One-dimensional Ground Response Analysis of Some Typical Sites in Ludhiana City

Simarpreet Singh Batra[1*][0000-0002-8748-8234] and Dr. B.S. Walia[2]

[1] Guru Nanak Dev Engineering College, Ludhiana, Punjab, India (141006)
[2] Guru Nanak Dev Engineering College, Ludhiana, Punjab, India (141006)
[1]simarpreet_batra@yahoo.com
[2]bswalia@gndec.ac.in

Abstract. Earthquake Geotechnical Engineering is the branch of engineering that deals with the effect of soil properties on different ground motion parameters due to seismic forces generated inside earth's crust. It has been observed by various researchers that the level of ground shaking on earth's surface lying on soft soil is much more than the hard rocky surface which forms the basis to go through the soil properties beneath the earth's surface for better prediction of ground motion during earthquakes to design more safe earthquake prone structures. According to IS:1893 published by Bureau of Indian Standards, Ludhiana City of Punjab situated in Northern part of India, comes under Zone IV having value of peak ground acceleration as 0.24g at rocky surface. But the actual ground surface acceleration is affected by the type of underlying soil at different regions for which One-Dimensional Equivalent Linear Ground Response Analysis of three different sites in Ludhiana LDN1, LDN2 and LDN3 namely Punjab Mata Nagar, Pokhwal Road; Sunil Park, Barewal Awana and Kangawal, Post Jugiana respectively was carried out considering Hard Bed Rock model using DEEPSOILv6.1 software under the earthquake motions of Loma Gilroy Earthquake (PGA 0.17g), Uttarkashi Earthquake (PGA 0.24g) and Artificial Earthquake Motion generated by SeismoArtif software (PGA 0.392g). All the sites under consideration fall under category 'D' as per NEHRP. The Maximum Surface Peak Ground Acceleration was observed to vary from 0.3979g to 0.8136g, Amplification Ratio from 1.999 to 2.502 and Peak Response Spectral Acceleration from 2.0203g to 3.4516g.

Keywords: One-dimensional, Equivalent Linear, Ground Response Analysis, Ludhiana, Peak Ground Acceleration.

1 Introduction

Geotechnical Earthquake Engineering is the branch of engineering that deals with the study of effect of earthquake on geotechnical properties of soil at various regions in the world. Earthquakes are one of the most dangerous natural disasters that exist around the globe and can cause further disaster in the form of volcano eruption in mountainous regions as well as in the form of Tsunamis in coastal regions. The cause of earthquakes is usually explained by using Plate Tectonic Theory now a days which states that the plates beneath continents of the world keep on moving to maintain thermal equilibrium due to difference in the temperature of core of earth and earth's crust. The collision of these plates during movement results in earthquake during which seismic waves are generated from the source which eventually reach the earth's surface after traveling thousands of kilometers through rocky strata and numerous layers of soil. Since last two decades research by various scholars in this field has proved that the different layers of soil overlying hard bedrock strata is although of relatively less thickness but it has great impact on amplifying different ground motion parameters like peak ground acceleration, peak ground velocity etc. since soil is less stiff than rock and movement of soil particles is much more as compared to rock due to which magnitude of ground motion parameters is increased. The process of evaluating the effect of soil properties at different regions on ground motion parameters on occurrence of earthquake is known as Site Specific Ground Response Analysis (GRA). GRA is classified into different types based on dimensionality namely One, Two and Three Dimensional Analysis as well as based on methods adopted namely Linear, Equivalent Linear and Non-linear Analysis. In year 2002, Bhuj Earthquake caused huge destruction in different parts of India with Gujarat state being the most affected region. After that researchers in India have been in process of designing and constructing more safe structures that can withstand large magnitude earthquakes. The process involves predicting ground motion parameters at different locations based upon probability of earthquake of certain magnitude striking the region and then designing the structures based upon evaluated values of ground motion parameters in that region. Since then scholars around the country have carried out GRA in different regions of India like Delhi [1], Mumbai [2], Goa [3], Guwahati [4], Chandigarh [5], Haryana [6], Kolkata [7], Gujarat [8] etc. But till date GRA of huge area of India is yet to be carried out. In state of Punjab, GRA of only Jalandhar city [9] has been carried out till date so in the current research attempt has been made to carry out Equivalent-Linear GRA at three different locations in Ludhiana city of Punjab state. Ludhiana city located at 30.9^{o}N 75.85^{o}E covering the area of approximately 310 sq. km. is the largest city of Punjab standing at the banks of Sutlej River. It is the industrial hub of Punjab due to which it was given the name of "Manchester of India". Being the industrial hub, it becomes necessary to design the earthquake prone structures based upon accurate prediction of ground motion parameters obtained from Ground Response Analysis.

