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Site Amplification Factor at Mardan

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Abstract

This paper presents site response analyses for a site at Mardan Campus of University of Engineering and Technology Peshawar. This study is a part of extensive instrumentation to be installed at Mardan Campus under Pak-US Earthquake Collaborative Research Program funded jointly by Higher Education Commission (HEC) and USAID. This program included installation of two subsurface and surface accelerometers in three boreholes connected to a common data acquisition system. The three boreholes 50m, 100m, and 150m deep were drilled at 3m spacing. Laboratory tests were conducted on the samples retrieved from these boreholes. The in-situ tests, which included Standard penetration test, cone penetrations test, and cross-hole test, were also conducted in the boreholes to characterize the soil at the site. Shear wave velocities at 1m depth interval were determined using cross-hole tests up to 50m depth. Seismic hazard analysis was performed and peak ground acceleration for rock was computed. To incorporate the effects of local soil geology, two compatible real time histories were selected from the data bank of Pacific Earthquake Engineering Center. Equivalent linear site response analysis was performed using DeepSoil software. Amplification spectrum was developed for the site and site response factors have been computed.

Keywords: Site Response Analysis; Seismic Hazard; Amplification Factor

1. Introduction

Seismic hazard at a site is characterized by considering earthquake source, path parameters and soil conditions at the site. Seismic Macrozonational maps generally define seismic hazard incorporating the effects of the first two factors. It does not consider the effect of local site conditions; rather, assume the ground to be flat and rock. Since buildings and other structures, however, most often rest on soil and sometimes on sloppy ground, Seismic Microzonational maps are developed to consider local site conditions. These maps can be used for design of structures, vulnerability analysis and risk assessment, city planning and land use. Consideration of local site effects is very important to define site specific seismic hazard as there have been numerous failures recorded in the history due to this phenomena. Some examples of earthquakes in which local site effects caused failures are Michoacan earthquake (1985) in Mexico City, Loma Prieta 1989 in San Francisco Bay area, Kobe earthquake (1995), Spitak earthquake (1988) in Leninakan, Kocaeli earthquake (1999) in Adapazari, Chamoli earthquake (1999) and Bhuj earthquake (2001).

Pakistan is located in one of the most seismically active regions of the world. It has experienced many damaging earthquakes over the last 100 years which include 1935 Quetta earthquake of magnitude 7.5, 1945 Makran Coast earthquake of magnitude 8 and 2005 Kashmir Earthquake of magnitude 7.6. After Kashmir 2005 earthquake several efforts have been made to characterize seismic hazard in different cities of Pakistan. Some of these studies include MonaLisa et al. (2007, 2008), a study conducted jointly by Pakistan Metrological Department and NORSAR, Norway (2007), a country-wide study conducted by National Engineering Services Pakistan (NESPAK) for Building Code of Pakistan, seismic provisions 2007. All these research activities produce macrozonation maps for different cities of Pakistan that define seismic hazard in terms of peak ground acceleration on rock. However, no microzonation map, incorporating the effects of local site, is developed for any city of Pakistan. It is highly required to direct research and efforts towards microzonation of different sites in Pakistan. It is worth stating that the importance of local site effects has been recognized world-wide. Countries that lie in seismically active regions, have conducted such studies. India, being neighboring country of Pakistan and sharing similar seismo-tectonic environment as that of Pakistan, had its first Microzonation map developed in 2002 for Delhi (Mukhopadhyay et al., 2002), after which there has been frequent up-gradations and extension to other cities.

Efforts are currently underway in Pakistan to highlight the importance of site response analysis. One such study has been conducted experimentally in the research project titled "Building capacity in Pakistani Engineering Community for seismic hazard characterization, analysis, and mapping for Pakistan" under Pak-US Earthquake Collaborative Research Program funded jointly by Higher Education Commission (HEC), Pakistan and USAID, USA (Ahmad and Hashash, 2007). The research has been jointly conducted by the department of Civil Engineering, University of Engineering and Technology Peshawar, and The University of Illinois at Urbana-Champaign. One part of this project is to deploy accelerometers in the boreholes and at the surface at the Mardan Campus. At the event of an earthquake shaking, the three accelerometers will record the shaking at 50m, 25m, and at ground surface. This would give amplification of earthquake shaking due to local soil conditions.

