Journal of Himalayan Earth Sciences 46(1) (2013) 73-82

Equivalent linear earthquake site characterization of layered soil deposits at Shakardarra and Muzaffarabad

MonaLisa[1] and Sarfraz Khan[2]
[1]COMSATS Institute of Information Technology (CIIT), Islamabad
[2]National Center of Excellence in Geology (NCEG), University of Peshawar

Abstract

The research work relates with the study of site characterization of layered soils. A linear approach is introduced that predicts response of soils against input motions. The equivalent linear damping ratio and normalized shear modulus for different soils are used to test the adequacy of response analysis. For this, two different sites Shakardarra (SHD) and Muzaffarabad (MUZ) on the basis of deposition histories and intensities are selected. Based on the available borehole logs, velocity profiles and geotechnical data of CPT and SPT test the response models are prepared. The equivalent linear site response analysis program (EERA) has been used for this purpose.

Two input strong motions of 0.07 g and 0.17 g of vertical component are introduced as input. The soil profiles are prepared using available set of data by neglecting the effect of water depth. The sites were test for maximum eight iterations and maximum fundamental frequency of 50 Hz for MUZ site and 100 Hz for SHD site is used to analyze the amplification ratio and response spectra against input motion (Inside and outcrop). Site amplification of 1.12-2.36 (clayey sand), 4.13-16.04 (sandy gravel), 1.13-7.15 (dry sand) and 1.24-5.87, is predicted by EERA at (SHD) site for acceleration of 0.17g and 0.007g respectively. While at Muzaffarabad (MUZ) site amplification of 12.189 (gravel, sand and silty clay) for acceleration of 0.17g and 2.224 (gravel, sand and silty clay) is predicted by EERA for acceleration of 0.07g. The results are beneficial for both the researchers and engineers alike.

Keywords: Soil profile; Damping ratio; Ground motion record; Response spectra; Fundamental frequency

1. Introduction

During past earthquakes, the ground motions on soft soil sites were found to be generally larger than those of nearby rock outcrops, depending on local soil conditions. EERA (Equivalent-linear Earthquake site Response Analysis) is a modern implementation of the equivalent-linear concept of earthquake site response analysis, which was previously implemented in the original and subsequent versions of SHAKE 91 (Schnabel et al., 1972; Idriss and Joseph, 1991).

The equivalent linear approach consists of modifying the Kelvin-Voigt model to account for some types of soil nonlinearities. An equivalent linear procedure, Idriss and Seed (1968), Seed and Idriss (1970) is used to account for the nonlinearity of the soil using an iterative procedure to obtain values for modulus, damping and spectra that are compatible with the equivalent uniform percent strain induced in each layer and sublayer. The analysis is conducted using a set of properties (shear modulus or shear wave velocity, damping, thickness and total unit weight of layers) that assigned to each layer of the deposited soil. The analysis is repeated until strain-compatible modulus and damping values are arrived. Starting with the maximum shear modulus for each sublayer and a low value of damping, essentially strain-compatible properties (difference less than about one percent) are obtained in 8 iterations for soil profiles.

2. Location of the areas

The study areas are a part of Kohat Plateau and Hazara Kashmir Syntaxis. The Shakardarra (SHD) area is easily accessible from the Bannu-Kohat road (Fig. 1), which runs all along its eastern periphery. The SHD site was selected about 20 km west of Indus River, in Shakardarra.

Several metalled and unmetalled side roads run east-west in the area which provides excellent sectional views. The area of Muzaffarabad is well connected by roads; however, there are some high mountains upto 3500 meters in elevation. The MUZ site is underlain by Holocene unconsolidated stream deposits and Pliocene and Pleistocene alluvial fan deposits of Siwalik group.

3. Generalized soil profile

Generalized soil profiles were established from the borehole drilled at SHD and MUZ. The sites are selected with the objective of minimizing encounters with coarse gravels associated with the high-gradient, high-stream-power regime of Indus River. This approach improves the chances of encountering over bank alluvial deposits with lower shear strengths, lower shear-wave velocities, and probable lower threshold of linear site dependent shaking behavior.

3.1. Soil profile for Shakardarra (SHD)

The SHD site was selected about 20 km west of Indus River, in Shakardarra. The Miocene to Pliocene deposits from the 10 meters to about 30 meters subsurface created some low velocity zones due to which there are change in velocities occurred that disturb the seismic data in the area. Low velocity zones occurred in the depth range of 12-22 meter on the basis of P-wave velocity data, the maximum exeedance of shear wave velocity is 507.9 m/sec.

