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Development of site specific equivalent linear seismic ground response for Abbottabad, Pakistan

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Abstract

The site specific seismic hazard was conducted at three different selected locations in Abbottabad, Pakistan. The site response was modeled using one dimensional analysis technique with data from site investigation from three selected locations from Abbottabad. Based on shear wave velocity, as per Building Code of Pakistan-2007 all the three locations were identified as stiff soil profile (SD). The seismic ground motions applied at the base of model were selected from worldwide database compatible to the seismic hazard of Abbottabad. The model used equivalent linear analysis approach, incorporating non-liner shear modulus degradation and damping curves for plastic soils. The analysis results for all sites showed amplification of input motions in term of surface response spectrums. The lowest surface amplification was obtained for site with highest fundamental natural period. Furthermore, the Peak Ground Acceleration (PGA) values showed increased toward surface. The strong amplitude short period motion was comparatively more amplified among suite motions and thus resulted in higher surface PGA value.

Keywords: Linear ground response modelling; Ground response spectrum; Amplification factor; Peak Ground Acceleration (PGA).

1. Introduction

The subduction of Indian plate under Eurasian plate at a rate of 47 mm per year has resulted in several seismogenic active faults in Northern and Southern Pakistan (Jain et al., 2000). The presence of these faults that are mostly reversed in mechanism have caused several devastating earthquakes in Pakistan (Waseem et al., 2013). The documented devastating earthquakes includes 1931 Mach (Mw=7.2), 1935 Quetta (Mw=7.8), 1945 Makran (Mw=7.0) and the recent 2005 Muzzaffarabad earthquake (Mw=7.5). The epicenter Muzzaffarabad earthquake was located 19 km North from Muzzafarabad city (Zare and Paridari, 2008). The Muzzafarabad earthquake caused severe loss of life and property in the northern region of Pakistan. About 80,000 people were killed and, the country economy was badly affected due to this devastating earthquake (Zare and Paridari, 2008). The presence of seismogenic faults will continue to pose a major threat to people and property in the northern region of Pakistan. Therefore the seismic hazard study is important for safe and sustainable development in earthquake prone regions of Pakistan.

The seismic hazard at a location is calculated based on deterministic or probabilistic seismic hazard analysis. Based on the Building Code of Pakistan (BCP 2007), the country has been divided in different seismic zones based on the PGA value for a return period 475 years. The PGA value for a target site is calculated based on the already established ground attenuation relationships developed for different parts of the world (Campbell, 1981; Boore et al., 1993; Toro et al., 1995; Boore, 2010; Boore and Atkinson, 2008; Cambell and Bozorgnia, 2008). There are local seismic hazard studies available based on these developed attenuation relationships (MonaLiza et al., 2004; Waseem et al., 2003; PDMA-NOSAR 2007; Khan et al., 2003).

Although the seismic waves travel hundreds of kilometers (KM) through rock medium and less than hundred meters in soil strata, however the later plays an important role in the modification of seismic waves. For the inclusion of soil affect usually the shear wave velocity in top 30 m, V_{S30} is taken into account. Although, based on V_{s30} the seismic hazard at the top of soil layer is evaluated, however the one dimensional ground response analysis can accurately model the propagation of seismic waves through a layered soil deposit. The effect of local soil condition on ground response analysis is referred as site specific seismic hazard analysis. There is a lot of research literature available on site specific seismic hazard worldwide such as that of (Govinda Raju et al., 2004; Grasso and Maugeri, 2009; Matasovic, 1993; Monaco, 2011). There is scarcity of research work on this topic in Pakistan and the limited studies available (Ahmad et al., 2015; Shahzada et al., 2012; Mahmood et al., 2016).

The site specific seismic hazard analysis can be calculated using dynamic properties and nonlinear behavior of soil. The soil nonlinear properties when subjected to seismic loading are usually calculated based on the effective linear analysis method that gives effective shear strain in each layer. The equivalent linear model has been successfully used in several site specific seismic hazard studies (Kaklamanos, 2015; Phillips and Hashash, 2009; Kim et al., 2016).

