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Deterministic seismic hazard analysis for Peshawar, Pakistan

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Abstract

Ground motion estimation for a site (34.01^{o}N, 71.45^{o}E) located in the Peshawar in terms of Peak Ground Acceleration (PGA) values is conducted. It is carried out with deterministic seismic hazard analysis approach using faults sources within a radius of one hundred kilometers around site. The results of this study indicate that the Main Boundary Thrust located at a distance of twenty nine (29) kilometers from the site with a maximum potential moment magnitude of 8.1 is potentially the most seismogenic source for an earthquake in the region. Such a scenario earthquake may generate a design earthquake with PGA values of 0.232 g in Peshawar. PGA map for area surrounding the site (33.75^o-34.15^{o}N; 71.29^o-71.50^{o}E) is also developed in this study. This map shows that the peak-ground acceleration values are highly variable around the site.

Keywords: Deterministic seismic hazard analysis; PGA Map; Deterministic response spectrum; Peshawar

1. Introduction

Seismic hazard assessment refers to estimation of ground motion parameters like peak-ground acceleration or peak-ground velocity, which are commonly used in earthquake-resistant design of structures. It is employed by two basic methodologies; one is known as the deterministic and the other, as the probabilistic seismic hazard analysis. In this study seismic hazard analysis for a site in Peshawar (34.01^{o}N, 71.45^{o}E) is performed with the deterministic approach.

Peshawar is the capital city of the Khyber Pakhtunkhwa province of Pakistan. The seismic hazard in Peshawar is aggravated by increasing vulnerability due to population growth and expansion in infrastructure due to its political and regional importance. It is located in the western Himalayan region characterized by high seismicity rates due to its vicinity to the active plate boundary between the Indian and Eurasian plates which are converging at rates of 37-42 mm/year (Chen et al., 2000; Shen et al., 2000). The Main Boundary Thrust (MBT) system along which the devastating Kashmir earthquake occurred in 2005 is located in the northern parts of the country together with some other active regional fault systems, which include Main Mantle Thrust (MMT) and Main Karakorum Thrust (MKT). These faults, if reactivated can act as a potential source of seismic hazard for the region including Peshawar.

The Building Code of Pakistan, Seismic Provisions (MOHW-PEC-NEPAK, 2007) conducted country-wide seismic hazard studies using probabilistic seismic hazard approach and smeared seismicity. This study used Boore et al. (1997) and three more attenuation relationships. The other three relations are not mentioned in the study.

According to MOHW-PEC-NEPAK (2007), Peshawar is placed in Zone 2B. The Zone 2B has Peak Ground Acceleration (PGA) in the range of 0.16g to 0.24g for a return period of 475 years. In comparison, this study uses deterministic seismic hazard analysis utilizing characteristics of discrete faults. In addition, Boore and Atkinson (2008) Next Generation Attenuation (NGA) attenuation relationship is selected for this study following Cotton et al. (2006) selection criteria. In the process, the study leads to developing deterministic response spectrum for Peshawar.

2. Seismic hazard analysis

Seismic hazard analysis for a site can be carried out with two approaches. These approaches are known as Deterministic Seismic Hazard Analysis (DSHA) and Probabilistic Seismic Hazard Analysis (PSHA). The DSHA approach consists of identification of potential sources, which in conjunction with appropriate ground-motion attenuation models yields expected ground shaking for the target area. PSHA is similar to deterministic approach except that the source seismicity is characterized using a recurrence relationship and the uncertainties in the size, location and in ground motion modeling is taken into account.

In the current study, seismic hazard analysis for a selected site in the University of Peshawar (34.01^{o}N, 71.46^{o}E) is carried out using DSHA. The faults likely to produce considerable shaking at the site are selected by considering one hundred kilometer radius circle around the site. The faults falling within this region are identified and their characteristics are determined. Then by using the selected attenuation relationship of Boore and Atkinson (2008), response spectrum is developed considering site as rock having shear wave velocity value of 760 m/s.