This paper presents deterministic seismic hazard and site response analyses of the same site, wherein accelerometers have been installed. Amplification factor for the site is determined. Laboratory tests were conducted on the samples retrieved from three boreholes. In the field, Standard penetration test, cone penetrations test, and Cross-hole test were also conducted in the boreholes to characterize the soil at the site. Shear wave velocities at 1m spacing are determined using cross-hole tests up to 50m depth. The Project site has co-ordinates 34.10^{o} N, 72.00^{o} E and seismic hazard analysis was performed using sixteen (16) faults within one hundred (100) km around the site. Peak ground acceleration (PGA) for rock is computed. Two real time histories are selected from the data bank of Pacific Earthquake Engineering Center for site response analysis. Equivalent linear site response analyses have been performed using DeepSoil software. Amplification factors were found and surface response spectrums were compared with rock response spectrum.

2. Site characterization

The site is located in the Mardan Campus of University of Engineering and Technology Peshawar. Different geotechnical and geophysical test were conducted to characterize the site. Among these tests are standard penetration test (Fig. 1), cone penetration test, and Cross-hole test (Fig. 2). Design soil profile is given in Figure 3 with average shear wave velocity for each layer. Average shear wave velocity for upper 30m layer (V_{30avg}) is

$$V_{30\,avg} = \frac{\sum_{i=1}^{N} h_i}{\sum_{i=1}^{N} \frac{h_i}{V_i}} = 321 m/s$$

Where, h is the thickness of soil layer, and V is the respective shear wave velocity. This corresponds to site class D according to the Building Code of Pakistan-Seismic Provisions 2007. The site amplification factor of this site class is 1.40.

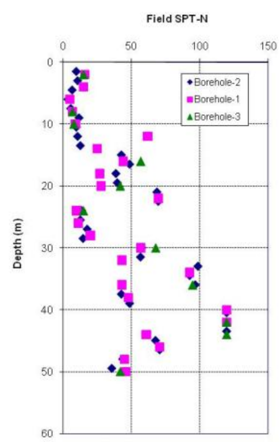


Fig. 1. Profile of Standard Penetration Test results

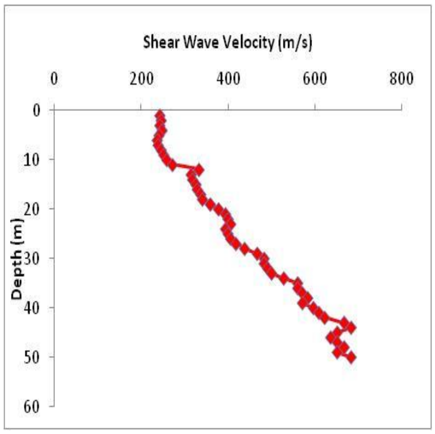


Fig. 2. Shear Wave Velocity profile

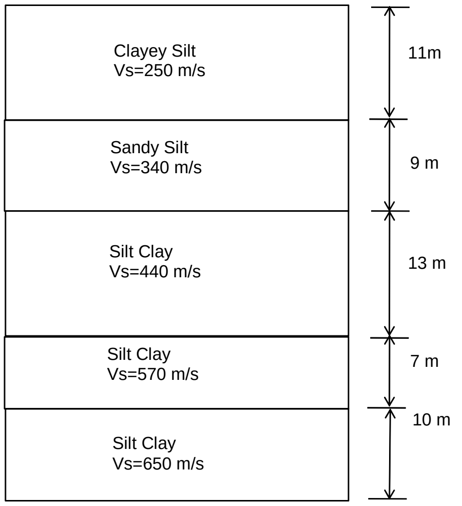


Fig. 3. Design soil profile

3. Seismic hazard analysis

Seismic Hazard analysis for Mardan site has been performed using deterministic approach. First, different faults likely to produce hazard at the site were identified and their characteristics found. Then using appropriate attenuation relationship, response spectrum produced by each fault is developed for rock site. Envelope of response spectra is selected for design and for selection of a suite of acceleration time histories. These time histories are used for site response analysis to incorporate the effect of local soil conditions in seismic hazard. Following is the detail.

