# The 8 October 2005 Muzaffarabad earthquake: Preliminary seismological investigations and probabilistic estimation of peak ground accelerations

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**This study is based on data obtained from the USGS and observatories in northern Pakistan for 251 earthquakes of magnitude ≥4.0 *M* for 8 October 2005 to 31 August 2006 period. Depth- and magnitude-based seismological characteristics and distribution pattern of the aftershocks define a 50 km wide NW-SE trending zone that extends for 200 km from the Main Mantle Thrust to the centre of the Hazara Kashmir Syntaxis. The focal mechanism solutions (FMS) of the main shock, and its two principal aftershocks having magnitude ≥6.0 *M* and located about 80 km NNW of the main shock, indicate thrusting to be the dominant mechanism with rupture planes having NW-SE trend and NE dip. This leads to the conclusion that the wedge-shaped NW-SE trending blind zone, referred to by earlier workers as Indus Kohistan Seismic Zone (IKSZ), has been activated. We propose that the IKSZ does not end at the nose of the syntaxis, but extends further into it. However, more FMS data are required to confirm this. Seismic hazard assessment, using probabilistic approach, for Muzaffarabad has also been carried out. Following the normal practice, peak ground acceleration (PGA) values with 10% probability of exceedance in the 50 years, i.e. the return period of 475 years, have been determined using two appropriate attenuation equations. The PGA values of 0.10 and 0.13 *g* obtained from two equations are not so high for the next 50 years, but the site (Muzaffarabad) has poorly constructed structures and can experience considerable damage as compared to other less populated sites in the surroundings.**

**Keywords:** Focal mechanism solution, Indus Kohistan Seismic Zone, Muzaffarabad earthquake, peak ground acceleration.

THE Himalayas stretches for about 2400 km from western Kashmir to the Indo-Burman border[1]. The ongoing convergence between the Indian and Eurasian plates has resulted in a high level of seismicity in the region. It has recently gained global attention because of the devastating Muzaffarabad earthquake of 8 October 2005. This 7.6 $M_w$ earthquake, with epicentre at 34.42°N, 73.52°E (local observatory), has shown that more than one tectonic subdivision of the Pakistan Himalayas, i.e. the Hazara Kashmir Syntaxis (HKS) and the crystalline nappe zone have been activated.

In this area of active convergence, transpressional tectonics also seems to be operative. A large number of faults have been recognized in the NW Himalaya of Pakistan. These include faults of very large extent, such as the Main Mantle Thrust (MMT; Indus Suture), the Main Boundary Thrust (MBT), and the Himalayan Frontal Thrust (HFT or Muzaffarabad Fault), as well as local faults. In addition, existence of subsurface faults, like the NW trending Indus Kohistan Seismic Zone[2] and Bagh Basement Fault (BBF based on gravity data)[3], are significant vis-à-vis the seismicity. According to the map of faults by MonaLisa *et al.*[4,5], compiled from various sources[6–9], there are at least 41 active faults in this fold and thrust belt of NW Himalayas (Figure 1). Many new faults are being delineated through geological mapping and use of remote sensing techniques. The presence of a large number of blind/subsurface faults, as delineated by focal mechanism studies[4,5,10–12], adds to the structural and tectonic complexities of this part of NW Himalayas.

The Muzaffarabad earthquake was a major seismological disturbance and the most devastating of the Himalayan earthquakes[13]. It occurred at 08 : 50 : 38 Pakistan Standard Time on 8 October 2005. The USGS measured it as 7.6 on the moment magnitude scale, with its epicentre at 34°29′35″N, 73°37″44″E, about 19 km NE of Muzaffarabad and 100 km NE of Islamabad. This article presents a preliminary seismological investigation of Muzaffarabad and adjacent areas devastated by the earthquake. This work includes the frequency of aftershocks, depth, magnitude and focal mechanism solutions (FMS) of the main earthquake and its subsequent two principal aftershocks (magnitude ≥ 6.0), and estimation of peak ground acceleration (PGA) values for Muzaffarabad, using probabilistic seismic hazard assessment (PSHA). This article

