THE KASHMIR, PAKISTAN
EARTHQUAKE OF 8 OCTOBER 2005

A FIELD REPORT BY EEFIT

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Introduction

Dr Navin Peiris
Risk Management Solutions

1.1 The Kashmir Earthquake

On October 8, 2005 at 0850 local time (0350 UTC) an earthquake of magnitude 7.6 (Mw) occurred in northern Pakistan (34.493°N, 73.629°E) with a focal depth of 26km. The epicentre was located about 10km northeast of Muzaffarabad (see Figure 1.1) the capital of Azad Jammu Kashmir (AJK) or Pakistan administered Kashmir. Widespread destruction resulted in AJK and in the eastern districts of North West Frontier Province (NWFP) of Pakistan. As of January 1, 2006, the total casualty figures in Pakistan stood at 72,763 deaths and 68,679 injuries, while in India they reached 946 deaths and 4,386 injuries. Close to 450,000 homes were fully destroyed and damaged leaving about 2.8million people without shelter. The heaviest damage occurred to the cities of Muzaffarabad (capital of AJK) and Balakot, which were nearest to the fault rupture responsible for the earthquake. Ground shaking was felt as far south as Islamabad, resulting in one spectacular building collapse in the Margalla apartment complex.

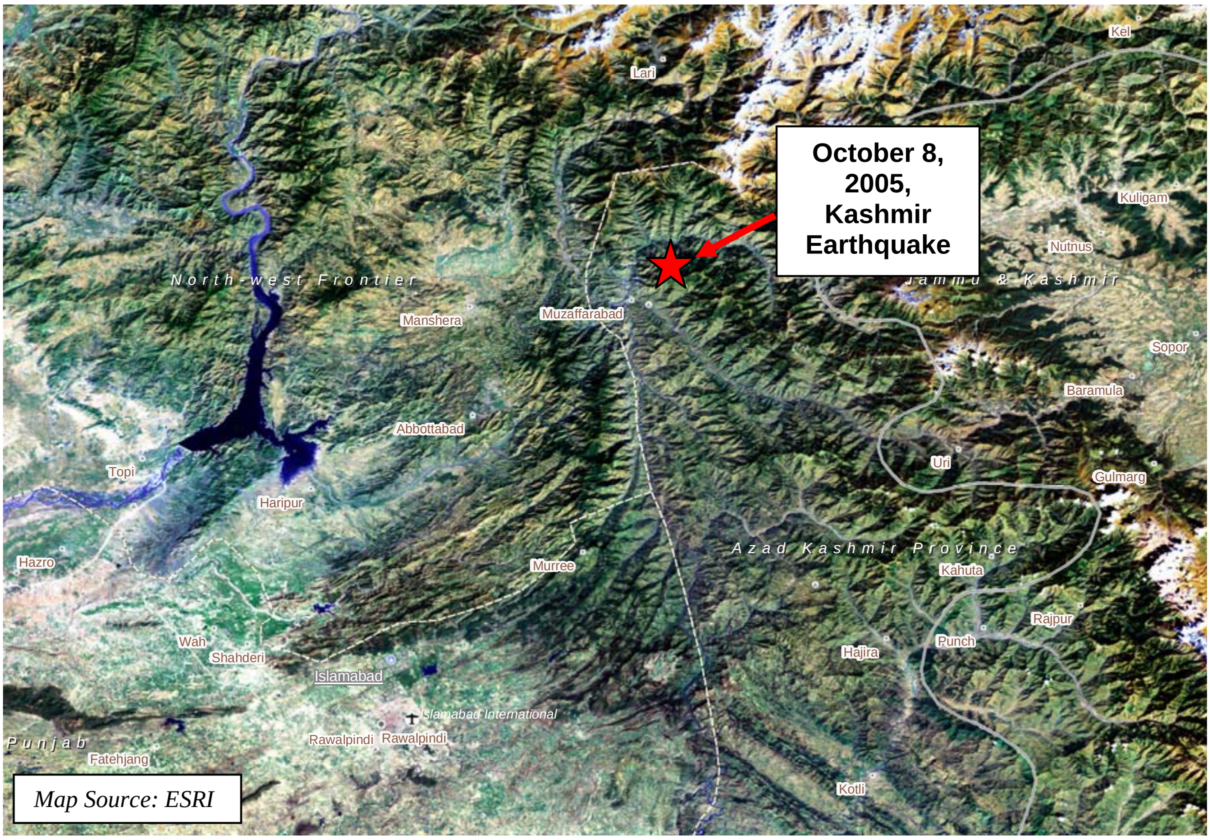

Figure 1.1: Location of October 8, 2005 Kashmir Earthquake

Given the geographical location of the event in a mountainous region, the earthquake resulted in numerous landslides and slope failures leading to damage to homes and commercial buildings alike. The landslides blocked roads thus hampering the emergency relief effort and supply of aid for the worst affected areas. Disrupted landslides also proved to be a hazard since they may be triggered again especially in the period following the winter snow melt. Geotechnical failures along the road network made many roads unstable and therefore unsuitable for heavy traffic. The total direct losses to public and private assets amount to US$2.3 billion with an overall estimated cost of US$5.2 billion when relief, recovery and reconstruction needs are added

(ADB-WB, 2005). The overall estimated cost is equivalent to around 4% of Pakistan's 2006 GDP. which stood at US$129billion (World Bank estimate).

1.2 The EEFIT Mission's Team Members

The Earthquake Engineering Field Investigation Team (EEFIT) of the Institution of Structural Engineers, London launched a field mission to the affected areas of Northern Pakistan on November 22, 2005 after the emergency phase of the earthquake was coming to an end. The team (Figure 1.2) consisted of Team Leader - Dr Navin Peiris (Risk Management Solutions ,formerly Arup), Dr Tiziana Rossetto (University College London), Dr Paul Burton (University of East Anglia) and Mr Suqalain Mahmood (Sir Robert McAlpine). The profile of the team listing their experience is shown in Table 1.1.

Figure 1.2: EEFIT team with the US Army helicopter crew in Muzaffarabad Airport

The team visited affected areas in Balakot, Muzaffarabad, Mansehra and Abbottabad in addition to Islamabad. They carried out walkover surveys and took aerial photos of the damaged areas in order to identify the distribution and extent of damage to structures, road and bridges due to the earthquake and associated landslides. The EEFIT team was accompanied by Mr Irshad Ahmed and Mr Javed from University of Engineering and Technology (UET), Peshawar who provided accommodation, transportation and aided in identifying damage locations and translations during the damage survey. Meetings were also held with various government officials including the Geological Survey of Pakistan, United Nations Camp officials and Halcrow (Pakistan) Ltd.

Table 1.1: Profile of the EEFIT team

Member	Affiliation	Skills/Experience
Dr Navin Peiris (Team Leader)	Risk Management Solutions (formerly Arup)	Geotechnical and seismic engineering, vulnerability and risk assessment
Dr Tiziana Rosetto	University College London (UCL)	Seismic structural engineering, vulnerability and risk assessment, seismic hazard assessment
Dr Paul Burton	University of East Anglia	Geophysics, geology, loss assessment
Mr Suqlain Mahmood	Sir Robert McAlpine	Structural engineering, construction, fluent in Urdu

1.3 Damage in Neighbouring Countries

The earthquake also resulted in heavy damage on the Indian side of Kashmir. The worst affected towns were Tangadhar in Kupwara district and Uri in Baramula district (see Figure 1.1) where about 80% of the town was destroyed. At least 946 people killed and 4386 injured in India (USGS, 2005). The earthquake also resulted in landslides and rockfalls damaging roads and bridges blocking access to heavily damaged areas hampering the relief effort. The extent of damage was not as severe as in NWFP and AJK due to the longer distance from the epicentre and the lower population density compared to affected areas of Pakistan and AJK.

1.4 The Social and Economic Significance of the Kashmir Earthquake

The Kashmir earthquake resulted in a large number of fatalities and injuries (72,763 deaths and 68,679 injuries) and severe damage to housing and infrastructure resulting in a direct economic loss estimated at US $2.3billion (ADB-WB, 2005). The direct economic loss of $2.3 billion largely comes from the damaged residential properties in the affected areas as they constituted 96% of the damaged building stock. The earthquake occurred in a region of Pakistan that is amongst the country's poorest and has seen the lowest levels of economic growth rates. The provinces of AJK and NWFP have the highest level of poverty at 45% (headcount index), well above the national average of 25% [The province of NWFP consist of about 13% of Pakistan's population]. The high levels of unemployment, poverty and lack of service provision meant that the population affected by the earthquake were among the most vulnerable population groups in Pakistan. Given this condition the overall cost of the earthquake was estimated at US $5.2billion, which includes a reconstruction cost of US $3.5billion and recovery cost of US $1.7billion consisting of relief, compensation and livelihood restoration. The above factors suggest that the region has had a high societal impact from the Kashmir Earthquake, which could take several years to recover.

The economic significance of the Kashmir earthquake could be measured in terms of macroeconomic impact and the ability of the Government of Pakistan to finance the reconstruction and recovery. The macroeconomic impact was assessed in terms of the impact on the Gross Domestic Product (GDP) of the affected provinces and the country from the earthquake. It has been estimated that the impact of the earthquake on Pakistan's official GDP, which excludes GDP from AJK is expected to be relatively small at about 0.4%. This is due to the affected districts in AJK and NWFP accounting for only 0.8% and 1.5% of the national GDP respectively. However, the government had a fiscal deficit of around US $5.4billion (-4.2% of GDP) in 2006 (EIU, 2007) and projected to remain in the red for the next 5years. Given this level of deficit, it would be difficult to finance the reconstruction and recovery programs without significant external assistance. Hence, the Kashmir earthquake could be considered to be economically significant to Pakistan given that fund diversification to the affected areas will have an impact on the rest of the country discounting any external factors.

Table 1.2: Fatalities and economic losses from selected earthquakes

Earthquake	Fatalities*	Total Loss (US$ Bln.)	Source
Kashmir, 2005	73,000	2.9	ADB – WB (2005)
N. Sumatra, 2004	228,000	11.5	EEFIT (2006)
Bhuj, 2001	13,800	4.6	EERI (2002)
Taiwan, 1999	2,297	11.5	EERI (2001)
Kocaeli, 1999	17,118	7.0 to 40.0	EERI (2000)
Kobe, 1995	5,502	150.0	RMS (2005)
Northridge, 1994	60	40.0**	Eguchi, et al. (1998)
Loma Prieta, 1989	63	10.0**	Rowshandel, et al (2006)

Note: Total loss above is the sum of direct and indirect economic loss
**Fatalities are from NGDC (2006)*
***Losses are direct economic only*

Table 1.2 compares fatalities and economic losses (direct and indirect) for a number of major earthquakes. The economic losses in Pakistan are comparable to those of Bhuj and Kocaeli earthquakes. The Indian Ocean tsunami resulted in a loss of $10-15 billion of direct economic loss (estimated by World Bank, Asian Development Bank and country specific sources) for all the affected countries in the Indian Ocean basin. The Kashmir Earthquake could therefore be placed as a major earthquake from the viewpoint of economic significance.

1.5 Community Vulnerability and Resilience

Figure 1.3 compares the fatality count from the Kashmir earthquake with other major earthquakes as a function of the earthquake magnitude. The Kashmir earthquake was comparable in magnitude to Bhuj, Kocaeli and Taiwan earthquakes but has the highest number of fatalities. Although there are several factors that affect the number of fatalities due to an earthquake of a certain magnitude such as the population density in the affected regions, it could be argued that the regions affected by the Kashmir Earthquake in general has a higher level of community vulnerability compared to other regions listed in Figure 1.3 when comparing the fatality figures. Table 1.2 compares the number of fatalities with economic loss estimates (values are not inflated to 2008 values). These figures are typical of developing nations where earthquakes result in very high fatality rates and lower direct economic losses compared to developed nations where the trend is the reverse. Ideally the economic losses should be compared with the GDP and the fiscal balances in order to understand the level of the economic impact. This was done for the Kashmir Earthquake as discussed in Section 1.4, where the higher social cost in addition to asset loss resulted in a major economic impact since substantial capital was necessary for the recovery and reconstruction.

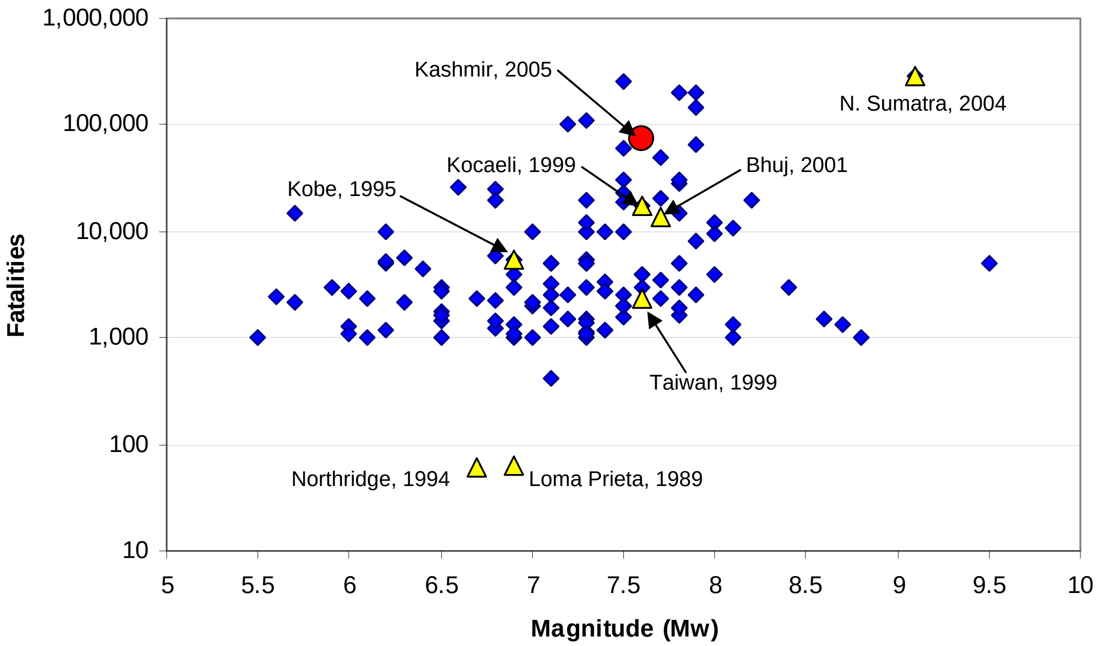

Figure 1.3: Fatalities (1000+) from earthquakes since 1900 (NGDC, 2006)

Pelling (2003) in the context of urban developments notes that nature does not cause natural disasters; natural disasters are a result of a cascading series of knock-on effects after an event breaches a critical threshold e.g. threshold of vulnerability. Vulnerability in a community has many dimensions as illustrated in Figure 1.4 (Thywissen, 2006, Pelling, 2003). The most visible elements of vulnerability following any disastrous event are the built environment (i.e. houses, commercial buildings, roads, bridges, industrial facilities etc.) and social element in terms of casualties (i.e. fatalities, injuries and displaced population). However, other elements become visible in time as the disaster moves through the phases of relief, short term recovery to long term reconstruction and recovery phases. These elements interact in such a way that there is interdependence among each element in contributing to the overall vulnerability of the region concerned. For instance, the level of robustness within each element of vulnerability, dominated by the built environment and the social element determines the level of the impact to the region concerned measured in terms of direct economic loss and casualty. Equally, the level of resilience in each vulnerability element perhaps dominated by the institutional, economic and environmental elements determines the direction of short term and long term recovery of the region following the disastrous event. Miles and Chang (2006) show that a region affected by a natural disaster reaches an equilibrium that is dependent on the pre-disaster state, community vulnerability and resilience. Figure 1.5 illustrates the levels at which equilibrium is reached depending on whether adequate aid and investments follow and implemented following well managed disaster recovery programmes. Most often curve C is the likely scenario in developing countries where post-disaster recovery takes place in a non-coordinated manner due to lack of disaster plans or management structures in place and inability to manage funds or lack of funds availability due to economic constraints.

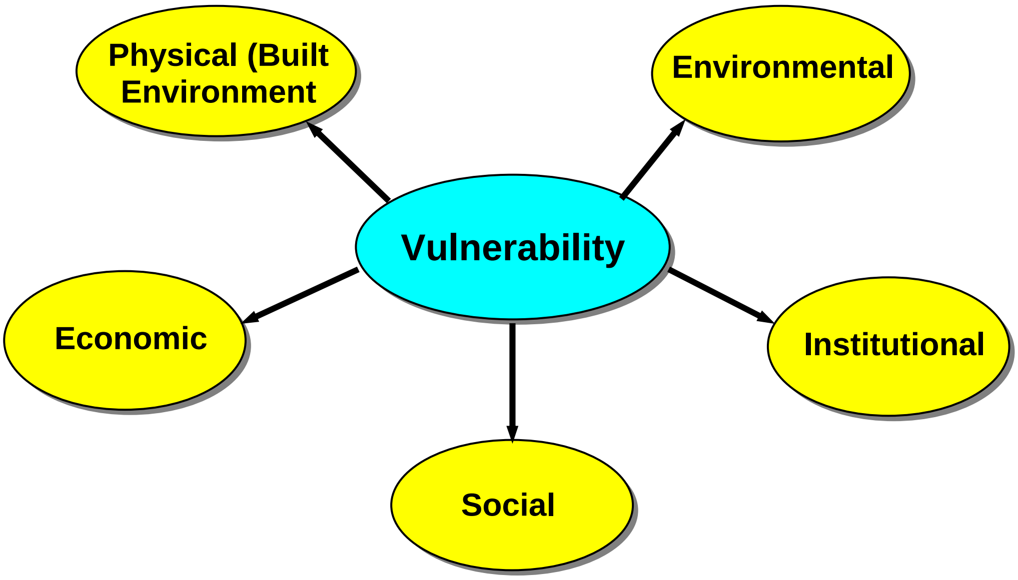

Figure 1.4: Elements of community vulnerability

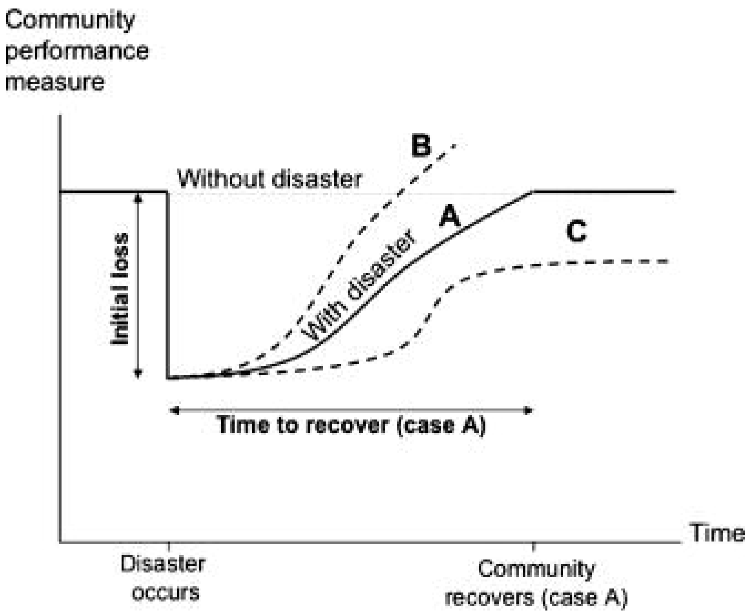

Figure 1.5: Measure of post-disaster community performance (Miles and Chang, 2006)

All of these issues point to the importance in ensuring that the built environment and the society are quite robust and resilient from such events in the future and that this should be borne in mind when developing reconstruction plans for the affected region. The October 8, 2005 Kashmir Earthquake was a wake-up call to the region's vulnerability to potential damaging large magnitude events. It is the intention of this report to put the findings of the field mission and the contributions of other parties in the context of identifying the level of vulnerability in northern Pakistan from future earthquake events. This will be largely focused on the built environment and secondly the social element. The report also discusses how the level of vulnerability identified within these elements could be reduced based on the knowledge and experience gained from the field missions to the region.

1.6 Structure of the Report

The report is structured to present the findings of the field mission integrated with the information from other sources in order to cover a range of topics from seismology of the region and seismic hazard to damage to the built environment and the socio-economic impact. Chapter 2 presents the seismology in northern Pakistan in order to explain the background to the event. The measured ground motion data are presented in order to understand any relationship with the damage observations in the cities from Islamabad toward Muzzafarabad near the epicentre. The seismic hazard in the region is discussed to explain the likelihood of a similar event occurring in the region, which could potentially have damaging consequences based on the findings of the damage survey of the region's vulnerability. Chapters 3 to 5 present the findings from the field mission on the impact to buildings, landslides and geotechnical aspects and the performance of lifelines during the event. These chapters attempt to identify the level of vulnerability of the built environment. Chapter 6 focuses on design codes in Pakistan and compares them with internationally accepted seismic oriented building codes such as Uniform Building Code (UBC) 1997 and Eurocode (EC) 8. The purpose of this exercise is to identify any potential weaknesses in the building codes in Pakistan so that recommendations could be made for improvements. Chapter 7 discusses the socio-economic impact of the disaster and attempts to relate the mission findings to the elements of community vulnerability in order to draw conclusions and recommendations in Chapter 8.0.

1.7 Acknowledgements

EEFIT gratefully acknowledges Arup, Sir Robert McAlpine and EPSRC for providing financial support to the team members, which enabled the mission to take place. EEFIT also acknowledges University of Engineering and Technology (UET) Peshawar for their kind support in providing accommodation, transportation and guidance in accessing the affected areas on NWFP and AJK. Special thanks also goes to the US Army crew for allowing the EEFIT team members to accompany their relief missions, which facilitated photographing landslide affected remote areas, which would otherwise have been difficult in the time period of the field mission.

1.8 Copyright Note

1.9 References

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2 Seismology and Seismic Hazard

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2.1 Regional Tectonics Structures

The epicentral region of the October 8, 2005 Kashmir earthquake lies on the western edge of the Himalayan Arc, which denotes the area of continental-continental convergence between the Indian and Eurasian tectonic plates. The Indian plate moves northwards at a rate of about 40mm/year and subducts below the Eurasian plate (see illustration in Figure 2.1, USGS (2006)). The resulting compression and uplift at this plate boundary over millions of years has resulted in the formation of the Tibetan Plateau (average elevation of 4600 m above sea level), the Himalayan mountain ranges (which have peaks reaching up to 8,854 m above sea level), as well as the Karakoram, Pamir and Hindu Kush ranges.

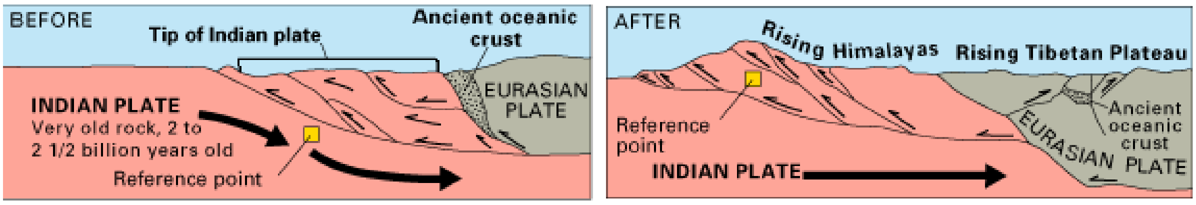


Figure 2.1: Illustration of the process of formation of the Himalayas (Source: USGS, 2006)

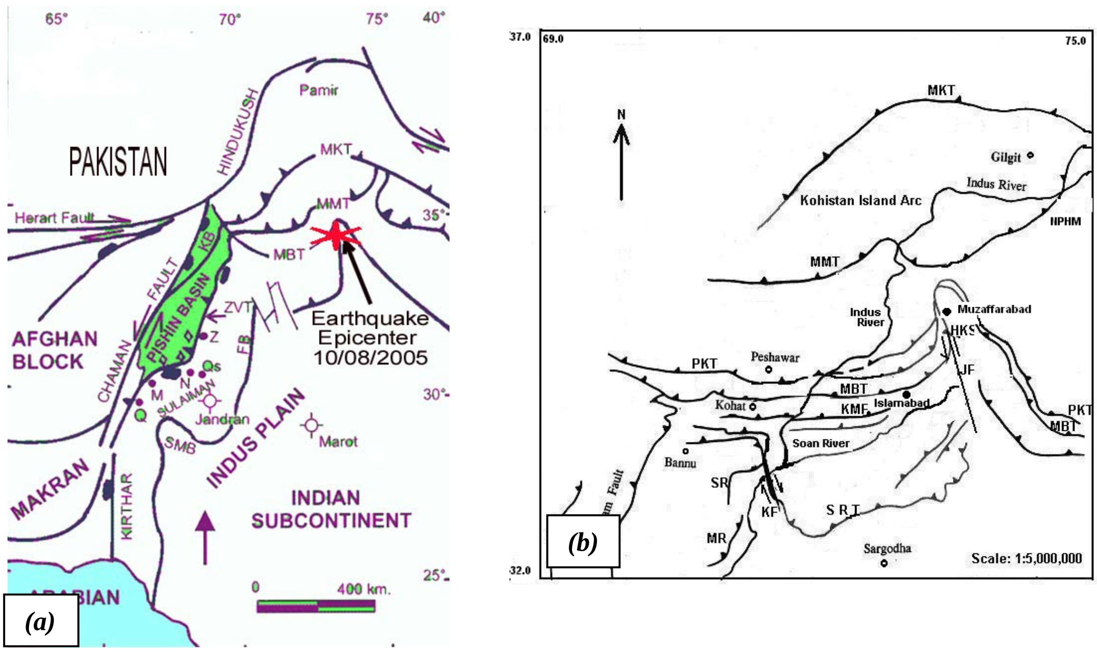


Figure 2.2: Main active faults in the Himalayan convergence zone (Source: (a) Pararas-Carayannis, 2006, (b) MonaLisa et al.,2005)

The compression between the Indian and Eurasian tectonic plates results in a series of large thrust (or reverse) faults, which delineate the Himalayan zone of convergence. These faults include the Main Karakorum Thrust (MKT), the Main Mantle Thrust (MMT), Main Boundary Thrust (MBT) and the Salt Range Thrust (SRT) (see Figure 2.2). The area between MMT and SRT is referred to as the NW Himalayan Thrust and Fold Belt (Armbruster et al., 1978), which is bounded by the Nanga Parbat Haramosh Massif and the Hazara-Kashmir Syntaxis (HKS). The structure on which the main shock occurred was the HKS, which has an uplift rate of about 1cm/year (Bilham, 2005).

