ESTIMATION OF PEAK HORIZONTAL ACCELERATIONS FOR THE SITE OF MUZAFFARABAD USING DETERMINISTIC APPROACH

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Abstract:

The site of Muzaffarabad is situated in the NW Himalayan Fold – and – Thrust Belt Pakistan, which occupies a 250 km wide and about 560 km long, irregularly shaped mountainous region stretching from the Afghan border near Parachinar, up to Kashmir Basin situated in the active zone of convergence thereby recording a large number of seismic events. Quite a large number of seismically active tectonic features like Main Mantle Thrust (MMT), Main Boundary Thrust (MBT), Mansehra Thrust, Jhelum Fault, Kotli Thrust, Raikot Fault, Thakot Fault, Riasi Thrust, Sangargali Thrust, Hissartang Fault and many others are located within this fold and thrust belt. Historical as well as Instrumental seismological data collected in the present study confirms the active nature of all these faults. In the present work, peak horizontal accelerations have been estimated for the site of Muzaffarabad using deterministic approach. The selection of this site has been based primarily due to the fact that this site is representing the location with heavy population, high seismicity and surrounded by active tectonic features. A total of twelve faults have been considered as a critical seismogenic features to the area and their 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, Main Boundary Thrust having peak horizontal accelerations of 0.47 g has been designated as the most hazardous for the site of Muzaffarabad.

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.

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Keeping the above fact in view, an estimation of peak horizontal accelerations have been carried out for the site of Muzaffarabad using deterministic approach. For this purpose twelve faults (Table.2) have been recognized as the critical features, which are representing a constant threat to the site through the observations of both historical and instrumental data and also the geological criteria such as fault rupture length-magnitude relationship. Maximum potential magnitudes are calculated using various regression relations and finally peak horizontal accelerations (Table.2) have been computed using seven different available attenuation equations.

Regional Tectonic Setting:

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 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 730 longitude east (Molnar and 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 and 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

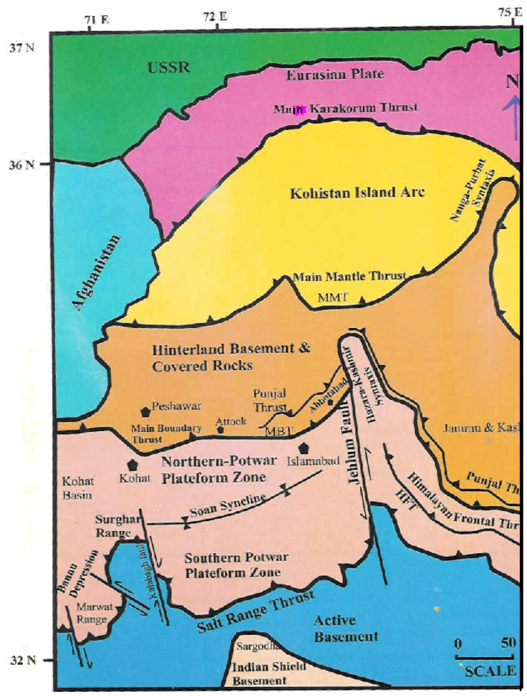


Figure. 1 – Regional Tectonic Map of Northwest Himalayas of Pakistan

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 and Yeats, 1979). However, structural mapping and focal mechanism solutions indicate that a large number of strike slip faults occur 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., 2003). On the regional scale Muzaffarabad is located in the Himalayan fold-and-thrust belt, which covers the area between the MMT and 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 Jhelum fault, whereas in the north they continue into the Nanga Parbat-Haramosh region. Muzaffarabad is located on the western side of the Hazara-Kashmir syntaxis, which is very sharp towards north and becomes less sharp towards south and south of Muzaffarabad, it appears to die out or turn towards east. 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).

Seismicity:

The 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 (Figs 1&2) like Main Mantle Thrust (MMT), Riwat Fault, Panjal-Khairabad Fault, Jhelum Fault, Kalabagh Fault and Main Boundary Thrust (MBT) etc make the study area very active. However, in this area of dominantly collisional tectonics a large number of focal mechanism solutions indicate strike-slip faulting and/or thrust faulting (Fitch, 1970; Rastogi, 1974; Armbruster et al., 1978; Verma et al., 1980; Verma and ChandraSekhar, 1986; Molnar and LyonCaen, 1989; Pivnik and Sercombe, 1993, MonaLisa et al., 1997, MonaLisa et al., 2003 and Khwaja et al., 2003). A kinematic change from compression to transpression is believed to be taking place (Pivnik and Sercombe, 1993).

