International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 06 | June 2021 www.irjet.net p-ISSN: 2395-0072

Modeling of Seismic Wave Propagation and Amplification in 1D Linear Unbounded Media

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Abstract - *To analyze seismic wave propagation in various locations in The Lucknow (UP). It is possible to consider various numerical approaches. The amplification of seismic waves in surface soil layers is mainly due to the velocity contrast between these layers and it is Earthquake response analysis has been carried out for soil adopting the equivalent linear approach in 1D. For this purpose, Geotechnical Data have been collected from different government and private organizations of Utter Pradesh. Soil amplification has been estimated at the surface using **DEEPSOIL** software. The result of have been formulated in terms of soil amplification graphs, the response spectra and surface acceleration time histories developed for these sites can be used for the dynamic analyses of important structures in the State.*

Key Words: Lucknow, numerical approaches, Earthquake response analysis, **DEEPSOIL** software.

1. INTRODUCTION

Any earthquake event is associated with a rupture mechanism at the source, propagation of seismic waves through underlying rock and finally these waves travel through the soil layers to the particular site of interest. The bedrock motion is significantly modified at the ground surface due to the presence of local soil layers above the bedrock beneath the site of interest.

In the present study, the effect of local soil sites in modifying ground response is studied by performing one dimensional equivalent-linear ground response analysis for some of the typical Lucknow in the state of Utter Pradesh, soil sites.

The ground responses are observed for range of input motions and the results are presented in terms of surface acceleration time history, ratio of shear stress to vertical effective stress versus time, acceleration response spectrum, Fourier amplitude ratio versus frequency etc.

1.1 Strong Motion Characteristics

Earthquake measurement is done by measuring ground displacement by seismograph instrument and recorded data is known as seismogram. Also ground acceleration can be measured by accelerograph and recorded and is known as accelerogram. This is usually preferred for strong ground motion. The ground velocity and displacement can be obtained by direct integration of an accelerogram.

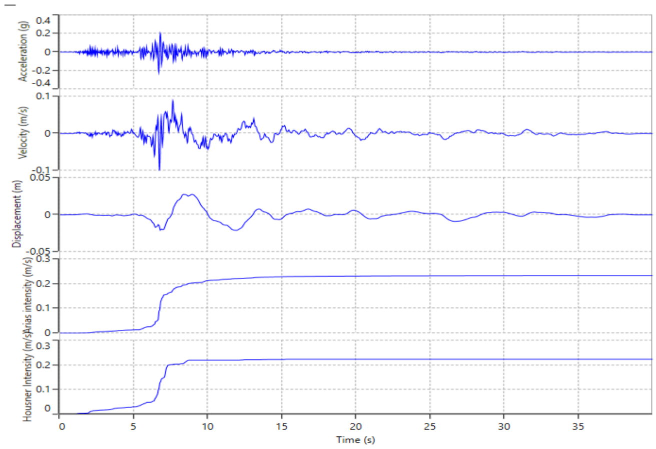


Fig -1: One dimensional system for ground response analysis

1.2 Seismic Design

The Seismic Design introduces additional difficulties with respect to the above ones. The most important aspect is the request that the structure is able to resist severe earthquakes with acceptable damage but without collapse, by exploiting its ductility properties. This modern design philosophy requires special design methodologies, very different from the conventional ones. its main tasks being the evaluation of the construction vulnerability against seismic actions.

1.3 Linear Analysis

Linear analysis, because of its simplicity, has been extensively used to study analytically the dynamic response of soil deposits. Closed form analytical solutions have been derived for idealized geometries and soil properties e.g., by assuming that the deposit consists of one uniform layer with soil stiffness either constant or varying with depth in a way which can be expressed by simple mathematical functions. In general, however, soil does not behave elastically and its material properties can change in space. In such situations, no analytical solutions are possible and numerical techniques such as finite element or finite difference method are used.

