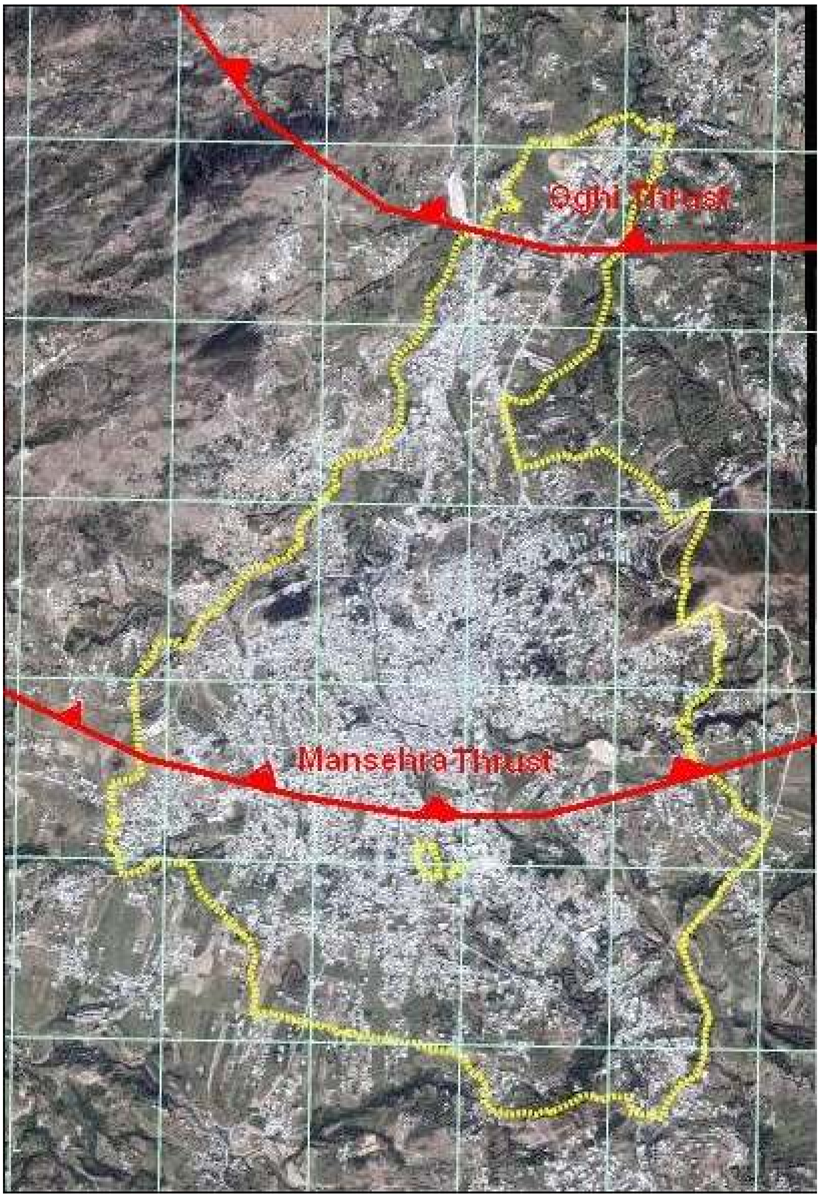
SEISMIC HAZARD ASSESSMENT OF MANSEHRA

A Product of Earthquake Risk Reduction and Preparedness Programme



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SEISMIC HAZARD ASSESSMENT OF MANSEHRA

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National Disaster Management Authority Pakistan

United Nations Development Programme Pakistan

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1. INTRODUCTION

The occurrence of the 7.6 M_w magnitude earthquake in north Pakistan in October 08, 2005 has increased the urban earthquake risk in the area due to high rate of urbanization, faulty land use planning and construction, and inadequate infrastructure. The seismic hazard assessment (SHA), which can be conducted in connection with risk analysis in urban areas, can be carried out using the usually adopted methodologies of deterministic and probabilistic approaches. The site of Mansehra has been selected for SHA determination. The SHA was carried out by considering the earthquake source zones, selection of appropriate attenuation equations, near fault effects and maximum potential magnitude estimation. The city is located tectonically in an active regime referred to the as crystalline nappe zone and Hazara-Kashmir Syntaxis. The Mansehra Thrust, Oghi Fault, Banna Thrust, Balakot Shear Zone, Main Boundary Thrust, Panjal Thrust, Jhelum Fault and Muzaffarabad Fault and, further to the south, the Sanghargali, Nathiagali, and Thandiani Thrusts are the most critical tectonic features within the 50 km radius of Mansehra. Using the instrumental seismological data from 1904 to 2007, SHA has been carried out. Other reactivated critical tectonic features in the area have been investigated. Among them the Balakot-Bagh fault, with the fault length of 120 km from Balakot to Poonch, has been considered as the most critical tectonic feature on the basis of geological/structural/seismological data. The potential earthquake of maximum magnitude 7.8 has been assigned to the Balakot-Bagh fault using four regression relations. The peak ground acceleration value of 0.25g (10% probability of exceedance for 50 years) and 0.5g has been calculated with the help of the attenuation equation using probabilistic and deterministic approaches.

2. SEISMIC MICROZONATION

Seismic microzonation is defined as the process of subdividing a potential seismic or earthquake prone area into zones with respect to some geological and geophysical characteristics of the sites such as ground shaking, liquefaction susceptibility, landslide and rock fall hazard, earthquake-related flooding, so that seismic hazards at different locations within the area can correctly be identified.

Microzonation provides the basis for site-specific risk analysis, which can assist in the mitigation of earthquake damages. In most general terms, seismic microzonation is the process of estimating the response of soil layers under earthquake excitations and thus the variation of earthquake characteristics on the ground motion.

In the present case ground shaking in terms of peak ground acceleration (PGA) has been determined which may be useful in the microzonation of Mansehra site. Since the regional geology/tectonics can have a large effect on the characteristics of ground motion. The site response of the ground motion may vary in different locations of the city according to the local geology. A seismic zonation map for a site may, therefore, be inadequate for detailed seismic hazard assessment of the city. This necessitates the development of microzonation maps for big cities for detailed seismic hazard analysis.

3. SEISMOTECTONIC SETTING

The site of Mansehra lies in the area where the Eurasian and Indo-Pak plates are colliding. Due to this collision, the Himalayas began uplifting about 50 million years ago, and continue to rise by about 5mm/year. Sella et al., 2002 believe that the Indo-Pak plate is currently penetrating into Asia at a rate of about 45 mm/year and rotating slowly anticlockwise. This rotation and translation results in left-lateral transform slip in Balochistan at about 42 mm/yr (Billham, 2004) and right-lateral slip relative to Eurasian plate in the Indo Burma ranges at 55 mm/year.

Kazmi and Jan, 1997 referred the northwestern portion of Himalayas as the NW Himalayan Fold-and-Thrust Belt. This belt has been the source of several major earthquakes in the past and is seismically very active. The city of Mansehra is situated within the crystalline nappe zone and the Hazara-Kashmir Syntaxis (HKS). A number of active surface features like Mansehra Thrust, Oghi Fault, Banna Thrust, Balakot Shear Zone, Thakot Fault, Main Boundary Thrust, Panjal Thrust, Jhelum Fault and Muzaffarabad Fault (Balakot-Bagh Fault) and, further to the south, the Sanghargali, Nathiagali, and Thandiani Thrusts (Fig.1 and 5) are located in the vicinity of Mansehra. Epicentral distribution of the earthquakes for the period

1904-2007 along with the aftershock distribution of main event (Figs.1-4) further confirm that overall the area is situated in a very active regime.