2.2 Seismicity

The historical record of Pakistan earthquakes is incomplete (Ambraseys et al. 2004). It is known that an earthquake occurred in 1555 near Srinagar which caused substantial damage and may have had a larger magnitude than the October 8, 2005 event (Figure 2.3, Bilham, 2005). Insufficient data exists for determining its precise magnitude and location. It may have occurred between the 1885 and 1905 earthquakes. Other less destructive earthquakes, which have affected the Kashmir region in the past are the 1842 Kunnar (M_w 7.5), 1878 Abbottabad (M_w 6.7) earthquake, the 1885 Srinigar (M_w 6.3) earthquake and the 1905 Kangra (M_w 7.8) earthquake (Bilham, 2005). The most recent large earthquakes to have occurred in the northeast and northern regions of Pakistan are the 1974 Pattan (M_w 6.2) earthquake, 1977 Rawalpindi earthquake, 2002 Bunji earthquake and 2004 Batgram earthquake (Mona Lisa, et al., 2005). Other large earthquakes that have occurred in Pakistan are the 1935 Quetta earthquake (M_w 7.5, Bilham, 2005) and the 1945 Makran coastal earthquake (m_b = 8.3, Mona Lisa, et al., 2005). The former was associated with the left-lateral Chaman fault (see Figure 2.2), caused 30,000 deaths and devastated the city of Quetta (Pararas-Carayannis, 2006).

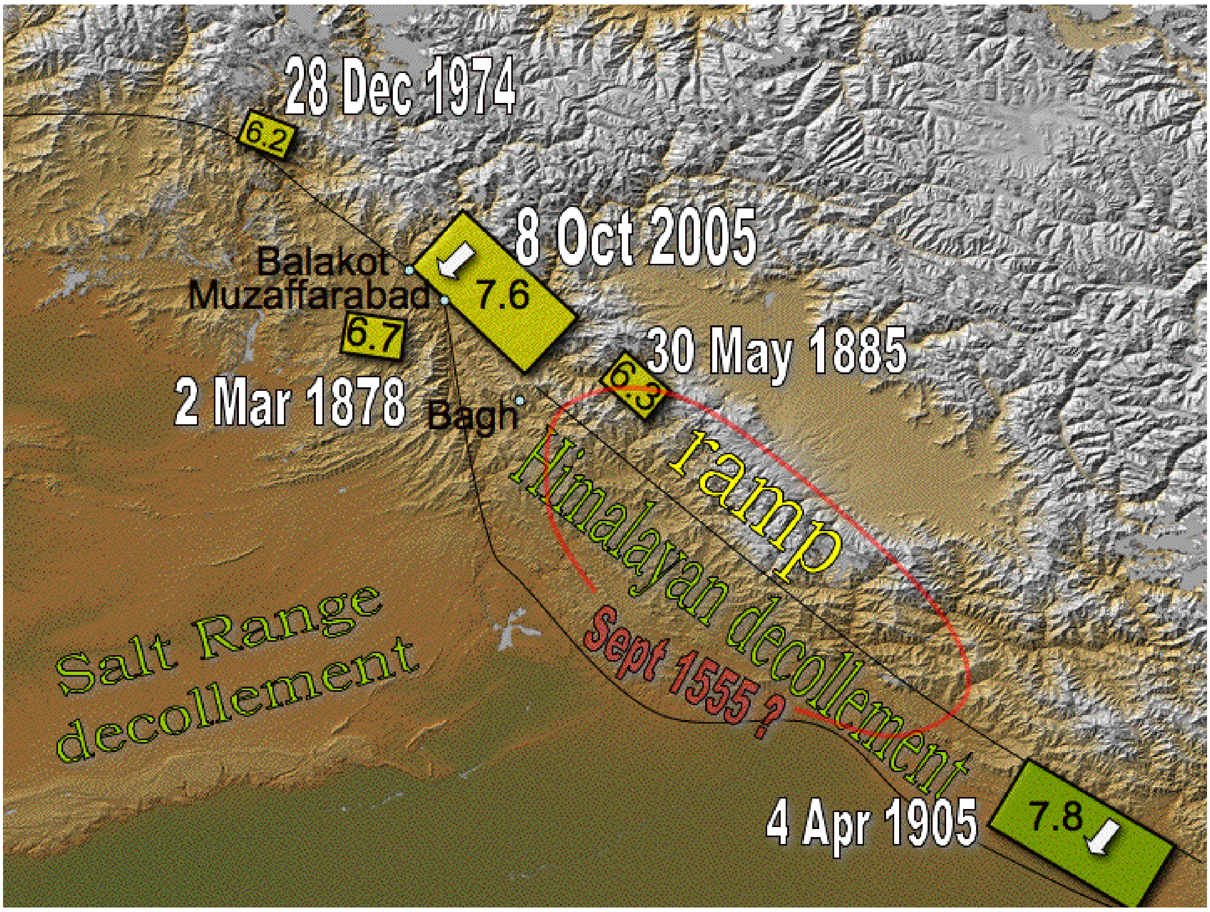


Figure 2.3: Large historical earthquake events in Northern Pakistan and India. The shaded areas show the approximate rupture zones. (Source: Bilham, 2005)

2.3 The Kashmir Earthquake

2.3.1 Fault Location

The October 8, 2005 Kashmir earthquake occurred at 03:50:40 UTC (08:50:40 am local time) at 34.493°N, 73.629°E, about 20 km NE of Muzaffarabad and 105 km NNE of Islamabad (USGS). The earthquake had moment magnitude 7.6 (M_w) and focal depth of 26 km (USGS).

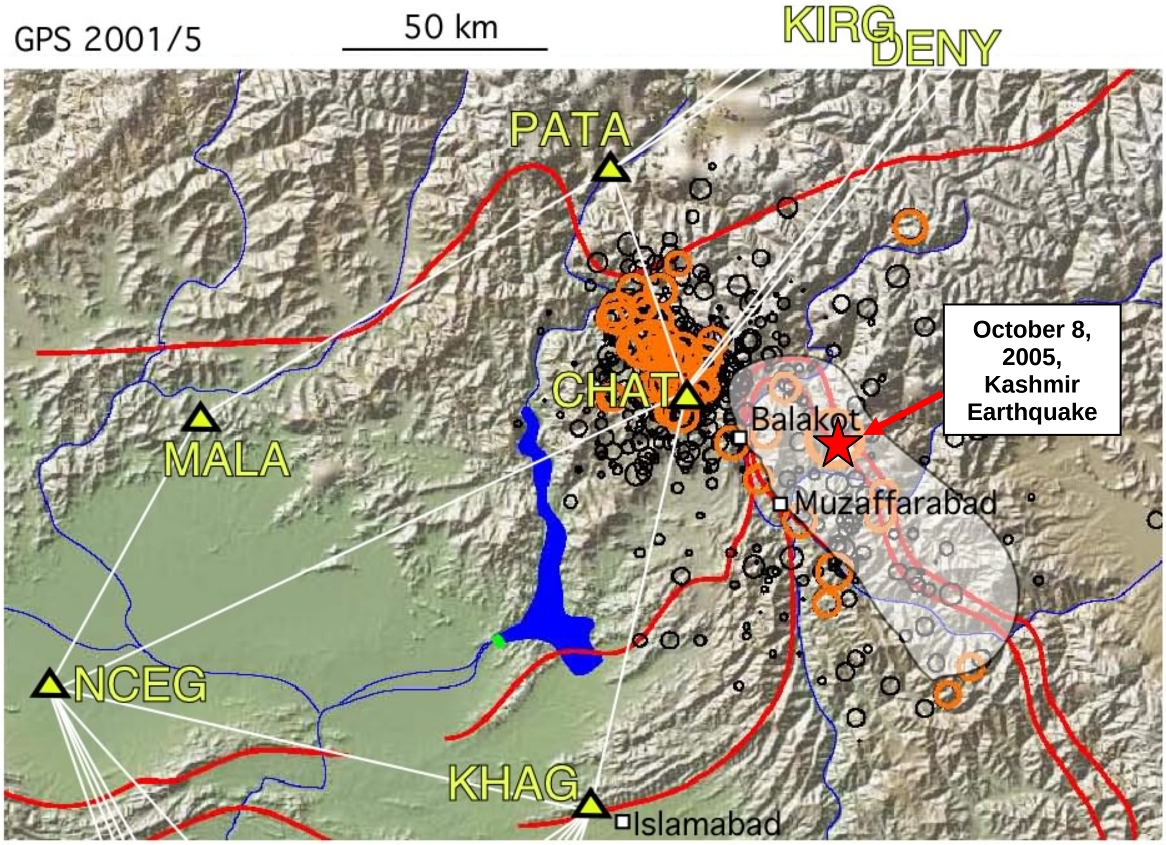


Figure 2.4: Earthquake location and aftershocks from USGS, and the inferred rupture zone of 90 km x 40 km (after Bilham, 2005)

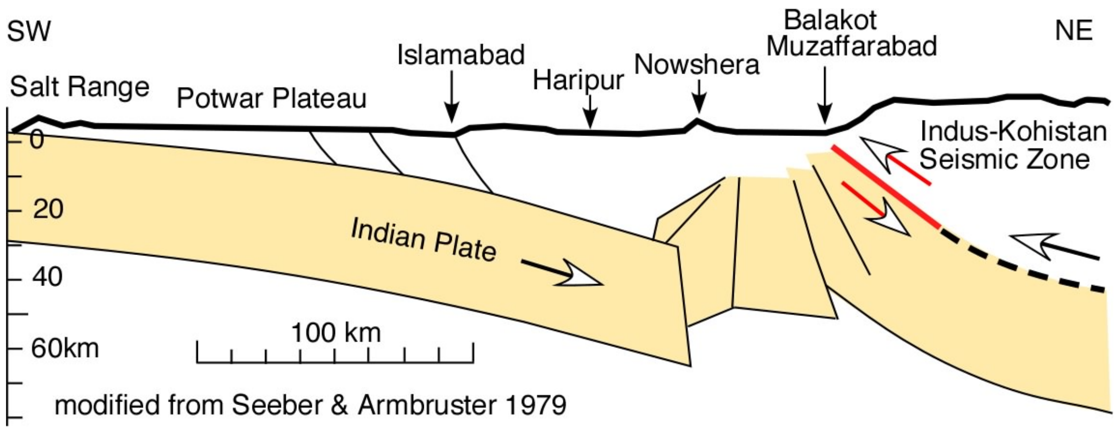


Figure 2.5: Cross-sectional view of the rupture area in the Indus-Kohistan Seismic Zone

Following the event, numerous aftershocks of moment magnitudes between 4.0 and 6.0 were recorded over a distance of about 150 km in the NNW-SSE direction. Figure 2.4 shows the location of the epicentre and the aftershocks (after USGS). Bilham (2005) describes the inferred rupture to be covering an area of 90 km x 40 km on the Indus-Kohistan Seismic Zone (shaded in Figure 2.4) with a 37º dip in the NE direction (see Figure 2.5).

According to Bilham (2005), the Kashmir 2005 earthquake and the Srinagar 1885 earthquake (6.3 M_w) may have occurred on the same 37º NE dipping ramp (see Figure 2.3).

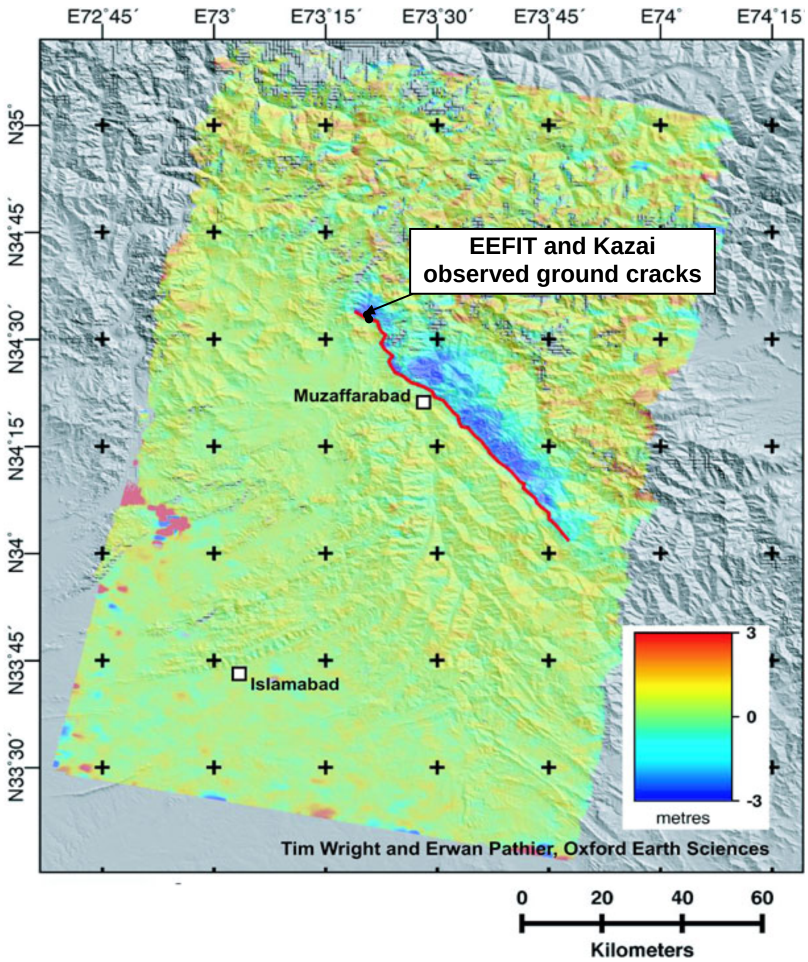


Figure 2.6: Map showing the location of the causative fault of the October 8, 2005 earthquake (Source: COMET, 2005)

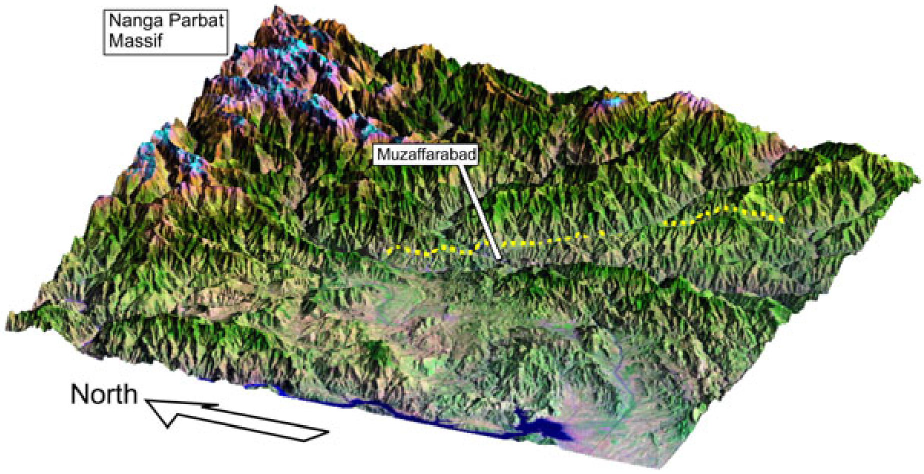


Figure 2.7: 3D perspective view of the Kashmir earthquake region and Muzaffarabad. The image is formed by draping LANDSAT 7 imagery over NASA SRTM (Shuttle Radar Topography Mission) digital topography. The fault identified by radar imagery is marked as a yellow dotted line. The mountains are higher on the far (north-eastern) side of the fault. (Source: COMET, 2005)

The fault segment on the Indus-Kohistan Seismic Zone that was responsible for the October 8, 2005 Kashmir earthquake was the reactivated Muzaffarabad fault, which is a thrust (reverse) fault. The causative fault of the main shock has been located by COMET (2005) using readings of ground displacements made using radar amplitude measurements from satellites and is shown in Figures 2.6 and 2.7. The fault strike lies in the N27E to N30E direction (Bilham, 2005; COMET, 2005) and the average slip was estimated to be in the range 2-4 m.

The surface trace of the causative fault as interpreted from the map of ground displacements from radar amplitude measurements (COMET, 2005) approximately coincides with that predicted by Bilham (2005) from observation of the location and orientation of large landslides resulting from the event. The majority of the landslides were indeed observed by Bilham (2005) and by EEFIT to extend from Balakot to a few kilometers SE of Muzaffarabad. An extension of this line of landslides was also observed by EEFIT together with Dr Bijan Kazai of the EERI team to coincide with a series of ground cracks running for 200-300 m through the town of Balakot (see Figure 3.2 for location). These were not associated with any direct land sliding and might be a further surface expression of the fault movement below the earth's surface or simply one of local slumping (Figure 2.8). The two black dots plotted on Figure 2.6 show some of the GPS readings taken of the crack trace. These dots are seen to lie almost directly over the fault line location prediction made by COMET (2005). However, this is a preliminary observation and more detailed follow up work on our observations is required before anything may be concluded. It is likely that fault rupture on the Muzaffarabad fault was mostly "blind" since there are many blind thrust faults in the region (MonaLisa, 2005).

Figure 2.8: Photos of ground cracks observed by EEFIT and Dr Bijan Kazai (of Columbia University, New York, and member of EERI team) to run through Balakot in a NNW-SSE direction

2.3.2 Strong Ground Motion

Strong motion recordings during the Kashmir earthquake are available in Abbottabad, Murree and Nilore (near Islamabad). Digitized strong ground motion data from the Kashmir Earthquake could not be accessed since the data are owned by the Pakistan Atomic Energy Commission (PAEC). However, images of the ground motion records and their corresponding response spectra were obtained from Chaudury (2006). Figure 2.9 shows the location of the recordings and Figure 2.10 shows the strong motion records for horizontal NS, EW and vertical components. Table 2.1 summarizes the location details and PGA values. Unfortunately, no strong motion records are available from locations close to the epicentre.

Table 2.1: Location details of strong motion records and PGA summary (Chaudury, 2006)

Location	Epicentral distance (km)	PGA (g)		
		NS	EW	Vert
Abbottabad	48.0	0.197	0.231	0.087
Murree	64.0	0.078	0.075	0.069
Nilore	100.0	0.026	0.023	0.30

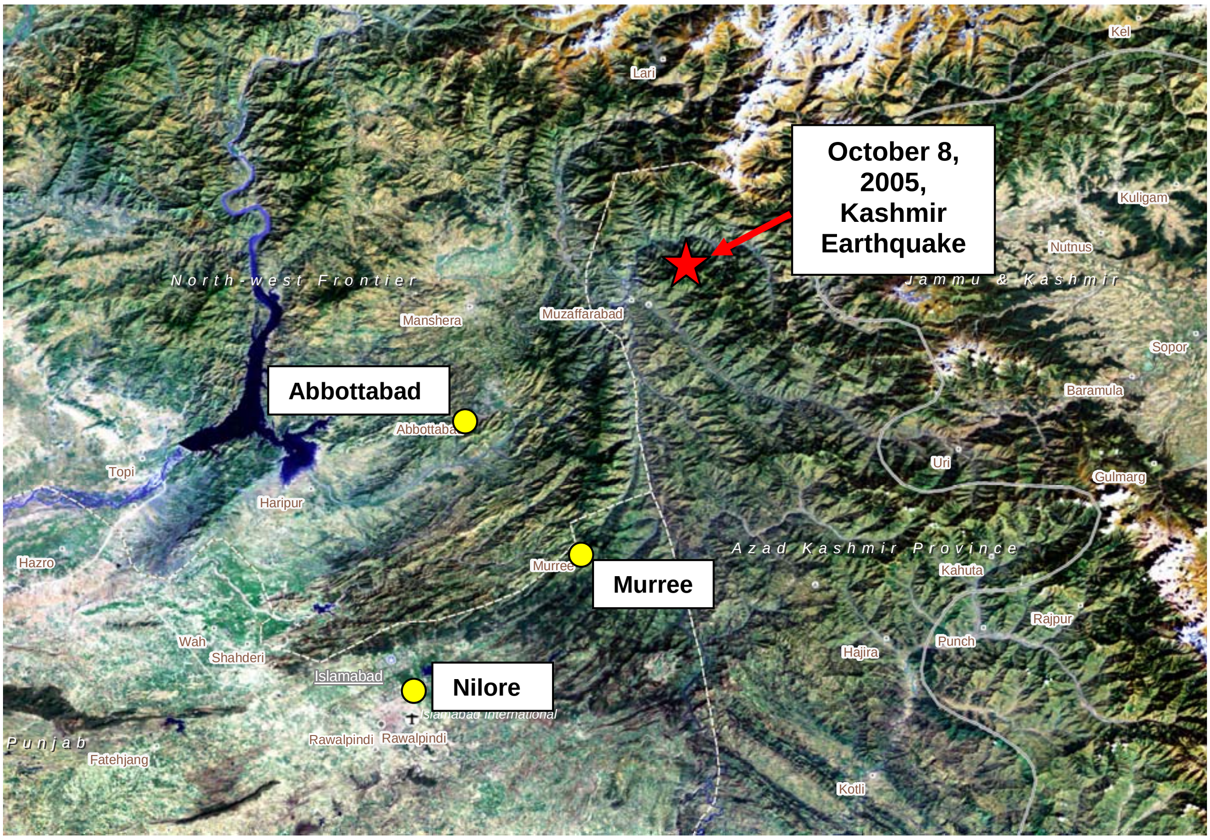


Figure 2.9: Location of the strong motion recordings from the 2005 Kashmir Earthquake

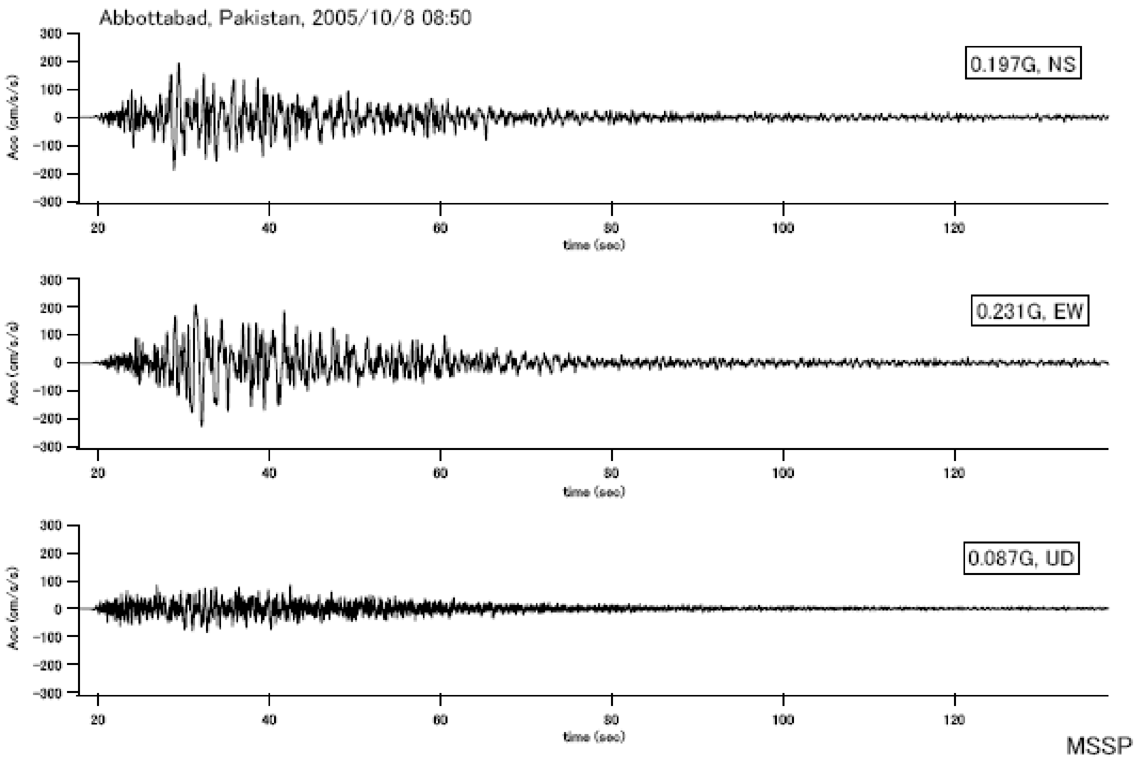
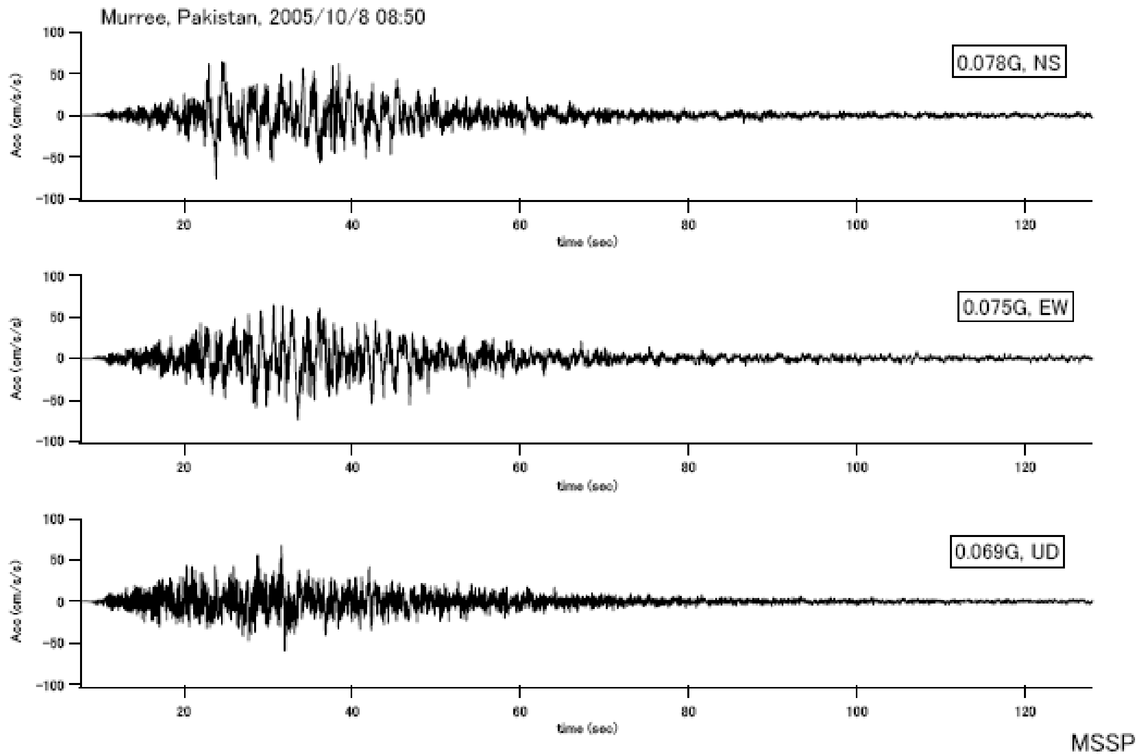


Figure 2.10: Strong motion records at Abbottabad, Murree and Nilore from the Kashmir Earthquake (Chaudury, 2006), contd. next page.