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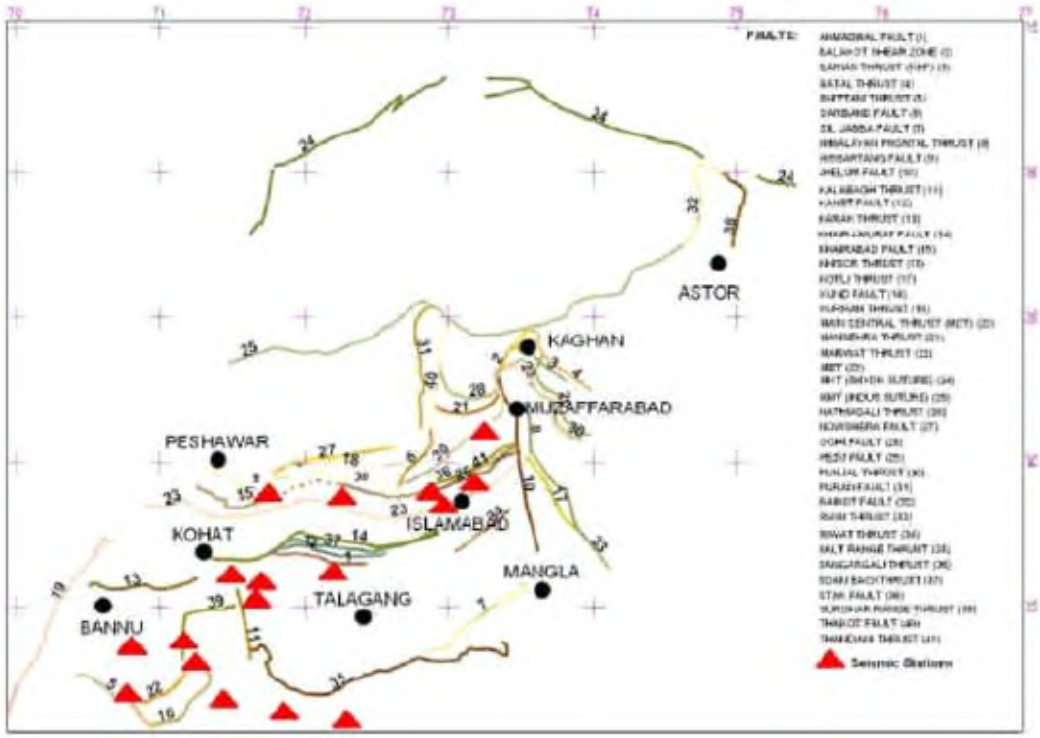


**Figure 1.** Tectonic map of the area showing the locations of 41 active faults and seismic stations (modified from MonaLisa *et al.*[4]). MBT; Main Boundary Thrust; MKT, Main Karakoram Thrust; MMT, Main Mantle Thrust.

may provide a basis for further geological/seismological studies. It may also be of use to planners and builders involved in the development of physical infrastructure in the area.

## Tectonic setting

Pakistan comprises the alluvium-covered Indian shield in the SE, the great Himalayan ranges in the NE, the Karakoram–Hindukush block in the north and northwest, the Suleman–Chaghai arc ranges in the southwest, and the Makran subduction zone in the south-southwest. Collision between the Eurasian blocks and the Indian Plate is responsible for the Himalayan orogeny and formulation of mobile belts. Northern Pakistan comprises at least three distinct tectonic blocks: the Karakoram Plate in the north, the Kohistan Magmatic arc (extending east of Nanga Parbat into the Ladakh arc) in the middle, and the Indian Plate in the south. Collision between Karakoram and Kohistan occurred during the Late Cretaceous (about 100 Ma ago) and between the Indian Plate and Kohistan during Paleocene–Early Eocene[14]. Yeats and Lawrence[15], Tahirkheli *et al.*[16] and Tahirkheli and Jan[17] have shown the presence of several regional thrusts: the Main Karakoram Thrust or the Shyok Suture; MMT or the Indus Suture; the MBT, the HFT, and the Salt Range Thrust (Figure 1). These are considered to demarcate the major subdivisional boundaries of the Karakoram–Kohistan–India collision zone. The extension of the Main Central Thrust in this part of the Himalayas, however, has been a subject of controversy[18].

The NW Himalayan Fold-and-Thrust Belt, along the northwestern margin of the Indian Plate, is an area of ongoing convergence. Kazmi and Jan[14] have subdivided it into a northern Hinterland Zone and a southern Foreland Zone, the two being divided by the Punjal and Khairabad Faults (Figure 1). The two zones comprise several tectonic subdivisions. Among these the Hazara Crystalline Zone[19], also called Crystalline Nappe Zone[14] or Himalayan Crystalline Zone[20] in the Hinterland Zone, and the HKS in the Foreland Zone experienced the recent (2005) seismic activity.

## Seismicity

The seismically active nature of an area is determined through the use of historical and instrumental data. Unfortunately, in the case of Pakistan, there exists poor documentation of pre-instrumental earthquakes. Some events that caused loss of life and destruction in northern Pakistan during the recent past are the 1974 Pattan earthquake of $m_b$ 6.0, the 1977 Rawalpindi earthquake of $m_b$