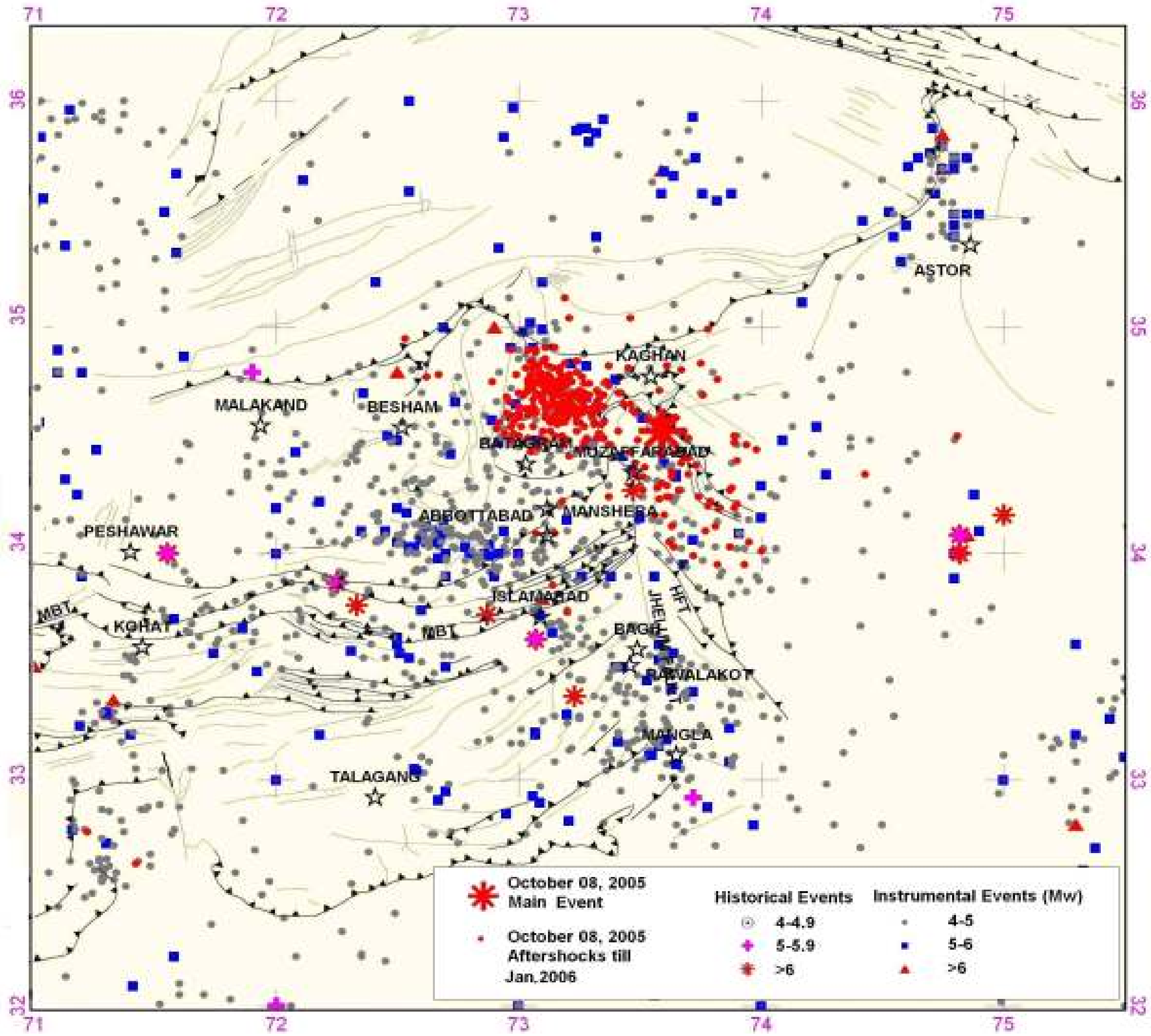

Figure.1. Seismotectonic setting of the area with October 8, 2005 Earthquake and its aftershocks (MonaLisa et al., 2006).

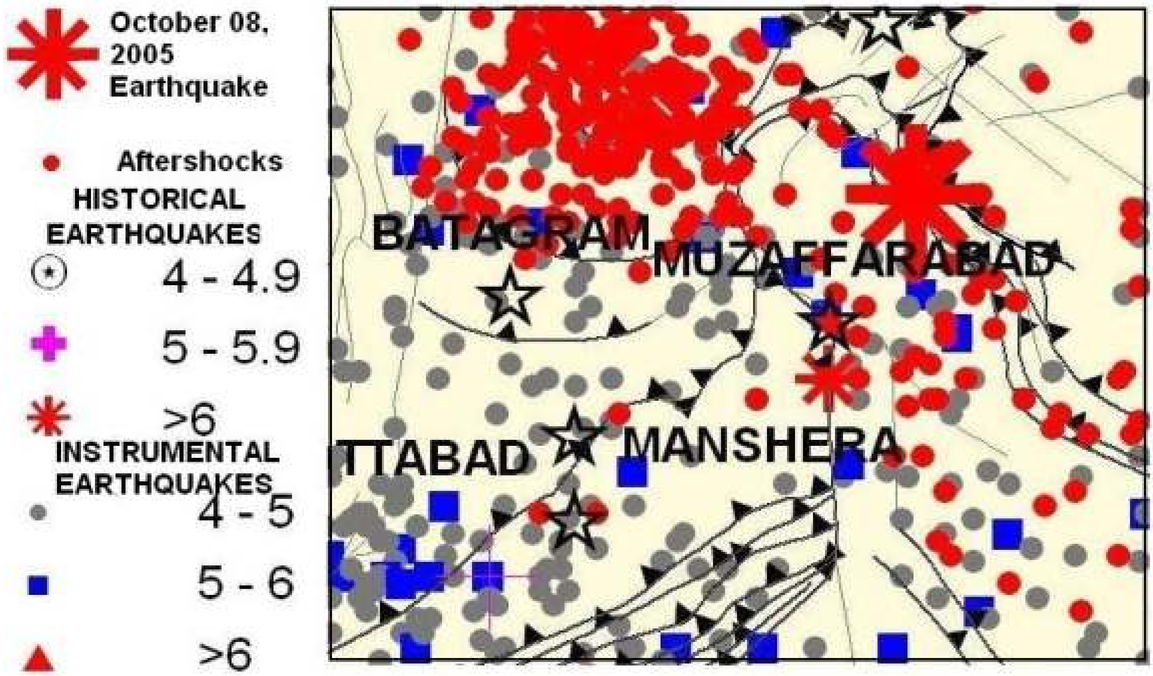

Figure.2. Seismicity and major faults around the site of Mansehra.

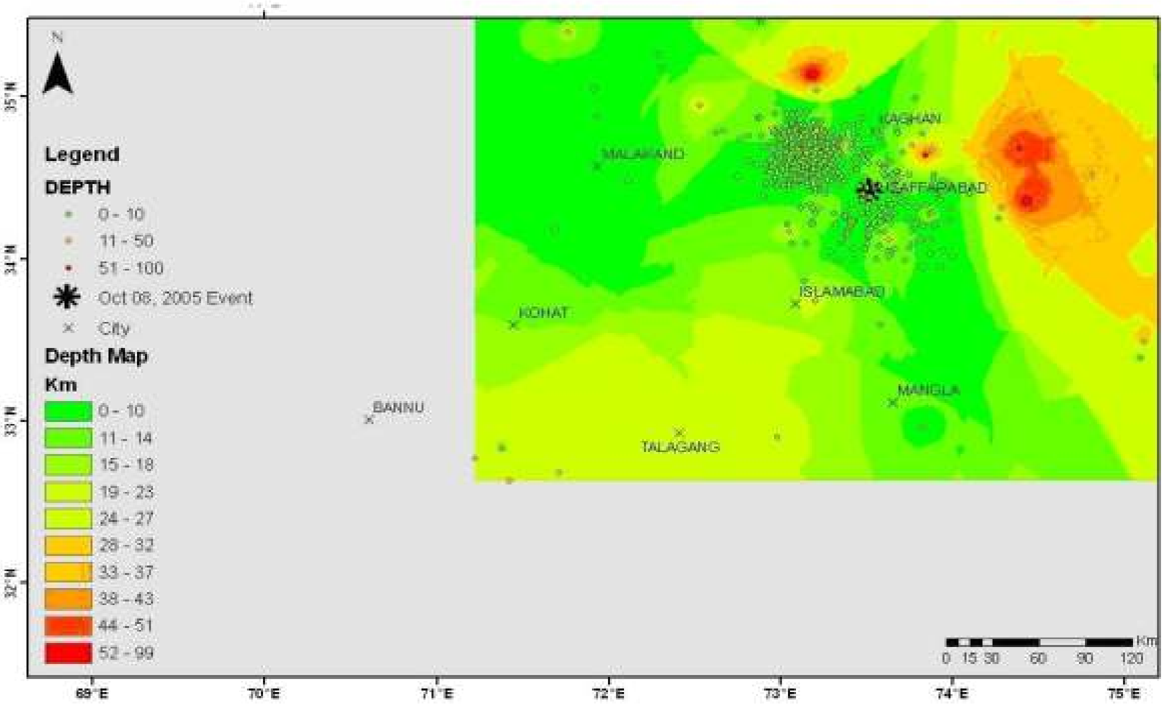

Fig 3. Depth variation of seismic activity in the study area (MonaLisa et al., 2008)

