Typical Sites in the Proposed Smart City Ludhiana

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Abstract Ground response analysis for a specific site plays an important role in designing earthquake-resistant structures as several conditions at the surface may occur due to the amplification of rock/hard layers at the bed level. In this study, 1D EQL ground response investigation has been conducted for sites of Ludhiana city using DEEPSOIL software. The analysis has been carried out by considering Sikkim 2011 and Uttarkashi 1999 earthquake. Geotechnical data have been collected from various organizations and Shear wave velocity estimated using already available correlation between SPT-N value and Vs. The sites were characterized on the basis of average SPT 'N' values as per the recommendations of National Earthquake Hazards Reduction Program (NEHRP). The peak ground acceleration for different sites has been calculated and found to vary between 0.173 and 0.254 g. It has been observed that sites of Ludhiana can amplify due to which site-specific seismic ground motion analysis should be adopted for RCC structures having high important value.

Keywords Equivalent linear ground response analysis · Input motion · SPT-N value · Soil characterization · Shear wave velocity · Peak ground acceleration

1 Introduction

Earthquake is a natural event which may cause tremendous loss of life and property. Earthquake can be explained as it is the process of rupture at the source, which causes movement of seismic waves through underlying rock. Seismic waves mostly travel deeply in rock through several kilometers surrounding as compared to rock individual having thrust up to shallow depth of few meters in soil layers but still it plays a significant role in identifying the earthquake motion characteristics. Because of the moments of earthquake motion, the equivalent motion is considerably improved at

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the ground surface. This happens due to the presence of local soil layers above the bedrock beneath the site of interest.

Ground response analysis is considered as one of the most important and commonly encountered problems in Civil Engineering. Ground response analysis is determined to study the effects of the soils on the rock motion available at bed surface. It is used to predict natural periods, evaluate ground motion amplification, provides, evaluate liquefaction potential, and to access the forces induced due to an earthquake which causes instability of structures supported on earth. The determination of the soil amplifications in ground response due to the local region is very complex problem to the structural designers. It is so important that all structure such as superstructure and sub structure should be designed for earthquake including rupture mechanics including nearest fault to the site of interest.

In northern India, Naval and Chandan (2017) and Siddhartha et al. (2017) carried out a lot of research, which has been undertaken for estimating surface PGA values. Deterministic Seismic Hazard Analysis of Jalandhar revealed that the maximum value of Peak Ground Acceleration is 0.454 g and it is much higher value as compared to the values published in IS 1893 (Part 1): 2001 by Bureau of Indian Standards. According to the National Centre for Seismology (NCS), Ludhiana featured among other 29 cities highly vulnerable to earthquakes. After carrying out Deterministic Seismic Hazard Analysis of Ludhiana city by dividing the whole city into $0.025° \times 0.025°$ grids and using ground motion equation developed by the National Disaster Management Authority (NDMA), the Peak Ground Acceleration obtained ranged from 0.10 to 0.392 g. So adequate measures must be adopted for the safety of structures falling in the high seismic hazard zone.

In this study, 1-D earthquake ground response investigation has been conducted on selected 05 sites of Ludhiana City using DEEPSOIL software using Sikkim 2011 and Uttarkashi 1999 earthquake. Geotechnical data have been collected from various organizations and Shear wave velocity was calculated using already available correlation between SPT-N value and Vs. The sites were characterized on the basis of average SPT 'N' values as per the recommendations of National Earthquake Hazards Reduction Program (NEHRP). The peak ground acceleration for different sites of Ludhiana city has been calculated and found to vary between 0.173 and 0.254 g. Desai and Choudhury (2015) and Phanikanth et al. (2011) performed the site specific ground response analysis for the sites of Mumbai, whereas Gupta et al. (2017) also conducted the equivalent linear ground response analysis for the sites of Haryana region.

2 Study Region

Ludhiana being an industrial center of northern India, is the largest city in the state, with an area of 310 km^2 and an estimated population of about 3 million (Census 2011). It lies under seismic zone IV as per the seismic zoning map of India. The earthquake database in India is yet to be completed and zoning offers a preliminary

guide to earthquake hazard for a particular region. Ludhiana district being central core of Punjab, is confined between latitude 30°33′N and 31°01′N and longitude 75°25′E and 76°27′E. The boundary of the Ludhiana district has been formed by Satluj in the North with Jalandhar and Hoshiarpur districts. In eastern and southern region, Ropar and Fatehgarhsahib districts marks limits of the Ludhiana district. The western border is adjoining Moga and Ferozpur districts. Ludhiana region is occupied with Indo-Gangetic alluvium with key drains are Satluj and its tributaries and Budha nala.