A composite fault map is developed to conduct this study (Fig. 1). The characteristics of individual faults are obtained from a compilation of the published maps and cross-sections of the region (Khan et al., 2010). These characteristics include dip values, dip direction, mechanism (i.e., sense of movement), length and total depth. A total of twenty one faults are considered and these faults along with their various properties are listed in Table 1.

2.1. Attenuation relationship

Pakistan lacks indigenous ground motion attenuation equation due to the lack of strong motion data. Therefore, attenuation equations are commonly adopted from those developed in different regions of the world having established datasets for strong motion. A summary of the attenuation equations used in the past studies are described in Table 2.

If these attenuation relationships are carefully reviewed, it is noticed that the above list includes attenuation relationships developed for both shallow crustal zones as well as for subduction zones. The equations of Youngs et al. (1997) and Atkinson and Boore (2003) are developed for subduction zones and the rest are developed for crustal earthquakes active tectonic regions. Usage of published attenuation models without critically evaluating the tectonic settings for the regions these were originally developed for and their compatibility to tectonic settings in Pakistan is problematic and may yield unrealistic results.

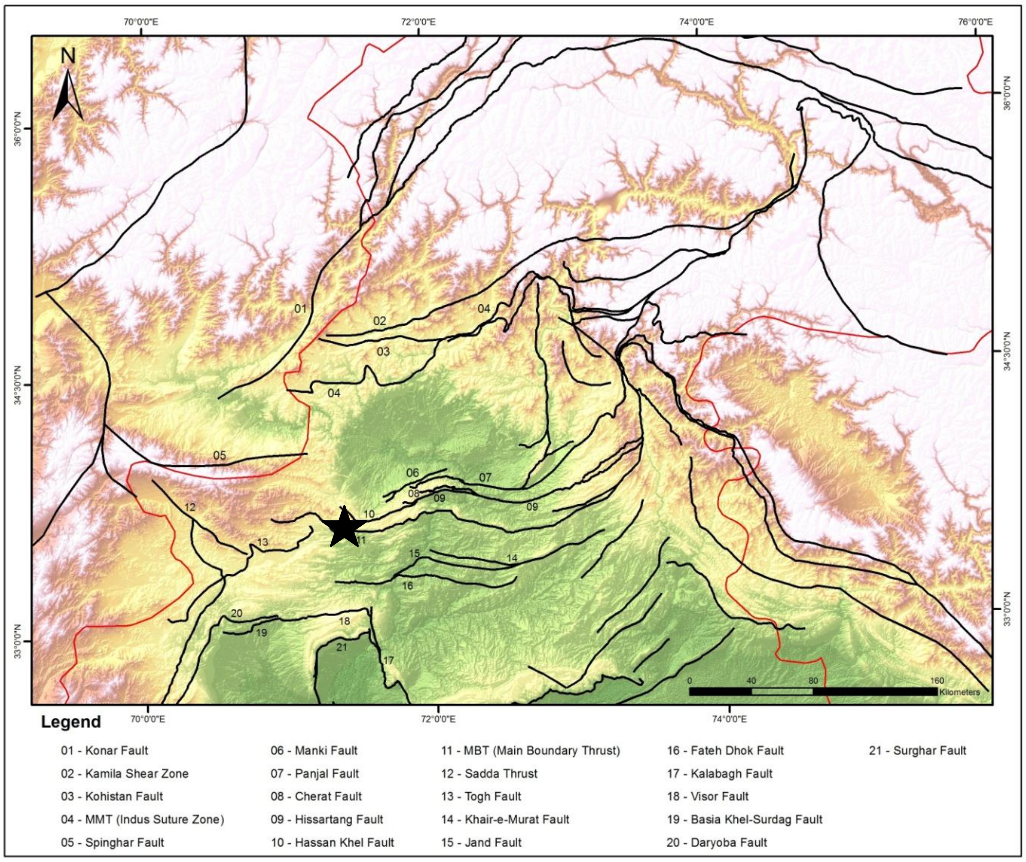

Fig. 1. Tectonic map of northern Pakistan and NE Afghanistan showing major regional faults (after Khan et al., 2011), star denotes the site location.