2 Literature Review

As per IS 1893published by Bureau of Indian Standards, the Indian subcontinent is divided into only 4 different zones varying from Zone II to Zone V based upon the peak ground acceleration that can be obtained in different regions but in practical conditions the soil overlying the rocky strata greatly influence that value and whole subcontinent of India needs to be divided at micro level and for that GRA needs to be carried out at different locations throughout India. Such attempt has been made by numerous researchers and scholars who tried to derive ground motion parameters at different locations by knowing the soil conditions in that area and by using certain earthquake motions as input to trigger the motion in that area. Most of the scholars in India who carried out research in this area had used DEEPSOIL [10] computer program to carry out GRA of different regions. Actual properties of soil can be determined accurately for shallow depths but for deeper layers of soil, empirical equations can be used to determine properties of soil like Shear Modulus, angle of internal friction and cohesion etc. from SPT N-values in that particular area. Nitish Puri et al. collected to geotechnical data from around 1053 borehole locations that covered almost whole district of Haryana to develop the relationship between SPT N-value and cohesion as well as angle of internal friction respectively with the help of machine learning techniques [11]. Similarly a number of empirical equations to determine the value of Shear Modulus from SPT N-value were used to determine ground motion parameters with the help of computer program and the obtained values were compared with actual ground motion parameters obtained in the region under consideration by P. Anbazhagan et al. [12]. The empirical equations giving the most accurate results are mentioned in Table 1.

Table 1. Correlations for determining Shear Modulus from SPT N-values

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)

The GRA is carried out for particular earthquake motion as input in the form of acceleration-time history. The earthquake motion to be used for carrying out GRA depends upon the values of ground motion parameters mostly in the form of peak ground acceleration obtained from Seismic Hazard Analysis that can be deterministic or probabilistic. The values of peak ground acceleration after carrying out Deterministic Seismic Hazard Analysis of Ludhiana city [13] varied from 0.100g to 0.392g against the maximum value of peak ground acceleration of 0.24g as given by Bureau of Indian Standards in IS 1893. In the study, Sanjeev Naval et al. used Ground Motion Prediction Equation (GMPE) given by National Disaster Management Authority (NDMA) based upon seven different potential seismogenic sources in the vicinity of Ludhiana city as given in seismo-tectonical atlas of India.

3 Methodology

Based upon the recent research, in the current study the three different locations in Ludhiana city were taken into consideration for carrying out GRA using DEEPSOIL v6.1 computer program. The borehole log data upto depth of 20m of these sites where maximum SPT N-value was around 50, was collected from Training and Consultancy Cell, Guru Nanak Dev Engineering College, Ludhiana which was further used to determine the Shear Modulus of soil at different levels beneath the surface by using correlations between SPT N-values and Shear Modulus as shown in Table 1. The sites under consideration are classified as per National Earthquake Hazard Reduction Program (NEHRP) [14] based upon average SPT N-value obtained from the Equation (1) given below.

$$N_{av} = \frac{\sum_{i=0}^{n} d_i}{\sum_{i=0}^{n} \frac{d_i}{N_i}} \quad (1)$$

Where N_{avg} = Average SPT N Value for particular borehole
d_i = Depth of soil layer ‘i’ where SPT N Value is determined
N_i = Observed SPT N Value in soil layer ‘i’

Table 2 shows the classification based upon average SPT N-values as per recommendations of NEHRP and Table 3 shows exact locations, geographical coordinates and classification of different sites under consideration.