Murree, Pakistan, 2005/10/8 08:50
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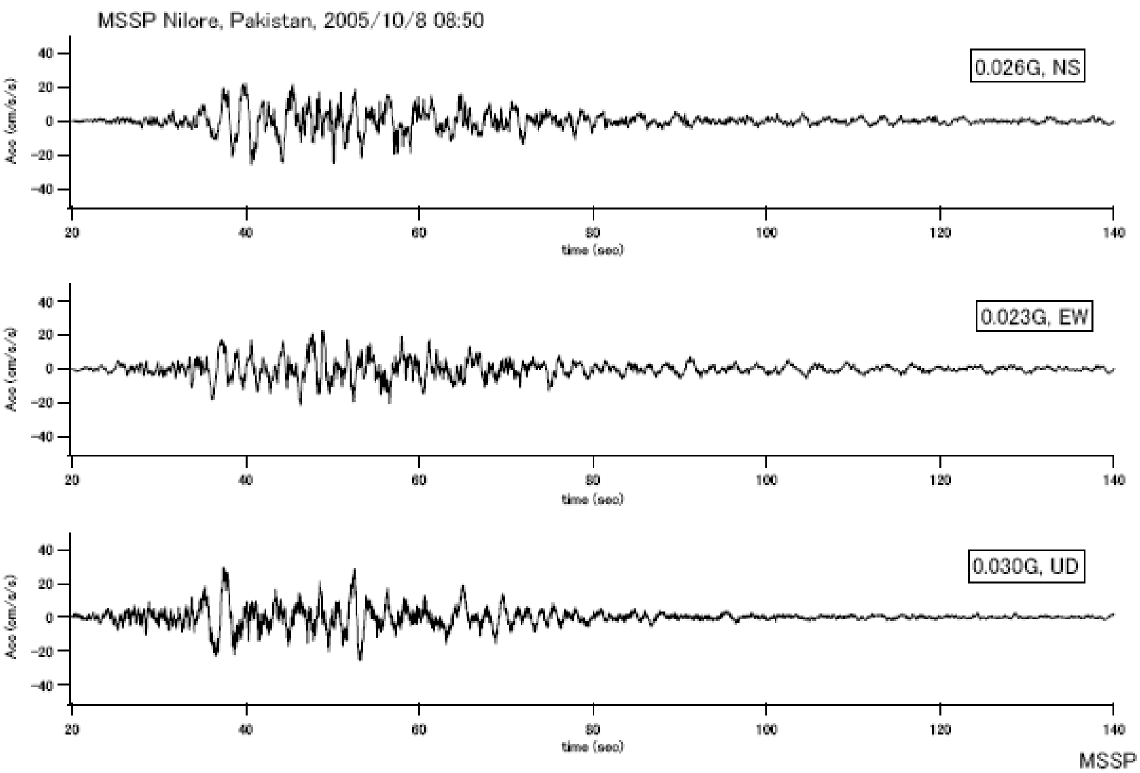
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0.023G, EW
0.030G, UD
Acc (cm/s/s)
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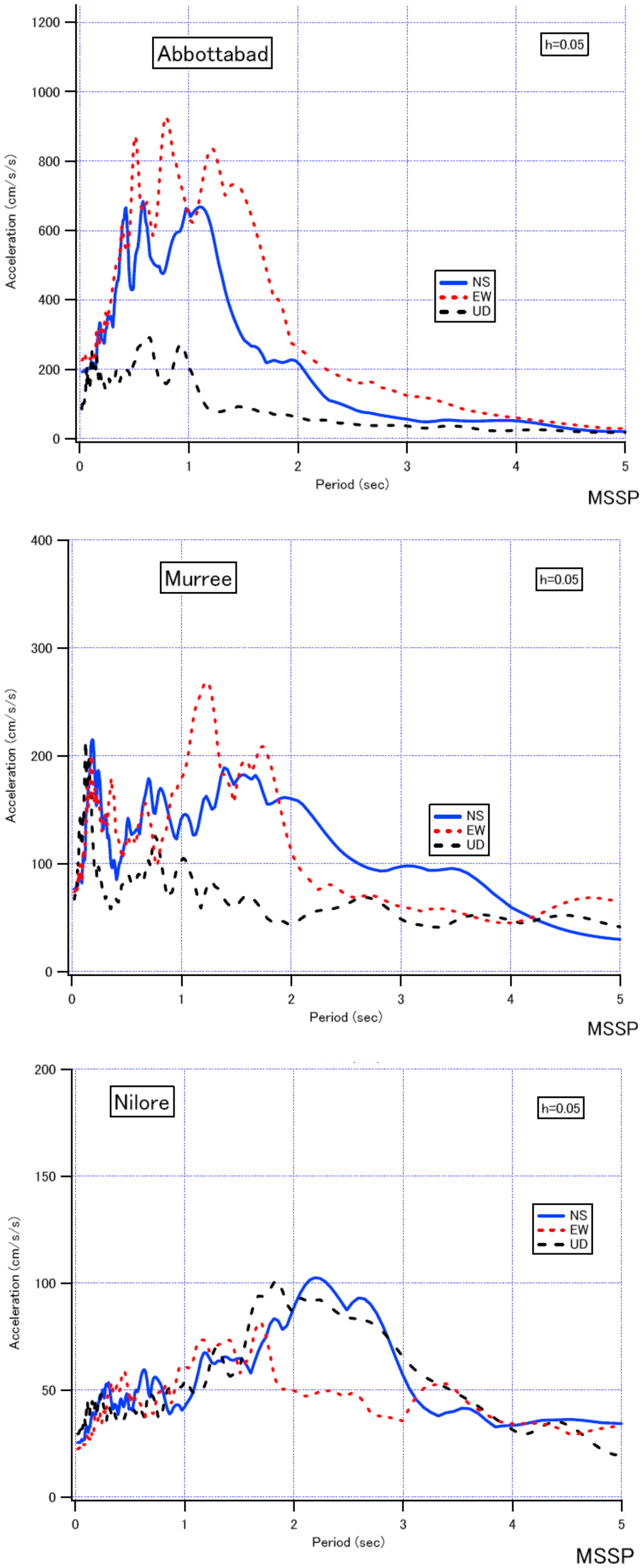


Figure 2.11: Response spectra of ground motions (5% damped, elastic) recorded at Abbottabad, Murree and Nilore (Chaudury, 2006)

Strong motion recordings obtained as accelerogram records during the Kashmir earthquake are few. EERI (2006) report some further data and report it slightly differently. They note instrumental observations of horizontal PGA as: Abbotabad, 35 km from rupture zone, 0.231g (227 cm s^{-2}); Murree, 34 km, 0.078g (77 cm s^{-2}); Nilore, 54 km, 0.026g (26 cm s^{-2}); base of Tarbela Dam, ~78 km, 0.1g (98 cm s^{-2}); downstream toe Mangla Dam, ~90 km, 0.1g (98 cm s^{-2}), thus identifying two additional recordings. The differences in distances noted in Table 2.1 and by EERI (2006) reflect the usual difficulties concerning definition of distance in strong motion seismology, in this case distance to the epicentre or distance to the rupture zone.

The ground motion of 0.231g in Abbotabad is quite significant in that this is an area that experienced substantial damage (see Chapter 3). Figure 2.11 shows the elastic, 5% damped response spectra for the recorded ground motions. The response spectra at Abbotabad show higher spectral accelerations over about 0.4 s to 1.5 s spectral period range. This indicates a higher elastic demand for low to intermediate rise structures.

2.4 Seismic Hazard Analysis and Zoning in the Region and in Pakistan

Following the October 8, 2005 Kashmir earthquake, there was wide recognition among the Pakistan authorities that the seismic hazard of the affected region and the country as a whole should be assessed in order to implement mitigation measures in areas that are vulnerable and of high seismic risk. The Geophysical Centre Quetta, Met Department of Pakistan had produced a seismic zoning map for Pakistan (see Figure 2.12), which could be considered the most reliable zoning map, given that the Geophysical Centre has a good network of seismometers and is responsible for collecting and disseminating earthquake hazard information (Ali and Khan, 2004). According to this map, the North-West Frontier Province (NWFP) and the Pakistan administered Kashmir (AJK) are in Zone II representing an expectation of moderate damage and peak ground accelerations (PGA) ranging from 0.07g to 0.1g. There is however no assignment of a return period to this zoning map. Following the October 8, 2005 Kashmir earthquake, the Geological Survey of Pakistan (http://www.gsp.gov.pk/earth_quake_update.html) published a revised zoning map shown in Figure 2.13.

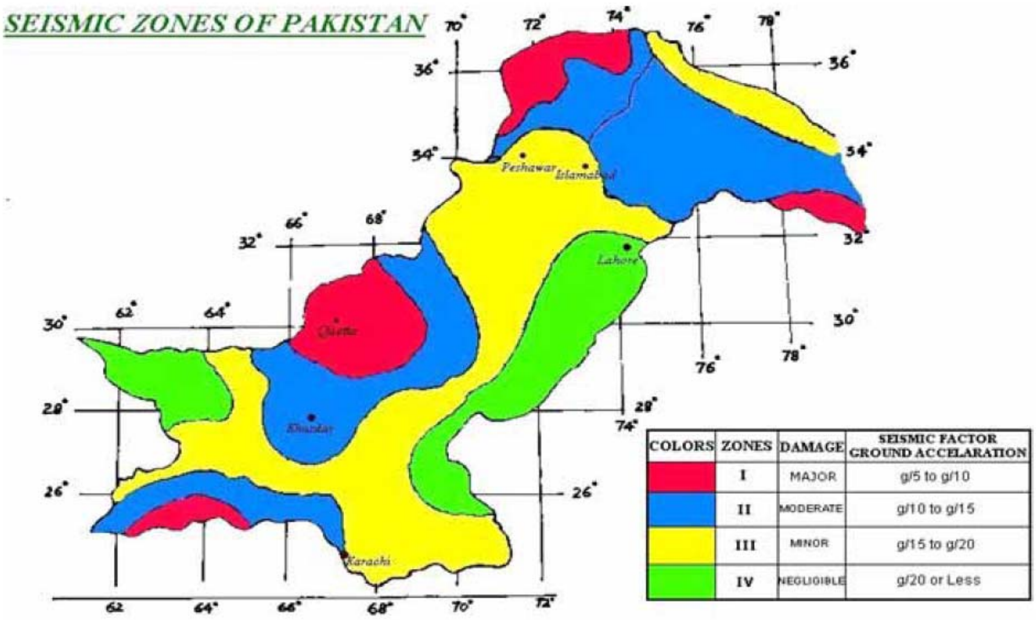


Figure 2.12: Seismic zoning map of Pakistan issued by the Geophysical Centre Quetta, Met Department of Pakistan (extracted from Ali and Khan, 2004)

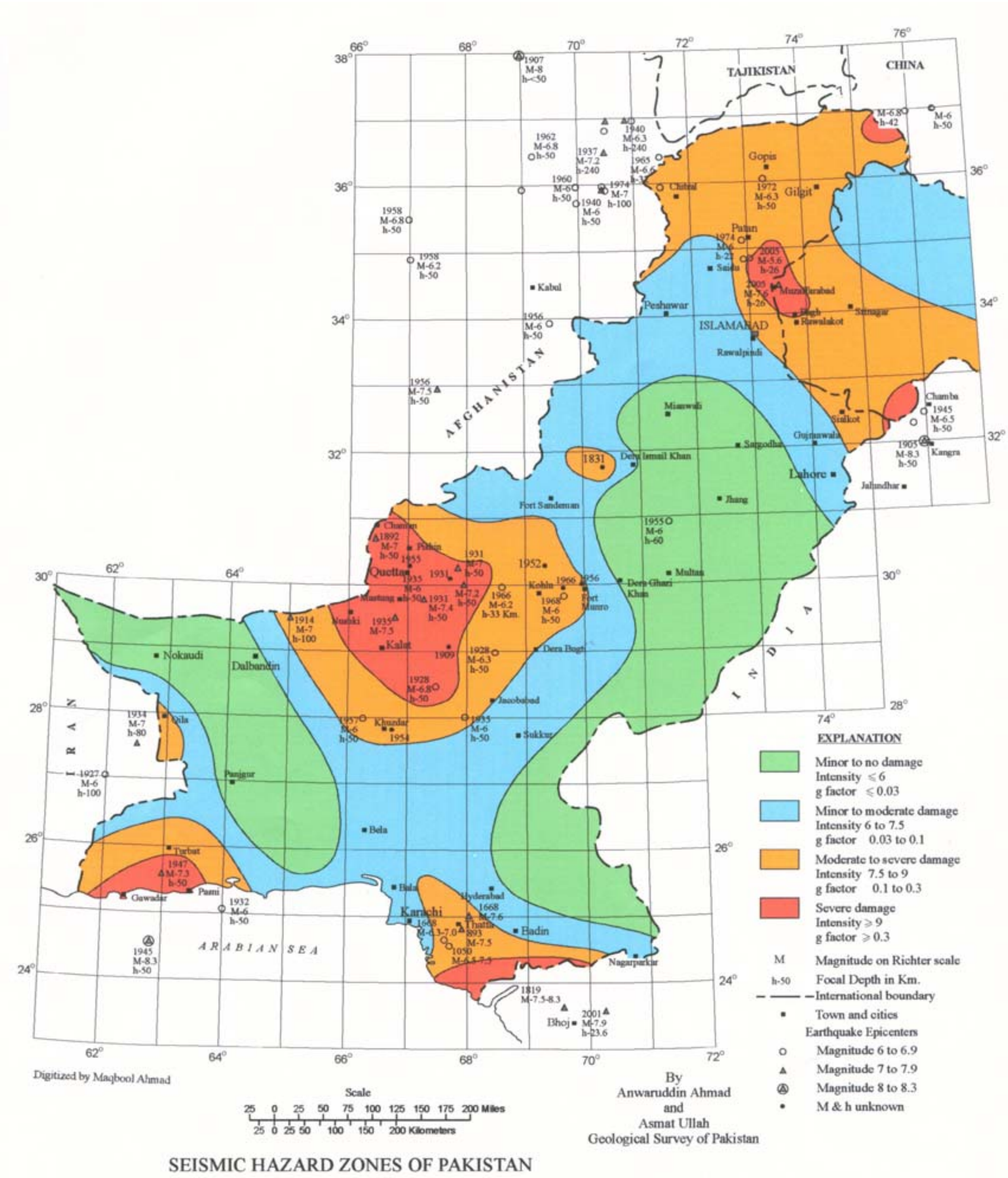


Figure 2.13: Seismic hazard zoning map of Pakistan issued by Geological Survey of Pakistan (after Ahmed et al., 2006)

This map places regions of Bagh, Muzaffarabad and Balakot in a zone with expectation of "Severe Damage" at Intensity IX or greater with a PGA of 0.3g or greater. There is also some modification to zoning boundaries and zones in other areas of Pakistan. However, no explanation is given as to the methodologies followed and the reasons for the revisions. Comparing Figures 2.12 and 2.13 may suggest that this revision was done to reflect the recent impact from the October 8, 2005 Kashmir earthquake and thus to maintain compatibility with known experience as input to future potential recurrence – it thus attempts to provide a map of historically known highest intensity impacts (from earthquakes of assessed magnitude indicated within the map) with commensurate g factors (or PGA values). It was developed "on the simple premise that the ground motion of a certain intensity experienced once in a certain place is likely to be experienced again" and thus believed appropriate for the design of ordinary structures. A next step would be to progress to probabilistic seismic hazard assessment (PSHA) in terms of strong ground shaking (intensity, PGA etc.) and magnitude recurrence (see later). Part of the EEFIT effort addressed PSHA in North Pakistan (Burton and Cole, 2006) recognising the need to review and reconsider such PSHA issues since the Global Seismic Hazard Assessment Program (GSHAP, Giardini, 1999) incorporated the analysis of Zhang et al. (1999) for continental Asia into the final GSHAP map.

The British Geological Survey (BGS) supplied an earthquake catalogue including data on over 3,000 earthquakes; the region spanned is of 10° latitude by 10° longitude centred approximately on the Kashmir 2005 epicentre. An important yet difficult issue addressed by Burton and Cole (2006) is the selection of a PGA attenuation law to use in the PSHA analysis as there are very few laws that appear to be directly pertinent to the Himalaya in general. The attenuation law of Sharma (1998) was derived from a dataset of 66 horizontal PGAs from five earthquakes in India, Singh et al. (1996) used data from earthquakes in Northern India and there is also the law adopted by Zhang et al. (1999) in GSHAP. More discussion on catalogue homogenisation and these attenuation laws is provided in Burton and Cole (2006) in which Sharma's law is preferred; it uses M_S rather than m_b and avoids measuring distances from projected fault ruptures at the surface.

The results obtained using Sharma's attenuation law and then mapped for the whole region are illustrated in Figure 2.14 which can be compared with the extract from the GSHAP map of Figure 2.15. The analysis, for which the map of Figure 2.14 is the contoured illustration, first estimates point values of PGA at a site centred in a 5° cell, with a 0.5° moving cell strategy to create a matrix of many points on which the PGA hazard is estimated and then the matrix of hazard values can be contoured. The analysis uses extreme values based on development of the HAZAN programme most recently applied and described in Burton et al. (2004). This strategy and analysis results in the seismic hazard map of Figure 2.14. These mapped values are for PGA in units of cm s^{-2} with 90% probability of non-exceedance in 50 years or a one-in-ten chance of being exceeded. Ahmed et al. (2006) in their figures 1 and 2 (their figure 2 is Figure 2.13 herein with slight modification to the legend) have provided maps of the "Maximum Intensity Isoseismals of Pakistan" and of "Seismic Hazard Zones of Pakistan" - these maps indicate isoseismals extending to intensity X on the Modified Mercalli Scale (MM) near Muzaffarabad and a red zone 4 described as "Severe damage g factor ≥0.3". The GSHAP work of Zhang et al. (1999) suggests that the collision zone of India with Asia is mainly subject to PGA ≥ 240 cm s^{-2} with Muzaffarabad appearing to fall in their 160-240 cm s^{-2} zone. The analysis summarized by contour map Figure 2.13 using Sharma's attenuation law indicates slightly lower values than these at about 150+ cm s^{-2} in the Muzaffarabad meizoseismal area. Difficulties of magnitude scale conversions and attenuation law selection deserve ongoing investigation. An additional difficulty for the larger earthquakes in this region is estimation of focal depth, estimates for the Kashmir 2005 earthquake spanned 13-26 km although the latter was adopted. Adopting the shallower focal depth 13 km into a deterministic estimate gives an increase in PGA of ~25 cm s^{-2} over that for 26 km focal depth at 20 km from the epicentre.

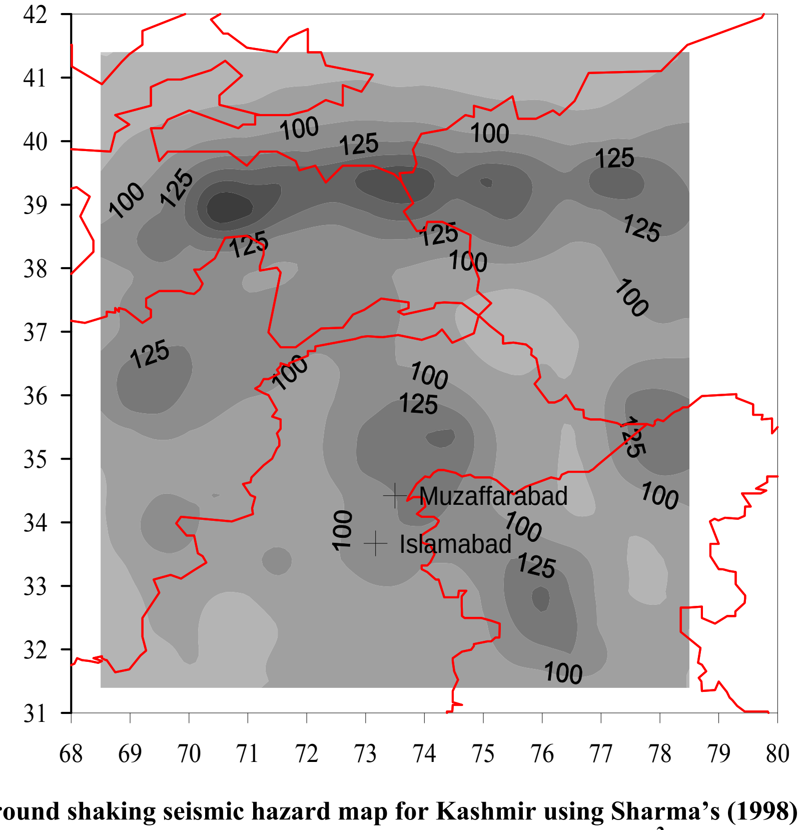


Figure 2.14: Ground shaking seismic hazard map for Kashmir using Sharma's (1998) attenuation law. The contours are expected maximum peak ground accelerations in cm s^{-2} with a one-in-ten chance of being exceeded during 50-years (extracted from Burton and Cole, 2006)

A probabilistic seismic hazard assessment carried out by MonaLisa et al. (2005) for the Northwest Himalayan Fold and Thrust Belt of Pakistan uses an earthquake catalogue compiled from catalogue data held at Imperial College, London (N.N. Ambraseys) and from events recorded by the PAEC. This study considers four seismic zones based on the tectonics, geology and the seismicity in the study region and attenuation relationships by Ambraseys et al. (1996) and Boore et al. (1997) since there are no precisely matched regional specific attenuation relationships available. This seismic hazard assessment was carried out using EZ-FRISK produced PGA values stated for "475 year return period", equivalent to the 90% probability of non-exceedance in 50 years statistic adopted above. Calculations were made for ten sites which include Islamabad and Muzaffarabad. The largest value derived from the two attenuation relationships applied to Muzaffarabad is 0.13g and for Islamabad is 0.15g. In this study of MonaLisa et al. Islamabad thus has a slightly higher PGA than Muzaffarabad for a 475 year return period whereas Burton and Cole (2006) find, with 90% probability of non-exceedance in 50 years, an identical statistic, a value of ~113 cm s^{-2} or 0.12g cm s^{-2} at Islamabad and 125 cm s^{-2} or 0.13g at Muzaffarabad with about 150 cm s^{-2} or ~0.15g in the epicentral zone.

Although these two studies use non-identical earthquake catalogue sources, different attenuation laws and quite distinct methodologies to assess probabilistic seismic hazard, they lead to a similarity of result. It should be noted that the authors in both studies do state that the results should be treated with caution, or as preliminary. It should also be noted that these PGA results are a substantial deviation from those recommended in Figure 2.13 by the Geological Survey of Pakistan in the region affected by the Kashmir 2005 earthquake.

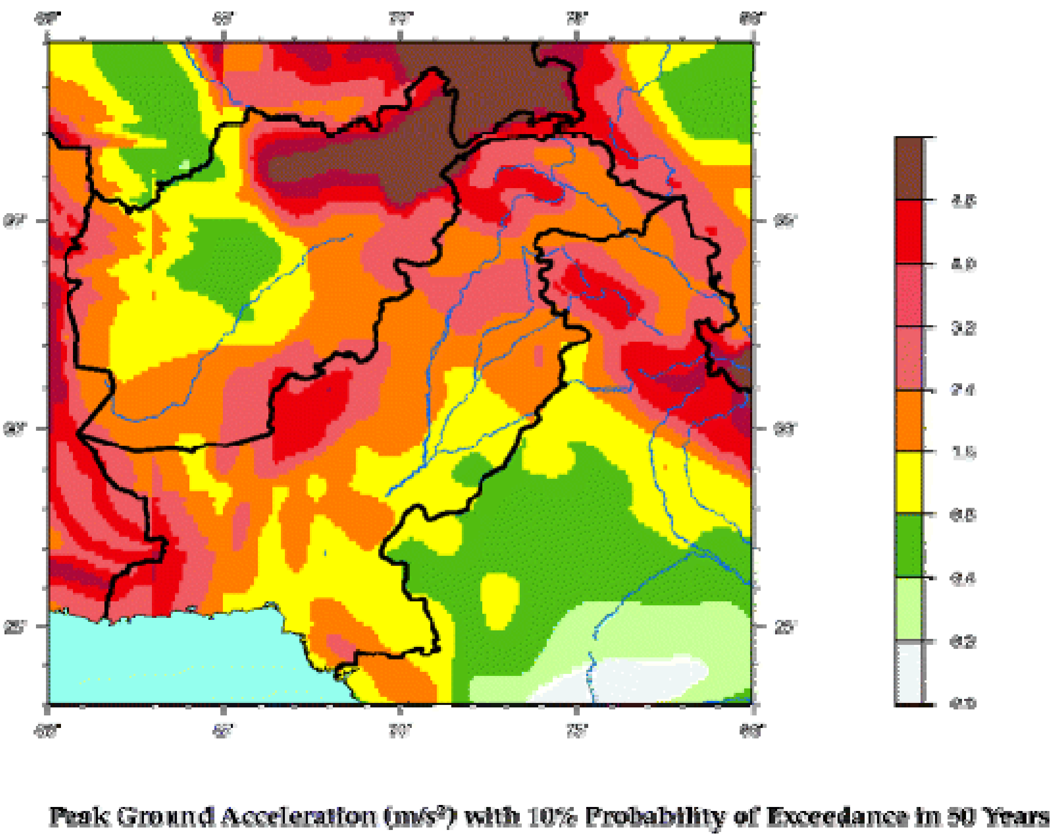


Figure 2.15: GSHAP map for Pakistan and the bordering regions (extracted from USGS and based on Zhang et al., 1999)

A deterministic seismic hazard assessment in MonaLisa et al. (2005) also provides parameters for the same ten sites as in the probabilistic study. This deterministic analysis relies on calculation of maximum potential earthquakes associated with specific tectonic features and the results for four cities are listed in Table 2.2.

Table 2.2: Results of deterministic seismic hazard assessment (MonaLisa et al., 2005)

Site	Tectonic feature*	Closest distance to faults (km)	Maximum potential magnitude (M_w)	PGA (g), 50-percentile	PGA (g) 84-percentile
Muzaffarabad	MBT	0.0	7.8	0.47	0.79
Peshawar	Khairabad Fault	12.0	7.5	0.38	0.64
Kaghan	MMT	12.0	7.8	0.27	0.46
Islamabad	MBT	4.0	7.8	0.44	0.75

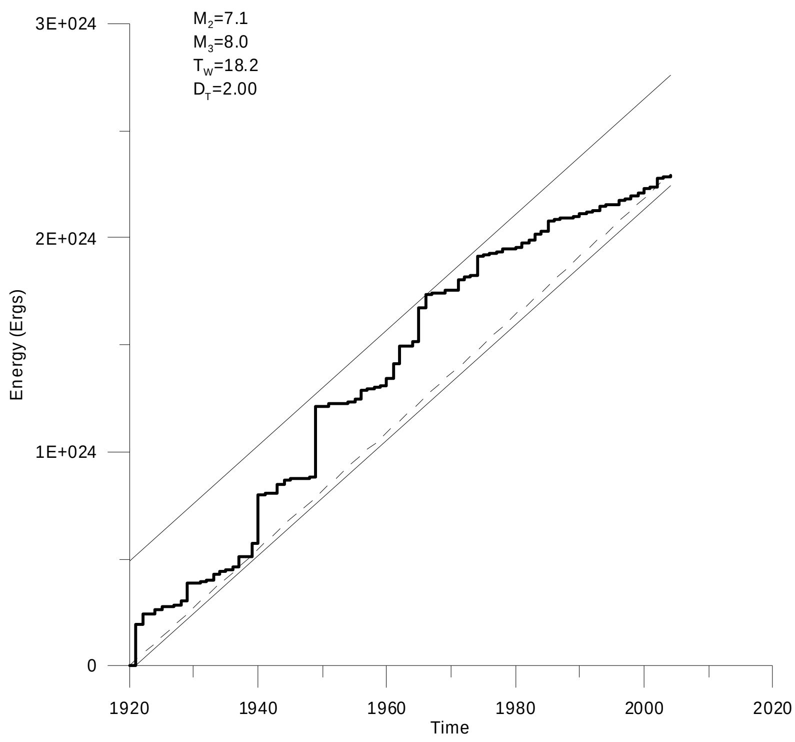
**See Figure 2.2 for details*

On this deterministic model the PGA predicted at Muzaffarabad is now slightly higher but comparable to Islamabad. There are no strong motion recordings from the earthquake in Muzaffarabad or its vicinity to compare (see sub-section 2.3.2). However, back calculations based on best estimate ground motion attenuation relationships matching to ground motions recorded in Abbottabad, Murree and Nilore suggest a PGA of 0.7g and 0.9g for stiff and soil site respectively (Durrani et al., 2005). This is close to the 84-percentile value of 0.79g in Table 2.2.

