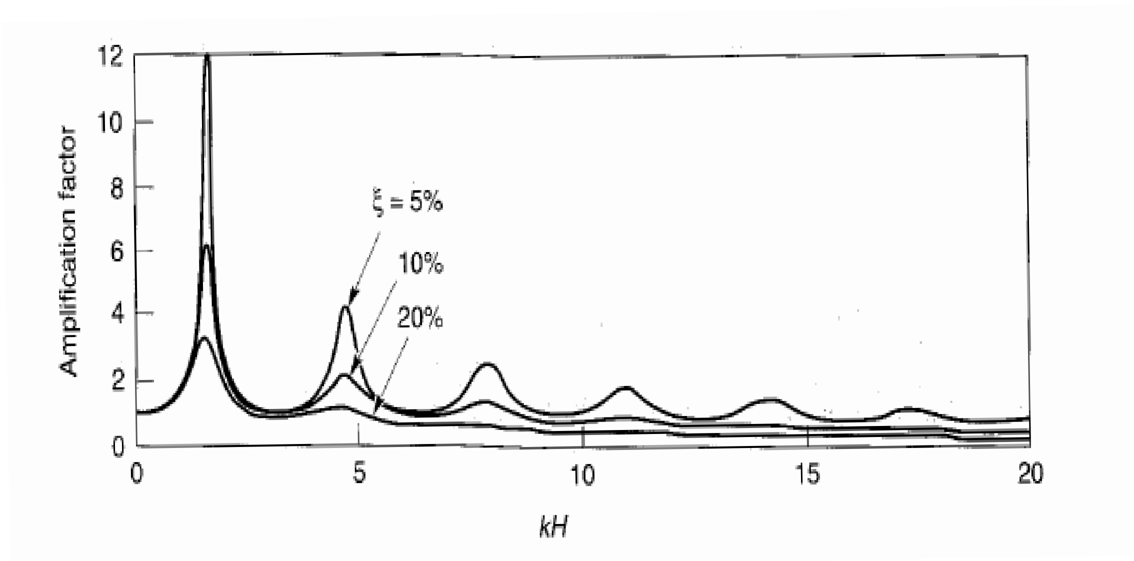


Fig 3.3 Influence of frequency on steady-state response of damped linear elastic layer

The natural frequency of the soil deposit is given by:-

$$\omega_o = \frac{\pi v_s}{2H}$$

where H is the depth of the bedrock below the soil deposit.

So the basic steps for linear ground response analysis are:-

- Obtain the acc'n time history plot (input) at the bedrock level.
- Compute the Fourier Transform of the time history.
- Compute the transfer function for the site. Compute the Fourier series of the surface as the product of transfer function and the Fourier series of input motion.
- The inverse fourier transform of the above will give the time history of the surface w.r.t the bedrock.

3.2 EQUIVALENT-LINEAR APPROACH

When the soil at the concerned site shows non-linear stress-strain behavior, the linear approach must be suitably modified to provide reasonable estimates of ground response for all practical problems. Since the approach is basically linear in nature, instead of a constant tangent shear modulus an equivalent linear shear modulus G is used which actually is the secant shear modulus. Similarly, the damping ratio is replaced by an equivalent damping $\dot{\varepsilon}$, which is defined as the damping ratio that produces the same energy loss as the actual hysteresis loop.

The equivalent linear approach requires constant values of G and $\dot{\varepsilon}$ for each layer of soil. So the problem becomes one of determining the values that are compatible with the level of strain induced in each layer. The lab tests that give the modulus reduction and damping ratio curves against the strain are based on the peak strain. However during a typical earthquake the peak strain occurs only a few times. So it would be uneconomical to design corresponding to peak strain. The equivalent linear approach solves this issue by using an iterative procedure to get the value of an effective strain which correctly fits for the site.

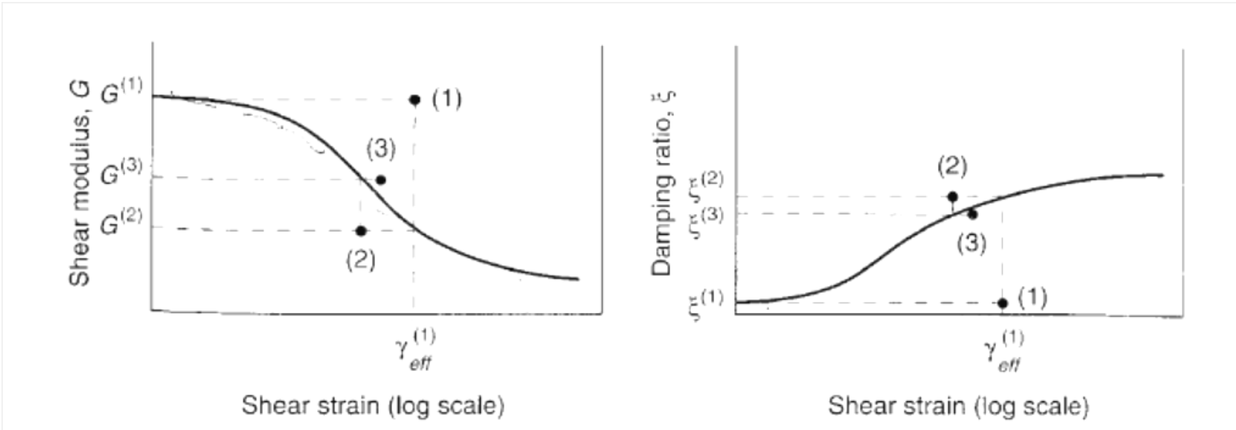


Fig 3.4 Iteration towards strain-compatible G and ξ in Equivalent Linear Analysis

Steps are as follows :-

1. Initial estimates of G and ξ are made for each layer. Low strain values are used for the initial estimate.
2. The estimated G and ξ values are used to compute the ground response for each layer.
3. The effective strain in each layer is determined from the computed shear strain time history. For layer j $\gamma_{eff,j}^{(i)} = R_\gamma \gamma_{\max,j}^{(i)}$

   where subscript i is iteration number and R_γ is the ratio of effective shear strain to the max shear strain. R_γ depends on magnitude of earthquake given by

$$R_\gamma = \frac{M-1}{10}$$

4. From this effective shear strain, new equiv values of G and ξ are chosen for next iteration.
5. Steps 2-4 are repeated till G and ξ values for two succesive iterations converge.

Now for these G, ξ and Strain values the response is computed.This is how we use the equivalent linear method for obtaining the ground response from the bedrock motion of an earthquake.

Equivalent Linear analyses can be much more efficient than the non-linear analyses, particularlywhen the input motion can be characterised with with acceptable accuracy by a small number of Fourier series terms. For all the profiles where the strain levels are low both equivalent and Non-Linear analyses give approx same Ground Response.

Chapter 4

NEAR-FIELD AND FAR-FIELD GROUND MOTIONS

Near-field ground motion refers to the earthquake ground motion within a distance of few kilometers from the fault while Far-field refers to ground motion at a large distance from the fault. No distance is specified as such for this purpose.

4.1 NEAR FIELD MOTION

The ground motion in the **near-field** is defined by two main features:-

- **Rupture Directivity Effect-** This is the manifestation of Doppler's effect in seismic waves when the velocity of rupture is close to the velocity of shear waves in the rock near the source.

  The seismic wave observed at a site in the direction of fault rupture will have higher frequency in comparison to waves observed at an equally spaced site in the direction away from the direction of fault rupture.

- **Fling Effect-** Due to large unidirectional velocity pulse in the slip parallel direction a static displacement is observed which is termed fling step. This effect is called fling effect.