Table 2. Classification of sites as per recommendations of NEHRP

Average SPT N-value	Classification
>50	C
15-50	D
<15	E

Table 3. Location and classification of sites under consideration in Ludhiana

Site	Location	Coordinates	Average SPT N-value	Classification
LDN1	Punjab Mata Nagar, Pokhwal Road	30.88082°N 75.82234°E	21.39	D
LDN2	Sunil Park, Barewal Awana	30.88838°N 75.78187°E	20.84	D
LDN3	Kangawal, Post Jugiana	30.84274°N 75.93443°E	19.96	D

For determining the acceleration time history of accelerogram having magnitude of peak ground acceleration same as the maximum value obtained from Seismic Hazard Analysis of Ludhiana i.e. 0.392g, SeismoArtif [15] computer program was used. Then in the current study the three input motion accelerograms are used for purpose of analysis, one as obtained from SeismoArtif software, second of Uttarkashi Earthquake having PGA value of 0.252g that is relatively closer to PGA value of 0.24g as given for Zone IV (in which Ludhiana city falls) as per IS1893 code published by BIS and third of Loma Gilroy Earthquake (inbuilt in DEEPSOIL software) whose PGA value is 0.17g that is relatively closer to minimum value obtained from Seismic Hazard Analysis of Ludhiana. The acceleration-time history of each of three input motions is shown in Figures 1 to 3 were used to carry out EL GRA using DEEPSOILv6.1.

The SPT N-value vs Depth graph for different sites under consideration is shown in Figure 4. Similarly the variation of Shear Modulus value with depth at different sites is shown in Figure 5.

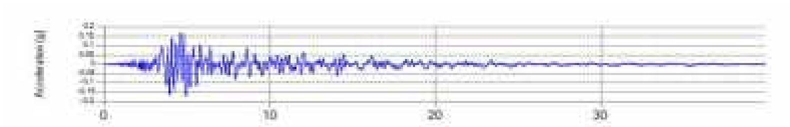

Fig. 1. Acceleration Time Motion History of Loma Gilroy Earthquake having PGA 0.17g

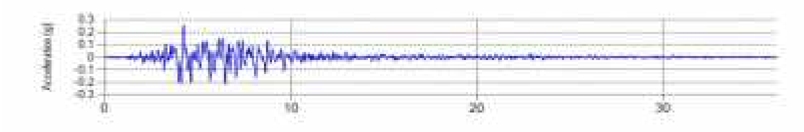

Fig. 2. Acceleration Time Motion History of Uttarkashi Earthquake having PGA 0.253g

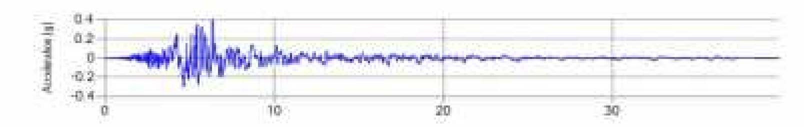

Fig. 3. Acceleration Time Motion History of Artificial Accelerogram obtained from SeismoArtif having PGA 0.392g

