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SEISMIC MICROZONING OF UPPER HAZARA REGION: BASED ON IMPACT ANALYSIS OF RECENT EARTHQUAKES

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ABSTRACT: *Microzoning of the strong ground motion hazard for the Upper Hazara region based on expected Peak Ground Acceleration (PGA) is carried out through deterministic approach by using the Maximum Credible Earthquakes (MCE) along faults and recent microintensity distribution data of 4 significant local earthquakes. The seismogenic faults are identified and MCE is estimated along each fault through considering its longest rupture segment. The microintensity data of significant earthquakes was used to estimate PGA through empirical relationships and correlated with locally recorded strong motion data. Attenuation relationships between seismogenic fault and distances on hanging and foot walls are developed by utilizing estimated PGA data. Finally, these relationships are applied to each seismogenic fault segment to estimate PGA value at 200m grid by assuming that the geomorphology of the region is same. The compiled seismic microzoning map indicates that most of the part of Balakot city area lies in high PGA value (0.5g) zone. Similarly, some areas of Muzaffarabad, Garhi Habib Ullah, Mansehra and Shinkiari cities are placed in high PGA zones, primarily depending on the closest distance to local seismogenic faults of the region. However, local instrumental strong motion data for different geological conditions is required to obtain more realistic microzoning.*

INTRODCUTION

Damage is caused due to ground shaking, which is generally stronger by the earthquake close to the seismogenic structure and gradually decreases away. Damage owes to the region indicate that the geological and geomorphologic conditions of top few tens of meters accompanied by the tectonic and seismic setup of area. Various studies have shown that the earthquake impacts also vary greatly within a few square kilometer of an area, depending upon the source geometry and site conditions (Schwartz et. al., 1986, Abrahamson et. al., 1996). It is, therefore, important to consider appropriate ground motion parameters that correlate well with the observed structural damage during strong ground motions and that can also be implemented in engineering design of structures.

The goal of this research is to delineate seismic zones in the Upper Hazara region and to prepare a realistic strong motion hazard map of the area.

METHODOLOGY

The methodology adopted for seismic microzonation of Upper Hazara region is based on the following steps:

I. Seismic analysis of recent instrumental seismicity performed to investigate seismic nature and its spatial distribution. Seismic, geologic and geomorphic studies of the region are carried through seismic data analysis, field surveys, GIS and remote sensing based geospatial data analysis.

II. Identification of seismogenic structures through spatial data sensing analysis, field observations of active seismogenic structures, distribution of seismicity pattern and focal mechanism studies of significant seismic events. In addition to demarcation of surface traces of seismogenic structures, their geospatial geometry and continuous rupture segments are also studied.

III. Maximum credible earthquake estimation on seismogenic faults using largest single continuous rupture segment identified by physical boundaries.

IV. The microintensity distribution data of the four major recent earthquakes in and around the region was collected from both hanging and foot wall sites of seismogenic faults, used to determine expected PGA by correlating the "Revised peak ground motion versus intensity relations" as given by Dave Wald 1999.

V. The attenuation relationships between PGA and horizontal distance away from surface trace of the seismogenic fault are developed for both hanging and foot wall sites.

VI. To develop seismic microzonation map of Upper Hazara region, attenuation relationships with local site amplification factors are utilized to estimate PGA on grid point bases.

SEISMOGENIC ANALYSIS

Tectonic Environment

The Upper Hazara region is a part of lower Himalayas and the seismicity of the area is associated with densely populated thrust fault systems that have generated a number of low to moderate earthquakes with shallow focal depths (Seeber and Armbruster 1979). The region has undergone tectonic compression resulting in various faults and fold systems (Baker et al. 1964). The seismicity in the area is mainly associated with tectonic faults.

Identification of Seismogenic Structures

The seismogenic structures are the main source of seismic activity in the region. It is observed that the strong ground motion distribution is strongly influenced by the spatial geometric character of its causative fault. Therefore, for deterministic seismic microzonation, identification of seismogenic structures is most significant, special care and reliable spatial, seismic and geologic, data are required to identify their geometric distribution. The analysis was made to observe general tectonic trend of the region and it was found that most of the fault systems are thrust in nature, which are directly or indirectly associated strike slip faults.

Special consideration is made to observe features related to thrust movements that include (a) monocline structure across strike of fault, (b) linear presence of continuous thrust born slides along the surface trace of fault, (c) significant lineation in surface geomorphology, (d) surface cracks parallel to fault strike, (e) presence of fault fluvial deposits on foot wall side, (e) discontinuities in rock formations, and (f) sharp change in stream patterns orientations along active fault.

In addition to geologic and seismic studies, analysis of the presence of these features in the region is more critically made by utilizing satellite imageries and digital elevation models of 0.5 arc second ground resolutions. However, more critical studies are still required to identify presence and nature of these seismogenic structures more accurately.

