



Preliminary Amplification Studies of Some Sites using Different Earthquake Motions

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Abstract

Stability of infrastructure during earthquakes demands ground response analysis to be carried out for a particular region as the ground surface may suffer from amplified Peak Ground Acceleration (PGA) as compared to bedrock PGA causing instability. Many studies have been carried out the world over using different techniques but very few studies have been carried out for the northern part of India, Punjab situated at latitude of 31.326° N and longitude of 75.576° E, which is highly seismic and lies in seismic zone IV as per IS:1893-2016. In this paper 1-D equivalent non-linear ground response analysis has been conducted for sixteen sites of Jalandhar region, Punjab (India) by using five earthquake motions. Input ground motions are selected from the worldwide-recorded database based on the seismicity of the region. Based on the average SPT-N values, all the sites have been classified as per the guidelines of National Earthquake Hazard Reduction Program (NEHRP). Shear modulus (G) was calculated using correlation between G and SPT-N Value. The ground surface PGA varies from 0.128 to 0.292 g for the sites of Jalandhar region with Amplification Factor values varying from 1.08 to 2.01. Hence the present study will be useful to the structural designers as an input towards suitable earthquake resistant design of structures for similar sites.

Keywords: Ground Response Analysis; Shear Modulus; Peak Ground Acceleration (PGA).

1. Introduction

The Indian Subcontinent has been witnessing the damaging Earthquakes since ancient times. The movement of Indian plate against the Asian plate at a rate of 47 mm/yr. [1]. Approximately is the main reason. Kramer and Steven (1996) [2] highlighted that though seismic waves generally travel several kilometres in rock but a few meters in soil, yet the soil plays a very important role in determining the characteristics of ground motion and its analysis. Ground response analysis is used to predict ground surface motions for development of design response spectra, to evaluate dynamic stress - strain for evaluation of liquefaction hazards and to determine the earthquake induced forces that can lead to instability of earth or earth retaining structures. In major part of Haryana state, carved out of the former state of East Punjab, the studies conducted by Puri and Jain (2015) [3] highlighted that codal acceleration values are found to be very conservative, and the local site conditions like the topography, nature of bed rock and the geometry of the deposits are the primary factors that influence the local modification of the wave motion between the bed rock and soil outcrop and have a profound influence on the ground response during an earthquake.

In North India, Himalayan and Kashmir region also has experienced many events of magnitude more than 8 during

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last two decades. Punjab and Haryana Region (PHR), being highly fertile, is one of the most populous areas and is filled-up in the form of loose soil deposits surrounded by high seismic region make the scenario more destructive and may result in casualties to human life or infrastructure from any large earthquake in the future [4]. Deterministic Seismic Hazard Analysis of few sites of Jalandhar city conducted by Naval and Chandan (2017) [5] revealed the variation of Peak Ground Acceleration values from 0.14g to 0.454g that was found to be much higher as compared to the values published in IS1893 (2016) [6]. Similar study on another City of Punjab, Ludhiana by the same authors using Deterministic Seismic Hazard Analysis by dividing whole city into 0.0250×0.0250 grids and using ground motion equation developed by National Disaster Management Authority (NDMA), revealed the higher Peak Ground Acceleration as compared to Indian codal stipulations. Sana et al. (2018) [7] conducted an experimental study using DEEPSOIL software on four locations of Kashmir namely Anantnag, Baramulla, Kupwara and Srinagar and it was concluded that the local site conditions play an important role in the transmission of ground motion from the bedrock to the surface in the Kashmir valley suggesting that it is imperative to consider the site effects in the seismic hazard assessment of the Kashmir valley.

Punjab is in a phase of Rapid Development and Urbanisation, lies in a fore-deep, a down warp of the Himalayan foreland, of variable depth, converted into flat plains by long-vigorous sedimentation.

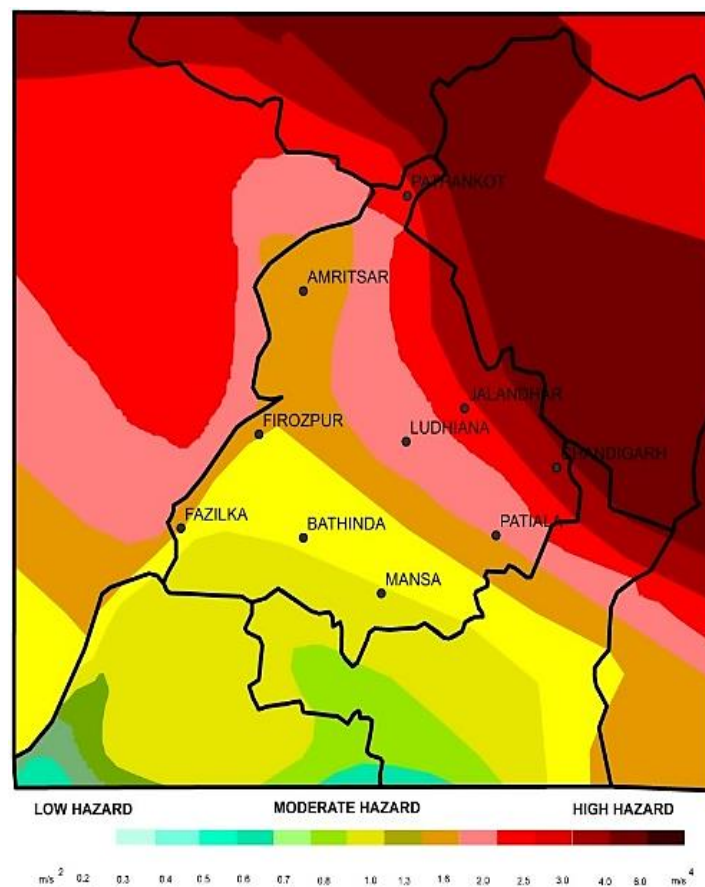


Figure 1. Earthquake Hazard Map of Punjab (www.asc-india.org)

Much of Punjab lies in the Punjab Shelf, bounded on the east by the Delhi-Haridwar Ridge and on the south by the Delhi-Lahore Ridge. Most earthquakes in this region are shallow though a few earthquake of intermediate depth have been recorded in Punjab. According to GSHAP, data the state of Punjab falls in a region of moderate to high seismic hazard and Jalandhar falls in the high seismic hazard zone as shown in Figure 1[8].

Interest in small-to-medium magnitude earthquakes and their potential consequences has increased significantly in recent years, mostly due to the occurrence of some unusually damaging small events, the development of seismic risk assessment methodologies for existing building stock, and the recognition of the potential risk of induced seismicity [9].

In this paper 1-D equivalent non-linear ground response analysis has been conducted for 16 sites of Jalandhar region by using 5 earthquake motions. Input ground motions are selected from the worldwide-recorded database based on the seismicity of the region. Based on the average SPT-N values, all the sites have been classified as per the guidelines of National Earthquake Hazard Reduction program (NEHRP) [10] Shear modulus (G) was calculated using

correlation between G and SPT -N Value. The ground surface PGA varies from 0.128 to 0.292 for the sites of Jalandhar region with Amplification Factor values varying from 1.08 to 2.011. Hence the present studies will be useful in carrying out a robust structural design for similar sites in Jalandhar region in the absence site-specific data that can withstand threat from a hazard. The flow chart related to the step by step process is shown below in Figure 2.