Table 1. Seismogenic faults in the surroundings of Peshawar, Pakistan.

S. #	Name	Mechanism	Dip value (Degree)	Dip Direction	Length (Km)	Depth (Km)
1	Konar fault	Reverse	30	-	170	8.0
2	Kamila Shear Zone	Reverse	60	North	333	8.0
3	Kohistan Fault	Strike-Slip	70	-	84	8.0
4	MMT (Indus Suture Zone)	Reverse	35	North	215	8.0
5	Spinghar Fault	Strike-Slip	70	-	140	8.0
6	Manki Fault	Reverse	35	North	45	8.0
7	Panjal Fault	Reverse	35	North	195	8.0
8	Cherat Fault	Reverse	30	North	40	1.5
9	Hissartang fault	Reverse	35	North	169	3.0
10	Hassan Khel Fault	Reverse	35	North	59	3.0
11	MBT (main Boundary Thrust)	Reverse	35	North	381	4.0
12	Sadda Thrust	Reverse	60	-	80	8.0
13a	Togh Fault I	Reverse	35	North	58	4.0
13b	Togh Fault II	Strike Slip	90	-	74	4.0
14	Khair-e-Murat Fault	Reverse	30	North	116	2.0
15	Jand Fault	Reverse	30	North	135	2.0
16	Fateh Dhok Fault	Reverse	30	North	89	2.0
17	Kala Bagh Fault	Strike Slip	90	North	52	3.0
18	Visor Fault	Reverse	40	North	45	3.0
19	Basia Khel-Surdag Fault	Reverse	40	North	58.0	3.0
20	Daryoba Fault	Reverse	30	North	42.0	2.0
21	Surghar Fault	Reverse	45	North	80.0	2.0

Table 2. Attenuation Relationships used in seismic hazard analyses in Pakistan in previous studies.

S. No	Attenuation Relationships	Previous Seismic Hazard Assessment Studies in Pakistan
1	Ambrassey et al. (1991)	Khan et al. (2003)
2	Ambrassey et al. (1996)	MonaLisa et al. (2007) Khan et al. (2003)
3	Ambrassey et al. (2005)	Kim and Elnashai (2009) NORSAR-PMD (2007)
4	Boore et al. (1997)	MonaLisa et al. (2007) Building Code of Pakistan (2007)
5	Boore and Atkinson (2008) NGA	Ahmad et al. (2010)
7	Campbell and Bozogania (2003)	Kim and Elnashai (2009)
8	Youngs et al. (1997)	Kim and Elnashai (2009)
9	Atkinson and Boore (2003)	Kim and Elnashai (2009)

Cotton et al. (2006) presented guidelines for selection of attenuation equations for regions where local equations do not exist. These guidelines are listed in Table 3, together with an evaluation of published international attenuation relations for usage in Pakistan. For this study, the relationship of Boore and Atkinson (2008) NGA is selected. This model estimates peak ground acceleration value and 5% damped spectral acceleration values for PGA and spectral periods from T= 0.01 seconds to 10.0 seconds. Boore and Atkinson (2008) NGA is developed by regression analysis of strong motion databank complied by PEER NGA (Pacific Earthquake Engineering Centre; Next Generation Attenuation) project for shallow crustal earthquake in active environments. This model considers faulting style, site characterization in terms of site specific shear wave velocity and gives good coverage for short and long periods. The strong-motion dataset used for its development has wide coverage including important earthquakes like Chi-Chi Taiwan, 1999 and Kocali Turkey, 1999. Moreover, worldwide applicability of NGA has also been demonstrated by a number of researchers (e.g., Boore, 2010; Taheri et al., 2010).

2.2. Maximum potential magnitude and PGA values

The maximum potential magnitude of each fault is determined by Wells and Coppersmith (1994) relationship between surface rupture lengths and magnitude values. Half lengths of the faults are assumed to rupture and are used to determine the expected magnitude values.

