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Seismic hazard assessment of Islamabad, Pakistan, using deterministic approach

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ABSTRACT: *Islamabad is located close to the axis of the Hazara- Kashmir Syntaxis. Seismically this area is very active due to the presence of some of very prominent tectonic features such as Main Boundary Thrust (MBT), Mansehra Thrust, Jhelum Fault, Kotli Thrust, Riasi Thrust, Sangargali Thrust, Hissartang fault etc. Historical as well as Instrumental seismological data confirms the active nature of all these faults. Keeping in view the active seismic nature, an attempt has been made to characterize the area on the basis of strong motion parameter. The peak horizontal acceleration, which is the most important and widely used strong motion parameters in all engineering purposes like constructions of dams, nuclear power plants, bridges and buildings etc, has therefore been calculated. Seventeen faults have been selected as a critical seismogenic feature whose nearest segment is ≤ 60 kms from the site and their maximum potential magnitudes have been calculated using four regression relations. With the help of these maximum potential magnitudes and seven available attenuation equations, peak horizontal accelerations have been determined. On the basis of these maximum potential magnitudes and the peak horizontal accelerations, five tectonic features i.e., MBT, Nathiagali Thrust, Thandiani Thrust, Sangargali Thrust and Riwat Thrust having peak horizontal accelerations of 0.44 g, 0.23 g, 0.18 g, 0.17 g and 0.13 g and maximum potential magnitudes of 7.8, 7,6.8, 6.9 and 6.8 out of seventeen have been designated as the most hazardous to the site of Islamabad.*

INTRODUCTION

Prevailing practice especially in earthquake prone regions is to carry out seismic hazard assessment so that remedial measures may be taken to prevent/lessen loss of life and damage to property. Such assessment depicting intensity and ground motion parameters like peak ground acceleration, peak ground velocity and peak ground displacement are increasingly being taken into consideration by different agencies involved in planning, design and construction of structures.

In Pakistan, numerous studies by various workers (Wellman, 1966; Abdel Gawad, 1971; Nowroozi, 1972; Ambraseys et al., 1975; Kazmi, 1979c; Seeber et al., 1980; Quittmeyer et al, 1979; Armbruster et al., 1980; Verma et al., 1980; Yeats and Hussain, 1987; Ansari, 1995; Bhatia et al., 1999) have brought into sharp focus the seismicity and active fault system in and around the area of Pakistan. However, none of them have used this information for the evaluation of seismic hazard assessment using deterministic approach.

Keeping the above fact in view, the site of Islamabad has been selected for carrying out the seismic hazard assessment using deterministic approach. For this purpose seventeen faults around Islamabad have been recognized as the critical features, which are representing a constant threat to the site as determined through the observations of both historical and instrumental seismic data and also the geological criteria such as evidence of fault movement during the Quaternary period. From the fault rupture length-magnitude relationship, maximum potential magnitudes of these faults are calculated using various regression relations and finally peak horizontal accelerations have been computed using seven different available attenuation equations.

REGIONAL TECTONIC ENVIRONMENT

Pakistan is mostly experiencing compressional and transpressional forces. The compressional forces are believed to be a result of the ongoing collision of the Eurasian and Indo- Pak continental plates that started in the late Eocene to Early Oligocene with the formation of the Himalayan ranges. The Indo-Pak plate, relative to the Eurasian plate is still moving northwards at a rate of about 3.7 cm/yr near 73^0 longitude east (Molnar & Topponnier, 1975). The major portion of this convergence was taken up by deformation along the northern collision boundary involving folding and thrusting of the upper crustal layers (Seeber & Armbruster, 1979) in the shape of MKT (Main Karakoram Thrust), MMT (Main Mantle Thrust), MBT (Main Boundary Thrust) and SRT (Salt Range Thrust) as shown in Figure 1.

Transpression is prevalent at the western boundary of the Indo-Pakistan plate with the 800 to 900 km long Chaman fault, a transform boundary (Lawrence & Yeats, 1979). However, structural mapping and focal mechanism solutions indicate that a large number of strike slip faults occur elsewhere in Pakistan. In the NW Himalayan Fold and Thrust Belt, the areas of Kohat and Potwar plateaus have been interpreted to be a result of transpression (Sercombe et al., 1998; MonaLisa et al., 2004). On the regional scale Islamabad is located in the Himalayan fold-and-thrust belt, which covers the area between the MMT and the SRT. The Panjal-Khairabad fault (Fig. 1) divides the belt into a northern hinterland zone and the southern foreland zone. The former is characterized by intensely deformed (tightly folded and imbricated) Precambrian to Early Mesozoic igneous and metamorphic rocks collectively called the Himalayan crystalline nappe-and-thrust belt by Kazmi and Jan, 1997.These crystalline rocks towards the south are thrusted over the rocks of the foreland zone. This foreland zone comprises of many thrust sheets (decollement zones) with a southward translation of up to 100 km.

In the east, separating the fold belt from the central Himalayas fold belt of India is the N-S trending complex tectonic zone called the Hazara-Kashmir Syntaxis (Fig. 1). Precambrian to Neogene rocks are present in the syntaxial zone although the Oligocene-Miocene Murree Formation predominates. Many thrust faults occur along the syntaxial loop, which on the western side terminate into the strike-slip Jhelum fault, whereas in the north they continue into the Nanga Parbat-Haramosh region. Islamabad is located on the western side of the Hazara-Kashmir Syntaxis. On the east of the axis, the geological features show predominantly northwest trend while their trend changes to northeast towards the west of the axis (Fig. 1).