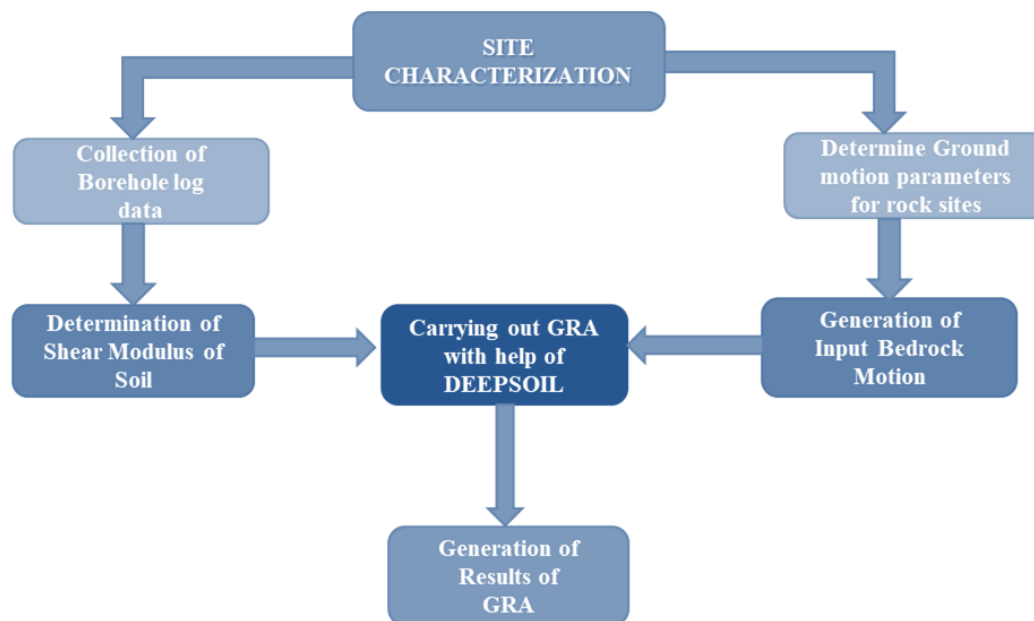


Figure 2. Step by step process ground response analyses

2. Ground Response Analysis

Ground response investigation is conducted to evaluate the response of delineated soil in terms of spectral acceleration, histories of stress and strain, variation of Peak Ground Acceleration with depth and response spectra of a soil withstand to input earthquake motion. There are three methods normally used to carry out investigation i.e., Linear, Non-Linear and Equivalent Linear [2]. Linear method of ground response depends on the presumption that the dynamic properties of soil i.e., shear modulus and damping is strain free and steady for every layer of soil column. On the other hand, equivalent linear ground response method was created to investigate the nonlinear reaction of soil using the analysis based on frequency domain with the help of linear transfer function. This study is an estimate technique wherein the non-linear conduct of the soil layer is demonstrated in terms of equivalent linear properties relating to effective shear strain utilizing iterative method [2]. The iterative method is administered by the objective of finding a compatible shear modulus and damping for a specific viable shear strain. For the most part, the successful shear strain is viewed as sixty five percent of the greatest shear strain created in the soil layer [2]. However, this strategy is computationally advantageous and gives sensible outcomes; it is unfit to speak to the adjustment in soil firmness that really happens during the seismic tremor [2]. In nonlinear technique of analysis, the unpredictable however reasonable stress strain conduct of soil is displayed for more realistic estimation of soil behaviour utilizing direct numerical integration in the time domain. Shear modulus and damping proportion of the dirt have been fused by pressure subordinate hyperbolic model. This requires reference strain, stress-strain bend parameter (β), stress-strain bend parameter (s), pressure subordinate (reference strain) parameter (b), reference pressure, pressure subordinate (damping bend) parameter (d) to be characterized for each layer of the soil.

The current investigation, ground response analysis is done with non-linear method of analysis using the DEEPSOIL software, created to conduct 1D analysis. This program has been created to perform one dimensional (1-D) ground reaction investigations [11]. Linear and Equivalent Linear analysis in DEEPSOIL is done in the frequency domain whereas linear and nonlinear investigations is carried out in the time domain to examine the response of soil under seismic loading and make a near investigation of the result from the above said technique. Soil Column is discretized in different layers in case of Non Linear model utilizing multi degree of freedom lumped parameter model in which mass is used to represent individual soil layer, nonlinear spring and dashpot for viscous damping. Non-linear properties of soil are dictated by direct numerical incorporation technique in time domain [12]. At first the parameters have been given the values that compare to non-linear modulus reduction and damping bends. A reference bend is then characterized for a soil layer dependent on its sort and related soil properties like Plastic Limit, Liquid Limit and so on. The modulus reduction and damping bends suggested by Darendeli (2001) for different types of soils such as clay and sand dependent on Atterberg limits have been allocated as reference bends in the current analysis [13]. At last for each and every layer, a bend fitting method is adopted to locate the above parameters that give a best fit to modulus

reduction and damping. The depth of the soil layers are changed in accordance with the point that the most extreme frequency that the layer can proliferate falls between 25 Hertz to 50 Hertz. In this analysis, elastic half space bedrock with damping of 2 percent is considered.

2.1. Study Region

Jalandhar is one of the most important and ancient city within the Doaba area of the northwestern Indian territory of Punjab as shown in Figure 3, situated on the intensively irrigated plain between the two streams i.e. Beas and Sutlej.



Figure 3. Map of Jalandhar Region, Punjab (India)

Jalandhar is the oldest inhabited major city in the Indian state of Punjab situated at latitude of 31.326° N and longitude of 75.576° E occupying a land of $2,632 \text{ km}^2$. It is encircled by Ludhiana region in East, Kapurthala in West, Hoshiarpur in North and Ferozepur in South. Jalandhar has likewise been chosen one of the smart city apart from Amritsar and Ludhiana in Punjab State under the Center's leader conspire, which would comprise of regular water and electricity supply, sanitation and solid waste management, proficient urban mobility and public transportation, IT network and e-administration, among others.. The geology characteristics of Jalandhar region contains loose silt and silty sand (SM) beneath the foundation level to high density sand at deeper layers of soil. As per the 2011 statistics, population of Jalandhar district is 2,193,590 with growth rate of 11.16 percent over the decade 2001-2011. Because of quick development in population, city has experienced fast urbanization and has formed into a profoundly industrialized focal point of business. Numerous elevated structures as shopping centers and Malls, Multilevel Car Parking's, clinics / hospitals and residential elevated structures are being set up at a fast pace, which is vulnerable to high hazard zone as Jalandhar lies in the Zone IV of the seismic zoning guide of India published in IS:1893 (2016) Part-I. This zone is known as the High Damage Risk Zone and covers zones subject to MSK VIII.

2.2. Site Characterization

In this study, 1-D Non-linear ground response analysis of sixteen selected sites of Jalandhar region, Punjab (India) is conducted using DEEPSOIL Software. The field borehole information of the sites were gathered from the distinctive division and private associations and screened dependent on profundity to get to the dirt properties (thickness of earth layers, standard penetration test (SPT) values, index properties) and ground water conditions. The selected 16 locations of the sites for the present study are shown in Figure 4.

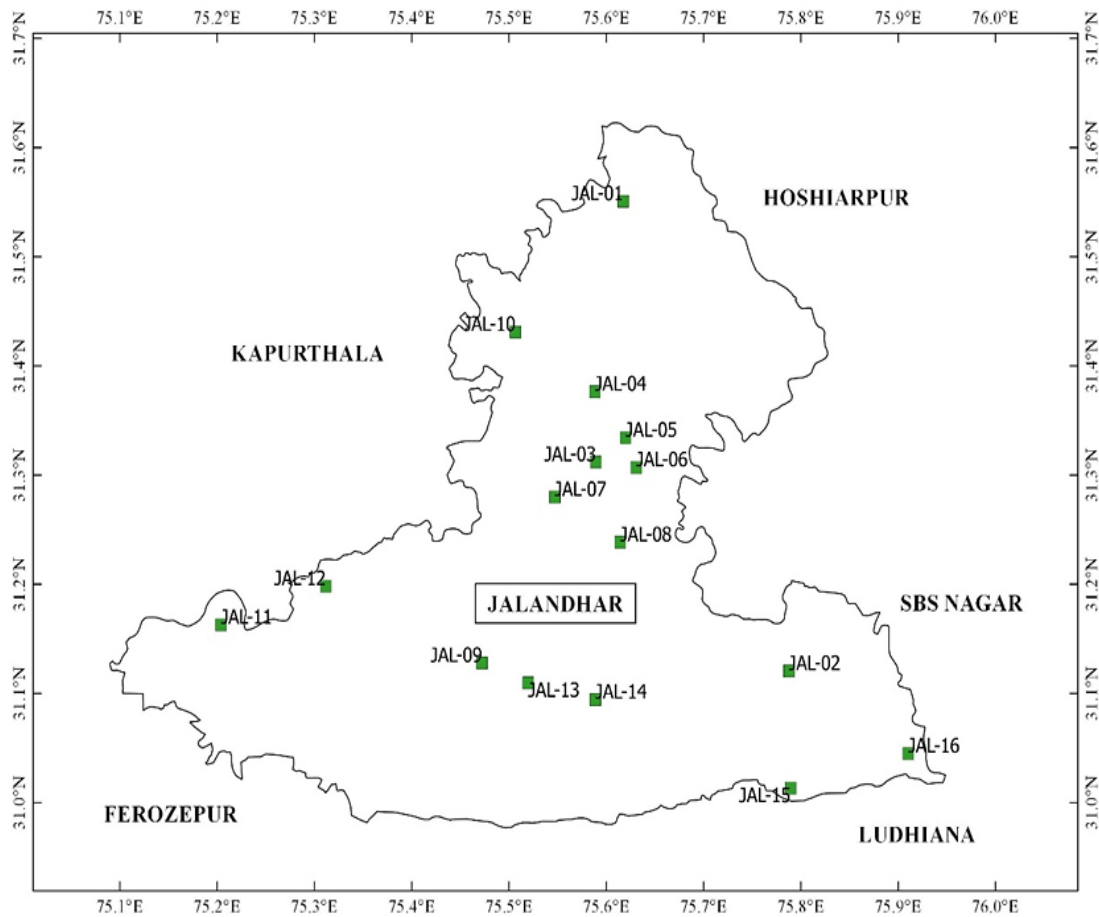


Figure 4. Map of Jalandhar region, Punjab (India) along with the location of boreholes considered for the study

