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Equivalent Linear Seismic Analysis of Some Specific Sites in Ludhiana City using DEEPSOIL

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Abstract— The seismic waves generated due to the occurrence of earthquake, travel through different layers of Earth's crust. The seismic properties of waves such as Peak Acceleration, Velocity and Peak Amplitude are greatly affected by the soil lying above relatively stiff bedrock. In the present research, an attempt has been made to analyze this effect at some typical sites in Ludhiana city. As per IS 1893 (Part 1):2002 published by Bureau of Indian Standards, Ludhiana is placed in Zone IV having Severe Seismic Intensity of 0.24g. Geotechnical data of some typical sites located at Delta City, Malerkotla Road, Bhai Bala Chowk and Sarabha Nagar Chowk in Ludhiana is collected. Field borehole log data is used to carry out Equivalent Linear Seismic Ground Response Analysis by computer program DEEPSOIL under the influence of Loma Gilroy Earthquake, Uttarkashi Earthquake and Artificially Generated Earthquake Motion using SeismoArtif respectively. The various sites are classified based on average SPT N-Value and were found to be under 'D' Class as per NEHRP. After Ground Response Analysis of these sites, Peak Ground Acceleration (PGA) at surface is found to vary from 0.3534g to 0.4524g, Amplification Ratio from 1.111 to 2.286 and Spectral Acceleration from 1.1945g to 1.8191g respectively.

Keywords— Ground Response Analysis, Ludhiana, Equivalent Linear, Peak Ground Acceleration (PGA), Amplification Ratio, Spectral Acceleration, Seismic, Earthquake

I. INTRODUCTION

Earthquakes keep on occurring on large scale in various parts of the world each second with varying intensity and time period. The reason of occurrence is explained by two theories namely Elastic Rebound Theory and Tectonic Plate Theory. Earthquakes themselves do not cause harm to lives but faulty structures and inappropriate investigation leads to loss of lives during earthquakes. The structures are required to be designed as per the intensity of earthquakes that are likely to occur in the particular regions.

The process of determining the intensity and time period of earthquakes along with various ground motion parameters like Peak Ground Acceleration is known as Seismic Hazard Analysis. Seismic Hazard Analysis can be classified into Deterministic Seismic Hazard Analysis (DSHA) based upon maximum intensity of earthquake in the particular region and Probabilistic Seismic Hazard Analysis (PSHA) based upon probability of most likely earthquake that can occur in particular region.

The waves generated from the source of earthquake travel through various layers of earth's crust to the surface of earth. In this process the properties of seismic waves like Peak Amplitude, Peak Velocity are greatly influenced by relatively soft soil in comparison to stiff rocks (at larger depth). It has been observed in past studies that the site specific soil conditions can greatly affect the properties of travelling seismic waves due to which it becomes necessary to carry out Site Specific Ground Response Analysis for determining exact ground motion parameters in that particular region. Ground Response Analysis can be classified into One Dimensional Analysis, Two Dimensional Analysis and Three Dimensional Analysis. One Dimensional Analysis is carried out where surface is flat or has gentle slope. Two-Dimensional Analysis is carried out in case of Earth Retaining Structures, Tunnels etc. Three-Dimensional Analysis is carried out where Interaction of structures is there with vibration of soil particles. Ground Response Analysis can be carried out in various manners namely Linear (where soil is assumed to be purely elastic material having stress directly proportional to strain), Equivalent Linear (where non-linear behavior of soil is converted to linear by taking into consideration Secant Shear Modulus of soil through iterative procedure) and Non-Linear (where non-linear behavior of soil is taken into consideration and analysis is carried out in time steps layer by layer).There are number of computer programs available to carry out Site Specific Ground Response Analysis like SHAKE, ProSHAKE, EduSHAKE, DEEPSOIL, PLAXIS etc. These various computer programs require soil profile of particular site and input ground motion accelerogram to carry out Ground Response Analysis.