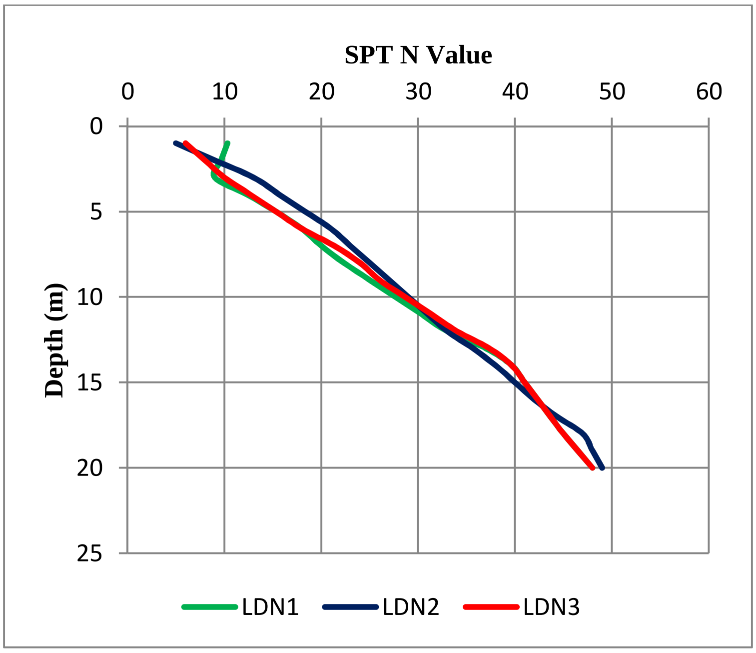

Fig. 4. SPT N-value variation with depth for different sites

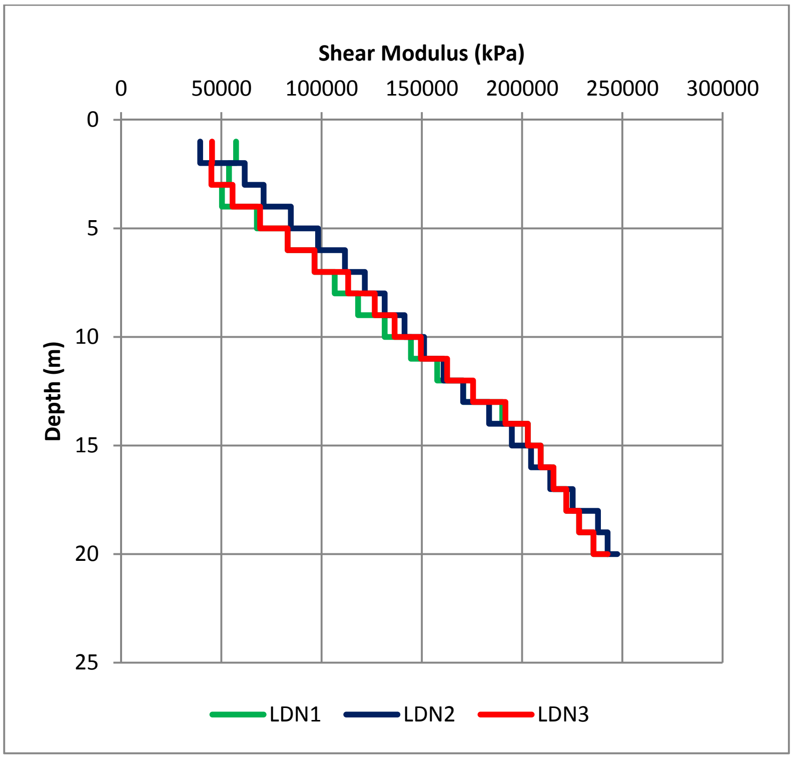

Fig. 5. Shear Modulus variation with depth for different sites

The data of inbuilt Loma Gilroy Earthquake was obtained from DEEPSOIL while the data of Uttarkashi Earthquake was obtained from open source platform i.e. www.pesmos.com [16] given by IIT Roorkee, Department of Earthquake Engineering. Loma Gilroy Earthquake Accelerogram was recorded on 18th October, 1989 having magnitude of 6.9 and PGA value of 0.17g while data of Uttarkashi Earthquake used in the study was recorded at Bhatwari station on 20th October, 1991.

The Equivalent Linear Ground Response Analysis of the sites LDN1, LDN2 and LDN3 was carried out considering hard bedrock strata having density of 3000 kg/m^3, Shear Wave Velocity of 3000 m/sec and Shear Modulus of 27× 10^9 N/m^2 with 2% damping.

4 Results

The Peak Ground Acceleration obtained at surface of different sites after carrying out Equivalent Linear GRA is given in Table 4 and the variation of PGA values with depth is shown in Figure 6. Similarly values of maximum surface PGA at different locations under different earthquake motions are depicted in Figure 7.

Table 4. Maximum surface PGA values for different sites under consideration

Site	**Lomagilroy earthquake (0.17g)**	**Uttarkashi earthquake (0.253g)**	**Artificial earthquake (0.392g)**
LDN1	0.4213g	0.6227g	0.7837g
LDN2	0.3979g	0.5233g	0.8136g
LDN3	0.4254g	0.6297g	0.7851g