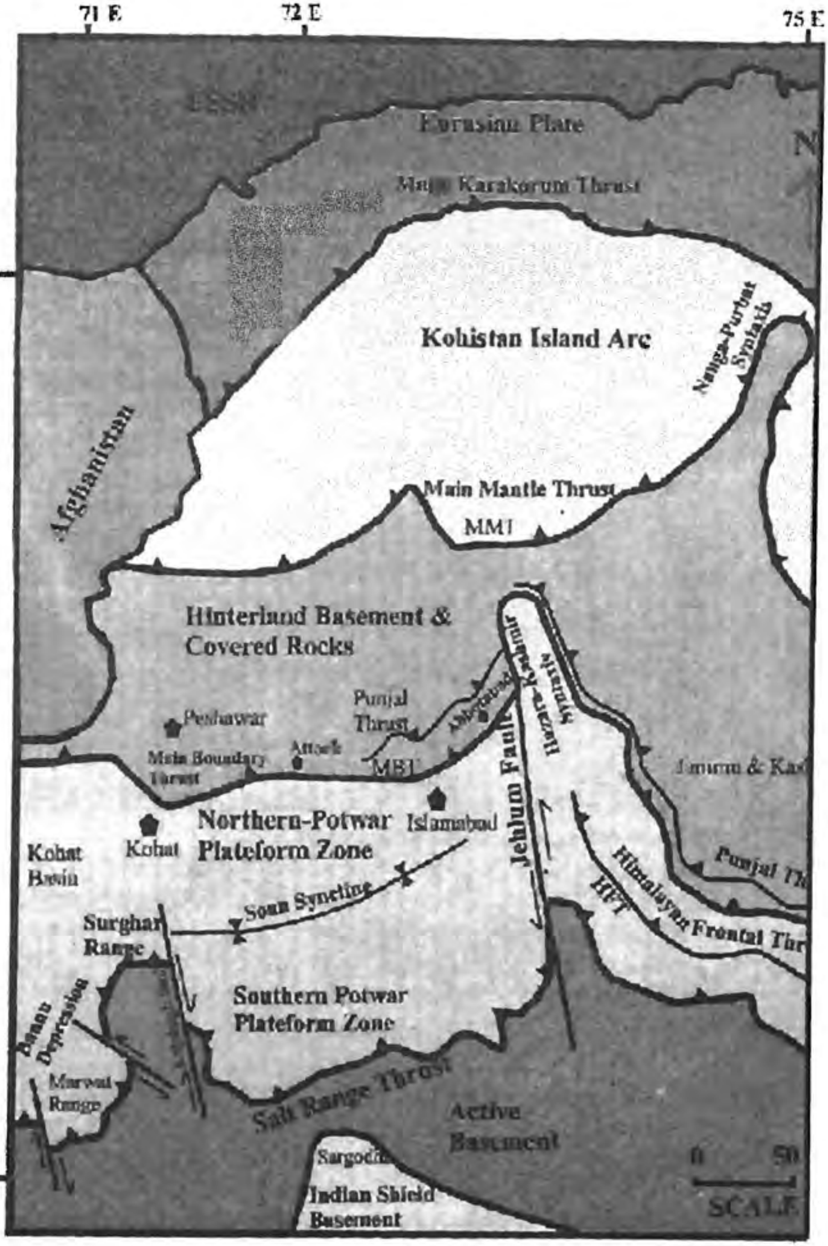

Fig. 1. Regional tectonic map of NW Himalayan Fold and Thrust Belt, Pakistan.

LOCAL TECTONIC SETTING

The city of Islamabad is situated in the Potwar plateau, which is an area between Main Boundary Thrust (MBT) and Salt Range Thrust (Fig. 1). In the north Margalla and Hazara ranges while in the west mountainous region of Kalachitta ranges covers the area.

The southward portion encompasses the Salt range. The area contains a series of thrusts. General trend of these thrusts changes from E-W to northeast direction in the eastern part of the Potwar Plateau. A number of workers have described these faults (Lillie et al., 1987; Jadoon et al., 1995; Jaswal et al., 1997).

Two seismically active faults i.e. MBT in the north and Riwat Fault in the south of Islamabad (Fig. 2) are passing nearby, indicating that the study area is located within the seismically active environment. The Riwat thrust trending in the NE-SW direction lies about 20 km south of Islamabad. Jadoon et al., 1995 believe that cessation of movement along the Riwat thrust stopped at about 2.7 Ma. Soan (Dhurnal) backthrust is another distinctive feature of the eastern Northern Potwar Deformed Zone. It occurs on the northern limb of the Soan Syncline immediately south of Islamabad (Fig. 2). The MBT itself is represented by many high angle thrusts along which Eocene and older rocks have been thrusted over the molasses of the Potwar plateau. The Soan (Dhurnal) backthrust is a passive back thrust and the area bounded by it and the Khair-i-Murat Fault (Fig. 2) is a triangle zone of complex geology (Jadoon et al., 1999). Pivnik and Sercombe (1993) and Sercombe et al. (1998) recognize the presence of strike-slip faults at the surface and even in the basement in this area. They relate the structures (high angle strike-slip faults and associated flower structures) to transpressional deformation.

SEISMICITY

The northern region of Pakistan has high frequency of earthquakes especially in the Himalayan orogenic belt. This belt represents the contact between Indo-Pak and Eurasian plates, which has always been the source of moderate to large earthquakes including Kangra (1905), Bihar-Nepal (1934) and Assam (1897) earthquakes that have left their landmarks in the history. The presence of some of the active faults (Fig. 1 & 2) like Main Mantle Thrust (MMT), Riwat Fault, Panjal-Khairabad Fault, Jhelum Fault, Salt Range Thrust, Kalabagh Fault and Main Boundary Thrust (MBT) make the region around Islamabad very active. However, in this area of dominantly collisional tectonics a large number of focal mechanism solutions indicate strike-slip faulting in addition to thrust faulting (Fitch, 1970; Rastogi, 1974; Armbruster et al., 1978; Verma et al., 1980; Verma & ChandraSekhar, 1986; Molnar & LyonCaen, 1989; Pivnik & Sercombe, 1993, MonaLisa et al., 1997, MonaLisa et al., 2004; Khwaja et al., 2003). This may suggest that a kinematic change from compression to transpression is believed to be taking place (Pivnik & Sercombe, 1993).

Both historical/non instrumental (Oldham, 1893; Ambraseys et al., 1975 and Quittmeyer et al., 1979) and instrumental seismicity data exist for the area. A list of historically recorded earthquake data around Islamabad is given in Table 1. The instrumentally recorded earthquake data are available only since 1904. The instrumentally recorded seismicity as reported by various international seismological networks like World Wide Standard Seismograph Network (WWSSN), United States Geological Survey (USGS) and International Seismological Centre (ISC), UK, is sparse and scattered and is limited to moderate to small earthquakes with unreliable epicenter locations. However after the installation of various local seismic networks, the recording of small magnitude with better precision of epicenter location is possible. The seismicity data recorded by local seismic networks indicates the high seismic activity all along the region around Islamabad, which is quite clear from Figure 2.

