SEISMIC HAZARD ANALYSIS OF ISLAMABAD

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ABSTRACT

Seismic Hazard Analysis (SHA) is carried out for the city of Islamabad using both deterministic and probabilistic approach. Earthquake catalogue compiled by National Engineering Services Pakistan (NESPAK) for the period of (1505-2006) has been used. All Quaternary faults in the vicinity of Islamabad have been considered for deterministic hazard analysis. Seismic zoning map of NESPAK has been utilized in the research. Earthquake catalogue contains total of 11,149 events. Earthquake events of moment magnitude (Mw>4.0) are taken for developing the recurrence relationships of selected four (04) seismic source zones. The attenuation equation of Boore and Atkinson 2008 next generation attenuation (BA08 NGA) has been used for the determination of the ground motion parameters. Maximum PGA of 0.49g by BA08 NGA obtained for Islamabad at rock site due to Main Boundary Thrust (MBT). In PSHA using the Crisis-2007 software, PGA values with 10% probability of exceedance in 50 years i.e. the return period of 475 years have been determined. The PGA results obtained at bedrock are 0.28g by BA08 NGA attenuation relation.

Key words: *Seismic Hazard Analysis (SHA), Peak ground acceleration (PGA), Probabilistic Seismic Hazard Analysis (PSHA), Deterministic Seismic Hazard Analysis (DSHA)*

INTRODUCTION

Pakistan is located in a seismically active region of the world and lies at the junction of Indian and Eurasian plate as shown in the Figure 1. Most of earthquakes in Pakistan are generated as a result of the collision between the Indian sub-continent and the Eurasia. Indian plate is moving to the north at a rate of about 4-5 cm/year. The collision causes the compression and uplift forming the Himalaya, Karakoram and Hindu Kush mountain ranges as shown in Figure 2. Although the historical record of Pakistan earthquakes is incomplete, but still some information is available regarding the intensity measures for many past earthquakes. An earthquake of Intensity (X) hit Taxila (the main centre of the Buddhist civilization) in 25AD and turned it into ruins (Pakistan Meteorological Department (PMD), and NORSAR, Norway[2] -2006). Another earthquake occurred in 1555 near Saringar, which caused substantial damage to the area (Earthquake Engineering Field Investigation Team[3] (EEFIT) 2006). It is believed that this earthquake had greater magnitude than the Kashmir earthquake of October 08, 2005. Some other earthquakes that have affected Pakistan in the past are the Kunnar earthquake of 1842 (Mw=7.5), Abbottabad earthquake of 1878 (Mw=6.7), Sarinagar earthquake of 1885 (Mw=6.3) and the Kangra earthquake of 1905 (Mw=7.8) (EEFIT[4] Mission report-2005). The most recent large earthquakes that have occurred in Pakistan are the Quetta earthquake of 1935 (Mw=7.5) and the Pattan earthquake of 1974 (Mw=6.2) (Bilham[5]-2005). The deadliest earthquake in the subcontinent was the earthquake of October 08, 2005 (Kashmir earthquake), which occurred along the MBT zone at the western limb of the Hazara-Kashmir Syantaxis (Hussain[6]-2008) and its rupture mechanism is shown in Figure 3 and 4. The Kashmir earthquake enhanced the consciousness about the SHA to be carried out properly due to the growing population, as more and more people are concentrated in smaller and larger cities and frequently in buildings with poor seismic resistance capacities. A summary of the most notable SHA studies in Pakistan is given in Table 1.

In this research, deterministic and probabilistic seismic hazard analyses are carried out for Islamabad city at location of 33.7118° N, 73.058° E). This site is the location of Islamabad stock exchange (ISE) building a high rise building of twenty one stories, and is located just two kilometers from Main Boundary Trust (MBT). The available recoded earthquake data, fault