II. LITERATURE REVIEW

Naval Sanjeev et al. [1] carried out Deterministic Seismic Hazard Analysis of Ludhiana city based on various Seismic sources present in the area and concluded that the maximum PGA value reaches 0.392g which is much higher value than given by Bureau of Indian Standards in IS 1893. Similar Seismic Hazard Analysis was carried out by Siddhardha et al. [2] for Chandigarh which was further used by Joseph T.M. et al. [3] to carry out Ground Response Analysis for Chandigarh city. In the same year One Dimensional Non Linear Ground Response Analysis was carried out for IIT

Guwahati by D Basu et al. [4] and various ground motion parameters were determined. Nitish Puri et al. [5] also carried out Deterministic Seismic Hazard Analysis of Haryana and determined PGA based on various seismic sources present in the region. B.J. Ramaiah et al. [6] carried out Site Specific Seismic Response analysis of Municipal Solid Waste Dump Site at Delhi with the help of software SHAKE2000 to determine Maximum Horizontal Acceleration and Amplification Ratio at that site. Gagandeep et al. [7] found PGA value obtained from Deterministic Seismic Hazard Analysis of Jalandhar to be double than value provided for Jalandhar in IS 1893 by Bureau of India Standards. Nika S Bhingarde et al. [8] carried out Site Specific Ground Response Analysis of Mormugao Port, Goa and various ground motion parameters were determined. It was observed that maximum amplification ratio reached about 12.69 for the site. Ground Response Analysis of Kanpur city was carried out by Jishnu R.B. et al. [9] and various ground motion parameters were obtained. In Lukhnow also, Ground response Analysis was carried out by Kumar Abhishek et al. [10] by SHAKE2000 and various ground motion parameters for that site were obtained. In 2009, Ground Response Analysis of Coastal soils near Kutch was carried out by T.P. Thaker et al. [11] from which peak spectral acceleration (0.33g to 0.73g) and amplification ratio (3.5 to 8.5) for the site were observed. From the previous studies carried out by various Academicians and Research scholars it is observed that very less research has been carried out regarding Ground Response Analysis in India till now and many areas are still to be evaluated that will be useful to make Microzonation Map of India based on ground motion parameters obtained from Ground Response Analysis.

In the present study the borehole details of three sites located at Delta City, Malerkotla Road (DC) upto 30m with water table at 26.7m, Bhai Bala Chowk (BB) upto 30m with ground water table at 24.8m and Sarabha Nagar Chowk (SN) upto 30m with ground water table at 25.2m in Ludhiana are collected to carry out Equivalent-Linear One-Dimensional Ground Response Analysis by using DEEPSOIL. Ludhiana is one of the main cities of North India famous for cycle industry and is also known as "Manchester of Punjab". It is located at 30.9010^0N, 75.8573^0E covering total area of 310 km^2. As per IS 1893 published by Bureau of Indian Standards, Ludhiana is placed in Zone IV having maximum seismic intensity of PGA (Peak Ground Acceleration) value of 0.24g. The Site Specific Ground Response Analysis of Ludhiana will help in further Microzonation of Punjab state and can help Structure designers to design the safe structures keeping into consideration the site specific ground motion parameters obtained from Ground Response Analysis. The study can be further utilized to carry out Liquefaction Hazard Assessment in Ludhiana.

III. METHODOLOGY

The collected borehole log details of three sites DC, BB and SN are analyzed to determine Shear Modulus by using empirical equations mentioned in **Table I** for different types of soils as verified by Anbazhagan, et al. [12]. These sites are classified based on average N value for the depth of 30 m as per recommendations given by NEHRP. The Average N Values and Site Classification are mentioned in **Table II.** The Equivalent-Linear Ground Response Analysis is carried out by DEEPSOIL [13] under the influence of Loma Gilroy Earthquake (PGA 0.17g), Uttarkashi Earthquake (PGA 0.24g) and Artificial Earthquake Motion generated with SeismoArtif (PGA 0.392g) considering Soft Bed Rock conditions having density 2.5g/cc, Shear Wave Velocity of 760 m/s and 5% Damping.