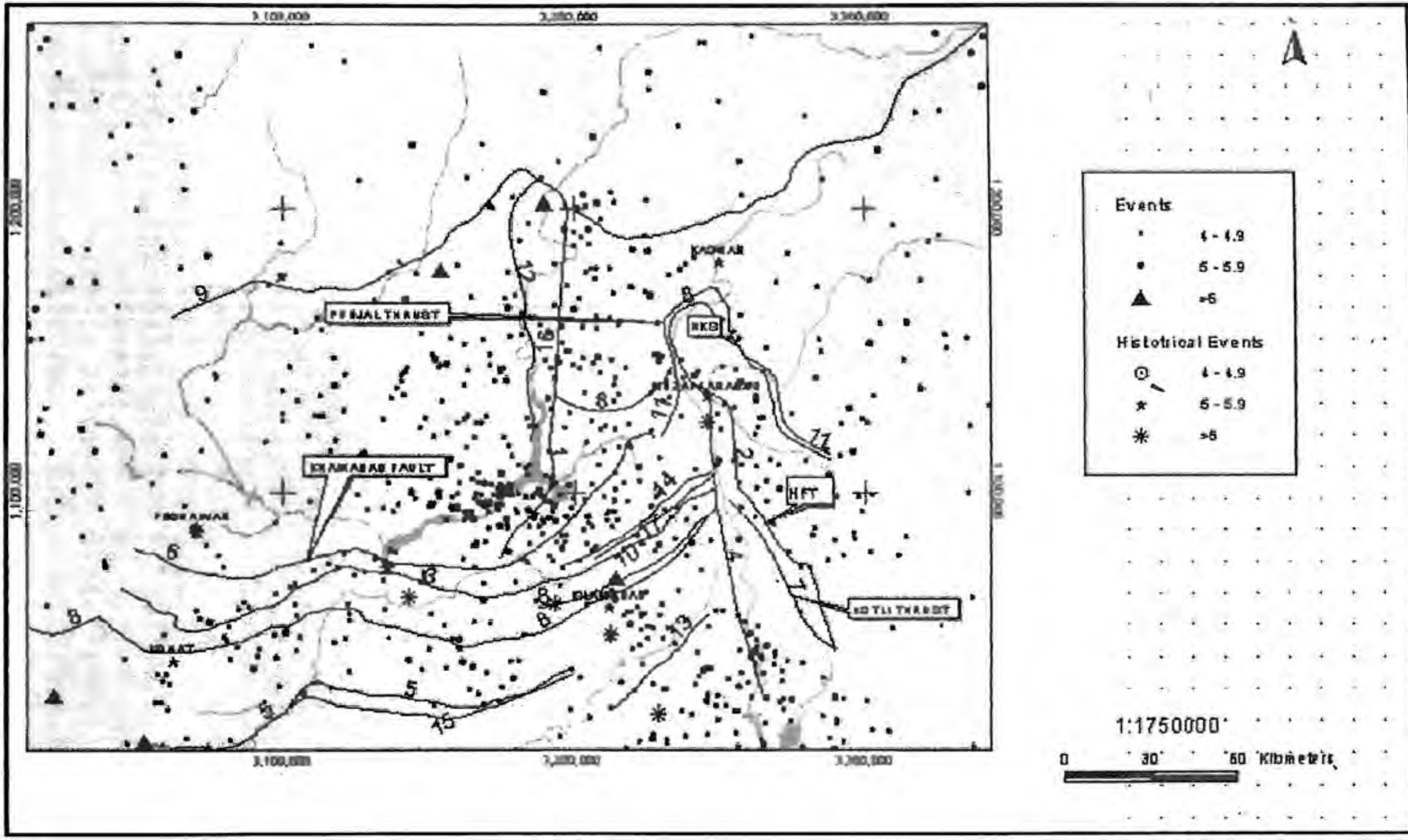

Fig. 2. Seismicity and structural map of the area surrounding Islamabad. (1. Darband Fault: 2. Himalayan Frontal Thrust: 3. Hissartang Fault 4. Jhelum Fault: 5. Khair-I-Murat Fault: 6. Khairabad Fault: 7. Kotli Thrust: 8. MBT: 9. MMT: 10. Nathiagali Thrust: 11. Punjal Thrust: 12. Puran Fault: 13. Riwat Thrust: 14. Sangargali Thrust: 15. Soan (Dhurnal) Backthrust: 16. Thakot Fault: 17. Thandiani Thrust).