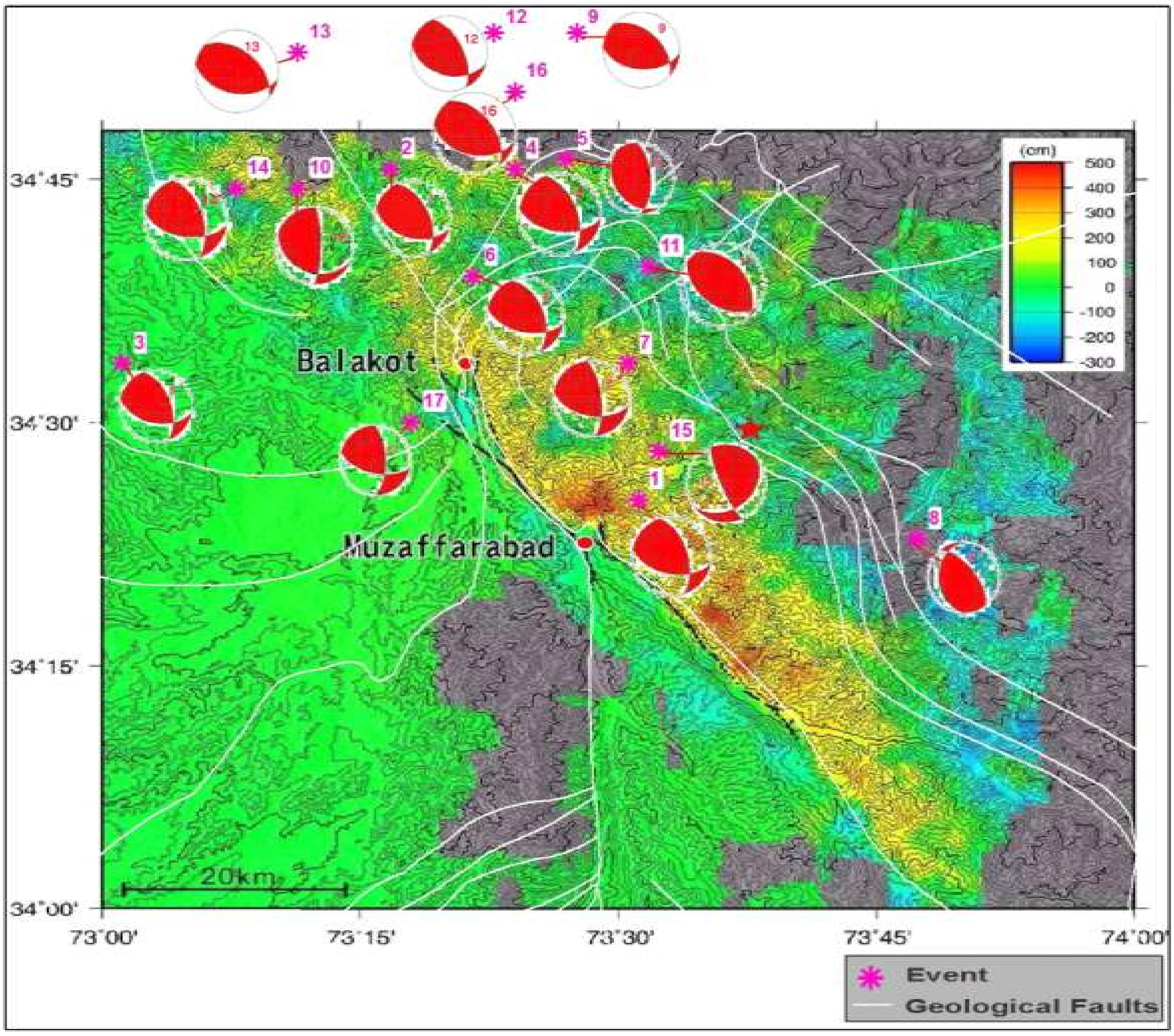

Fig 4. Correlation of Synthetic Aperture Radar (SAR) data of Fujiwara et al (2006) with fault plane solutions (MonaLisa et al., 2008)

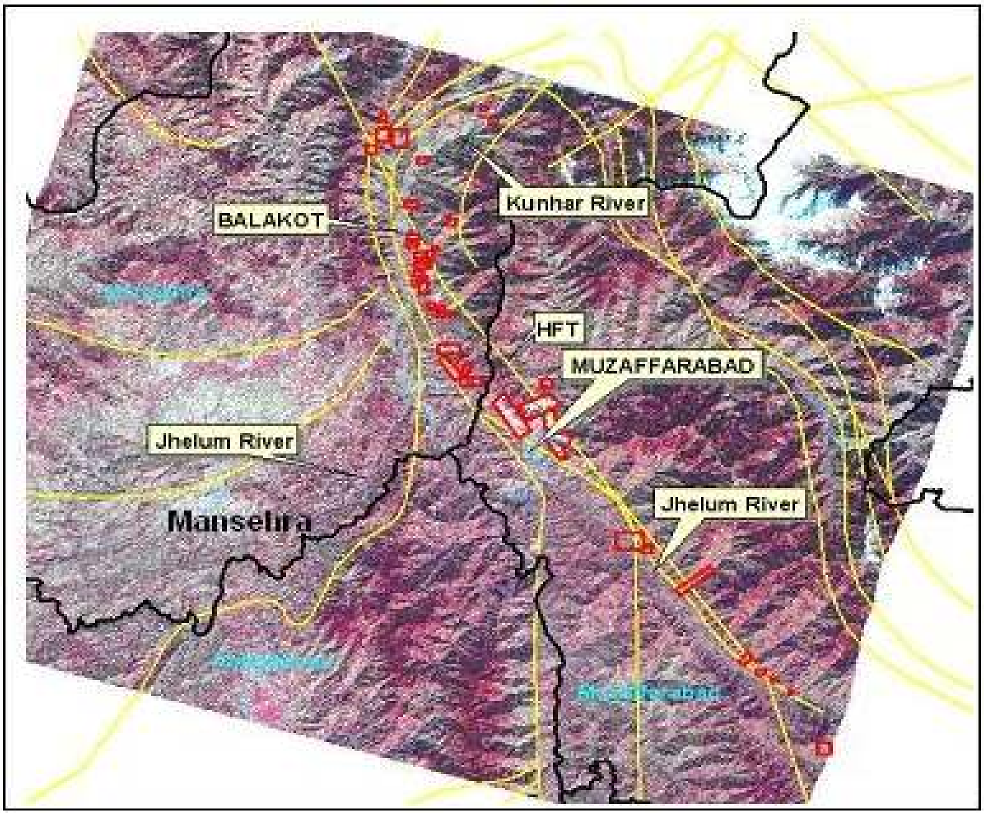

Figure 5. Major Faults, landslides distribution and main sites on the satellite image (MonaLisa et al., 2008).

4. SEISMIC HAZARD ASSESSMENT (SHA)

There are commonly two approaches used for the determination of seismic hazard assessment (SHA)

1. Deterministic Seismic Hazard Assessment (DSHA)
2. Probabilistic Seismic Hazard Assessment (PSHA)

The DSHA is comparatively simple and does not account for the uncertainties and probability of occurrence of an earthquake. 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.