The dissimilarities in the characteristics of soil profile are much more pronounced due to the regional climatic differences. The soil of this sector has established under semi-arid situation. The soil is sandy loam to clayey with normal reaction.

3 Site Characterization

In this study, 1D EQL ground response analysis of five sites of Ludhiana city is carried out. The field borehole data of the sites were collected. The sites selected in Ludhiana region for GRA has been shown in Fig. 1. SPT-N values are found at 1.5 m intervals. The geologic strata contain shallow silt and clay layer (up to 3 m) at top with layer of sand at the bottom up to 20 m depth.

The details of SPT test of the five sites of Ludhiana region have been presented in Table 1a–e. The laboratory tests results on disturbed and undisturbed samples provide the information regarding thickness of subsoil strata, standard penetration test values, and index properties of the soil deposits. The SPT site effects that represent seismic ground response characteristics are usually incorporated as amplification factors in seismic codal provisions (e.g. NEHRP 2001, UBC 97, IBC 2000 and EC8
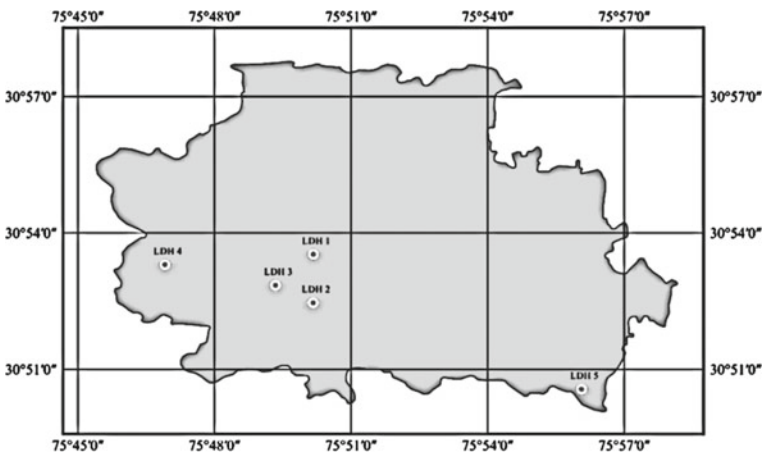

Fig. 1 Location of bore hole in Ludhiana district

Table 1 Soil profile with shear wave velocity at the investigated sites (LDH-01 to LDH-05)

Layer no.	Depth (m)	Soil type	Thickness (m)	SPT-N value	Vs (m/s)
(a) South model gram (LDH-01)					
1	1.50	SP	1.50	6	178.48
2	3.00		1.50	9	212.47
3	4.50		1.50	12	240.45
4	6.00		1.50	16	272.11
5	7.50		1.50	19	292.98
6	9.00		1.50	22	312.05
7	10.50		1.50	27	340.77
8	12.00		1.50	30	356.57
9	13.50		1.50	38	394.72
10	15.00		1.50	39	399.15
11	16.50		1.50	42	412.08
12	18.00		1.50	47	432.50
13	20.00		2.00	51	447.96
(b) Urban phase I (LDH-02)					
1	1.50	SP	1.50	5	165.02
2	3.00		1.50	9	212.47
3	4.50		1.50	12	240.45
4	6.00		1.50	15	264.67
5	7.50		1.50	19	292.98
6	9.00		1.50	23	318.05
7	10.50		1.50	27	340.77
8	12.00		1.50	31	361.63
9	13.50		1.50	35	381.00
10	15.00		1.50	39	399.15
11	16.50		1.50	43	416.27
12	18.00		1.50	45	424.48
13	20.00		2.00	48	436.43
(c) South model gram (LDH-03)					
1	1.50	SP	1.50	10	222.32
2	3.00		1.50	9	212.47
3	4.50		1.50	14	256.93
4	6.00		1.50	18	286.25
5	7.50		1.50	21	305.87
6	9.00		1.50	25	329.68