TABLE 1. LIST OF THE HISTORIC EARTHQUAKES OCCURRED IN THE REGION SURROUNDING ISLAMABAD

S. No.	Date	Lat. N	Lon. E	Mag.	Max. Intensity
1.	25 AD	33.73	72.87	7.0	IX-X
2.	03.01.1519	34.80	71.90	5.0	VI-VII
3.	03.01.1552	34.00	76.00	6.0	VII-IX
4.	04.06.1669	33.37	73.23	6.5	VI-IX
5.	22.06.1669	34.00	76.00	5.0	VI-VII
6.	23.06.1669	33.87	72.25	6.5	VII-IX
7.	15.07.1780	34.00	76.00	6.0	V-VII
8.	24.09.1827	31.57	74.35	6.5	VIII-IX
9.	06.06.1828	34.08	74.82	7.0	IX-X
10.	17.07.1831	34.00	71.55	5.0	IV-VI
11.	22.09.1831	34.00	74.82	5.0	IV-VI
12.	22.01.1832	31.57	74.35	5.5	V-VI
13.	30.03.1847	32.00	72.00	4.5	III-IV
14.	17.01.1851	32.43	74.12	5.0	VI-VII
15.	30.11.1853	33.87	72.25	4.9	VI
16.	07.04.1857	32.07	76.28	5.5	V-VI
17.	23.08.1858	31.57	74.35	4.0	V
18.	10.07.1863	34.08	74.82	5.0	VI-VII
19.	10.07.1863	31.57	74.35	5.5	VI-VIII
20.	22.01.1865	34.00	71.55	5.0	V
21.	04.12.1865	31.57	74.35	6.0	VII-VIII
22.	11.08.1868	34.00	71.55	5.5	V-VII
23.	12.11.1868	31.57	74.35	5.0	V-VI
24.	13.11.1868	33.87	72.25	4.5	IV
25.	24.03.1869	32.92	73.72	5.0	VI-VII
26.	24.04.1869	34.00	71.55	6.0	VII-VIII
27.	20.12.1869	33.77	72.33	5.5	VII-VIII
28.	20.12.1869	33.62	73.07	5.5	VII-VIII
29.	28.04.1871	33.62	73.07	5.2	VI-VIII
30.	12.12.1875	34.00	71.55	6.0	VII-VIII
31.	23.12.1875	31.57	74.35	6.0	VII-VIII
32.	02.03.1878	31.57	74.35	5.0	VI-VII
33.	30.04.1883	34.00	71.55	5.0	VI-VII
34.	15.01.1885	34.00	74.82	6.0	VII-VIII
35.	30.05.1885	34.28	73.47	6.5	VIII
36.	06.06.1885	34.17	75.00	7.0	IX-X
37.	20.10.1886	34.08	74.82	5.0	VI-VII
38.	05.11.1893	34.00	71.55	5.0	VI-VII
39.	20.09.1902	34.00	74.82	5.5	VI
40.	04.04.1905	32.13	76.28	8.6	X

The fault plane solutions of some of the earthquakes, determined by the authors (MonaLisa et al., 1997; MonaLisa et al., 2004; Khwaja et al., 2003) and the previous workers like (Armbruster et al., 1978; Verma et al., 1980; Verma & ChandraSekhar, 1986; Molnar & LyonCaen, 1989; Pivnik & Sercombe, 1993) suggest that while predominant faulting mechanism in this region was thrusting, strike slip faulting was also present.

SEISMIC HAZARD ASSESSMENT USING DETERMINISTIC APPROACH

Procedure adopted

The principle of analysis involved in the deterministic approach is to evaluate the critical seismogenic sources, like capable faults and the selection of a maximum potential magnitude assigned to each of these faults. Then with the help of suitable attenuation equations, peak horizontal accelerations associated with maximum earthquake along these faults are determined. Therefore the deterministic method includes the following steps:

- Identify all critical tectonic features in the vicinity of the site likely to generate significant ground motions.
- Assign to each of these a maximum potential magnitude on the basis of key fault parameters like fault rupture length, displacement or slip rate.
- Compute the ground motion parameters at the site associated with each feature as a function of magnitude and distance using the appropriate attenuation relationships.

Critical tectonic features

As mentioned in the Introduction, seventeen faults (listed in Table 2) have been selected as the critical tectonic features for the seismic hazard assessment to the site of Islamabad. In addition to these faults, there are also other active features within NW Himalayan Fold-and-Thrust Belt but since their nearest segment is more than 60 km from Islamabad, the ground motion from these features would not be as critical as for the features given in Table 2. Also this selection is primarily based upon the association of seismicity along each fault and the geological criteria such as the fault rupture length-magnitude relationships. The level of seismicity has been considered by observing both the historical and instrumental earthquake data along each feature. Although the entire region surrounding Islamabad is dominantly representing the thrust faulting but some strike-slip component is also present. This is the reason that out of seventeen selected faults, thirteen are thrusts and four faults i.e., Jhelum Fault, Nowshera Fault, Kund Fault and Thakot Fault are strike-slips. It is beyond the scope of this paper to describe each and individual fault in detail, therefore only those faults have been discussed in detail which can cause appreciable peak horizontal acceleration values, among these are the MBT, Nathiagali thrust, Thandiani thrust, Sangargali thrust and the Riwat thrust. All these faults along which earthquakes can produce the appreciable ground motions are shown in Figure 2 and are briefly discussed below:

According to Baig and Lawrence (1987), Main Boundary Thrust (MBT) or Margalla Thrust or Murree Thrust (Fig. 2) is the main frontal thrust of the Himalayan range. From Assam in the east to Kashmir in the west it runs about 2500 kms. This thrust continues northwestward, turns westward near the apex of the Hazara-Kashmir Syntaxis (HKS) and then bends southward towards Balakot (Kazmi & Jan, 1997). It dips about 50^0 to 70^0E northwest of Muzaffarabad (Calkins et al., 1975) and runs in E-W direction south of the Margalla Hills. As mentioned previously the MBT itself is represented by many high angle thrusts due to which it is known as MBT fault zone.

TABLE 2. MAXIMUM POTENTIAL MAGNITUDES OF THE FOURTEEN ACTIVE FAULTS PRESENT AROUND THE SITE OF ISLAMABAD USING FOUR REGRESSION RELATIONS

Fault Names	Total Fault Length (Kms)	Fault Rupture Length (Kms)	Maximum Magnitude Calculations				Maximum Potential Magnitudes (Mw)
			Bonilla et al (1984)	Nowroozi (1985)	Slemmons et al (1985)	Wells and Coppersmith (1984)	
MBT	600	300	8.4	8.1	7.8	8	7.8
Thakot Fault	85	42.5	7.2	7	7.1	7	7.1
Nowshera Fault	80	40	7.2	7.0	7.1	7.0	7.1
Kund Fault	70	35	7.2	7.0	7.1	6.9	7.0
Kanet Fault	77	38.5	7.2	7.0	7.1	7.0	7.1
Himalayan Frontal Thrust	112	56	7.8	7.5	7.5	7.5	7.6
Jhelum Fault	82	41	7.2	7	7.1	7	7.1
Kotli Thrust	64	32	7.1	6.9	7	6.8	7
Sangargali Thrust	62	31	7.1	6.8	7	6.8	6.9
Thandiani Thrust	51	25.5	7	6.7	6.9	6.7	6.8
Nathiagali Thrust	70	35	7.1	6.9	7	6.9	7
Darband Fault	47	23.5	6.9	6.7	6.9	6.7	6.8
Khairabad Thrust	205	102.5	7.8	7.5	7.4	7.4	7.5
Hissartang Thrust	160	80	7.6	7.3	7.3	7.3	7.4
Khair-i-Murat Thrust	164	82	7.7	7.4	7.3	7.3	7.4
Riwat Thrust	48	24	6.9	6.7	6.9	6.7	6.8
Soan (Dhurnal) Backthrust	103	51.5	7.4	7.1	7.2	7.1	7.2