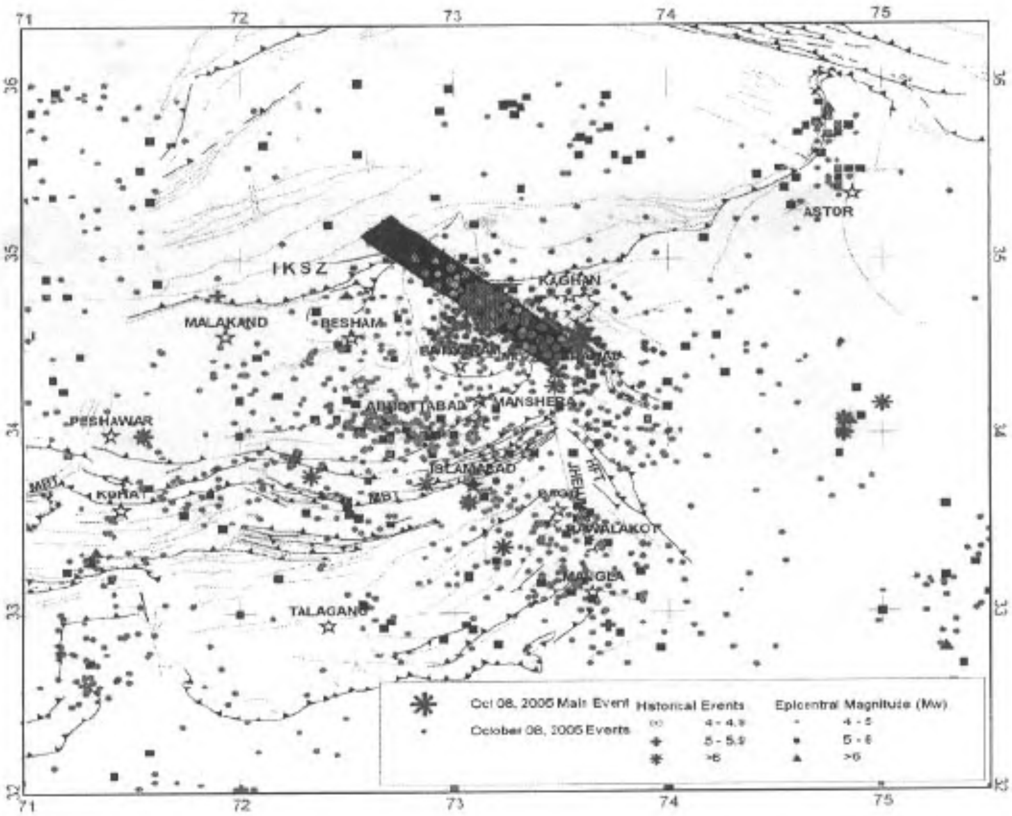


**Figure 2.** Seismicity map of the northwestern Himalayan Fold-and-Thrust Belt, including the 8 October 2005 Muzaffarabad earthquake (modified from MonaLisa *et al.*[5]).

5.2, the two Bunji earthquakes of $m_b$ 5.3 and 6.0 in 2002, and the 2004 Batgram earthquakes of $m_b$ 5.3 and 5.5. The present-day seismicity in the area has been reported by both local as well as international observatories: United States Geological Survey (USGS), International Seismological Centre, and British Association for the Advancement of Science. The quality of the older data can be debated; however, it has improved since 1964, after the installation of World Wide Seismographic Stations Network comprising about 120 stations in 20 countries.

In the present study, 251 aftershocks of the 8 October 2005 earthquake, obtained from 17 seismic stations of the Pakistan Atomic Energy Commission (PAEC), have been plotted on the seismicity map of MonaLisa *et al.*[4]. The locations of the PAEC stations are shown in Figure 1. Hypo71, Hypo inverse and SEISAN software are used by PAEC to compute epicentral locations and depths. For locating the aftershocks, PAEC uses its own *P*-wave velocity model, and for *S*-wave velocities it is assumed that the $V_P/V_S$ ratio is 1.73. For magnitude calculation, correction and simulation of standardized instruments have been done using peak-to-peak amplitudes. PAEC data have an error of ± 2 to 5 km for location and depths for the 251 readings. Figure 2 shows the pre-instrumental (before 1904) and instrumental (after 1904) seismicity data based on a composite earthquake catalogue prepared by MonaLisa *et al.*[5] for the area bounded by lat. 32°–35°30′N and long. 70°–75°15′E. It is based on moment magnitude ($M_w$) ≥ 4.0. A brief account of the preparation of this composite catalogue is given below.

## *Historical seismicity*

Historical earthquake data constitute an important foundation for seismic monitoring, earthquake forecast and seismic safety evaluation. However, recognition of the earthquake is limited by the scientific and technological level. Therefore, the earthquake can only be described using perfect earthquake catalogues. For the study area, documentation of historical seismicity is poor. However, information exists in some catalogues[13–21], and at the seismic observatories of Pakistan Meteorological Department, Atomic Energy Commission, and Tarbela and Mangla Dams. These catalogues handle the epicentral location of an historical event by combining the latitude, longitude and epicentral location where the disaster is the most serious, whereas for magnitudes, the empirical relationships between magnitude and intensity are used. All this information, although incomplete, forms part of the composite catalogue of MonaLisa *et al.*[4].