Table 1 (continued)

| Layer no.	Depth (m)	Soil type	Thickness (m)	SPT-N value	Vs (m/s)
7	10.50		1.50	29	351.41
8	12.00		1.50	33	371.48
9	13.50		1.50	39	399.15
10	15.00		1.50	41	407.83
11	16.50		1.50	43	416.27
12	18.00		1.50	45	424.48
13	20.00		2.00	48	436.43
(d) Punjab Mata Nagar (LDH-04)					
1	1.50	SP	1.50	7	190.71
2	3.00		1.50	13	248.87
3	4.50		1.50	17	279.30
4	6.00		1.50	21	305.87
5	7.50		1.50	24	323.94
6	9.00		1.50	27	340.77
7	10.50		1.50	30	356.57
8	12.00		1.50	33	371.48
9	13.50		1.50	37	390.22
10	15.00		1.50	40	403.52
11	16.50		1.50	43	416.27
12	18.00		1.50	47	432.50
13	20.00		2.00	49	440.32
(e) Kangawal (LDH-05)					
1	1.50	SP	1.50	7	190.71
2	3.00		1.50	13	248.87
3	4.50		1.50	17	279.30
4	6.00		1.50	21	305.87
5	7.50		1.50	24	323.94
6	9.00		1.50	27	340.77
7	10.50		1.50	30	356.57
8	12.00		1.50	33	371.48
9	13.50		1.50	37	390.22
10	15.00		1.50	40	403.52
11	16.50		1.50	43	416.27
12	18.00		1.50	47	432.50
13	20.00		2.00	49	440.32
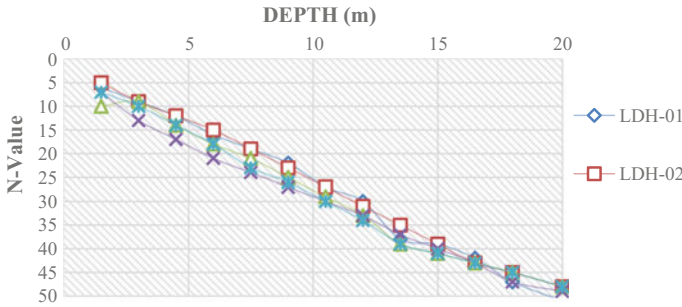
Fig. 2 Variation of N-value with depth for Ludhiana sites (LDH-01 to LDH-05)
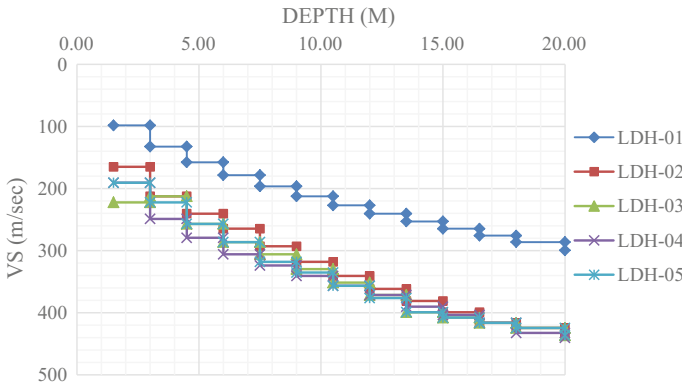

Fig. 3 Variation of Vs with depth for Ludhiana sites (LDH-01 to LDH-05)

2003). So, that site effects can be accounted for while designing. These factors are based on average shear wave velocity of top 30 m of the soil profile (Vs30). It is a general recommendation to use the actual shear wave velocity of the bedrock in site classification. However, due to non-accessibility of Vs profiles, sites have been classified using N30 values as per the recommendations of NEHRP. The present NEHRP provisions categorize soils into the classes A, B, C, D, E and F based on average N-value of the profile (BBSC 2000).

For the calculation of average N-value (N_{30}) for the soils of Ludhiana region, the following equation can be used:

$$N_{30} = \frac{\sum_{i=1}^{n} di}{\sum_{i=1}^{n} \frac{di}{Ni}} \tag{1}$$

where N_{30} = average SPT-N value of the soil for 30 m depth, Ni = SPT-N value of soil layer and di = depth of soil layer. It has been witnessed that all five sites of Ludhiana city falls in the D category with the average N-value for the soil varies from 17.85 to 22.77 with lowest and extreme values observed at LDH-02 and LDH-

04 sites. The thickness of the deposits is so adjusted that the extreme frequency of particular layer can transmit is always beyond 25 Hz. The engineering bedrock is usually expected to be the topmost deposit with a shear wave velocity of soil (V_s) $\geq$ 760 m/s as per the provisions of NEHRP (Puri and Jain 2016). Figure 2 shows the variation of N-value with depth for the sites of Ludhiana (LDH-01 to LDH-05).

Therefore, for the present study, for N-value greater than 50 has been considered as a refusal for bedrock for 15 cm penetration or N-value greater 100 for 30 cm penetration. Hence, for this analysis, the boreholes bored up to refusal have been considered. Solid rock has been modeled as an elastic half-space while considering the density of soil 2.5 g/cc with damping of 2% and shear wave velocity (Vs) of 760 m/s.