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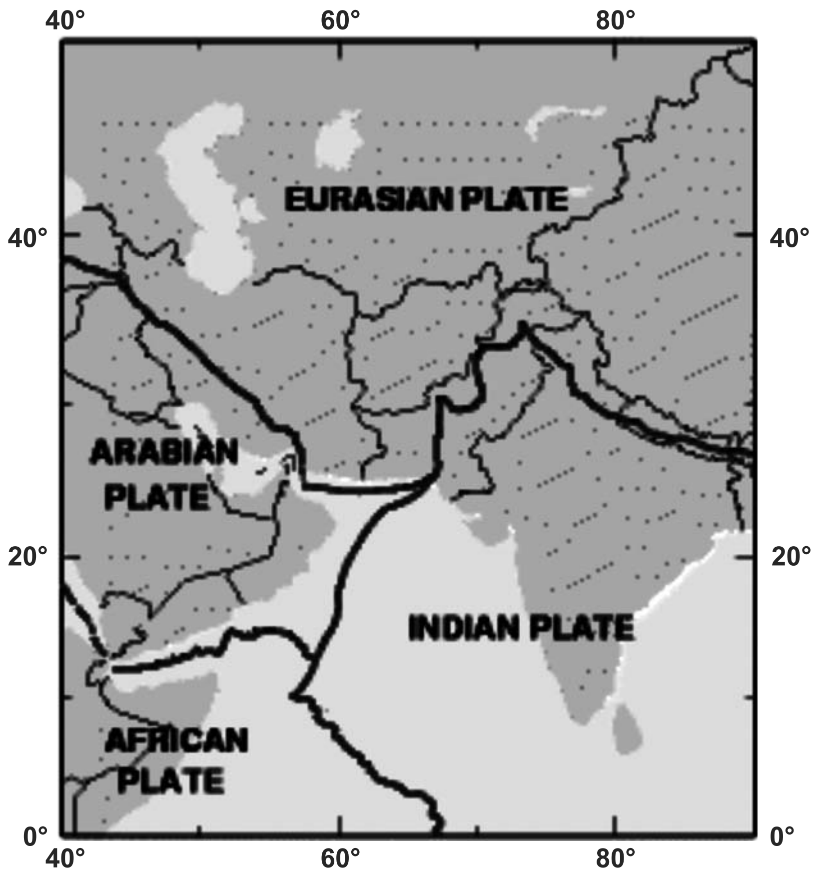

Figure 1: Tectonic setting of Pakistan (USGS)

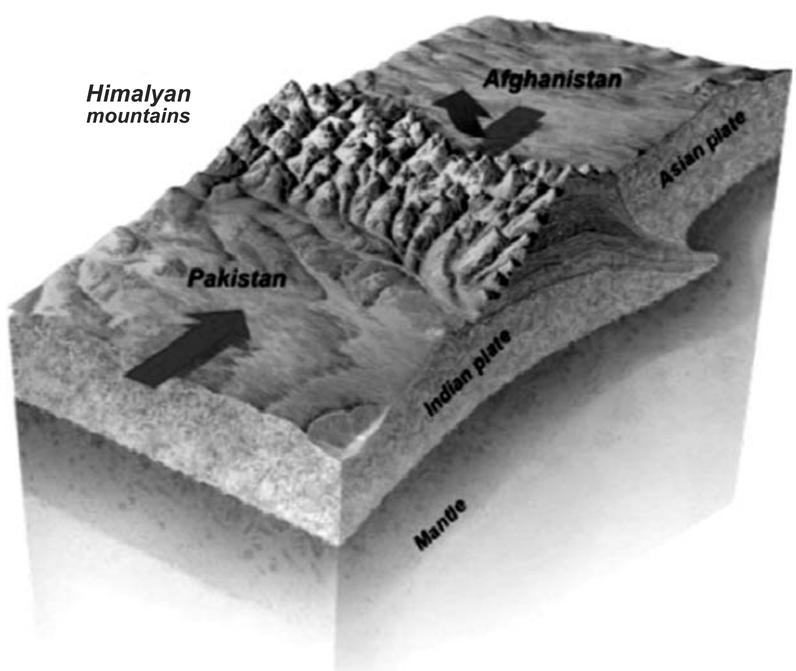

Figure 2: Subduction of Indian plate beneath the Eurasian plate and formation of Himalayan mountains (MAEC Report No. 05-04)