A hairpin-shaped system of faults truncates the Hazara-Kashmir Syntaxis both on the east and western sides (Kazmi & Jan, 1997). Within the MBT fault zone, on the western side of HKS, the number of thrust faults like Sangargali, Thandiani, Nathiagali (Hazara) Thrusts (Fig. 2) is situated and they dip to the north and northwest (Baig & Lawrence, 1987). Structurally they overlie each other so that the Sangargali Thrust overlies the Thandiani Thrust and Nathiagali (Hazara) Thrust lies below the Thandiani Thrust. Nathiagali or Hazara Thrust branches 5 kms south of Muzaffarabad and forms the northern boundary of MBT fault zone (Antonio, 1991). In the west of HKS, where the MBT is correlated with the Triassic to Paleogene sequence of the Kala Chitta Range near Attock, the Nathiagali Thrust can be equivalent to the Hissartang Fault of Yeats and Hussain (1987). The alignment of epicenters (Fig. 2) along all these faults shows that seismically they are active. This MBT fault zone and the area around HKS is the source of many earthquakes in the region and therefore represents high earthquake potential. The MBT east of HKS has been the source of many large earthquakes, which include 1905 Kangra earthquake of M 8.6, 1934 Bihar-Nepal earthquake of M 8.4 and the great Assam earthquakes of 1897 and 1950. The rupture, which caused these earthquakes, is occurred in the detachment in the vicinity of the surface trace of MBT (Seeber & Armbruster, 1979).

Riwat Thrust (Fig. 2) is a NE-SW trending thrust, which lies about 21 km south of Islamabad. According to Jadoon and Frisch (1997) the Riwat thrust dies out at a depth of 4 km, where it merges into a hinterland vergent blind thrust. Earlier Johnson et al. (1986) had interpreted the Riwat Thrust as an emergent thrust propagating up section from the basement.

MonaLisa et al. (2004) carried out the fault plane solutions of four major earthquakes (magnitude range from 4.8 to 5.5) occurred in the North Potwar during the period of 1977-1993. One of these earthquakes i.e. 14 February 1977 (magnitude 5.5) occurred in the vicinity of Riwat Thrust and the Soan (Dhurnal) backthrust. Two of them i.e. 17 February and 8 June, 1993 earthquakes (magnitude 5.4 and 5.1 respectively) were located between MBT and the Khair-i-Murat fault while the fourth one i.e., of 17 Feb, 1991 (magnitude 4.8) was located near the eastern limb of the Khair-i-Murat fault. The occurrence of these significant earthquakes and the distribution of epicenters in the vicinity of these faults not only represent the active nature of these individual faults but also confirm the overall high seismicity of the area.

Maximum earthquake potential

The methods assigning a maximum potential magnitude to a given active fault are based on empirical correlations between magnitude and key fault parameters such as fault rupture length, fault displacement, fault area and slip rate (Idriss, 1985). Selection of a maximum magnitude for each source, however, is ultimately a judgment that incorporates understanding of specific fault characteristics, the regional tectonic environment, similarity to other faults in the region and data on the regional seismicity. The peak horizontal accelerations calculated by deterministic approach is largely affected by the choice of the maximum magnitude of an earthquake that can occur within the certain critical feature. The procedure followed in assigning the maximum potential magnitude of an earthquake depends upon the maximum magnitudes of earthquakes experienced in the past, the tectonic history and the geodynamic potential for generating earthquakes. In the present case, the fault length is the parameter which is most reliably known for this area, therefore, the maximum potential magnitudes of seventeen faults in the vicinity of Islamabad are calculated on the basis of rupture of 50 % of total fault length (ICOLD, 1989) using various available relationships by different authors like Bonilla et al. (1984), Nowroozi (1985), Slemmons et al. (1989) and Wells and Coppersmith (1994). Table 2 gives all these active faults present in the study area, their total lengths, rupture lengths and the calculated maximum potential magnitudes.

TABLE 3. PEAK HORIZONTAL ACCELERATIONS COMPUTED CONSIDERING THE MAXIMUM EARTHQUAKE THAT CAN OCCUR AT THE CLOSEST DISTANCE FROM THE SITE USING 7 AVAILABLE ATTENUATION EQUATIONS

Tectonic Features	Maximum Magnitude (Mw)	Closest Distance to Faults (Kms)	Computed Accelerations (g) Median (50-perecentiles)						
			1	2	3	4	5	6	7
MBT	7.8	4	0.56	0.64	0.54	0.39	0.44	0.44	0.47
Thakot Fault	7.1	46	0.09	0.09	0.08	0.06	0.07	0.08	0.07
Nowshera Fault	7.1	58	0.07	0.11	0.06	0.08	0.06	0.07	0.06
Kund Fault	7	44	0.09	0.13	0.08	0.10	0.07	0.08	0.07
Kanet Fault	7.1	60	0.07	0.09	0.06	0.04	0.06	0.08	0.05
Himalayan Frontal Thrust	7.6	55	0.1	0.15	0.08	0.05	0.08	0.11	0.08
Jhelum Fault	7.1	39	0.11	0.16	0.09	0.08	0.08	0.09	0.08
Kotli Thrust	7	55	0.07	0.1	0.06	0.04	0.06	0.08	0.06
Sangargali Thrust	6.9	18	0.22	0.3	0.17	0.22	0.14	0.17	0.15
Thandiani Thrust	6.8	15	0.24	0.3	0.18	0.19	0.15	0.18	0.17
Nathiagali Thrust	7	10	0.35	0.53	0.26	0.27	0.21	0.23	0.23
Darband Fault	6.8	40	0.09	0.12	0.08	0.06	0.07	0.09	0.07
Khairabad Fault	7.5	31	0.18	0.21	0.15	0.16	0.13	0.16	0.13
Hissartang Thrust.	7.4	39	0.14	0.19	0.11	0.08	0.1	0.13	0.09
Khair-I-Murat Fault	7.4	27	0.2	0.27	0.16	0.13	0.14	0.17	0.14
Riwat Thrust	6.8	26	0.15	0.2	0.12	0.1	0.1	0.13	0.1
Soan Backthrust	7.2	28	0.17	0.24	0.14	0.11	0.12	0.13	0.12

1, 2, 3 etc. are representing the attenuation equations used in the study (i.e., 1. Joyner & Boore, 1982: 2. Sadigh et al., 1987: 3. Ambraseys & Bommer, 1991: 4. Campbell & Bozorgnia, 1993: 5. Ambraseys et al., 1996: 6. Boore et al., 1997: 7. Tromans and Bommer, 2002).