Critical Seismogenic Structures

The major seismogenic structures identified (Fig. 1) through study of tectonic setup, surface geology, seismic and spatial data include Main Boundary Thrust (MBT) structure, the Kashmir Thrust, the Panjal Thrust, the Oghi Thrust and the Mansehra Thrust structure.

Main Boundary Thrust Structure

The Main Boundary Thrust (MBT) is a regional thrust dipping northward and oriented sub-parallel to the MMT (Treloar et al. 1989a). It is located at the northern margin of Indian Plate and is younger to MMT in age. It comprises a set of north-dipping faults and forms a boundary between the Sub-Himalayas and the Lesser Himalayas (Calkins et al. 1975). It has generated low to moderately high and frequent seismicity, with characteristically shallow focal depths. The various sections of MBT are locally named by different workers as Hazara Fault, Parachinar Fault, Kala Chita Fault and Murree Fault. It forms an intensely deformed and tectonised belt with isoclinal folds and several thrust sheets.

a. Kashmir Thrust Structure

The Kashmir Thrust structure comprises a series of parallel thrust faults including Kashmir Thrust, Garhi-Batgram Thrust and Rawalkot-Besham Thrust. The Kashmir Thrust is an active fault structure dipping northward and passing just beneath the city of Balakot (MSSP 2005). This Thrust has generated disastrous earthquake (M_L=7.0) of October 8, 2005 followed by 341 aftershocks of magnitude greater than 4.0 (M_L) (MSSP 2005).

b. Panjal Thrust Structure

The Panjal Thrust structure is sited parallel to MBT on the eastern limb of the Syntaxis. The Panjal Thrust probably separates from MBT about 6 km south of Balakot and continues beneath Kaghan Valley alluvium up to Ghari Habib Ullah. Panjal Thrust is an active fault and represents southeastern tectonics of the area. Panjal Fault appears as reverse fault with strike-slip component, in the south of Abbottabad (Calkins et al. 1975).

c. Mansehra Thrust Structure

This is an arc shaped small active fault structure present in the south of Mansehra Basin. The local seismic data analysis indicates that this fault has produced numerous and frequent earthquakes of low to moderate magnitude of very shallow depths.