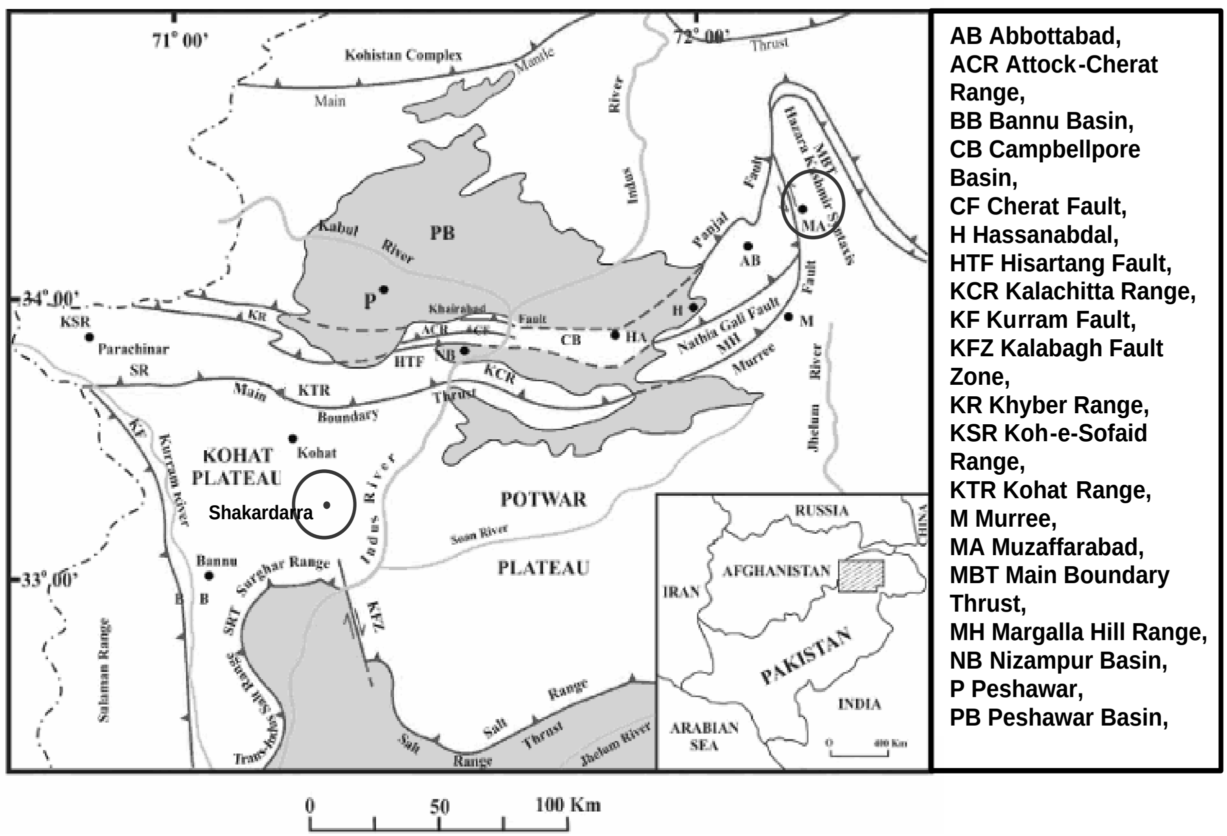


Fig. 1. Location map of study area (Shakardarra, and Muzaffarabad are shown by circles) with major structural boundaries (modified after Hylland et al., 1988).

In the valley the Quaternary floodplain deposits are transported via local stream channels and Indus River that are represented by upper 5 meter thick deposits. These deposits consist mainly of gravels and sandy gravel, conglomerates, silt and clays. The uppermost 3 meter layer (*Vs* = 140 m/s), with some conglomerates at the near surface followed by slightly dense, medium to coarse grained, greenish grey (bluish grey to dull red with salt and pepper in some upholes) dry sand layers (*Vs* = 227 m/s) of Nagri Formation, the gravel content decreases downward (Fig. 2).

At a depth of 12 meters shear velocity suddenly increases from 287 m/sec to 316 m/sec and decreases to 306 m/sec, shows change in lithology from greenish grey dry sand into reddish grey sandy clay and pale orange clay of Chinji formation, at some places grey clay also reported that occasionally containing dense reddish sand stringers with lack of microfossils.

Here the velocity increases gradually to 335 m/sec at depth of 20 meters. Due to porosity shear velocity increases gradually at depth of 20 meter in red clay with subordinate ash grey or brownish grey sand and sandy clay of Chinji formation from 458.5 m/sec to 414 m/sec, at depth of 26 meters fine to medium grained, brownish grey wet sand encountered.

3.2. *Soil profile for Muzaffarabad (MUZ)*

The MUZ site is underlain by Holocene unconsolidated stream deposits and Pliocene and Pleistocene alluvial fan deposits of Siwalik group. The alluvial fan deposits at depth contain gravel derived from two distinct crystalline basement terrains. The dominant contribution is from Paleozoic and Mesozoic bedrock of the Northern Sedimentary terrain.

In this area also a low velocity zone encountered at a depth of 3 meter on the basis of P-wave velocity data due to which there are change in velocities occurred that might disturb the seismic data if it is available, the maximum exeedance of shear wave velocity is 185 m/sec. The borehole penetrated recent stream channel deposits of Siwaliks to a depth of 4 to 7 meters. The drill hole encountered slightly compact but poorly consolidated Holocene and Pleistocene greenish grey gravelly sand (alluvial fan deposits to 2 meters with a Vs equal to 185 m/s).