2. STUDY AREA AND DATA COLLECTION

Utter Pradesh is non-costal state in India with its capital is Lucknow. It is a large sized state having an area of 240,928 sq. km, which lies in the Gangetic Plain. Uttar Pradesh can be divided into two distinct hypsographical regions:

1. The Gangetic plain
2. The Vindya hills and plateau in the south

The state is covered by three Seismic Zones, II, III and IV, making it prone to low to moderate damage risk from earthquakes.

3. MODELING SEISMIC WAVE PROPAGATION

Predicting the ground motion amplifications of a layered soil deposit in the regions where earthquake hazards exist is a challenging task to the geotechnical engineers and the problem become more important for a highly populated city. In the present study an attempt has been made to evaluate the effect of local soil conditions in modifying the ground response. Equivalent linear ground response analysis using computer-based program namely DEEPSOIL is used. Field borehole data of some typical sites of Lucknow are considered for the analysis.

3.1 One-Dimensional Wave Propagation Analyses

One-dimensional wave propagation analysis is widely used for 'ground response analysis' or 'soil amplification studies' as it provides reasonable estimates of ground motion (Choudhury and Savoikar 2009). Also large numbers of commercial computer programs with different soil models are available with the advent of technology such as SHAKE (Schnabel et al. 1972), DEEPSOIL v7 (Hashash et al. 2008) etc.

The following assumptions are considered in this analysis:

1. The soil layers are horizontal and extend to infinity.
2. The ground surface is level.
3. The incident earthquake motions are spatially uniform, horizontally-polarized shear waves, and propagate vertically.

The basic wave equation for uniform damped soil on rigid rock is given as (Kramer 2005)

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

The solution to the above wave equation (1) is of the form (Kramer 2005)

The solution to the wave equation can be expressed in the form as:

$$u(x,t) = U(x).e^{i\omega t}$$

Substituting the above solution into the equation of motion gives an ordinary differential equation of the form as given below:

$$(G + i\omega\eta)\frac{\partial^2 U}{\partial x^2} = \rho\omega^2 U$$

This has the general solution of the form as:

$$U(x) = Ee^{ikx} + Fe^{-ikx}$$

where ,

$$k^2 = \frac{\rho\omega^2}{G+i\omega\eta} = \frac{\rho\omega^2}{G^*}$$

where, k is the complex wave number and G^* is the complex shear modulus. The critical damping ratio, β, is related to the viscosity η by:

$$\omega\eta = 2G\beta$$

Further, the complex shear modulus can be expressed in terms of the critical damping ratio instead of viscosity as G and β are nearly constant over the frequency range of interest in the analysis.

$$G^* = G + i\omega\eta = G(1 + 2i\beta)$$

Thus, the solution to the wave equation for a harmonic motion of a frequency ω is given as:

$$u(x,t) = Ee^{i(kx+\omega t)} + Fe^{-i(kx+\omega t)}$$

where, the first term represents the incident wave travelling in the negative X-direction (upwards) and the second term represent the reflected waves travelling in the positive X-direction (downward). The solution given by above equation is valid for each layer. The shear stress is then given by the product of the complex shear modulus G^* and the shear strain:

$$\tau(x,t) = G^*\frac{\partial u}{\partial x} = (G + i\omega\eta)\frac{\partial u}{\partial x} = (G + 2i\beta)\frac{\partial u}{\partial x}$$

The displacement at the top and bottom of layer '***m***' in its local coordinate system, X, is given as:

$$u_m(X_m = 0, t) = (E_m + F_m)e^{i\omega t}$$

$$u_m(X_m = h_m, t) = (E_m e^{ik_m^* h_m} + F_m e^{-ik_m^* h_m})e^{i\omega t}$$

Similarly, shear stresses at the top and bottom of layer m are:

$$\tau_m(X_m = 0, t) = ik_m^* G_m^* (E_m - F_m)e^{i\omega t}$$

$$\tau_m(X_m = h_m, t) = ik_m^* G_m^* (E_m e^{ik_m^* h_m} - F_m e^{-ik_m^* h_m})e^{i\omega t}$$

Displacements at layer boundaries must be compatible (i.e. displacements at the top of a particular layer must be equal to the bottom of the overlying layer). Applying compatibility requirements at the boundary between layer '***m***' and layer '***m+1***', i.e.