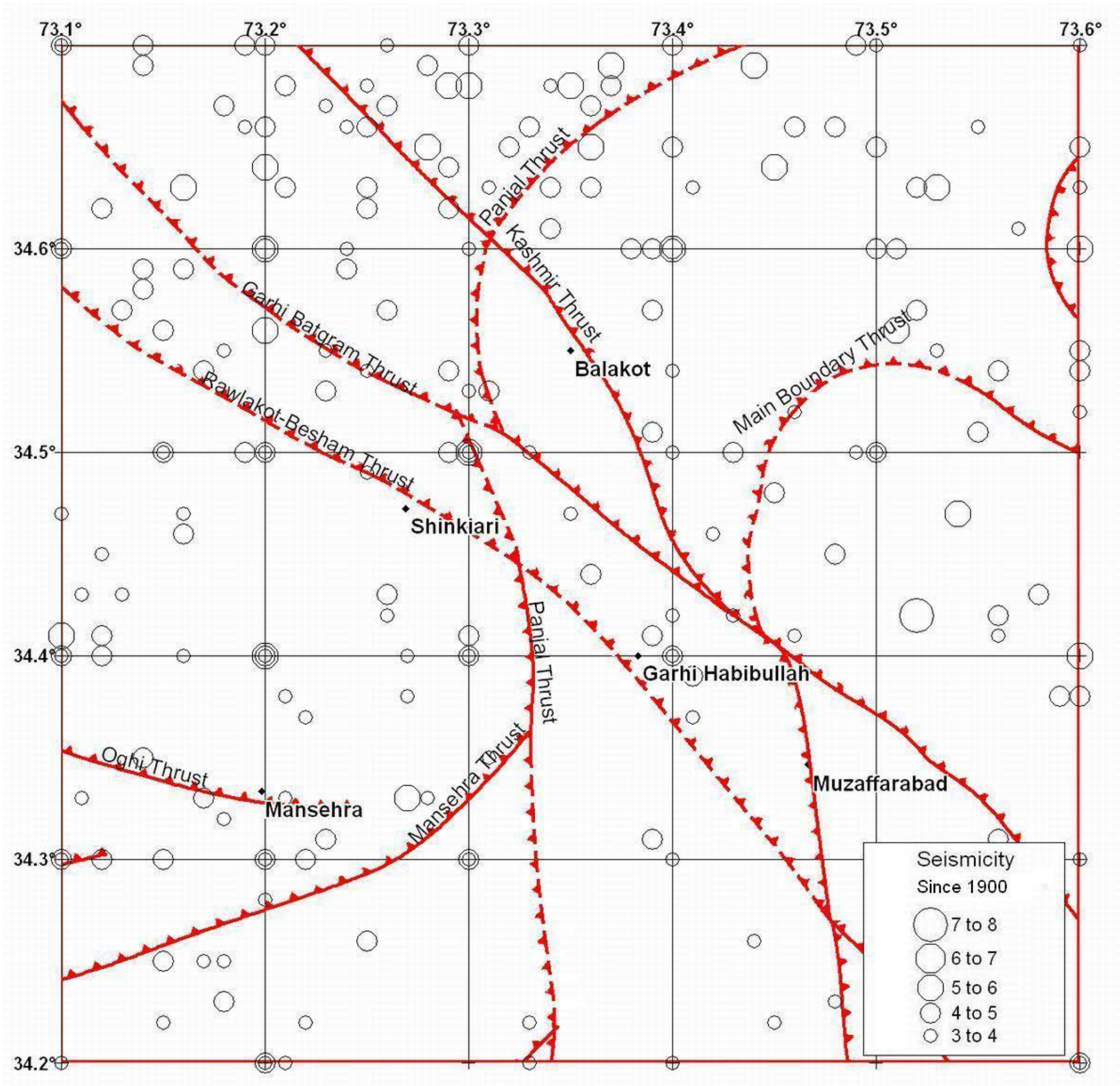

Fig. 1. Map showing seismogenic structures (dashed lines with possible presence) and instrumental seismicity of the study area (Since 1900).

d. *Oghi Fault Structure*

The Oghi Fault structure strikes northwest to southeast direction and is sited near the Oghi Fort in Mansehra district. The nearest surface trace of Oghi Fault is about 30km west of Balakot city.

Seismogenic Fault Segment Determination

The fault-segmentation method is commonly used to estimate the potential earthquake. Segment boundaries play an important role in confining earthquake ruptures from event to event. Earthquake rupture terminations are commonly associated with structural discontinuities, but not all-structural discontinuities have the capability to terminate an earthquake rupture. The size of structural discontinuities with respect to the rupture length and displacement may play an important role in controlling rupture termination. The size of structural discontinuities that stopped the earthquake seems to scale with the length and displacement of earthquake surface rupture (Zhang et. al., 1998). The seismogenic fault segments of the region are identified with their spatial geometry through satellite image and digital elevation data processing (Fig. 1). In addition to earthquake ruptures examined in this study, fault segmentation studies along major active thrust fault systems also show that many of the segmentation boundaries are commonly marked by large structural discontinuities. However, precise and better understanding for the identification of continuous fault segments is subject to the availability of more accurate and reliable seismic as well as geologic data of the region.

MAXIMUM MAGNITUDE POTENTIAL

The analysis of recorded instrumental seismicity of the region shows that the thrust fault systems are mainly responsible for the significant seismic events. The maximum credible earthquake on seismogenic faults can be estimated through the study of geology and physical nature of seismogenic faults. Studies of worldwide earthquakes have shown that faults do not rupture over their entire lengths during an individual event. Instead, individual fault segments with physically controlled boundaries rupture repeatedly (Schwartz and Coppersmith 1986, Schwartz 1988). Fault rupture length has often been used to estimate earthquake magnitude by considering maximum single rupture segment along the fault (Wells and Coppersmith 1994). Empirical relationships for estimation of maximum credible earthquake based on statistical analyses of worldwide historical earthquake data are developed by Wells and Coppersmith, 1994 as

Strike Slip Fault $M_w=5.16+1.12 \log L$

Reverse Fault $M_w=5.00+1.22 \log L$

Normal Fault $M_w=4.86+1.32 \log L$

Where M_w is Moment magnitude and L is the rupture length in km.

The estimated maximum credible earthquakes on the different seismogenic faults of the region are listed in the Table 1.

Table 1.
Estimated maximum credible earthquake of faults of the region (Wells and Coppersmith, 1994 relationships)

Fault	Movement	Total Length (km)	Longest Rupture Segment (km)	Max. Credible Earthquake (M_w)
Kashmir Thrust	Reverse	224	112	7.6
Main Boundary Thrust	Reverse/ Strike Slip	> 300	98	7.4
Panjal Thrust	Reverse/ Strike Slip	225	64	7.2
Garhi-Batgram Thrust	Reverse	53	53	7.0
Rawlakot-Besham Thrust	Reverse	> 250	78	7.2
Havailian Thrust	Reverse	44	22	6.6
Oghi Thrust	Reverse/ Strike Slip	54	27	6.7
Mansehra Thrust	Reverse	29	15	6.4