During Standard Penetration Test, N values at every 1.5 meter interval are measured upto the base of borehole. The geologic layer contains generally sand, sandy-sediment, silty-sand and little pockets of clay having low compressibility at lesser profundities. Effects of sites that represent earthquake ground response qualities are typically consolidated as amplification factors in seismic codal provision (for example Uniform Building Code 1997, National Earthquake Hazard Reduction Program 2001, International Building Code 2000 and Eruocode 8 2003). So, that while designing of structures or foundations those site parameters can be considered. These variables depend on Avg shear wave velocity of thirty meter of the soil profile (V_{s30}). It is a general suggestion to utilize the actual shear wave velocity of the bed rock in site characterization. Be that as it may, due to non-accessibility of shear wave velocity profiles, sites have been grouped utilizing N_{30} values according to the proposals of National Earthquake Hazard Reduction Program [14]. Currently, provision of NEHRP orders soil into six classes i.e., A, B, C, D, E and F dependent on Avg-N Value of the soil profile. Using the Equation 1 given below, Avg-N Value (N_{30}) for the soil profile is calculated.

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

Where, N_{30} is the average N-value for 30 meter Soil Column depth, N_i is the SPT N-value of particular soil layer and d_i is the thickness of particular soil layer. It has been observed that all the sites of Jalandhar region come under class D with the average N value for the profiles ranging from 19.29 to 45.11 with minimum and maximum values observed at JAL-10 and JAL-04 sites respectively. Also as per classification given by IS1893 (2016) [6], 8 sites come under Class-C and 8 under Class-D in Table 1. The thickness of the layers is so adjusted that the maximum frequency that a layer can propagate is always above 25 Hz. The engineering bedrock is generally assumed to be the uppermost layer, having a shear wave velocity (V_s) ≥ 760 m/s of the soil column in accordance with NEHRP provisions [3].

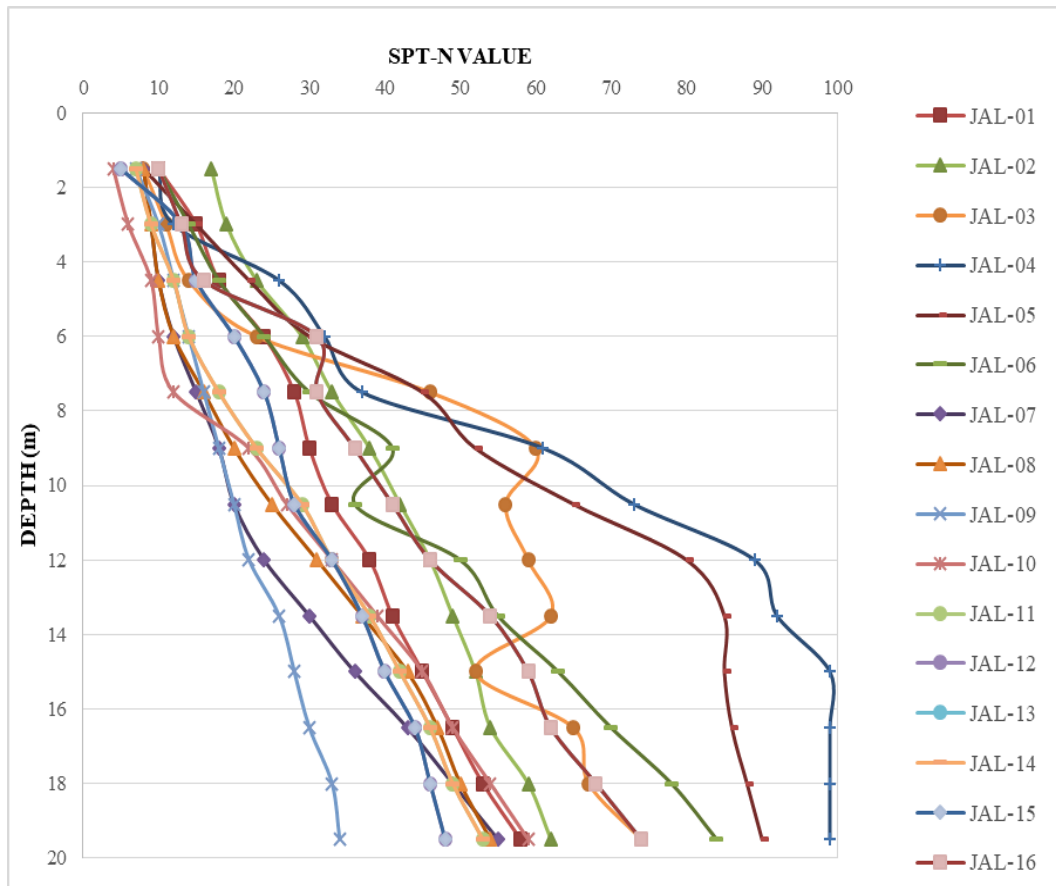


Figure 5. Collected Borehole data showing the variation of N- value with depth

Therefore, in present study, engineering bedrock has been assumed at refusal, i.e. for $N > 50$ for 15 cm penetration or $N > 100$ for 30 cm penetration of SPT split-spoon sampler. Hence, N-value has been extrapolated upto 30 m depth (for classification of site class as per NEHRP and IS1893) in case if available depth of drilled boreholes is less than 30 m. The site classes of selected sites of Jalandhar region have been presented in Table 1. All the sites are comes under site class-D as per NEHRP.

Table 1. Detail of selected sites considered for the study

Site Code	Area	Latitude	Longitude	Avg. N-Value (N_{30})	Site Class as per NEHRP	Site Class as per IS:1893
JAL-1	Bhogpur	31.5508	75.6174	32.38	Class – D	Class-C
JAL-2	Goraya	31.1204	75.7877	40.91	Class – D	Class-C
JAL-3	MS Nagar	31.3118	75.5892	34.61	Class – D	Class-C
JAL-4	Bulandpur	31.3764	75.5883	45.11	Class – D	Class-C
JAL-5	Karol Bagh	31.3341	75.6199	42.09	Class – D	Class-C
JAL-6	Jal Cantt	31.3070	75.6309	37.70	Class – D	Class-C
JAL-7	Shankar	31.2797	75.5470	22.54	Class – D	Class-D
JAL-8	Shakot	31.0895	75.3365	24.07	Class – D	Class-D
JAL-9	Jalandhar	31.3774	75.6525	21.57	Class – D	Class-D
JAL-10	Kartarpur	31.1278	75.4722	19.29	Class – D	Class-D
JAL-11	Lohian	31.4310	75.5065	24.73	Class – D	Class-D
JAL-12	Lohian	31.1627	75.2039	25.75	Class – D	Class-D
JAL-13	Nakodar	31.1981	75.3115	35.16	Class – D	Class-C
JAL-14	Nurmehal	31.1618	75.6150	24.73	Class – D	Class-D
JAL-15	Phillaur	31.0943	75.5888	25.75	Class – D	Class-D
JAL-16	Phillaur	31.0131	75.7895	34.16	Class - D	Class-C

2.3. Dynamic Properties of Soil

One of the most significant input parameter i.e., Shear Modulus (G_{max}) represent the stiffness of the soil layers. It likewise assumes a fundamental job in earthquake ground response analysis. The ground motion parameters at the ground surface are normally acquired by performing one dimensional ground response analysis considering just the upward proliferation of shear wave. As shear modulus for study area isn't available so it has been determined utilizing available relationships SPT – N value and shear modulus (G) for various soil types. Connections can be chosen dependent on the type of soil and estimation of relationship coefficient (R). In the present study, correlations given in Table 2 have been selected as per the recommendations of Anbazhagan et al. (2012) [15].