TABLE I
CORRELATIONS FOR DETERMINING SHEAR MODULUS FROM SPT N VALUE

Correlations	Soil Type	Units	Author(s) Name
$G = 11.96 (N^{0.62})$	Clay	MN/m^2	Ohba and Toriumi (1970)
$G = 6.374 (N^{0.94})$	Sand	MN/m^2	Ohsaki and Iwasaki (1973)
$G = 11.59 (N^{0.76})$	Intermediate Soils	MN/m^2	Ohsaki and Iwasaki (1973)

TABLE II
SITE CLASSIFICATION AS PER NEHRP

Site	Average N Value (N_{30})	Classification as per NEHRP
BB	19.764	D
DC	19.273	D
SN	19.998	D

The Time Motion history of these earthquakes is shown in **Figures 1 to 3.** The Spectral Acceleration, Amplification Ratio (Ratio of PGA at Surface to PGA at Bed Rock level) and Peak Ground Acceleration on Surface are determined and compared.

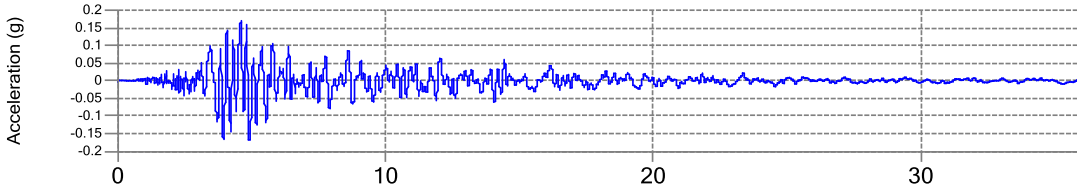


Figure 1: Accelerogram for Lo,a Gilroy Earthquake with maximum PGA 0.17g

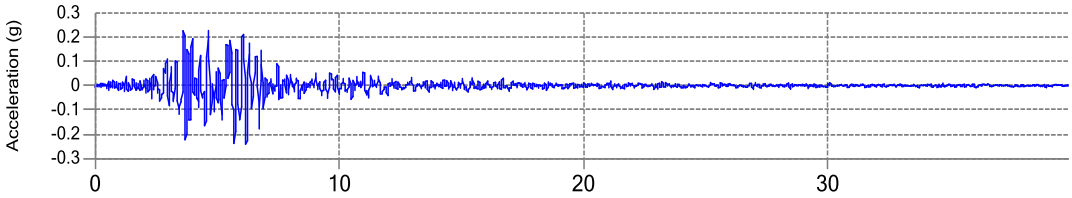


Figure 2: Accelerogram for Uttarkashi Earthquake with maximum PGA 0.24g

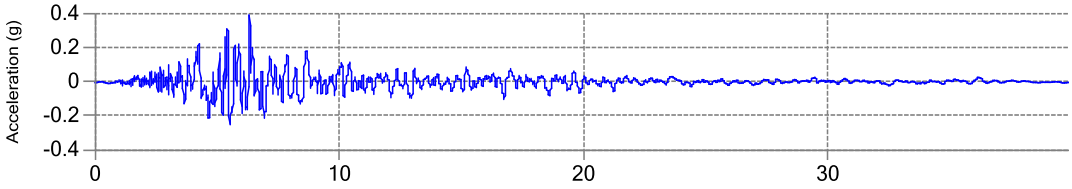


Figure 3: Accelerogram for Artificial Earthquake generated by SeismoArtif with maximum PGA 0.392g

IV. RESULTS

The Maximum Spectral Acceleration for different earthquakes at various sites under consideration are given in **Table III**.

TABLE III
MAXIMUM SPECTRAL ACCEERATION FOR DIFFERENT EARTHQUAKES AT DIFFERENT SITES

Earthquake / Site	Loma Gilroy	Uttarkashi	Artificial
BB	1.7547g	1.3782g	1.5734g
DC	1.7183g	1.1945g	1.5010g
SN	1.8191g	1.2828g	1.6838g

The variation of Spectral Acceleration with different Earthquakes for different sites are shown in **Figures 4 to 6**.