4.2 FAR-FIELD GROUND MOTION

Far-Field Motion is not dominated by the earthquake faulting. The response is more dependent on the vibration of ground resulting from seismic waves propagating from the earthquake source. Thus the response depends more on the path and site soil conditions.

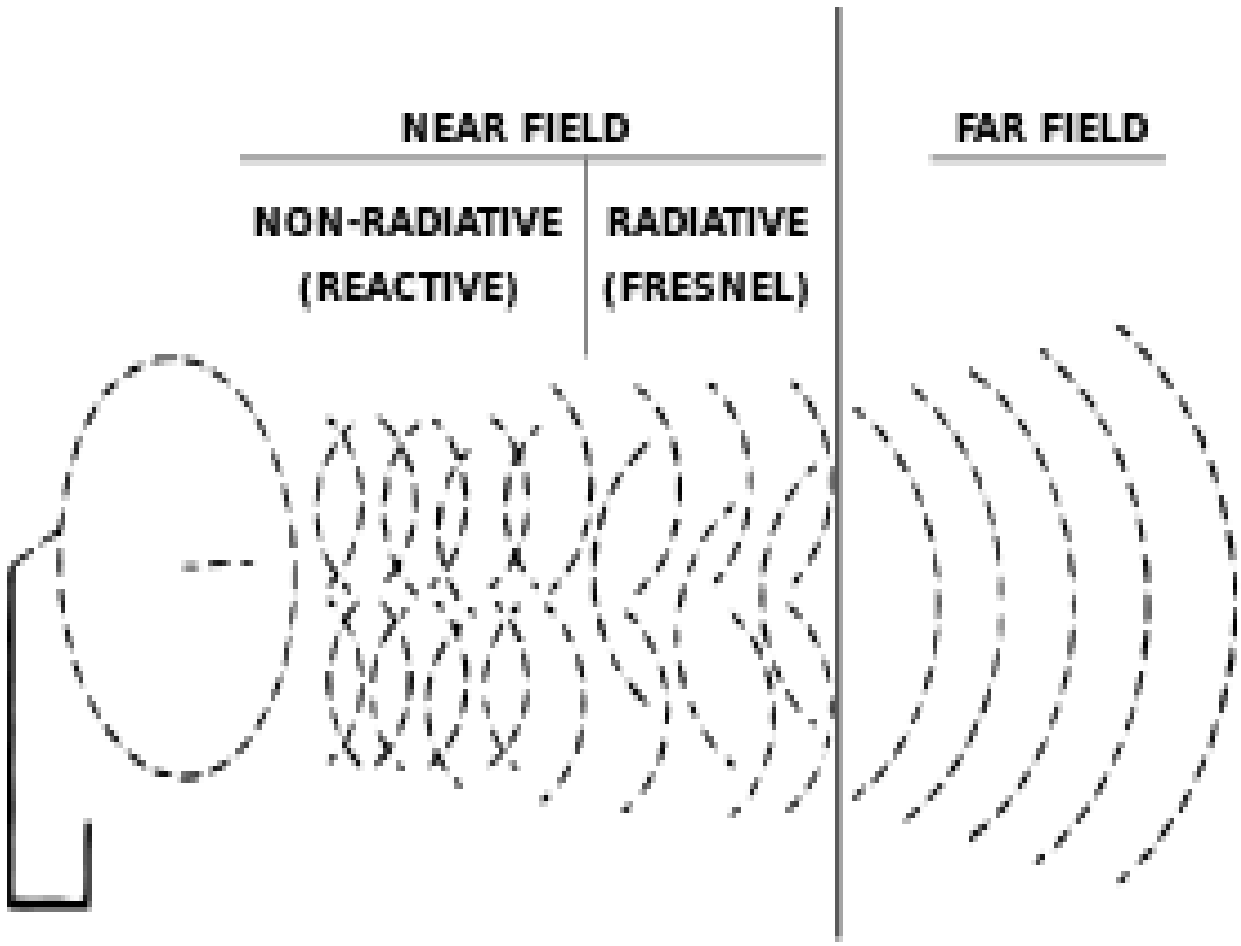


Fig. 4.1 Near and far-field motions

Chapter 5

GROUND RESPONSE ANALYSIS (DELHI AND GUWAHATI)

The site response analysis for Delhi region has been done for both near-field as well as far-field excitations. The near-field excitation was of the Delhi- Haryana border region with details as below:-

Origin time	**25/11/2007 23:12:20**
Latitude	**28.6^{o} N**
Longitude	**77.0^{o} E**
Depth (km)	**20.30**
Magnitude	**4.3**
Region	**Delhi-Haryana Border Region**
Site Class	**C V_s30 between 200 m/sec to 375 m/sec**
Record Time	**25.11.2007 23:11:56.775**
Sampling Rate	**200. Hz**
Record Duration	**137.655 Sec**
Direction	**Vert. (Up positive)**
Max. Acceleration	**8.403 cm/sec^2**