MICROINTENSITY ANALYSIS

The seismicity of the region shows a number of low to moderate earthquakes with only a few of magnitude greater than 5.0 (M_L). The distribution of the recorded instrumental seismicity in the region by local seismic network is shown in figure 1. The significant earthquakes that have been used in present study are the Muzaffarabad Earthquake (M_L=7.0) of Oct. 8, 2005 (MSSP 2005), the Kaghan Valley Earthquake (M_L =5.2) of Feb. 14, 2004 (Khan et. al., 2004, Mahmood et. al., 2004), the Astor Valley Earthquake (M_L=6.2) of Nov. 20, 2002 (Mahmood et. al., 2002) and the Mangla Earthquake (M_L=5.0) of March 10, 2006 (Talat, et. al. 2008). The microintensity distributions of each earthquake are investigated with determination of seismogenic fault through the focal mechanism solutions and geospatial data analysis. Observations indicate that the microintensity decreases away from the seismogenic ruptures of the earthquake as shown in table 3. The seismic data analysis shows that the region comprises shallow seismogenic clusters of shallow depth range. Therefore, these seismic events may produce almost maximum possible strong ground motion impacts at surface. These impacts may be of localized nature extended over a few tens of kilometers away from the seismogenic structure.

Table 2.
PGA values during Oct. 8, 2005 earthquake recorded by MSSP strong motion network

Recording Station	Closest Distance from Rupture (km)	PGA (g) East-West	PGA (g) North-South	PGA (g) Vertical
Abottabad	43	0.231	0.197	0.087
Cherat	144	0.042	0.037	0.021
Fateh Jang	126	0.051	0.053	0.032
Murree	60	0.076	0.078	0.069
Nilore	92	0.023	0.026	0.030
Peshawar	190	0.054	0.051	0.022
Thamewali	245	0.019	0.014	0.009

Table 3.
Intensity distribution of four major recent earthquakes in the region

Seismic Rupture Distance (Km)	Intensity (MMI)							
	Muzaffarabad Earthquake of Oct. 8, 2005 (M_L 7.0)		Mangla Earthquake of Mar. 10, 2006 (M_L 5.0)		Kaghan Valley Earthquake of Feb. 14, 2004 (M_L 5.6)		Astor Valley Earthquake of Nov. 20, 2002 (M_L 6.2)	
	Hanging Wall Region	Foot Wall Region	Hanging Wall Region	Foot Wall Region	Hanging Wall Region	Foot Wall Region	Hanging Wall Region	Foot Wall Region
0	XI	X	VII	VII	VIII	VIII	VIII	VIII
5	X	VIII	VII	VI	VIII	VII	VIII	VII
10	IX	VIII	VI	V	VII	VI	VII	VI
15	IX	VII	VI	V	VII	VI	VII	VI
20	VIII	VII	V	IV	VI	V	VI	V
25	VIII	VI	V	IV	VI	V	VI	V
30	VII	VI	IV	IV	VI	V	VI	V
35	VI	V	IV	<IV	V	IV	V	IV
40	VI	V	IV	<IV	V	IV	V	IV
45	VI	V	IV	<IV	V	IV	V	IV
50	V	IV	IV	<IV	IV	<IV	V	IV
55	V	IV	<IV	<IV	IV	<IV	IV	<IV
60	V	IV	-	-	<IV	<IV	IV	<IV
65	V	IV	-	-	-	-	IV	<IV
70	IV	<IV	-	-	-	-	<IV	<IV

Muzaffarabad Earthquake of Oct. 8, 2005

The Muzaffarabad Earthquake of Oct. 8, 2005, magnitude (M_L) 7.0 (Ms=7.7, M_w=7.6, m_b=6.8 USGS), occurred at 03:50:38 GMT near the city of Muzaffarabad at a focal depth of about 13km (Qaisar et. al 2007). The main shock was followed by more than 6400 aftershocks within one month with 296 having magnitude (M_L) greater than 4. The maximum net slip of 4.2m±0.5m mainly between Muzaffarabad and Balakot areas and surface features of thrust fault were observed at a number of places along the fault structure, named Kashmir Thrust (KT). Earthquake caused a death toll of more than 95,000 with 100,000 people injured and about 4 million people in the affected area were left homeless. The maximum intensity, XI on Modified Mercalli Intensity (MMI) scale, was observed along the strike of causative seismogenic fault where as maximum horizontal strong ground motion was 0.231g (Table 2). It was found that the ground shaking was not symmetrical around the epicenter, but was intensive along the strike of KT and on the hanging wall areas, mainly due to fault rupture directivity and near-fault effects. The microintensity distribution and respective strong ground motion generated by the main shock was believed to be the function of the 3-dimentional spatial geometry of the causative fault i.e. KT and the closest distance to seismogenic fault plane. Some significant local variations in microintensity were also observed due to site effects like thin soil amplification, ridge effect, basin edge and basin trapping etc (Qaisar et. al 2007).