The PSHA is denoted by the probability that ground motion (acceleration) reaches certain amplitudes or seismic intensities exceeding a particular value within a specified time interval. Inverse of the probability of exceedance is known as the return period for that acceleration and is used to define the seismic hazard. In probabilistic hazard evaluation, the seismic activity of seismic sources (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 intensities or ground accelerations expected with a given probability for a specified interval of time. In the present work, PSHA has been carried out using the software EZ-FRISK (6.2 beta version, 2004 modified form). The program calculates earthquake hazard at a site under certain assumptions specified by the user. Further information about the specific contributory parameters has been obtained by applying disaggregation (deaggregation).

I. DETERMINISTIC SEISMIC HAZARD ASSESSMENT (DSHA)

The deterministic method includes the following steps:

1. Identify all the critical tectonic features in the vicinity of the Mansehra likely to generate significant ground motions.
2. Assign to each of these a maximum magnitude on the basis of key fault parameters.
3. Compute the ground motion parameters (Peak Ground Acceleration) at the site of Mansehra associated with each feature as a function of magnitude and distance.

1. CRITICAL FEATURES

A total of twelve faults (Table. 1) have been selected as the most critical tectonic features for the seismic hazard assessment for the site of Mansehra. In addition to these faults, there are alsoother active features wit hin NW Himalayan Fold-and-Thrust Belt but since their nearest segment is more than 40 km from the site, the rock motion from these features would not be as critical as for the features given in Table 1. 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 is dominantly representing the thrust faulting but some strike-slip component is also present. All these faults along which earthquakes can produce the appreciable strong ground motions are shown in Fig. 6.

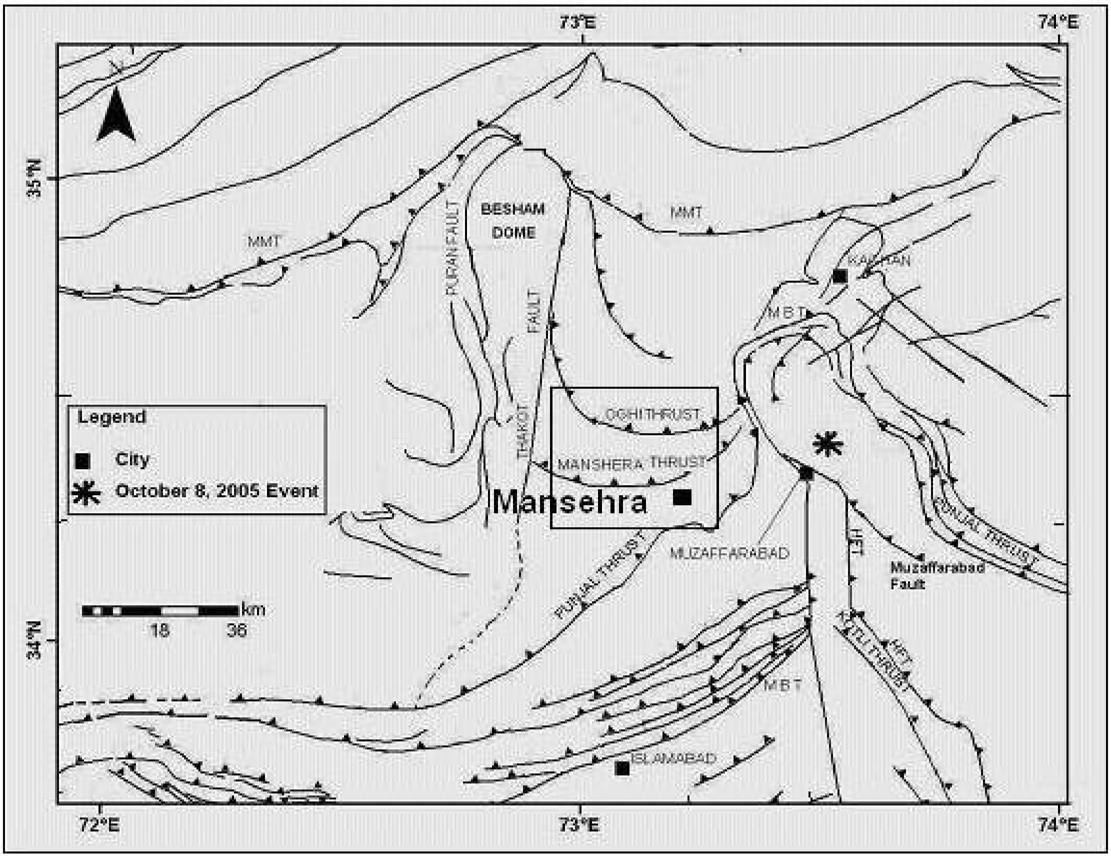

Figure 6. Critical tectonic features near the site of Mansehra. MMT: Main Mantle Thrust, MBT: Main Boundary Thrust, HFT: Himalayan Frontal Thrust (MonaLisa et al., 2008).

2. 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 (Fig 6 and Table 1) calculated on the basis of 50 % of total length and using available relationship by Wells and Coppersmith (1994). Table.1 gives all these active faults present near Mansehra, their total length, rupture length and maximum potential magnitudes calculated in the present study.

Faults Nos.	Tectonic Feature	Maximum Magnitude (Mw)	Closest Distance to Faults (Km)	PGA (%g)	
				50%	84%
1	**Punjal Thrust**	7.0	5	0.24	0.37
2	**MBT**	8.0	2	0.30	0.41
3	**Oghi Thrust**	7.1	8	0.15	0.25
4	**Mansehra Thrust**	7.6	0	0.21	0.31
5	**Thakot Fault**	7.1	15	0.08	0.14
6	**Muzaffarabad Fault (Balakot-Bagh Fault)**	7.8	10	0.21	0.34
7	**Himalayan Frontal Thrust**	7.6	21	0.11	0.27
8	**Jhelum Fault**	7.1	18	0.27	0.45
9	**Sangargali Thrust**	6.9	32	0.11	0.19
10	**Thandiani Thrust**	6.8	34	0.10	0.18
11	**Nathiagali Thrust**	7	36	0.11	0.19
12	**Balakot Shear Zone (BSZ)**	6.8	30	0.09	0.16

Table.1. Twelve most critical tectonic features (faults), their maximum potential magnitudes, closest distances and PGA's (%g) using Boore et al., 1997 equation.

3. 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.

In the present study, peak horizontal accelerations have been calculated using the attenuation equation Boore et al (1997) as shown in Table 1. The equation 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 > 30 km i.e. both for the shallow as well as for the intermediate earthquakes.

The equation is given below.

$$\ln(PGA) = -0.117 + 0.527(M-6) - 0.778\ln(r) - 0.271\ln(V_{s,30}/1396) + 0.52P$$

Here $r = (d^2 + 5.57^2)$

M = Moment Magnitude

d = Horizontal distance from the source to site (km)

P = dummy variable, takes the value of 0 for mean values of PGA and 1 for 84 percentiles.

Vs, 30 = Average shear wave velocity over the uppermost 30m at the site with values of 750 m/s or greater for rock and values of less than 360m/s for soft soil (Fig 13).

4. DISTANCE FROM THE SITE

The closest distances of all causative sources from the site of Mansehra are shown in Table 1 and Figs. 7&8. The constant depth of 10 km has been taken for all these causative sources as the shallow earthquakes are of more concern to seismic hazard assessment.

5. PEAK HORIZONTAL ACCELARTIONS

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 attenuation law of Boore et al., 1997 (Table. 1).

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 km.

6. MAXIMUM CREDIBLE EARTHQUAKE (MCE)

MCE i.e. the Maximum Credible Earthquake is the largest reasonable conceivable earthquake that appears possible along a recognized fault or within a geographically defined tectonic province, under the presently known or presumed tectonic framework (Mahdi, 2003). MCE can be calculated by both the deterministic or probabilistic approach. In the present work, it is calculated by the deterministic approach and is 8.0.