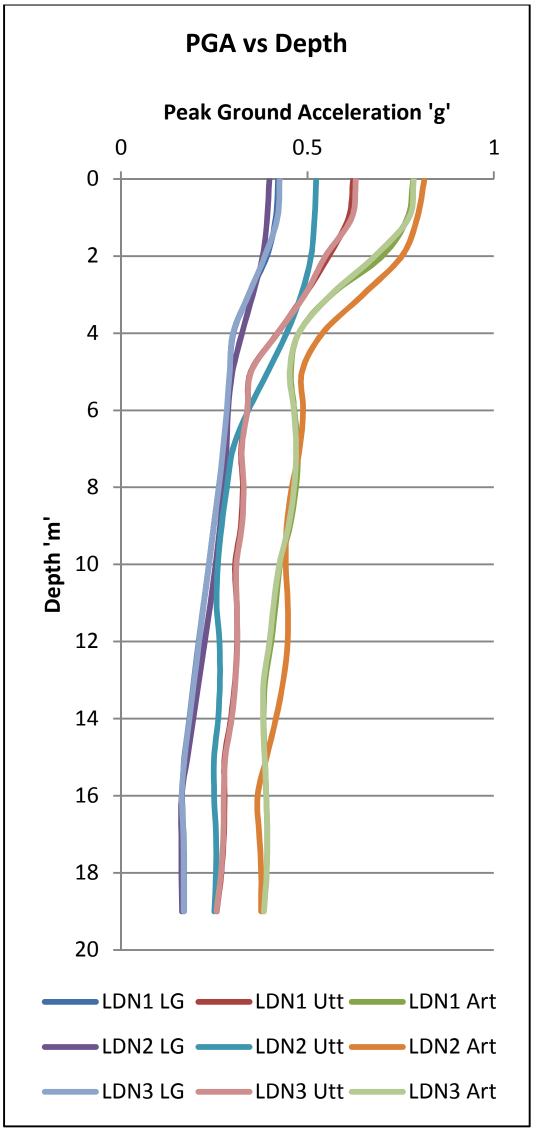

Fig. 6. PGA vs Depth graph for different sites under different earthquakes.

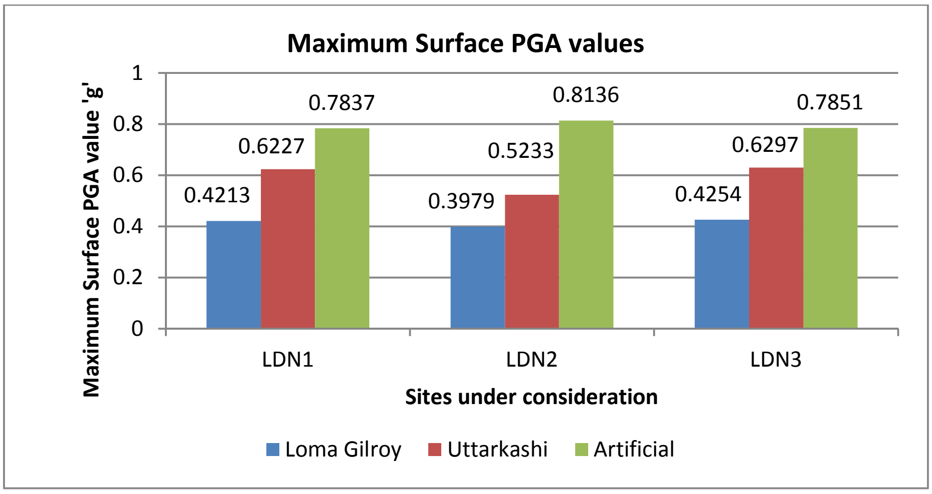

Fig. 7. Maximum surface PGA values at different locations under consideration.

After carrying out GRA the Amplification Ratio i.e. the ratio of PGA value at surface to the PGA value of input motion at bedrock level is given in Table 5 and depicted in Figure 8. The values of Peak Spectral Acceleration obtained after carrying out GRA are mentioned in Table 6 and same is depicted in Figure 9.

Table 5. Amplification Ratio values at different locations under consideration.

Site	Lomagilroy earthquake (0.17g)	Uttarkashi earthquake (0.253g)	Artificial earthquake (0.392g)
LDN1	2.478	2.461	1.999
LDN2	2.341	2.068	2.076
LDN3	2.502	2.489	2.003