Kaghan Valley Earthquake of Feb. 14, 2004

The Kaghan Valley Earthquake (M_L=5.6) of February 14, 2004 was located in Mansehra district near the town of Paras with shallow focal depth (Khan et. al., 2004, Mahmood et. al., 2004). The focal mechanism solution shows thrusting on the fault plane with strike ENE-WSW and dip in the NNW direction. The event struck near the northern margin of Indian Plate on the Main Boundary Thrust (MBT) with scattered aftershock distribution. The main shock was followed by more than 30 aftershocks, 6 of which had magnitude greater than (M_L) 4. The seismic as well as geological data suggest that the tectonic movement was concentrated in upper crust down to a depth of about 18 km. The observations made during the field work indicated that the intensity contours converged around the town of Paras in Kunhar Valley in an elongated shape trending NW-SE. The isoseismal map shows that the lateral extent of the intensity contours did not extend significantly far from peak intensity (MMI VIII) point near Paras. Most of the damage took place along the strike of seismogenic fault. Sharp relief and loose/thin fluvial filled narrow valleys contributed more to the damage in the affected area. The Earthquake was felt over an area of about 8000 sq. km whereas the damage occurred over an area of about 1200 sq. km. Damage and other surface evidence indicated a sharp decrease in the intensity away from the causative fault i.e. MBT. The Earthquake caused deaths of 26 persons, 43 injured, about 95 houses collapsed and 186 houses received damage.

Astor Valley Earthquake of Nov. 20, 2002

The Astor Valley Earthquake (M_L=6.2) of Nov. 20, 2002 occurred about 60 km southeast of Gilgit near Bunji in northern areas of Pakistan (Mahmood et. al., 2002). The estimated seismic moment of the November 20, 2002 main shock is 9.4×10^{17} Nm which gives M_w=5.9. The focal mechanism solution indicates normal faulting with a small component of strike slip on source fault whose strike is parallel to the local trend of MMT. The results indicate that the Astor Valley Earthquake may be considered to have occurred in an uncoupled region, in response to the gravitational pull due to internal tensional environment.

Mangla Earthquake of March 10, 2006

The Mangla Earthquake magnitude 5.0 (M_L) occurred at 12:50 PST (07:50 GMT) on March 10, 2006, near Mangla Lake about 95 km south-east of Islamabad (Talat et. al.,. al., 2008). One person was killed, and 22 injured in Mirpur District. The epicenter was located in the area of Mangla anticline near the town of Kalial on Kalial Thrust with the fault plane oriented in NW-SE direction with strike 293°, dip 20° and rake 117° respectively. The focal mechanism solution determined predominantly as thrust with a slight strike slip component, striking northwest and dipping northeast, coincides well with the slip nature of the fault and also supported by surface evidences. The intensity survey indicated maximum intensity along Kalial Thrust with some higher intensity values on hanging wall sites. The intensity contours are found elongated in the direction parallel to the strike of the observed fault.

MICROZONATION PARAMETERIZATION

The effects of earthquake are controlled by earthquake magnitude, wave propagation from source to site region, site distance and site characteristics. The other important influence on strong motion are near fault rupture directivity effects, basin response effects, rock edge effects, hanging wall effects, style of faulting, focal depth, basin edge effects and valley front effects.

Seismogenic Characteristics

he moment magnitude of the earthquake generated by the seismogenic fault is the measure of the energy released and thus directly sets the levels of strong ground motion. However, it has been observed during a number of catastrophic seismic events that the ground shaking was not symmetrical around the epicenter. The spatial geometry of the seismogenic rupture was found responsible for the surface distribution of the strong ground motion. During the study of Oct 8, 2005 earthquake, the high damage in Balakot and Bagh, located about 28km and 40km respectively from the epicenter, was the result of near seismogenic fault effect. Similarly, microintensity levels of the earthquake were considerably high along and near the Kashmir Thrust, i.e. the causative seismogenic fault. This phenomenon gives importance to evaluate 3-dimensional characteristics of the seismogenic fault in terms of nature, sense, movement and depth.

3D Definition and Nature of Faulting

The variability in the earthquake microintensity has long been recognized and taken into account in engineering applications. There is a large amount of variability in ground motion due to effects that are more complex than the simple parameterization using magnitude, epicenter distance, and site category. In addition to magnitude, the additional parameters like faulting style, near surface rupture, hanging wall etc. cause spatial variation in the ground motion around a fault. There is a well established difference in ground motion amplitudes between reverse and strike-slip faulting mechanism for crustal earthquakes where ground motion for reverse earthquakes typically exceed those for strike-slip earthquakes by a factor ranging from about 1.3 to 1.4 (Somerville and Sato 1998).