3.1. Identification of faults

A total of sixteen faults are recognized potentially capable of producing significant ground shaking at the site of interest. The maximum magnitude that each fault could produce is estimated with Wells and Coppersmith (1994) regression relationship assuming half of the total fault length as ruptured length during earthquake. The maximum earthquake magnitudes along respective faults are mentioned in table 1.

3.2. Response spectra

Attenuation relationships are very important in seismic hazard analysis because they convert earthquake characteristics into strong motion parameters at site. In Pakistan, due to lack of strong motion data, no attenuation relationship could be developed. Therefore, equations are adopted from other regions of the world. After the advent of New Generation Attenuation (NGA) models, which have been developed using worldwide strong motion data base from shallow crustal earthquakes, their use in Pakistan is increasing. In this study Next Generation Attenuation model of Boore and Atkinson (2008) is selected for calculating the peak ground acceleration (PGA) and peak spectral accelerations at different time periods for response spectrum development.

Response spectra of seven faults are shown in Figure 4. Response spectra for the remaining faults do not have significant spectral accelerations and are therefore omitted from the graph for brevity. Two response spectra control at different time periods (Fig. 5). Panjal Fault control at short time periods, whereas Nowshera fault control for longer time periods. Envelope of these two response spectra (Fig. 6) is used for selection of time histories. Peak ground accelerations produced by selected faults are listed in table-1. Panjal thrust 30 Km away from the site has a potential for causing an earthquake of magnitude 8.0. This scenario produces largest peak ground acceleration of 0.186 g.

Table 1. Faults and their characteristics

S.NO	Name of Fault	Fault Length (km)	Mw	Joyner and Boore Distance (Rjb) km	PGA (g)
1	MMT	380	8.06	58.35	0.116
2	Panjal Fault	333	8	30.61	0.186
3	Oghi Fault	64.01	7.11	95.47	0.014
4	Nowshera Fault	78.77	7.22	19.43	0.179
5	Puran Fault	103.05	7.36	73.19	0.065
6	Darband Fault	53.78	7.02	67.57	0.061
7	Hissartang Fault	230	7.79	39.18	0.146
8	MBT	273.25	7.88	52.15	0.122
9	Khair-e-Murat Fault	190.34	7.69	77.55	0.074
10	Soan Backthrust	67.89	7.14	82.43	0.051
11	Kanet Fault	78.2	7.22	87.16	0.050
12	Ahmadwal Fault	84.41	7.26	93.81	0.046
13	Manshera Fault	52.18	7	84.12	0.047
14	Thakot Fault	85	7.3	78.86	0.059
15	Sangargali Fault	64.31	7.11	88.06	0.046
16	Kund Fault	77	7.2	26.48	0.148