Both historical/non instrumental (Oldham, 1893; Ambraseys et al, 1975 and Quittmeyer et al., 1979) and instrumental data exist in the area. The instrumentally recorded earthquake data are available only since 1904.

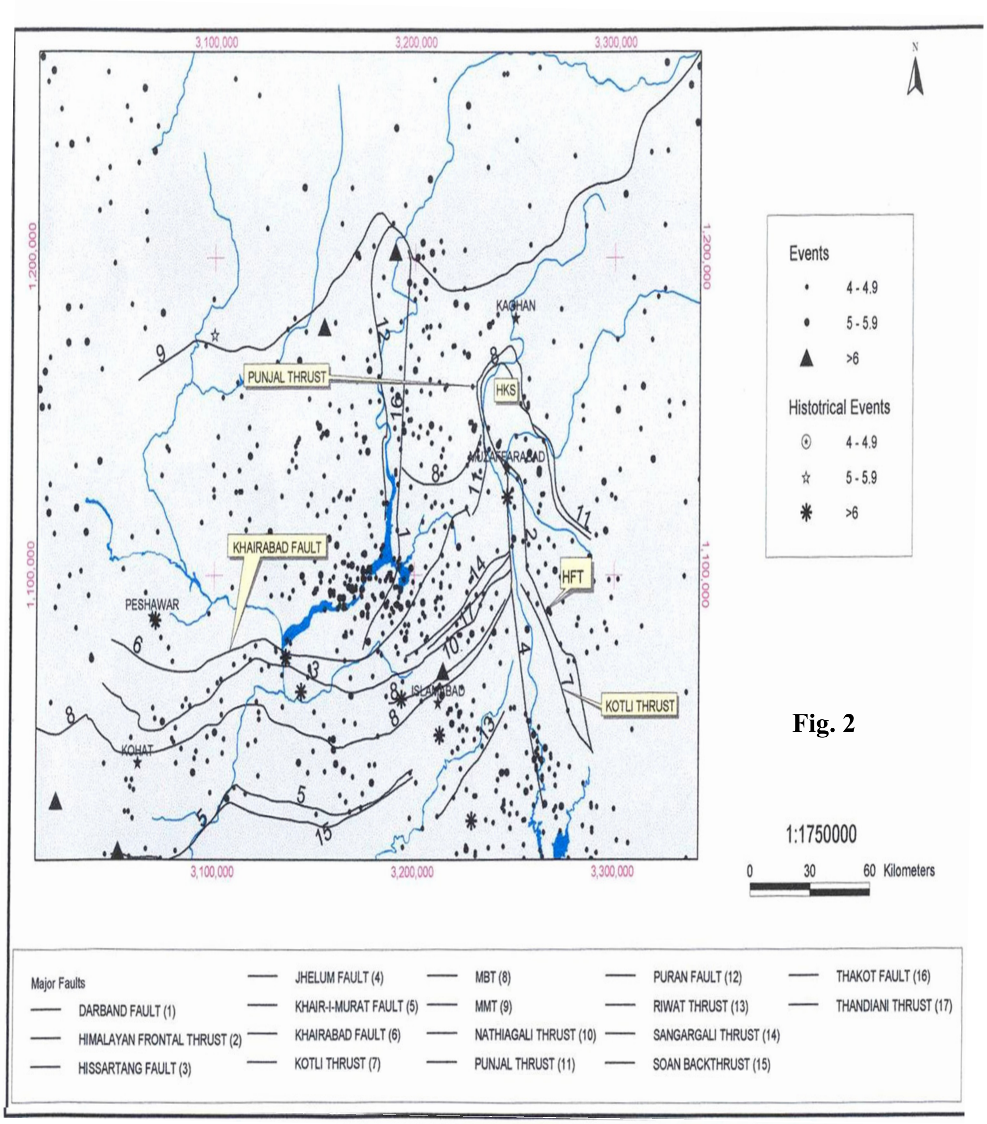


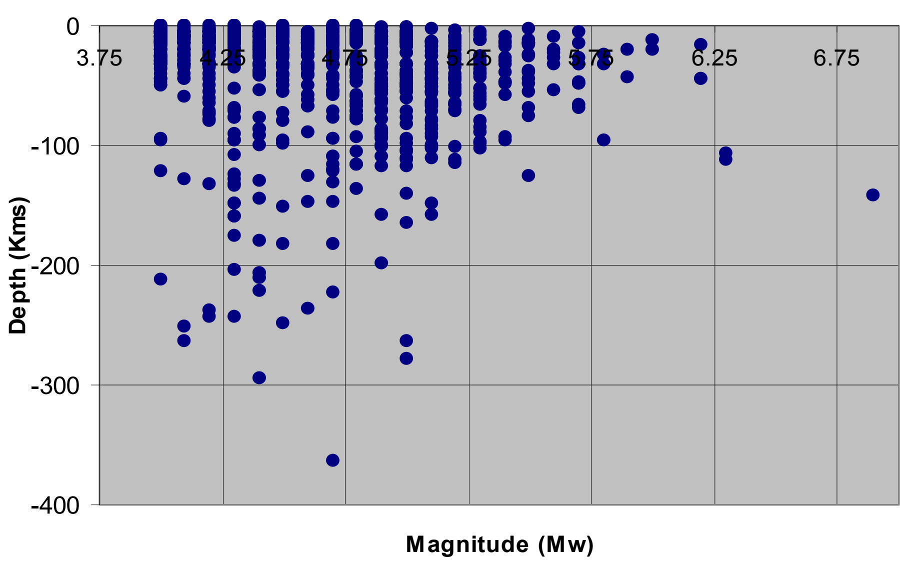
Fig. 2

This modern seismicity as reported from 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 large earthquakes with unreliable epicenter locations. However after the installation of various local seismic networks indicates the high seismic activity all along the study area, which is quite clear from Fig. 2.

Seismicity pattern:

A total of 40 pre-instrumental (before 1905) given in Table.1 and 1631 instrumental (after 1905) earthquakes are used in the present study. The study of this macro-earthquake data recorded since 1904 shows that the area lies in an active tectonic belt where several moderate earthquakes (less than magnitude 7) have been recorded. A major earthquake having a magnitude of 5.5 Mw recorded near Islamabad occurred on Feb.14, 1977 (Fig. 2). Fig. 3 shows distribution of seismicity with respect to focal depth in the study area. From this figure it is quite clear that the earthquakes having magnitude 5.0 or greater are originated within the shallow depth (i.e. <70 kms) showing that earthquake forces are more active at this depth indicating a severe earthquake hazard within this region. Moreover, the