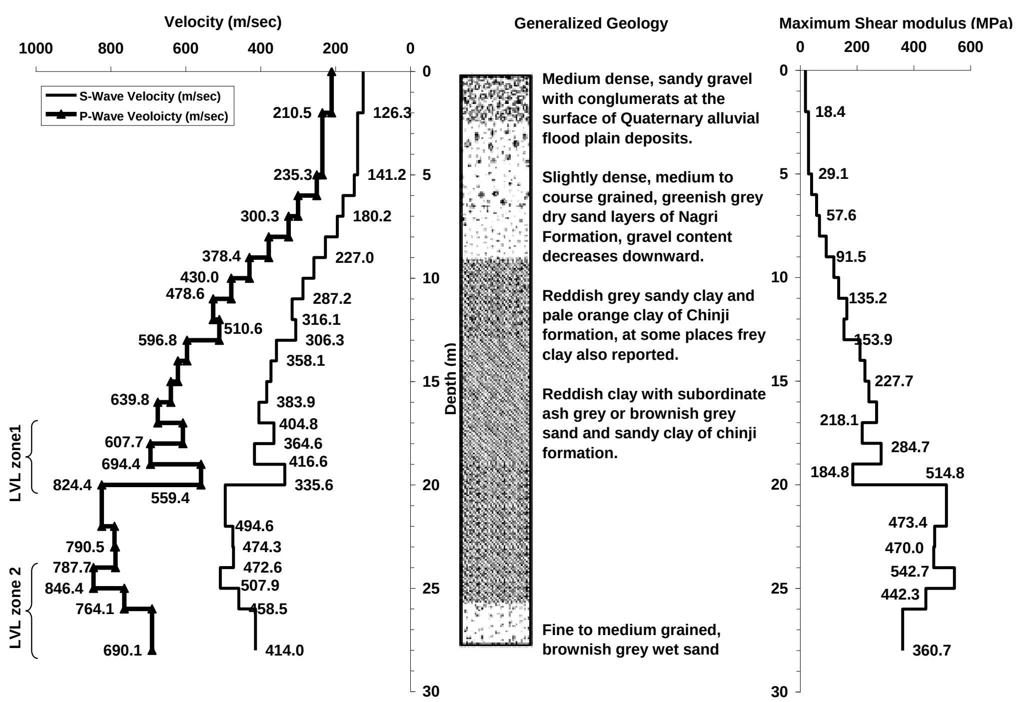


Fig. 2. Profile of generalized geology, shear wave velocity, compression wave velocity and maximum shear modulus for the vertical array at the Shakardarra site (SHD).

Below 2 m, the deposits become harder to drill and are much less permeable. Shear wave velocity increases slightly to 185 m/s (Fig. 3). At a depth of 5 meters the shear velocity decreases from 185 m/sec to 178 m/sec, shows change in lithology from greenish grey dry sand into reddish grey sandy clay and pale orange clay of Murree Formation (Siwaliks), at some places grey clay also reported.

4. Modeling of profile geometry and soil properties

The present work required several major assumptions in view of the scarcity of data on soil mechanical properties at the SHD and MUZ sites. These assumptions were however kept to a minimum to generate the geometry of soil layers and material properties.

4.1. Soil unit weights

Unit Weight parameter is the weight of a unit volume of soil is referred to as its unit weight. The unit weights were calculated using relation $\gamma_d = \rho_d$ g, for different soil layers at MUZ and SHD. At MUZ site the unit weight used were 19.13kN/m^3 for gravel, 11.77 kN/m^3 for clay and 12.00 kN/m^3 for silty clay an at SHD site 16.09 kN/m^3 for clayey sand, 14.32 kN/m^3 for sandy gravel, 20.64 kN/m^3 for clay and 17.41 kN/m^3 for dry sand.

4.2. Shear modulus

Modulus of rigidity or shear modulus can be explained using elastic properties of materials. The quantity G_{max}, sometimes also called the rigidity, which is experimentally observed to relate stress and strain according to Hooke's law can also be explained as, a measure of the resistance of the body to shearing strains.

Shear modulus of soils for the site analysis is determined by equation-1 of Hardin and Drnevich (1972), in this study.

$$G_{max} = \frac{[326(2.973-e)^2 \sigma_o^{1/2}]}{(1+e)} \quad \text{........ (1)}$$

Where e is the void ratio, the shear modulus 'G_{max}' and confining pressure σ_o are in kg/cm/cm. The result given by this equation may be small for 'G_{max}' when e>2 (MonaLisa and Khan, 2010). This parameter is used if shear wave velocity of the material is not known. The shear modulus increases drastically from 18.4 MPa to 227 MPa at depth of 15 meters and decreases drastically from 224 MPa to 187 MPa at depth of 20 m in SHD site (Fig. 2), and shear modulus increases from 59 MPa to 69 MPa at depth of 5 meters and decreases from 70 MPa to 38 MPa at depth of 7 meters at MUZ site (Fig. 3).

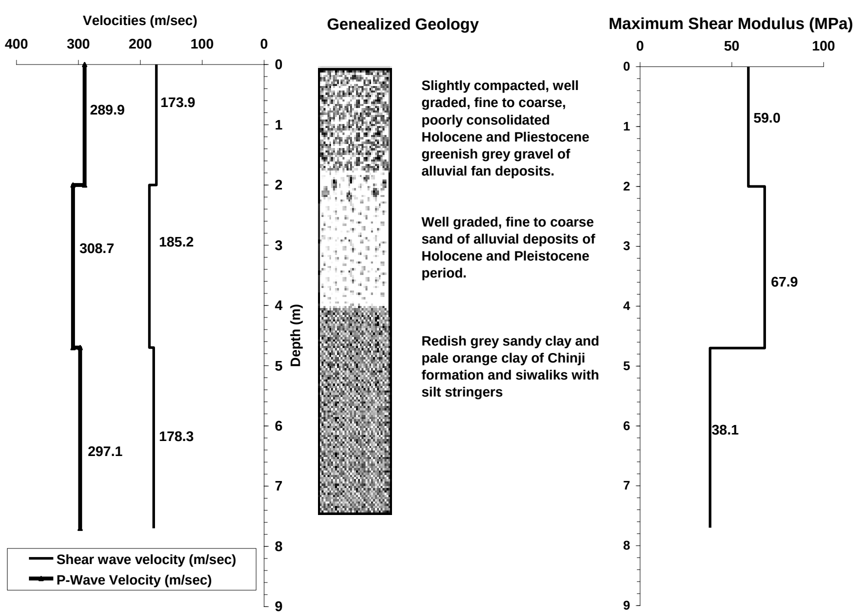


Fig. 3. Profile of generalized geology, shear wave velocity, compression wave velocity and maximum shear modulus for the vertical array at the Muzaffarabad site (MUZ).