In the present study the equivalent linear seismic hazard has been conducted for selected locations in Abbottabad city that was also severely affected during 2005 Muzzaffarabad, earthquake. BCP (Building Code of Pakistan-Seismic Provisions) (2007), has placed Abbottabad in zone 3 with PGA range between 0.32-0.44g on bedrock. The following work is aimed at quantify the effect of soil medium on seismic waves as it travels to the surface from bedrock. This effect is studied in term of ground response spectra, amplification and PGA along soil profile.

2. Equivalent linear one dimensional ground response analysis

The one dimensional ground response analysis is based on the assumption of vertically propagating seismic stress waves from bedrock through horizontal layered soil deposit. The incident seismic waves when travelling through the layered soil deposit are either reflected or refracted at interface. The Numerical modeling tool DEEPSOIL is extensively used to conduct the equivalent linear ground response analysis (Hashash, 2012). The input wave of circular frequency w are refracted and reflected at interface in a layered soil deposit. The wave solution mechanism in the form soil particle displacement u_i at depth z_i and time t has been expressed in Kramer ,1996) as follow:

$$u_i(z_i,t) = A_i e^{i(\omega t + k_i^* z_i)} + \quad B_i e^{i(\omega t - k_i^* z_i)} \qquad (1)$$

Where A_i and B_i are the magnitudes of reflected and refracted wave; k_i^* is the complex shear wave number and can be defined as:

$$k_i^* = \omega\sqrt{\rho/G^*} \qquad (2)$$

Where G^* is the complex shear modulus.

In case of equivalent linear analysis the spring and dashpot are used to represent shear modulus and damping parameters at a given applied strain in the soil deposit. The shear modulus and damping value of degraded soil is evaluated based on an iterative procedure. First the initial shear modulus and damping is selected for a reference strain. The iteration process is further repeated until the strain compatible shear modulus and damping value is obtained. During the modelling the relevant shear modulus and damping was assigned to each element corresponding to the given strain level (Kramer, 1996).

3. Ground motions

The ground input motion is an important parameter in the analysis of ground response analysis. The complete ground response analysis requires modeling of fault rupture mechanism and the propagation of seismic stress waves to target location. Although the worldwide global and local seismograph networks have now improved our understanding regarding tectonic process, however such type of seismograph network is not available in Pakistan. Therefore in the absence of seismograph network the recorded accelerograms of similar tectonic setting are commonly used in seismic hazard studies. The seismic hazard for Peshawar basin based on deterministic study (Waseem et al., 2013). According to their results most of the faults that causes seismic hazard have reversed faulting mechanism. In this research work the earthquake records compatible to the seismic hazard of Abbottabad are selected from Pacific Earthquake Engineering Research Center (PEER) NGA West 2 database (Ancheta et al,. 2014).

In the present study thus compatible to the seismic hazard of Abbottabad were selected from the strong motion database of Pacific Earthquake Engineering Research center and matched with target response spectrum of Abbottabad according to BCP (2007).

4. Ground response analysis methodology

The flow chart for one dimensional ground response analysis is shown in Fig. 1. The input accelerograms were selected from the earthquake records PEER database for the target spectrum of Abbottabad as defined by BCP (2007) and compatible seismic hazard parameters. The ground was modeled in DEEPSOIL by defining the unit weight, height and shear wave velocity of different layers in ground profile. The shear wave velocity