The time history plot for the same has been shown:-

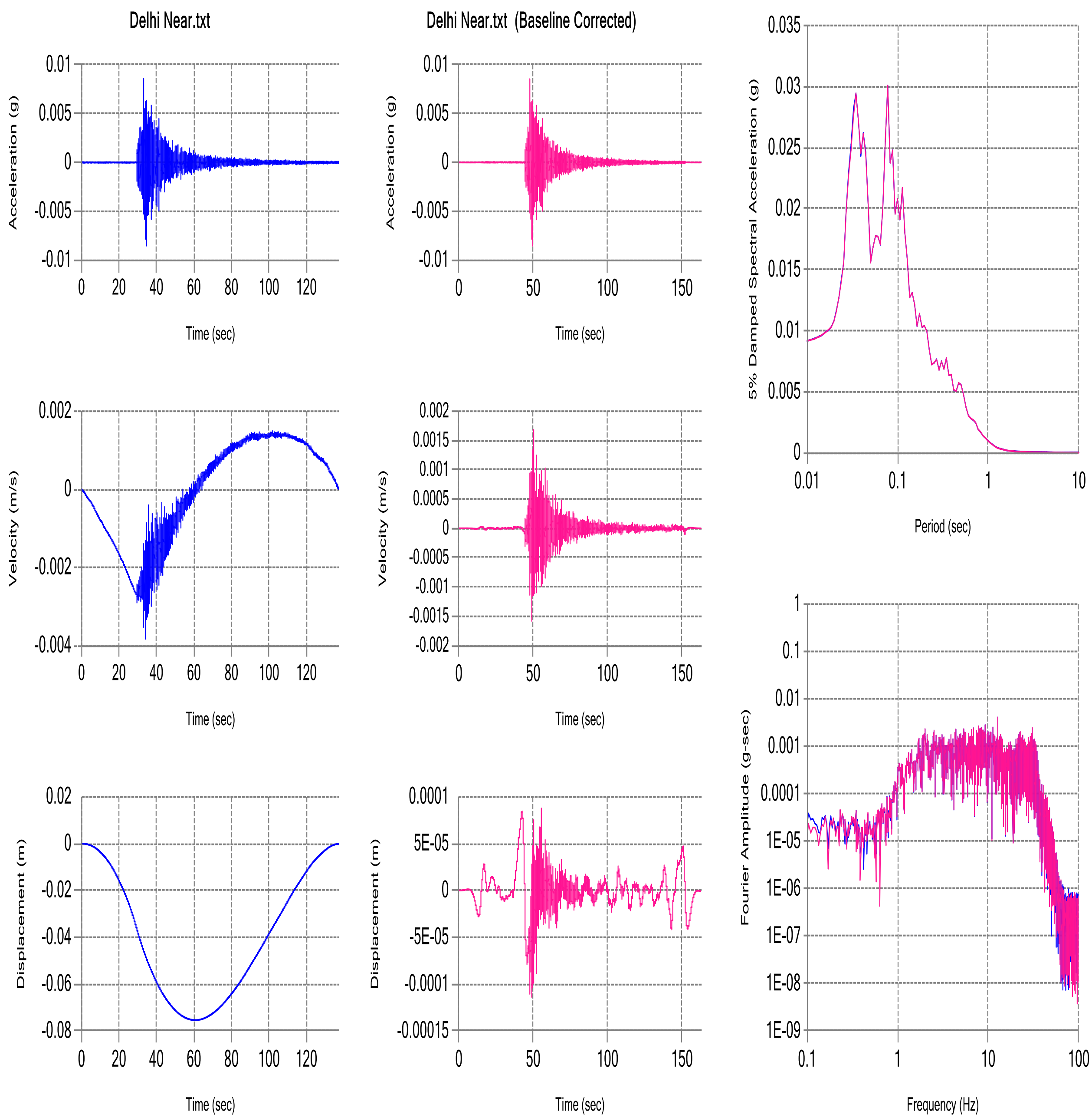


Fig 5.1 Time history plot of Delhi-Haryana border Earthquake

The soil properties along with their plots with increase in shear strain have been shown for the Delhi region:-

Table 5.1 Soil properties of station at Delhi

Strain (%)	**G/G_{max}**	**Damping (%)**	**Shear Strength (psf)**
0.0001	1	0.5	3.884
0.0002	0.998	0.8	7.753
0.0005	0.98	1.3	19.033
0.001	0.949	1.9	36.862
0.002	0.917	2.5	71.240
0.005	0.832	3.7	161.591
0.01	0.729	5.3	283.173
0.02	0.6	7.7	466.128
0.05	0.421	12	817.666
0.1	0.291	15.3	1130.360
0.2	0.188	18.7	1460.534
0.5	0.098	22.6	1903.356
1	0.06	24.4	2330.640
2	0.036	25.9	2796.768
5	0.016	27.3	3107.520

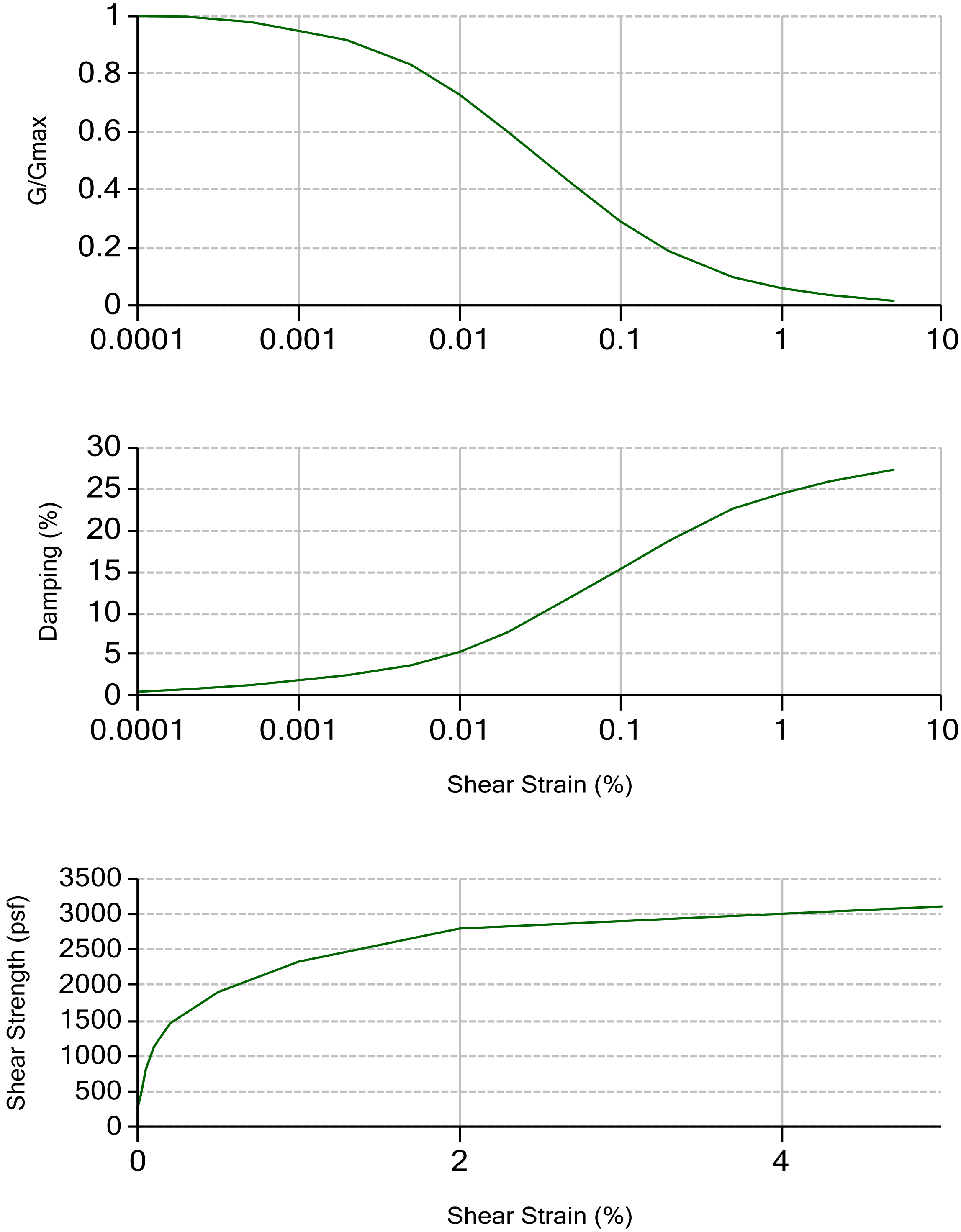


Fig 5.2 Curves showing various soil properties of the station (Delhi)

The far-field excitation was of South-western Pakistan Earthquake with details as follows:-

Origin time	**18/01/2011 20:23:27**
Latitude	**28.9^o N**
Longitude	**64.0^o E**
Depth (km)	**50.0**
Magnitude	**7.4**
Region	**South-western Pakistan**
Site Class	**C V_s30 between 200 m/sec to 375 m/sec**
Record Time	**18.01.2011 20:09:29.829**
Sampling Rate	**200. 0Hz**
Record Duration	**80.030 Sec**
Direction	**Vert. (Up positive)**
Max. Acceleration	**0.610 cm/sec^2**

The time history plot for the South-western Pakistan Earthquake has been shown in Figure 5.3.