The pattern and focal mechanism study of the Oct 8, 2005 earthquake accompanied with seismic microintensity surveys, utilized to identify 3-dimensional geometry of the Kashmir Thrust. Based on the surface evidence and rapid decrease in the microintensity, it was observed that the seismic attenuation was considerably high in the direction perpendicular to the strike of seismogenic fault or rupture zone.

Strong Motion Relationship to Seismogenic Structure

The ground motion amplitude in near-fault region is strongly influenced by the fault geometry (Abrahamson and Somerville 1996). For vertical strike slip faults, rupture directivity effects cause a strong spatial variation in ground motion for given close distance to the fault. For a dipping fault, there are two prominent effects; the rupture directivity effect and the hanging wall effect. The effects of the hanging wall on strong motion were previously analyzed by Abrahamson and Somerville (1996). They found larger short period ground motions for sites on hanging wall compared with those on the foot wall at equivalent distance. The effect is greatest (a factor of 1.45) in the closest distance range of 8 to 18 km, and is significant (larger than a factor of 1.2) in the distance range of 6 to 22 km (Abrahamson and Somerville 1996). The rupture directivity effect is due to rupture propagation and damping of seismic wave along rupture plane (Archuleta and Hartzell 1981, Somerville et al. 1997).

During the study of Oct. 8, 2005 earthquake, it was found that the ground shaking was not symmetrical around the epicenter, but was intensive along the strike of KT and on areas on the hanging wall side, mainly due to fault rupture directivity and near-fault effects respectively. It was also observed that the intensity levels were considerably high at and near the causative faults and sharply decreased perpendicularly away from the causative fault plane. During the earthquake of Oct. 8, 2005, seismic intensity and associated damage was observed at near-fault areas in Balakot, Jabbori, Baso, which were located about 28km, 35km, and 43km respectively from the epicenter of the earthquake (Ali et. al., 2008).

The microintensity variations of the earthquakes at various places across the strike of causative faults are used to determine respective peak ground motion by correlating the "Revised peak ground motion versus intensity relations" as given by Dave Wald 1999.

$$\mathbf{I_{(MMI)} = 3.66\ Log\ (PGA_{(g)}) - 1.66} \quad \ldots\ldots\ldots\ldots 1$$

After assessment of peak ground acceleration ($PGA_{(g)}$,) distribution, the empirical relationship between $PGA_{(g)}$ and closest distances from causative fault plane was determined for both hanging and foot walls. The polynomial regression analysis method applied to draw graphs of PGA - fault distance (Fig. 2a, 2b) for maximum recorded earthquake of magnitude 7.0 (M_L), using the following empirical relationships;

$$\mathbf{PGA_{(g)} = 1.59 + 6.0x10^{-4}\ D_{hw} - 6.35\ x10^{-4}\ D_{hw}^{\ 0.2}} \quad \ldots..2$$
$$\mathbf{PGA_{(g)} = 1.59 + 2.4x10^{-3}\ D_{fw} - 7.20x10^{-1}\ D_{fw}^{\ 0.2}} \quad \ldots..3$$

Where "D_{hw}" and "D_{fw}" are the closest distance in kilometers from the seismogenic fault plane on hanging wall and foot wall, respectively.

From comparison of microintensity distribution of earthquake of Oct. 8, 2005, it was observed that these regression relationships are more appropriate between the intensity range of MMI≥IV and MMI≤XI with up to a distance of 100km.