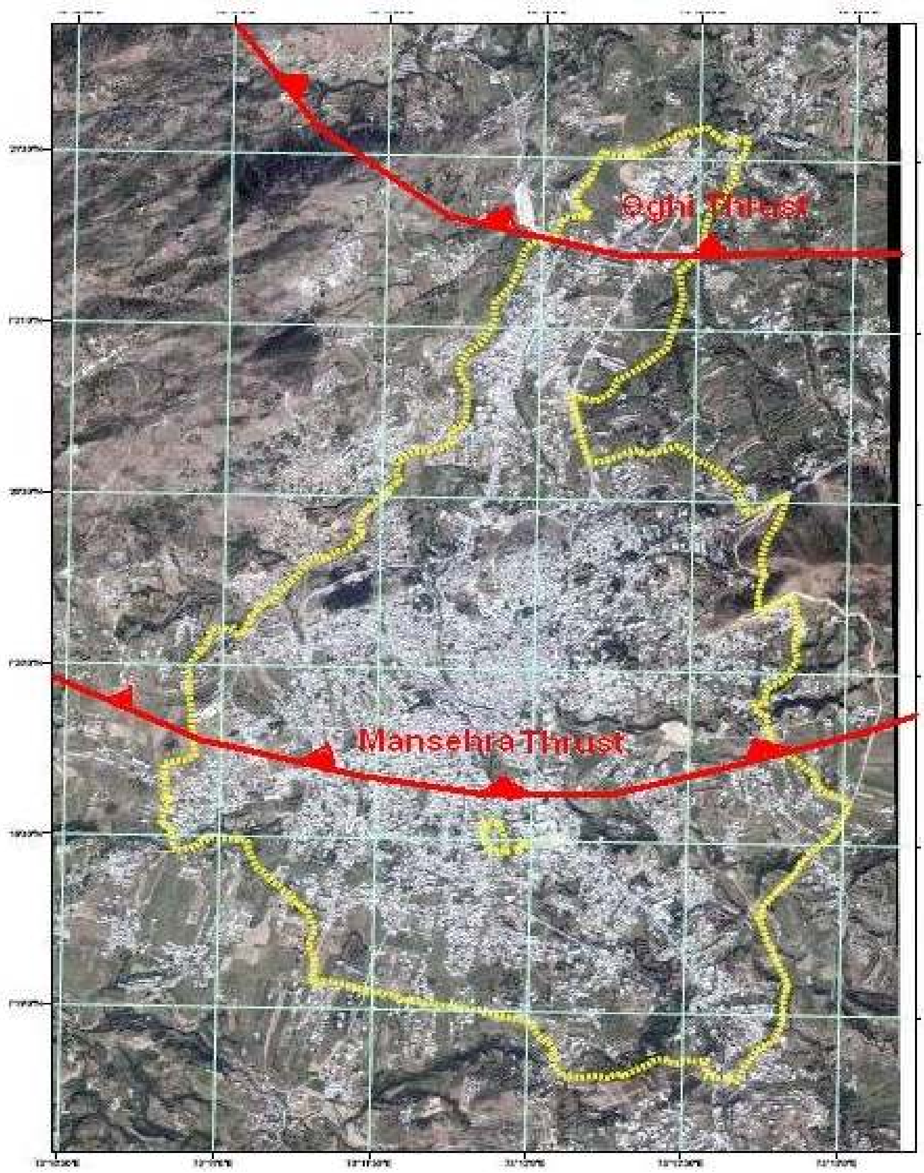

Figure 7. The site of Mansehra and the faults (Mansehra Thrust and Oghi Thrust) passing through.

II. PROBABLISTIC SEISMIC HAZARD ASSESSMENT (PSHA)

The estimation of PGA has also been carried out using the Probabilistic Seismic Hazard Assessment (PSHA). The conventional approach has been adopted for the site of Mansehra. PSHA is denoted by the probability that ground acceleration reaches certain amplitudes or 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 accelerationand is used to define the seismic hazard.

In PSHA, the seismic activity of 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 and their seismic hazard parameters evaluated by MonaLisa et al, 2007, have been used for the estimation of PGA using PSHA. The calculation of PGA involves the use of an appropriate attenuation equation. In the present case the attenuation equation Boore et al 1997 have been used

The PSHA results are in the form of the hazard curve (Fig .9) that has been generated using the software EZ-FRISK (6.2 beta version, 2004 modified form). 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, threshold magnitude and b-value characteristics of the region as input parameters (Table 2). Results obtained are in the form of hazard curve 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.

Seismic Zone	b value	β value	Annual activity rate λ	Minimum magnitude m_0	Threshold magnitude m_1	Focal depth (km)
SZ1	0.95	2.19	2.62	4.0	7.8	25
SZ2	1.16	2.67	4.26	4.0	7.8	20
SZ3	0.95	2.19	2.07	4.0	7.4	10
SZ4	1.12	2.58	1.73	4.0	7.4	10

Table 2. Input parameters for EZ-FRISK assigned to four seismic zones (SZ) used in PSHA.

Following the normal practice, the PGA values with 10% probability of exceedance in the 50 years, i.e., the return period of 475 years, are calculated (Figure 9). PGA values of 0.17g have been obtained using Boore et al., 1997 equations. The value of 0.17g is not so high for the next 50 years, but the site (Mansehra) consists of poorly constructed structures and can experience appreciable damage as compared to other, less populated, sites in the surroundings.

On the basis of the PGA value and the active faults, the study area is divided into three zones (Figs. 10 and 11).

HIGH HAZARD	≥0.23 g
MODERATE HAZARD	≥0.14 g
LOW HAZARD	≥0.08g

3D projection is also shown (Fig. 12) in order to have a more clear view of the area.

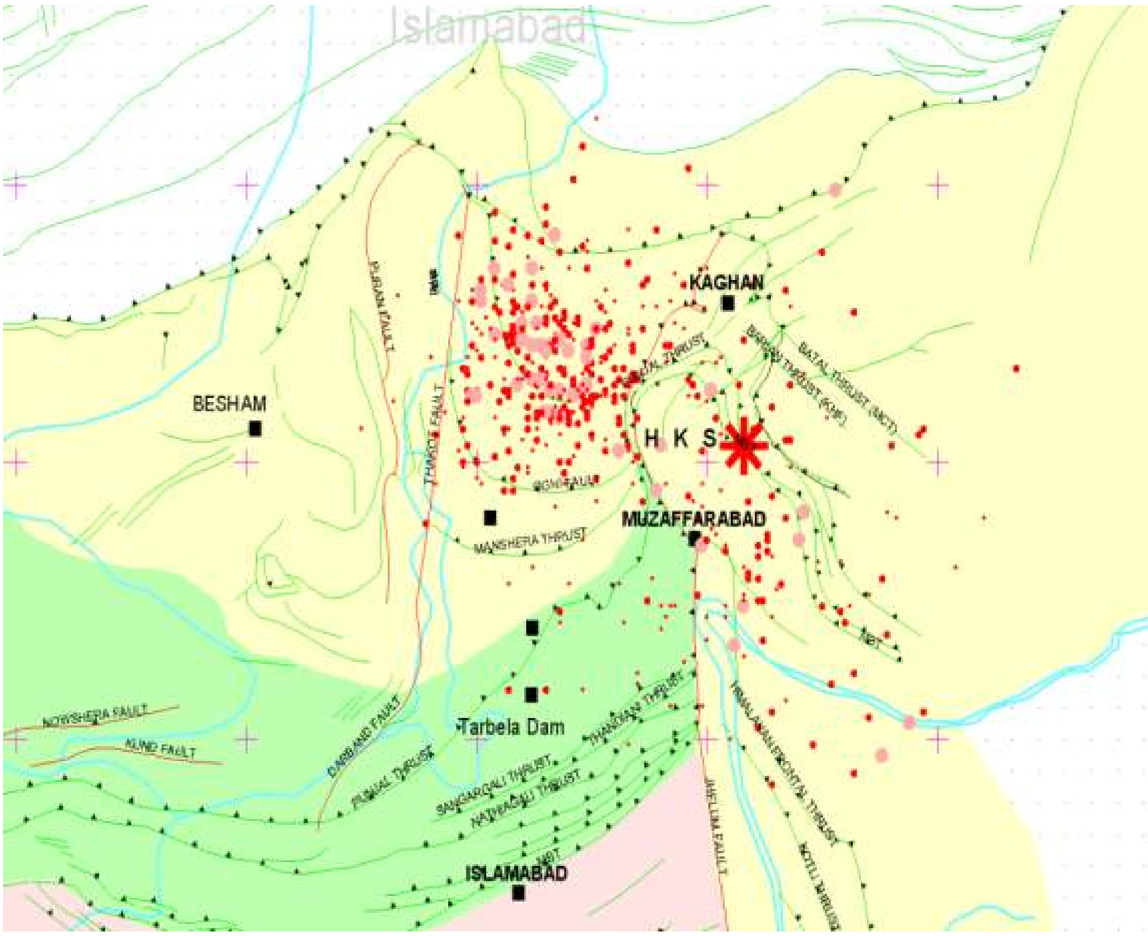

Figure 8. Seismic zones, faults and October 08, 2005 Muzaffarabad Earthquake aftershocks near Mansehra.