These analyses also raise other questions. For instance, was the October 8, 2005 earthquake the maximum potential magnitude earthquake to affect the region near Muzaffarabad? Do we know sufficient about earthquake recurrence rates in Pakistan?

The Burton and Cole (2006) analysis also addresses these questions - coseismic strain energy and seismic moment release rates have been much used to characterise seismicity in different regions and explore such questions. Cumulative coseismic strain energy release (CSER) diagrams illustrate the potential for maximum potential earthquake in a straightforward graphical way (e.g. see Makropoulos and Burton, 1984). On this model a maximum credible earthquake is defined if all energy throughout an earthquake cycle were to be released in one single earthquake; it would be of magnitude equivalent to the energy gap between lower and upper enveloping lines in Figure 2.16. There would be a waiting time between such maximum credible events corresponding to the horizontal time gap between the same enveloping lines. Figures 2.16a-b provide CSER diagrams for the region as a whole around the Kashmir 2005 epicentre prior to the earthquake, and then for the region as a whole after the earthquake had occurred. Figure 2.16a is compatible with a regional storage of strain energy i.e. the tip of the staircase graph is close to the lower enveloping line and distant from the upper enveloping line, implying energy available for release. After the earthquake when the energy of Kashmir 2005 is included then Figure 2.16b results: the tip of the staircase has move upwards towards the upper enveloping line, but there is still an energy gap that could be released. Bilham and Ambraseys (2005) have for some time suggested recognition of a CSER deficit in the Himalaya thrust belt as a whole. Figure 2.16a is in agreement suggesting that energy was available for release; Figure 2.16b suggests that a regional earthquake might have been even larger than occurred. The maximum potential earthquake indicated by these CSER graphs is a magnitude 8.0 with this estimate being unaffected by inclusion or exclusion of the recent Kashmir 2005 earthquake, both Figures 2.16a and b return the same value. The values in Table 2.2 for Muzaffarabad and Islamabad are controlled by the MBT to which MonaLisa et al. (2005) have associated maximum potential at magnitude 7.8, close to results from the CSER analysis – these values are both slightly higher than the recent earthquake.

a)



b)

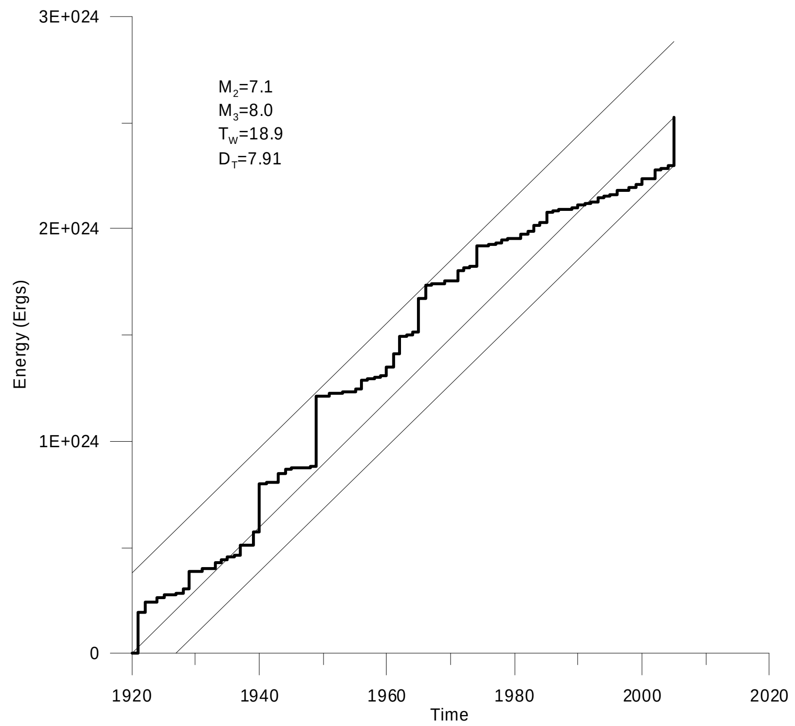


Figure 2.16: Cumulative Strain Energy Release (CSER) for non-probabilistic modelling of seismicity and estimation of maximum credible earthquake in a region. The region occupies 10° of latitude and longitude centred on the Kashmir 2005 earthquake epicentre: a) excludes the Kashmir earthquake and b) includes the Kashmir earthquake as the last step in the energy release staircase (after Burton and Cole, 2006)

2.5 Conclusions

The Zhang et al. (1999) component of the Global Seismic Hazard Assessment Program (GSHAP) places Islamabad and Muzaffarabad in zones bordering PGA varying from 160-240 cm s^{-2} and 240-320 cm s^{-2} for 10% probability of exceedance in 50 years (475 year return period). Figure 2.15 shows the GSHAP map for Pakistan and the bordering regions. The GSHAP study is a probabilistic seismic hazard assessment following the methodology of Cornell similar to the study of MonaLisa et al. (2005), however, the ensuing PGA values differ substantially between these two studies for the same return period. Burton and Cole (2006) apply a different methodology and use different strong motion attenuation laws and ensuing results are similar to those of MonaLisa et al. (2005). There are fundamental issues in seismology and engineering seismology in Pakistan that require further study: earthquake catalogue homogenisation and magnitude conversion scales, choice of suitable regional strong motion attenuation laws, focal depths of damaging earthquakes – all of these issues contribute to epistemic uncertainties that have not been investigated fully in any of these studies.

The non-probabilistic modelling of maximum potential magnitudes by Burton and Cole (2006) based on a Cumulative Strain Energy Release model of seismicity, and deterministic modelling of maximum potential magnitudes by MonaLisa et al. (2006) based on tectonic fault data, both suggest that a regional earthquake could have been slightly larger than the Kashmir earthquake that transpired in 2005. Bilham (2005) and Bilham and Ambraseys (2005) had previously noted that the region has a potential for recurrence of large magnitude earthquakes (8.0 M_w or greater) along the Himalayan Arc as a whole and Figure 2.16 concurs with this in the region of the Kashmir 2005 earthquake. This and the variation in the estimated seismic hazard level to be used for engineering and risk mitigation to date, suggests that there is a strong need to pursue a detailed seismic hazard assessment of the affected region as well as in Pakistan as a whole as a matter of priority – the concurrence between results of Burton and Cole (2006) and MonaLisa et al. (2005) who apply different methodologies to these same questions is encouraging of a consensual outcome.

2.6 References

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3 Buildings

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The October 8, 2005 Kashmir Earthquake destroyed over 270,000 buildings and partially damaged about 180,000 buildings in the affected districts of North West Frontier Province (NWFP) and the Pakistan administered Kashmir (AJK). A number of building types ranging from masonry to reinforced concrete structures exists that have a variety of occupancies. This chapter presents the building typologies in the earthquake affected region and discusses the observations from the building damage surveys using a pre-defined damage scale. The performance of the buildings is discussed in order to identify the building vulnerabilities.

3.1 Building Typologies

The building typology in the earthquake affected region could be broadly divided into four categories as encountered during the field mission supplemented by those presented in other sources. These structure types exist for a variety of occupancies, i.e. residential, commercial (including retail), government administration, educational institutions etc. The building typology divisions reflect the different construction practices adopted (engineered and non-engineered) and the observed vulnerability to the Kashmir earthquake. The building typologies are discussed below.

3.1.1 Unreinforced Stone Masonry Buildings

These buildings consist of walls made of stone (mostly rounded) irregularly laid in a cement, sand mud mortar or in some cases dry stacked. The roof is either a flat thatch/mud roof supported on wood beams or irregularly placed corrugated galvanized iron (GI) sheets. Figure 3.1 shows a typical unreinforced stone masonry building used for residential purpose. These types of houses locally known as “Katcha” or non-permanent houses are very common in rural or village areas rather than in the cities. Stone masonry buildings used for government or official buildings have stones that are cut and laid regularly using cement sand and mud mixtures with lintel beams above openings. Figure 3.2 shows the cracked walls of a government agricultural research office building north of Mansehra.

3.1.2 Unreinforced Concrete Block Masonry Buildings

These buildings typically consist of 6.0in. (150mm) thick walls made of concrete blocks (6.0in. thick, 6.0in. wide and 12.0in. long) laid in cement and sand mortar. The roof is made of corrugated GI sheets supported on a timber truss or flat reinforced concrete slab. Figure 3.3 shows an example of a damaged concrete block masonry building south of Balakot used as an office. This type of construction is widely used in city areas for both residential and commercial/retail buildings and less common in the rural or village areas. Some 2-storey buildings of this type exist. These use reinforced concrete slabs for the first storey floors and roof, which are supported by the concrete block masonry walls without RC columns. Figure 3.4 shows a damaged 2-storey concrete block masonry building used by the Sectretariat of Agriculture in Muzaffarabad.

Figure 3.1: Typical unreinforced stone masonry wall house (Katcha house)

Figure 3.2: Typical unreinforced stone masonry government or official building

Figure 3.3: Damaged unreinforced concrete block masonry office building south of Balakot

Figure 3.4: Damaged 2-storey concrete block masonry building in Muzaffarabad

Figure 3.5: Collapsed unreinforced brick masonry house in Balakot

Figure 3.6: Unreinforced brick masonry government building in Muzaffarabad

Figure 3.7: Moderately damaged commercial/retail building of RC frame and slab construction with brick masonry infill in Abbotabad

Figure 3.8: Multi-storey RC building under construction adjacent to an existing office building in Muzaffarabad

3.1.3 Unreinforced Brick Masonry Buildings

Unreinforced brick masonry is mostly used for commercial/retail and government buildings in city areas. Very few are used for residential purposes since the unit cost of brick is higher than other forms of masonry. The residential buildings are knows as "Pucca" or permanent houses. The roof of these structures is either made of light-weight pitched wood truss covered with corrugated GI sheets or of flat reinforced concrete (RC) slabs. Figure 3.5 shows a collapsed unreinforced brick masonry house in Balakot. Some brick masonry buildings are two storeys high with a RC slab roof. Figure 3.6 shows a government building (Muzaffarabad tourist information office) built using fired brick masonry walls with rendering.

3.1.4 Reinforced Concrete Framed Buildings

Reinforced Concrete (RC) construction is primarily used for commercial and retail buildings. The configuration consists of an RC frame with masonry infill. Figure 3.7 shows a typical RC frame commercial building, which was moderately damaged during the earthquake. Multi-storey RC structures have a composite RC frame and slab structure which extends to the roof level often used for housing services such as water tanks, air conditioning units etc. Figure 3.8 shows a multi-storey building in Muzaffarabad under construction adjacent to an existing multi-storey building used for office and retail.

3.2 Building Damage Scale

Table 3.1 shows the damage scale used to categorize damage observed in the building survey. This damage scale was based on that used in HAZUS-MH earthquake model (FEMA 2006).

Table 3.1: Building damage scale (FEMA 2006)

Damage Level	Damage Description	
	Unreinforced Masonry (URM)*	RC Construction
Slight Damage	Diagonal, stair-step hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with large proportion of openings; movements of lintels; cracks at the base of parapets	Diagonal (sometimes horizontal) hairline cracks on most infill walls; cracks at frame-infill interfaces.
Moderate Damage	Most wall surfaces exhibit diagonal cracks; some of the walls exhibit larger diagonal cracks; masonry walls may have visible separation from diaphragms; significant cracking of parapets; some masonry may fall from walls or parapets	Most infill wall surfaces exhibit larger diagonal or horizontal cracks; some walls exhibit crushing of brick around beam-column connections. Diagonal shear cracks may be observed in concrete beams or columns.
Extensive Damage	In buildings with relatively large area of wall openings most walls have suffered extensive cracking. Some parapets and gable end walls have fallen. Beams or trusses may have moved relative to their supports.	Most infill walls exhibit large cracks; some bricks may dislodge and fall; some infill walls may bulge out-of-plane; few walls may fall partially or fully; few concrete columns or beams may fail in shear resulting in partial collapse. Structure may exhibit permanent lateral deformation.
Collapse	Structure has collapsed or is in imminent danger of collapse due to in-plane or out-of-plane failure of the walls.	Structure has collapsed or is in imminent danger of collapse due to a combination of total failure of the infill walls and non-ductile failure of the concrete beams and columns.

**URM abbreviation is used to describe all types of unreinforced masonry buildings in this report*

The above URM damage scale was used to describe damage to all types of masonry structures even though the HAZUS descriptions are intended for brick masonry structures in the US. The variation from the damage descriptions given exists primarily in unreinforced stone masonry buildings where some dry stacked buildings may not show any visible cracking in the slight and moderate damage levels. While the damage scale in Table 3.1 is used to describe damage to individual buildings, a separate damage scale has been used to describe the extent of building damage over a spatial region using satellite images. This damage scale is summarized below;

- Extensive (E) – More than 70% of buildings have collapsed or heavily damaged by visual inspection of the satellite image

- Moderate (M) – Between 30% and 70% of buildings have collapsed or heavily damaged by visual inspection

- Slight (S) – Less than 30% buildings have collapsed or heavily damaged by visual inspection

The above damage scale relies on visual identification of damage to buildings over a certain spatial region, i.e. grid cell. Hence it is a measure of the density of damage as well as the extent of building specific damage that could possibly be identified.

3.3 Building Damage Surveys in the Earthquake Affected Region

Building damage surveys were carried out on the ground supplemented by satellite images in the cities of Balakot, Muzaffarabad, Abbottabad, Islamabad and the small towns on route to these cities. Figure 3.9 shows the GPS waypoints of the survey locations plotted on a topographical map of northern Pakistan. The observations of building damage are discussed below.

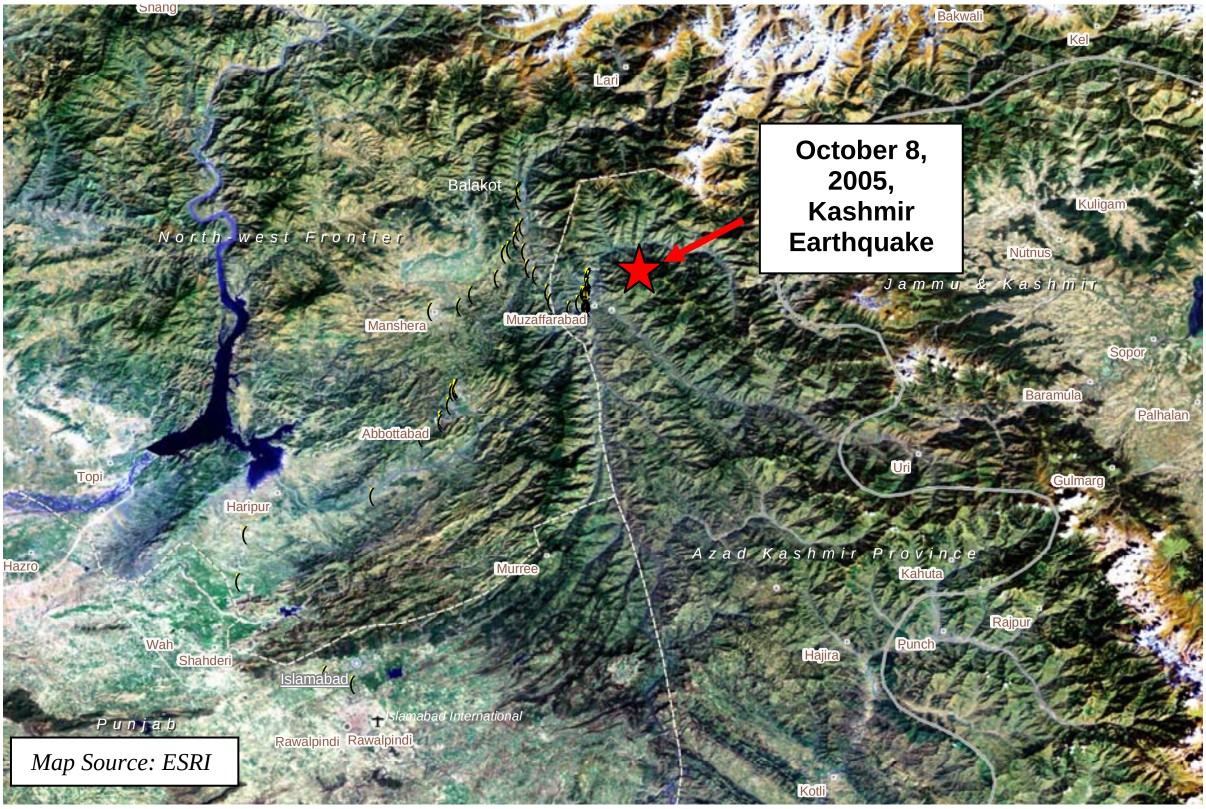

Figure 3.9: Locations of the EEFIT ground survey

3.3.1 Balakot

Balakot is one of the worst affected cities in NWFP with a population of about 80,000. The city is located at approximately 15km north-west of the epicentre, which was also in the zone of aftershocks (see Figure 2.4).

Figure 3.10 shows a satellite image of Balakot taken after the earthquake (Digital Globe, 2005), which was used to identify key locations of building damage. The city was divided into several zones and each zone was assigned a damage level (using the 3-level damage scale for satellite imagery described above) based on visual inspection of the satellite image, photos taken during the ground survey and those from close-up helicopter flights by the US Army (see Figures 3.11 to 3.18). The damage zoning indicates that Balakot largely experienced moderate to extensive damage with some areas experiencing slight damage. The extensive damage occurred in the residential areas of the city, particularly on the hill north-west of the city centre (zone 1) also shown in Figure 3.11. There was no indication of landslide activity in this zone hence the collapse of largely residential buildings may have been due to strong ground shaking, possibly amplified due to the ridge effect. The moderate and heavily damaged zones appear to follow a linear trend from north-west (zone 1) to east of Kunhar River (zone 10). This direction appears to be parallel to the inferred strike direction of the fault that ruptured causing the October 8 earthquake (see Figure 2.6).

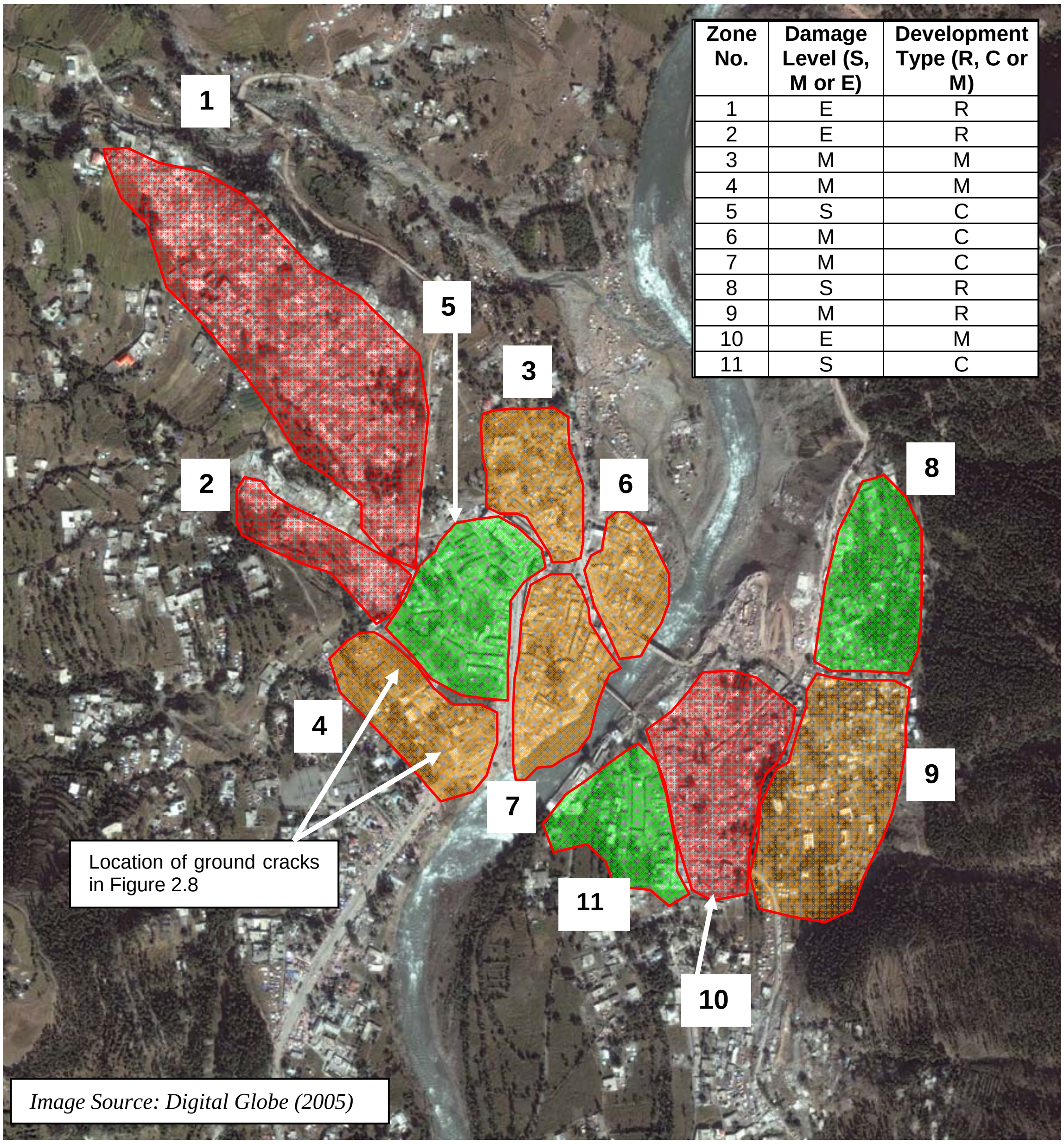

Figure 3.10: Selected damaged areas in Balakot city

Figure 3.11: Collapsed and extensively damaged concrete block URM residential units on a hill northwest of Balakot city centre (zone 1)

The residential buildings in Balakot were a mixture of unreinforced stone and concrete block masonry. The residential buildings in zone 1 were largely concrete block URM with RC slabs as roofs (or floors in the case of 2-storey buildings). Figures 3.11 and 3.12 show some of these collapsed or extensively damaged buildings on the hill (see Zone 1, Figure 3.10). The mode of damage appears to be the collapse of heavy RC roofs following the out-of-plane displacement/failure of the concrete block masonry bearing walls. Figure 3.13 shows a stone URM building, used by the government audit office, which sustained extensive damage due to out-of-plane failure of its walls. The adjoining building only suffered cracks to the stone masonry wall (Figure 3.14). This may be due to better use of mortar and the regularity of the stones. Figure 3.15 shows a concrete block URM residential building where the RC roof has collapsed as the concrete block walls failed during ground shaking. This mode of failure was commonly observed where the inertia of the heavy RC roofs could not be resisted by the masonry bearing walls. The roofs collapsed when the walls shear in-plane or collapse out-of-plane. Diaphragm action in these buildings is considered negligible as no evidence of ties between the walls and the roofs were found.

Figure 3.16 shows an aerial view of one of the commercial areas of Balakot city (zone 7 in Figure 3.10) that experienced moderate damage. The buildings were largely of RC construction and a mixture of single and multi-storey. Connection failure at the beam-column or slab-column joints was seen to be the main cause of collapse or permanent deformation in these buildings. Some buildings collapsed at upper floor levels. Figure 3.17 shows an example of single storey RC frame and slab commercial structure that collapsed due to beam-column connection failure. Some RC frames showed permanent deformation as in Figure 3.18, which also reveals the extent of the weakness of beam-column connections in the construction of RC buildings.

Figure 3.12: Collapsed and extensively damaged concrete block URM residential units in zone 1 overlooking Balakot city centre (photo by Kathrin Renner (Arup) and US Army)

Figure 3.13: Extensively damaged stone URM building with metal roof in Balakot, used by the local audit officer

Figure 3.14: Cracks through stone and mortar in a stone URM building adjacent to the extensively damaged stone building in Figure 3.5

Figure 3.15: Collapsed concrete block URM residential building in Balakot

Figure 3.16: Aerial view of the damaged Balakot city commercial area (photo by Kathrin Renner (Arup) and US Army)

Figure 3.17: Collapsed single storey RC frame and slab commercial/retail building in Balakot city centre

Figure 3.18: Deformed RC frame structure with rotation at the column/slab connection

3.3.2 Muzaffarabad

Muzaffarabad is the capital of Azad Jammu Kashmir or AJK (Pakistan administered Kashmir). The city is located at the confluence of the Jhelum and Nelum rivers and has a population of about 80,000 (Risepak, 2005). This city was observed to suffer heavy damage due to the earthquake due to its close proximity to the epicentre (only 10km south-west of the epicentre as shown in Figure 3.9). Figure 3.19 shows a satellite image of the central part of the city taken following the earthquake (UNOSAT, 2005). The satellite image was used to identify the damage areas and assign a damage level to each 250m by 250m grid cell. The damage scale used was that described in section 3.2 and the colour scheme is such that yellow represents moderate and red represents extensive damage to buildings within the grid cells (please note that blue coloured cells represent infrastructure damage). According to Figure 3.19, most of the city east of Nelum river was in a zone of moderate damage with some zones having severe damage. This is consistent with the observations from the EEFIT ground survey carried out at selected locations in the city. Most of the city is residential while commercial and government buildings are located adjacent to the major routes through the city. There is also a concentration of government buildings to the south of Jhelum river. The extent of damage ranged from slight to complete collapse across all types of occupancies.