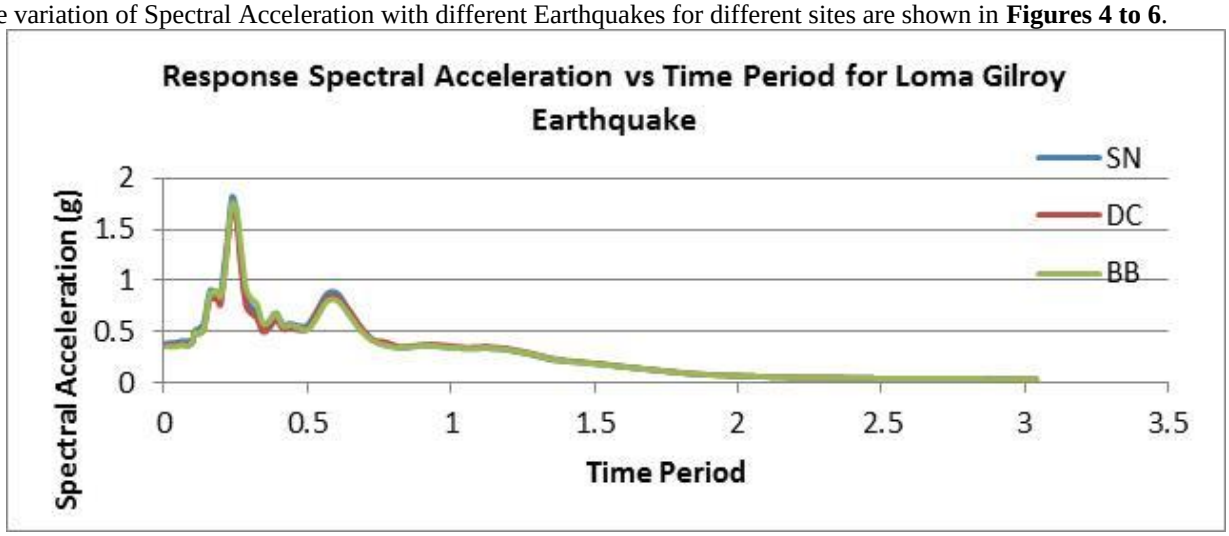


Figure 4: Response Spectral Acceleration for Loma Gilroy Earthquake

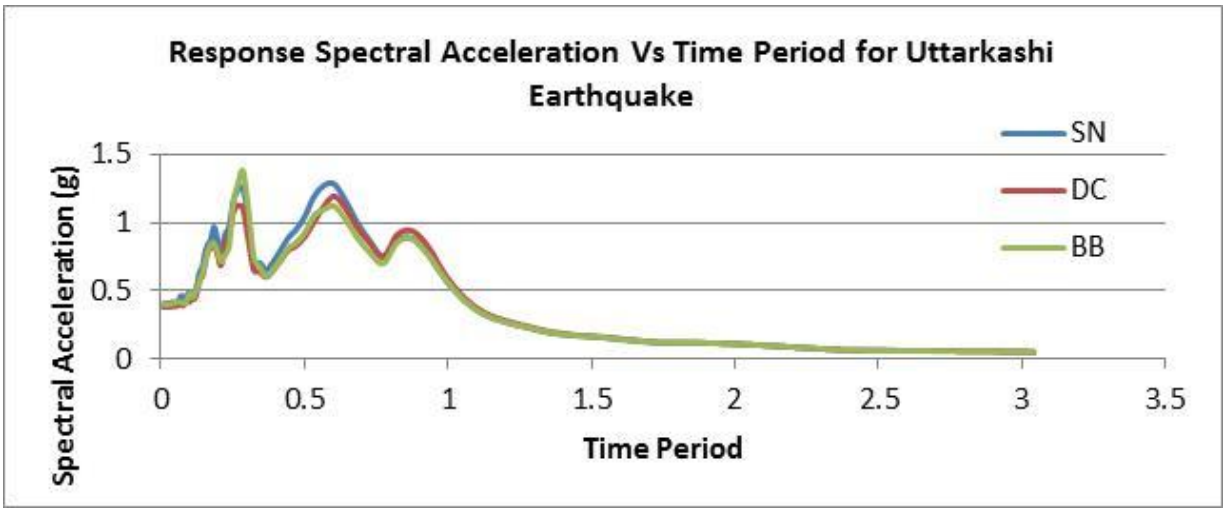


Figure 5: Response Spectral Acceleration for Uttarkashi Earthquake

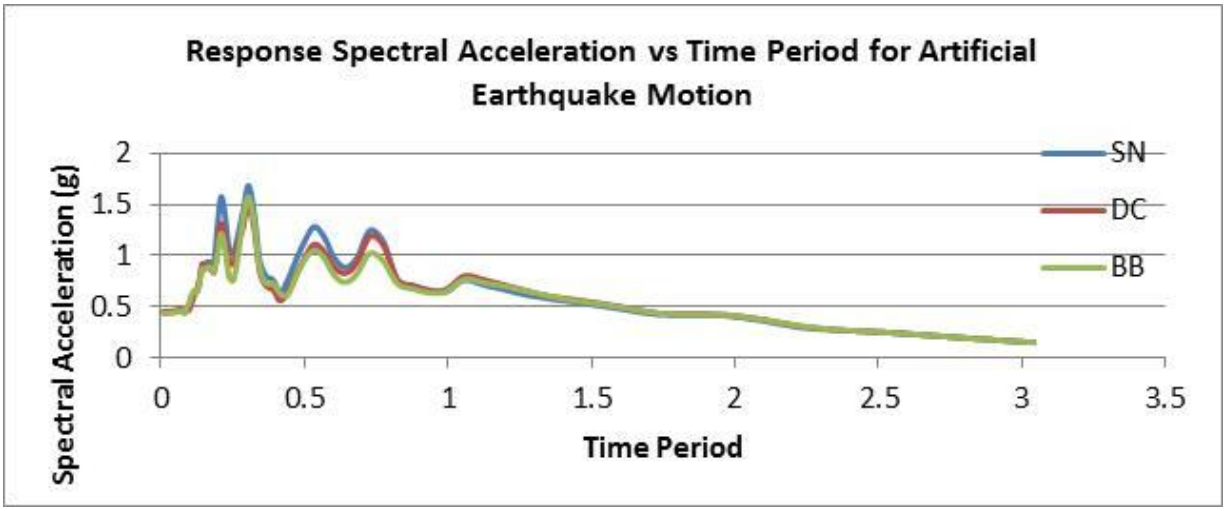


Figure 6: Response Spectral Acceleration for Artificial Earthquake Motion

The maximum value PGA on surface and corresponding Maximum Amplification Ratio at different sites for different earthquakes is given in **Table IV and Table V** respectively**.** The variation of PGA at various depths for different sites is shown in **Figures 7 to 9**.

TABLE IV
MAXIMUM PGA ON SURFACE AT DIFFERENT SITES FOR DIFFERENT EARTHQUAKES

Earthquake / Site	Loma Gilroy	Uttarkashi	Artificial
BB	0.3534g	0.3987g	0.4354g
DC	0.3659g	0.3783g	0.4524g
SN	0.3886g	0.4019g	0.4453g

TABLE V
MAXIMUM AMPLIFICATION RATIO FOR DIFFERENT EARTHQUAKES AT DIFFERENT SITES

Earthquake / Site	Loma Gilroy	Uttarkashi	Artificial
BB	2.079	1.576	1.111
DC	2.152	1.495	1.154
SN	2.286	1.589	1.136