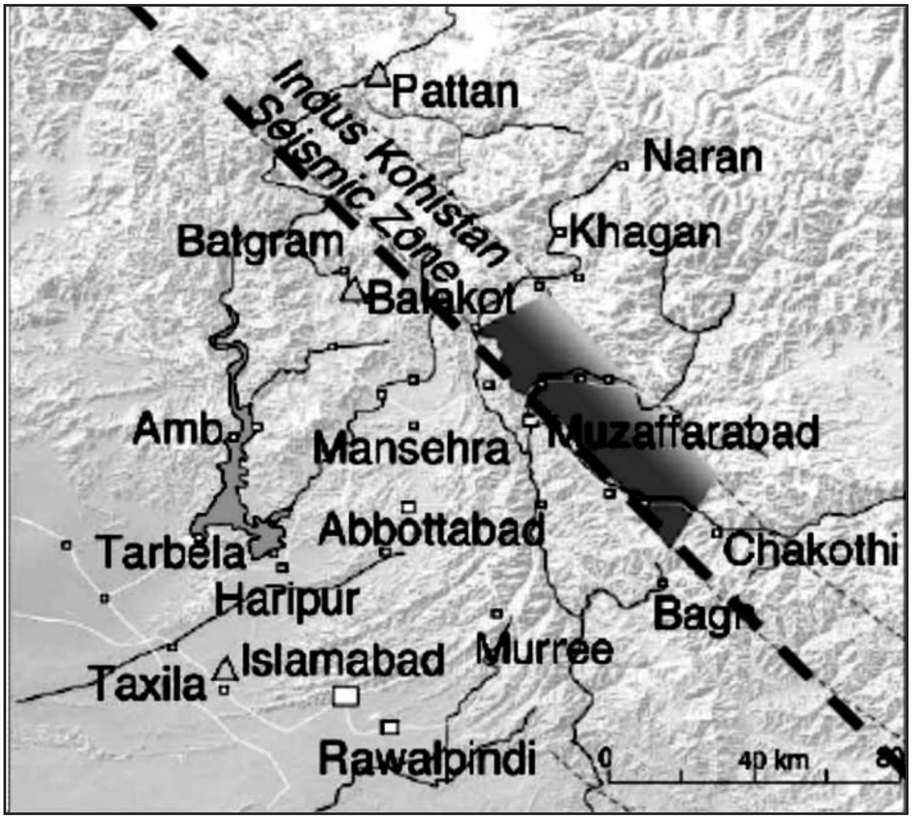

Figure 3: Rupture region of the Kashmir earthquake (http://cires.colorado.edu/~bilham/kashmir 202005.htm)

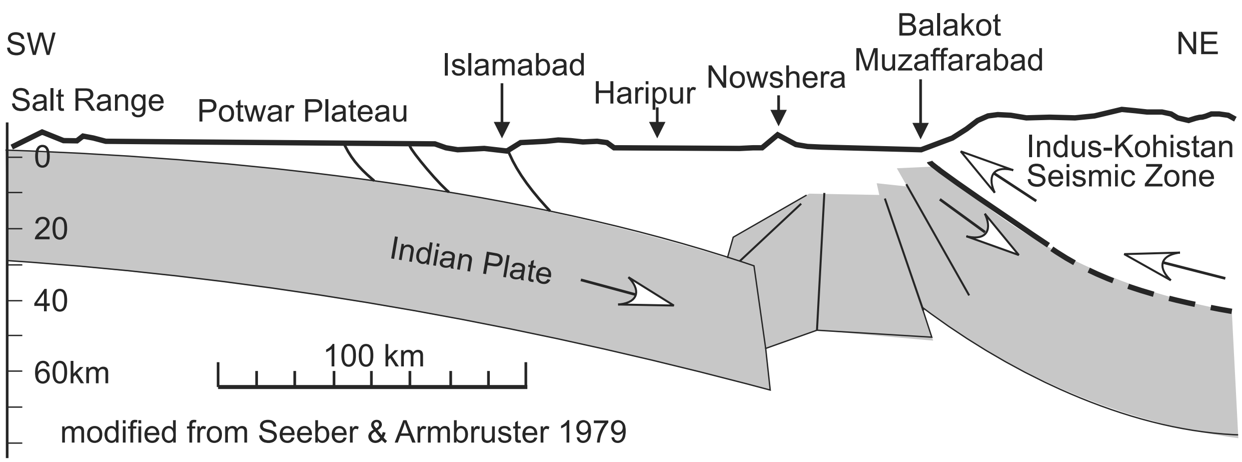

Figure 4: X-section along the blue line of Figure 3 (http://cires.colorado.edu/~bilham/kashmir 202005.htm)

maps and areal source zone maps are utilized. Next generation attenuation (NGA) equation of Boore and Atkinson[1], 2008 (BA08) has been used.

ATTENUATION EQUATION USED IN THIS STUDY

Due to insufficient data no attenuation relationship has been developed for Pakistan so far and hence equations developed for other areas are routinely used for Pakistan. Mona[7] et al., (2007) used the attenuation relation of Boore[8] et al., (1997) and Ambraseys[9] et al., (1996). PMD & NORSAR[2], 2006 used Ambraseys[9] et al. (1996) attenuation equation, and in the Building codes of Pakistan (Seismic Provisions), 2007 Boore[8] et al. (1997) attenuation equation is used.

Table 1: PGA values obtained in previous studies for Islamabad

Region	References	PGA for Islamabad	Remarks
Himalayan Fold & Thrust belt	Mona Lisa et al, 2006	0.15g	Earthquake data upto 2005 is used. Attenuation relations used are Ambraseys et al., [1996] and Boore et al., [1997]
Islamabad & Rawalpindi	PMD & NORSAR (Norway), 2006	0.18g	PSHA is conducted. Area of study was (72.95-73.07ºE & 33.58-33.74ºN). Attenuation relation used is Ambraseys et al., [1996].
Pakistan	Building codes of Pakistan Seismic Provisions-2007	(0.16-0.24g)	PSHA study is conducted for the whole country. Attenuation relation used is Boore et al., [1997].