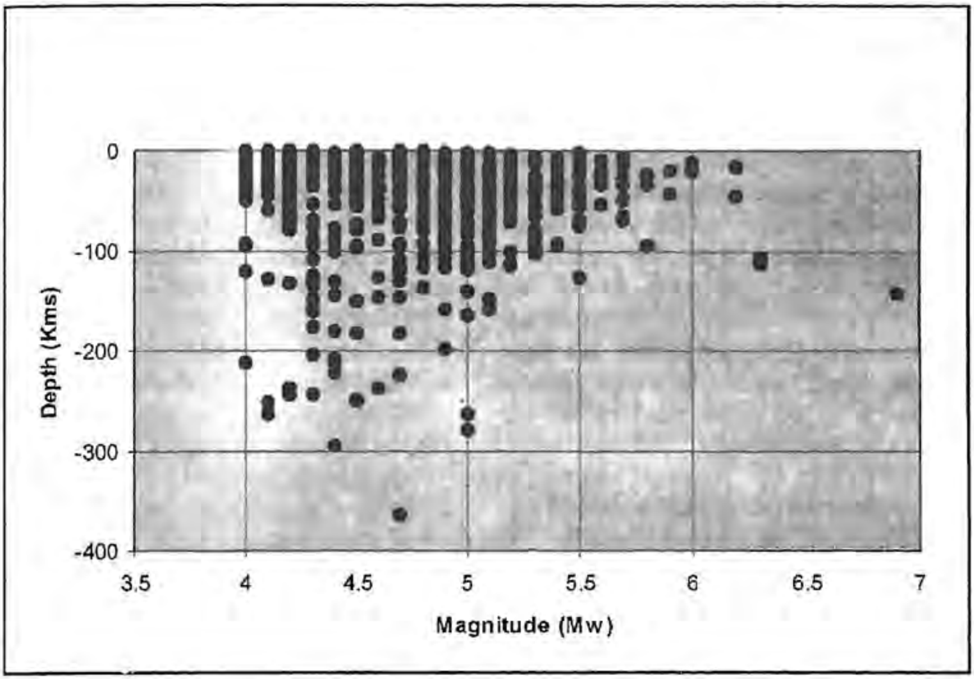

Fig. 3. Distribution of seismicity with respect to focal depth in and around the Islamabad region.

Attenuation relationships

The strong-motion attenuation relationship depicts the propagation and modification of strong ground motion as a function of earthquake size (magnitude) and the distance between the source and the site of interest. The lack of the local strong motion data in Pakistan makes it difficult to establish an attenuation equation of this region. Taking into consideration the seismicity pattern, faulting mechanism and the local geological conditions, various attenuation equations are developed by many workers for different regions of the world. Several countries/regions that do not have their own attenuation equations use these equations for their own areas depending upon the local conditions similar to those areas for which they are formulated.

In the present study, peak horizontal accelerations have been calculated using seven attenuation equations as shown in Table 3. Out of these seven equations the results of Boore et al. (1997) have been preferred due to the two reasons. Firstly, this equation is based on a high quality data set and including the term specifying for reverse faulting, which is the dominant mechanism of earthquakes in this region. Secondly the same equation can also be used for earthquakes of focal depth >70 km i.e., both for the shallow as well as for the intermediate earthquakes.

Distance from the site

The magnitude and distance of the causative sources from the site are used for the application of the attenuation equation. Within the radius of a few kilometers from the fault trace, the peak ground accelerations are very heterogeneous and display no significant attenuation with distance. Also the recent attenuation equations flatten in the near field range and a constant term has been included in the distance expression to account for the fact that focus lies at several kilometers below the surface (Ambraseys et al., 1996). Table 3 presents the closest distances of all the causative sources from the site of Islamabad. Also a constant depth of 10 km has been taken for the origin as the shallow earthquakes are of more concern to the seismic hazard assessment.

Peak horizontal accelerations

The estimation of peak horizontal acceleration at the site depends upon the maximum potential magnitude, epicentral or hypocentral distance and local geological site conditions. Therefore on the basis of maximum potential magnitudes and shortest possible distance from the site, the peak horizontal accelerations have been determined using the various attenuation relationships (Table 3). As already mentioned no attenuation law could be developed for the South Asian region due to the absence of enough strong motion data, the attenuation equations developed for other regions of the world have been used.

The peak horizontal accelerations were computed assuming that maximum earthquake along a fault occurs at the shortest distance of this fault from the site. For attenuation laws, which take into account focal depth also, acceleration values have been computed for focal depth of 10kms. Therefore the computed acceleration values represent the maximum possible seismic hazard at Islamabad due to these critical faults. All these values of peak horizontal accelerations computed by applying attenuation relationships proposed by various workers are summarized in Table 3.