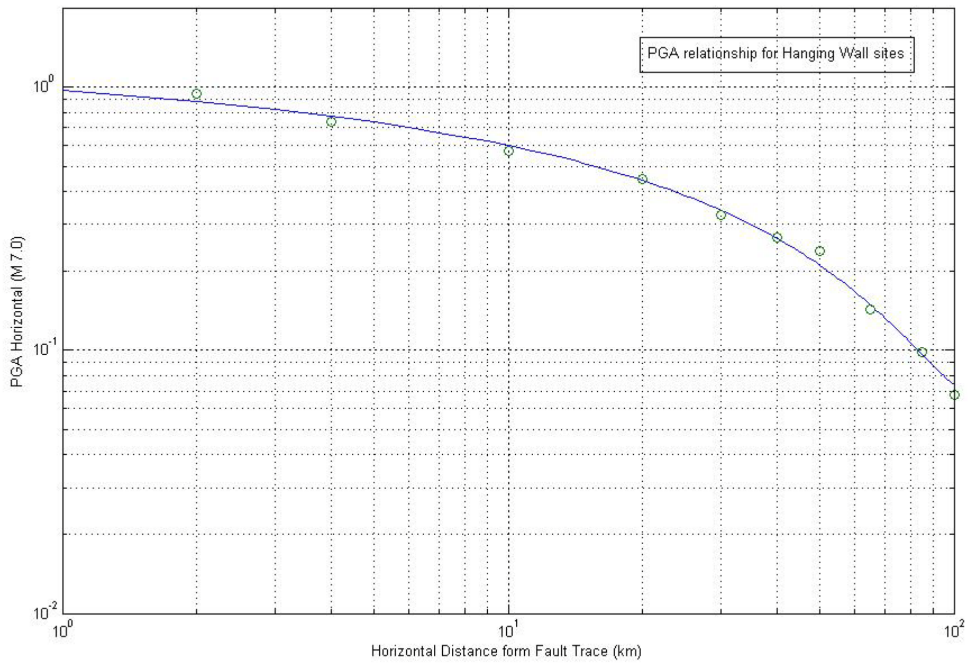

Fig. 2a. PGA relationship to distance from fault on hanging wall sites for max. recorded magnitude 7.0 (M_L).

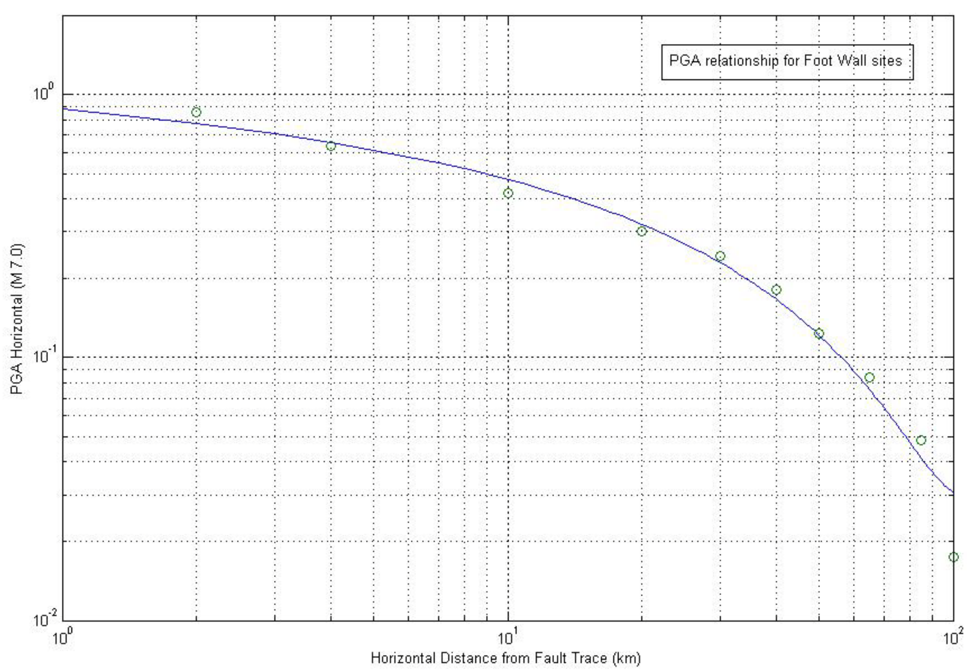

Fig. 2b. PGA relationship to distance from fault on foot wall sites for max. recorded magnitude 7.0 (M_L).