seismicity pattern, in most of the cases follows the mapped surface trend of the structures present in the area. towards north of Muzaffarabad, seismic activity near Pattan could be associated with Main Mantle Thrust (MMT), towards northwest Hindukush seismic zone is present in which some recent earthquakes resulting in some damage at Muzaffarabad have been recorded. Around Muzaffarabad, a lot of seismic activity has been recorded which could be associated mostly with Hazara Kashmir Syntaxis (HKS), Main Boundary Thrust (MBT) Fault zone and Panjal-Khairabad Thrust (Fig. 2). The level of seismicity however decreases from north to south and becomes quite less south of Salt Range (Fig. 1). This low level of seismicity may be true as no prominent causative seismotectonic feature is mapped

Fig. 3



in the plain areas of Punjab due to thick alluvial cover. However, another factor for this reduced level could be the fact that no local seismic network properly covers this area.

The fault plane solutions of some of the earthquakes, determined by the authors (Mona Lisa et al., 1997, Mona Lisa et al., 2003 and Khwaja et al., 2003) and the previous workers like (Armbruster et al., 1978; Verma et al., 1980; Verma and Chandra Sekhar, 1986; Molnar and Lyon Caen, 1989; Pivnik and Sercombe, 1993) suggest that while predominant faulting mechanism in this region is thrusting, strike slip faulting is also present.