Figure 3.20 shows an area of collapsed stone and concrete block URM residential buildings on a hill north of Muzaffarabad city centre. Similar buildings experienced only slight to moderate damage in other parts of the city, and it can be seen that the buildings at the foot of the slope have fared rather better. The higher level of damage may be attributed to the ridge causing a local amplification of the ground motion and possibly slope failure; there appears to be ground movement cracks in the lower part of the photograph. Similar patterns of building failurewere observed in Balakot (see sub-Section 3.3.1). Figure 3.21 to 3.23 show some of the typical damage observed in URM residential buildings. Shear cracks through walls indicate a lack of confinement of masonry bearing walls in these structures. Figure 3.24 shows an undamaged RC residential building where the load bearing structure is an RC frame with concrete block masonry infill walls.

Figures 3.25 to 3.29 show typical damage observed among 2-3 storey commercial structures. Figure 3.25 shows an example of a collapsed RC roof caused by weak beam-column connections at the upper floor. However, the ground floor has survived with moderate damage, possibly due to shear resistance from the combined RC frame and concrete masonry infill. Where RC frames do not provide the load bearing system, the buildings suffered extensive damage to total collapse. Figure 3.26 shows a collapsed 2-storey commercial building where the RC slabs and the roof were supported by concrete masonry URM bearing walls. An example of where an RC frame system helped reduce building damage is shown in Figure 3.27, where the commercial building suffered moderate damage with visible large shear cracks in the masonry infill walls. Figure 3.28 shows an example good confinement of the masonry infill walls where the RC lintel beam is continuous over the perimeter of the structure. This has resulted in no visible damage to the bearing walls or the frame of the commercial building. Figure 3.29 shows a collapsed RC frame under construction in a 3-storey commercial building. The beam/column connections were inadequately detailed and of the structure did not act like a moment-resisting frame in the absence of infill walls at the time of the earthquake. An example of typical beam-column connection detailing is shown in Figure 3.30, where no continuity of the reinforcement between the beam and column can be observed. Poor detailing of this kind were visible in many damaged RC frames. Figure 3.31 shows another example of poor reinforcement detailing where splicing of the bars was carried out at the beam-column connection. The shear link configuration is also inadequate for seismic shear forces. Figure 3.32 to 3.34 shows the range of damage observed among commercial buildings of more than 3-storeys. The collapsed section of the Sangam Hotel was due to the failure of the beam-column connections. It is unclear whether the collapsed section had a soft-storey ground floor. The adjacent building sections had masonry infill walls at the ground floor level. Most multi-storey RC structures survived with slight to moderate damage.

Figures 3.35 to 3.40 show damage to some of the government buildings in Muzaffarabad. The Muzaffarabad Supreme Court building was built using brick masonry with an RC roof structure. Both diagonal and horizontal cracks were observed at numerous locations (Figures 3.35 and 3.36). The building however was functional and its ground floor was used as a makeshift hospital by the Turkish Red Crescent. Figure 3.37 shows an example of diagonal shear cracks through brick URM walls in the Muzaffarabad Tourist Information Office. Shear cracks were also visible inside and outside of the State Bank of Pakistan Building (Figure 3.38) where the walls were brick URM. Despite the damage, both buildings were fully functional at the time of the survey. The 3-storey concrete block URM building of the AJK Secretariat of Agriculture suffered extensive damage (Figure 3.39). A wall section in the ground floor collapsed and the RC roof slab collapsed onto the 1st floor. There is no visible sign of an RC frame present, hence the RC roof and floor slabs are supported by concrete block URM walls.

Many of the educational institutions in Muzaffarabad suffered extensive damage or collapse. Figure 3.40 and 3.41 show examples of damaged schools where large sections of the buildings have collapsed. Both of the collapsed structures had RC floors and roofs supported by concrete block URM bearing walls. The cause of the collapse appears to be the failure of the bearing walls. Teaching sessions were being conducted on the school grounds in makeshift buildings at the time of the survey. Most of the buildings in the University of AJK had collapsed as shown in Figure 3.42. It should be noted that the many of the school buildings including those presented here were built by the government.

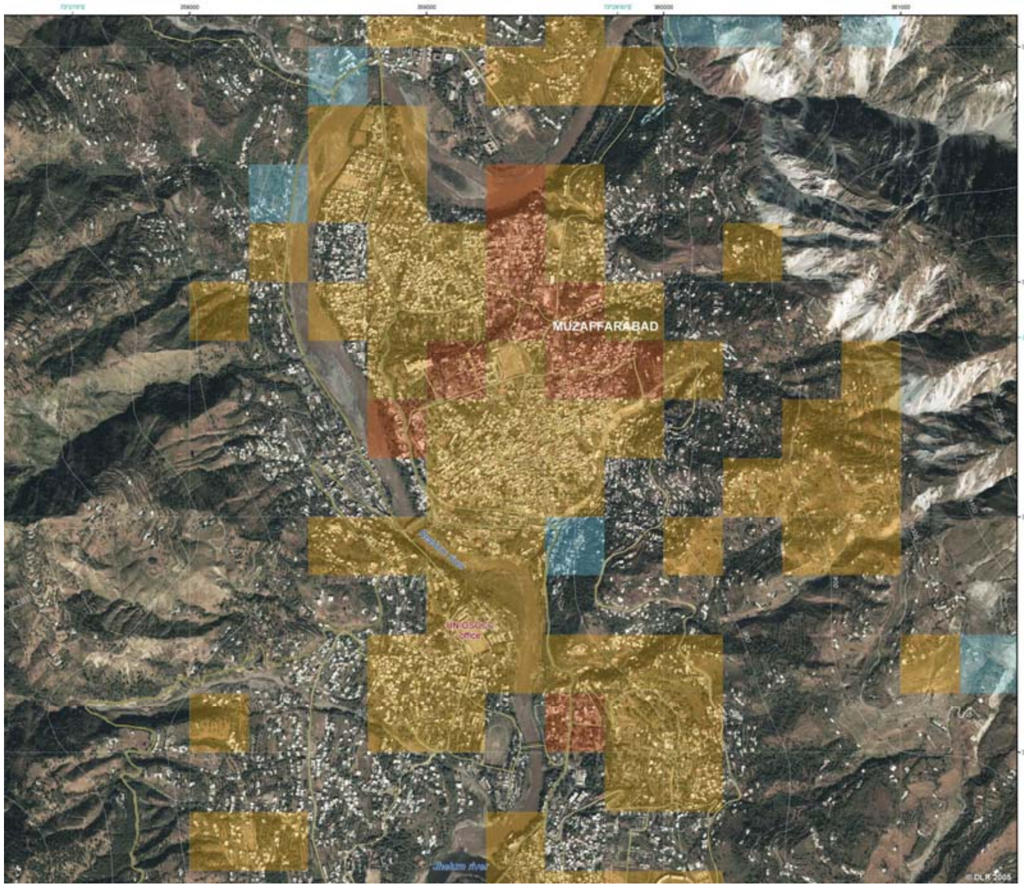

Figure 3.19: Satellite image of Muzaffarabad city centre after the earthquake with spatial damage levels (UNOSAT, 2005)

Figure 3.20: Collapsed stone and concrete block URM residential buildings on the hill and slight to moderately damaged residential buildings in the valley below. Collapse may be due to ridge effect or slope failure, Muzaffarabad

Figure 3.21: Diagonal shear cracks through window on a brick URM residential building, moderate damage, Muzaffarabad

Figure 3.22: Partially collapsed upper floor walls of a 2-storey concrete block URM residential building with RC slab floors and roof. Shear and out-of-plane failure of concrete block bearing walls, Muzaffarabad

Figure 3.23: Shear cracks through the concrete block masonry wall of a residential building, moderate damage, Muzaffarbad

Figure 3.24: Undamaged RC frame and slab residential building with concrete block masonry infill walls, Muzaffarabad

Figure 3.25: Collapsed roof of 2-storey RC frame and slab commercial buildings with concrete block masonry infill walls. Failure of beam/column connections at upper floor. Intact ground floor walls and first floor slab, Muzaffarabad

Figure 3.26: Collapsed 2-storey concrete block URM commercial building. Floor and roof collapse possibly due load bearing wall failure in shear and out-of-plane and high inertia loads from RC slabs, Muzaffarabad

Figure 3.27: Diagonal shear cracks through concrete block wall of RC frame and slab commercial building with masonry infill walls, moderate damage, Muzaffarabad

Figure 3.28: Undamaged RC frame and slab commercial building with concrete block masonry infill walls. RC lintel beam continuous over the structure perimeter, Muzaffarabad

Figure 3.29: Collapsed RC frame of upper floor of 3-storey commercial building with concrete block masonry infill walls. Failure at beam/column connections of upper floor frame, Muzaffarabad

Figure 3.30: Example of poor beam/column reinforcement detailing. No proper connection of column and beam reinforcement for moment resisting action

Figure 3.31: Incorrect splicing of reinforcing bar at beam/column connection of a moment frame under construction. Shear links configuration inadequate for seismic shear forces

Figure 3.32: Collapsed section of Samgam Hotel, RC frame and slab construction, 5-storey. Collapse due to failure at beam/column connections, Muzaffarabad

Figure 3.33: Slightly damaged 4-storey RC frame and slab commercial building with concrete block masonry infill, Muzaffarabad

Figure 3.34: Undamaged RC frame and slab commercial building, Muzaffarabad

Figure 3.35: Shear cracks through the brick masonry walls of the Muzaffarabad Supreme Court building. Cracking visible at the roof/wall intersection, moderate damage

Figure 3.36: Shear cracks through the brick masonry column and roof beam connection at the Muzaffarabad Supreme Court building. Damaged glass due to shearing through the window

Figure 3.37: Diagonal shear cracks through the brick URM walls of the Muzaffarabad Tourist Information Office, moderate damage

Figure 3.38: Shear cracks through the brick URM walls of the State Bank of Pakistan building, moderate damage

Figure 3.39: Collapsed wall sections of the concrete block URM, 3-storey building of the AJK Secretariat of Agriculture, Livestock and Food. Collapsed RC slab roof, extensive damage

Figure 3.40: Collapsed sections of the concrete block URM, 2-storey school building. Roof and floor slab collapse due to failure of masonry bearing walls, Muzaffarabad

Figure 3.41: Collapsed concrete block URM school building, Muzaffarabad

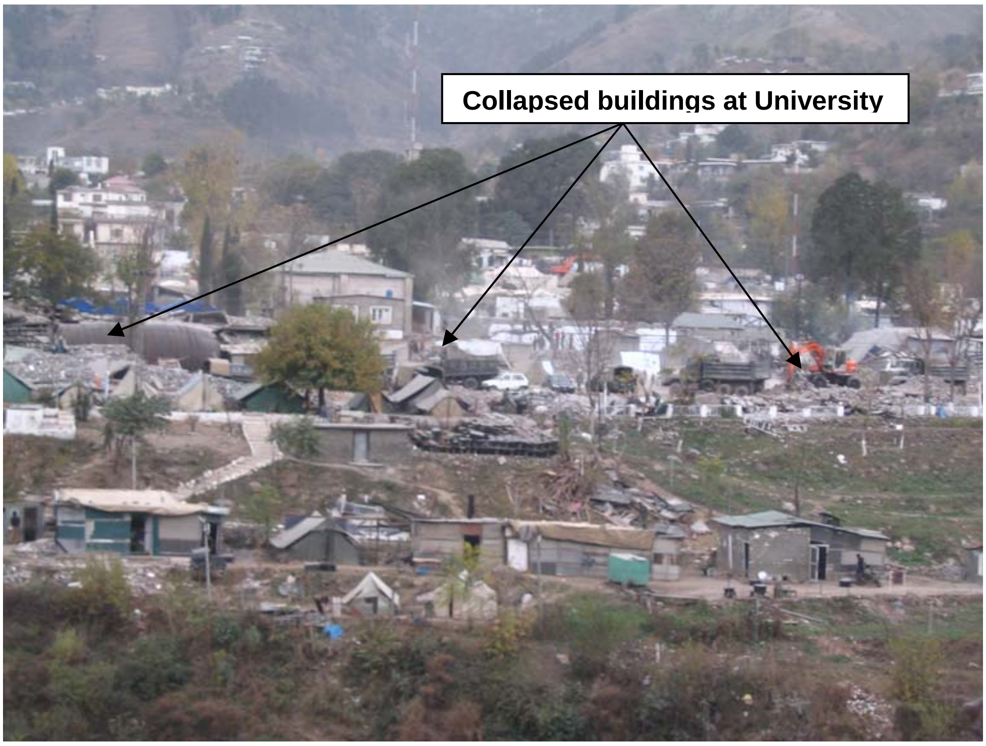

Figure 3.42: Collapsed concrete block URM buildings of the University of AJK, Muzaffarabad

3.3.3 Abbottabad

Abbottabad city located about 50km southwest of the epicentre suffered little damage. However, some commercial structures in the northern part of the city did collapse or suffer heavy damage. These structures are a mix of concrete block masonry URM bearing walls supporting RC slabs and RC frame and slab structures with concrete block or brick masonry infill walls. The heavy damage seen in Abbottabad appears to be on the marshland area north-west of the city. However, there was no visible evidence of liquefaction or foundation settlement.

Figure 3.43 shows a collapsed RC 3-storey building where the ground floor was a commercial outlet and the upper two floors were used for residential purposes. This building, only 3 months old, was one of the few that collapsed in Abbottabad city. As for similar buildings in Muzaffarabad, the cause of collapse appears to be failure at the beam-column connections. Figure 3.44 shows a view of the reinforcement detailing at the beam-column connection where the lack of continuity of the reinforcement and shear links is evident. Figure 3.45 shows the reinforcement layout of a collapsed slab revealed after removal of the concrete. The layout of the reinforcement does not show continuity and different bar sizes appear to have been used.

Figure 3.46 shows a 3-storey RC commercial building that suffered extensive damage. The beam-column joints have failed due to lack of proper shear or confinement reinforcement detailing. The building appears to be supported by the brick masonry columns adjacent to the RC columns added after the earthquake. The brick masonry infill walls inside the building have either collapsed out–of-plane or have in-plane shear cracks. Another example of beam-column connection failure is shown in Figure 3.47, which is typical of most RC frame and slab buildings that were damaged beyond the moderate damage level. The weakness of beam/column connections is also evident in the RC frame building shown in Figure 3.48, which has a permanent drift of the column minor axis at the first floor after the earthquake. The ground floor drift may have been prevented by the stiffening effects of the infill walls. Figure 3.49 shows an RC frame and slab commercial building with a soft-storey at ground floor hence the deformation was concentrated at this floor also evident from no damage to the glass frontage at upper floors.

Figure 3.43: Collapsed RC 3-storey commercial and residential building. Collapse appears to be due to failure of beam/column connections, Abbottabad

Figure 3.44: Lack of continuity of reinforcement detailing at the beam/column connection

Figure 3.45: Reinforcement layout of a collapsed slab revealed after removing the concrete

Figure 3.46: Extensively damaged 3-storey RC commercial building. Failed beam/column connections due to lack of shear or confinement reinforcement and inadequate layout, collapsed and cracked brick masonry infill walls inside the building, Abbottabad

Figure 3.47: Example of failed beam/column connection due to poor shear and confinement reinforcement detailing

Figure 3.48: Permanent drift at the first floor of an RC frame and slab 4-storey commercial structure under construction, Abbottabad. Ground floor drift may have been prevented by the infill masonry walls

Figure 3.49: Permanent drift at ground floor due to soft-storey in RC frame and slab 3-storey commercial structure, Abbottabad. The ground floor drift prevented large deformation at upper floors, hence glass frontage was intact

3.3.4 Islamabad

Islamabad is located about 100km southwest of the epicentre and experienced moderate ground shaking from the earthquake. The only major collapse reported was one of the 11-storey residential apartment buildings in the Margala Towers complex constructed just over 10 years ago. Figure 3.50 shows the site after clearance where the adjacent buildings were unoccupied at the time of the survey.

Figure 3.50: Margalla Towers and the site of the collapsed building in Islamabad

Figure 3.51: Soft-storey basement in a building adjacent to the collapsed building at Margalla Towers

About 100 people died during the building collapse, however there were no reported secondary damage or casualties due to fires. Inspection of adjacent buildings gave clues on the nature of the construction of the collapsed building. The floors of the building are reinforced concrete slabs supported on reinforced concrete beams and columns founded on probably a raft foundation. Each building has a basement and therefore the basement floor is a soft storey as shown in Figure 3.51. The adjacent buildings do not indicate damage to the reinforced concrete elements except spalling of concrete at the movement joints between adjacent buildings due to pounding during the earthquake. The masonry walls acting as partition walls for the apartments show in-plane and out-of-plane shear cracks. The building that collapsed was the last to be constructed in the complex. The fact that adjacent buildings did not suffer major damage to the structural load bearing elements suggests that the collapsed building may have been defective, for it to suffer a major collapse due to the ground motion 100km from the epicentre.

3.4 Performance of Buildings

The seismic performance of buildings could be evaluated in terms of the extent of their damage and the post-earthquake usage using a performance indicator. FEMA 356 presents such a performance indicator and the corresponding building damage level for buildings that are rehabilitated further to a performance evaluation. Table 3.2 summarizes the damage states and corresponding performance levels from FEMA 356 modified to account for the local building characteristics. The use of these performance levels in this report is restricted to comparing Table 3.2 with the observed damage states. Ideally, the performance evaluation should be carried out by comparing the observed performance to the designed performance level against the observed ground motion level from the event. The latter could not be ascertained since there is uncertainty on the regional seismic hazard representation and there are few ground motion recordings from the event (see Chapter 2). Furthermore, a detailed building study examining the building capacity is required, which is outside the scope of the field mission.

Table 3.2: Building damage states and performance levels (FEMA 356)

	Building Performance Level			
	Collapse Prevention Level	**Life Safety Level**	**Immediate Occupancy Level**	**Operation Level**
Overall Damage State	Severe	Moderate	Light	Very Light
General Description	Little residual stiffness and strength, but load bearing columns and walls function. Large permanent drifts. Some exits blocked. Infills and unbraced walls failed or at incipient failure. Building is near collapse.	Some residual strength and stiffness left in all stories. Gravity-load bearing elements function. No out-of-plane failure of walls or tipping of parapets. Some permanent drift. Damage to partitions. Building may be beyond economical repair.	No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, infill walls, and ceilings as well as structural elements.	No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, infill walls, and ceilings as well as structural elements. All systems important to normal operation are functional.

The building stock in the EEFIT surveyed areas could be broadly divided into four occupancy types; residential, commercial (including retail), government and educational institutions. Their performance based on the EEFIT survey observations as described in the preceding sections are discussed below.

3.4.1 Residential Buildings

Residential buildings performed very poorly during the Kashmir earthquake as noted from the damage statistics (see Table 7.2, Chapter 7) where some 97% of the collapsed and partially damaged buildings were residential properties. This was evident in cities such as Balakot and Muzaffarabad where a substantial number of residential buildings were above moderate damage state. The poor performance could be attributed to basic structural deficiencies, when it comes to resisting seismic forces. The structural typology is such that most of the observed residential structures had unreinforced masonry bearing walls supporting the roof or upper floors. The use of a concrete roof without any ties to the walls meant that the structure could not take advantage of the diaphragm action of a single unit to resist the seismic shear forces. The poor quality of the mortar and that of the concrete blocks meant that shear cracks formed easily in the walls and many walls displaced out-of-plane during the earthquake. The loss of the load bearing capability led to the collapse of the heavy RC roofs or upper floors, which was the predominant mode of failure among residential homes in the surveyed city areas. Based on the damage observations in the surveyed regions, the building performance could be categorized as collapse prevention performance level or worse.

3.4.2 Commercial Buildings

The commercial buildings had a mixed performance according to the survey observations. The commercial structures consisting of masonry bearing walls supporting RC roofs or upper floors either collapsed or experienced extensive damage in areas closer to the epicentre such as Balakot and Muzaffarabad. These structures were therefore either at the collapse prevention performance level or worse. Commercial structures of RC frame and slab load bearing system with masonry infill performed reasonably well with some buildings experiencing collapsed sections. Based on the survey observations, these buildings could be assigned either immediate occupancy or life safety performance level. This is also evident from the fact that many of the commercial buildings that had not suffered extensive damage or collapse were back in use at the time of the survey. The cause of damage to RC frame and slab structures appears to be weakness at the beam/column connection detailing and generally poor detailing of RC members.

3.4.3 Government Buildings

Government buildings in the surveyed areas were largely of concrete block or brick URM with RC slab roofs. Their performance was poor in that many of the buildings had major cracks within the load bearing walls or suffered collapsed sections. The government buildings observed in Muzaffarabad could be rated as at life safety performance level or collapse prevention performance level.

3.4.4 Educational Institutions

Performance of schools and the AJK University in Muzaffarabad was very poor and led to many casualties among students and staff. These structures largely consisted of concrete block URM load bearing walls supporting the RC roof or upper floors. The collapse of unreinforced bearing walls led to the RC roof or floor collapse. The overall performance could be assigned as collapse prevention or worse.

3.5 Conclusions

The building damage survey revealed deficiencies in the construction practices in the earthquake affected region of NWFP and AJK provinces. These deficiencies resulted in a substantial building stock, particularly among the residential occupancy, being at a collapse prevention performance level or worse. This meant that there was an urgent need for temporary shelters for the displaced population, who could not return to their damaged homes in the short term. The damage survey and the damage analyses conducted in this chapter reveal the extent of vulnerability of the built environment and how it differs among different occupancy categories. This should be borne in mind when planning the reconstruction and future disaster management plans for the region.

3.6 References

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4 Landslides and Geotechnical Aspects

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A major catastrophic earthquake occurring in mountainous terrain was provided by the Kashmir, Pakistan earthquake of October 8, 2005. This earthquake amply illustrated landslide behaviour from minor geotechnical failures through to massive landslides: it included very small slippage on slopes; landslides and cobble showers that interrupted lifelines (particularly roads), and did so over an extensive area; landslides that undermined buildings; deep cutting landslides; and one landslide that precipitated additional hazards through the damming of two tributary rivers. The landslides observed were responsible for casualties, building damage and disruption to the road network that was vital for the relief effort following the earthquake. Some slides were triggered, but disrupted ,hence they posed a danger of sliding following the winter snow melt or from another earthquake.

4.1 Introduction to Landslides and Slope Failures

Cruden (1991) defines a landslide simply as a mass-movement of rock, mixed debris, or earth down a slope. Down-slope movement indicates that they are mainly gravity controlled. Landslides range over many orders of magnitude in size and extent, and the process includes several different types e.g. rock falls, rock and soil slides, and slumps, spreads and flows. Different failure types are influenced by slope stability and materials. Landslides can obviously become common in mountainous terrain, but they may also occur in a submarine environment. Some types of landslide occur slowly, others rapidly. They are caused by various triggers e.g. earthquake, volcanic eruption, heavy rainfall and even directly by man's intervention (road cuttings and mining). A world map of significant landslide related disasters since 1750 is provided in McGuire *et al.* (2004) and many of these – not all – were caused by earthquakes.

Physical properties of landslides vary. They occur in various earth materials but essentially require unstable rock or soil on a slope. The instability may be due to bedding or sedimentary interface or simply rock debris under gravitational loading. The main materials that slide are: rock with weakness planes or rock debris or wet porous soil. Landslide failure mechanisms are typically: falling or toppling, sliding, and spread or flow mechanisms. Failure surface and slope stability governed by geotechnical properties are defined and discussed at length by Kramer (2004). Landslide speed technically ranges from order metre/century to above 100 km/hour. The famous earthquake triggered rock-ice avalanche-landslides from Huascaran Mountain in the northern Andes of Peru, in 1970, are believed to have travelled with average speed around 320 km/hour (Cluff, 1971; Bolt et al., 1975). The size of slip on a slope may be tiny, or just sufficient to damage the foundation of a wall, at the other extreme it may move a volume in excess of one thousand million cubic metres and spread this material over area greater than 40 km^2.

The classification of earthquakes owes much to the study of historical earthquakes with landslides carried out by Keefer (1984). Table 4.1 follows Keefer's classification and landslide description and his detailed terminology. It is based on the study of 40 historical earthquakes during 1811-1980. Detailed interpretation of these descriptions of "internal disruption" and quantification of "velocity" in Table 4.1 can be found in Keefer (1984).

Table 4.1 Keefer's classification of landslide types following earthquake (after Keefer, 1984)

Name	Type of movement	Internal disruption	Velocity
LANDSLIDES IN ROCKS Disrupted slides and falls			
Rock falls	Bounding, rolling, free fall	High or very high	Extremely rapid
Rock slides	Translational sliding on basal shear surface	High	Rapid to extremely rapid
Rock avalanches	Complex, involving sliding and/or flow, as stream of rock fragments	Very high	Extremely rapid
Coherent slides			
Rock slumps	Sliding on basal shear surface with component of headward rotation	Slight or moderate	Slow to rapid
Rock block slides	Translational sliding on basal shear surface	Slight or moderate	Slow to rapid
LANDSLIDES IN SOIL Disrupted slides and falls			
Soil falls	Bounding, rolling, free fall	High or very high	Extremely rapid
Disrupted soil slides	Translational sliding on basal shear surface or zone of weakened, sensitivity clay	High	Moderate to rapid
Soil avalanches	Translational sliding with subsidiary flow	Very high	Very rapid to extremely rapid
Coherent slides			
Soil slumps	Sliding on basal shear surface with component of headward rotation	Slight or moderate	Slow to rapid
Soil block slides	Translational sliding on basal shear surface	Slight or moderate	Slow to very rapid
Slow earth flows	Translational sliding on basal shear surface with minor internal flow	Slight	Very slow to moderate, with very rapid surges
Lateral spreads and flows			
Soil lateral spreads	Translation on basal zone of liquefied gravel, sand, or silt or weakened, sensitive clay	Generally moderate, occasionally slight, occasionally high	Very rapid
Rapid soil flows	Flow	Very high	Very rapid to extremely rapid
Subaqueous landslides	Complex, generally involving lateral spreading, and/or flow; occasionally involving slumping and/or block sliding	Generally high or very high; occasionally moderate or slight	Generally rapid to extremely rapid; occasionally slow to moderate

Alongside the physical properties of earthquake-triggered landslides are the accompanying seismological parameters. Of prime interest are the minimum magnitude and minimum intensity that may cause landslide, and maximum distance (causative fault rupture to landslide) that may be affected. Such quantified linkages between earthquake-triggered landslides and seismological parameters can facilitate risk analysis. Again, resort can be made to Keefer's study of 40 historical earthquakes.

It seems that rock falls and soil falls can be triggered by an event as small as 4 M_L (Richter local magnitude) whereas it requires 6-6.5 M_S (surface wave magnitude) to trigger rock and soil avalanches. The Kashmir earthquake had magnitude 7.6 M_W (moment magnitude). The minimum level of ground shaking to cause disrupted slides and falls is intensity VI Modified Mercalli (modal value) and VII MM for coherent slides and similarly for lateral flows. Note for present purposes Modified Mercalli MM values are synonymous with MSK and EMS intensity values. The Kashmir earthquake was locally IX, even X MM.