*Instrumental seismicity*

For instrumentally recorded earthquakes, catalogues prepared by Ambraseys[22–26] have been used by MonaLisa *et al.*[4]. In order to compile the composite earthquake catalogue, the generally used approach of Stepp[27] has been adopted to remove or minimize the effects of incompleteness in the data. This method involves the grouping of earthquake classes on the basis of different time intervals and magnitude ranges, determination of mean rates of occurrence of earthquakes within each magnitude range, and the recurrence relationship ($b$-value) using the least square method. In the case of magnitude, a single scale, i.e. moment magnitude ($M_w$), was adopted using the following relationships[28].

$$0.87(m_b) - 0.50(M_S) = 1.91, \quad (1)$$

$$0.82(M_L) - 0.58(M_S) = 1.20, \quad (2)$$

$$\log M_o = 19.24 + M_S \quad \text{for } M_S < 5.3, \quad (3)$$

$$\log M_o = 30.20 - \{92.45 - 11.40\ M_S\}\ 0.5 \quad \text{for } 5.3 \le M_S \le 6.8, \quad (4)$$

$$M_w = (2/3)\log(M_o) - 10.73, \quad (5)$$

where $m_b$ is the body wave magnitude, $M_S$ the surface wave magnitude, $M_L$ the local magnitude, $M_w$ the moment magnitude, and $M_o$ the seismic moment. This has helped create uniformity in the catalogue. The results of the incompleteness analysis show that the catalogue data are totally incomplete for magnitudes 3–3.9, whereas they are complete for $M > 4$ since 1960, for $M > 5$ since 1930, and for $M > 6$ since 1900.

Next, we discuss the seismicity pattern in terms of frequency of aftershocks, depth, magnitude and FMS of the main event, and its two aftershocks with magnitudes 6.0 and 6.4.

## Seismicity pattern

Magnitude, depth and FMS are the seismological parameters that are considered to be essential in the analysis of the seismicity pattern. These parameters provide valuable information about the subsurface/blind tectonic features that may be responsible for the earthquake activity. Magnitude, a measurable seismological parameter, is considered to be one of the important criteria when interpreting the future and past seismic activity in an area. In the present case, the seismicity map of the NW Himalayan Fold-and-Thrust Belt (Figure 2) with ≥4 magnitude earthquakes shows that majority of the earthquakes are in the range 4–5.9, with some isolated events of >6.0 magnitude. Epicentral distribution shows that all are not associated with the known active faults, thereby indicating activation of blind faults in the region. Earlier studies have indicated the presence of a 100 km long and about 50 km wide-wedge shaped structure between the MMT and the nose of the HKS known as the Indus Kohistan Seismic Zone (IKSZ). Seismic activity is being recorded from it at two distinct levels. An upper part extending from the surface to a depth of about 10 km and the lower part in which earthquakes mostly occur within a depth range 10–25 km. The 8 October 2005 Muzaffarabad earthquake and its aftershock distribution (Figure 2) follow a pattern similar to the IKSZ even within the HKS, thereby indicating the extension of the IKSZ in this part. This is also confirmed by the focal depths and FMS of the main earthquake and its two principal aftershocks, as can be seen in the following sections.

Based on local data for the period from October 2005 to August 2006, 205 of the 251 aftershocks were in the range 4–4.9 $M_w$, and 44 in the range 5–5.9 (Figure 3). There are only two events with magnitude 6. The major concentration of the 4–4.9 $M_w$ events is along the nappe zones, known as the Hazara nappe zone and Banna nappe zone[29]. These nappe zones are encased by the Thakot Fault in the west, Balakot Shear zone in the east, Oghi and Mansehra thrusts in the south, and the MMT in the north. The HKS also showed seismic activity during the

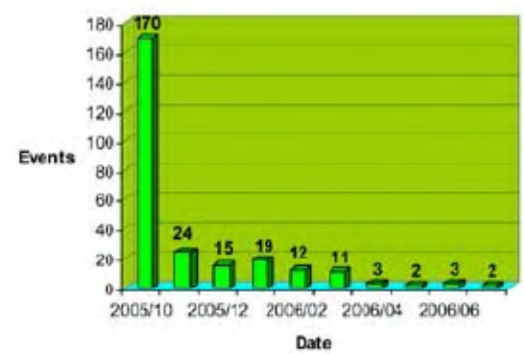


**Figure 3.** Frequency of aftershocks with respect to time for the period 8 October 2005–31 August 2006.

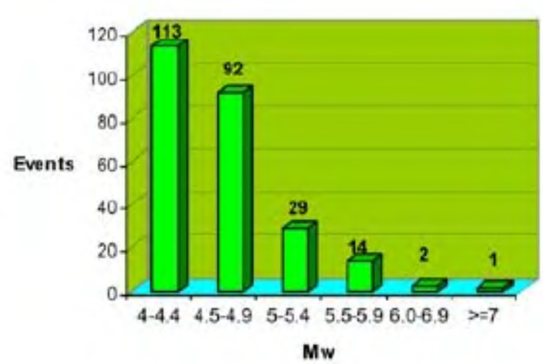


**Figure 4.** Number of aftershocks versus magnitude ($M_w$) for the period 8 October 2005–31 August 2006.

reported period from October 2005 to August 2006 (Figure 2). Based on aftershock distribution, a 200 km long and 50 km wide area seems to have been activated. From slip distribution, Singh *et al.*[30] estimated the rupture area at 100 × 15 sq. km.