Estimation of Peak Horizontal Acceleration 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 identification of a maximum magnitude assigned to each of these faults. Then with the help of suitable attenuation equations, peak horizontal accelerations are determined. Therefore the deterministic method includes the following steps:

- Identify all tectonic features in the vicinity of the site likely to generate significant ground motions.
- Assign to each of these a maximum magnitude on the basis of key fault parameters.
- Compute the ground motion parameters at the site associated with each feature as a function of magnitude and distance.

Critical features:

As mentioned above, twelve faults (Table.2) have been selected as the critical features for the seismic hazard assessment to the sites. In addition 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 is dominantly representing the thrust faulting but some strike-slip component is also present. This is the reason that out of twelve selected faults, nine are thrust and three are strike-slips. All these faults along which earthquakes can produce the appreciable strong ground motions are shown in Fig. 2. It is beyond the scope of this study to describe all these twelve faults therefore only those faults are discussed which has the peak horizontal accelerations greater than 0.3g.

Table: 1

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

Main Boundary Thrust (MBT):

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 syntaxis and then bends southward towards Balakot (Kazmi and Jan, 1997). It dips about 500 to 700E 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.

A hairpin-shaped system of faults truncates the Hazara-Kashmir Syntaxis (HKS) both on the east and western sides (Kazmi and 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 and 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). On the Kashmir side (i.e. eastern side of Hazara Kashmir Syntaxis) between MBT in the east and Jhelum Fault in the west, Himalayan Frontal Thrust (HFT) and Kotli Thrust are situated (Fig. 2). Near Kotli, Himalayan Frontal Thrust and the Kotli Thrust appear in the northwestern direction and run parallel to Jhelum Fault till the Kaghan Valley where the Jhelum Fault truncates the Himalayan Frontal Thrust (Baig and Lawrence, 1987). The alignment of epicenters (Fig. 2) along all these three faults shows that seismically they are active. This MBT fault zone and the area around HKS is the source of many strongest ever-recorded earthquakes in the region and therefore represents very high earthquake potential. These 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 and Armbruster, 1979).

In the present study, MBT and HFT are found to be the most hazardous for the site of Muzaffarabad with the peak horizontal acceleration of 0.47g and 0.42g respectively.

Table 2:

Tectonic Features	Maximum Magnitude (Mw)	Closest Distance to Faults (Kms)	Computed Accelerations (g) Median (50-percentiles)						
			1	2	3	4	5	6	7
Punjal Thrust	7.2	1.61	0.51	0.56	0.41	0.39	0.32	0.34	0.46
MBT	7.8	0	0.59	0.7	0.58	0.41	0.47	0.47	0.62
Oghi Thrust	6.9	22	0.19	0.25	0.14	0.13	0.12	0.15	0.16
Mansehra Thrust	6.8	14	0.26	0.33	0.20	0.20	0.16	0.18	0.22
Thakot Fault	7.1	44	0.10	0.14	0.08	0.06	0.08	0.08	0.09
Puran Fault	7.2	65	0.06	0.09	0.06	0.03	0.06	0.08	0.06
Himalayan Frontal Thrust	7.6	1	0.56	0.63	0.52	0.41	0.42	0.42	0.56
Jhelum Fault	7.1	0	0.51	0.55	0.39	0.32	0.31	0.27	0.44
Sangargali Thrust	6.9	32	0.13	0.17	0.10	0.08	0.09	0.11	0.11
Thandiani Thrust	6.8	34	0.11	0.15	0.09	0.07	0.08	0.10	0.10
Nathiagali Thrust	7	36	0.12	0.16	0.10	0.08	0.08	0.11	0.10
Balakot Shear Zone (BSZ)	6.8	30	0.13	0.18	0.10	0.08	0.09	0.09	0.11

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

Panjal Thrust:

Panjal Fault is a thrust fault, which runs parallel to MBT on the eastern limb of the Hazara-Kashmir Syntaxis and on the western side it lies over the Sangargali Fault with its nearest segment passing about 1.61kms from Muzaffarabad (Fig.1). Panjal Thrust curves around the apex of the syntaxis then bend southward (Kazmi and Jan, 1997). On both eastern and western limb of the syntaxis this fault has different tectonic and stratigraphic setting. Due to this reason Greco, 1991, has named the Panjal Thrust as Mansehra Thrust on the western side of the syntaxis. Further westward it apparently links up with the Khairabad Thrust (Yeats and Hussain, 1987). However Baig et al., 1989, Treloar et al., 1989a; 1990 and Coward et al., 1986 used the name Mansehra Thrust for another thrust passing close to Mansehra north of the Panjal Thrust. Therefore in order to avoid this confusion the term Abbottabad Thrust is used for that part of Panjal thrust passing on the western side of the HKS as suggested by Baig and Lawrence, 1987. They are also of the opinion that the Mansehra and Oghi Thrusts are the extension of Balakot shear zone in the Kaghan Valley and both of them are structurally above the Panjal Thrust.