It is also important to understand how far from the fault rupture that slides might occur, or be of significance. The maximum distances of landslide occurrence from a causative fault, for different types of landslide, are shown as a function of magnitude in Figure 4.1. Figure 4.1c compares the relationships for disrupted slides (dashed line), coherent slides (dash-double-dot line) and lateral spreads (dotted line). The 7.6 M_W Kashmir earthquake plotted in Figure 4.1c suggested a potential for landslide occurrence to a distance of about 200 km from the fault ruptures in the epicentral region. Within Figure 4.1a the data points 5 and 16 were derived by Keefer (1984) for the great earthquakes of 1934 January 15 Bihar, India-Nepal (8.3 M_W) and 1964 March 28 Alaska (8.3-8.4 M_W) respectively.

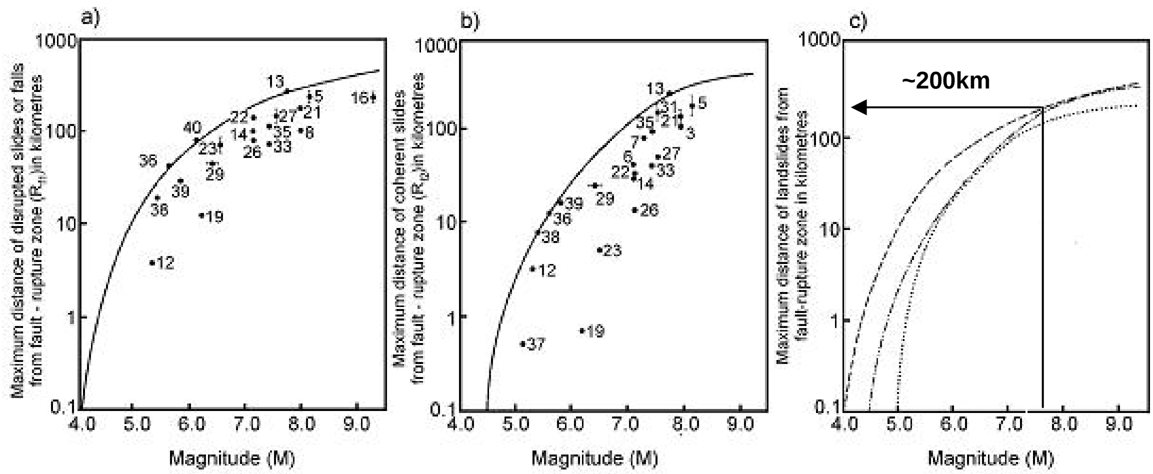

Figure 4.1: Relationships between maximum distance of landslides from causative fault and earthquake surface wave magnitude: a) disrupted slides and falls, b) coherent slides, c) envelopes to a) and b) and lateral spreads (dotted line) (after Keefer, 1984)

Within the above framework in the context of the Kashmir earthquake it is important to note that *no liquefaction features* were observed by the EEFIT team. There was no evidence of any lateral spreading or flow in soils. Otherwise landslides of many sizes and types were observed. Detailed geotechnical investigation of individual landslides was not possible although the type of failures could be broadly divided into the following relatively simple categories compatible with the field observations:

- Deep slip landslide – this type involves a deep slip failure and extends over a larger area, resulting in a large mass of rock debris moving downhill leaving the scarp clearly visible. This type of failure involves large sections of the mountain side

- Shallow depth landslide – this type of slip involves a slip of material usually overlying rock or relatively strong soil and covers a larger or smaller area, still resulting in a considerable volume of material sliding down and slumping

- Local slope failure – slope failure involves a flow of material overlying more competent material and the slip is localized. The depth, volume and the slip displacement of the sliding material is less than a shallow depth landslide. This type of slip can be very small while having an impact

- Rock fall – typically rocks and cobbles that have bounded downhill, perhaps arrested by a road

Additionally, incipient landslides were also observed – these held the potential for failure later.

EEFIT carried out survey on foot, by vehicle and aerial survey conducted on board US Army Chinook helicopters while on relief missions between Islamabad and Muzafarrabad and the affected areas. The two main places visited on foot and by vehicle were Balakot and Muzafarrabad. and local linking roads. The four places visited in the higher hills during US Army relief missions involved nine flights and are: Nausari, Pattika, Conoko and Dhanni Nelam. Several of the flights were from the airbase at Muzafarrabad allowing over flight of the landslides adjacent to Muzafarrabad city.

The investigation of ground failure at each observed location was done by visual inspection, still and video photography and notes of observations at the time of the survey, accompanied by GPS location where possible. EEFIT observations are also supplemented by photographs kindly supplied by others, and by satellite imagery, where appropriate. The following sections describe material from the ground survey and aerial survey observations, and also discuss the relationship between the observed landslide distributions, fault rupture and coseismic ground displacement field in general. Emphasis is on impacts on landscape, built structures (including lifelines) and lifestyle.

4.2 The Larger Landslides and the Regional Ground Displacement Field

This thrust earthquake had magnitude 7.6 M_W. As indicated above an earthquake of magnitude 7.6 M_W might be expected to trigger landslides of various types in susceptible terrain to a distance of about 200 km. COMET (2005) used remote observations from satellites and correlations made using Synthetic Aperture Radar (SAR) images to determine the fault position indicated in Figures 2.6 and 2.7. Also determined was a 3D surface displacement field including surface-displacement vectors, and these shed considerable light on the overall landslide activity in the affected area. Fig. 4.2 emphasizes the vector field of horizontal displacement (TJ Wright, personal communication; Pathier *et al.*, 2006). The thrust fault strikes SE-NW and dips under the high mountains to the NE in Fig. 4.2 in a SW towards NE dipping direction under the hanging wall to the NE. Two characteristics stand out. The maximum uplifts of ~5 m lie just to the E of the fault on the hanging wall. Horizontal displacements are far greater in the hanging wall to the E than in the foot wall to the W, and in the hanging wall there is greatest density of large displacements to the NE of the Balakot-Murree-Muzaffarabad fault strike. Many landslides occurred in the hills just E of the fault as elastic rebound in the hanging wall took it upwards and forwards by several metres during the earthquake, almost literally throwing the SW facing hillsides into landslides. Many of the largest displacements lie in the zone NE of Balakot-Muzaffarabad which extends into the Kagan Valley. The displacement pulse was not only effective in triggering landslides over a selective area but also in damaging houses.

There were two particularly significant landslides during this earthquake and displacement maps deduced from SAR data help to provide interpretational understanding on their location. These landslides are the main Muzaffarabad landslide and the Hattian landslide located at positions “slide A” and “slide B” respectively in Fig. 4.2, and lying on the general NW-SE strike of the fault. Infra-red imagery of the topography in Figure 4.3 also picks out these two significant slides in addition to other large and visible landslides, many of which lie between Muzaffarabad and Balakot. This latter distribution is also consistent with the location of aftershocks as indicated in Figure 2.4. So within this background of widespread surface displacement and shaking there was also a spectrum of smaller landslips and geotechnical failures up to major landslide, all of which contribute to impact. Lifelines, particularly roads were affected in a variety of ways. These smaller landslip failures and related issues will be considered later. However, this section will concentrate on the two large deep-cutting landslides: at Chela Bandi, Muzafarrabad and at Hattian.

4.2.1 Landslide at Chela Bandi, Muzafarrabad

The Chela Bandi, Muzaffarabad landslide is viewed in Figures 4.4 and 4.5 along the eastward pointing arrow indicated in the satellite imagery of Figure 4.6. This landslide temporarily blocked the Nilam River which can be seen in the satellite image (Fig. 4.6) flowing N to S and around the city of Muzaffarabad, but this blockage was quickly breached. This impressive landslide, although deep cutting, is largely surficial. Most of the debris detached from the dolomite limestone mountain side is shale and dolomite. Its extent is about 1.5 x 0.5 km^2 and probably has volume close to 10^6 m^3. Other landslides are visible in this image to the E of Muzaffarabad and elsewhere. The fault (Balakot-Murree-Muzaffarabad) probably lies at the foot of the landslide in these photographs and satellite image. The main face of this mountainside and landslide runs NNW-SSE and faces WSW and the hanging wall along the Balakot-Murree-Muzaffarabad Fault underwent elastic rebound of at least 3 m horizontally to the SW accompanied by 4-5 m uplift (Figure 4.2). An additional but vital point is that the Muzaffarabad landslide at A in Figure 4.7 is adjacent to the maximum coseismic slip in the major asperity on the fault plane model between Balakot and Muzaffarabad.

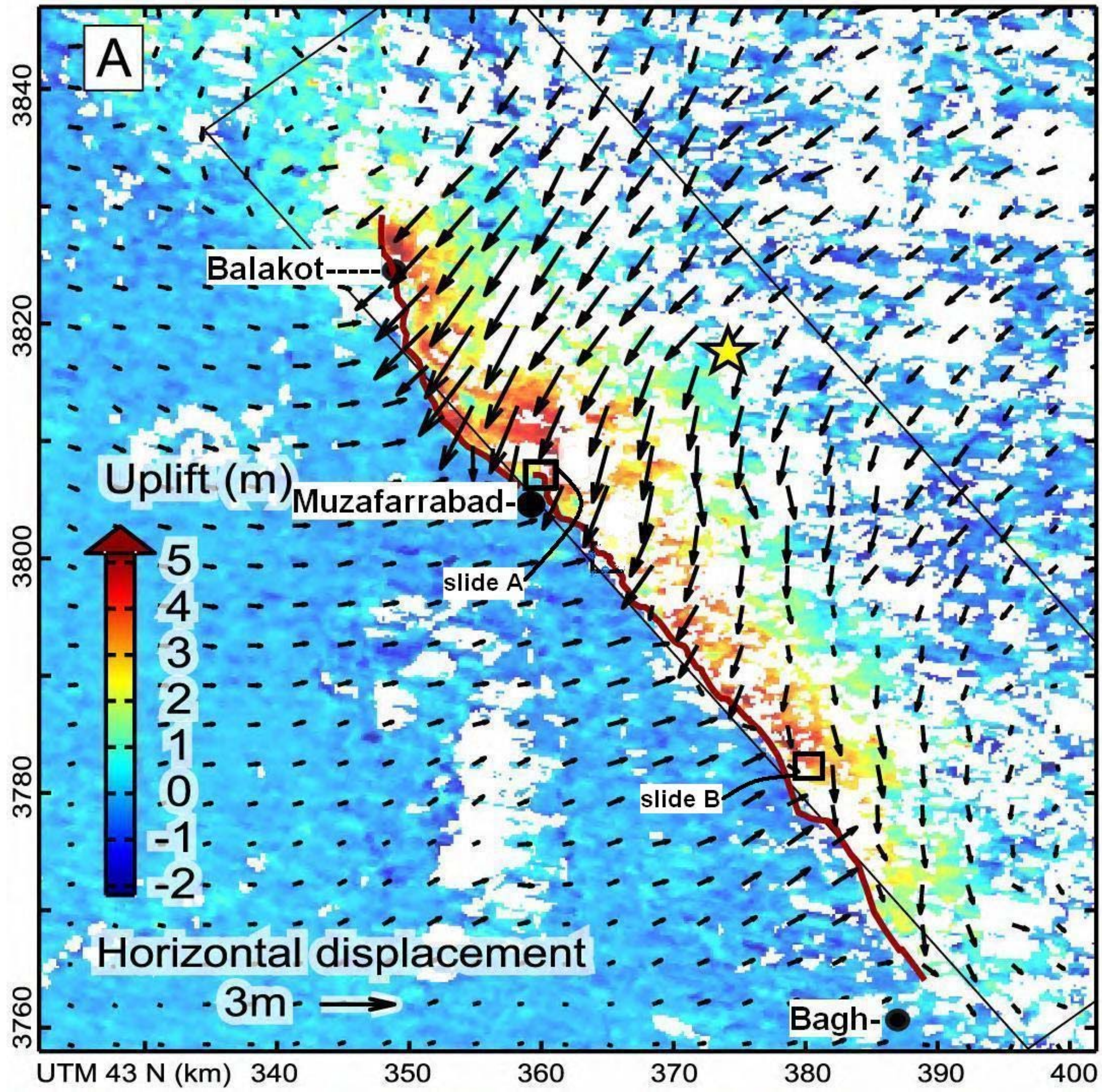

Figure 4.2: Displacement of the Earth's crust caused by the Kashmir 2005 earthquake. Black arrows indicate horizontal displacement and colour vertical uplift, the star indicates the epicentre (adapted from Pathier *et al.*, 2006). Significant landslides discussed in the text occurred at "slide A" (Muzafarrabad slide) and at "slide B" (Hattian slide)

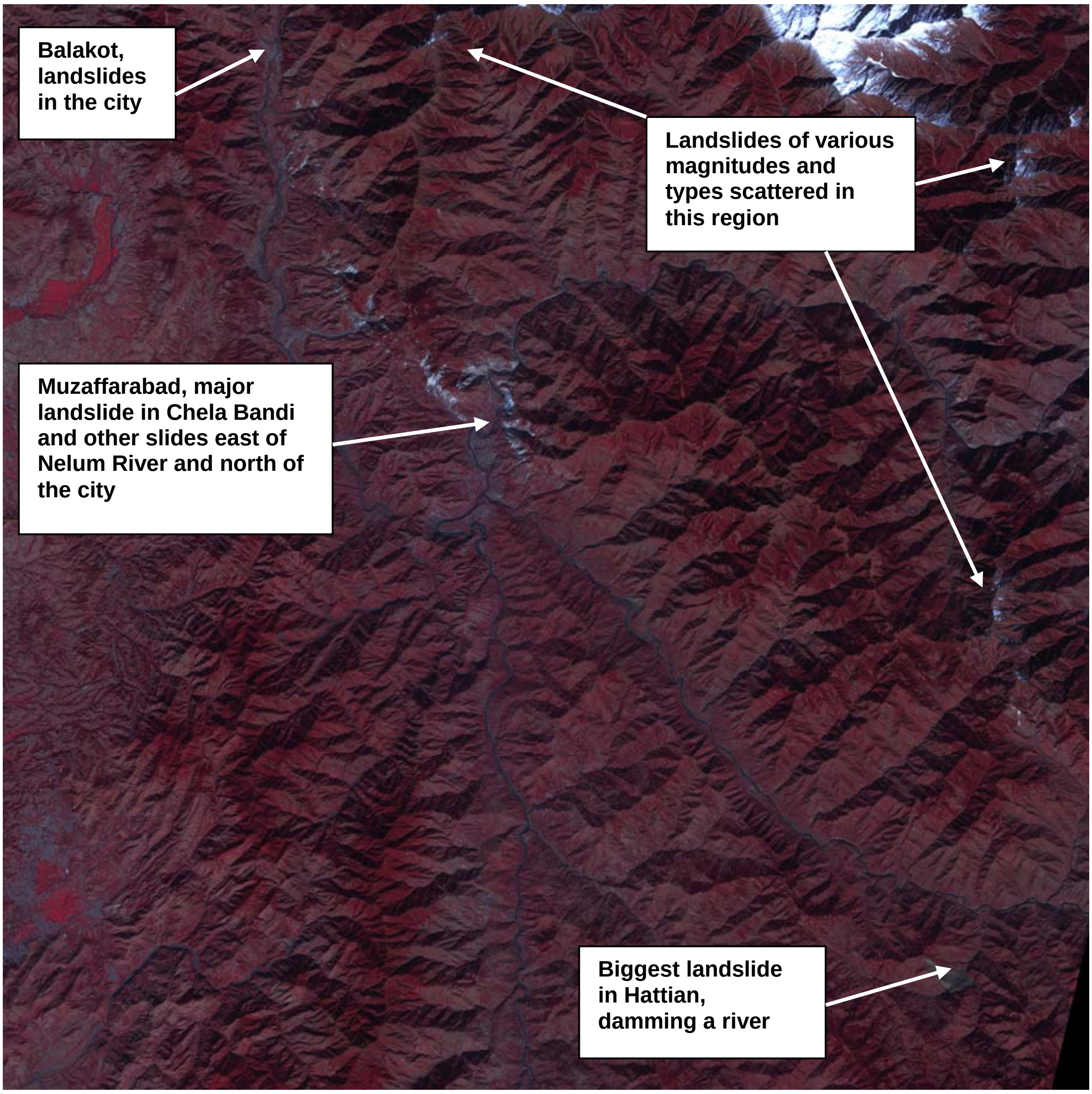

Figure 4.3: Infra-red image of topography of NWFP and AJK provinces after the October 8, 2005 Earthquake (source: NASA)

Figure 4.4: Kashmir earthquake October 8, 2005. Landslide in dolomite mountainside just north of Muzafarrabad at Chela Bandi

Figure 4.5: Kashmir earthquake October 8, 2005. Landslide in dolomite mountainside just north of Muzafarrabad at Chela Bandi. Also note cracks through road in foreground and damage to buildings in mid-distance

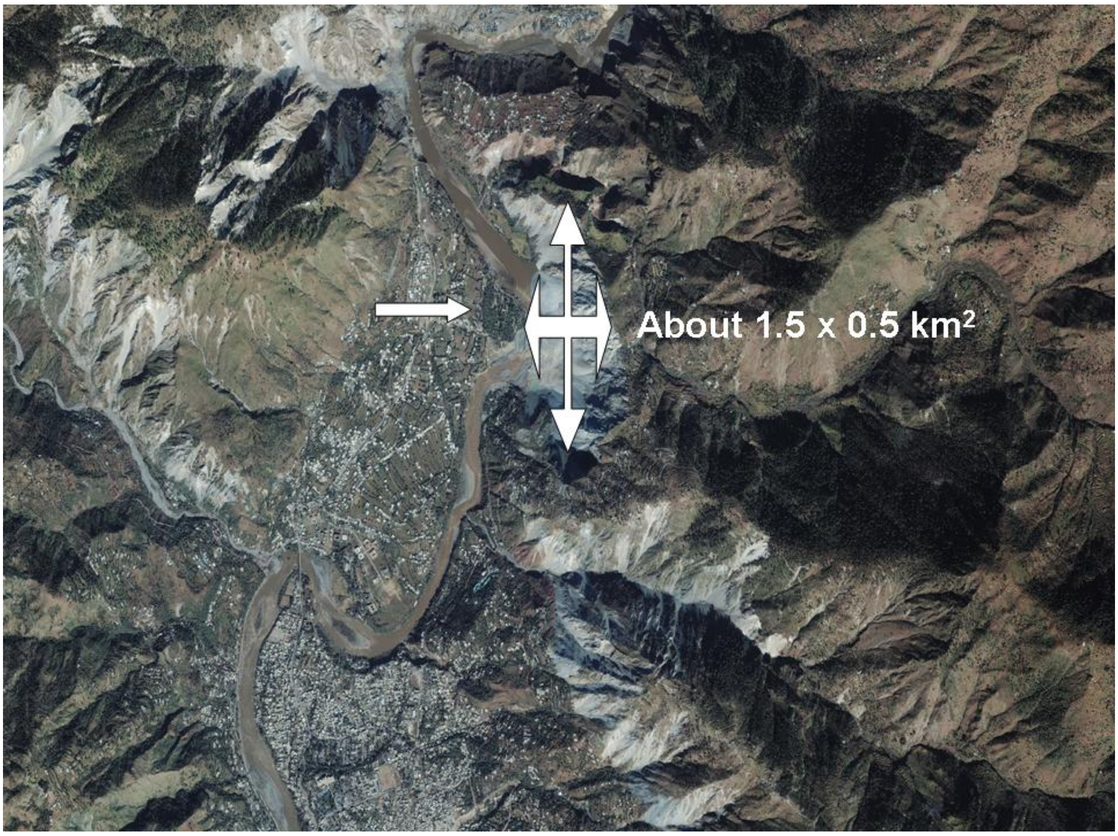

Figure 4.6: Main landslide at Chela Bandi, north of Muzafarrabad, imaged from space (Image NASA) with extent 1.5 km N-S and 0.5 km E-W. Arrow to the left indicates point of view in photographs of Figures 4.4 and 4.5

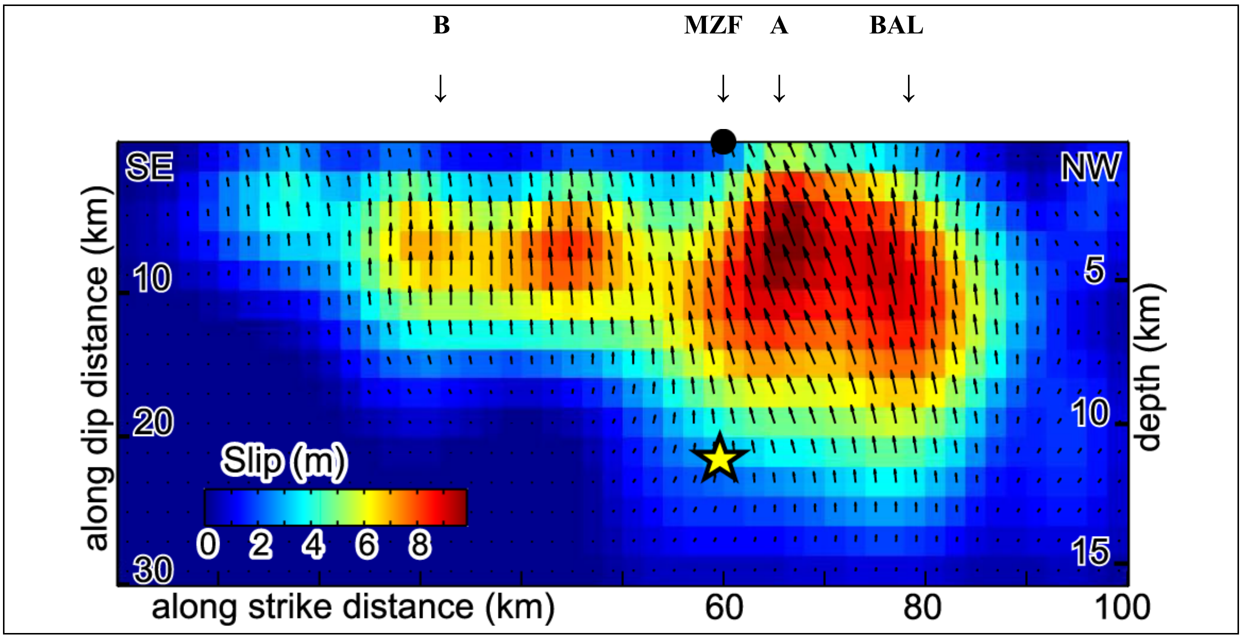

Figure 4.7: Slip distribution mapped in the fault plane (after Pathier *et al.*, 2006): BAL = Balakot; MZF = Muzafarrabad. Position A = Chela Bandi, Muzafarrabad slide seen in Figures 4.4, 4.5 and 4.6 and position B = Hattian slide as seen in Figures 4.8, 4.9 and 4.10

4.2.2 Landslide at Hattian, Pir Punjal Mountains

The second deep cutting landslide to be considered is the most significant; this is the Hattian slide (according to Schneider, 2006, also referred to as the Chikar slide, the Dana slide, or the Dandbeh slide,) and this occurred at location “slide B” in Fig. 4.2 displacement map, which is just south of the township of Bhagsar and the Jhelum River in the Pir Punjal Mountains. Schneider (2006) places the origin of this slide on Dana Hill (2080 m above sea level at 34° 09′ N, 73° 43′ E) and its run (Fig. 4.8a-b buried the village of Dandbeh. The extent of the slide from origin scarp to toe indicated by arrow in the photograph Fig. 4.9 is about 2,850 m long (C. Scawthorn, personal communication) with volume in the range 1-6 10^6 m^3. The run down reported by Schneider was a drop of 1,000 m and distance of 2.75 km covering an area of 5 km^2 within half a minute. The slide then ran up the far side of the valley, overtopping the crest and into the next valley. It dammed two tributaries of the Jhelum River and so also formed a tertiary hazard of future flooding from two dammed lakes, the larger being in the first valley crossed and the second smaller dam and lake being in the second valley. There is evidence of an earlier slide at this locality, overridden by the Hattian slide and perhaps associated with an earthquake in 1955 (Schneider, 2006). The Hattian slide is also very visible in satellite imagery Fig. 4.10. The Hattian slide is again on the hanging wall of the fault located at “slide B” in the Muzaffarabad-Bagh segment of the fault. Although this location is associated with high uplifts of 4-5 m in the displacement map (Fig. 4.2) it was not subjected to the very large 3 m SW horizontal elastic rebounds that occurred in the thrusting along the Balakot-Murree-Muzaffarabad segment. Instead, just W of the Hattian slide location the pure thrust mechanism changes to include a significant component of right lateral strike-slip motion in the remainder of the Muzaffarabad-Bagh segment. At B in Fig. 4.7 the Hattian slide is also adjacent to significant coseismic slip in the lesser asperity on the fault plane model that exists in the SE part of the Muzaffarabad-Bagh fault segment.

a) b)

Figure 4.8: The Hattian slide, Pir Punjal Mountains: the major landslide in the Kashmir 2005 earthquake. a) the source and high energy channel of the slide b) landslide material resulting in damming of two tributaries of the Jhelum River (photos by Charles Scawthorn)

Figure 4.9: The Hattian slide, Pir Punjal Mountains: the major landslide in the Kashmir 2005 earthquake. This deep cutting landslide from source scarp to toe (white arrow) stretches over approximately 2,850 m (photo collage by Charles Scawthorn)

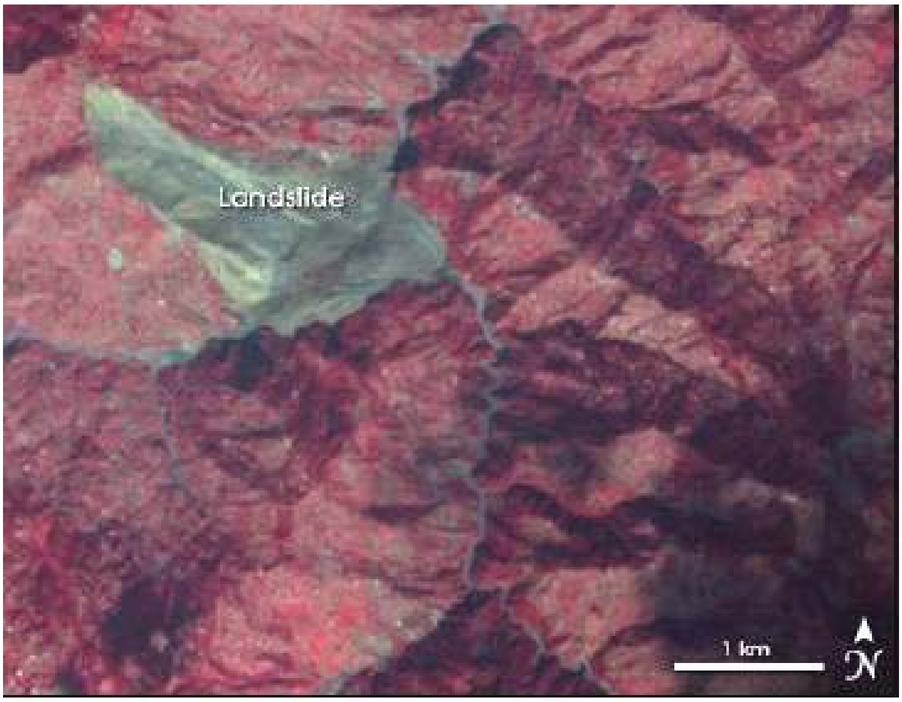

Figure 4.10: The Hattian slide, Pir Punjal Mountains: the major landslide in the Kashmir 2005 earthquake. An overall perspective from space (image by NASA), note the tributary rivers

4.2.3 Perspective on Great Landslide Potential

The Hattian landslide in the Pir Punjal Mountains was deep cutting, had volume approximately 1-6 10^6 m^3 and blocked two tributary rivers of the Jhelum River. This was the largest landslide caused by the Kashmir 2005 earthquake and it is informative to compare this landslide with other great landslides and their impact. Can landslides be bigger?