In this study Next generation attenuation (NGA) equation of Boore[1] et al., (2008) has been used. The BA08 equation calculates the PGA and 5% damped spectral acceleration for the range of periods from T=0.01 sec to T=10.0 sec. The equation was derived by empirical regression of an extensive strong motion database compiled by the "PEER NGA" (Pacific Earthquake Engineering Research Centers Next Generation Attenuation) project and for shallow crustal earthquakes in active tectonic environments. This equation represents a substantial update to the ground motion prediction equations that were published by Boore and his colleagues in 1997. Furthermore, Boore[10] (2010) recommended that NGA models are applicable to shallow crustal tectonically active regions worldwide.

DSHA METHODOLOGY

For DSHA the procedure described by Reiter[11] (1990) has been adopted. A circle of about 100 km radius is drawn form ISE in Islamabad as the centre and all faults within this circle or touching/crossing it are considered. The available empirical relations for calculating the maximum magnitude earthquakes are used and the maximum potential magnitude earthquake are obtained for each fault.

Different relationships are available to obtain the maximum potential magnitude generated by faults. Various input parameters such as fault rupture length, fault displacements etc are required for these relations to obtain the maximum potential magnitude. Although due to the efforts of Geological Survey of Pakistan better quality fault maps are available for most part of the country. Only length of faults can be determined with some confidence from these maps and data regarding activeness of these faults, their attitude with depth and slip rates are rare. Due to lack of data 50% of the fault length is considered as rupture length (ICOLD[12], 1989). The relationships of Bonilla[13] et al., (1984), Nowroozi[14] (1985), Slemmon[15] et al., (1989) and Wells and Coppersmith[16] (1994) have been used for determination of the maximum potential magnitude earthquake from each fault and the results obtained are shown in Table 2. The maximum of these magnitudes is assigned to each fault for carrying out the study. The selected attenuation relations of BA08 NGA is used to obtain the PGA values for Islamabad due to different faults in the study area. The results obtain are shown in Table-3.

PSHA METHODOLOGY

Earthquake catalogue compiled by NESPAK for Pakistan are used in the study. This earthquake catalogue contains a total of 11,149 events out of which 6% are from (1505-1970), 51% are from (1970-2000) and the rest 43% are from (2000 to July 2006). The temporal distribution of earthquakes is shown in Figure-7. The catalogue contains magnitude values in the form of surface wave magnitude (Ms), body wave magnitude (M_b), local (M_L) and duration magnitude (M_D). All earthquake events were therefore converted to moment magnitude by the following relations.

- Conversion from M_s to M_w (Scordilis-2006 equations)

$M_w=0.67M_s+2.07$ for $3.0<M_s<6.1$

$M_w=0.99M_s+0.08$ for $6.2<M_s<8.2$

Table 2: maximum potential magnitude earthquakes of selected faults

Fault Name	Type	Length (Km)	Fault Rupture Length (Km) 50% of rupture length	Ms				Ms, max	Mw
				Bonilla et al., (1984)	Nowroozi (1985)	Wells and Copper Smith (1994)	Slemmons et al., (1989)		
Ahmadal Fault	Reverse	64	32	7.1	6.9	6.8	7.0	7.1	7.1
Darband Fault	Strike Slip	47	24	7.1	6.7	6.7	6.9	7.1	7.1
Diljabba Fault	Strike Slip	85	43	7.2	7.0	7.0	7.1	7.2	7.2
Himalayan Frontal Thrust	Reverse	225	113	7.8	7.5	7.5	7.5	7.8	7.8
Hissaratang Thrust	Reverse	160	80	7.6	7.4	7.3	7.4	7.6	7.7
Jhelum Fault	Strike Slip	82	41	7.2	7.0	7.0	7.1	7.2	7.2
Kanet Fault	Reverse	77	39	7.2	7.0	6.9	7.1	7.2	7.2
Khair-I-Murat Thrust	Reverse	164	82	7.7	7.4	7.3	7.4	7.7	7.7
Khairabad Fault	Reverse	205	103	7.8	7.5	7.4	7.5	7.8	7.8
Kotli Thrust	Reverse	64	32	7.1	6.9	6.8	7.0	7.1	7.1
Kund Fault	Strike Slip	77	39	7.2	7.0	6.9	7.1	7.2	7.2
Mansehra Thrust	Reverse	48	24	7.0	6.7	6.7	6.9	7.0	7.0
MBT	Reverse	353	177	8.1	7.8	7.7	7.7	8.1	8.1
Nathiagali Thrust	Reverse	70	35	7.2	6.9	6.9	7.1	7.2	7.2
Nowshera Fault	Strike Slip	80	40	7.2	7.0	6.9	7.1	7.2	7.2
Pezu Fault	Reverse	23	12	6.5	6.3	6.3	6.7	6.7	6.7
Punjal Thrust	Reverse	98	49	7.4	7.1	7.0	7.2	7.4	7.4
Puran Fault	Strike Slip	99	50	7.3	7.1	7.0	7.2	7.3	7.3
Raisi Thrust	Reverse	200	100	7.8	7.5	7.4	7.5	7.8	7.8
Riwat Thrust	Reverse	48	24	7.0	6.7	6.7	6.9	7.0	7.0
Sangargali Thrust	Reverse	62	31	7.1	6.8	6.8	7.0	7.1	7.1
Soan Backthrust	Reverse	103	52	7.4	7.1	7.1	7.2	7.4	7.4
Thakot Fault	Strike Slip	85	43	7.2	7.0	7.0	7.1	7.2	7.2
Thandiani Thrust	Reverse	51	26	7.0	6.7	6.7	7.0	7.0	7.0