$$u_m(X_m = h_m, t) = u_{m+1}(X_{m+1} = 0, t)$$

yields,

$$E_{m+1} + F_{m+1} = E_m e^{ik_m^* h_m} + F_m e^{-ik_m^* h_m}$$

Also stresses must be continuous at boundaries which yield:

$$\tau_m(X_m = h_m, t) = \tau_{m+1}(X_m = 0, t)$$

$$E_{m+1} - F_{m+1} = \frac{k_m^* G_m^*}{k_{m+1}^* G_{m+1}^*}(E_m e^{ik_m^* h_m} - F_m e^{-ik_m^* h_m})$$

Solving for constants gives the recursion formulas as:

$$E_{m+1} = \frac{1}{2}E_m(1+\alpha_m^*)e^{ik_m^* h_m} + \frac{1}{2}F_m(1-\alpha_m^*)e^{-ik_m^* h_m}$$

$$F_{m+1} = \frac{1}{2}E_m(1-\alpha_m^*)e^{ik_m^* h_m} + \frac{1}{2}F_m(1+\alpha_m^*)e^{-ik_m^* h_m}$$

where, α_m^* is the complex impedance ratio at the boundary between layers '***m***' and '***m+1***':

$$\alpha_m^* = \frac{k_m^* G_m^*}{k_{m+1}^* G_{m+1}^*} = \frac{\rho_m (V_S^*)_m}{\rho_{m+1}(V_S^*)_{m+1}}$$

At the ground surface, the shear stress must be equal to zero, which requires that $E_1 = F_1$. If the above derived recursion formulas are applied repeatedly for all layers from 1 to m, functions relating the amplitudes in layer m to those in layer can be expressed by

$$E_m = e_m(\omega)E_1$$

$$F_m = f_m(\omega)F_1$$

The transfer function relating the displacement amplitude at layer ***i*** to that at layer ***j*** is given by:

$$F_{ij} = \frac{|u_i|}{|u_j|} = \frac{e_i(\omega)+f_i(\omega)}{e_j(\omega)+f_j(\omega)}$$

as the acceleration and velocities are related to the displacement by equation given below:

$$|\ddot{u}| = \omega\frac{du}{dt} = \omega^2\frac{d^2u}{dt^2}$$

The same transfer function can also be used for determining the amplification of acceleration and velocities from layer ***i*** to layer ***j***.

3.2 Method of Analysis

The solution steps involved in the one-dimensional equivalent linear ground response analysis are:

1. The time history of earthquake ground motion is broken down into sum of series of simple harmonic Fourier loading functions.
2. Response is evaluated for each individual Fourier series loadings.
3. The responses are combined to get the output time history.

Also, the equivalent-linear method is an iterative approach and is defined as below (Kramer 2005).

A set of material curves have been defined in DEEPSOIL for modulus reduction curves and damping ratio curves for different soils. In case of sands by defining effective vertical stress, the appropriate modulus reduction curves may be arrived. In case of clays, effective vertical stress and plasticity index is required to be defined, for estimating modulus reduction and damping curves.

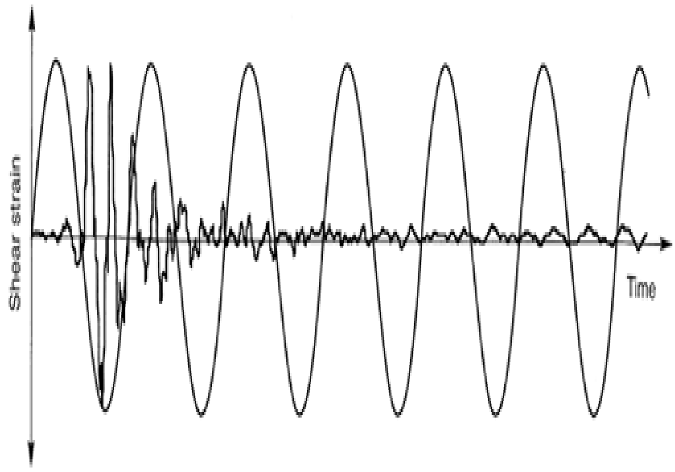
Thus, for a given time history at the bedrock location and by knowing the dynamic soil characteristics i.e., shear wave velocity profile with depth, modulus reduction and damping curves, the ground motions amplifications may be obtained by performing ground response analysis.