In this study the shear modulus ranges from 153 MPa to 257 MPa for clay at SHD site and decreases when wet sand occurred at depth of 20 m. Where as silty clay encountered at depth of 7 m when shear modulus decreases drastically from 70 MPa to 38 MPa at MUZ site (Fig 4a and 4b).

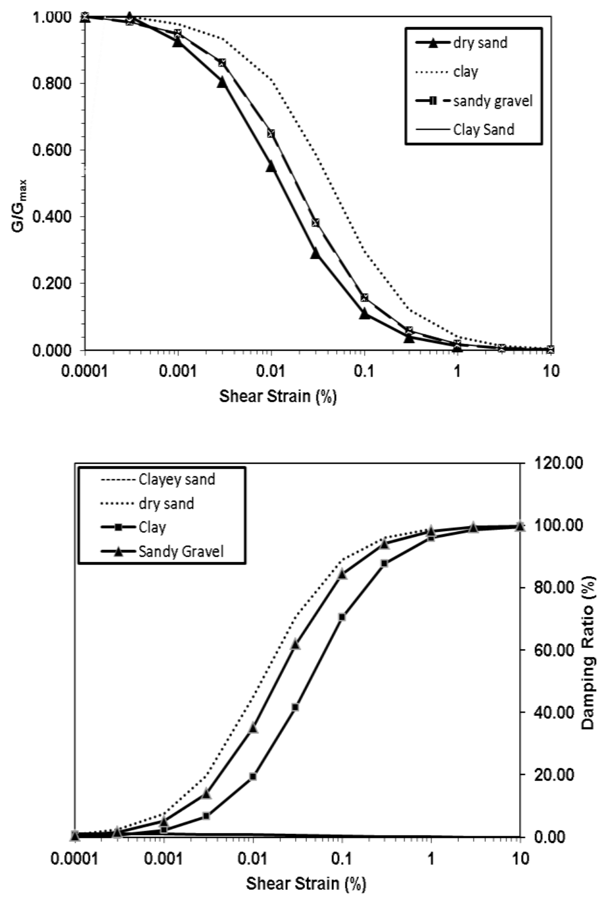


Fig. 4a. Normalized shear modulus (above) and linear damping ratio (below) with respect to shear strain for clay, dry sands, clayey sandy and sandy gravel at SHD site.

5. Selection of Ground Motion Records

The studied sites are subjected to ground motion caused by events originated in the inplate inshore seismic zones. Two acceleration records from inplate zones were selected for the site response analysis of the soil deposit. These were of Bhuj earthquake 2001, with PGA (magnitude = 5.3 mb) value of 0.07g, at Bhuj station (Fig. 5a) and Chamba earthquake 1995, with PGA value of 0.17 g at Rakh station (Fig. 5b) for both sites, the Fourier spectra are shown in figure 6. Local soil is mainly bouldery gravel, poorly graded but usually very dense. It can be seen that these time histories present relatively high frequencies, high accelerations and long durations as it is common in this region.

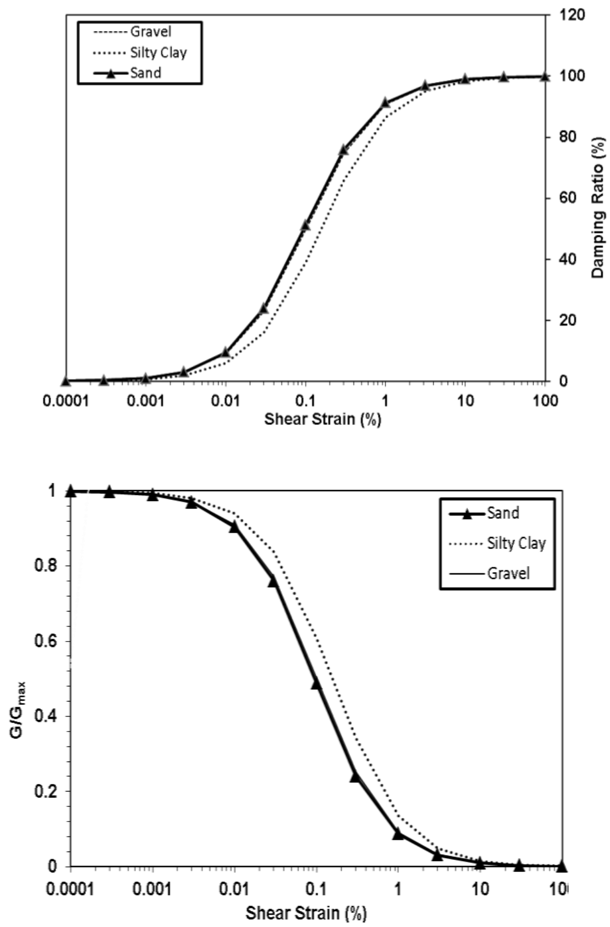


Fig. 4b. Normalized shear modulus (above) and linear damping ratio (below) with respect to shear strain for gravel, silty sand and sand at MUZ site.