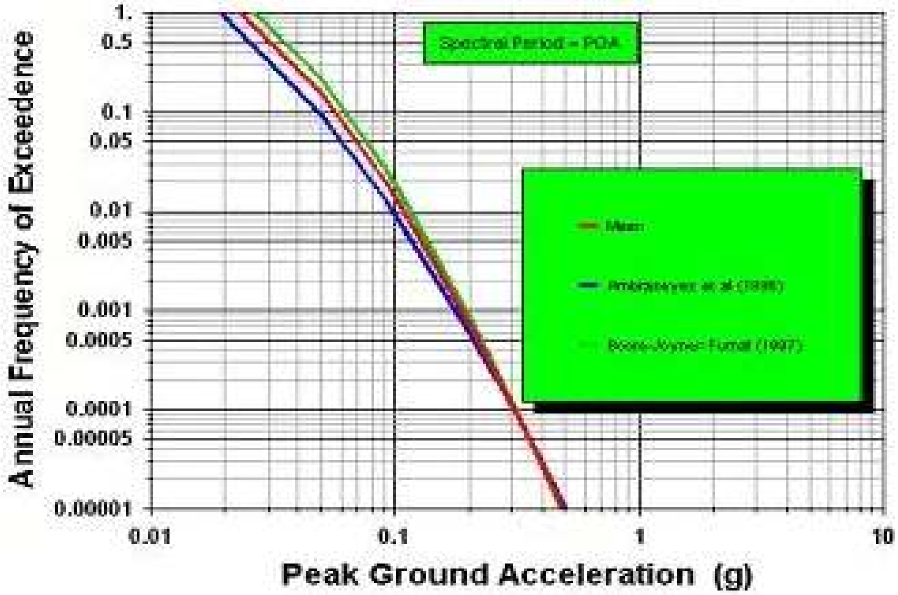

Figure9. Total seismic hazard curve for the site of Mansehra for various return periods.

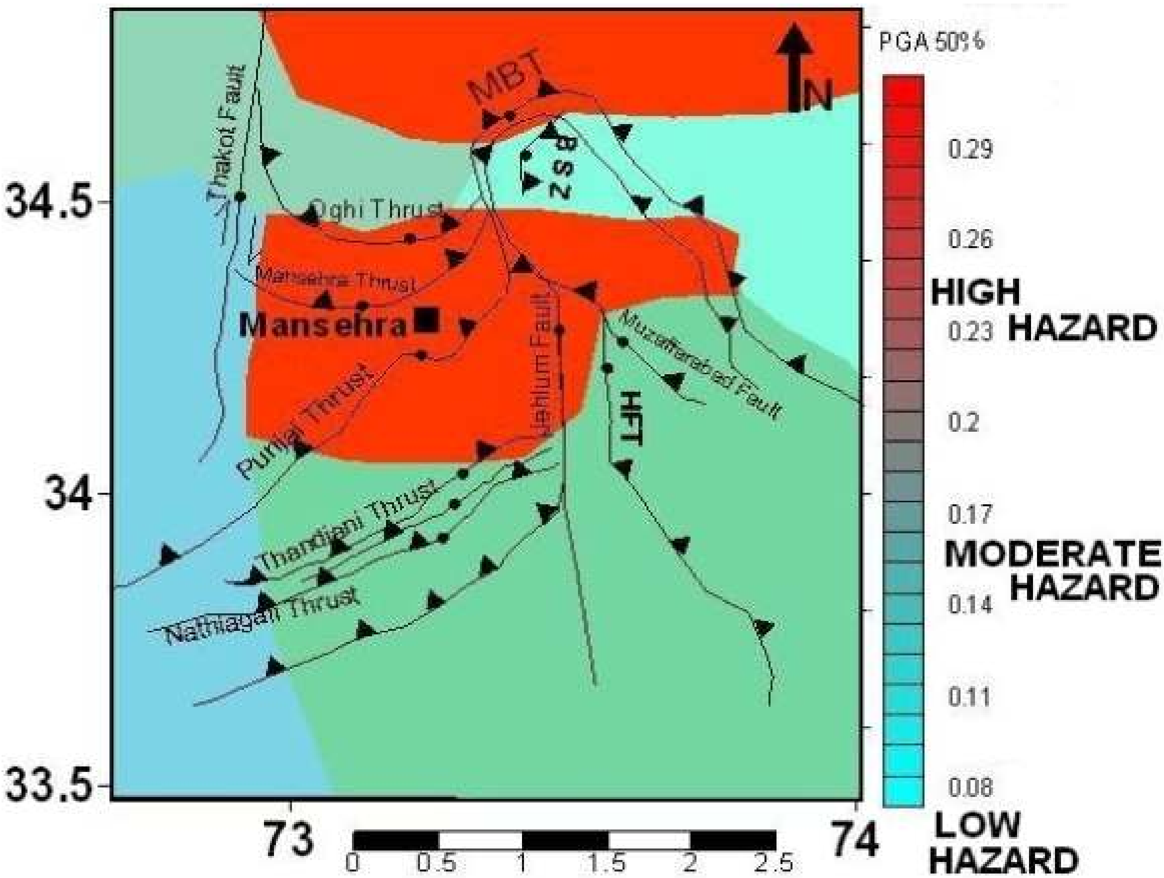

Figure 10. Seismic hazard zonation for the site of Mansehra and surrounding area.