4. Methodology

The procedure in the simplest form consists of the following steps:

1. to collect data,
2. to model them for computer programs,
3. to execute computer program, and
4. to interpret the results. Several input data are required in the ground response analysis.

They are classified into four categories:



Site Characterization: It includes site classification, geological or topological configuration such as development of soil profiles and cross-sectional shape.

Dynamic Characterization: It includes the assessment of dynamic soil properties either by laboratory experimentations or by using standard curves and correlations.

Input earthquake motion: Suitable time histories are selected in line with the expected earthquake hazard in area.

Analysis Type: The parameters to control the flow of the computer program are selected such as linear, nonlinear or equivalent linear. These analyses types can further be 1D as per the requirement or degree of accuracy required.

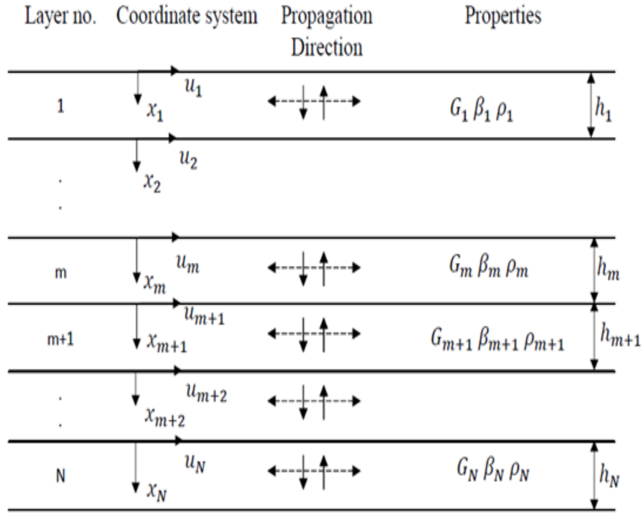


Fig -2: One dimensional system for ground response analysis

4.1 Soil Classification

Layer Number	Layer Name	Thickness (m)	Unit Weight (KN/m^3)	Shear Wave Velocity (m/s)
1	Layer 1	0.5	18	205
2	Layer 2	0.5	19	218
3	Layer 3	0.5	18	226
4	Layer 4	0.5	20	245
5	Layer 5	0.5	18	220