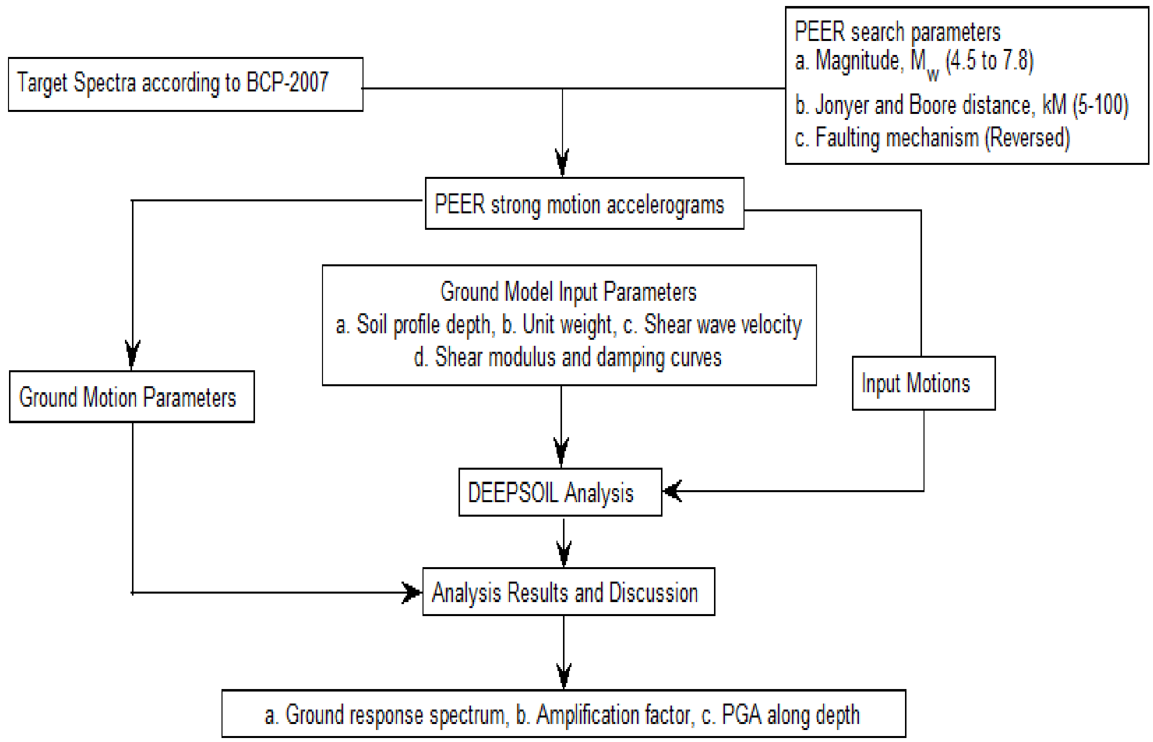

Fig. 1. Flow chart for ground response analysis

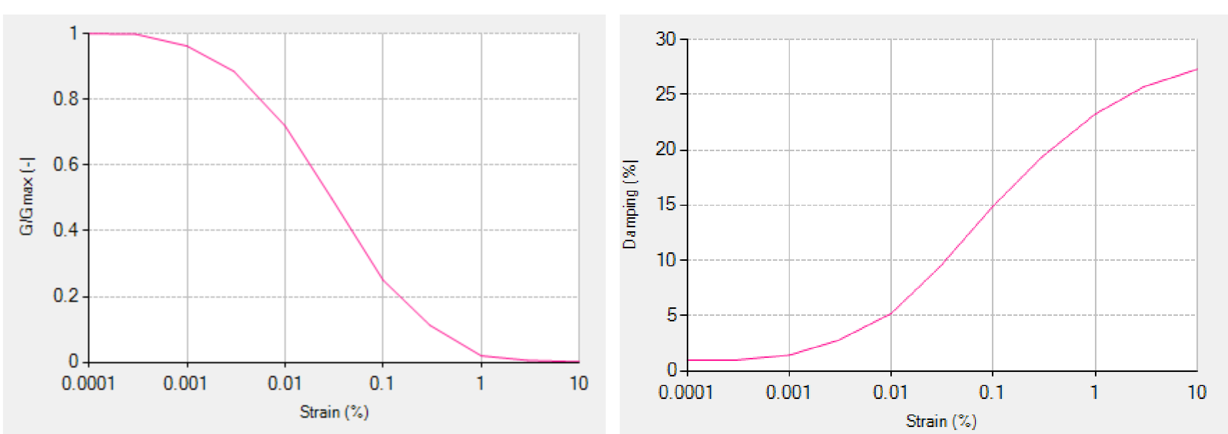

Fig. 2. Typical (a) shear modulus and damping curve used in equivalent linear ground response analysis.