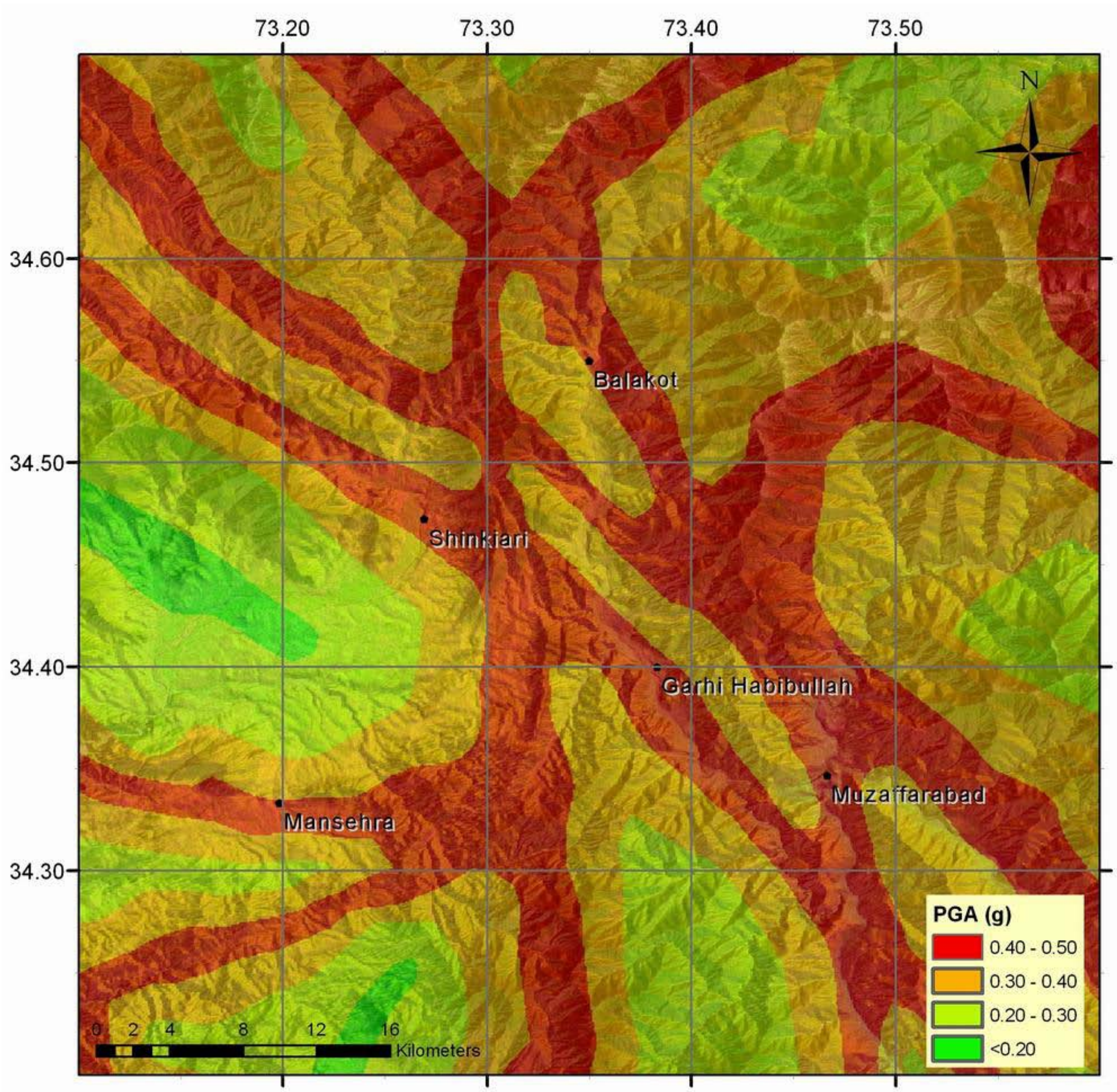

Fig. 3. Seismic microzonation map of Upper Hazara and surrounding regions showing zones of expected peak horizontal acceleration (PGA).

SEISMIC MICROZONING

Expected peak ground acceleration (PGA) microzonation map of Upper Hazara region (Fig. 3) is compiled on the basis of maximum credible earthquake along seismogenic structures where the PGA is determined by applying equation 2 and 3 on the largest rupture segments of Kashmir Thrust, MBT, Panjal Thrust, Mansehra Thrust, Manshera Thrust and Oghi Fault at 200m horizontal surface grid spacing. For estimation of expected strong ground motion, percentage impact factors to these parameters are assigned at 200m grid spacing on ground. In the zoning map, following 4 strong ground motion hazard zones are defined.

PGA 0.40 – 0.50 **-** Zone of very high seismic hazard
PGA 0.30 – 0.40 **-** Zone of high seismic hazard
PGA 0.20 – 0.30 **-** Zone of moderate seismic hazard
PGA < 0.20 **-** Zone of low seismic hazard

CONCLUSION

The microintensity distribution and expected peak ground motion generated by the seismogenic structures are the function of the 3-dimentional spatial geometry of their seismogenic faults. It is found that the ground shaking was not symmetrical around the epicenter, but was intensive along the strike of causative fault and on area on the hanging wall side, mainly due to fault rupture directivity and near-fault effects, respectively. Therefore, in addition to seismic potential and tectonic setup of an area, understanding the spatial spreading and orientation of seismogenic structures are essential to determine PGA. In addition to seismic and geologic data, the advance techniques of Geographic Information System (GIS) and Remote Sensing (RS) are very helpful tools to identify seismogenic structures. These tools greatly facilitate to analyze geoscientific data to investigate earthquake source parameters and their impacts on grounds at different site conditions. Based upon the maximum credible earthquakes along the seismogenic structures of the area and PGA-distance attenuation relationships, the most part of the Balakot city fall in the zone of very high seismic threat where expected horizontal PGA may raise up to 0.50g. However, local site conditions and distances may modify the PGA up to about a factor 1.45. Similarly, some areas of Muzaffarabad, Garhi Habib Ullah, Mansehra and Shinkiari cities are placed in high PGA zones, primarily depending upon the closest distance to local seismogenic faults. The local instrumental strong motion data with sufficient geospatial coverage and different site and geological conditions is required for more realistic microzoning at small scale.

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