Table 2. Correlations for Calculation of Shear Modulus

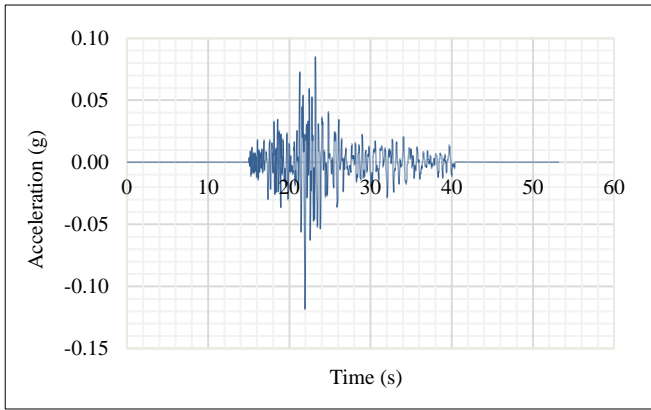
Correlations	Soil Type	Author(s) Name
$G=24.28N^{0.55}$	Silty Sand with Less Percentage of Clay	Anbazhagan and Sitharam

2.4. Input Ground Motion

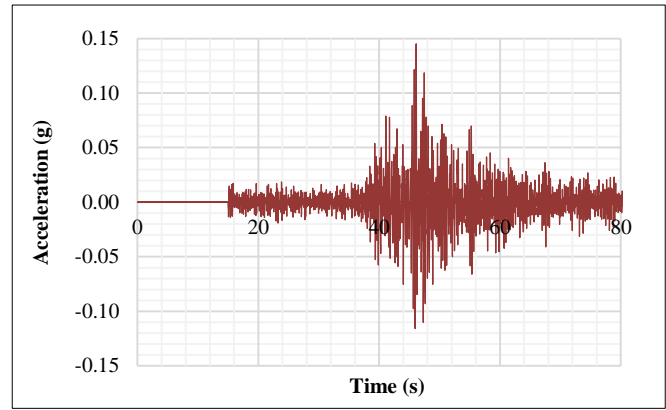
Earthquake Ground response investigation includes the selection of appropriate input earthquake ground motion based on Peak Ground Acceleration, earthquake's magnitude, distance from earthquake source to site under consideration and site class, which is compatible with the maximum dynamic loading expected at the site of interest [16]. It is commonly recognized that the choosing suitable earthquake input motion is one of the important function that affect site response investigation. Although site response studies have been carried out in India, yet majority of them are without of representative input ground motions. The selection of time histories includes records that intently coordinate the tectonic environment of particular site, magnitudes of controlling earthquake and site distances, local site conditions, characteristics of response spectra and, duration of strong ground shaking [17]. The Worldwide Standard Seismograph Network (WWSSN) in 1961, Global Digital Seismometer Network (GDSN) and Global Seismographic Network (GSN) in 1980 have significantly improved the comprehension of seismic tremor and tectonic process. Territorial varieties of seismographs are presently available in most seismically active nations [2]. For present analysis, PGA values for rock sites given in IS: 1893-2016 are used for the selection of acceleration time histories. Five ground motions are selected covering seismic hazard values of the region. Table 3 illustrates five earthquake records and their characteristics such as date of occurrence, recording station, Location, Magnitude and Maximum horizontal acceleration. Suitable recorded acceleration time histories of Sikkim earthquake (2011), India-Mayanmar earthquake (1997) and India-Burma earthquake (1988) recorded at rock sites have been selected for carrying out ground response analysis as shown in Figure 6.

Table 3. Strong Motion Characteristics considered in the present

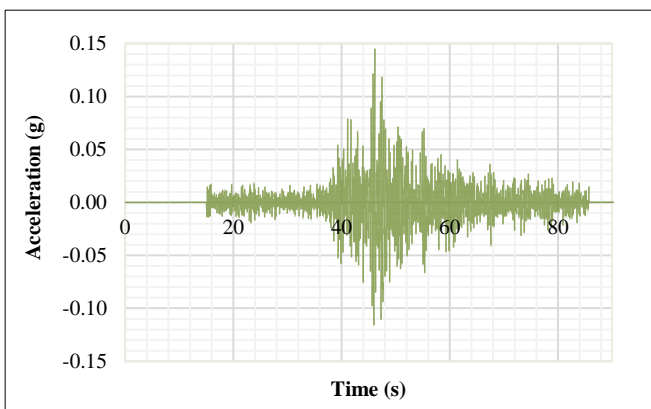
Strong Motion Parameter	Earthquake Input Ground Motion Considered				
	India Myanmar Earthquake	India Burma Earthquake	India Burma Earthquake	India Burma Earthquake	Sikkim Earthquake
Date of Occurrence	1997	1988	1988	1988	18-09-2011
Magnitude, Mw	6.0	7.3	7.3	7.3	6.8
Location of Epicentre	24.894 N 92.250 E	26.020 N 93.770 E	26.000 N 92.860 E	25.980 N 91.480 E	27.723 N 88.064 E
Recording Station	Jellapur	Bokajan	Hojai	Nongston	Gangotak
PGA (g)	0.118	0.150	0.113	0.145	0.152
Designation	IEM-01	IEM-02	IEM-03	IEM-04	IEM-05



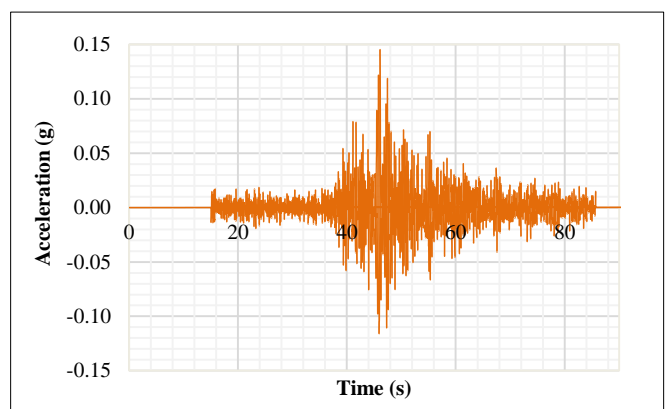
(a). India-Myanmar Earthquake (1997) Time History recorded at Jellapur



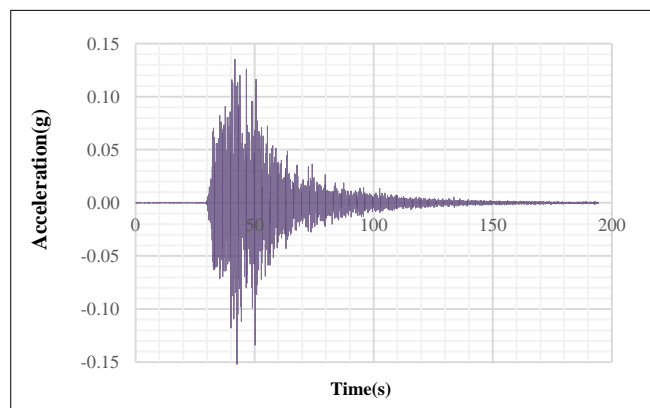
(b). India-Burma Earthquake (1988) Time History recorded at Bokajan



(c). India-Burma Earthquake (1988) Time History recorded at Hojai



(d). India-Burma Earthquake (1988) Time History recorded at Nongston



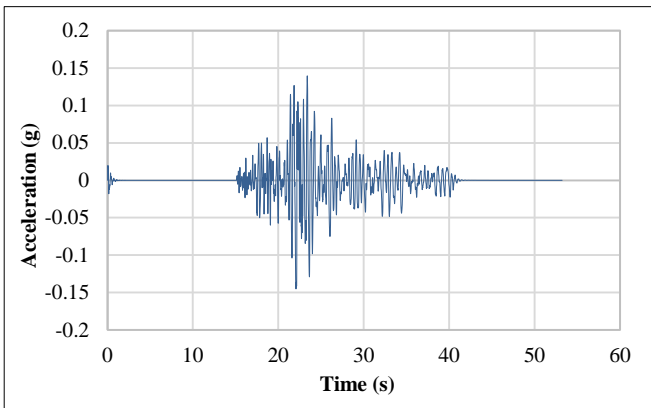
(e). Sikkim Earthquake (2011) Time History recorded at Gangotak