Table 1. Input parameters in deep soil for ground profile 1, *H=21.34m*

Layer Depth (m)	Average SPT (N values)	Shear wave velocity (m/sec)	Soil Plasticity Index (PI %)	Avg. Shear Wave Velocity (m/sec)	Site as per BCP-2007	Site profile Name
1.52	4	246.25	7.7	$V_s = \frac{\sum_{i=0}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{V_i}}$ = 305.22	S_D	Stiff soil profile (average shear wave velocity) 175 - 350
1.52	11	321.31	7.7			
3.05	9	304.79	6.4			
3.05	9	304.79	6.7			
6.1	9	304.79	7.5			
6.1	11	321.31	5.5			

Table 2. Input parameters in deep soil for ground profile 2, *H=12.19 m*

Layer Depth (m)	Average SPT (N values)	Shear wave velocity (m/sec)	Soil Plasticity Index (PI %)	Average Shear Wave Velocity (m/sec)	Site as per BCP-2007	Site profile Name
1.52	8	295.50	6.1	$V_s = \frac{\sum_{i=0}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{V_i}}$ = 313.58	S_D	Stiff soil profile (average shear wave velocity) 175 to 350
1.52	10	313.36	6.1			
3.05	8	295.50	6.2			
3.05	8	295.50	1.8			
3.05	12	328.75	6.1			

Table 3. Input parameters in deep soil for ground profile 3, *H=18.29 m*

Layer Depth (m)	Average SPT (N values)	Shear wave velocity, (m/sec)	Soil Plasticity Index (PI %)	Average Shear Wave Velocity, (m/sec)	Site as per BCP-2007	Site profile Name
1.52	5	261.14	6.5	$V_s = \frac{\sum_{i=0}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{V_i}}$ = 329.54	S_D	Stiff soil profile (average shear wave velocity) 175 to 350
1.52	15	348.62	12.1			
3.05	7	285.30	7.7			
3.05	14	342.35	4.9			
3.05	17	360.29	6.7			
3.05	16	354.59	6.7			
3.05	17	360.29	5.2			

5. Example problem

The site specific seismic hazard is conducted at three selected locations in Abbottabad. The input parameters needed in the ground response analysis and as defined in Fig. 1 is shown in Table. 1, 2 and 3. The unit weight of soil and rock were assumed 16.5 and 22 kN/m3 respectively. Furthermore, elastic half space bedrock was assumed with 2% damping value. Based on BCP-2007 all the three sites have an average shear wave velocity in the range of 175 to 350 m/sec and the site was classified as stiff soil profile, SD.

The input motions were selected in the form of accelerograms from earthquake records taken from PEER database for the target response spectrum based on BCP-2007 for zone 3 (0.32-0.44g) along with the search parameters (Fig. 1). A suite of total seven input motions were used as base motion to the ground model for seismic hazard analysis of each site. Figure. 3 shows the input motions selected from PEER strong motion database while Fig. 4 shows the ground response spectrum along with code specified spectrum for zone 3. The characteristics of input motions are given in Table. 4. The v_{max}/a_{max} (sec) ratio defines the frequency content of a strong motion and, the quantity $2\pi\, v_{max}/a_{max}$ (sec) is referred as the predominant period. According to Table. 4, input motion 7 and 1 has respectively the largest and shortest predominant period. The arias intensity in m/sec of a strong motion is related to root mean acceleration (rms) that defines amplitude and frequency of strong motion. Furthermore, the input motion 3 and 7 has respectively the lowest and highest arias intensity among suite input motions. Accordingly input motion 7 with short time period and high intensity.

6. Analysis results and discussion

In case of layered ground the average shear wave velocity V_s in m/sec is calculated as:

$$V_s = \left[\frac{1}{H}\left(\sum_{i=1}^{n}\frac{h_i}{V_{s_i}}\right)\right] \qquad (1)$$

From equation 1, the natural period for total height, H of the soil deposit is calculated as:

$$T_n = \frac{1}{f_n} = \frac{4H}{V_s} \qquad (2)$$

The site natural time period and frequency are given in Table. 5. According to Table. 5, site 1 and 2 has respectively the largest and shortest natural time period is the strongest among suit motions.

A comparison of surface and bedrock response spectra for suite motions of all three sites is shown in Fig. 4. Figure 4 show that all suite input motions have been amplified near the fundamental period of the site. Furthermore, the higher amplification of surface response spectra can be noted for ground profile with lower natural site period i.e., shallow depth. In general it can it can be concluded that with increase in site depth H (i.e., higher the natural period) there is a decrease in amplification of surface spectral acceleration.