About 147 aftershocks were documented on the first day after the initial shock, one of which had a magnitude of 6.4 $M_w$ (local observatory). Twenty-eight occurred with a magnitude greater than five during four days after the main event. Major shocks ($M_w \geq 4.5$) continued to occur for many days. On 19 October there were a series of strong aftershocks; one with a magnitude of 5.8 occurred about 65 km NNW of Muzaffarabad. More than 2000 aftershocks were recorded till 30 April 2006 (USGS). There is a clear indication of decrease in the frequency of aftershocks with passage of time, as evident from Figure 4.

The depth distribution of the Muzaffarabad earthquake and its aftershocks is shown in Figure 5. The occurrence of 214 out of 251 aftershocks within the depth range of 5–20 km, clearly indicates activation of the IKSZ of Armbruster *et al.*[2]. The relationship between depth and magnitude ($M_w$) displayed in Figure 6 also shows that there exits a small concentration of 4–4.5 magnitude earthquakes at greater depth zones (up to 35 km). Two records (of 3.5 and 4.5 magnitude) of deeper origin do not conform to the rest, and may be erroneous.

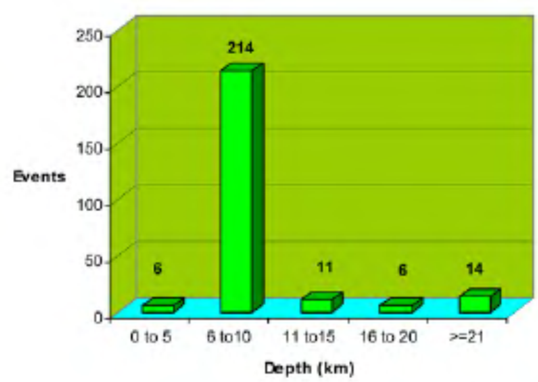


**Figure 5.** Number of aftershocks versus depth (km) for the period 8 October 2005–31 August 2006.

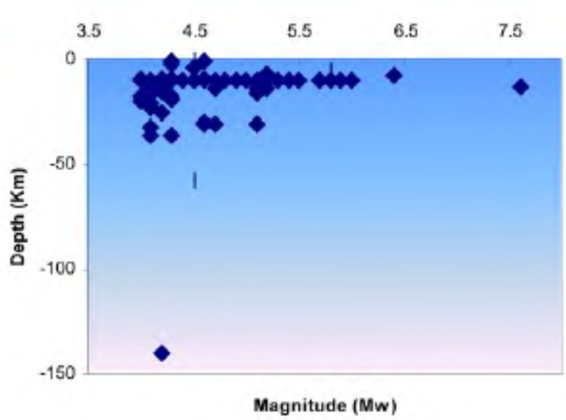


**Figure 6.** Depth (km) vs magnitude ($M_w$).

## Focal mechanism solutions

The main shock of 8 October 2005, and its subsequent two principal aftershocks (≥6.0 $M_w$) that occurred on the same day (Table 1) have been selected for the determination of FMS and are shown in Figure 7 *a–c*, respectively. The main shock, which occurred about 19 km NE of Muzaffarabad (Figure 8), is structurally surrounded by a number of active faults, e.g. MBT, Jhelum Fault, Punjal Thrust, Himalayan Frontal Thrust, etc. The two principal aftershocks, which are located about 80 km NNW of the main shock (Figure 8), occurred in the Banna nappe zone[29]. Previous focal mechanism studies[4,5,10–12] have shown thrusting (pure thrusts and reverse faulting) followed by strike-slip faulting to be the deformation style of the region. Beach-ball diagrams of all these three events (Figure 7) indicate the operation of thrust mechanism with some strike-slip component. Nodal planes having a NW-SE trend and dipping towards the NE are the rupture planes in accordance with the trend and dip of the IKSZ. The current seismic activity, however, is yet to be fully analysed.