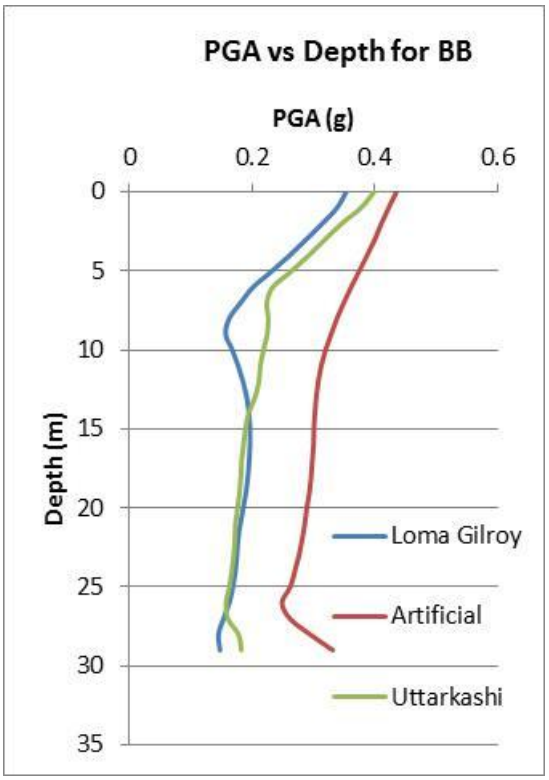


Figure 7: PGA variation with depth for BB site

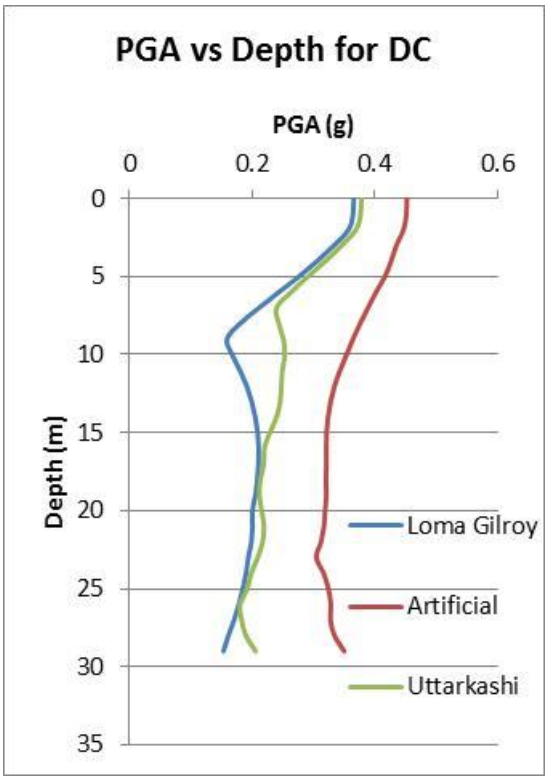


Figure 8: PGA variation with depth for DC site

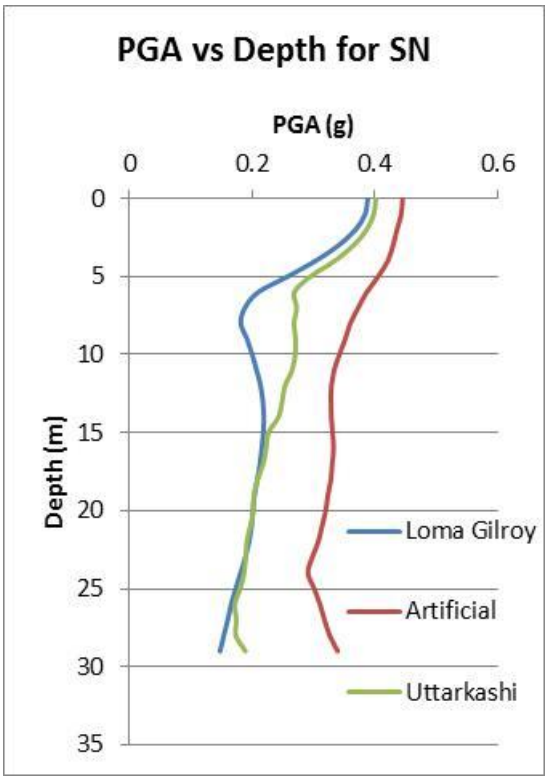


Figure 9: PGA variation with depth for SN site

V. CONCLUSION

From the research the following points are observed:

i. The maximum Amplification Ratio was observed for SN site in case of Loma Gilroy Earthquake motion of PGA 0.17g.
ii. The maximum Spectral Acceleration of 1.8191g was observed at SN site under the influence of Loma Gilroy Earthquake motion of PGA 0.17g.
iii. The maximum value of Surface PGA was observed to be 0.4524g at DC site under the influence of Artificial Earthquake motion of PGA 0.392g.
iv. With increase in the PGA value of input motion, Amplification Ratio decreases for all sites under consideration.
v. The maximum value of Surface PGA increases with increase in PGA value of input motion.
vi. The Surface PGA value obtained is much higher than value given in IS 1893 for Ludhiana i.e. 0.24g as well as than value obtained from DSHA of Ludhiana i.e. 0.392g that shows ability of local soil to amplify the input ground motion acceleration.

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