Peak ground acceleration values are obtained using attenuation equation of Boore and Atkinson (2008). These values are determined for rocks assuming a shear wave velocity of 760 m/s. The peak ground acceleration for each fault and Joyner and Boore (R_{JB}) distances are given in Table 4. Joyner and Boore distance (R_{JB}) is defined as the distance of the site to the nearest projection of fault on Earth surface (Boore and Atkinson, 2008). Joyner and Boore (R_{JB}) distances are calculated for each fault using dip values and depth of the faults.

3. Deterministic response spectrum

Peak ground acceleration value does not correlate well with the damage potential of an earthquake (PMD and NORSAR, 2007). Therefore, modern building codes base their measurement of seismic hazards on spectral values (Bhatti et al., 2011). Response spectra describe the spectral values of the amplitude. Therefore, deterministic response spectrum for the governing MBT is developed using the selected attenuation relationship of Boore and Atkinson (2008). The response spectrum for Peshawar is shown in Figure 2. The figure shows that the peak spectral acceleration is about 0.451 g for a structure with fundamental time period of 0.15 sec.

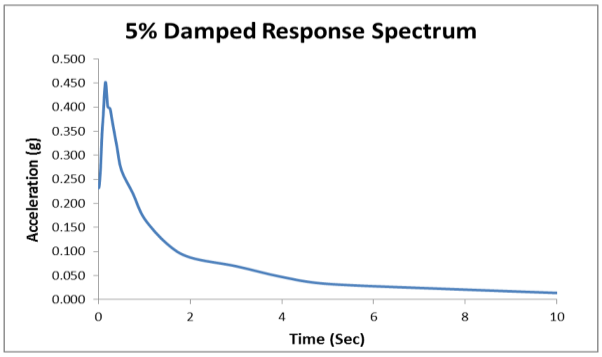

Fig. 2. Deterministic Response Spectrum for MBT.

4. Peak ground acceleration map

Peak ground acceleration intensity map is shown in Figure 3. Site location is indicated by a star in the figure. The developed map has coverage from (33.75°-34.15° N; 71.29°-71.50° E) around the selected site and total of twenty five (25) points at which PGA values were determined to compile this map.

5. Discussions and conclusions

It is generally advisable to use Deterministic Seismic Hazard Analysis (DSHA) for seismic hazard assessment in conjunction with Probabilistic Seismic Hazard Analysis (PSHA), particularly for regions where seismicity data is inadequate in quality and quantity. This is particularly true for Pakistan, where instrumental earthquake data cover hardly past 50 years

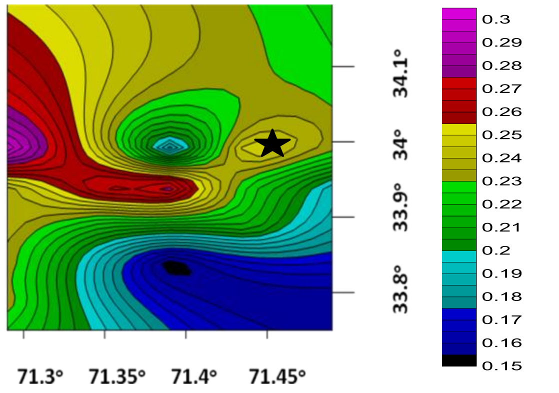

Fig. 3. PGA (g) contour map (Star is showing the location of the site).

Using DSHA in this paper, the peak ground acceleration of 0.238g is estimated at the selected site at Peshawar, which is within the range of PGA (0.16g to 0.24g) proposed by Building Code of Pakistan. However, the PGA values are exceeding 0.24g limit to the south of the site. The deterministic response spectrum developed in this paper indicates peak spectral acceleration of 0.452g at fundamental time period 0.15sec of the structure. For the higher time periods the spectral acceleration decreases (Fig. 2). The structures with time period of 0.15 seconds are critical for the scenario earthquake.

Peak ground acceleration map for site is developed which shows peak ground acceleration values are highly variable with maximum of 0.30g at the extreme south. This variation is caused by variations in distances to accusative faults. These high values to the south are due to the increasing proximity to the MBT.