The high mountain of Nanga Parbat is about 150 km NE of Muzaffarabad and the Karakoram Range beyond this. This area includes the River Indus and observations there provide some answers. Glacial moraines from Quaternary and Holocene events in this area were once identified as glacial moraines but Hewitt (1999) reclassified these as huge postglacial rock avalanches. Some deposits examined by Hewitt ran up mountain ridge sides, overtopped them and also blocked rivers similarly to the Hattian slide. One example from Hewitt (1999) refers to a landslide at Skardu; this is about 250 km ENE of Muzafarrabad. The related deposits at one time blocked the River Indus.

The maximum distance travelled by these deposits was estimated to be 11 km and highest run-up generated was 600 m. Total deposit volume is $120x10^6$ m^3, but originally deposits may have amounted to $200x10^6$ m^3. Much of these present deposits now lie on either side of the Indus. Hewitt suggests that the Indus was dammed to 40-50 m above present day flood level. The volume of landslide deposits at Skardu are two orders of magnitude greater than those at Hattian. The Karakoram landslides classified as catastrophic by Hewitt have volumes in the range: $1.5x10^6$ m^3 to in excess of $1000x10^6$ m^3. The upper end of this range involves a billion cubic metres. This is three orders of magnitude in excess of the million cubic meters involved in the Hattian slide. Given that these events are pre-historic in very recent geological time, a proven link with seismicity is clearly unavailable.

In the Pamir Mountains of Tajikistan an earthquake on February 18, 1911, precipitated what is now known as the Usoy landslide. This landslide dammed the River Murgab and formed Lake Sarez, and the smaller Lake Shadau. Usoy dam is huge with volume estimates of $2,200x10^6$ m^3. The dimensions of Lake Sarez are 55.8 km with width 3.3 km and maximum depth 0.5 km (seco, 2003). The landslide-formed dam at Usoy has remained stable since its formation; although a more recent issue is that a further landslide may cause the waters of the lake to overtop the dam thus potentially affecting about 4 million people downstream by flooding. The volume of Usoy dam is three orders of magnitude larger than estimates of the Hattian slide material. These landslides are both unequivocally linked with earthquake triggering.

4.3 The Intermediate and Smaller Landslides

The ground surveys primarily saw landslides near Muzafarrabad and Balakot and alongside connecting roads. The airborne surveys viewed landslides near villages visited during relief flights and in valleys and mountainsides along flight paths (from Islamabad and Muzafarrabad). Satellite imagery in Figures 4.3 and 4.6 previously illustrated the many superficially large but shallow cutting landslides close to the fault between Muzafarrabad and Balakot and NE into the higher hills on the hanging wall of the thrust fault.

In addition to the deep slip slide already described at Chela Bandi, just north of Muzafarrabad, there were several landslides of different sizes as imaged in Figures 4.11 and 4.12. A number of deep slips and shallow slips of large volume movements occurred north of Muzaffarabad City. The deeper slips involved large sections of the mountains sliding down and slumping. Figure 4.13 shows in greater detail the shallow depth large landslides east of Nelum River in Muzaffarabad City.

Balakot, although not affected by deep cutting landslides, was greatly affected by other landslides. Figure 4.14 shows locations of landslides and geotechnical failures identified using a satellite image of Balakot. The type of landslides in Balakot was shallow depth slides, where the steep sloped surficial soils have slipped and slumped to form a less steep profile. Access on some roads to the city were blocked – impact to roads is discussed later. Figure 4.14 also illustrates some surface flows into gullies as a common feature of these landslides.

In addition aerial observation provided a most useful general reconnaissance of regional landslide examples and impacts.

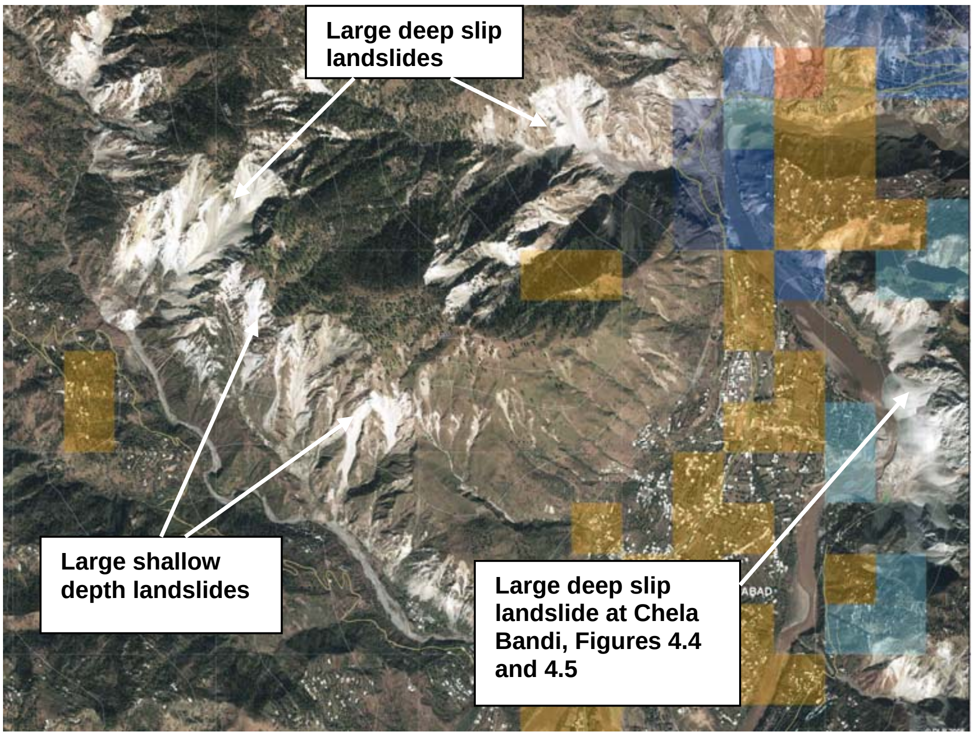

Figure 4.11: Landslides in the northern part of Muzaffarabad City, AJK (UNOSAT, 2005)

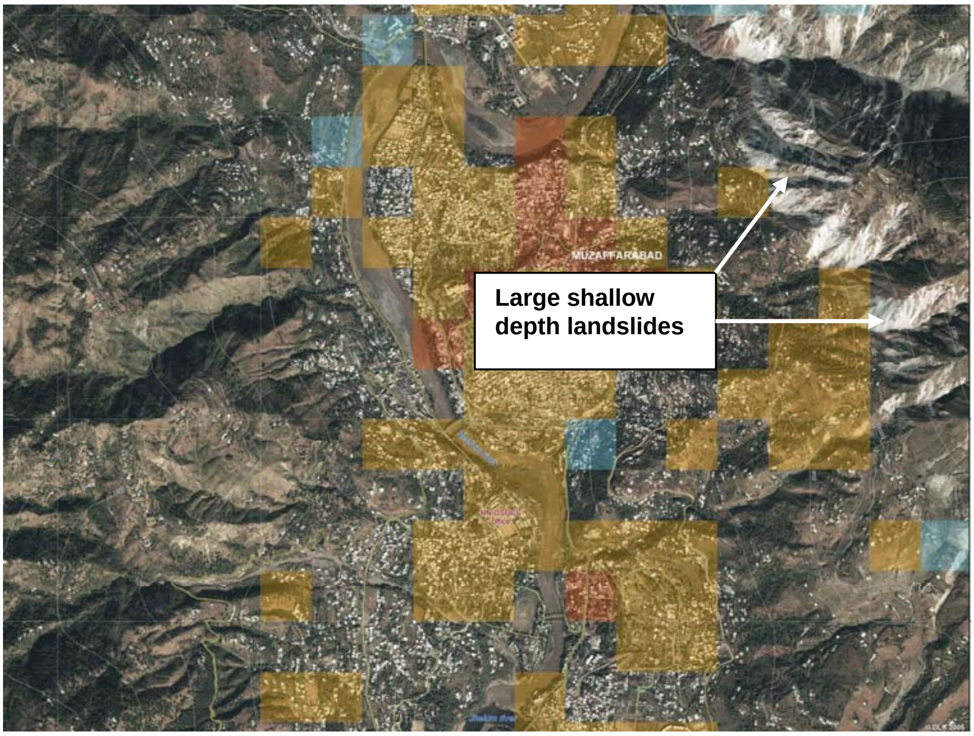

Figure 4.12: Landslides in the central part of Muzaffarabad City, AJK (UNOSAT, 2005)

Figure 4.13: Large shallow depth landslides east of Nelum River in Muzaffarabad

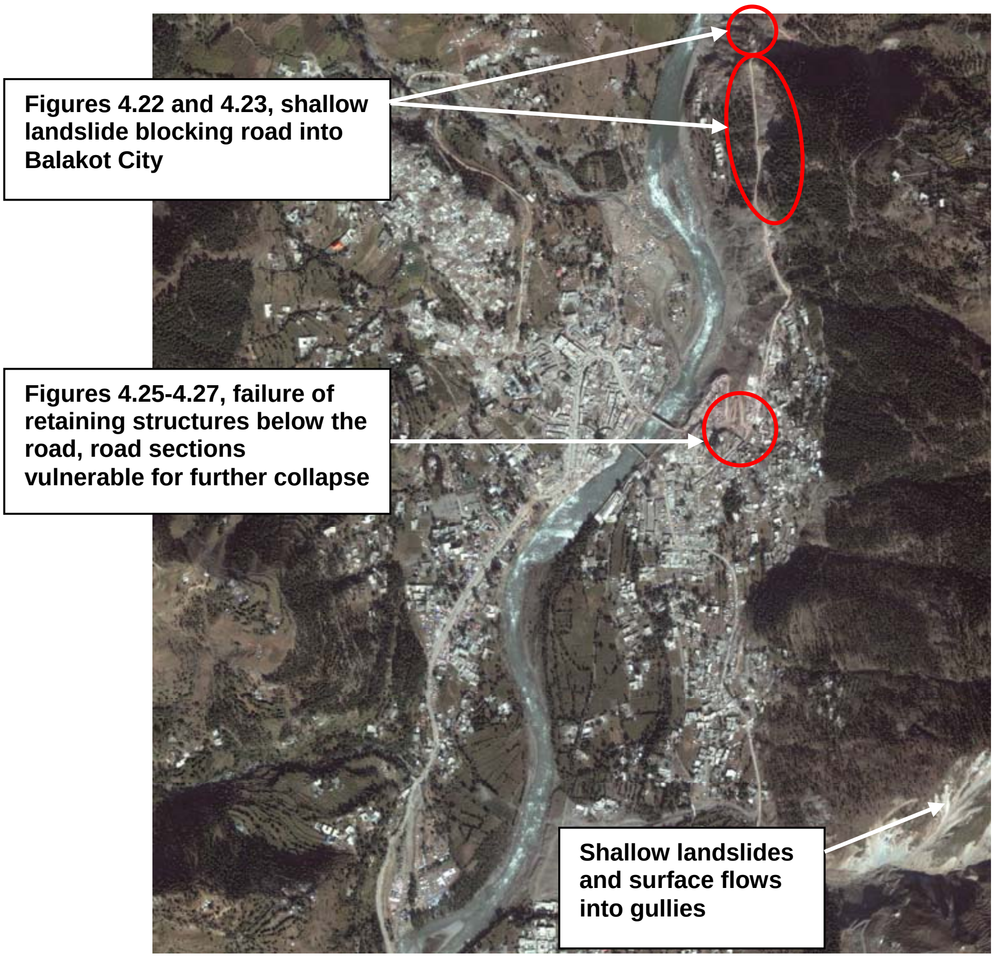

Figure 4.14: Location of landslides and ground failures in Balakot City (Digital Globe, 2005)

4.3.1 Steep Terrain and General Aerial Observation

Aerial reconnaissance and observation took place during nine US Army Chinook relief flights. Observation involved still photography and camcorder video. Villages to where relief was delivered were also inspected on the ground on foot, albeit briefly due to the overriding requirement of delivering relief supplies.

Relief flights used the Chakalla Airbase in Islamabad and the American Airbase (AAB MZF). Seven flights were undertaken 25 November in the sequence: flights 1-7: AAB MZF → Chakalla Islamabad → Nausari → AAB MZF → Pattika → AAB MZF → Conoko → AAB MZF. Two flights were undertaken 28 November: flights 8-9: Chakalla Islamabad → Dhanni Nelam → Chakalla Islamabad. Target destinations for local observation were thus Nausari, Pattika, Conoko and Dhanni Nelam, while landslides in the vicinity of Muzafarrabad were overflown several times. Figure 4.15 shows the locations of the relief drops as noted in the GPS unit overlaid on the ground survey locations shown in Figure 3.9.

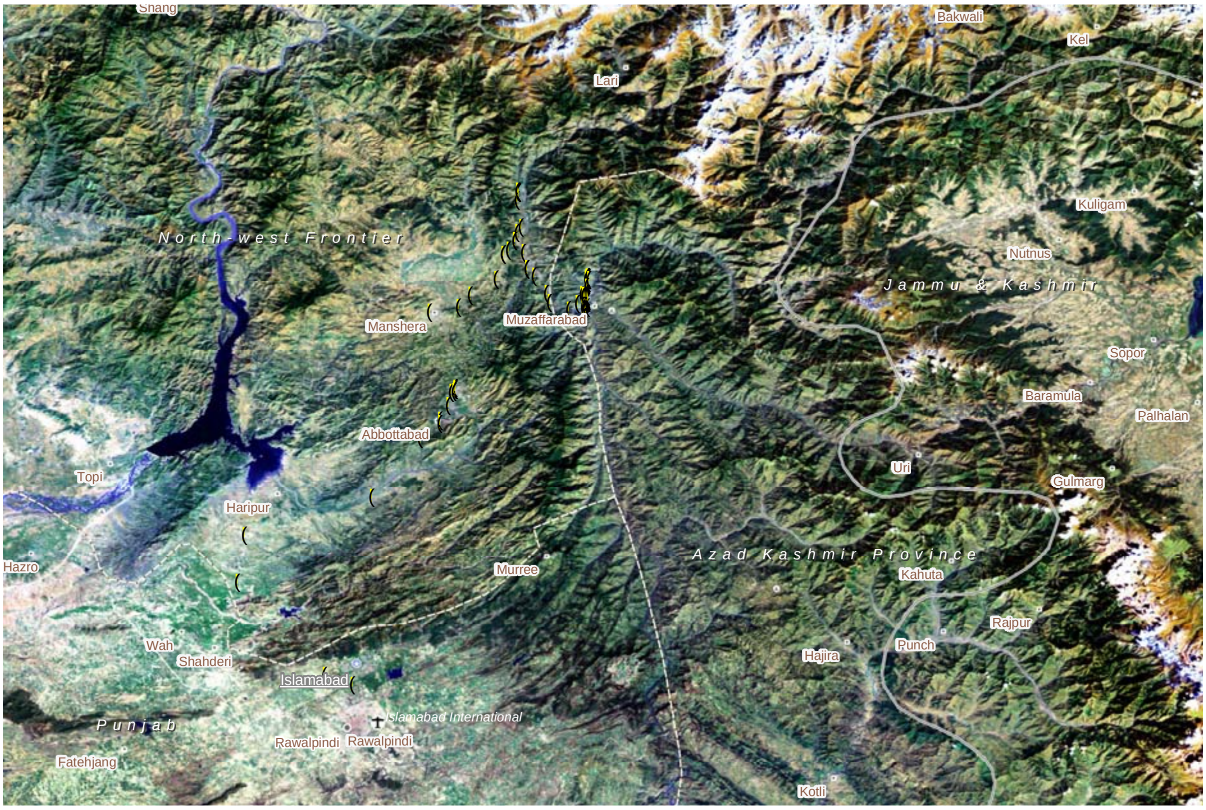

Figure 4.15: Locations of the EEFIT aerial and ground survey

A selection of general observations of landslides and slope failures from these flight paths are described by and within the sequence of photographs in composite Figure 4.16 that follows. As these are observations made in general reconnaissance, detailed location is not usually available.

Specific issues such as impact on roads, impact on buildings on slopes and impact on agricultural terraces are considered in more detail in later sections after this photographic overview.

a)

b)

c)

d)

e)

f)

g)

h)

i)

j)

k)

l)

m)

n)

o)

p)

Figure 4.16: General overview of airborne observations:

a) Shallow depth large landslides on both sides of the mountain (Muzaffarabad-Nausari),
b) Shallow landslide evident from the change in colour and movement of vegetation (Muzaffarabad-Nausari),
c) Shallow landslides and flows into gullies (Muzaffarabad-Nausari),
d) Shallow landslide blocking a road and exposing the foundations of a building above. Other slope failures blocking the same road (Muzaffarabad-Nausari),
e)Collapse of buildings on a shallow landslide (Muzaffarabad-Nausari),
) Large shallow depth landslide and a disrupted landslide evident from the scarp and cracks outlining the displaced volume (Muzaffarabad-Ghari),
g)Numerous shallow depth landslides (Muzaffarabad-Ghari),
h) Small shallow landslides blocking a mountain route (Muzaffarabad-Ghari),
i) Large shallow depth landslides blocking two mountain roads at several locations (Muzaffarabad-Ghari),
j) Shallow landslides and rock falls blocking the road (Muzaffarabad-Ghari),
k) Terraces and damaged buildings (Muzaffarabad-Conoko),
l) Two river side landslides (Islamabad-Dhanni Nelam),
m) Evidence of dwellings on high ridge tops (Islamabad-Dhanni Nelam),
n) Road following river along steep valley side, also see Figure 4.43 for upper terraces (Islamabad-Dhanni Nelam),
o) Terraces, buildings and road in valley head terrain near Dhanni Nelam (Dhanni Nelam-Islamabad),
p) High density housing, Islamabad (Dhanni Nelam-Islamabad)

4.3.2 Buildings, Roads and Geotechnical Structures

4.3.2.1 Undercut and Slipped Buildings

Apart from ground displacement and shaking from the earthquake, landslides and slope failures have also resulted in total collapse or heavy damage of buildings that are on the sliding mass, which could not be easily identified on large deep slips since the building becomes buried in the flowing mass. However, building failure from landslides is visible when the extent of the landslides or slope failure is smaller in volume. Figure 4.17 shows a house that has collapsed with the sliding mass of a shallow landslide north of Muzaffarabad City. The structure of the house was dragged downhill and the RC roof visible on the slope. Figure 4.18 shows a commercial building that was extensively damaged due to a slope failure above where the soil has entered the building premises and collapsed some sections of the building. The same failure has led to the collapse of the commercial building shown in Figure 4.19, possibly due to the weight of the failed mass of soil and rock. This slope failure poses a danger to the residential structure above the slip since its foundation is exposed and further failure of the bare slope is possible.

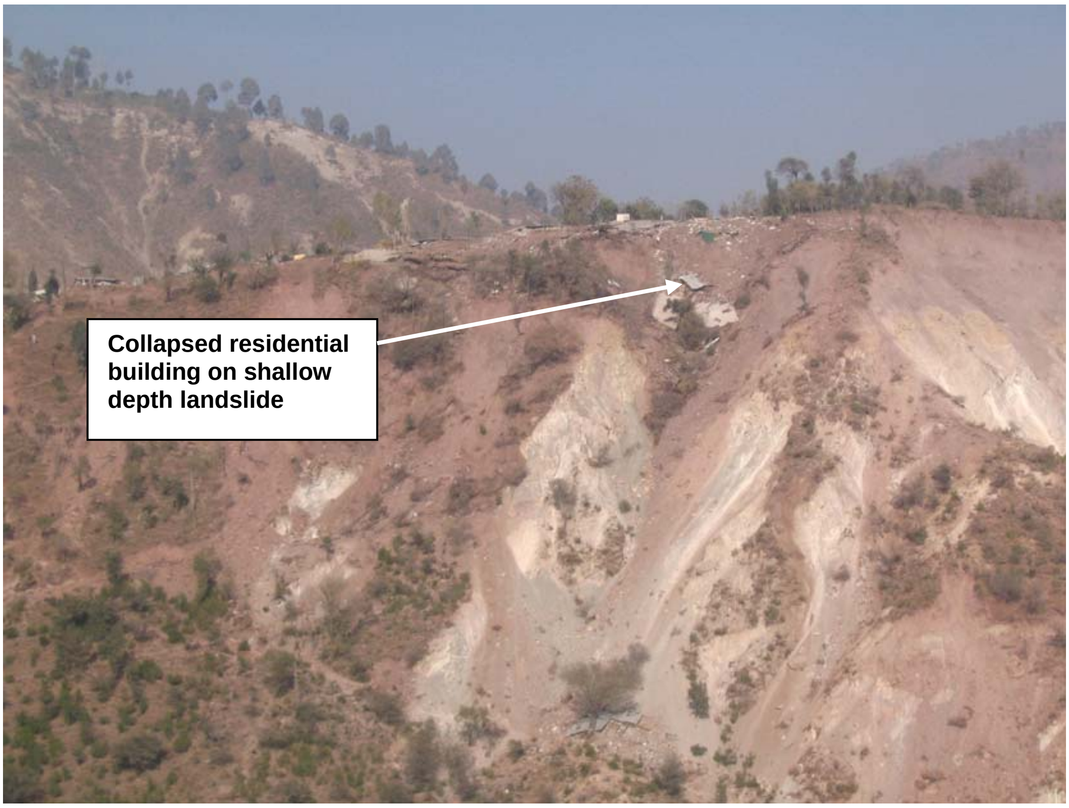

Figure 4.17: Collapsed residential building due to a shallow depth landslide north of Muzaffarabad City

Figure 4.18: Slope failure burying and extensively damaging the commercial building below and destabilising the residential structure above, Muzaffarabad

Figure 4.19: Collapsed and buried commercial building from the soil and rock due to the slope failure shown in Figure 4.18, Muzaffarabad

4.3.2.2 Embankments and Retaining Walls

There were several geotechnical structures that performed badly during the Kashmir Earthquake. These primarily impacted the roads and adjacent structures and lifelines, and many of these were either retaining structures or structures providing facing protection to slopes. Figure 4.20 shows a collapsed concrete retaining wall and facing structure below a road descending into Balakot from the north (see also Figure 4.14). The damaged retaining wall does not appear to have any anchoring to provide sufficient support to the road above. The damage to the retaining structures poses a danger to the road above as it is exposed from slope failure or erosion from rain. A concrete gravity retaining wall by the Kunhar River in Balakot appears to have displaced toward the river as shown in Figure 4.21. However, there is no evidence of any impact on the retained side from this movement.

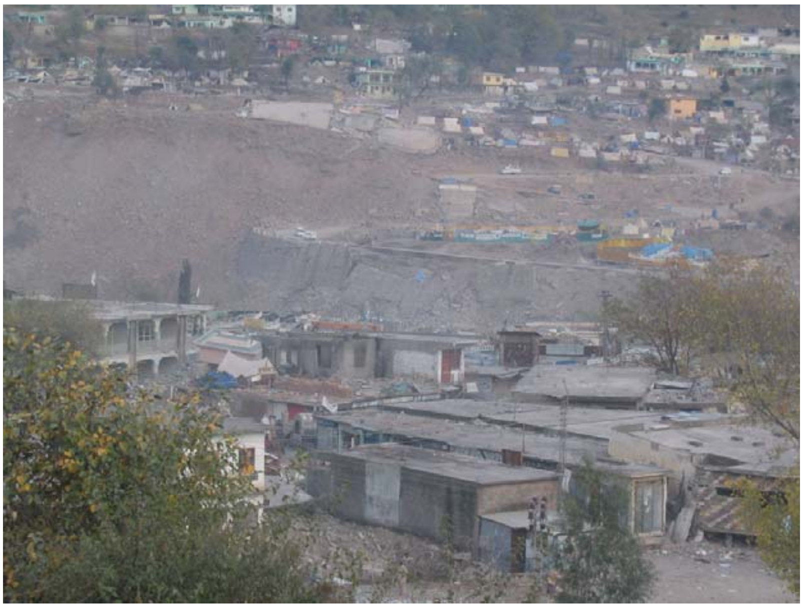

Figure 4.20: Collapsed retaining wall and concrete facing structures in Balakot

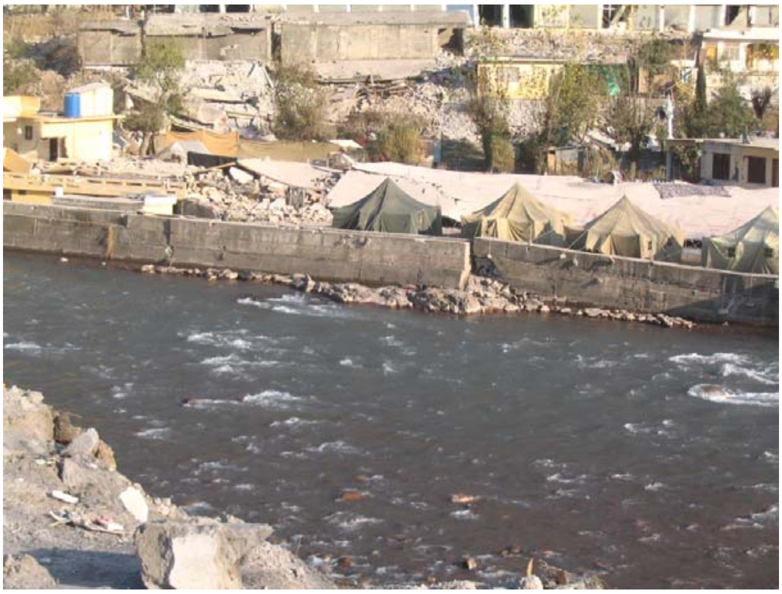

Figure 4.21: Displaced concrete gravity retaining wall by Kunhar River in Balakot

4.3.2.3 Roads and Road Networks: Retaining Walls, Buttresses, Rockfalls and Other Landslides

The nature of the mountainous terrain and topography meant that the road network or system was heavily exposed. Figures 4.22 shows a shallow depth landslide in Balakot, where the northern access road to the city was blocked. Figure 4.23 shows another landslide on the same route where there was a combination of rock falls and soil flow. The landslide here exposed the underlying rock that makes up the mountains in this region. Although the landslides in Figures 4.22 and 4.23 are local events, impact of such local events is broader as they degrade the road network by temporarily blocking the road, and thus removing a link from the network.