CONCLUSIONS

In order to assign the maximum possible peak ground accelerations associated with the critical features present in the vicinity of Islamabad, the seismic hazard assessment using deterministic approach has been carried out on the basis of Quaternary faults study and the available tectonic and seismological information. The main conclusions based on this study are as follows:

- The Islamabad is located close to the Hazara arc region, which is seismically very active. Seventeen faults around Islamabad have been considered as the critical features located at the shortest surface distance of less than 60 km from the site.
- The distribution of both historical and instrumental earthquake data in and around Islamabad show that seismically the area is very active.
- Although several epicenters of recorded earthquakes can be associated with the known faults of the area but in order to find out the precise nature of the faults, focal mechanism studies of earthquakes should also be carried out.
- The historical seismic data (before 1904) show that apart from the frequent occurrence of VII-VIII intensity earthquakes in and around Islamabad, the maximum intensity of X on MM intensity scale was also felt in 25 AD near Islamabad (Table 1).
- The instrumental seismic data (after 1904) indicate that the earthquakes of magnitude 5-5.9 have frequently been recorded in the area (Fig. 2). The microseismicity recorded by local networks confirms the still ongoing crustal deformation in the area.
- Since Pakistan does not have the attenuation equation of its own therefore seven different available attenuation

equations are applied. Out of these seven equations the results of Boore et al. (1997) equation have been preferred due to the two reasons. Firstly, this equation is based on a high quality data set and including the term specifying for reverse faulting, which is the dominant mechanism of earthquakes in this region. Secondly the same equation can also be used for earthquakes of focal depth >70km i.e., both for the shallow as well as for the intermediate earthquakes.

- On the basis of maximum potential magnitudes and the associated peak horizontal accelerations, the following five tectonic features out of seventeen have been designated the most hazardous for the Islamabad site.
  a) MBT 0.44g
  b) Nathiagali Thrust 0.23g
  c) Thandiani Thrust 0.18g
  d) Sangargali Thrust 0.17g
  e) Riwat Thrust 0.13g
- Main Boundary Thrust (MBT) with nearest segment at 4 km north of Islamabad has the maximum potential magnitude of 7.8 which can cause peak horizontal acceleration of 0.44g and therefore represents the most critical feature of all the seventeen faults around Islamabad but since it is dipping away from Islamabad therefore the center of main energy release during the maximum potential magnitude of 7.8 earthquakes could be away from Islamabad, in that case the expected ground motions would be reduced.
- In the present work, the seismic hazard assessment has been carried out by using the deterministic approach only which gives the maximum possible seismic hazard for Islamabad, however in order to generate more realistic seismic hazard picture applicable for different category of structures present in the area, the probabilistic approach should also be applied.

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REFERENCES

Abdel-Gawad, M., 1971. Wrench movements in the Baluchistan arc and relation to Himalayan - Indian Ocean tectonics, Bull.Geol. Soc. Am. 82, 1235-1250.

Ambraseys, N.N., Lensen, G. & Monifer, A., 1975. The Pattan earthquake of 28 December 1974. UNESCO publications.

Ambraseys, N.N. & Bommer, J., 1991. The attenuation of ground accelerations in Europe, Earthquake Engin. Struct. Dynam., 20, 1179-1202.

Ambraseys, N. N., Simpson, K.A. & Bommer, J.J., 1996. Prediction of horizontal response spectra in Europe. Earthquake Engin. Struct. Dynam., 25,371-400.

Ansari, Y.S., 1995. Seismic risk analysis of Pakistan. Bull. Inst. Seism. Earthquake Engin., Japan, 31, 103-115.

Antonio, G., 1991. Stratigraphy, metamorphism and tectonics of the Hazara-Kashmir Syntaxis area. Kashmir J. Geol. 9, 39-66.

Armbruster, J.G., Seeber, L. & Jacob, K. K., 1978. The northwest termination of the Himalayan mountain front: active tectonics from micro earthquakes. J. Geophy. Res., 83, 269-282.

Armbruster, J., Seeber, L., Quittmeyer, R. & Farah. A., 1980. Seismic network data from Quetta, Pakistan: The Chaman Fault and the fault related to the 30th May, 1935 earthquake. Geol. Bull. Univ. Peshawar, 13, 129-142.

Baig, M.S. & Lawrence, R.D., 1987. Precambrian to Early Paleozoic orogenesis in the Himalayas. Kashmir J. Geol., 5, 1-22.

Bonilla, M.G., Mark, R.K. & Lienkaemper, J.J., 1984. Statistical relations among earthquake magnitude, surface rupture length and surface fault displacement. Bull. Seism. Soc. Am., 74, 2379-2411.

Boore, D.M., Joyner, W.B. & Fumal, T.E., 1997. Equations from estimating horizontal response spectra and peak acceleration from western North American earthquakes: a summary of recent work. Seismol. Res. Letters, 68, 128-153.

Bhattia, S.C., Kumar, M.R. & Gupta, K.H., 1999. A probabilistic seismic hazard map of India and adjoining areas. Annali Di Geophysica, 42, 1153-1164.

Calkins, J.A., Offield, T.W., Abdullah. S. K. N. & Ali, S. T., 1975. Geology of the southern Himalayan in Hazara, Pakistan and adjacent areas. U.S. Geol. Surv, Prof. Pap., 716-C, CI-29.

Campbell, K.W. & Bozorgnia, 1993. Near source attenuation of peak horizontal acceleration from worldwide accelerograms recorded from 1957-2993. Proceedings 5th US National Conference on Earthquake Engineering. V.III.

Fitch, T.J., 1970. Earthquake mechanisms in the Himalayan, Burmese and Andaman regions and continental tectonics in central Asia. J. Geophys. Res, 75, 2699-2709.

Idriss, I.M., 1985. Evaluating seismic risk in engineering practice. Proceedings of the 11th Int. Conference on soil mechanics and foundation engineering, 6, San Francisco.

International Commission on Large Dams (ICOLD), 1989. Guidelines for selecting seismic parameters for large dams, Paris.

Jadoon, I.A.K., Khawaja, A.A. & Jamshed, S.Q., 1995. Thrust Geometries and Evolution of the Eastern North Potwar Deformed Zone, Pakistan. Geol. Bull. Univ. Peshawar, 28, 79-96.

Jadoon, I.A.K. & Frisch, W., 1997. Hinterland – Vergent Tectonic Wedge Below the Riwat Thrust, Himalayan Foreland, Pakistan: Implications for Hydrocarbon Exploration. AAPG Bulletin, 81, 438-448.

Jadoon, I.A.K., Frisch, W., Jaswal, T. M., & Kemal, A., 1999. Triangle Zone in the Himalayan foreland, north Pakistan. In: Himalayas and Tibet: Mountain Roots to Mountain Traps: Boulder, Colorado, (A., Macfarelane, R.B. Sorkhabi & J. Quade, eds.). Geol. Soc. Am., Sp. Paper, 328.