Figure 1. Acceleration Time History of all 5 Input Ground Motion

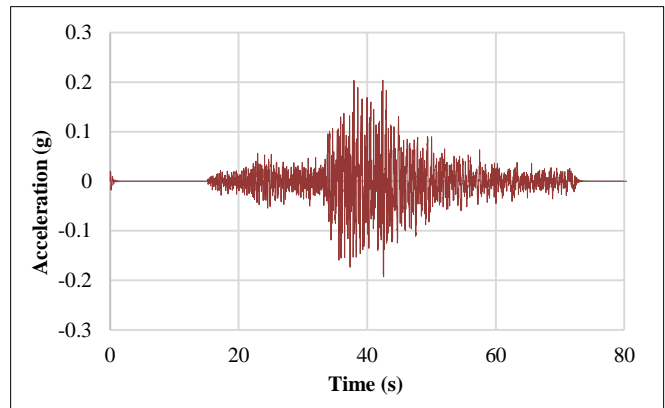
3. Results and Discussions

Non-linear ground response analyses have been carried out to study the effect of local ground conditions for the sites of Jalandhar region using DEEPSOIL v6.1 software [18]. Knowing the substrata details, one dimensional soil column is being generated in DEEPSOIL up to 30 m for all 16 boreholes of Jalandhar region. Using 30 m available data, input ground motions of Sikkim earthquake (2011), India-Myanmar earthquake (1997) and India-Burma earthquake (1988) applied at the base of all soil columns and surface motion is obtained from DEEPSOIL. One typical modified rock motion observed at surface for 30 m depth soil column for JAL-01 is shown in Figure 6 for all 5 input

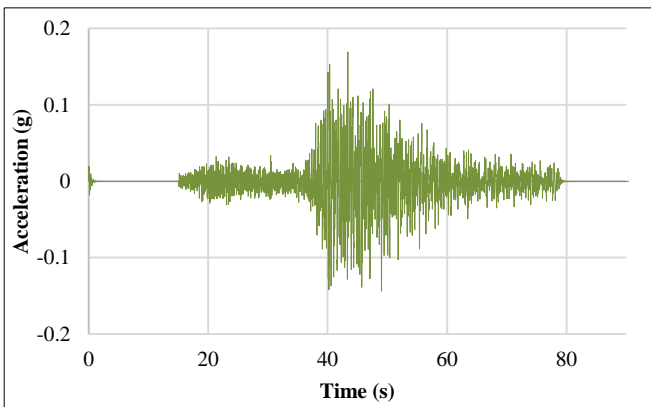
ground motions. As can be seen in Figure 6a, the input bed rock motion IEM-01 has PGA of 0.118 g (g =acceleration due to gravity), whereas the maximum output surface PGA is observed as 0.145 g, Figure 7a. This shows amplification of ground acceleration of about 1.23 times the PGA at bed rock level. Similarly the analysis for JAL-01 is carried out for IEM-02, IEM-03, IEM-04 and IEM-05 input ground motion and resulted in an amplification of 1.35, 1.50, 1.32 and 1.45 times the PGA at bed rock level.



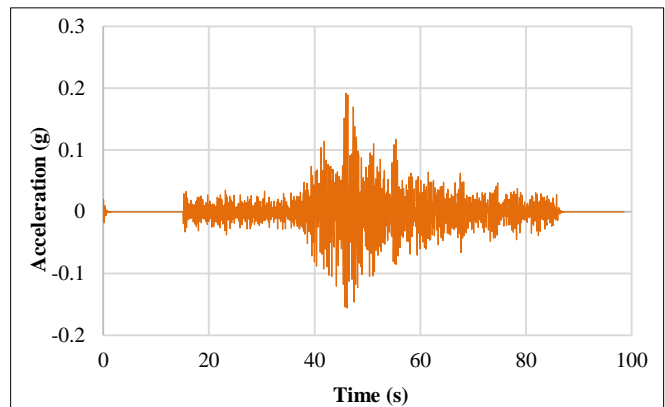
(a). Surface motion as a result of local soil amplification for JAL-02 due to IEM-01 Eq. Motion



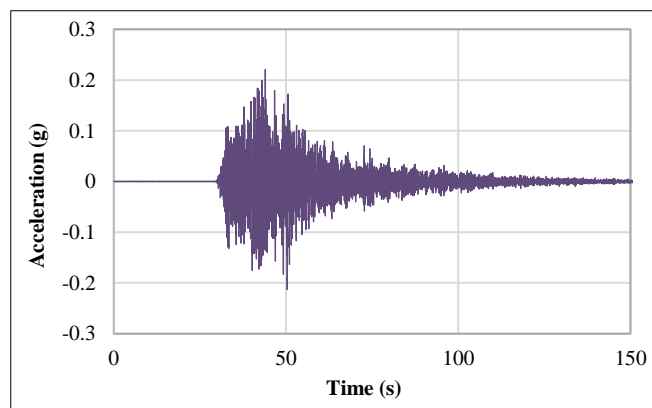
(b). Surface motion as a result of local soil amplification for JAL-02 due to IEM-02 Eq. Motion



(c). Surface motion as a result of local soil amplification for JAL-02 due to IEM-03 Eq. Motion



(d). Surface motion as a result of local soil amplification for JAL-02 due to IEM-04 Eq. Motion



(e). Surface motions as a result of local soil amplification for JAL-02 due to IEM-05 Eq. Motion

Figure 2. Modified Rock Motion Observed at surface for all 5 input ground motions

The impact of soil layers on ground amplification is likewise endeavoured in this study. The variation of PGA along the depth is presented for JAL-01 in Figure 8. For all the five input ground motion, PGA amplification is seen from base of the soil profile to top for site JAL-01 respectively. Remarkable deviations in PGAs at each soil layer can

be seen for high intensity input ground motion. From, Figure 8 it can also be observed that PGA for IEM-04 input ground motion deviate much from the bedrock level PGA. These outcomes obviously show the impact of local soil conditions in amplifying the ground response.

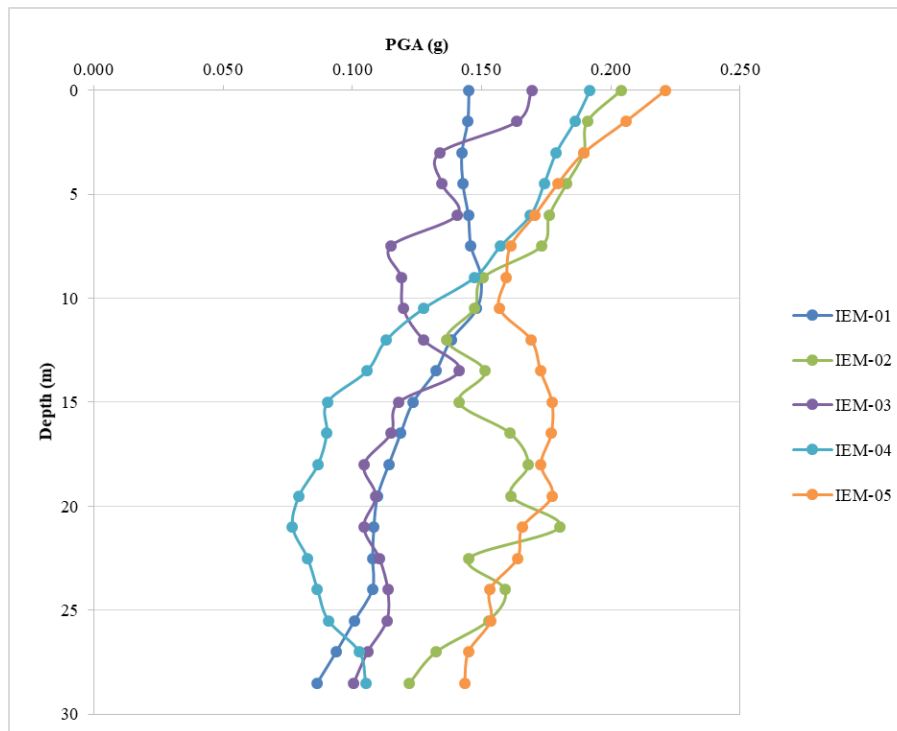


Figure 8. PGA vs. Depth profile for JAL-01 with all Input Ground Motion

Following similar approach, ground surface PGA ground surface PGA is of Jalandhar region is calculated for 16 locations corresponding to all 5 input ground motions and results has been summarized in Table 4. It has been observed that Ground Surface PGA values for the Jalandhar region varies from 0.128 g to 0.292 g observed at JAL-16 and JAL-10 with IEM-01 and IEM-04 input ground motion respectively. Further, surface PGA values for input ground motion IEM-01 varies from 0.128 g (JAL-16) to 0.204 g (JAL-10), IEM-02 varies from 0.196 g (JAL-16) to 0.280 g (JAL-10), IEM-03 varies from 0.164 g (JAL-16) to 0.224 g (JAL-10), IEM-04 varies from 0.177 g (JAL-1) to 0.292 g (JAL-10) and IEM-05 varies from 0.192 g (JAL-1) to 0.266 g (JAL-10) respectively. The variation of ground surface PGA for all the sites of Jalandhar region is presented in Figure 9.