4 Dynamic Soil Properties

Shear wave velocity (Vs) is being the most important input parameters to represent the stiffness of the soil layers. The Earthquake motion factors at the top of ground is achieved using one-dimensional ground response investigation allowing only the upward movement, the stiffness of various layers of soil is represented by shear wave velocity (dynamic properties). As shear wave velocity profile is not available for the study region, it has been calculated using SPT-N values through available correlations. In the present study, the relation, $V_s = 82.6N^{0.43}$, suitable for all types of soil is used. This equation was developed by considering the data of more than 200 borelogs and shear wave velocity profiles at more than 80 boreholes available at several locations for Delhi (Hanumantharao and Ramana 2008). For the Ludhiana sites (LDH-01 to LDH-05), shear wave velocity varies from 165.02 to 222.32 m/s at the top layer of 1.5 m thickness and from 436.43 to 447.96 m/s at 20 m depth. The variation of Vs with depth for the sites of Ludhiana is shown in Fig. 3.

The maximum and minimum value of Shear Wave velocity at the top layer is achieved at LDH-03 and LDH-02 sites, respectively. Sites LDH-02, LDH-03 and LDH-05 show minimum Shear Wave velocity at 20 m depth whereas, LDH-01 site exhibits maximum Shear Wave velocity at 20 m depth.

5 Input Motions

For the present analysis, two earthquake motions Sikkim earthquake motion (2011) and Uttarkashi earthquake motion (1991) having PGA values 0.152 and 0.253 g have been applied at the bedrock level to study the soil effects.

The time history of 1991 Uttarkashi earthquake and for 2011 Sikkim earthquake considered in this study is shown in Fig. 4 and the earthquake characteristics of these motions are given in Table 2.
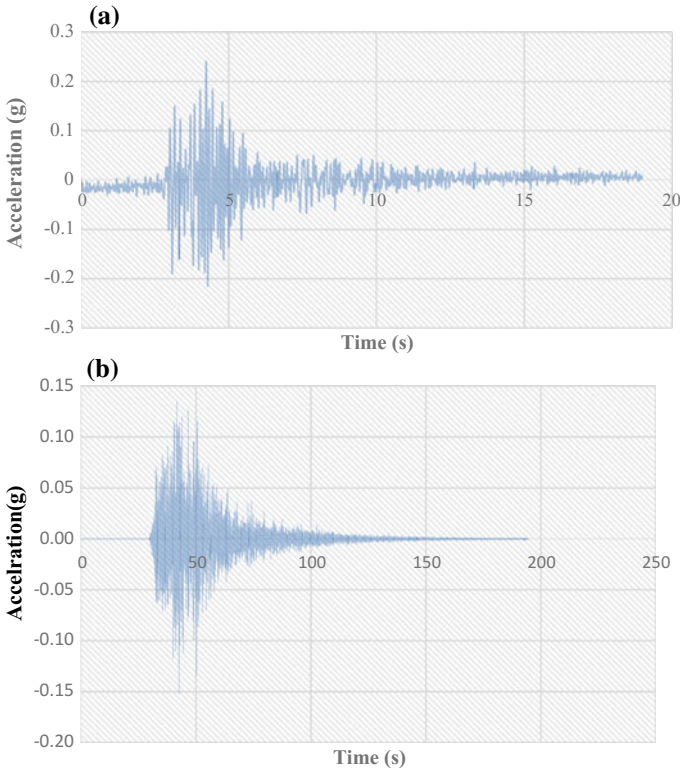
Fig. 4 Acceleration (g) versus time graph of Sikkim (2011) and Uttarkashi (1991) motion. **a** Acceleration versus time graph of Sikkim. **b** Acceleration versus time graph of Uttarkashi earthquake (1991)