The amplification factor (AF) is commonly defined as the ratio between the spectral acceleration values at surface to that at bedrock at different time period (or frequency). A value greater than unity suggest that the bedrock input motion has been amplified at that time period. Figure. 6 shows the AF for all three sites in term of suite input motions. Although it can be seen that despite the difference in site depth and also natural time period, the AF is almost similar for all sites. The reason for this can be attributed to the first major impedance contrast observed (Zhao, 2011). The maximum AF obtained for all three sites is about 2.4. The soil particle displacement at any layer is depended on the impedance ratio between layers, their damped shear modulus in soil deposit.

In case of same soil deposit the soil particle displacement is further depended on the frequency and magnitude of input motion during the propagation time. The velocity and acceleration can then be calculated at different layers from the soil particle displacement.

In 1-D ground response analysis the inverse Fourier Transformation is used to evaluate the acceleration time history at the top of a specified layer. The peak acceleration along depth of ground profile for the three sites is shown in Fig. 8. Fig. 8 shows that for a given ground profile, the peak acceleration for all input motions are gradually increased toward the surface. The reason for this is the higher impedance contrast as the seismic waves from the stiffed bedrock crosses into comparatively softer material i.e., soil medium. Higher surface peak acceleration may obtain if the fundamental frequency is matched or nearly matched to the fundamental frequency of the site. Although, there is little discrepancy among ground profiles in term of peak acceleration at different depth, however, the ground profile 2 and 3 resulted in higher peak acceleration in case of input motion 7. The reason for this may be that, the short time period motion with high magnitude were more amplified by sites with shorter time period.

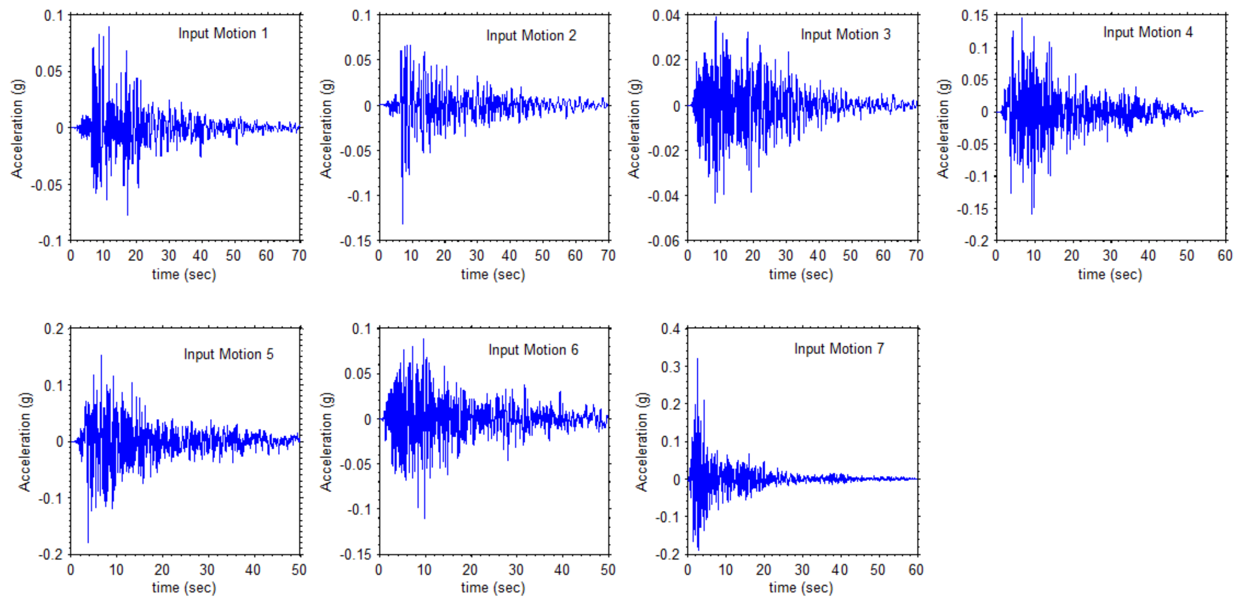

Fig. 3. Input motions applied at base of bedrock.

Table 4. Characteristics of bedrock input motions.