Table 4. Ground Surface PGA of Jalandhar region with different input ground motion

Site Code	Ground Surface PGA (G) with Different Input Ground Motion				
	IEM-01	IEM-02	IEM-03	IEM-04	IEM-05
JAL-01	0.145	0.204	0.169	0.192	0.221
JAL-02	0.174	0.233	0.186	0.223	0.228
JAL-03	0.174	0.240	0.194	0.238	0.247
JAL-04	0.162	0.239	0.187	0.275	0.234
JAL-05	0.165	0.240	0.188	0.266	0.238
JAL-06	0.188	0.237	0.200	0.279	0.238
JAL-07	0.156	0.217	0.154	0.228	0.224
JAL-08	0.190	0.253	0.197	0.260	0.249
JAL-09	0.166	0.231	0.181	0.209	0.237
JAL-10	0.204	0.280	0.224	0.292	0.266
JAL-11	0.177	0.240	0.195	0.238	0.243
JAL-12	0.174	0.230	0.186	0.222	0.243
JAL-13	0.179	0.230	0.204	0.222	0.235
JAL-14	0.177	0.240	0.195	0.238	0.243
JAL-15	0.147	0.220	0.187	0.204	0.224
JAL-16	0.128	0.196	0.164	0.177	0.192

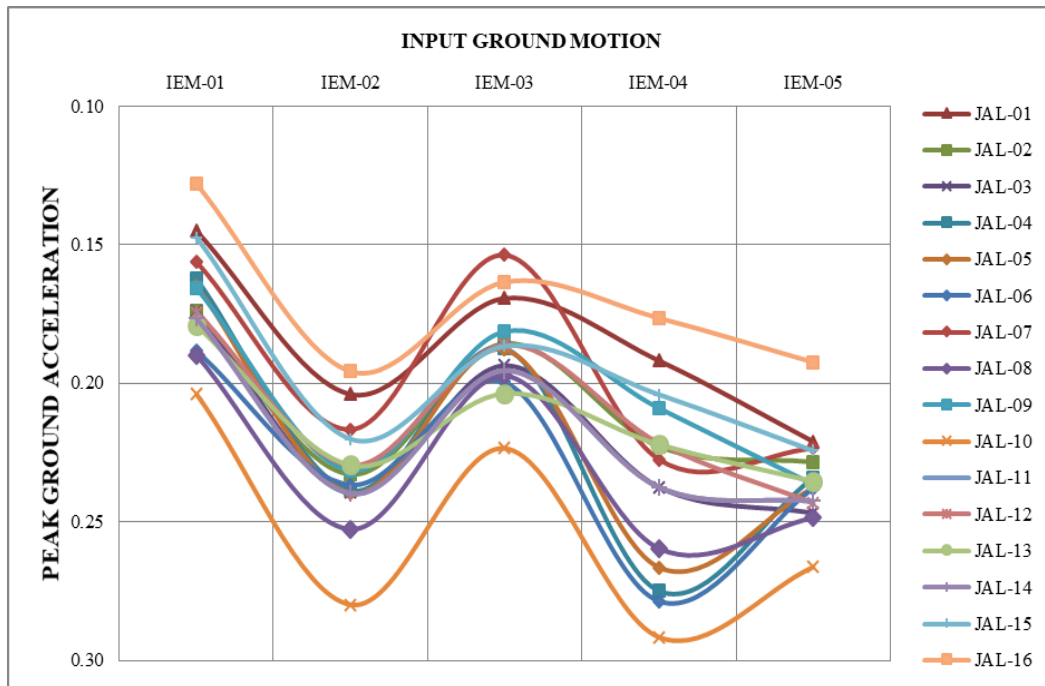


Figure 9. Variation of Ground Surface PGA of Jalandhar region w.r.t. to different Input Ground Motion

Similarly, maximum, minimum and average surface PGA of 16 sites of Jalandhar region for different strong motion is calculated. From the results, maximum and minimum PGA of 0.29 g and 0.06 g observed at site JAL-10 and JAL-04 respectively. Also the contour map showing the variation of maximum, minimum and average surface PGA of 16 sites of Jalandhar region is shown in Figures 10 to 12.

Table 5. Minimum, Maximum and Average PGA (Soil) values of Jalandhar region

Site Code	PGA (Soil) values (g)		
	Min. PGA	Max. PGA	Avg. PGA
JAL-01	0.145	0.221	0.186
JAL-02	0.174	0.233	0.209
JAL-03	0.174	0.247	0.218
JAL-04	0.162	0.275	0.219
JAL-05	0.165	0.266	0.219
JAL-06	0.188	0.279	0.228
JAL-07	0.154	0.228	0.196
JAL-08	0.190	0.260	0.230
JAL-09	0.166	0.237	0.205
JAL-10	0.204	0.292	0.253
JAL-11	0.177	0.243	0.218
JAL-12	0.174	0.243	0.211
JAL-13	0.179	0.235	0.214
JAL-14	0.177	0.243	0.218
JAL-15	0.147	0.224	0.197
JAL-16	0.128	0.196	0.171

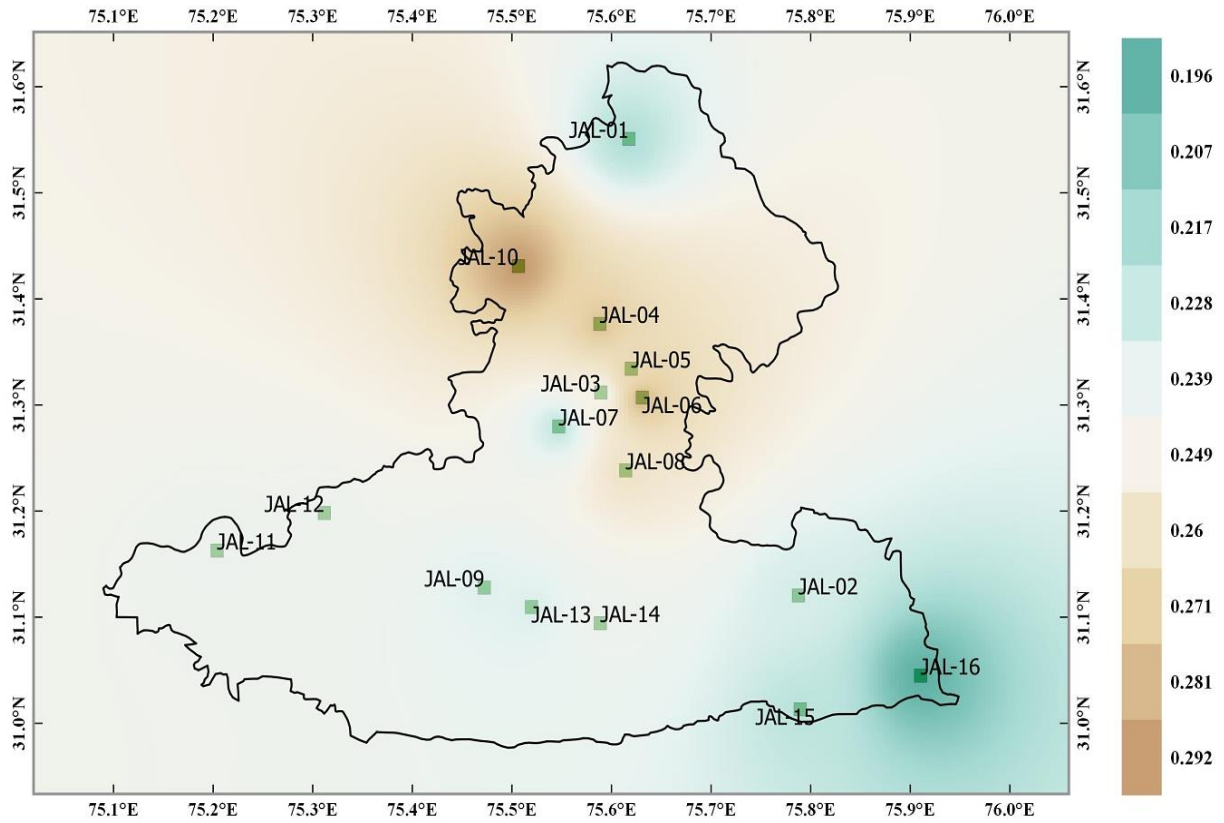


Figure 10. Contour Map showing the Maximum PGA (Soil) values of Jalandhar region, Punjab (India)