Table 3: PGA values obtained from different faults for Islamabad

S. No	Fault Name	Distance (Km)	Mw	PGA (g) (BA08)	PGA (g) (SEA99)
1	Ahmadal Fault	87.31	7.1	0.05	0.03
2	Darband Fault	39.86	7.1	0.10	0.07
3	Diljabba Fault	96.80	7.2	0.04	0.03
4	Himalayan Frontal Thrust	72.12	7.8	0.09	0.06
5	Hissaratang Thrust	24.67	7.7	0.18	0.16
6	Jhelum Fault	43.65	7.2	0.10	0.07
7	Kanet Fault	70.22	7.2	0.07	0.04
8	Khair-I-Murat Thrust	26.57	7.7	0.18	0.15
9	Khairabad Fault	43.65	7.8	0.13	0.10
10	Kotli Thrust	60.73	7.1	0.07	0.05
11	Kund Fault	56.94	7.2	0.08	0.05
12	Mansehra Thrust	93.00	7.0	0.04	0.03
13	MBT	1.90	8.1	0.49	0.72
14	Nathiagali Thrust	20.88	7.2	0.17	0.14
15	Nowshera Fault	70.22	7.2	0.07	0.04
16	Pezu Fault	17.08	6.7	0.16	0.13
17	Punjal Thrust	36.06	7.4	0.13	0.09
18	Puran Fault	83.51	7.3	0.06	0.04
19	Raisi Thrust	66.43	7.8	0.09	0.06
20	Riwat Thrust	32.27	7.0	0.12	0.08
21	Sangargali Thrust	22.78	7.1	0.16	0.13
22	Soan Backthrust	26.57	7.4	0.16	0.13
23	Thakot Fault	81.61	7.2	0.06	0.04
24	Thandiani Thrust	34.16	7.0	0.11	0.08

- Conversion from M_b to M_w (Scordilis-2006 equation)

  $M_w=0.85M_b+1.03$ for $3.5<M_b<6.2$

- Conversion from M_L to M_w

As suggested by Idriss[17] (1985) and supported by local network in Pakistan ML upto 5.7 is taken equal to Mw. Conversion of ML beyond magnitude 5.7 was done, by using the following equations suggested by Ambraseys and Bommer[18] (1990) and Ambraseys and Bilham[19] (2003)

Table 4: Completeness of various magnitude earthquakes

S.No	EQ Magnitude Completeness	
	Range	Year
1	3.0-3.5	1990
3	3.6-3.8	1987
4	3.9-4.1	1973
5	4.2-4.4	1972
6	4.5-4.7	1971
7	4.8-5.0	1966
8	5.1-5.3	1964
9	5.4-5.6	1970
10	5.7-5.9	1962
11	6.0-9.6	1944

$$0.82M_L - 0.58M_s = 1.20$$

$$\log_{10} M_o = 19.09 + M_s \quad \text{for } M_s < 6.2$$

$$\log_{10} M_o = 15.94 + 1.5M_s \quad \text{for } M_s > 6.2$$

$$M_w = (2/3)\log_{10} M_o - 10.73$$

while, M_o is the seismic moment.

Completeness analyses are performed for different magnitude range earthquake events and the results obtained are shown in Table-4. As in every PSHA study seismic source zones must be modeled as a line (i.e. fault) or area sources. Due to uncertainty in the epicenter locations, it is not possible to relate the recorded earthquakes to the faults and to develop recurrence relationship for each fault and use them as G-R recurrence model. Therefore the areal seismic source zone map developed by NESPAK (shown in Figure-6) based on their homogeneous tectonic and seismic characteristic keeping in view the geology, tectonics and seismicity of each area source zone have been selected for the study. With Islamabad as centre a circle of 100 Km radius is drawn and four (04) source zones are obtained. These zones are Himalayas, Hazara, Potwar-Salt Range, and Bannu. G-R (Gutenberg-Richter) recurrence relationships are established for the selected zones. The maximum and minimum earthquake magnitude, the "a" and "b" values for each source zone are given in table-5. Using the parameters obtained from the G-R relationship, maximum potential magnitude earthquake and the corresponding attenuation relationship as input values to the Crisis software the PGA value for Islamabad at rock site due to 10% probability of exceedance in 50 years i.e. return period of 475 years are obtained. The results of PSHA are shown in Figures 7-9.