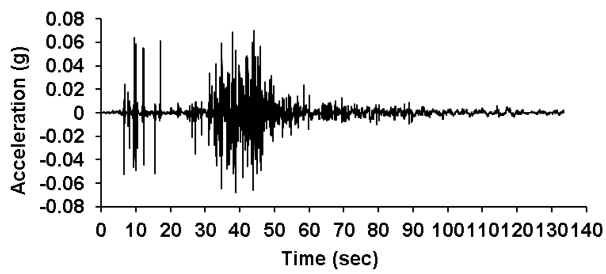


Fig. 5a. Record of accelerograph of vertical component of Bhuj earthquake 2001 at Bhuj station obtained from COSMOS online virtual data center.

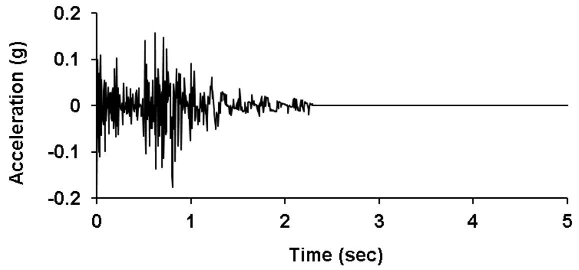
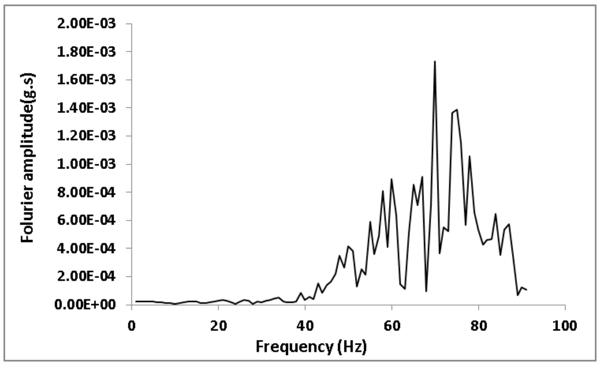
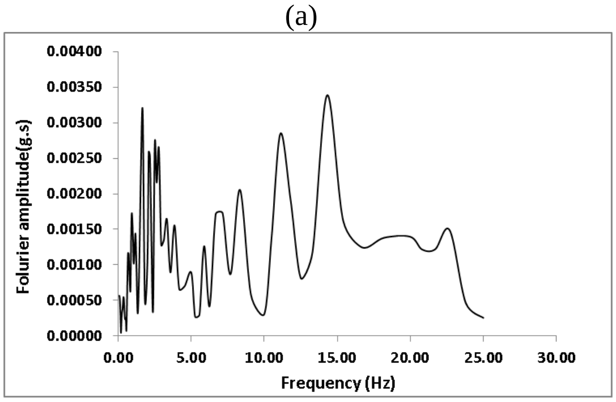


Fig. 5b. Record of accelerograph of vertical component of Chamba earthquake 1995 at Rakh station obtained from COSMOS online virtual data center.



(a)



(b)

Fig. 6. Fourier spectra of (a) Bhuj earthquake and (b) Chamba earthquake

6. Fourier spectrum

The Fourier response in the form of spectra indicates the ideal situation of variation in amplitudes at different frequencies.

Depends on the fundamental frequency for layered soil, it ranges from 3.97 to 6.75 Hz in sandy gravel, 4.42 to 29.35 Hz in clayey sand, 3.97 to 8.59 Hz in dry sand and 4.15 to 7.11Hz in clay, when input ground motions of 4.9 mb to 5.3 mb in magnitude are used in analysis at SHD site (Fig. 7).

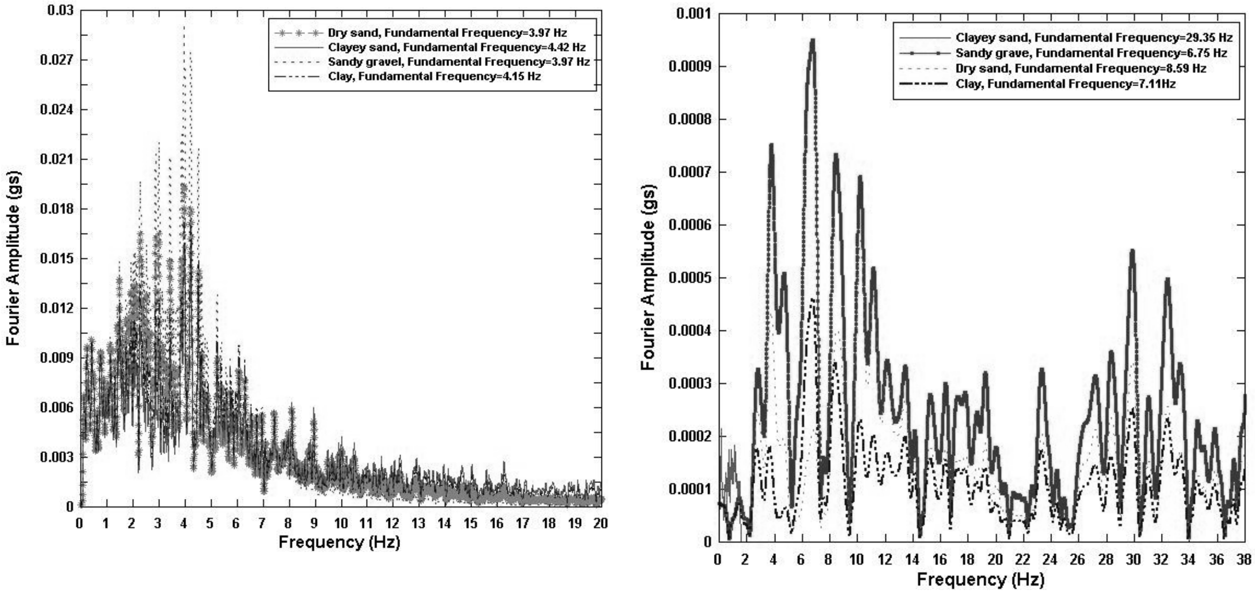
Similarly the fundamental frequency in gravel ranges from 4.223 to 4.74 Hz, in sand 4.221 to 4.69 Hz, in silty clay 4.221 to 4.69, when input ground motions of 4.9 mb to 5.3 mb in magnitude are used in the analysis at MUZ site (Fig. 8). This results when an event of magnitude less then 4.5 mb occurred in both areas then the subsoil are not affected but with passage of time fractures ay occure.