## Probabilistic seismic hazard assessment for Muzaffarabad

PGA values have been estimated using the PSHA. The conventional approach of Cornell[31] has been adopted for Muzaffarabad. PSHA is denoted by the probability that ground acceleration reaches certain amplitudes or by seismic intensities exceeding a particular value within a specified time interval. The inverse of probability of exceedance is known as the return period for that acceleration and is used to define seismic hazard. In PSHA, the seismic activity of the seismic source (line or area) is specified by a recurrence relationship, defining the cumulative number of events per year versus their magnitude. Distribution of earthquakes is assumed to be uniform within the source zone and independent of time. Seismic hazard calculated for different sites can be used to generate maps or curves (hazard curves) with ground accelerations expected with a given probability for a specified interval of time. In the present work, the four seismic source zones (Figure 9) and their seismic hazard parameters evaluated by MonaLisa *et al.*[4] have been used for the estimation of PGA using PSHA. The calculation of PGA involves the use of an appropriate attenuation equation.

An attenuation equation is the mathematical/statistical relationship that correlates the ground acceleration to magnitude and distance, and needs strong motion data.

**Table 1.** Source parameters of earthquakes whose FMS have been determined

| | | | Location | | | |
|---|---|---|---|---|---|---|
| Sol. no. | Date Y : M : D | Time (GMT) H : M : S | Latitude (°N) | Longitude (°E) | Depth (km) | Magnitude ($M_w$) |
| FMS 1 | 2005 : 10 : 08 | 3 : 50 : 38.00 | 34.42 | 73.52 | 13.0 | 7.6 |
| FMS 2 | 2005 : 10 : 08 | 10 : 46 : 28.00 | 34.76 | 73.28 | 8.0 | 6.4 |
| FMS 3 | 2005 : 10 : 08 | 21 : 13 : 31.00 | 34.77 | 73.45 | 10.0 | 6.0 |

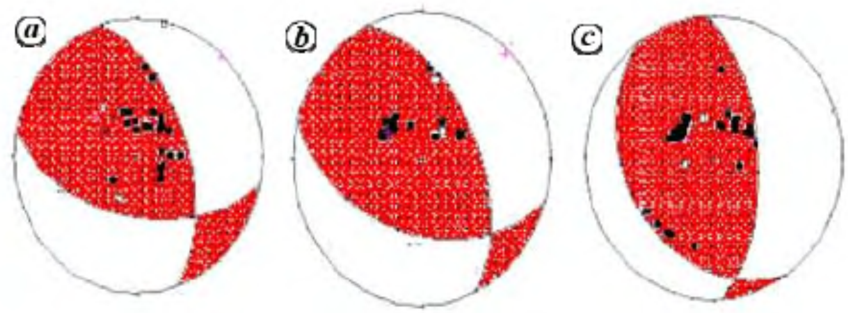


**Figure 7.** Focal mechanism solutions (FMS) of the main shock and its two principal aftershocks. ***a***, FMS 1 (main event); ***b***, FMS 2 (first aftershock); ***c***, FMS 3 (second aftershock).

Due to lack of the strong motion data, Pakistan does not have an attenuation equation of its own. The relationships of other countries with similar tectonic and geological conditions as those of our region are usually employed in seismic hazard assessment. In the present case the attenuation equations of Ambraseys *et al.*[32] and Boore *et al.*[33] have been used. Bommer[34] in his detailed work on attenuation equations for Pakistan, concluded that there are no equations available even from the neighbouring countries that can be adopted for seismic hazard assessment. For northern Pakistan, he selected the attenuation equation of Boore *et al.*[33] that has been derived from western North America. In the present study also, the same equation has been used for the PGA calculations based upon the fact that it is valid for crustal earthquakes and for thrust/reverse faults, which are the dominant mechanisms of the study area. The equation of Ambraseys *et al.*[32] has been used for the sake of comparison only.

Both these equations are reproduced below:

$$\ln Y = C_1 + C_2M + C_3r + C_4\log(r) + \sigma P. \quad (6)$$

$$\ln (Y) = b_1 + b_2(M - 6) + b_3(M - 6)^2 + b_5\ln r + b_v\ln V_{S,30}/V_A, \quad (7)$$

where $Y$ is the parameter being predicted, in our case peak horizontal ground acceleration in $g$, $M$ the surface wave magnitude in eq. (6) and moment magnitude in eq. (7), $r = (d^2 + h_0^2)^{1/2}$ in eq. (6) and $(r_{jb}^2 + h^2)^{1/2}$ in eq. (7), $d = r_{jb}$ the shortest distance (in km) from the station to the surface projection of the fault rupture, $h_0$ a constant to be determined with $C_1$, $C_2$, $C_3$ and $C_4$, $h$ the regression parameter and $V_{S,30}$ the shear wave velocity $b_{1SS}$ for strike-slip earthquakes, $b_1 = b_{1RS}$ for reverse-slip earthquakes, $b_{1ALL}$ if mechanism is not specified.

In the relationship of Ambraseys *et al.*[32], the standard deviation of log($y$) is $\sigma$, and the constant $P$ takes a value of 0 for mean values and 1 for 84-percentile values of log($y$). This relationship is considered valid for $M_S$ = 4.0 to 8.5 for source distance of up to 200 km. On the other hand, the relationship of Boore *et al.*[33] is valid for $M_w$ = 4.0 to 8.5 and $r_{rup} \leq 80$ km.