DEAGGREGATION

The deaggregation is performed in Crisis-2007 software for PGA at rock sites and for return period of 475 years. The results of deaggregation suggests that magnitude 5.09-6.71 with a distance of 0-10 Km governs the hazard.

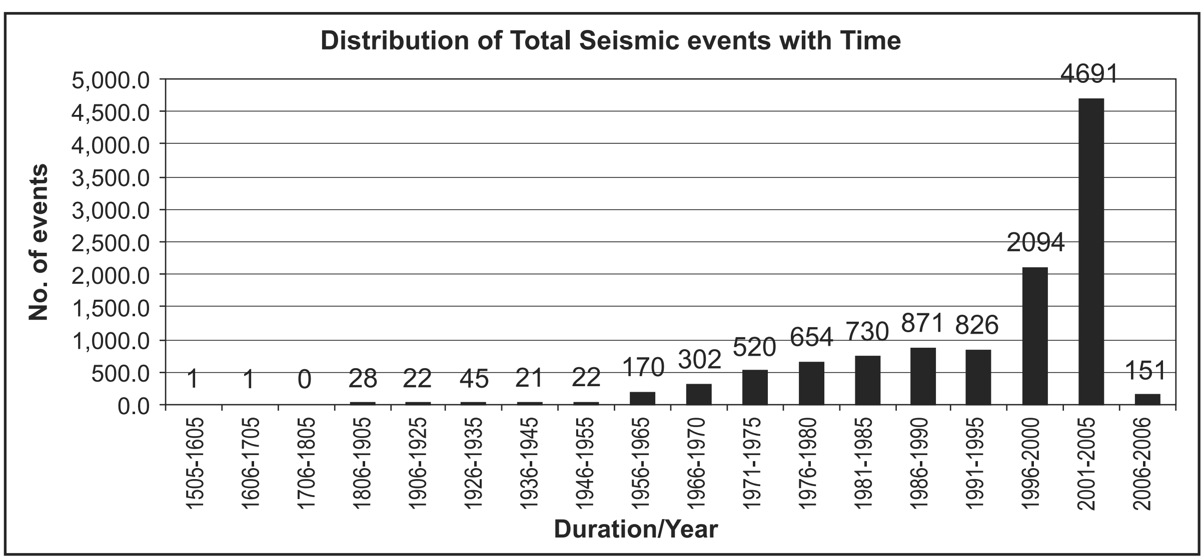

Figure 5: Temporal distribution of earthquake events

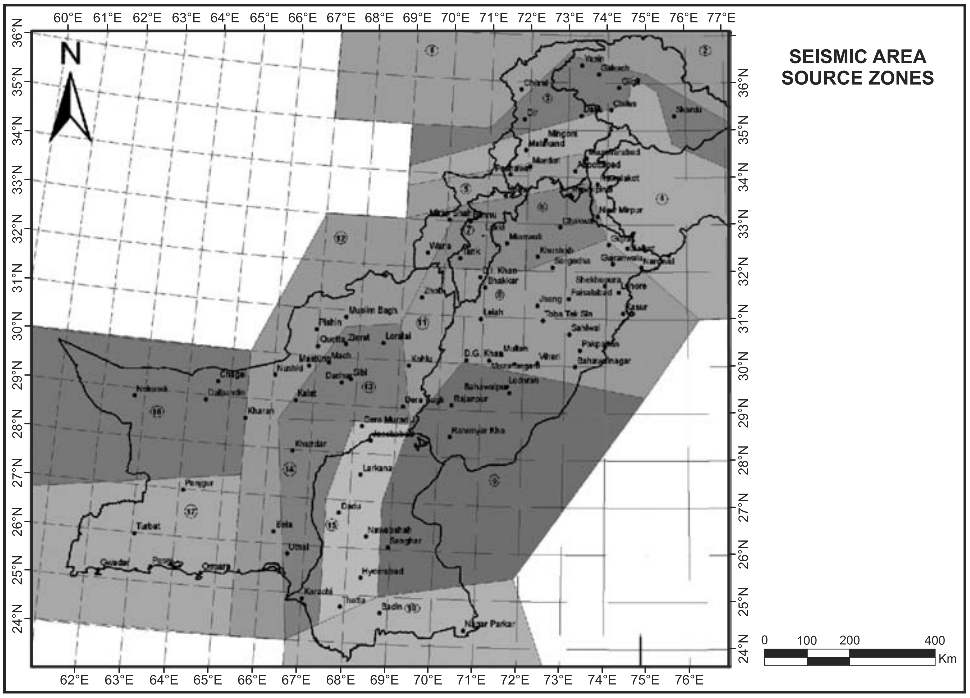

Figure 6: Areal source zones of Pakistan (NESPAK)