7. Response spectrum

In order to determine the peak responses of the soil layers, single degree of freedom is idealized as a system. Two acceleration records were used as an input motion having PGA values of 0.17 g and 0.07 g which were applied on sublayers (i.e. sand, gravel, clay) using EERA program. The analysis is done by keeping constant damping ratio of 5%.

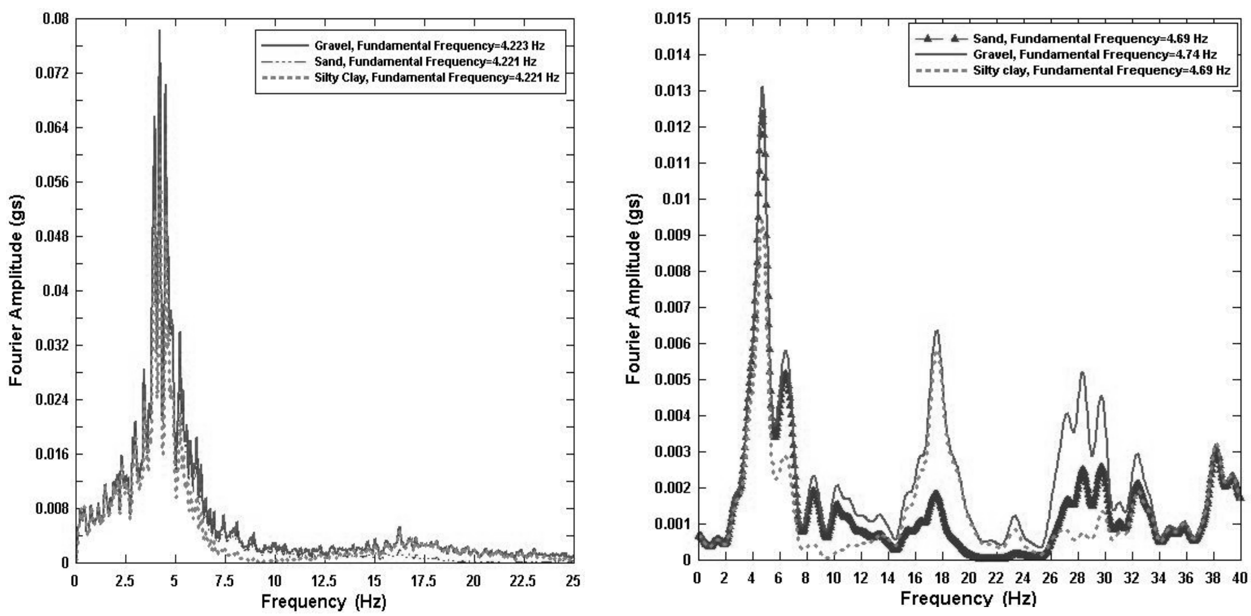
Depends on the thickness and depth of layers at SHD site, the spectral acceleration resulted 0.29g for sandy gravel, 0.16g for clayey sand, 0.20g for dry sand and 0.18g for clay when ground motion data of Bhuj earthquake is used as input (Fig. 9). Similarly, the spectral acceleration values resulted 0.05g for sandy gravel, 0.02g for clayey sand, 0.03g for dry sand and 0.03g for clay when ground motion data of Chamba Earthquake was used as input (Fig. 10).

Similarly for MUZ site, the spectral acceleration values for gravel, sand and silty clay resulted as 0.83 g, 0.79 g and 0.63 g respectively, when ground motion data of Bhuj Earthquake was used as input (Fig. 11).



(a) (b)

Fig. 7. Fourier amplitude spectra showing fundamental frequencies for different soil layers at SHD site (a) Bhuj earthquake and (b) Chamba earthquake.



(a) (b)

Fig. 8. Fourier amplitude spectra showing fundamental frequencies for different soil layers at MUZ site (a) Bhuj earthquake and (b) Chamba earthquake.