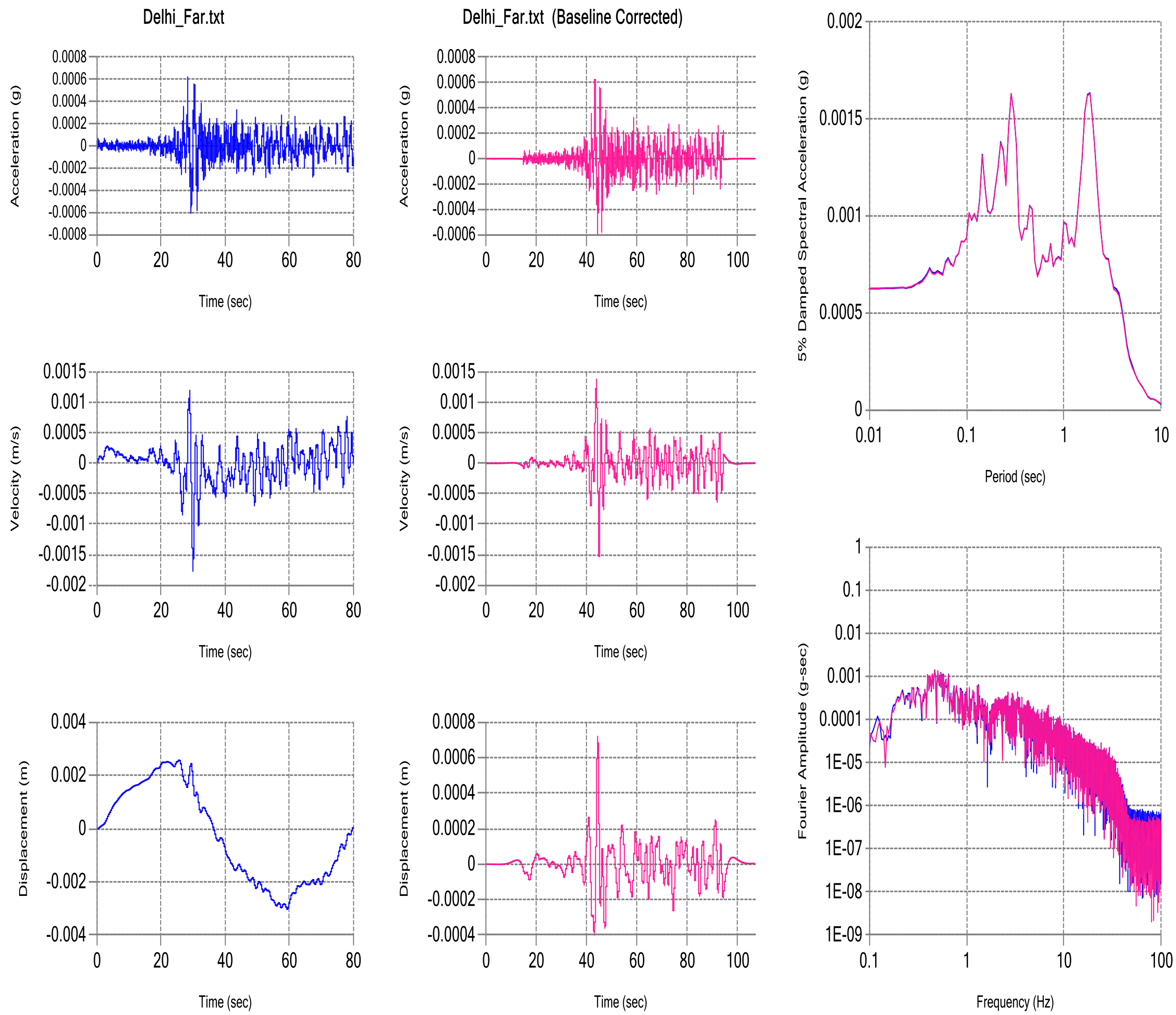


Fig 5.3 Time history plot of earthquake in South-western Pakistan

On analyzing the above two excitations by DEEPSOIL the following result was obtained.

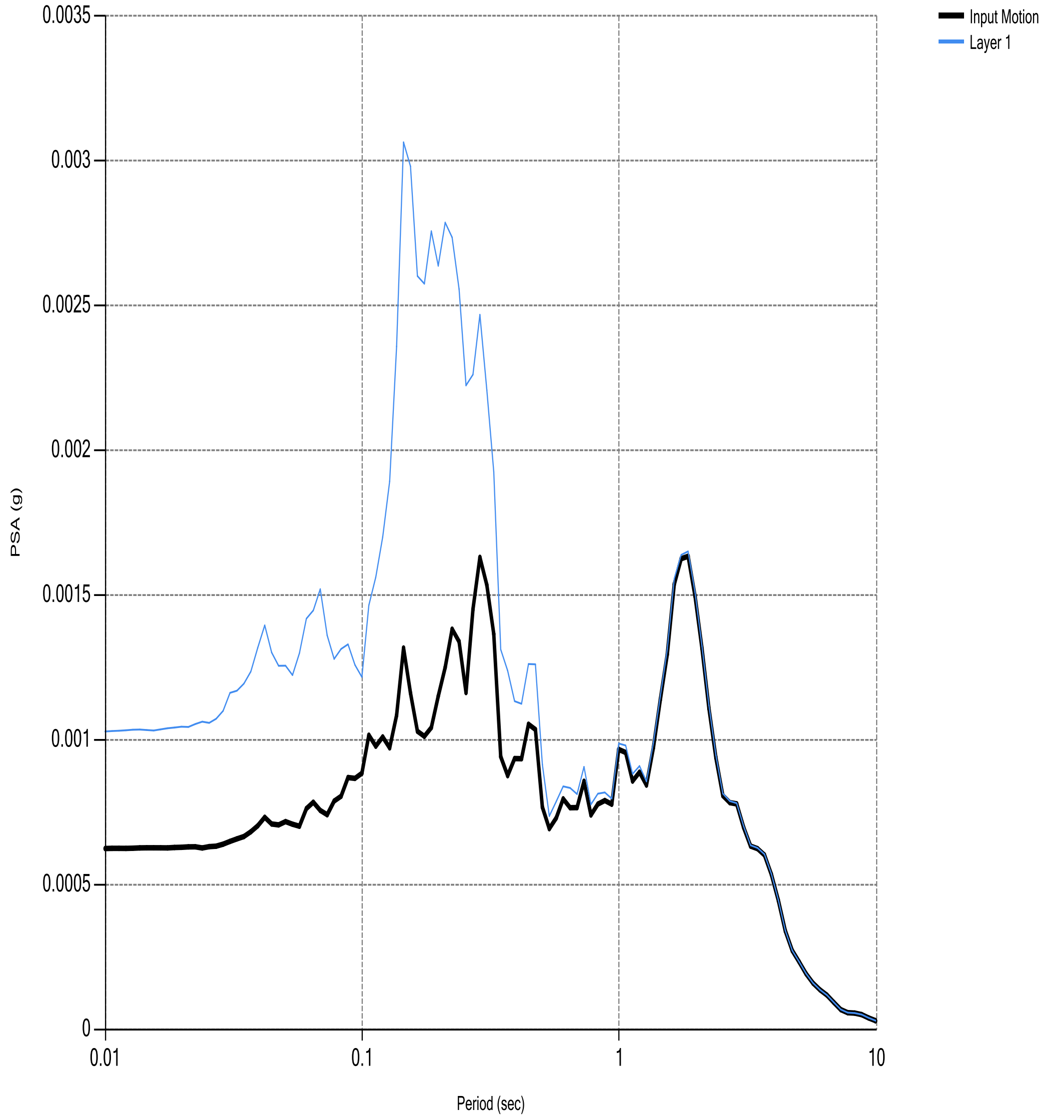


Fig 5.4 Response for the Far-Field excitation (i.e. for South-western Pakistan EQ)