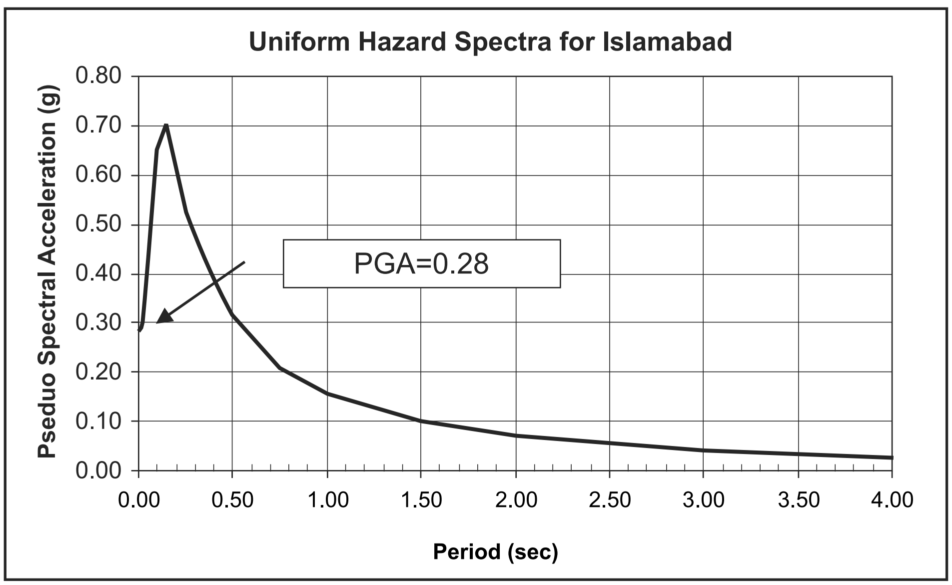

Figure 7: Result of PSHA (UHS for Islamabad, BA08 Attenuation relationship)

Table 5: Summary of parameters of the source zones

Zone Name	**Total events (Mw >=4.0)**	**Main shocks**	**Min observed Magnitude**	**Max observed Magnitude**	**a**	**b**
Himalayas	711	364	4	7.6	4.39	0.83
Hazara	208	129	4	6.1	5.80	1.23
Potwar-Salt Range	141	91	4	5.7	4.38	0.95
Bannu	108	82	4	6.1	5.10	1.11

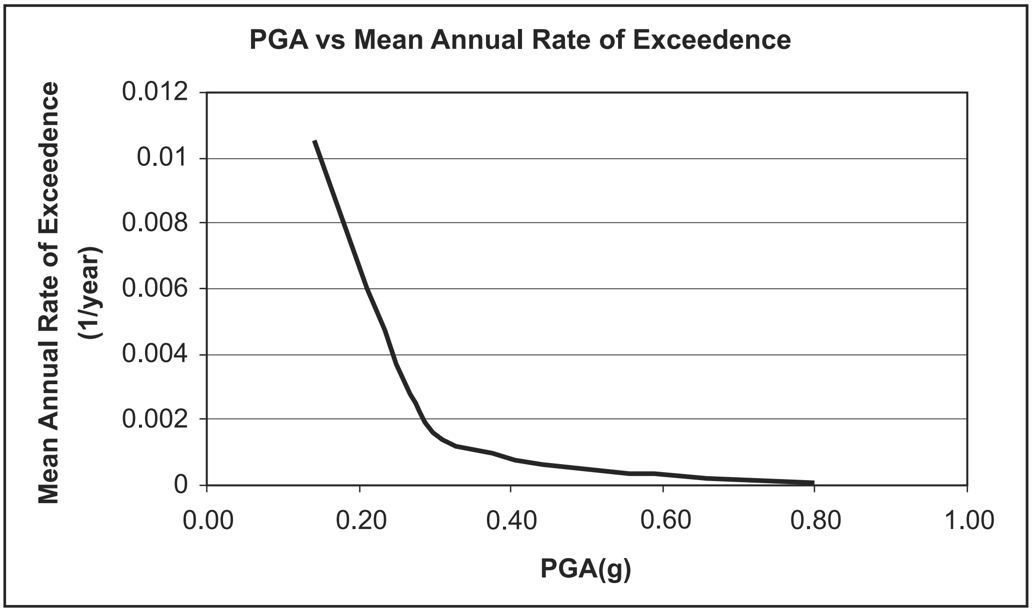

Figure 8: PGA Vs mean annual rate of exceedance (BA08)