The PSHA results are in the form of the hazard curve that has been generated using the software EZ-FRISK (6.2 beta version, 2004 modified form). This program calculates earthquake hazard at a site under certain assumptions specified by the user. These assumptions involve identifying sites where earthquakes will occur, their characteristics and the ground motions generated. Its easy use allows identifying the critical inputs and definitions affecting seismic hazard evaluations. Further, seismic hazard is determined using the standard methodology[35]. The range of values used as input parameters can account for multiple hypotheses and computation of uncertainty in the resultant hazard values. It uses the seismic hazard parameters such as annual activity rate, minimum magnitude, maximum magnitude and $b$-value characteristics of the region as the input parameters (Table 2). The maximum magnitudes for all zones have been estimated using the available relationships[36–39]. The results, summarized in Table 2, show the maximum potential magnitude (which is the mean of the maximum magnitudes obtained from all four relationships in the most critical tectonic feature in each zone). Results obtained are in the form of hazard

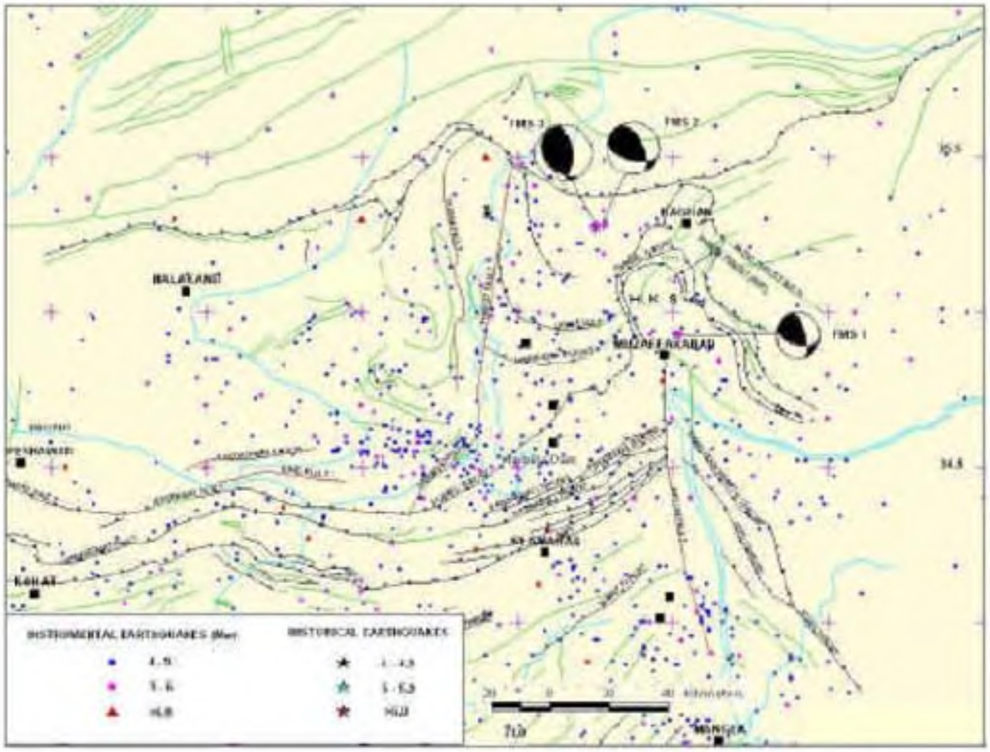


**Figure 8.** Seismicity and detailed structural map of the area with the location of FMS of the 8 October 2005 Muzaffarabad earthquake (FMS 1) and its two principal aftershocks (FMS 2 and FMS 3).

**Table 2.** Input parameters for EZ-FRISK assigned to four seismic zones (adapted from MonaLisa *et al.*[4])

| Seismic zone | $b$ value | $\beta$ value | Annual activity rate $\lambda$ | Minimum magnitude $m_0$ | Threshold magnitude $m_1$ | Focal depth (km) |
|---|---|---|---|---|---|---|
| Swat–Astore Seismic Zone | 0.95 | 2.19 | 2.62 | 4.0 | 7.8 | 25 |
| Peshawar–Hazara Seismic Zone | 1.16 | 2.67 | 4.26 | 4.0 | 7.8 | 20 |
| Kohat–Potwar Seismic Zone | 0.95 | 2.19 | 2.07 | 4.0 | 7.4 | 10 |
| Surghar–Kurram Seismic Zone | 1.12 | 2.58 | 1.73 | 4.0 | 7.4 | 10 |