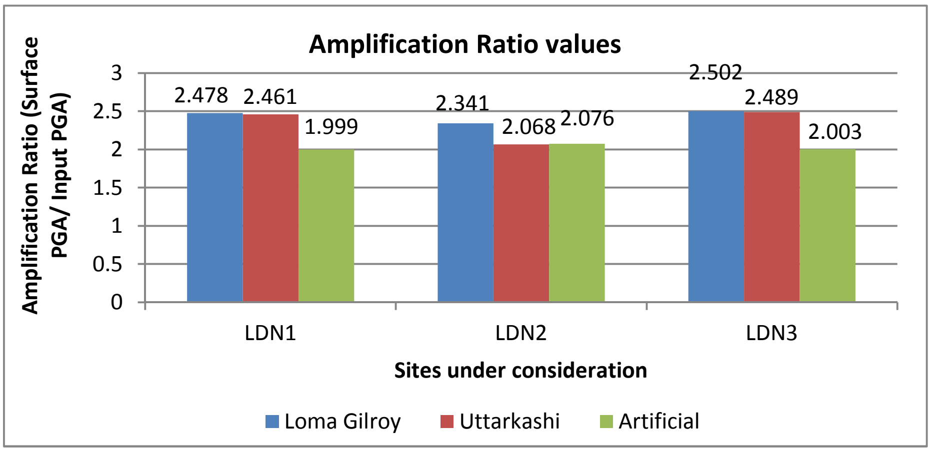

Fig. 8. Amplification Ratio at different locations under consideration.

Table 6. Peak Spectral Acceleration values at different locations under different earthquake motions.

Site	Lomagilroy earthquake (0.17g)	Uttarkashi earthquake (0.253g)	Artificial earthquake (0.392g)
LDN1	2.0203g	2.3757g	3.4202g
LDN2	2.041g	2.3523g	3.2944g
LDN3	2.0262g	2.3967g	3.4516g

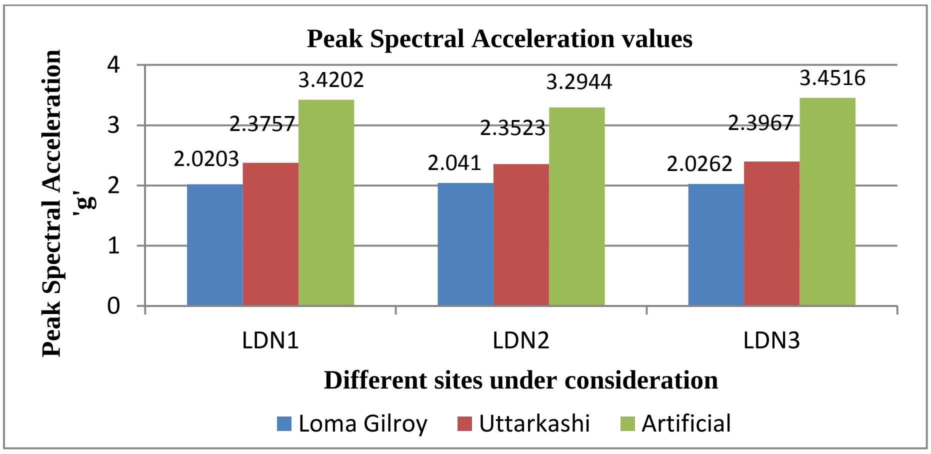

Fig. 9. Peak Spectral Acceleration at different locations under consideration.

5 Conclusion

The borehole log data of three sites under consideration namely Punjab Mata Nagar, Sunil Park and Kangawal respectively shows that the average SPT N-values at all three sites come under the category D as per NEHRP since average SPT N-values lie between 15 to 50.

The results obtained from the current research show that the values of peak ground acceleration at surface vary from 0.3979g to 0.8136g with minimum and maximum values occurring at Sunil Park site under the effect of Loma Gilroy earthquake of PGA 0.17g and Artificial accelerogram of PGA 0.392g respectively.

The values of Amplification Ratio obtained after carrying out Equivalent Linear GRA at three sites under consideration vary from 1.999 to 2.502 with minimum value occurring at Punjab Mata Nagar site under the effect of Artificial Accelerogram of PGA 0.392g and the maximum value obtained at Kangawal site under the effect of Loma Gilroy earthquake having PGA value of 0.17g.

Similarly the values of Peak Spectral Acceleration obtained at different locations after carrying out GRA vary from 2.0203g to 3.4516g with minimum value obtained at Punjab Mata Nagar site under the effect of Loma Gilroy earthquake of PGA 0.17g and the maximum value obtained at Kangawal site under the effect of Artificial Earthquake motion.