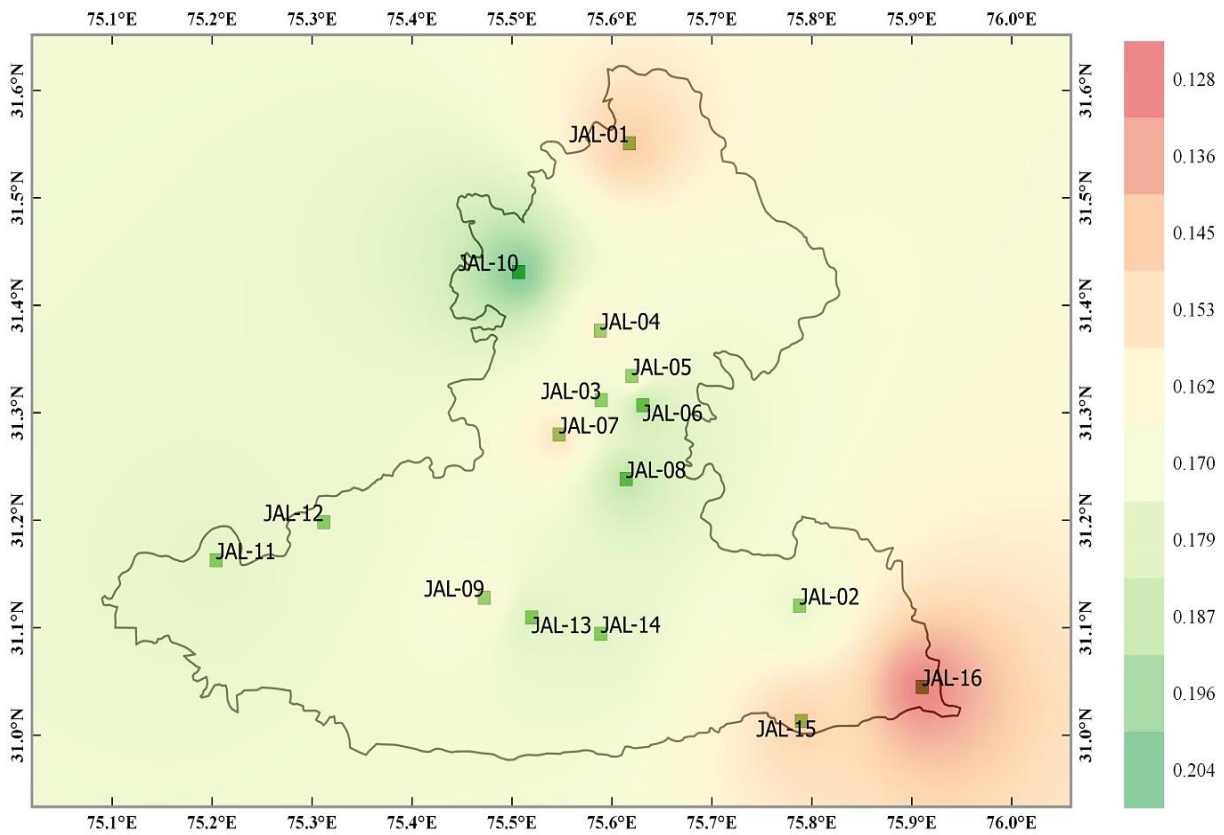


Figure 11. Contour Map showing the Minimum PGA (Soil) values of Jalandhar region, Punjab (India)

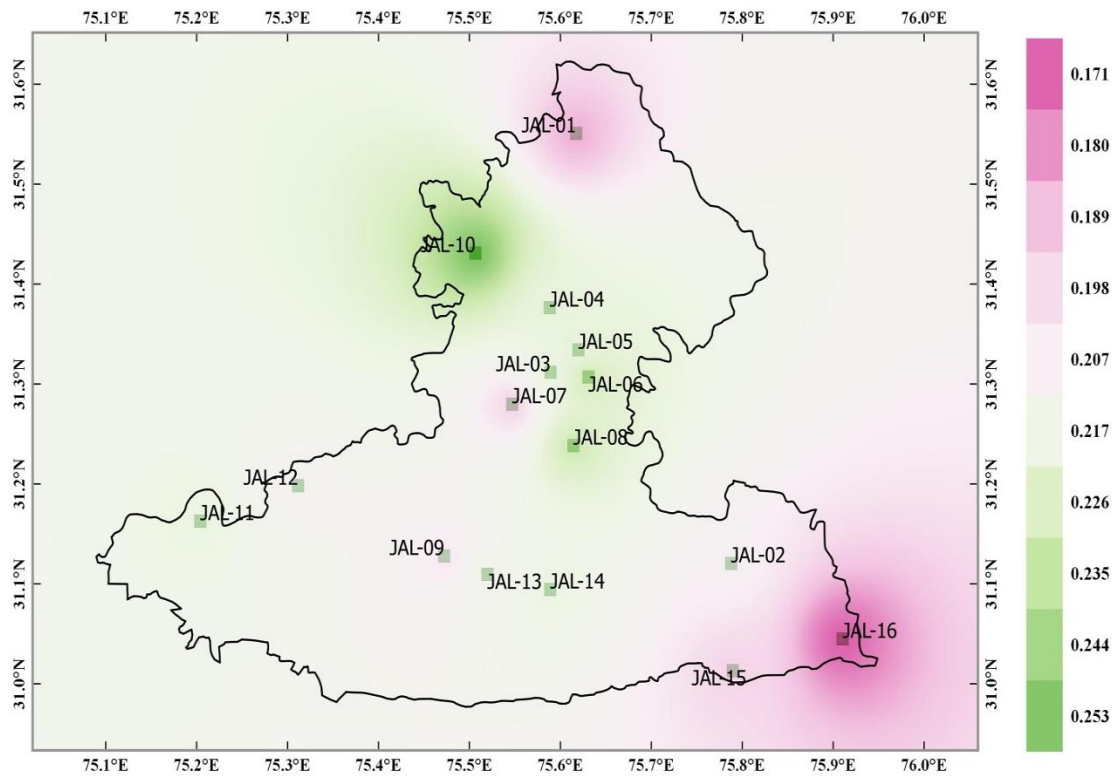


Figure 12. Contour Map showing the Average PGA (Soil) values of Jalandhar region, Punjab (India)

Amplification is a key parameter considered to account modification of seismic waves in the soil for earthquake resistance design of structure. The amplification factors (AF) considering the observed peak ground acceleration at surface layer with respect to the peak ground acceleration at bedrock obtained by using DEEPSOIL for 16 soil sites in Jalandhar region for different strong motion earthquakes have been summarized in Table 6. It has been observed that AF for the sites of Jalandhar region varies from 1.08 to 2.01, observed at JAL-16 and JAL-10 with IEM-01 and IEM-04 input ground motion respectively. Further, AF for input ground motion IEM-01 varies from 1.08 (JAL-16) to 1.73 (JAL-10), IEM-02 varies from 1.30 (JAL-16) to 1.85 (JAL-10), IEM-03 varies from 1.45 (JAL-16) to 1.98 (JAL-10), IEM-04 varies from 1.22 (JAL-16) to 2.01 (JAL-10) and IEM-05 varies from 1.27 (JAL-16) to 1.75 (JAL-10) respectively.