Bedrock Motion	Moment Magnitude, (M_w)	PGA, (g)	v_{max}/a_{max} (sec)	Arias Intensity (m/sec)
Input Motion 1	7.36	0.089	0.15	0.24
Input Motion 2	7.36	0.136	0.12	0.30
Input Motion 3	7.36	0.041	0.12	0.07
Input Motion 4	6.61	0.155	0.08	0.55
Input Motion 5	6.61	0.183	0.10	0.60
Input Motion 6	6.61	0.114	0.07	0.25
Input Motion 7	6.61	0.341	0.05	0.70

Table 5. Ground profile fundamental period and frequency.

	Ground Profile 1	Ground Profile 2	Ground Profile 3
Site fundamental period, *T (sec)*	0.28	0.20	0.22
Site fundamental frequency, *f (Hz)*	3.58	5.08	4.52

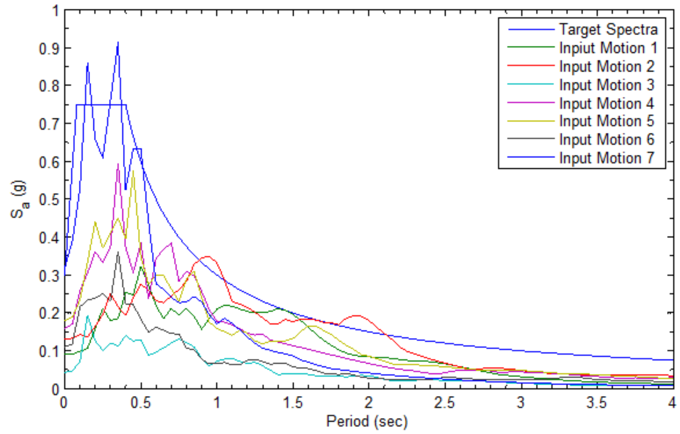

Fig. 4. Ground response spectra for input motion.

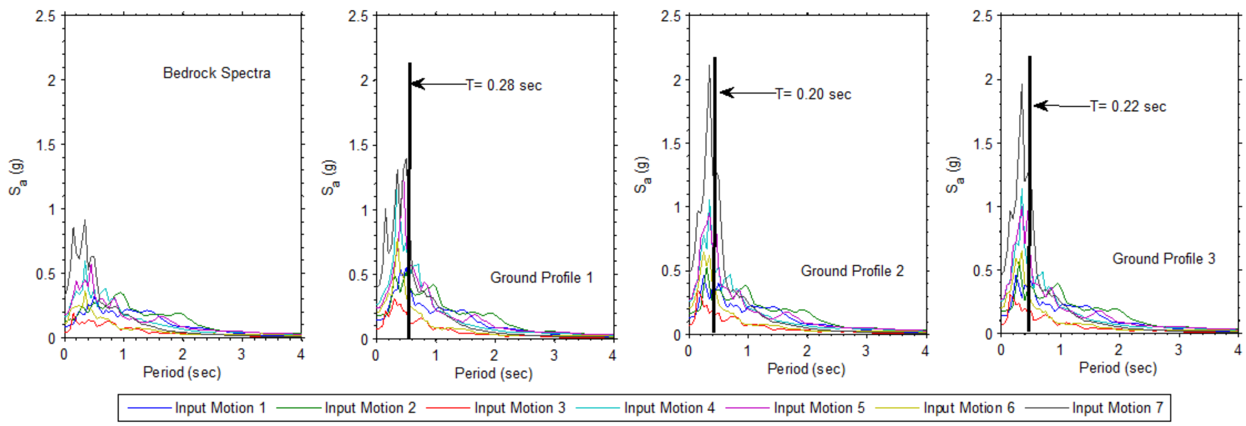

Fig. 6. Response spectra comparison of suite motion for all sites at bedrock and surface.