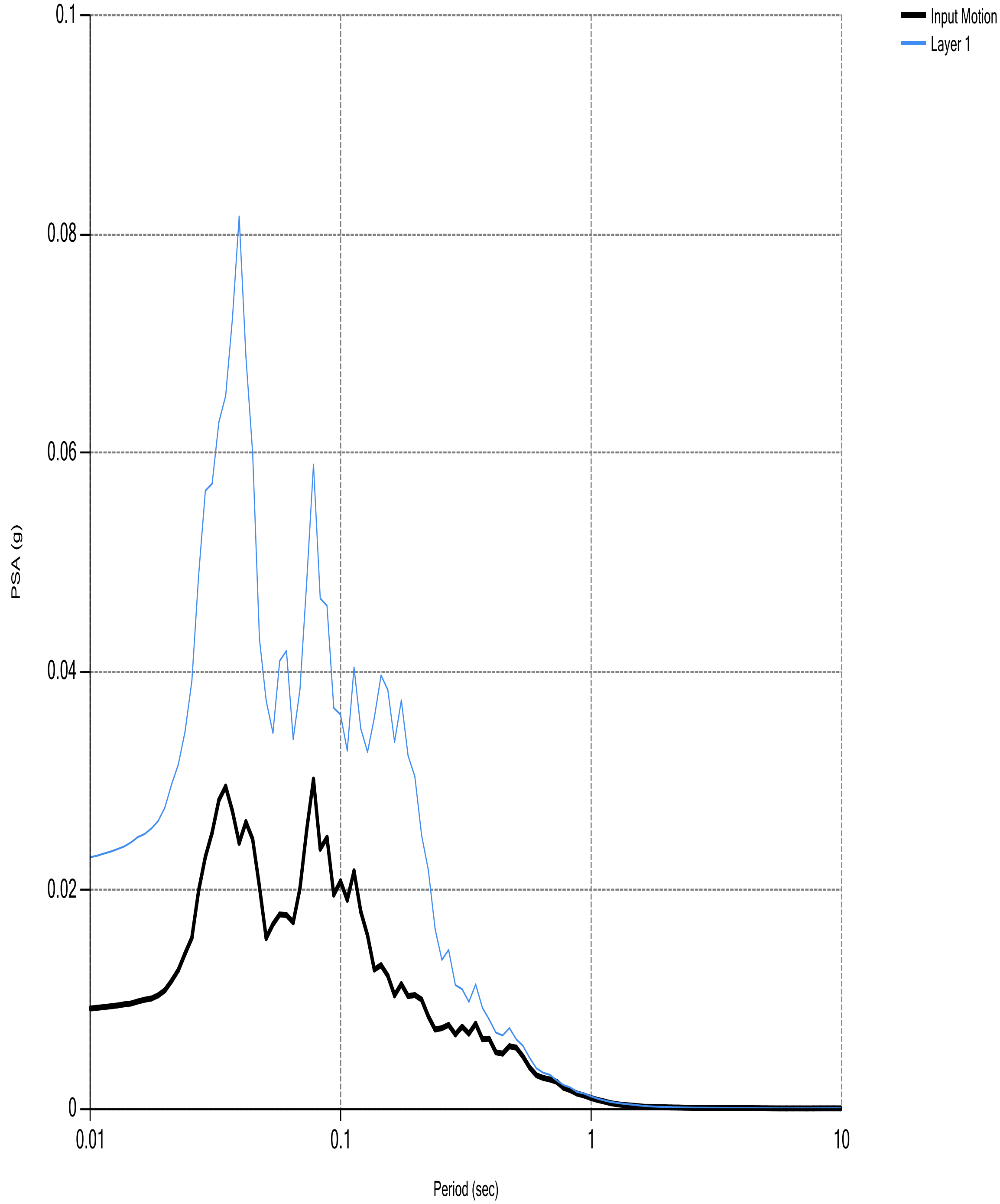


Fig 5.5 Response for Near-Field motion (i.e., Delhi-Haryana Region)

The near-field excitation for Guwahati region was of Sonitpur (Assam) India with details as follows:-

Origin time	**19/08/2009 10:45:15**
Latitude	**26.6^{o} N**
Longitude	**92.5^{o} E**
Depth (km)	**20.0**
Magnitude	**4.9**
Region	**Sonitpur (Assam)**
Site Class	**C V_s30 between 200 m/sec to 375 m/sec**
Record Time	**19.08.2009 20:09:29.829**
Sampling Rate	**200 Hz**
Record Duration	**71.660 Sec**
Direction	**Vert. (Up positive)**
Max. Acceleration	**20.664 cm/sec^2**

The soil properties of the Guwahati site are given below:-

Table 5.2 Soil properties of station at Guwahati

Strain (%)	G/Gmax	Damping (%)	Shear Strength (psf)
0.0001	1	0.0	182.071
0.0002	0.998	2.0	68.178
0.0005	0.98	2.0	30.565
0.001	0.949	5.0	48.346
0.002	0.917	5.0	47.036
0.005	0.832	5.0	38.283
0.01	0.729	5.0	84.498
0.02	0.6	5.0	90.597