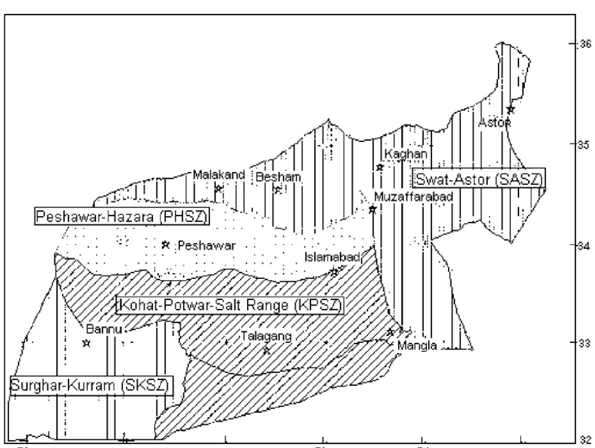


**Figure 9.** Seismotectonic zones of North Pakistan (adapted from MonaLisa *et al.*[4]).

curves, which represent the annual frequencies of exceedance of various ground motion levels at the site of interest. From these curves, acceleration values for different return periods can be determined.

In the present case, following normal practice, PGA values with 10% probability of exceedance in 50 years, i.e. the return period of 475 years, are calculated (Figure 10). PGA values of 0.10 and 0.13 *g* have been obtained using the equations of Ambraseys *et al.*[32] and Boore *et al.*[33], respectively. It should be noted that this calculation of PGA involves seismological data till 2004. The value of 0.13 *g* is not so high for the next 50 years. MonaLisa *et al.*[40] have estimated 0.47 *g* and expected magnitude of 7.6 for the HFT by applying deterministic seismic hazard assessment (DSHA) before the occurrence of the 8 October 2005 Muzaffarabad earthquake. It is well known that PGA values obtained from PSHA are always lower than

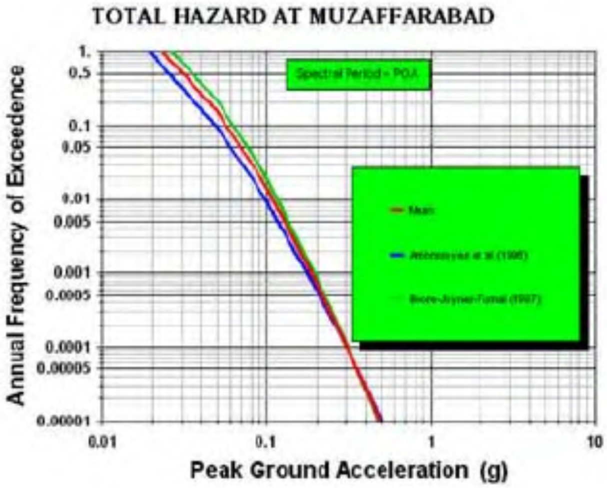


**Figure 10.** Total hazard curve at Muzaffarabad.

DSHA values. Also, the site (Muzaffarabad) consists of poorly constructed structures and can experience appreciable damage compared to other less populated sites in the surroundings, even if PGA values determined only from PSHA are considered. Keeping in view the recent tragedy in Kashmir and the comparatively low values of PGA, it is recommended that a detailed seismic hazard assessment (both PSHA and DSHA), including the 8 October 2005 Muzaffarabad earthquake data, may be carried out.

## Conclusion

The NW Himalayan Fold-and-Thrust Belt has experienced a number of devastating earthquakes in the recent past. The earthquakes at Pattan (1974; 6.0 $m_b$), Rawalpindi (1977; 5.2 $m_b$), Bunji (2002; 5.3 and 6.0 $m_b$), and Batgram (2004; 5.3 and 5.5 $m_b$) testify the high level of seismic risk in the area. The 8 October 2005 Muzaffarabad earthquake ($M_w$ 7.6) claimed more than 75,000 lives and caused a damage of 5 billion US dollars. From the preliminary seismological investigations of this recent event, carried out using data obtained from USGS and local observatories, the following conclusions can be drawn.

1. The depth- and magnitude-based seismological characteristics and distribution pattern of 251 aftershocks having magnitude ≥4.0 *M* for the period from 8 October 2005 to August 2006 clearly define a NW-SE trending zone about 200 km long and 50 km wide.
2. The FMS of the main shock and its two principal aftershocks (≥6.0 *M*) that occurred about 80 km NNW of the main shock indicate thrusting to be the dominant mechanism, with rupture planes having a NW-SE trend and dipping towards the NE.
3. The aftershock distribution and the FMS result lead to the conclusion that IKSZ, a wedge-shaped NW-SE trending blind zone, has been activated.
4. It appears that the IKSZ does not end at the nose of, but extends into, the HKS. However, more FMS data are required to confirm this suggestion.
5. Seismic hazard assessment using probabilistic approach for Muzaffarabad shows the PGA values of 0.10 and 0.13 *g* (using two appropriate attenuation equations) with 10% probability of exceedance in 50 years, i.e. return period of 475 years.
6. Structures are poorly constructed in Muzaffarabad. Thus the calculated PGA values, though not so high, are indicative of appreciable damage here compared to the less populated sites in the surroundings.


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