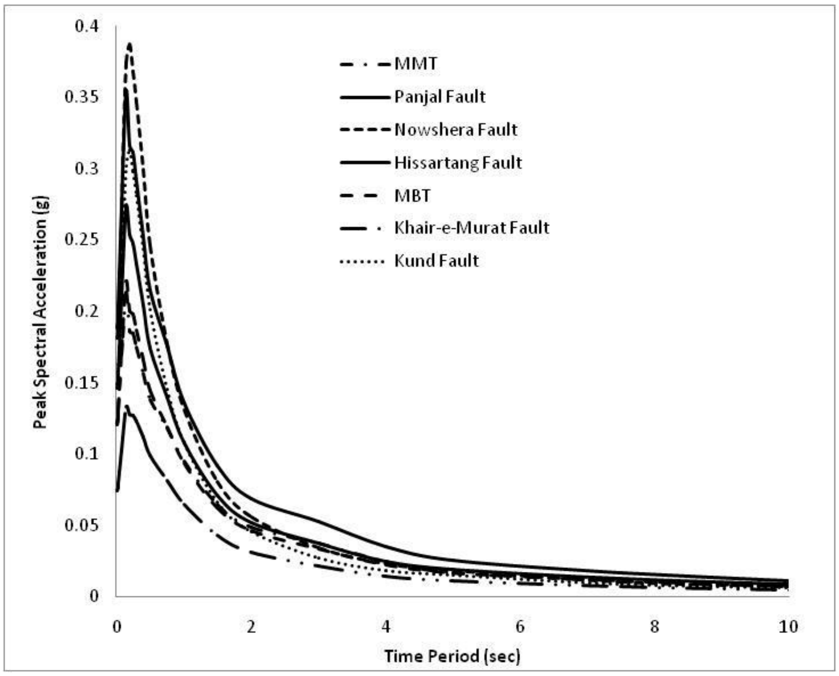


Fig. 4. Response spectra

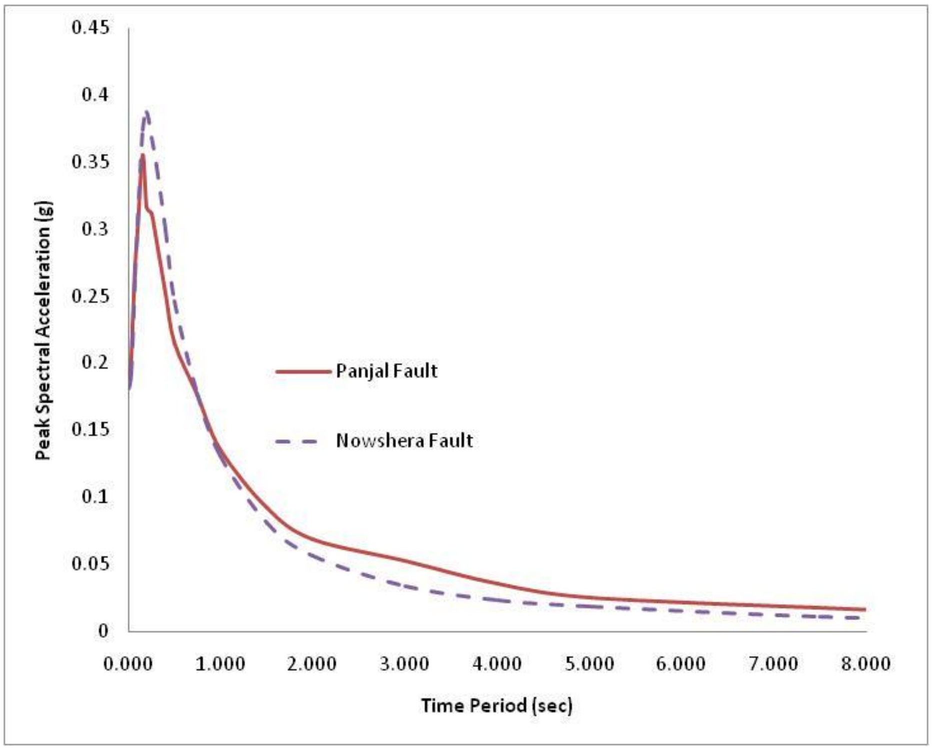


Fig. 5. Controlling response spectra at different periods

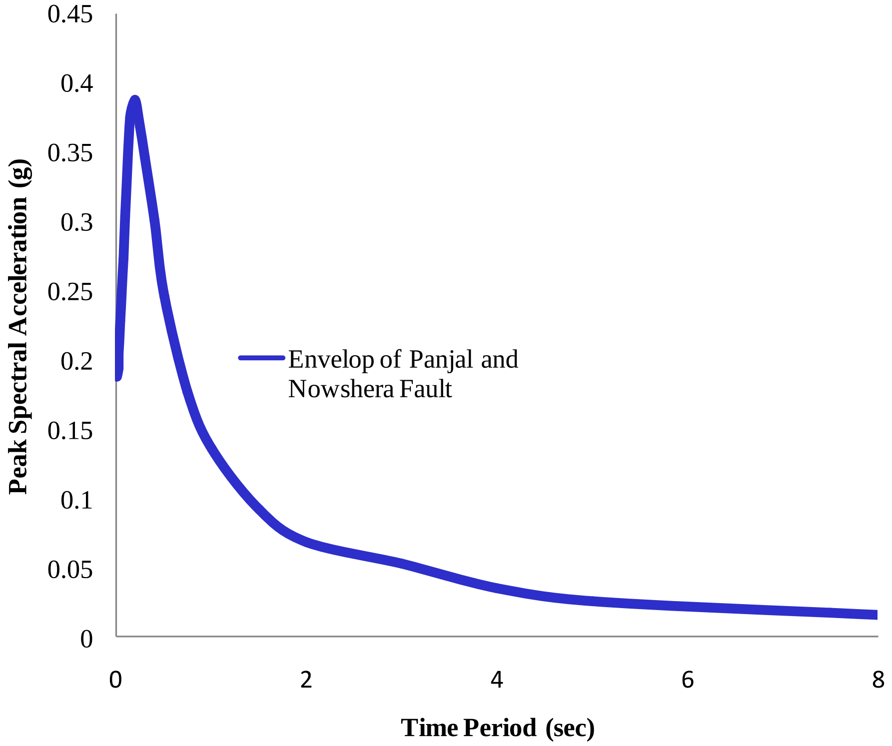


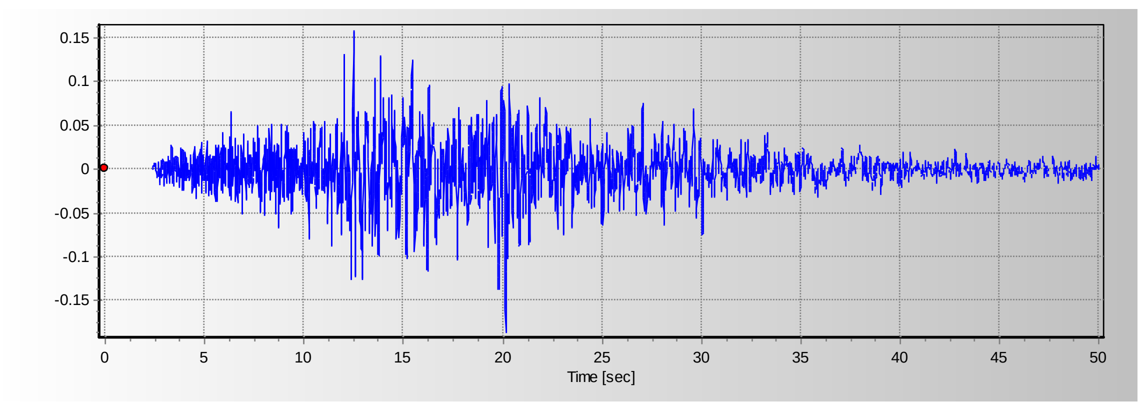
Fig. 6. Envelop of spectral ordinates

3.3. *Selection of time histories*

Two time histories (Table 2, and Fig. 7) are selected in this study for carrying out site response analysis. These time histories are taken from the database of Pacific earthquake engineering research center. These time histories are: Denali, Alaska 2002 earthquake of magnitude 7.9 with PGA of 0.0926g and Kocaeli, Turkey 1999 earthquake of magnitude 7.51 producing PGA of 0.1833 at the recording station. Both these PGAs are recorded at rock site. Scaling factor of 2.0 and 1.015 are used respectively to convert the recorded PGAs to target PGA of 0.186g. Response spectra of these time histories are compared with target response spectrum in Figure 8. This shows reasonable matching of the ordinates, particularly by averaging the ordinates of response spectra of the two selected time histories (Fig. 9).

Table 2. Parameters of acceleration time histories

Earthquake	M	Rjb (km)	Vs (m/s)	PGA	Scaling factor
Denali, Alaska2002-11-03	7.9	49.94	963.9	0.0926	2.0
Kocaeli, Turkey 1999-08-17	7.51	7.57	792	0.1833	1.015