The response spectrum presented is only for the site. It has been developed for rock site having shear wave velocity of 760 m/s. The soil effects are not considered in the study due to un-availability of shear wave velocity for soil layers. Where shear wave velocity for soil layers becomes available the respective amplification factor given in Building Code of Pakistan can be multiplied with the spectral values to get amplified values.

Table 3. Evaluation of published international attenuation relations in the context of Pakistan, using criteria of Cotton et al. (2006).

	Guidelines for Evaluation of published attenuation relationships	Evaluation in the context of Pakistan
1.	Comparison of tectonic setting of the host region (for which the attenuation relations were originally established) with that of the target region. If the target region tectonic setting is different from the host, then model should be eliminated.	The candidate attenuation relationships for north Pakistan should be the one developed for the active tectonic crustal earthquake region. This excludes Youngs et al. (1997) and Boore and Atkinson (2003) relationships which were specifically developed for active subduction tectonic settings.
2.	The candidate attenuation relationship should be published in an international peer-reviewed journal.	All the previously used in Pakistan were published in the international journals. Therefore no elimination is made.
3.	The documentation and its underlying dataset should be sufficiently extensive.	All the attenuation relationships listed in Table (2) have substantial dataset information.
4.	The candidate attenuation relationship should not have been superseded by the recent publications.	Attenuation equations of Ambrassey et al. (1991) and Ambrassey et al. (1996) are excluded on the basis of their updating by Ambrassey et al. (2005).
5.	The frequency range of the candidate attenuation relation should be appropriate for engineering applications.	Since we are using PGA values, only upper frequency limit of equation was considered and no elimination is made.
6.	The candidate attenuation relationship should have appropriate function form.	Campbell and Bozorgnia (2003) is excluded due to its complex functional form and Ambrassey et al. (2005) is not considered because it does not consider quadratic relationship of magnitude in its functional form and due to the fact that dependent variable in the functional form is not a continuous function of the site shear wave velocity.
7.	The candidate attenuation relationship regression co-efficient or regression method is appropriate.	No elimination is made considering this guideline as all the attenuation relationships have appropriate regression co-efficient and regression methods.

Table 4. Maximum Magnitudes potential of faults and expected PGA values.

S.No	Fault	Maximum Potential Magnitude (Mw)	Joyner and Boore Distance (R_{JB})	Site Location	PGA (g)
1	Konar Fault	7.6	73.30	Hanging wall	0.075
2	Kamila Shear Zone	8.0	83.0	Footwall	0.080
3	Kohistan Fault	7.3	76.0	Footwall	0.062
4	MMT (Indus Suture Zone)	7.8	51.0	Footwall	0.118
5	Spinghar Fault	7.5	25.0	-	0.174
6	Manki Fault	6.9	27.0	-	0.123
7	Panjal Fault	7.7	27.0	Footwall	0.178
8	Cherat Fault	6.9	50.0	-	0.079
9	Hissartang Fault	7.6	42.0	-	0.127
10	Hassan Khel Fault	7.1	19.0	Hanging wall	0.174
11	MBT (Main Boundary Thrust)	8.1	22.0	Hanging wall	0.232
12	Sadda Thrust	7.2	81.0	-	0.054
13a	Togh Fault I	7.1	46.0	-	0.093
13b	Togh Fault II	7.2	82.0	-	0.052
14	Khair-e-Murat Fault	7.4	69.0	-	0.073
15	Jand Fault	7.5	75.0	Hanging wall	0.069
16	Fateh Dhok Fault	7.3	72.0	Hanging wall	0.065
17	Kala Bagh Fault	7.0	93.0	-	0.040
18	Visor Fault	6.9	92.0	Hanging wall	0.038
19	Basia Khel-Surdag Fault	7.1	95.0	Hanging wall	0.043
20	Daryoba Fault	6.9	97.0	-	0.037
21	Surghar Fault	7.2	100.0	Hanging wall	0.040

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