The time history plot for the above earthquake is given below:-

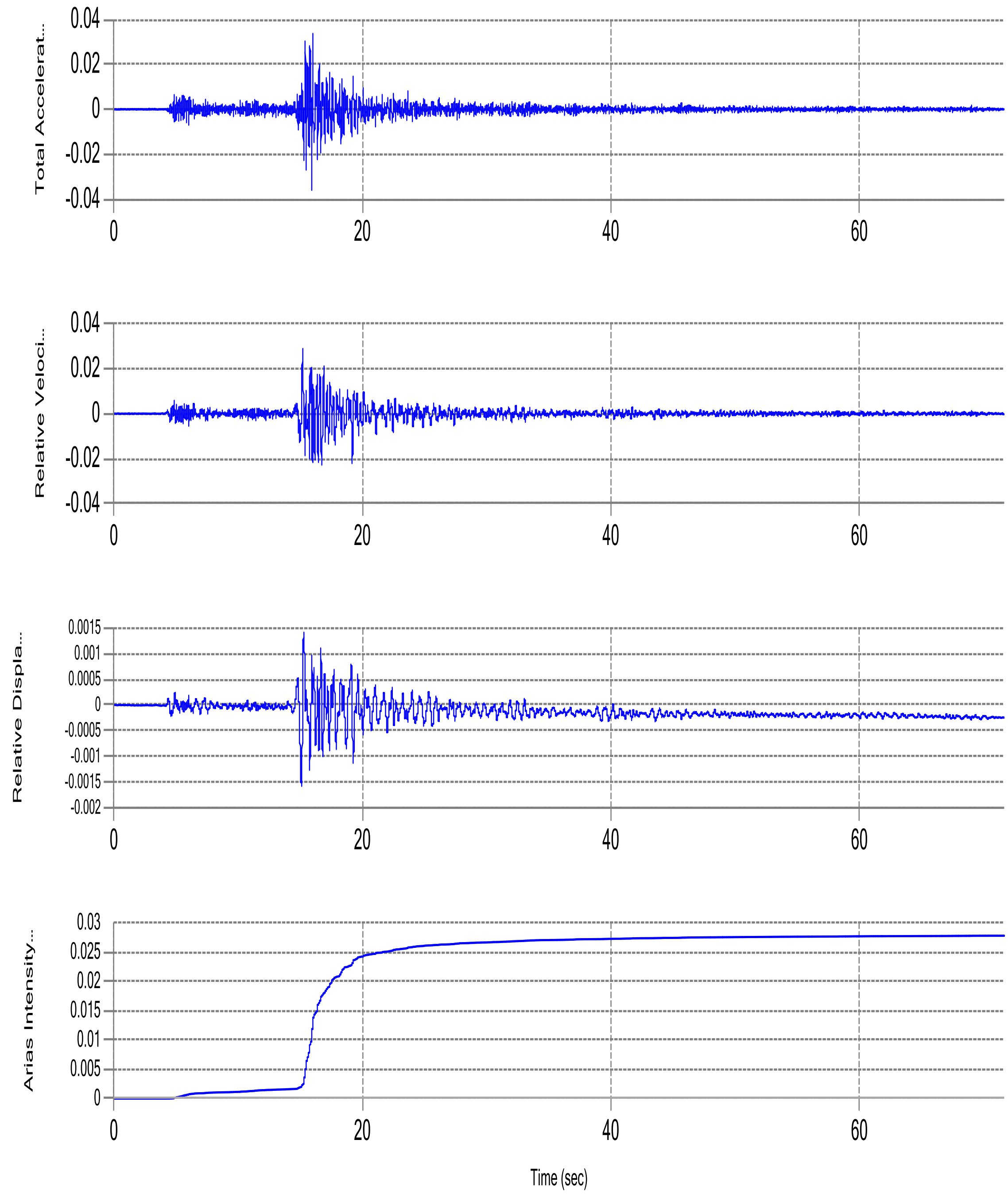


Fig 5.6 Time history plot for Sonitpur-Assam earthquake

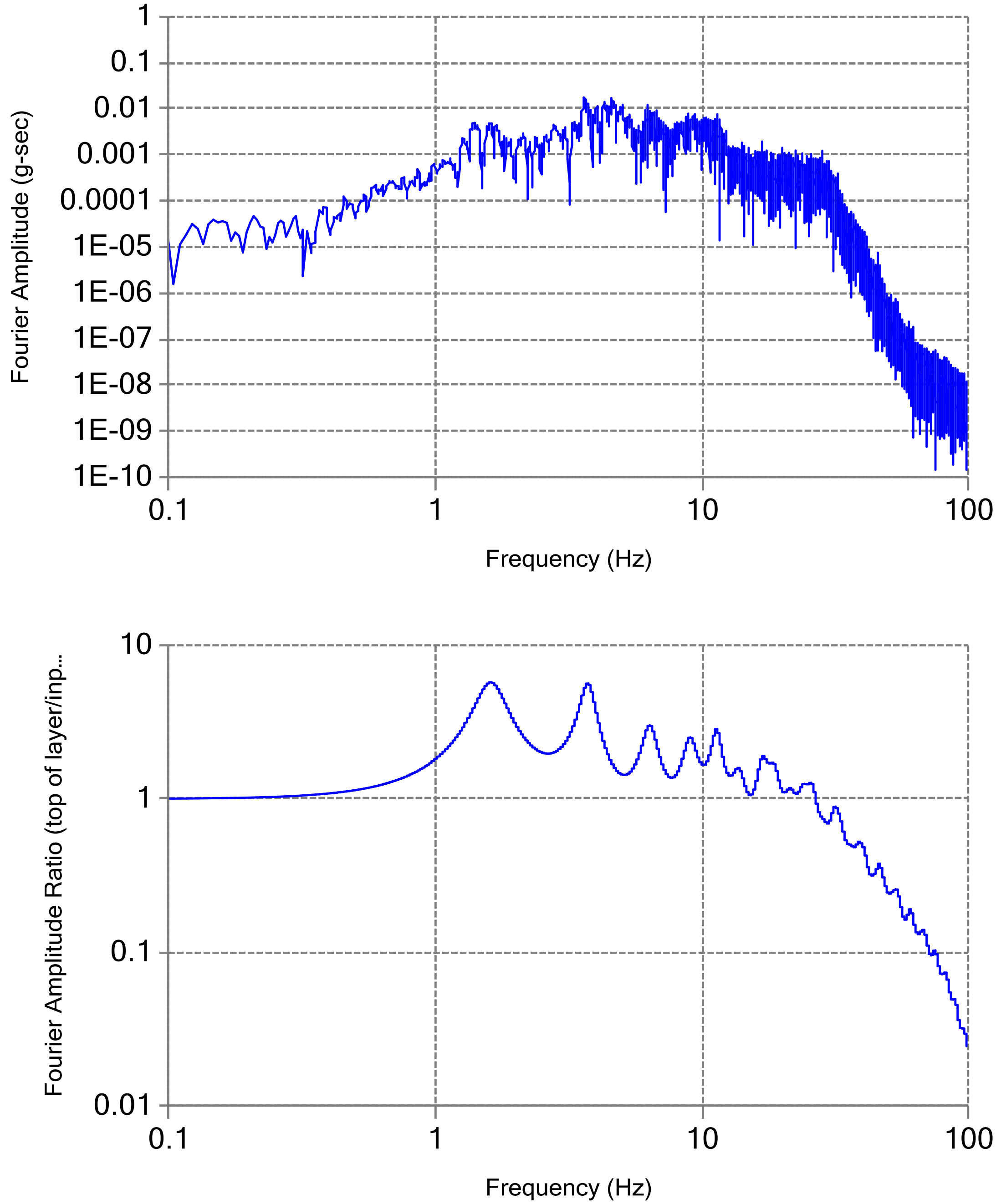


Fig 5.7:- Fourier spectra of Sonitpur-Assam earthquake time history

The far-field excitation for Guwahati region was of India-Myanmar Border (Manipur) Earthquake with details as follows:-

Origin time	**11/08/2009 21:43:39**
Latitude	**24.4^{o} N**
Longitude	**94.8^{o} E**
Depth (km)	**22.0**
Magnitude	**5.6**
Region	**India-Myanmar Border (Manipur)**
Site Class	**C V_s30 between 200 m/sec to 375 m/sec**
Record Time	**18.01.2011 21:44:54.729**
Sampling Rate	**200. Hz**
Record Duration	**73.040 Sec**
Direction	**Vert. (Up positive)**
Max. Acceleration	**-13.084 cm/sec^2**