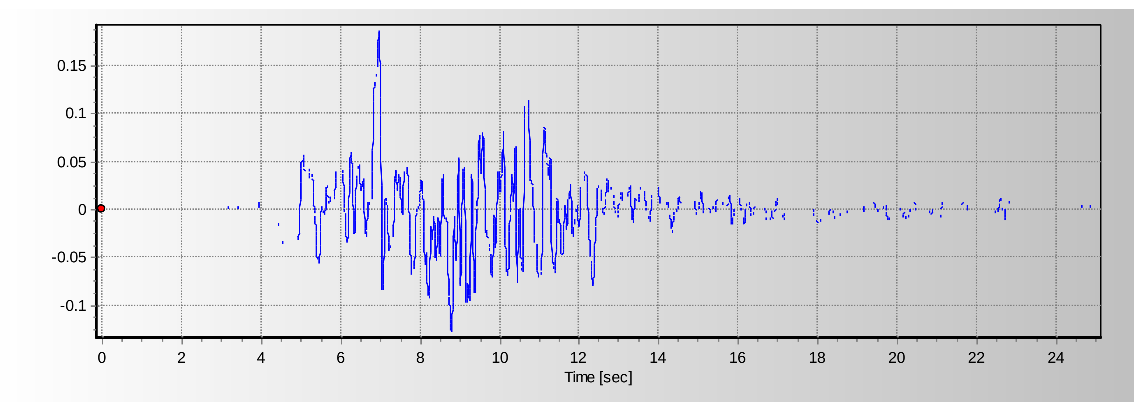


Fig. 7. Scaled acceleration time histories (Denali, Alaska (top) and Kocaeli, Turkey (bottom)