Table 2 Strong motion characteristics considered in the present study

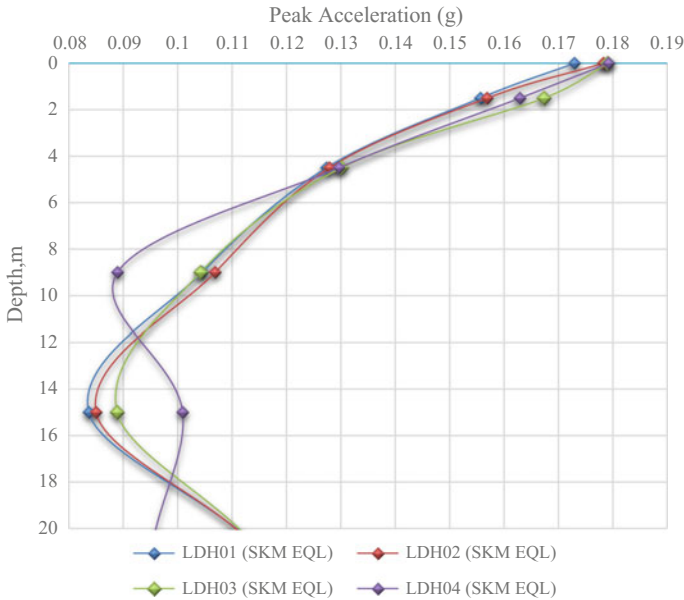| S. no	Seismic motion	Date of occurrence	Location of epicenter	Recording station	Magnitude	Distance from source (km)	PGA (g)
1	Sikkim earthquake	18 September 2011	27.723°N 88.064E	Gangotak	6.8	68	0.152
2	Uttarkashi earthquake	19 October 1991	30.837N 78.984E	Uttarkashi	7.0	34	0.253

Fig. 5 PGA variations with depth due to 2011 Sikkim earthquake for all sites of Ludhiana city

6 Results and Discussion

EQL ground response investigation has been conducted to study the effect of local ground conditions for the sites of Ludhiana city using DEEPSOIL v6.1 software (Hashash et al. 2016). The ground surface acceleration with time history was computed at all five locations in response to the 1999 Uttarkashi and 2011 Sikkim earthquake applied at the bedrock. The variation of PGA with depth at all the locations is presented in Fig. 5. It has been observed that under the influence of Sikkim earthquake all the sites under consideration show surface PGA value varies from 0.173 to 0.183 g with maximum surface PGA at LDH5 and minimum surface PGA at LDH1 (Fig. 5). Similarly after carrying out euivalent linear GRA for sites LDH1 to LDH5 with strong input motion of Uttarkashi earthquake having PGA 0.24 g, the surface PGA was observed to vary from 0.241 to 0.254 g (Fig. 6).

When using Uttarkashi earthquake motion, LDH2 site was observed to have maximum surface PGA and minimum surface PGA was observed at LDH4 site under consideration. The average surface PGA for various sites under consideration comes out to be 0.179 g and 0.248 g against input motion of Sikkim earthquake having PGA 0.153 g and Uttarkashi Earthquake having PGA 0.24 g, respectively.
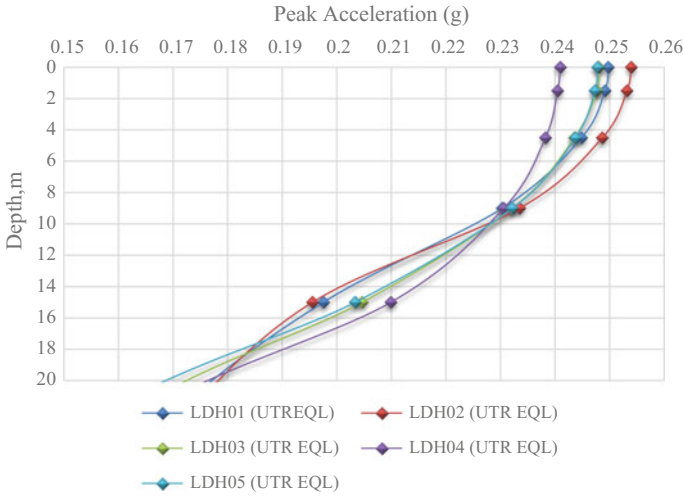
Fig. 6 PGA variation with depth due to 1991 Uttarkashi earthquake for all sites of Ludhiana city

7 Conclusion

EQL ground response investigation has been conducted to study the effect of local ground conditions for the sites of Ludhiana city using DEEPSOIL v6.1 software. The following points were observed:

1. The maximum value of Shear Wave Velocity in top layer and bottommost layer was found to be 222.32 m/s at LDH3 and 440.32 m/s at LDH4, respectively..
2. The minimum value of Shear Wave Velocity in top layer and bottommost layer was found to be 98.33 m/s at LDH1 and 299.52 m/s at LDH1, respectively.
3. Two input bedrock motions Sikkim and Uttarkashi earthquakes having PGA of 0.152 g and 0.253 g, respectively, were used for carrying out Equivalent Linear GRA.
4. The maximum value of PGA on surface was found to be 0.183 g at LDH5 and 0.254 g at LDH2 for input bedrock motions of Sikkim and Uttarkashi earthquakes, respectively.
5. The minimum value of PGA on surface was found to be 0.173 g at LDH1 and 0.241 g at LDH4 for input bedrock motions of Sikkim and Uttarkashi earthquakes, respectively.

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