Table -1: Layers of model

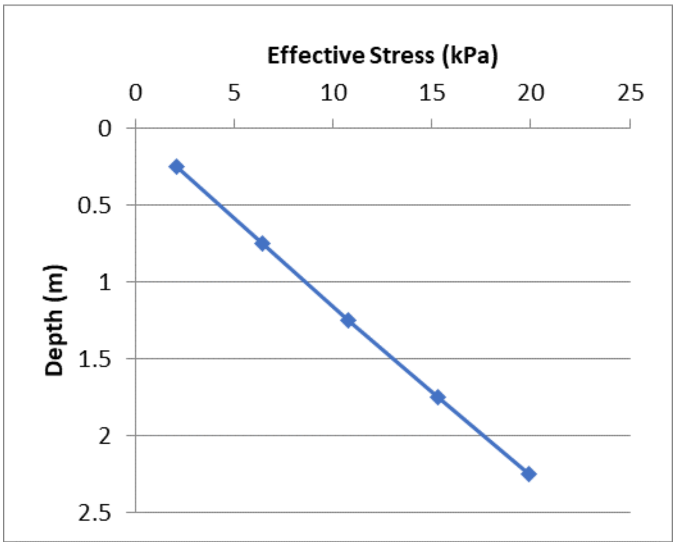


Fig -3: Effective Stress in kPa

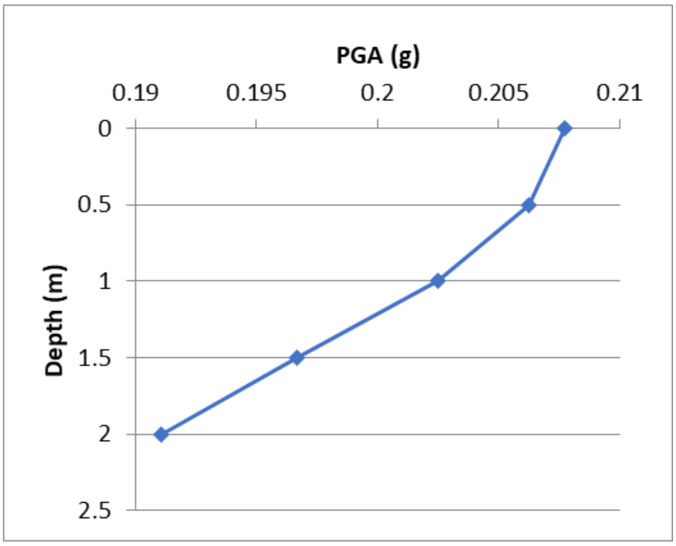


Fig -4: PGA in g

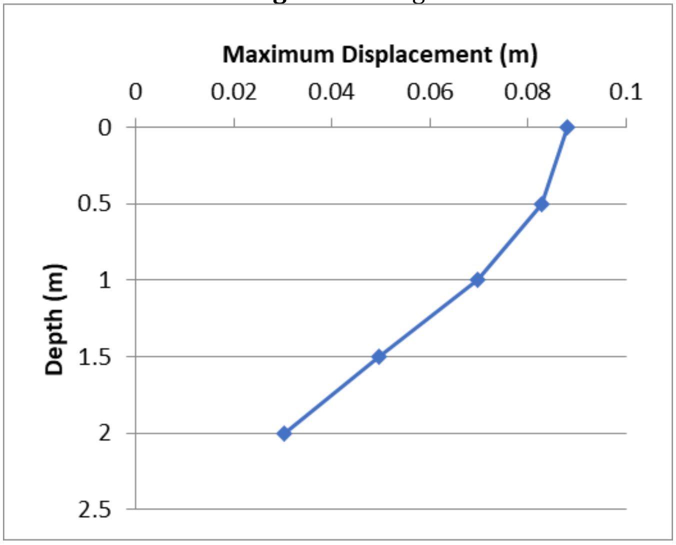


Fig -5: Maximum Displacement in m

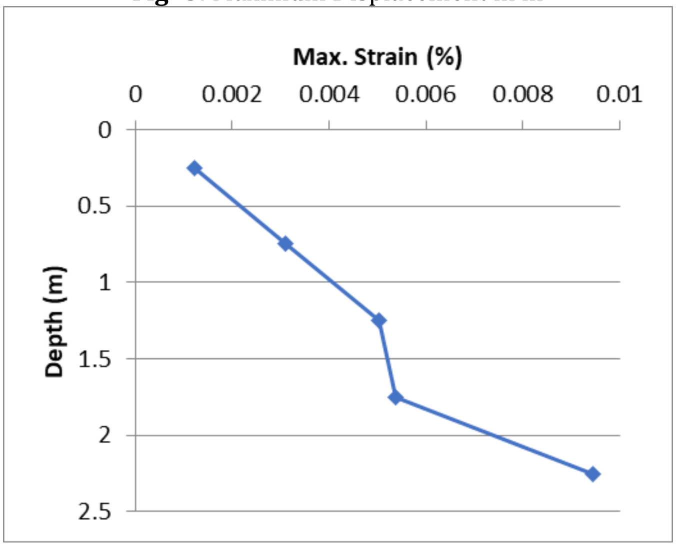


Fig -6: Maximum Strain in %

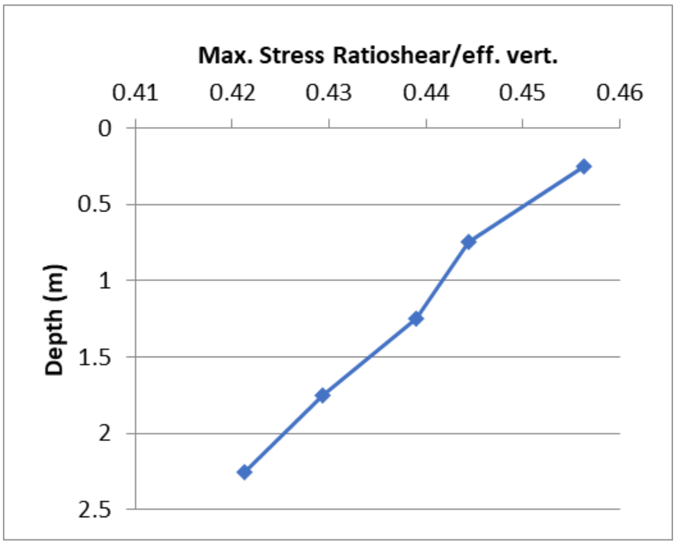


Fig -7: Maximum Stress Ratio

4.2 Input Data of Soil Layers

Layer	Shear Strength(kPa)	Friction Angle(deg)
1	0.9	24.5
2	2.8	24
3	4.7	23.7
4	6.6	23.2
5	8.4	22.8

Table-2: Soil Properties of Layers

5. RESULTS

Earthquake response analysis has been carried out for various layers of Lucknow. It has been observed that amplification factor for PGA range 0.192 to 0.211, which shows that soils in Lucknow are capable of amplifying earthquake ground motion.

PGA (g)		Maximum Displacement	
Depth (m)	PGA (g)	Depth (m)	Displacement (m)
0	0.207746963	0	0.08801719
0.5	0.206231386	0.5	0.082736039
1	0.202481222	1	0.069696444
1.5	0.196698921	1.5	0.049671998
2	0.191037975	2	0.030197113

Table -3: Displacement Result of Layers

Max. Strain		Max. Stress Ratio	
Depth (m)	Strain (%)	Depth (m)	Shear Stress Ratio (Shear/Eff. Vert.)
0.25	0.00121163	0.25	0.456307099
0.75	0.00308684	0.75	0.444469112
1.25	0.0050298	1.25	0.439003856
1.75	0.00537936	1.75	0.42934932
2.25	0.00945378	2.25	0.421309652

Table-4: Max. Strain Developed

This behavior must be accounted in the earthquake resistant design of important structure in the city. The amplified acceleration time histories for the site at various depth can be used for carried out dynamic analysis of structure in the region.