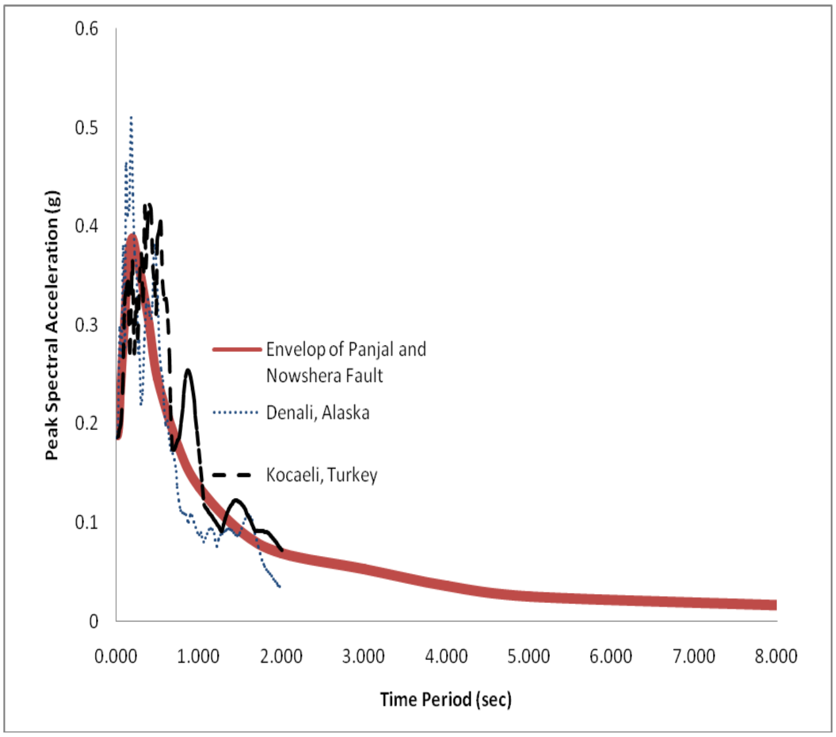


Fig. 8. Two scaled response spectra Vs design response spectrum

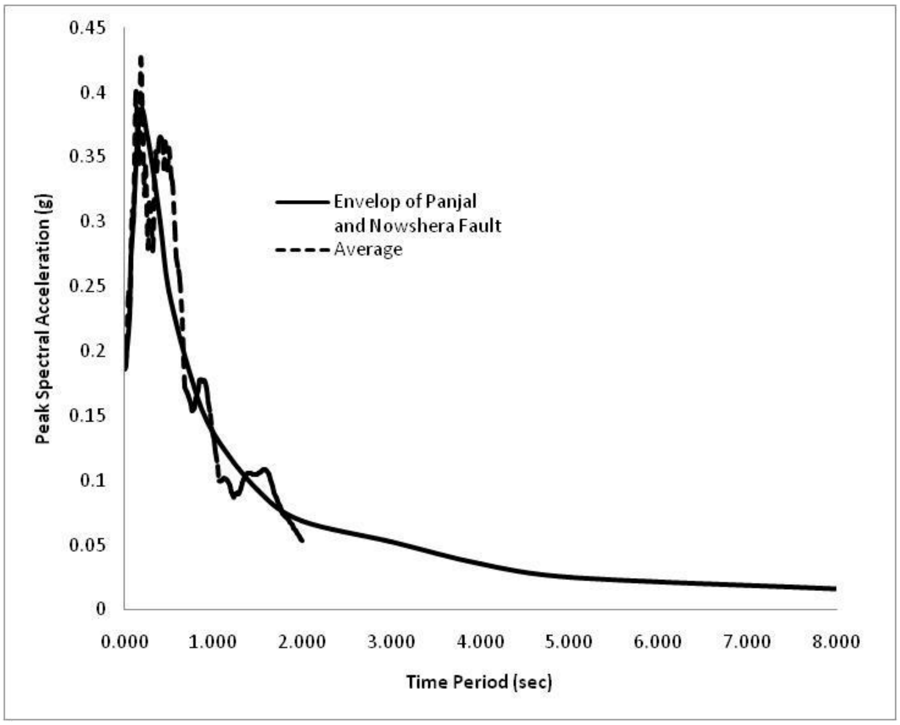


Fig. 9. Target response spectrum Vs average response spectrum

3.4. Site response analysis

The design soil profile is excited with two time histories to determine the dynamic response of local soil. Equivalent linear approach is used for site response analysis. The stiffness and damping properties of soil layers are used from the Deepsoil material library based on Vucetic & Dobry, 1991. This requires plastic index (PI) of the soil layer and effective stress at the point of interest in the soil.

The soil column is excited at the bottom with time histories shown in Figure 7. As the seismic waves travel up and down, the soil vibrates. The acceleration of soil at the ground surface is shown in Figure 10. It is noted that the PGA and the ordinates of the response spectra increased. The amplification factors (defined as PGA recorded at ground surface divided by rock PGA) are determined as;

Amplification Factor = PGA recorded at ground surface / rock PGA

Amplification Factor (For Denali, Alaska earthquake) = 0.265/0.186 = 1.42

Amplification Factor (For Kocaeli, Turkey earthquake) = 0.236/0.186 = 1.27

The amplified response spectra for the two earthquake excitations are given in Figure 11.