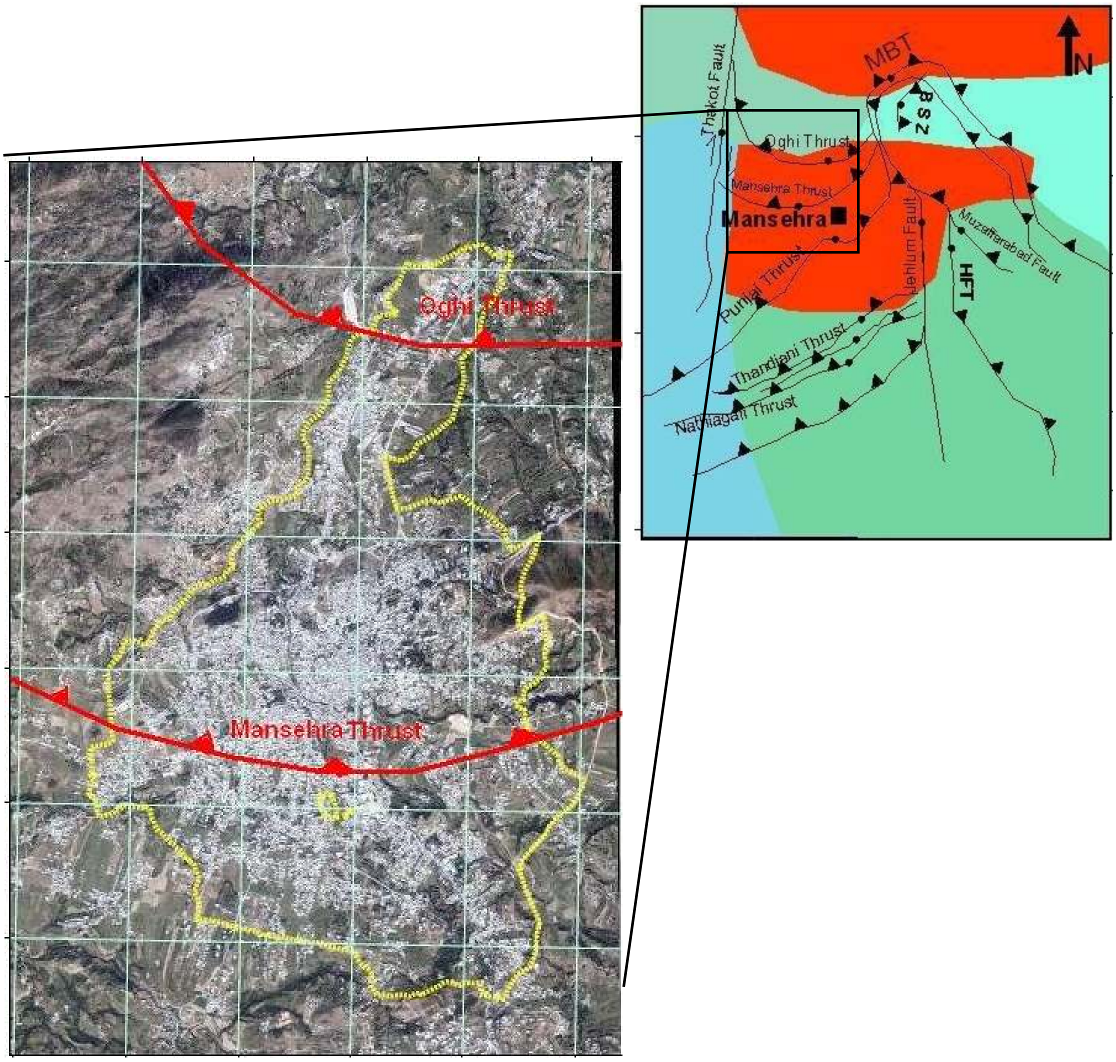

Figure 11. Seismic hazard zonation for the site of Mansehra.

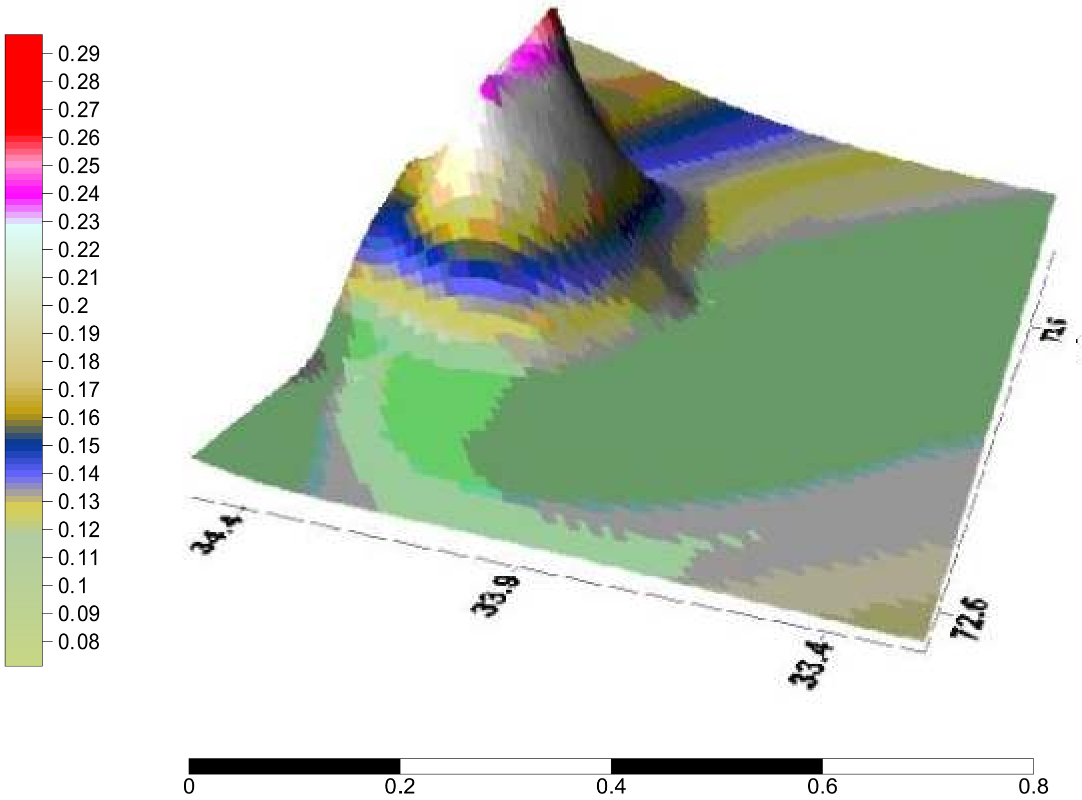

Figure 12. 3D view of PGA values for the site of Mansehra for various return periods.

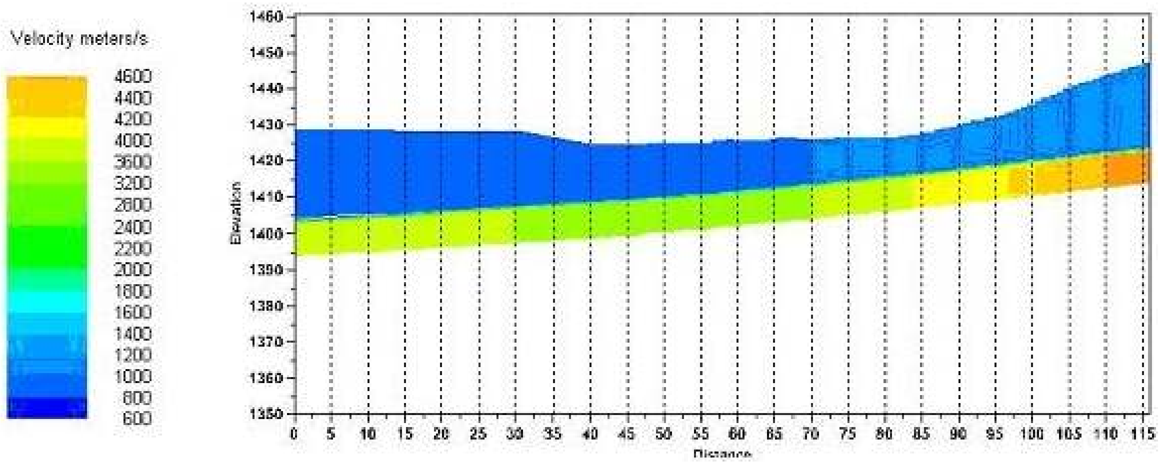

Figure 13. Seismic Refraction profile for a nearby profile to the site of Mansehra.

5. PEAK GROUND ACCELERATIONS AND MACROSEISMIC INTENSITIES (MMI SCALE) BASED UPON SURFACE GEOLOGY

As per maps provided by the Geological Survey of Pakistan (GSP), the Mansehra district is covered by the Mansehra Granites-Gneiss of Cambrian age, with Quaternary Alluvium of surficial deposits (unconsolidated deposits, clay, silt and gravel), and flood plain deposits (clay silt with subordinate gravel and pebbles).

The peak ground accelerations for Mansehra is given for rock foundation condition i.e. for Soil Profile Type S_B with shear wave velocity of 750 m/sec in the previous sections. Using the guidelines of UBC 97 and Pakistan Building Code Seismic Provisions 2007, the district Mansehra lays on the soil profile type S_A (Granite-Hard Rock) and S_C (Alluvium-Very Dense Soil and Soft Rock) as shown in Table 3. The corresponding shear wave velocity and other properties of top 30 m of soil profile is also given in the table 3.

Soil Profile Type	Soil Profile Name/ Generic Description	Average Properties for Top 30 M (100 ft) of Soil Profile		
		Shear Wave Velocity, v_s m/sec (ft/sec)	Standard Penetration Tests, N [or N_{CH} for cohesionless soil layers] (blows/foot)	Undrained Shear Strength, s_u kPa (psf)
S_A	Hard Rock	>1,500 (>4,920)	–	–
S_B	Rock	750 to 1,500 (2,460 to 4,920)		
S_C	Very Dense Soil and Soft Rock	350 to 750 (1,150 to 2,460)	>50	>100 (>2,088)
S_D	Stiff Soil Profile	175 to 350 (575 to 1,150)	15 to 50	50 to 100 (1,044 to 2,088)
S_E[1]	Soft Soil Profile	<175 (<575)	<15	<50 (<1,044)
S_F	Soil requiring Site-specific Evaluation. See 4.4.2			

Table 3. Soil Profile Types with other geotechnical parameters.