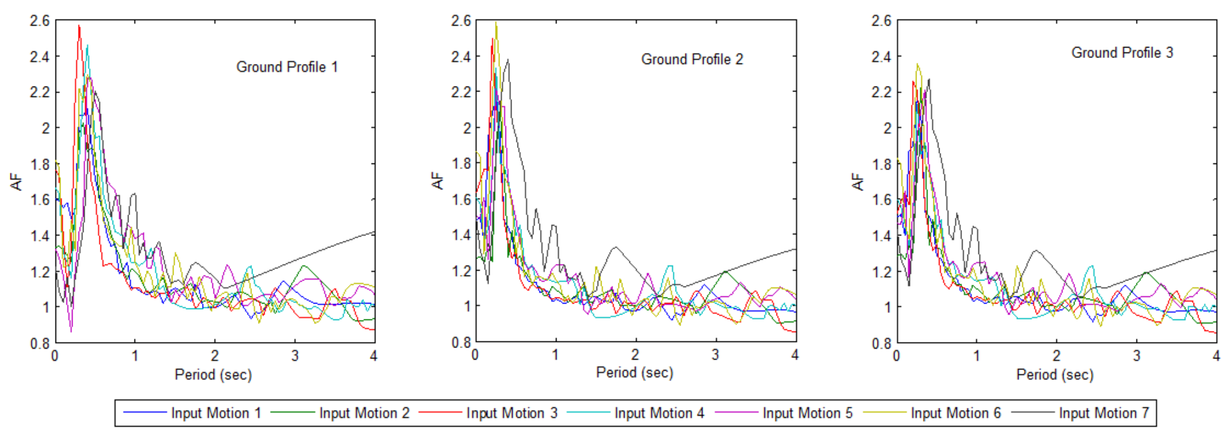

Fig. 7. Amplification factor for input motions at three different sites.

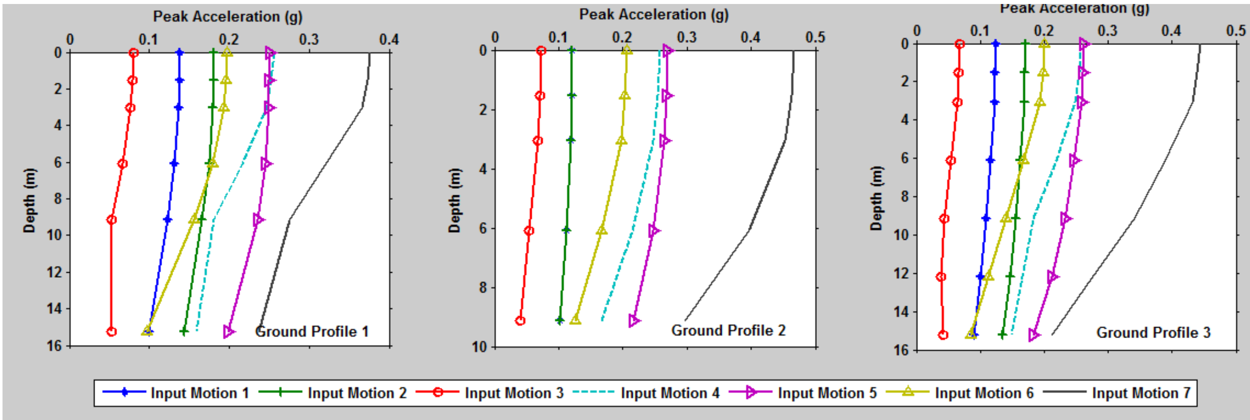

Fig. 8. Peak acceleration along depth in term of input motion.

7. Conclusion

Based on the numerical study conducted for determination of site specific response for Abbottabad City, the following conclusions can be drawn;

- All the three sites selected were Stiff soil profile (with Average S Wave velocity ranging from 175 to 350 m/sec) and were classified as SD according to BCP-2007.
- The surface ground response spectra indicate that all the input motions were amplified at different sites close to the fundamental period of the site. The difference in results of surface response spectrum can be attribute to the difference in profile depth. The lowest surface amplification in response spectrum was obtained for site with highest fundamental natural period.
- The AF again confirmed the amplification of surface response spectrum by all three sites. The maximum amplification factor obtained for these sites was about 2.4.
- The analysis results showed that higher PGA values were obtained for all input motions along the depth of ground profile. The variations in PGA values at different depth in same soil deposit are depended on the characteristic of input motion. The higher PGA value was obtained when a strong input motion with shorter time period was applied at the base of soil deposit.

Author's contribution

Khalid Mahmood, proposed the main concept, involved in field data collection and manuscript write up. Qaiser Iqbal, did provision of relevant literature review and proofread of the manuscript. Shahid Iqbal, was involved in manuscript write-up and proofread of the manuscript. Bilal Siddiq, was involved in field data collection. Hassan Khan, was involved in field data collection.

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