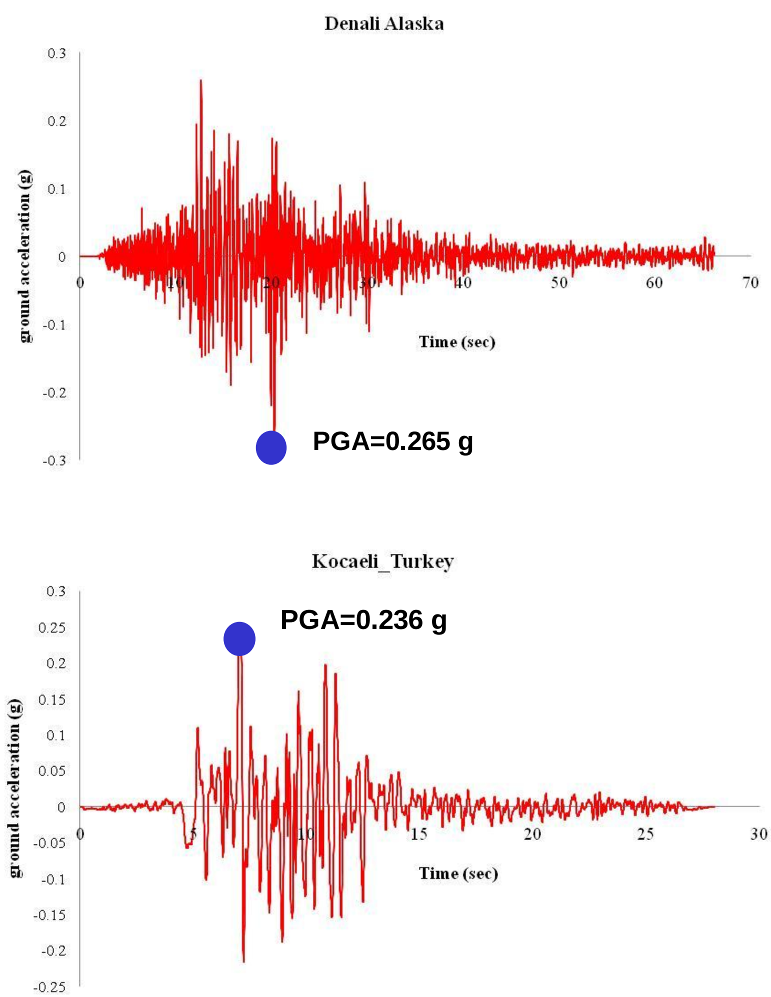


Fig. 10. Time histories for local site effects

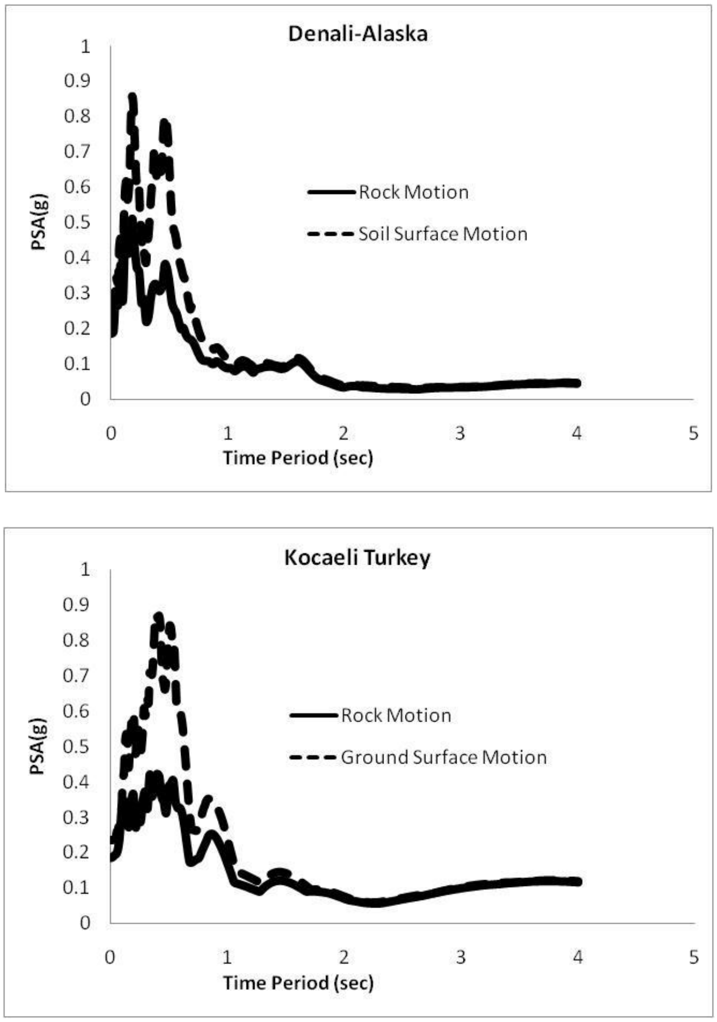


Fig. 11. Response spectra for soil and rock

4. Conclusions and Recommendations

Site response analysis has been carried out which would subsequently be verified through actual instrumentation as well. Site response factors for PGA are found to be 1.42 and 1.27 with average of 1.34 which is close to 1.4 specified by Pakistan Building Code. Surface Response Spectra, surface accelerograms, amplification factors are developed that take into account the effect of local geology. These products can be used for pseudo-static and dynamic analysis of structures. This paper also demonstrates the relationship of different disciplines like seismology, geology, geotechnical and structural engineering. The geologists identify different faults and their characteristics while seismologists work on the seismicity of the faults and hazard analysis. The geotechnical engineers incorporate the effect of local site into hazard and find its effects on soil itself and underground and above ground structures. The results are used by structural engineers for the analysis and design of structures. All these experts must work together to realistically propose surface motion for the structure. The procedure just described in this paper can be extended to develop Microzonation map for different cities of Pakistan, amplification Factors for Code, and design response spectrum for Code.

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