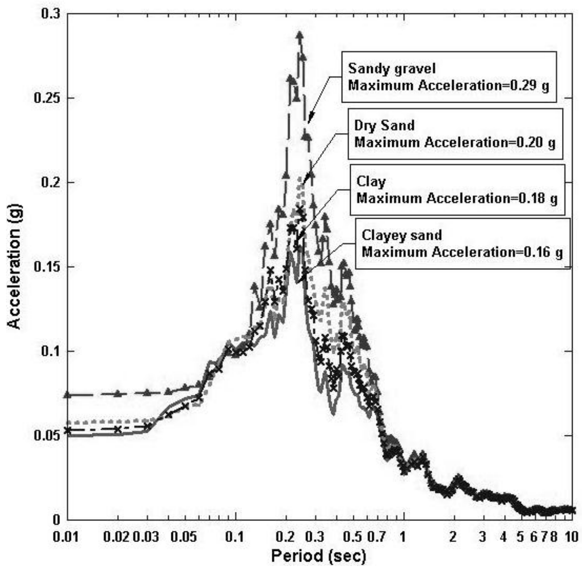


Fig. 9. Response spectrum curves for different soils at SHD site in upholes against the input motion of Bhuj earthquake with PGA values of layers.

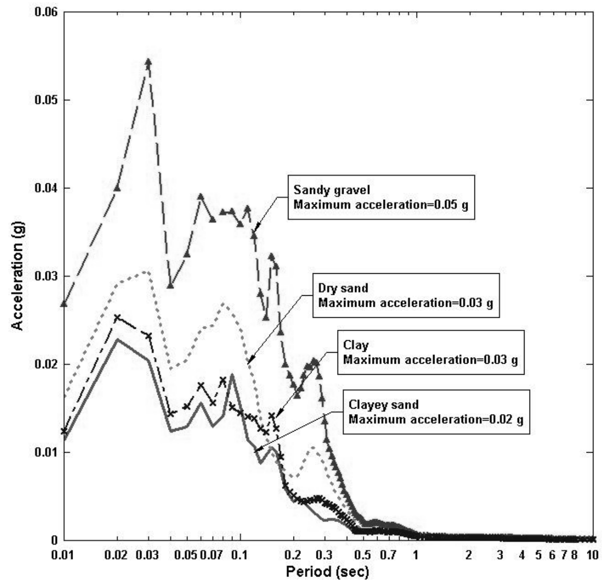


Fig. 10. Response spectrum curves for different soils at SHD site in upholes against the input motion of Chamba earthquake with PGA values of layers.

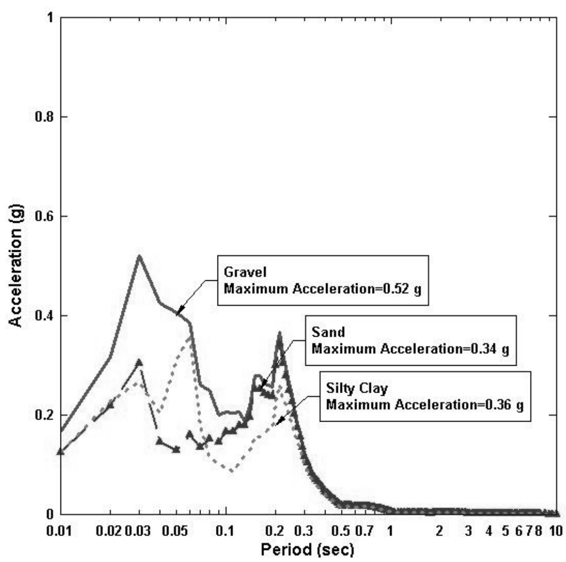


Fig. 11. Response spectrum curves for different soils at MUZ site in upholes against the input motion of Chamba earthquake with PGA values of layers.

The spectral acceleration values for gravel, sand and silty clay resulted as 0.52 g, 0.34 g and 0.36 g respectively, when ground motion data of chamba earthquake was used as input (Fig. 12).

By comparing spectral acceleration values obtained using two different ground motions the peak values in layered soil deposits are greater in case of larger magnitude as compared to smaller magnitude, this results that for larger magnitude the sites are less resistant (Figs. 13 and 14). Therefore according to design spectra there will be high risk of constructing large buildings and man-made structures at both sites. Spectral amplification ratio between ground surface and soil-bedrock and also between different layers of soil was computed for a particular acceleration levels. In the analysis the Fourier amplitude spectra were smoothened using a three point moving average that is repeated four times. This technique eliminates some noisy signals in the amplification spectra for the given fundamental frequency.

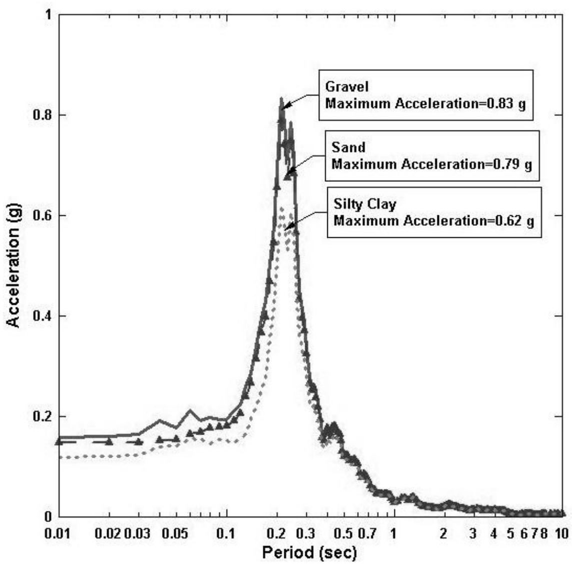


Fig. 12. Response spectrum curves for different soils at MUZ site in upholes against the input motion of Bhuj earthquake with PGA values of layers.