Modeling of soil layers using DEEEPSOIL v7

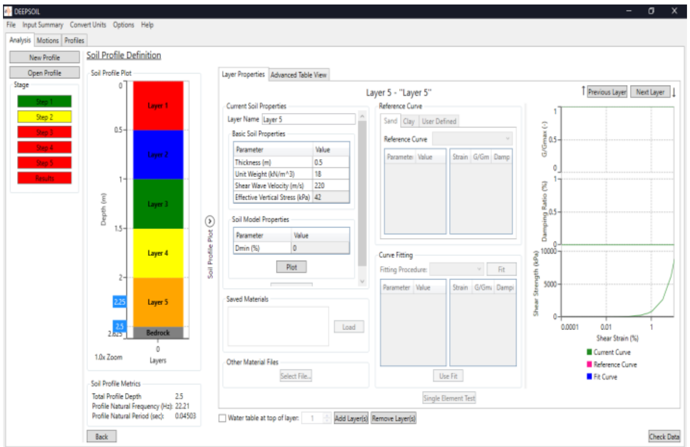


Fig -8: Input soil data in 5 different Layers

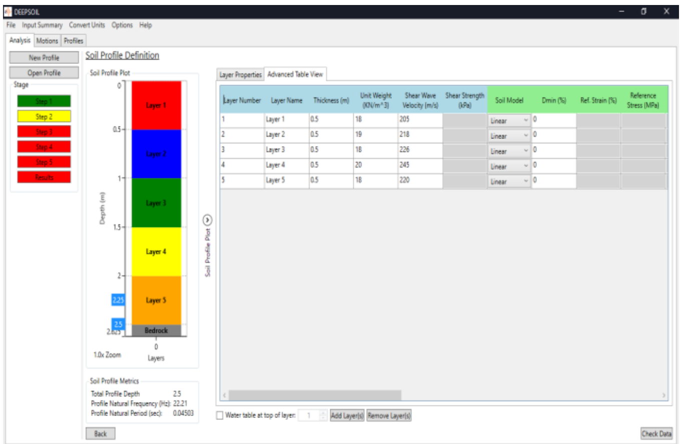


Fig -9: Input Data with Table in software

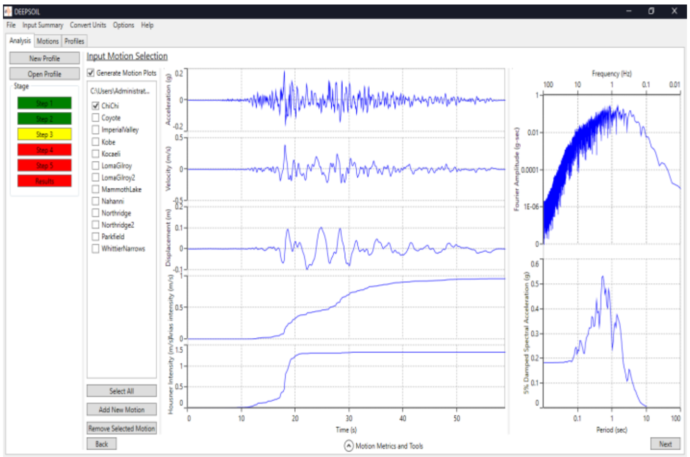


Fig -10: Input Motion using reference ChiChi

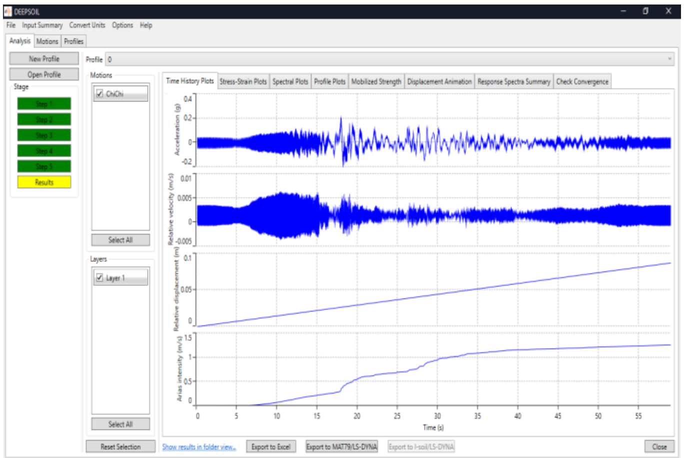


Fig -11: Time History Plot

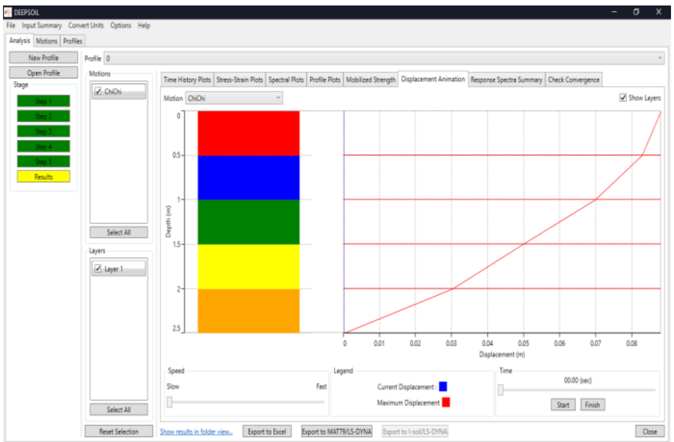


Fig -12: Displacement Animation with Time

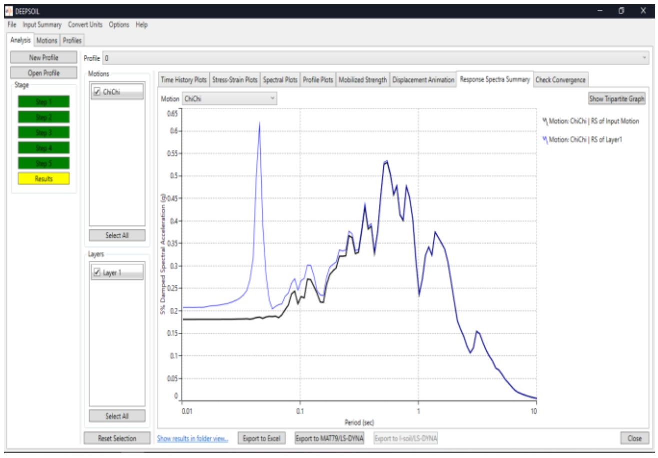


Fig -13: Variation Response Spectra Summary

Table-5: Results of Strain Developed in Tabular form

Time (s)	Acceleration (g)	Strain (%)	Shear Stress Ratio (Shear/Eff. Vert.)	Shear Stress(kPa)
0	-0.00152	-8.7E-06	-0.00329	-0.00675
0.005	0.014032	8.15E-05	0.030687	0.062831
0.01	0.022778	0.000132	0.049783	0.101931
0.015	0.019595	0.000114	0.042863	0.087762

6. CONCLUSIONS

A study on the ground response analysis of some typical Lucknow soil sites considering four different strong motion earthquakes are presented. The following conclusions are obtained.

1. The role of local soil sites in amplification of responses has found to be significant and has been discussed thoroughly. It is observed that local soil sites have a profound influence in modifying the ground response.

2. The peak ground acceleration amplification factors for input motion are found to be about 0.21 site been evaluated and can readily be used by designers.

3. Natural frequencies of the soil sites have also been evaluated by using both analytical formula and DEEPSOIL program and found to match well which in turn shows the validation of DEEPSOIL program for such problem. Response