The macro-instrumental seismic record since 1904 shows that the earthquakes with magnitude ranging between 4-5.5Mw have occurred along these faults. On January 04, 1984 an event of magnitude 4.7 was located by MSSP, Nilore along the Panjal Thrust with its epicenter west of Haripur. The seismic data of Tarbela microseismic network since 1973 also show a lot of seismic activity along the Panjal fault.

In the present work, Panjal thrust is also found to be hazardous tectonic feature with the peak horizontal acceleration of 0.34g.

Maximum Earthquake Potential:

The methods assigning a maximum potential magnitude to a given active fault based on empirical correlations between magnitude and key fault parameters such as fault rupture length, fault displacement and fault area (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. Thus in the present case, the maximum potential magnitudes of twelve faults in the study area calculated on the basis of 50 % of total length (ICOLD, 1989) and 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 length, rupture length and maximum potential magnitudes calculated in the present study.

Attenuation equation 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 its own. Taking into consideration the seismicity patterns and the local geological conditions, various attenuation equations are developed by various workers for different regions. Several countries/regions that do not have their own attenuation equations use these equations for their own areas depending upon the local soil conditions similar to those areas for which they are formulated.

In the present study, peak horizontal accelerations have been calculated using seven attenuation equations of Joyner and Boore (1982); Sadigh et al (1986); Ambraseys and Bommer (1991); Campbell and Bozorgnia (1993); Ambraseys et al (1996); Boore et al (1997); Tromans and Bommer (2002) as shown in Table. 2. 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 > 30 kms i.e. both for the shallow as well as for the intermediate earthquakes. It should be noted that the values of peak horizontal accelerations given in the section of critical tectonic features is based upon this Boore et al., 1997 equation.

Since attenuation relationships are based upon magnitudes of given type, a single scale must be selected. All the magnitudes in the composite list of earthquakes from 1904 to 2002 are therefore converted to moment magnitudes using the relationships of Ambraseys and Bommer (1990).

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 laws. 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 laws developed for other regions of the world and recommended by ICOLD (1989) 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 10 kms. All these values of peak horizontal accelerations computed by applying attenuation laws proposed by various workers are summarized in Table. 2.

Conclusion:

In order to assign the peak ground accelerations associated with the critical features present in the area of NW Himalayan Fold and Thrust Belt, 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 area surrounding the Muzaffarabad is seismically very active. Twelve faults shown in Table.1have been considered as the critical features at the shortest surface distance of 100 kms from the site.
- The distribution of both historical and instrumental earthquake data in and around the study area shows 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 must have also carried out.
- The historical seismic data (before 1904) shows that apart from the frequent occurrence of VII-VIII intensity earthquakes in and around the area, the maximum intensity of X on MM intensity scale also occurred in 25 AD in the area.
- The instrumental seismic data (after 1904) indicates that the earthquakes of Mw 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 nine 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 > 30 kms i.e. both for the shallow as well as for the intermediate earthquakes.

- The selection of the site of Muzaffarabad is primarily based upon the fact that this represents the well populated locations with appreciable level of seismicity and the active tectonic features are present around it.
- On the basis of maximum potential magnitudes and the peak horizontal accelerations, the tectonic features have been designated as the most hazardous to the site are shown in Table.2.
- MBT i.e. Main Boundary Thrust representing the maximum potential magnitude of 7.8 and peak horizontal acceleration of 0.47g and therefore representing the most critical feature of all twelve features selected for the site of Muzaffarabad (Table.2).
- In the present work, the seismic hazard assessment has been carried out using the deterministic approach only, however in order to generate more precise and accurate seismic hazard picture of the area, the probabilistic approach must be applied also.

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