The time history plot for the earthquake is shown below:-

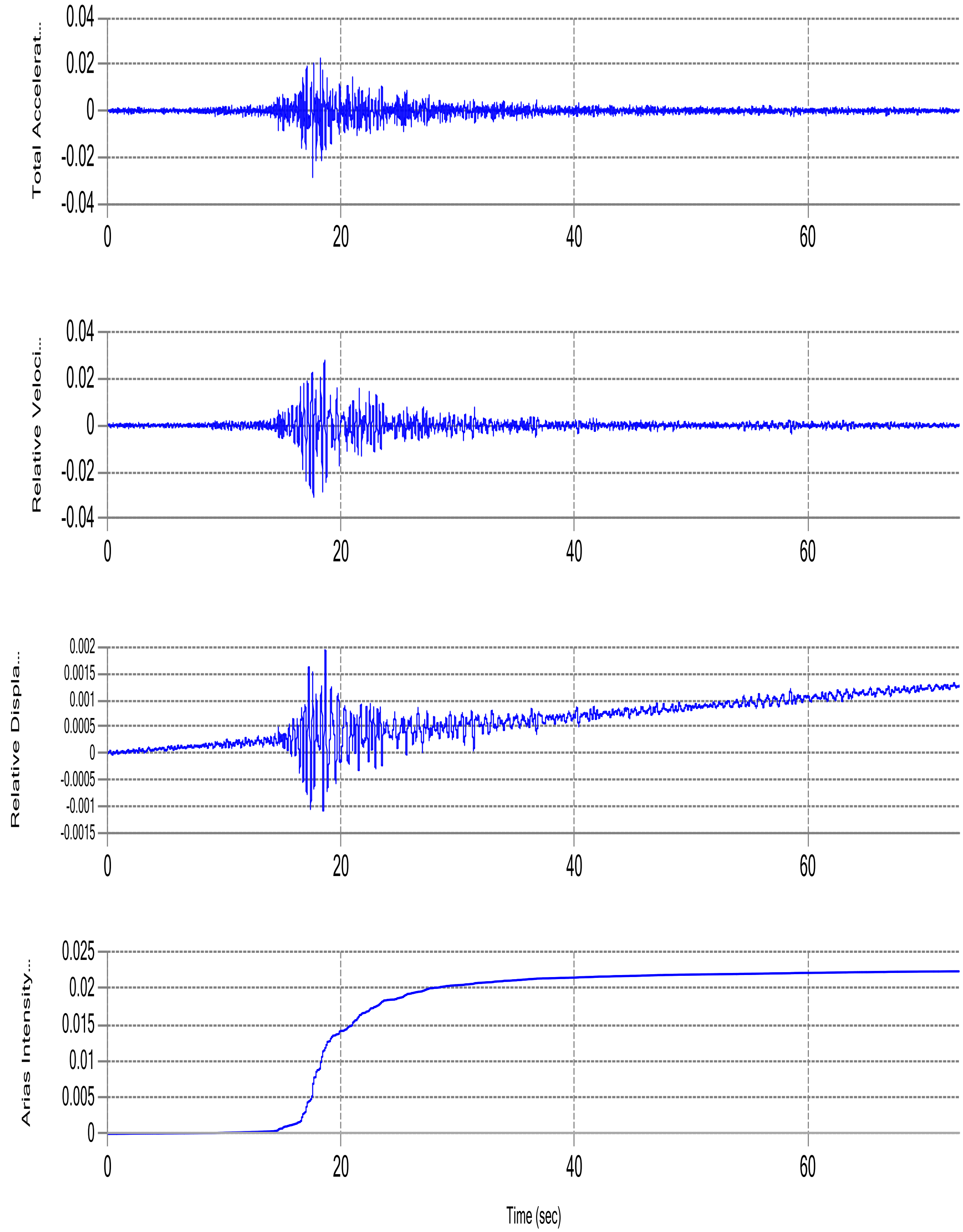
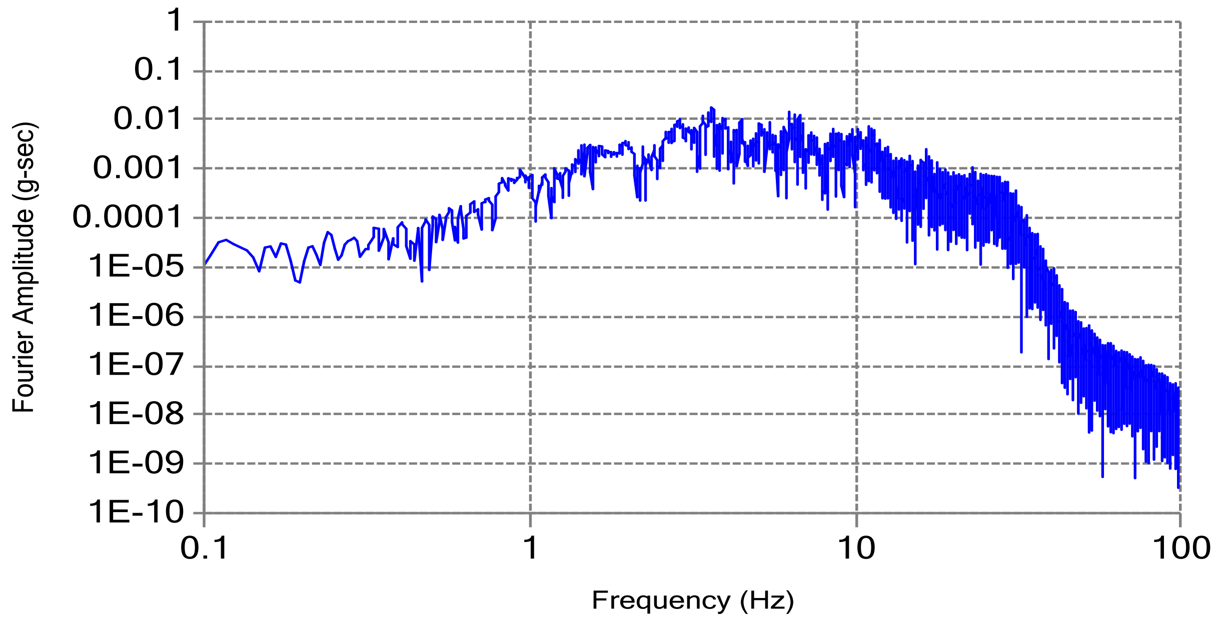


Fig 5.8 Time history plot for India-Myanmar border earthquake



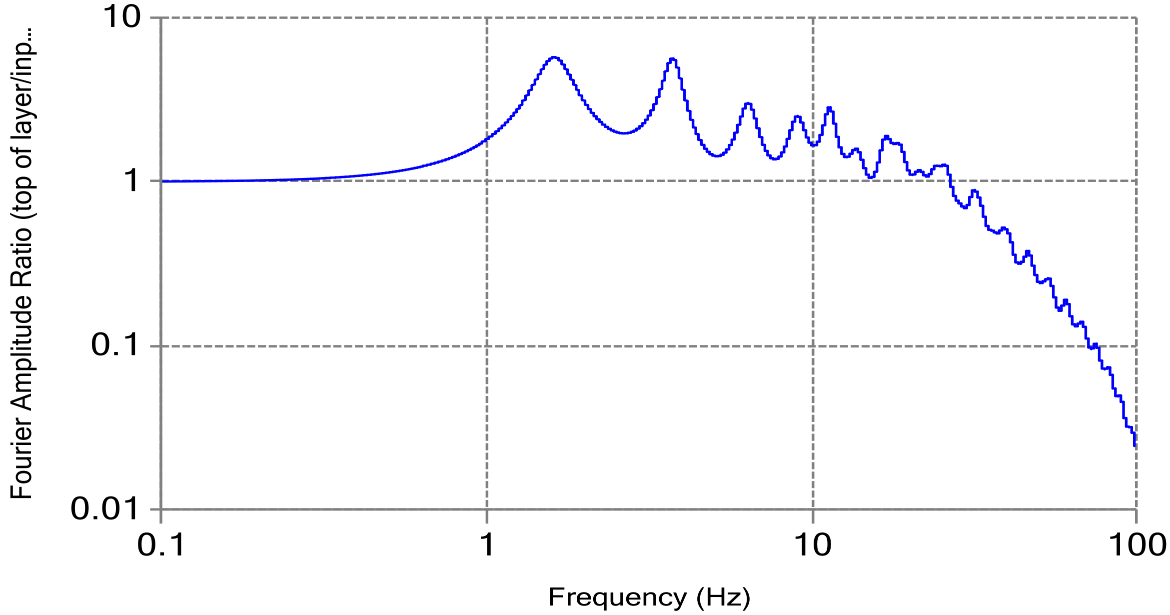


Fig 5.9 Fourier spectra for time history of India-Myanmar border earthquake

On analyzing the above two excitations by DEEPSOIL following results were obtained:-