spectra considering 5% damping and Fourier amplitude ratio's have been obtained for these soil sites with different input motions.

4. The response spectrum along various soil layers for four strong motion earthquakes with wide variation from low to high MHA and mean time periods are obtained. These results may be used alternatively in the absence of any site-specific data for similar sites of Lucknow region.

REFERENCES

1. Steven L Kramer. Geotechnical Earthquake Engineering. Prentice-Hall International series in Civil Engineering and Engineering Mechanics, Second Impression, 2008.

2. V. S. Phanikanth, Deepankar Choudhury, G. Rami Reddy, "Equivalent-Linear Seismic Ground Response Analysis of Some Typical Sites in Mumbai" published in 2011.

3. Hashash, Y.M.A., Musgrove, M.I., Harmon, J.A., Ilhan, O., Groholski, D.R., Phillips, C.A., and Park, D. (2017) "DEEPSOIL 7.0, User Manual".

4. C.S. Markham, J.D. Bray, J. Macedo, "Deconvolution of Surface Motions from the Canterbury Earthquake Sequence for use in Nonlinear Effective Stress Site Response Analyses".

5. Silva, W. J., (1988). "Soil response to earthquake ground motion", EPRI Report NP-5747, Electric Power Research Institute, Palo Alto, California.

6. Idriss, I.M. and Akky, M.R. (1979). "Primary Variables Influencing Generation of Earthquake Ground Motions by a Deconvolution Process." Paper K 1/3. Proceedings of the 5th Annual SMiRT Conference, August 1979.

7. SHAKE 2000 Manual.
8. Chandrakanth Bolisetti, Andrew S. Whittaker, Ibrahim Almufti, H. Benjamin Mason, Michael Willford (2013). "Numerical methods in site response analysis for nuclear applications". SMiRT-22, August 2013