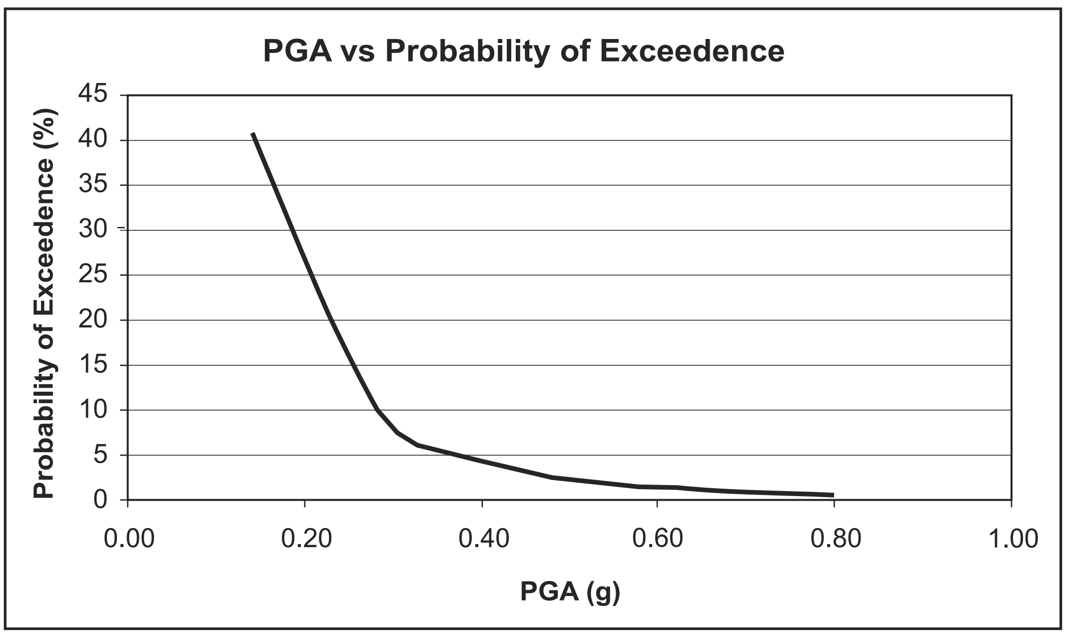

Figure 9: PGA Vs probability of exceedance (BA08)

CONCULSTIONS AND RECOMMENDATIONS

In DSHA Islamabad being the centre a circle of about 100 Km was drawn and all faults lies inside the circle or just touching/crossing the circle are considered in the research. In this way a total of twenty four (24) active faults have been obtained. The result of DSHA shows that MBT is the most critical fault for Islamabad and its vicinity. This fault can generate an earthquake with moment magnitude (M_w=8.1) and PGA values of 0.49g at bedrock by using the BA08 NGA attenuation relation. The main reasons for it are (1) it passes at a nearest distance of about 2 Km from Islamabad, and (2) it is one of the largest faults of Pakistan that can generate greater magnitude earthquakes.

Similarly in PSHA and within 100 Km radius circle of Islamabad four (4) areal source zones are selected and their recurrence relationships have been developed. Among these source zones the Himalaya and Potwar-Salt range zones show low b-values (0.83 and 0.95 respectively) and can be termed as hazardous while the other two i.e. Hazara and Bannu show high b-values (1.23 and 1.11 respectively) and are apparently seismically stable zones. The peak ground acceleration (PGA) of 0.28g is obtained at bedrock for 10% probability of exceedance in 50 years i.e. return period of 475 years for the city of Islamabad. From the results of PSHA it is evident that Islamabad is should be placed in Zone-III of Uniform Building Code (UBC) and Pakistan Building Codes- Seismic Provisions[20]-2007 (PGA values of 0.25g to 0.32g).

Peak ground acceleration obtained from DSHA and PSHA are drastically different being 0.49g and 0.28g. The reason for this huge difference is that DSHA considers direct contribution of Main Boundary Thrust (MBT) fault just 2Km away from the study area, whereas, for PSHA, areal seismic source zones developed by NESPAK are considered in which the seismicity is spread over seismic source zones. It is therefore recommended that for important city like Islamabad procedure defined by the U.S. Geological Survey for developing the U.S. National Seismic Hazard Maps should be adopted which considers individual fault zones. However this procedure requires precise information regarding seismicity and geometry of individual faults which currently are unavailable. Efforts and research must now be directed towards characterization of faults in Pakistan.

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