Table 6. Amplification factor of Jalandhar region, Punjab (India) with different input ground motion

Site Code	Amplification Factor (AF) using different motion				
	IEM-01	IEM-02	IEM-03	IEM-04	IEM-05
JAL-01	1.23	1.35	1.48	1.32	1.45
JAL-02	1.48	1.54	1.64	1.54	1.50
JAL-03	1.47	1.59	1.71	1.64	1.62
JAL-04	1.38	1.58	1.66	1.90	1.54
JAL-05	1.40	1.59	1.66	1.84	1.56
JAL-06	1.60	1.57	1.77	1.92	1.56
JAL-07	1.32	1.44	1.50	1.57	1.47
JAL-08	1.61	1.67	1.75	1.79	1.64
JAL-09	1.40	1.53	1.60	1.44	1.56
JAL-10	1.73	1.85	1.98	2.01	1.75
JAL-11	1.50	1.59	1.73	1.64	1.60
JAL-12	1.48	1.52	1.65	1.53	1.60
JAL-13	1.52	1.52	1.80	1.53	1.55
JAL-14	1.50	1.59	1.73	1.64	1.60
JAL-15	1.25	1.46	1.65	1.41	1.48
JAL-16	1.08	1.30	1.45	1.22	1.27

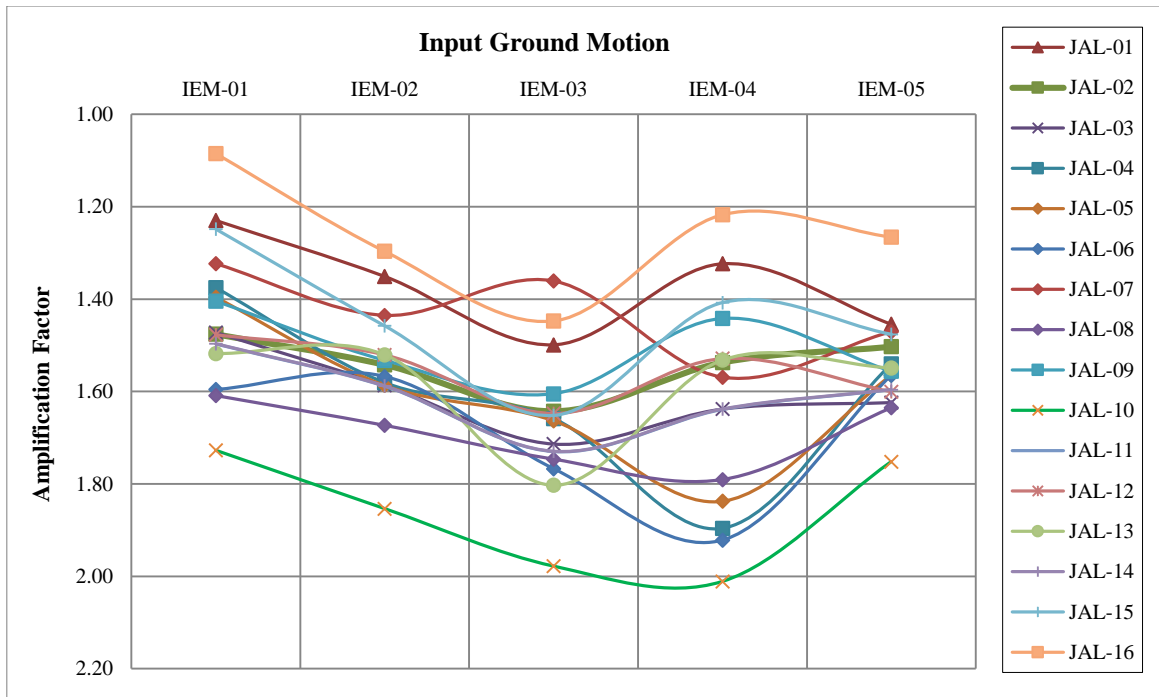


Figure 13. Variation of AF w.r.t. to different Input Ground Motion of Jalandhar Region, Punjab (India)

The Variation of AF of Jalandhar region w.r.t. to different Input Ground Motion for soils of Jalandhar region is presented in Figure 13 and Contour Map for AF values for the soils of Jalandhar region is presented in Figure 14. Furthermore, amplification of the entire region of Jalandhar has been observed but regions of JAL-03, JAL-05, and JAL-06 and JAL-10 are more capable of amplifying the ground motion as compared to other regions of Jalandhar such as JAL-01, JAL-02, JAL-08, JAL-11, JAL-12, JAL-14, JAL-15, and JAL-16.

The results show that the sites of Jalandhar region are capable of amplifying earth-quake ground motions, so a site - specific design approach should be adopted for important structures. The present study utilized empirical correlations to evaluate shear wave velocity from SPT N value however extensive field tests such as MASW (Multichannel analysis of surface wave) and SASW (spectral analysis of surface wave) over the entire port areas would help to model the soil deposit more realistically and to refine the results further

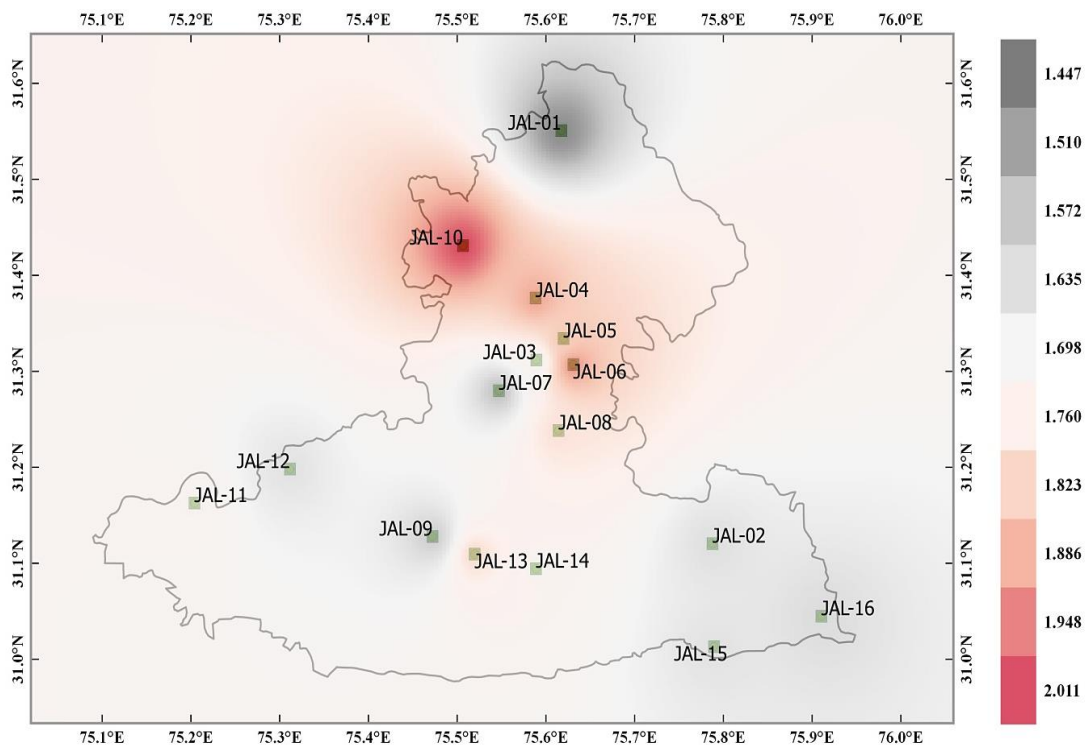


Figure 14. Contour Map showing AF values of Jalandhar region, Punjab (India)

4. Conclusions

One dimensional Non-linear ground response analysis for sixteen sites of Jalandhar region, Punjab (India) has been carried out with DEEPSOIL Software using five input ground motions. It is observed that the local site conditions and characteristics of input motion equally influence the seismic response at a site. All the sites considered for the present analysis are having a profound influence in modifying the ground response.

On the basis of the results obtained, it may be concluded under:

- That all sixteen sites of Jalandhar region fall under the category of Class D as per the NEHRP (2003) provisions whereas as per IS:1893, eight sites fall under category of Class C and rests of the sites under Class D. The Avg. N-Value (N_{30}) varies from 19.29 to 45.11 for the JAL-10 and JAL-16 respectively.
- The Peak Ground Acceleration for the Jalandhar region varies from 0.128 to 0.292 g for JAL-16 and JAL-10 respectively with IEM-01 and IEM-04 input motions.
- The Amplification Factor for the sites of Jalandhar region varies from 1.08 to 2.01 observed at JAL-16 and JAL-10 with IEM-01 and IEM-04 input motion respectively.

There is a considerable variation in ground response even though input depth and average shear wave velocities are similar. This study shows the importance of site specific ground response analysis required in order to ascertain the stability of the structures against similar future earthquakes. Hence the present studies will be useful as input in carrying out suitable earthquake resistant design of structures for similar sites in Jalandhar region in the absence site-specific data that can withstand threat from a hazards [19].

5. Conflicts of Interest

The authors declare no conflict of interest.

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