Acknowledgement

The authors wish to express their gratitude to Training and Consultancy Cell of Guru Nanak Dev Engineering College, Ludhiana, India for providing the borehole log data of the sites under consideration. The authors are thankful to Prof. Y.M.A. Hashash of University of Illinois for providing the DEEPSOILv6.1 computer program to carry out GRA of the sites under consideration.

References

1. Ramaiah, B.J., Ramana, G.V. and Bansal, B.K.: Site-Specific Seismic Response Analysis of a Municipal Solid Waste Dump Site at Delhi, India. In: 4th Geo-China International Conference Proceedings, pp. 191-198. ASCE, Shandong, China (2016).
2. Desai, Sarika S. and Choudhury, D.: Site-Specific Seismoc Ground Response Study for Nuclear Power Plants and Ports in Mumbai. Natural Hazards Review 16(4), 04015002, 1–13 (2015).
3. Bhingarde, Nika S. and Naik, Nisha P.: Site-Specific Seismic Ground Response for Mormugao Port, Goa, India. In: Geo-Chicago International Conference Proceedings, pp.227-236. ASCE, Chicago, Illinois, USA (2016).
4. Kumar, Shiv Shankar and Krishna, A. Murali: Site-Specific Seismic Ground Response to different Earthquake motions. In: Indian Geotechnical Conference Proceedings. Indian Institute of Technology, Delhi, India (2012).
5. Joseph, T.M., Siddhardha, Puri, N. and Jain, A..: Assessment of Site Response and Liquefaction Potential for some sites in Chandigarh city. In: 6th Young Indian Geotechnical Engineers Conference Proceedings, pp. 416-421. National Institute of Technology, Trichy, India (2017).
6. Puri, N., Jain, A., Mohanty, P. and Bhattacharya, S.: Earthquake Response Analysis of Sites in State of Haryana using Deepsoil software. In: 6th International Conference on Smart Computing and Communications Proceedings, pp. 357-366. Elsevier, Kurukshetra, India (2018).
7. Akhila, M., Ghosh, C. and Satyam, D. Neelima: Detailed Ground Response Analysis at Park Hotel in Kolkata city, India. In: 15th World Conference on Earthquake Engineering Proceedings, pp. 1-8. International Institute of Information Technology, Lisbon (2012).
8. Thaker, T.P., Rao, K.S. and Gupta, K.K.: One Dimensional Ground Response Analysis of Coastal Soil near Naliya, Kutch, Gujarat. In: Indian Geotechnical Conference Proceedings, pp. 531-535. Indian Geotechnical Society, Guntur, India (2009).
9. Bhardwaj, N., Bhutani, M. and Naval, S.: Ground Response Analysis of Proposed Smart City Jalandhar. International Journal for Science Management and Technology 114(1), 7-10 (2017).
10. Hashash, Y.M.A., Musgrove, M.I., Harmon, J.A., Groholski, D.R., Phillips, C.A., and Park, D.: DEEPSOIL 6.1, User Manual. University of Illinois, Urbana, Champaign (2016).
11. Puri, N., Prasad, H. and Jain, A.: Prediction of Geotechnical Parameters using Machine Learning Techniques. In: 6th International Conference on Smart Computing and Communications Proceedings, pp. 509-517. Elsevier, Kurukshetra, India (2018).
12. Anbazhagan, P., Manohar, D.R., Sayed, S.R. Moustafa and Nassir, S.N. Al-Arifi: Selection of Shear Modulus correlation for SPT N-value based on site response studies. Journal of Engineering Research 4(3), 18-42 (2016).

13. Naval, S. and Chandan, K.: Deterministic Seismic Hazard Analysis for proposed Smart City, Ludhiana (India). Electronic Journal of Geotechnical Engineering 22(11), 4255-4270 (2017).
14. Building Seismic Safety Council: NEHRP Recommended Provisions for Seismic regulations for new buildings and other structures (National Earthquake Hazard Reduction Program). National Institute of Building Sciences, Washington, D.C. (2004).
15. Seismosoft [2016] "SeismoArtif 2016– A computer program for generating artificial earthquake accelerograms matched to a specific target response spectrum," available from http://www.seismosoft.com.
16. PESMOS/ DEQ IIT Roorkee, http://www.pesmos.com.