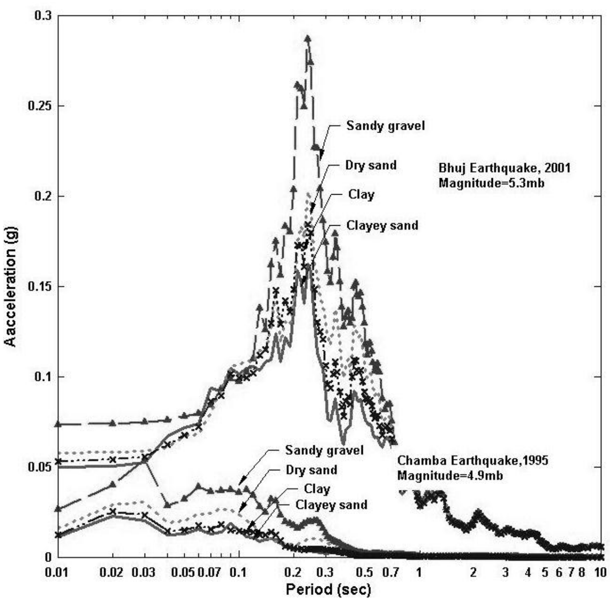


Fig. 13. Comparison of response spectrum curves for different soils at SHD site in upholes against the input motions of Bhuj and Chamba earthquakes.

The amplification spectrum predicts that soil deposits at SHD site and MUZ site have low level of amplification and attenuate earthquake acceleration of high level.

The amplification ratio varies from soil to soil corresponding to frequency at both sites. The results predict that the amplification ratio is high in sandy clayey material as compare to sandy gravel and dry sand.

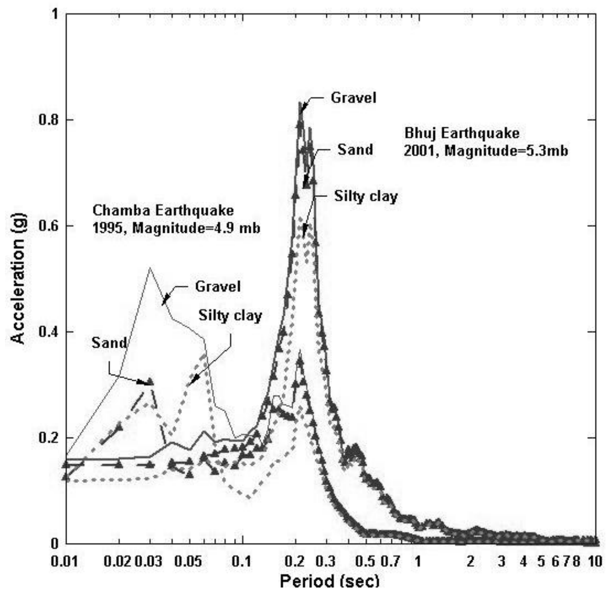


Fig. 14. Comparison of response spectrum curves for different soils at MUZ site in upholes and correspondent points for the two earthquake scenarios.

8. Summary and conclusions

The study areas are located in a moderate to high seismicity zone. The intensities of earthquakes according to historical and recent earthquakes at the sites were found to be V to IX in range on MMI scale. The areas are studied after the great Muzaffarabad earthquake, 2005. To obtain response spectra for design of structures the spectal acceleration values for layers deposited at the sites were defined using a computer program EERA.

The areas are found to be complex for man-made structures i.e., buildings, dams etc., this was the fact due to thickness, compaction and overburden pressures, and low velocity zones encountered at the sites.

Using linear approach the parameters for earthquakes of large magnitude and duration are easily simulated, which result in exeedance of the shear strength of the soil, and in turn results in high strain values.

The profiles of soils at both sites indicate the variation of velocities due to porosity, permeability properties.

At both sites amplification ratios were also calculated. These ratio are applied to the base rock spectra toe developed surface response spectra.

Acknowledgments

The author wishes to thank the directorate general of Petroleum Concession (DGPC), Islamabad for his contribution of data at SHD site, Geosciences Lahore for his contribution of data at MUZ site and COSMOS online virtual data center for strong motion data.

References

Hardin, B.O., Drnevich, V.P., 1972. Shear Modulus and Damping in Soils: I. Measurement and Parameter Effects; Journal of Soil Mechanics and Foundation Division, ASCE, 98(6), 603-624.

Hylland, M.D., Riaz, M., Ahmed, S., 1988. Stratigraphy and structure of Southern Gandghar Range, Pakistan. Geological Bulletin University of Peshawar, 21, 1-14.

Idriss, I.M., Seed, H.B., 1968. Seismic Response of Horizontal Soil Layers, Journal of the Soil Mechanics and Foundations Division, ASCE, 94 (4), 1003-1031.

Idriss, I.M., Joseph, I. S., 1992. User's Manual for Shake91, Center for Geotechnical Modeling, Department of Civil & Environmental Engineering, University of California, Davis, November.

MonaLisa, Khan, S., 2010. Non Linear Earthquake site response analysis of the layered soil deposits at Shakardarra and Muzaffarabad, PAPG/SPE Annual technical conference, November, 10, 415-423.

Schnabel, P.B., Lysmer, J., Seed, H.B., 1972. Shake a computer program for Earthquake Response Analysis of Horizontally Layered Sites, EERC, Report No. 72-12, University of California, Berkeley.

Seed, H.B., Idriss, I.M., 1970. Soil Moduli and Damping Factors for Dynamic Response Analysis, Report No. UCB/EERC-70110, Earthquake Engineering Research Center, University of California, Berkeley, December, 48.