Based upon the surface geological site conditions and following the guidelines of UBC 97 and Pakistan Building Code Seismic Provisions 2007, and the accelerations for Granite (hard rock) and Alluvium (soft soil) and amplification factors are given as in Table 4 below and are shown on the geological map of GSP (Fig. 14) along with the macroseismic intensity.

Soil Profile Type	Seismic Zone Factor Z (>0.2)
S_A	0.16
S_C	0.24

Table 4. Site Specific geotechnical investigation based upon ground accelerations.

It is not possible to show variation of peak ground acceleration in the form of city map, as the available geological maps are generalized only and do not show correct soil profile (or foundation condition) at each location in the city which could vary from place to place. The exact soil profile for a site is defined through site geotechnical investigations

For each specific site or structure, the peak ground acceleration given for rock foundation condition could be modified by using above tables, according to the soil profile information of that particular site which is obtained as part of subsurface geotechnical investigations. The soil profile type of the site can be classified as per properties for top 30 meters of soil profile.

The Mansehra city, as explored through pits by an oil company, shows the following description of subsoil strata.

DEPTH	**DESCRIPTION**
0.0 - 1.1 ft.	Soft Clay, Pebbles with Gravels
1.1 - 2.0 ft.	Soft Clay with Gravels
0.0 - 1.8 ft.	Earth Filled Material (Soft Clay)
1.8 - 2.5 ft.	Soft Clay with Pebbles & Gravels

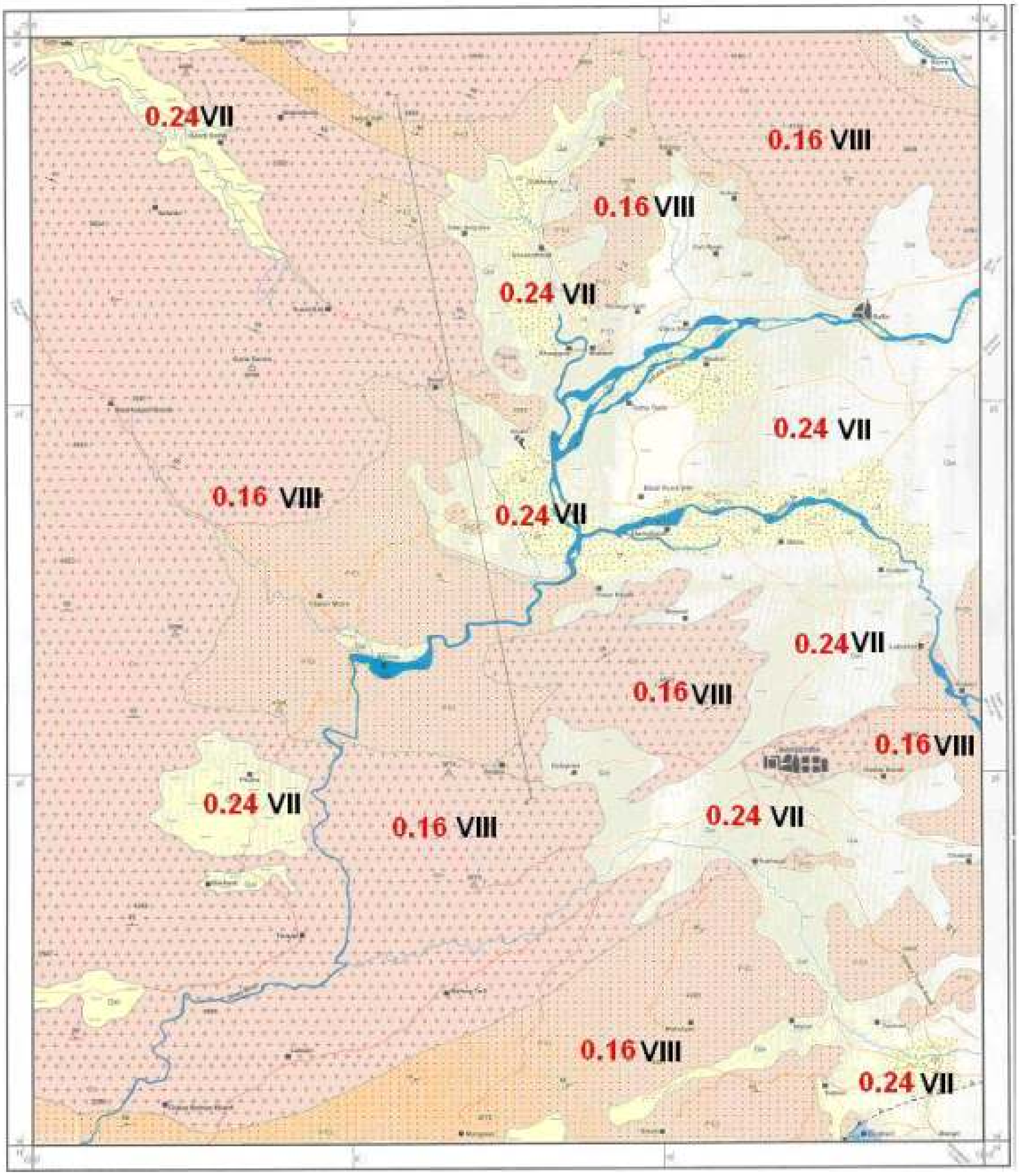

Fig. 14. Peak Ground Accelerations for surface rocks and the macroseismic intensity based upon MMI scale for Mansehra.

6. CONCLUSIONS

- 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 can be 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.
- The seismic hazard assessment (SHA), for Mansehra has been carried out using deterministic and probabilistic approaches
- This has been done considering the earthquake source zones, appropriate attenuation equations, near fault effects and maximum potential magnitude estimation.
- Tectonically the city is located in an and around an active regime referred to the as Crystalline nappe zone and Hazara-Kashmir Syntaxis.
- The Mansehra Thrust, Oghi Fault, Banna Thrust, Balakot Shear Zone, Main Boundary Thrust, Panjal Thrust, Jhelum Fault and Muzaffarabad Fault and, further to the south, the Sanghargali, Nathiagali, and Thandiani Thrusts are the most critical tectonic features within the 50 km radius of Mansehra.
- Using the instrumental seismological data from 1904 to 2007, SHA has been carried out. Other reactivated critical tectonic features in the area have been investigated.
- On the basis of maximum potential magnitudes and the peak horizontal accelerations, twelve faults (Table. 1) have been designated as the most hazardous for the site of Mansehra.
- Among them the Balakot-Bagh fault, with the fault length of 120 km from Balakot to Poonch, has been considered as the most critical tectonic feature on the basis of geological/structural/seismological data.
- The potential earthquake of maximum magnitude 7.8 has been assigned to the Balakot-Bagh fault using four regression relations.

- PSHA results shows the peak ground acceleration value of 0.25g (10% probability of exceedance for 50 years) and DSHA shows 0.5g value for the site of Mansehra.
- The significant damage was observed in the prevailing stone masonry residential, community, and government buildings, particularly those of random-rubble, a type which is well-known for poor seismic resistance.
- Buildings should not only meet the functional needs of their occupants but also the essential requirement of safety, based on sound earthquake resistant design and construction.
- Most of the residential units in the affected area relied on load-bearing masonry walls for seismic resistance. Much of the damage could be attributed to inferior construction material, inadequate roof support, poor wall-to-wall connections, poor detailing work, weak in-plane wall due to large openings, out-of plane instability of the walls, asymmetric floor plans, and aging.
- There is an urgent need to revive these traditional masonry practices which have proven their ability to resist earthquake loads. Modern bridges, roads, water tanks, etc., which have been constructed without due consideration of the potential high seismic forces associated with the Himalayan region make such civil infrastructure extremely vulnerable to future earthquakes.

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