Jaswal, T.M., Lillie, R.J. & Lawrence, R.D., 1997. Structure and Evolution of the Northern Potwar Deformed Zone, Pakistan. AAPG Bulletin, 81,308-328.

Johnson, G.D., Raynolds, R.G., & Burbank, D.W., 1986. Late Cenozoic Tectonic and Sedimentation in the Northwestern Himalayan Foredeep: I. Thrust Ramping and Associated Deformation in the Potwar Region. In: Foreland Basins, (P. Allen and P. Homewood, eds.). Intern. Assoc. Sediment. Spec. Publ., 8, 273-291.

Joyner, W.B. & Boore, D.M., 1982. Prediction of earthquake response spectra. US Geol. Surv, Open File Rep., 82-977.

Kazmi, A.H., 1979c. Preliminary seismotectonic map of Pakistan (1:2,000,000). Geol. Surv. Pak. Quetta.

Kazmi, A.H. & Jan, M.Q., 1997. Geology and Tectonics of Pakistan. Graphic Publishers. Karachi. Pakistan.

Khwaja, A. A., MonaLisa, Khan, S.A., Chaudhry, Q.Z., Rafiq, M. & Khan, A.T., 2003. Recent Seismic Activity along the Western Margin of the Nanga Parbat Haramosh Massif, Pakistan. Islamabad. J. Sci., 13, 18–27.

Lawrence, R.D. & Yeats, R.S., 1979. Geological reconnaissance of the Chaman

Fault in Pakistan. In: Geodynamics of Pakistan (A. Farah, & K.A. DeJong, eds.). Geol. Surv. Pak. Quetta, 351-357.

Lillie, R.J., Johnson, G.D., Yousaf, M., Zamin, A.S.H. & Yeats, R.S., 1987. Structural development within the Himalayan foreland fold-and-thrust belt of Pakistan. In:. Sedimentary Basins and Basins forming mechanisms (Beaumont & Tankard, eds.). Can. Soc. Petro. Geol. Memoir, 12, 379-392.

Molnar, P. & Tapponier, P., 1975. Cenozoic tectonics of Asia: effects of a continentall collision. Science, 189, 419-426.

Molnar, P. & Lyon-Caen, H., 1989. Fault plane solutions of earthquakes and active tectonics of the Tibetan plateau and its margins. Geophy. J. Intern., 99, 123-153.

MonaLisa, Khwaja, A.A., Ghazi, G.R., Jadoon, I.A.K. & Hashmi, S., 1997. Nature of faults and focal mechanism solutions of a part of northern Pakistan. Geol. Bull. Univ. Peshawar, 30, 143-151.

MonaLisa, Khwaja, A.A. & Khan, S.A., 2004. Focal Mechanism Studies of North Potwar Deformed Zone (NPDZ), Pakistan. Acta Seismologica Sinica, China. 17 (3), 255-261.

Nowroozi, A.A., 1972. Focal mechanism of earthquakes in Persia, Turkey, West Pakistan and Afghanistan and plate tectonics of the Middle East. Bull. Seismol. Soc. Am., 62, 823-850.

Nowroozi, A.A., 1985. Empirical relations between magnitudes and fault parameters for earthquakes in Iran. Bull. Seism. Soc. Am., 75, 1327-1338.

Oldham, T., 1893. A catalogue of Indian earthquakes. Mem. Geol. Surv. India, 19.

Pivnik, D.A. & Sercombe, W.J., 1993, Compression and transpression-related deformation in the Kohat Plateau, NW Pakistan. In: Himalayan Tectonics (P.J. Treloar & M.P. Searle, eds.). Geol. Soc. Lond., Spec. Publ. 74, 559 - 580.

Quittmeyer, R.L., Farah, A. & Jacob, K .H., 1979. The Seismicity of Pakistan and its relation to surface faults. In: Geodynamics of Pakistan (A. Farah, & K.A. DeJong, eds.). Geol. Sur. Pak., Quetta, 271-284.

Rastogi, B.K., 1974. Earthquake mechanisms and plate tectonics in the Himalayan region. Tectonophysics, 21, 47-56.

Sadigh, K., Egan, J.A. & Youngs, R.R., 1986. Specification of ground motion for seismic design of long period structures. Earthquakes Notes, 57, 13.

Seeber, L. & Armbruster. J., 1979. Seismicity of Hazara Arc in Northern Pakistan: Decollement vs. Basement Faulting. In: Geodynamics of Pakistan (A. Farah & K.A. Dejong, eds.). Geol. Surv. Pak, 131-142.

Seeber, L., Quittmeyer, R.C. & Armbruster, J.G., 1980. Seismotectonics of Pakistan: A review of results from network data and implications for the central Himalayas. Geol. Bull. Univ. Peshawar, 13, 151-168.

Sercombe, W.J., Pivnik, D.A., Wilson, W.P., Albertin, M.L., Beck, R.A. & Stratton, M.A., 1998. Wrench Faulting in the northern Pakistan foreland. AAPG Bulletin, 82, 2003 -2030.

Slemmons, D.B., Bodin, P. & Zhang, X., 1989. Determination of earthquake size from surface faulting events: Proc. Inter. Seminar on Seismic Zoning, China.

Tromans, I.J. & Bommer, J.J., 2002. The attenuation of strong motion peaks in Europe. Proceedings of Twelfth European Conference on Earthquake Engineering. Paper No. 394.

Verma, R.K. & ChandraSekhar, Ch., 1986. Focal mechanism solutions and nature of plate movements in Pakistan. J. Geodyn., 5, 331-351.

Verma, R.K., Mukhopadhyay, M. & Bhanja, A.K., 1980. Seismotectonics of the Hindukush and Baluchistan Arc. Tectonophysics, 66, 301-322.

Wellman, H.W., 1966. Active wrench faults of Iran, Afghanistan and Pakistan. Geol. Rundchau, 55, 716-735.

Wells, D.L. & Coppersmith, K.J., 1994. Updated empirical relationships among magnitude, rupture length, rupture area and surface displacement. Bull. Seism. Soc. Am., 84, 4.

Yeats, R.S. & Hussain, A., 1987. Timing of structural events in the Himalayan foothills of north-western Pakistan. Bull. Geol. Soc. Am., 99, 161-175.