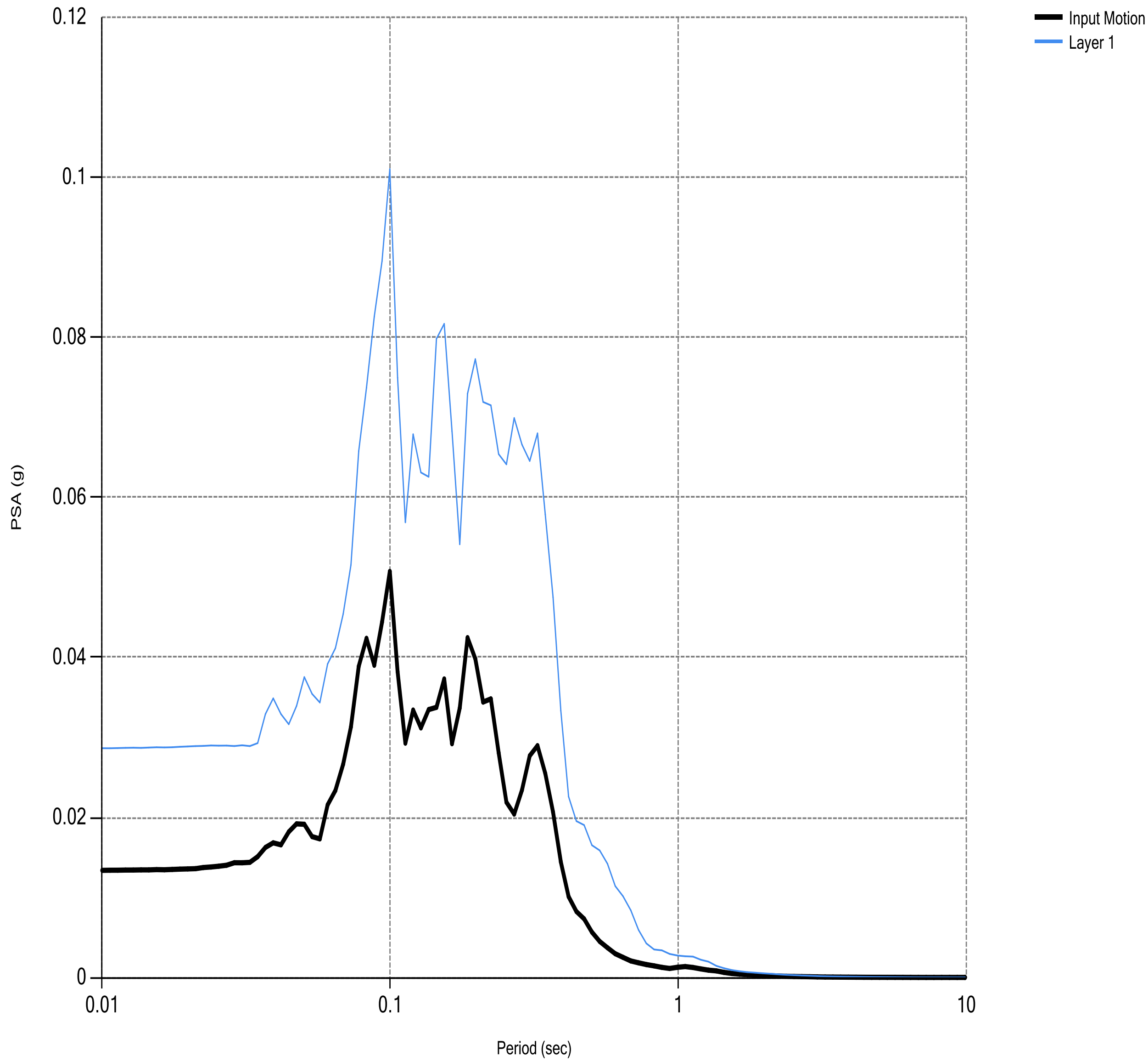


Fig 5.10 Response for the Near-Field Excitation, i.e. Sonitpur (Assam)

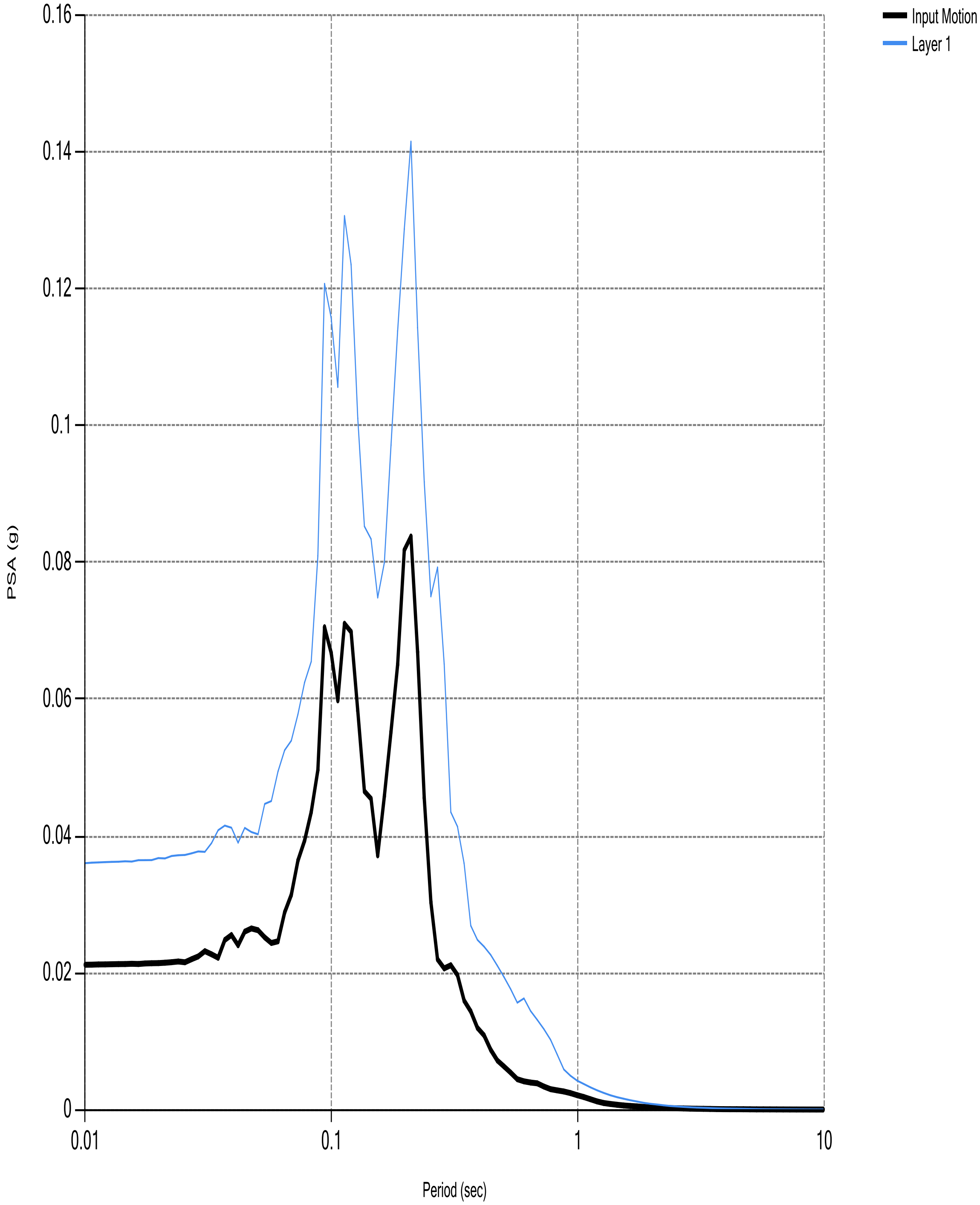


Fig 5.11:- Response for the far-field excitation i.e. (India-Myanmar Border)

Chapter 6

CONCLUSIONS

- For Delhi as well as Guwahati, it is observed that the amplification for near-field excitation has been more as compared to the far-field excitation. This implies that the site has natural frequency on the higher side due to which it amplifies the near-field excitation more as compared to the far-field excitation.

- Also the near-field excitations have more higher frequency components than far-field excitations which is seen from the response curve showing maximum acceleration at lower time period while for far-field excitations maximum acceleration is at higher time period.

- It can thus be safely concluded that the ground response not only depends on the magnitude of excitation but also on the natural frequency of the site.

- This problem needs to be further studied by taking Far-field excitations due to large earthquakes with epicentral distance of the range 250-300 km, i.e. for Western Himalayan earthquakes, to see the order of amplification levels for probable earthquakes.

FURTHER SCOPE OF STUDY

While performing the ground response analysis we have assumed the values of G and ξ to be constant throughout the vibration. However G and ξ both vary during the vibration. This can be taken into account by performing the Non-linear analysis. In the Non-linear approach we take into account the effect of Source as well as the path of wave propagation which appears to be more rational approach. So this can be the field which needs to be looked upon.

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