Figure 4.22: Shallow depth landslide and slumping of soils blocking an access road to Balakot City, NWFP (photo by Kathrin Renner (Arup) and US Army)

Figure 4.23: Shallow depth landslide exposing the underlying rock. Mixture of rock fall and soil flow block the northern access road to Balakot City, NWFP (photo by Kathrin Renner (Arup) and US Army)

Many examples were seen of localised difficulties with roads attributable to inadequate retaining walls and buttresses and also attributable to rock falls.

Figure 4.24 shows a distant view of collapsed concrete retaining wall section below a major route in Muzaffarabad City that runs just above the Nelum River. This collapse is similar to that in Balakot in Figure 4.20 where there appears to be no anchoring in the retaining wall system. The collapsed section leaves the road vulnerable to further damage from slope failures or erosion from rain. A few hundred metres further along this route to the north (leftwards in Figure 4.24), a stone masonry built retaining wall had failed and slipped slightly down slope. It was not keyed in to the slope it was intended to maintain. Slippage of this gravity retaining wall undercut buildings as seen in Figure 4.25**.**

Such gravity retaining walls often supplied only superficial facing support against a slope. The same wall when it slipped not only undercut housing, but also roads and pavements as shown in Figure 4.26. In this photograph in Muzaffarabad the stone block wall has slipped and cracked; the yellow ochre band top-left is a surviving length of safety railing along a pavement behind which the road itself has also slipped away down slope.

Figure 4.24: Collapsed concrete retaining wall section in Muzaffarabad leaving the road above vulnerable to further collapse

Figure 4.25: Stone block masonry retaining wall in Muzaffarabad: slippage and collapse of this wall undermined buildings

Figure 4.26: Stone block masonry retaining wall in Muzaffarabad, just to the right of Figure 4.25: slippage and collapse of this wall also undermined pavement and road

The road above the retaining wall of Figures 4.25 and 4.26 is illustrated in Figures 4.27 and 4.28.Figure 4.27 shows a collapsed section of this major route through Muzaffarabad city. The collapse of the retaining wall led to the collapse of a section of the road and the pavement and cracks to appear on the road surface. Similar cracking was also observed further along the same route as shown in Figure 4.28. The cracked road sections are exposed to likely further damage unless the collapsed retaining wall sections are quickly repaired to prevent further slope failure or soil erosion.

Figure 4.27: Retaining wall collapse leading to unstable pavement and road sections on a major route through Muzaffarabad

Figure 4.28: Cracks through a major route through Muzaffarabad due to collapsed retaining wall section

The danger of further undercutting and erosion to road surfaces was a common problem in Muzaffarabad. Figure 4.29 shows an unstable slope cutting back through a road in Muzaffarabad.

Figure 4.29: Slope failure adjacent to a major route through Muzaffarabad City, danger of further erosion of the road surface

In addition to these containment and continued erosion problems, there had been severe rock falls and showers during the earthquake. A minor rock fall that had been partially cleared is shown in Figure 4.30. The slope material seen behind the skeletal building in Figure 4.31 lies directly behind the road edge seen in Figure 4.5. Road cracking is clear in Figure 4.5. In addition, at the time of the earthquake, it was reported that the cobble and boulder material that constitutes the slope in Figure 4.31 showered down on to vehicles on the road below causing fatalities.

Figure 4.30: Minor rock fall onto a main route through Muzaffarabad City

Figure 4.31: Rock falls and showers. Cobble and boulder material on slopes showered down on road transport during the earthquake. This site in Muzaffarabad City is above and behind the cracked road edge visible in Figure 4.5

Finally there are more strategic difficulties for the roads attributable to the general interaction of the whole road network with the terrain.

The nature of the mountainous terrain and topography meant that the road lifeline system was heavily exposed. It remains so. Roads of necessity either contour along river valley sides or hair-pin bend their way up hillsides; the photograph Figure 4.32 illustrates the Balakot-Muzaffarabad valley road south of the Masher junction. Photograph Figure 4.33 is from the same point; this road was cut by landslide reactivation of the scree slope during the earthquake. Undercutting of the abutment is also apparent as an ongoing problem. Incipient landslides also pose a further ongoing problem.

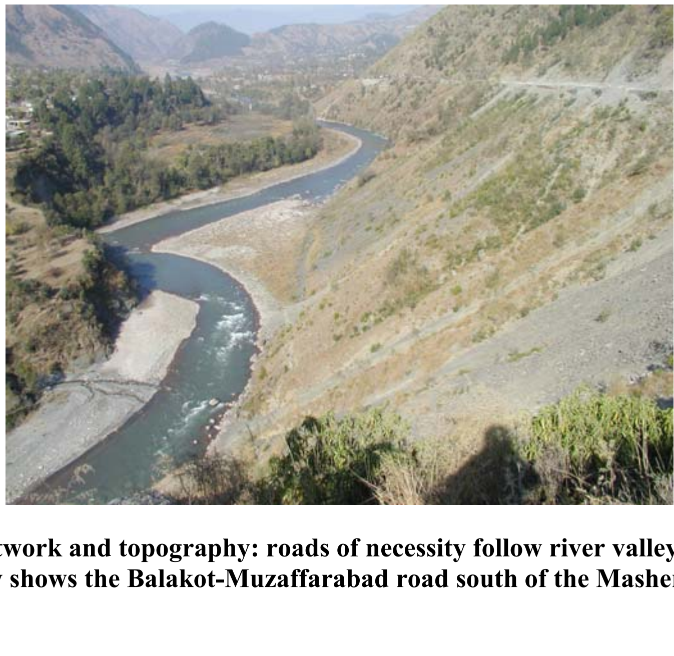

Figure 4.32: Road network and topography: roads of necessity follow river valleys through the terrain. This view shows the Balakot-Muzaffarabad road south of the Masher junction

Figure 4.33: Road network and topography: reactivated landslide blocked this road for about 24 hours and has started to undercut the abutment. View from the same position as Figure 4.32

There were many locations where similar rock falls and slides had occurred. In addition to those caused by the earthquake it has also to be recognised that rock fall and slides are endemic in the region and frequently occur at a small size following heavy rainfall. However, in addition to these detailed and individual examples of impact, an impression of the enormity of the task of road protection in this terrain is given by the snake-like road in Figure 4.34. The lower edge of one S-bend in this photograph has been slightly clipped by a landslide (visible in the lower centre of the photograph), but attempts to protect all parts of such roads that are prevalent throughout such a mountainous area appears to be a task approaching the impossible. This road in itself in Figure 4.34 is just one link in the overall road network.

Figure 4.34: Road network and topography: one example of a snake-like road winding up steep sided terrain

4.3.3 Incipient and Disrupted Slides

Not all visible ground cracks and potential slides had reached maturity as full landslides, several preserved a threat for the futurity. Figure 4.35 shows a mountain side viewed during a relief flight Muzaffarabad-Ghari in which ground cracks are visible. A more extreme example is apparent in Figure 4.36 in which the upper extension crack of an incipient landslide is visible. This incipient landslide has cracked through the road in two places.

Figure 4.35: Ground cracks indicating a possible disrupted landslide

Figure 4.36: Incipient landslide threat to road: the road is cut in two places by cracking (photo by Charles Scawthorn)

In addition to the incipient landslides on mountainside there was also observation of disrupted slides in soil. Figure 4.37 shows a scarp of one disrupted slide, near Muzaffarabad, and the ground cracks that were extending from the scarp are shown in Figure 4.38. These ground cracks extended almost parallel to the slope and some of the cracks had resulted in damage to buildings due to foundation differential settlement. These disrupted landslides also pose a danger to the people living on the landslide, as well as those in the area downhill, since the disrupted slide could eventually flow due to the weight of water from a heavy rainfall or snow melt following the winter, or through disturbance in a future earthquake.

Figure 4.37: Scarp of a disrupted landslide west of Nelum River, Muzaffarabad

Figure 4.38: Ground cracks, an extension of the scarp of the disrupted landslide west of Nelum River shown in Figure 4.8

4.4 Other Impacts and Slope Failures

4.4.1 Minor Lifelines: Waterpipes

Locally small scale subsidence and geotechnical failure was common. The photographs in Figure 4.39 were taken a few km north of Muzaffarabad in exactly the same locality as Figure 4.5. The cracks in the foreground running to the edge of the road in Figure 4.5 are exactly the ones visible in the concrete road edge in the upper left of Figure 4.39. To the right of the road edge is a multiply fractured small-diameter cast iron water pipe. Cracking and subsidence in the road left and next to the water pipe has propagated causing the water pipe to fracture and subside in segments in turn.

Figure 4.39: Smaller geotechnical failures: ruptured cast iron water pipe adjacent to the cracked and subsided road visible in the foreground of Figure 4.5

4.4.2 Agricultural Terraces and Livelihood

The landslides also created impacts on a traditional way of life in the mountains that is endemic. Agriculture in these hills is linked to preservation and tending of terraces on steep slopes. Evidence of such terracing is visible in Figure 4.40 on the hill tops even above the large landslide at Chela Bandi (see Figures 4.4-4.6) north of Muzaffarabad City overlooking Nilam River. This type of agricultural terracing is a characteristic of the region. A typical mountain rural view is shown in Fig. 4.41. In this example the terracing extends down a spur of a hill on which some buildings are visibly damaged and some have collapsed. Relief shelters are also visible. In some cases agricultural terraces were simply truncated by steep landslide as in Figure 4.42. Others, on a typical hill side in the upper part of Figure 4.43, have been partly truncated by a reactivated slide and slipped, while in the foreground the valley-side road is also threatened.

Figure 4.40: Agricultural terraces disturbed above the Chela Bandi landslide of Figure 4.5

Figure 4.41: Agricultural terraces on a steep terrain hill spur near Dhanni Nelam (Dhanni Nelam-Islamabad flight)

Figure 4.42: Agricultural terraces simply truncated by a steep landslide (photo by Charles Scawthorn)

Figure 4.43: Agricultural terraces slipping down steep terrain and valley-side road, all threatened by landslide, near Dhanni Nelam (Dhanni Nelam-Islamabad flight)

This type of devastation to livelihood and a way of life is not unknown in the Karakoram and has been reported before even from moderate sized earthquakes. In 1974 an earthquake with magnitude only 5.5 M_S, with epicentre in the Indus Kohistan near Afghanistan, caused great distress and fatalities over an area of about 300 square miles. The effects on livelihood and casualties reported by Hewitt (1976) included, in addition to humans, "uncounted tiers of terraced fields".

4.5 Conclusions

Field observations yielded no evidence of soil liquefaction effects and the corresponding landslide classes wre absent. There were numerous landslides of many sizes and types in rock, rock debris and soil, all observed during the ground and aerial surveys in the earthquake affected region.

The landslides and ground failure types could be broadly categorized into deep slip landslides, shallow depth slips and localized slope failures. The largest landslides at Chela Bandi, Muzaffarabad and Hattian, Pir Punjal Mountains had volumes close to 10^6 m^3 and in the range 1-6 10^6 m^3 respectively. The latter deep slip landslide caused further hazards by damming river tributaries; large though this landslide was, nevertheless it is three orders of magnitude smaller than other known catastrophic landslides. The distribution of larger shallow depth landslides correlates well with the large horizontal coseismic displacements on the hanging wall inferred for this thrust earthquake NE of the Balakot-Murree-Muzaffarabad fault strike. The locations of the Chela Bandi and Hattian landslides correlate with inferred coseismic asperities on the Balakot-Bagh fault strike.

The major impact of landslides was twofold: firstly, blocking and destabilizing road sections, which were vital to providing relief to remote areas, and secondly, denudation of agricultural terraces that are fundamental to livelihood and a mountain way-of-life. Although the regional terrain and geology is such that landslides and rock falls are a regular occurrence, the Kashmir Earthquake triggered a large number of landslides beyond that normally experienced. What individually might be judged as not-unusual impacts by landslides to roads in this area, were so frequent that the road network was degraded with many links missing from the road system. This required the relief to be airlifted to locations that were not accessible by any route for days.

The collapsed road sections could not be repaired soon after the event since material and equipment could not be readily mobilized. Apart from coherent slides, there were a number of disrupted landslides, which could potentially be precipitated by a heavy rain fall, snow melt following winter or another earthquake. The disrupted landslide cannot be easily detected hence they pose a danger to people living on them. Apart from the major impact on the road network, landslides and slope failures also resulted in damage to buildings and casualties.

Some smaller geotechnical failures observed also showed continuing danger to road sections. Existing damaged and collapsed sections of roads could potentially be damage further from slope failures or soil erosion. The retaining structures do not appear to have a proper anchoring system to provide a function of a retaining structure.

Overall the observations have shown that landslides and other geotechnical failures are a major secondary hazard in the earthquake affected region, and that the road network is the strategic regional system most vulnerable to this hazard, whereas denuded agricultural terraces impact on a mountain way-of-life.

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5 Lifelines

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The damage to lifelines due to the October 8, 2005 Kashmir Earthquake was largely due to the secondary hazard of landslides and other geotechnical failures. Many of the roads, water supply, electricity and telecommunication systems were damaged at locations of landslides and geotechnical failures. This chapter presents the findings from the observations made during the ground and aerial surveys conducted by EEFIT.

5.1 Roads and Bridges

5.1.1 Roads

The impact on roads due to landslides and geotechnical failures was extensively discussed in Chapter 4. Please refer to Chapter 4 for details.

5.1.2 Bridges

The bridges in the EEFIT surveyed areas have performed well during this earthquake. Some bridges suffered minor damage but were fully functional at the time of the survey. The bridges are largely used for vehicular traffic. Some dedicated pedestrian bridges also exist, however, these are also used by vehicles where the deck width is adequate. Figure 5.1 shows a road bridge crossing Kunhar River in Balakot City that was displaced laterally during the earthquake.

Figure 5.1: Laterally displaced RC deck of the vehicle bridge in Balakot

The RC simply supported deck has moved uniformly about 1m relative to initial position as estimated from the gap on the RC bridge pier. There was no visible damage to the RC deck or the piers so the bridge was fully functional despite the misalignment with the approach roads. Figure 5.2 shows a pedestrian foot bridge adjacent to the road bridge shown in Figure 5.1. The approach sections to the bridge have been damaged but the bridge structure itself, a suspension bridge with a timber deck supported by steel cables spanning between two RC towers appears undamaged. This bridge was also fully functional at the time of the survey.

Figure 5.2: Pedestrian bridge with damaged approaches in Balakot

Figures 5.3 and 5.4 show two undamaged pedestrian footbridges of similar construction. However, the bridge in Figure 5.4 shows missing timber deck elements, which may or may not have been removed following the earthquake. Figure 5.5 shows undamaged bridges in Muzaffarabad. The pedestrian bridge shown in Figure 5.8 has a visible crack running through one of its masonry abutments (see Figure 5.9). Again, this bridge was fully functional at the time of the survey.

Surveys carried out by Durrani et al (2005), which cover the region outside the EEFIT surveyed areas indicated good performance of bridges. For instance some of the bridges on the Muzaffarabad to Murree route suffered minor damage, such as crushing at expansion joints and abutments due inadequate expansion gaps between deck segments.

Figure 5.3: Undamaged pedestrian footbridge crossing Kunhar River on route to Balakot

Figure 5.4: Undamaged pedestrian footbridge in Ghari Habibullah, near the NWFP/AJK border

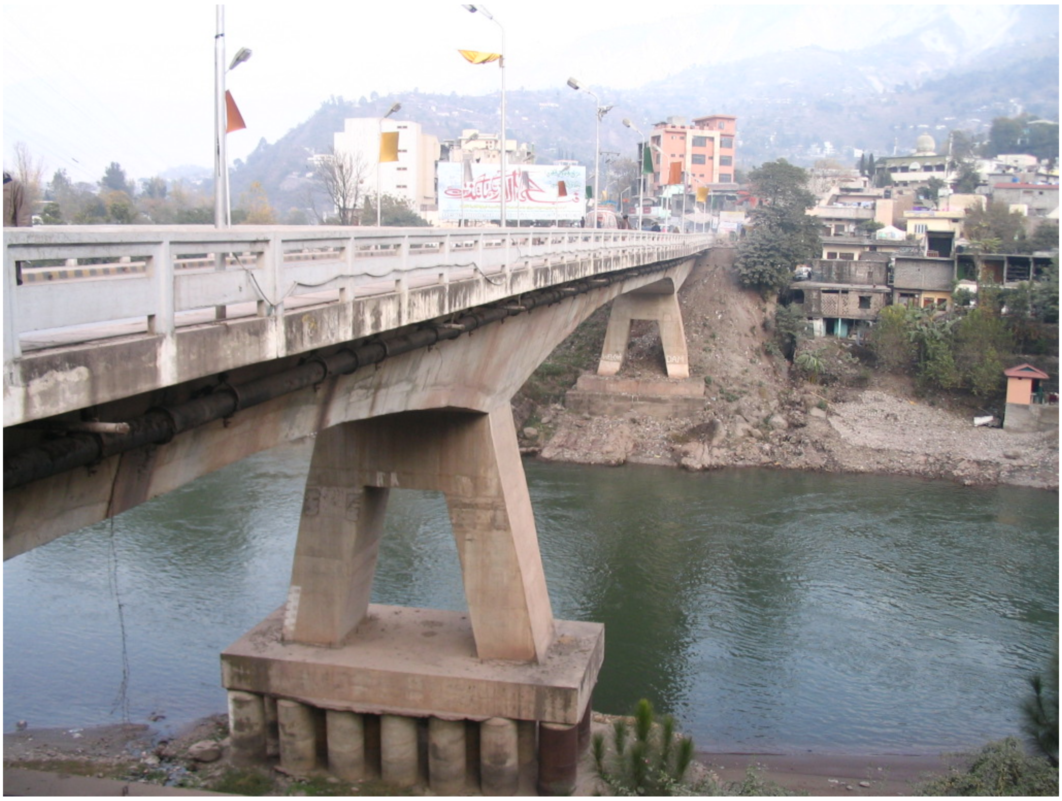

Figure 5.5: Undamaged vehicle bridge across Jhelum River in Muzaffarabad. RC bridge deck, multi-span with integral abutments supported on RC piles with steel casing

Figure 5.6: Undamaged pedestrian bridge across Jhelum River, Muzaffarabad. Bridge consists of steel truss single span simply supported on brick masonry gravity abutments

Figure 5.7: Undamaged vehicle bridge across Nelum River, Muzaffarabad. RC spans simply supported on RC piers and abutment

Figure 5.8: Slightly damaged pedestrian bridge across Nelum River, Muzaffarabad. Steel truss single span simply supported on brick masonry abutments

Figure 5.9: Crack at one of the masonry abutments of the pedestrian bridge shown in Figure 5.8

5.2 Water Supply, Electricity and Telecommunications

The gravity fed water supply systems in NWFP and AJK suffered substantial damage during the earthquake (ADB-WB, 2005). Damage to water distribution systems occurred due to ground shaking, ground cracking and landslides. Water distribution systems often follow the road network. Hence they are vulnerable when roads are damaged. An example of this is shown in Figures 5.10 and 5.11 where a road section in Muzaffarabad was heavily cracked resulting in the separation of water pipe segments.

The electricity distribution systems ranging from the primary and secondary distribution networks to consumer substations suffered damage during the earthquake (ADB-WB, 2005). Figure 5.12 shows a local distribution transformer that has detached itself from the supporting frame. The transmission networks are vulnerable from landslides as shown in Figure 5.13 where a transmission tower is located on a scarp of a shallow depth landslide.

The EEFIT surveys did not observe any damage to telecommunication systems.

Figure 5.10: Ground cracks through a road in Muzaffarabad

Figure 5.11: Separated segments of a water supply system due to ground cracks, Muzaffarabad

Figure 5.12: Transformer unit detached from the supporting structure, Muzaffarabad

Figure 5.13: Potentially vulnerable transmission tower on the crest of a shallow depth landslide

5.3 Conclusions

The damage to the roads was largely from the landslides and geotechnical failures which made the roads impassable or vulnerable to further damage. The bridges in the earthquake affected region performed well despite experiencing minor damages. The vehicle bridges typically consisted of RC deck supported on RC piers and abutments on piles. The pedestrian bridges were largely suspension bridges where the timber deck is suspended on steel cables supported by RC towers at the abutment with an RC approach span. Pedestrian bridges made of steel truss deck were also used for some vehicle traffic. There was substantial damage to the water supply and electricity distribution systems. The EEFIT survey noted some of these damages. The electricity transmission systems are particular vulnerable to landslides and the water supply system is vulnerable to road damage.

5.4 References

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6 Design Codes and Regulations

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The building damage observations discussed in Chapter 3 revealed the extent of the vulnerability of buildings of different occupancy categories in the epicentral area. For instance, residential buildings, which were largely non-engineered structures performed very poorly at or beyond the collapse prevention performance level in earthquake damage terminology. Commercial buildings had a mixed performance depending on the building typology. Masonry buildings with RC floors and roofs achieved at collapse prevention level or worse. RC frame and slab structures, which could be considered engineered, performed at immediate occupancy or life safety performance levels. Government buildings and educational institutions performed poorly. The former reached life safety or collapse prevention levels whilst the latter performed even worse. The importance of these occupancy categories justifies their being engineered structures, however their poor performance raises questions as to how they were designed and built. The varying building performance levels, particularly among the engineered structures, raises questions as to whether the Pakistan building code was followed, whether its seismic provisions were applied, and whether these provisions are adequate for the seismic regions of Pakistan.

The Pakistan seismic code was published in October 1986 and quoting the document is "an advisory document for use throughout Pakistan with a view to achieve uniform objectives…" with "legal enactment are expected to be sought under various laws of the land framed for the purpose of building activities". Indeed the seismic code was never enforced in Pakistan (few Pakistani structural engineers have even heard of it). It has been used only occasionally, mainly in special structures or in major cites that were practically unaffected by the October 8, 2006 earthquake due to their distance from the earthquake source. This chapter is dedicated to the review of the Pakistan seismic code as it represents the current level of seismic design guidance available to the Pakistan building industry. It is demonstrated that an improved seismic code is required for Pakistan..

6.1 Summary of the Pakistan Seismic Code Prescriptions

The Pakistan seismic code defines a static lateral force procedure for determining the seismic actions on buildings (these actions do not apply to nuclear power stations, dams and other important structures). The design base shear (*V*) is given by the following formula:

$$V = ZIKCSW \quad \text{and} \quad CS \le 0.14$$

Where *Z* is the zone factor, *I* is the occupancy importance factor, *K* is the horizontal force factor, *C* is the base shear coefficient, *S* is a numerical coefficient for site-structure resonance and *W* is the total dead load. *Z* is determined from the seismic zoning map of Pakistan presented in the code, and shown in Figure 6.1. The values of *Z* for each zone are presented in Table 6.1. It should be noted that the *Z*-values do not represent the peak ground acceleration associated with the zones.

The value of *I* is given by the code to equal 1.5, 1.25 and 1.0 for essential facilities, facilities assembling more than 300 people and all other structures, respectively. Essential facilities are defined by the Pakistan code as hospitals, fire and police stations. This category therefore does not include schools, which were a major cause of life loss during the Kashmir earthquake. *K* is defined based on the arrangement of structural resisting elements, and takes a value of 0.8 for dual bracing systems, 0.67 for ductile moment resisting frames and 1.0 for all other frame building systems.

The base shear coefficient, *C*, is determined similarly to Uniform Building Code (UBC) 1997 as:

$$C = \frac{1}{15\sqrt{T}} \quad \text{where} \quad T = \frac{0.05h_n}{\sqrt{D}} \text{ and } C \le 0.12$$

Where T is the fundamental period of vibration of the structure, h_n is the height of the building above ground level and D is the length of the building plan in the direction of applied load. Both h_n and D are measured in metres. An alternative equation ($T = 0.1N$, where N is the number of stories in a building) is also proposed for calculating the fundamental period in ductile moment resisting frames.

S, the numerical coefficient for site-structure resonance, must always be greater than or equal to 1.0, and is evaluated from the following equations relating S to the ratio of structure to characteristic site period (T/T_s):

For $T/T_s \leq 1.0$ $$S = 1.0 + \frac{T}{T_s} - 0.5\left(\frac{T}{T_s}\right)^2$$

For $T/T_s > 1.0$ $$S = 1.2 + 0.6\frac{T}{T_s} - 0.3\left(\frac{T}{T_s}\right)^2$$

Where T is to be established by a properly substantiated analysis but shall not take a value less than 0.3s. If T has been established from a properly substantiated analysis but exceeds 2.5s, the value of S is found by assuming $T_s = 2.5$s. When instead T_s is not properly established then a value of S of 1.5 should be taken.

For structures with regular configurations the total base shear is distributed along the height of the structure according to the following formula:

$$V = F_t + \sum_{i=1}^{n} F_i$$

In this equation n is the uppermost floor number and F_i is the horizontal load applied to level i. F_t is a concentrated load applied to the top floor of a building (in addition to F_n) when its fundamental period exceeds 0.7s. This provision is also present in UBC 1997 and is included to account for the increasing contribution of higher modes in more flexible structures. F_t and F_i are determined from the following expressions, which assume a predominant first mode response:

$$F_t = 0.07TV \leq 0.25V \quad \text{and} \quad F_i = \frac{(V - F_t)W_i h_i}{\sum_{x=1}^{n} W_x h_x}$$

In these equations W_i and h_i are the effective dead weight and height of storey i, respectively. T is the fundamental elastic period of vibration of the structure in the direction of the loading.

Insufficient information was available to the authors at the time of writing this report to allow for comment on the detailing criteria included in the code. It can possibly be assumed that no capacity design criteria are included in the code but that some seismic detailing criteria are included, in a similar way to what is found in European seismic codes published in the mid 1970's.

6.2 Discussion of the Pakistan Seismic Code Zoning Map

The seismic zoning map in the Pakistan Seismic Code is shown in Figure 6.1. The map divides Pakistan into four zones, (see Table 6.1), based on instrumental data collected from the Quetta Geophysical Centre between 1905 and 1979, and on values of felt intensity in each region during past earthquakes. Quoting the code: "the maps are based on a simple premise that the ground motion of a certain intensity experienced once in a certain area is likely to experience again in that area", and "the map does not take into account recurrence intervals of different magnitude earthquakes". These are serious assumptions which severely affect the usefulness of the code. In view of the large return periods associated with major earthquake events, 74 years of instrumental data and associated observed effects cannot be deemed a sufficient basis for defining a seismic zone map. The exclusion of historical events can lead to an under estimation of the design base shear for areas where the seismicity is characterised by large earthquakes of infrequent occurrence.

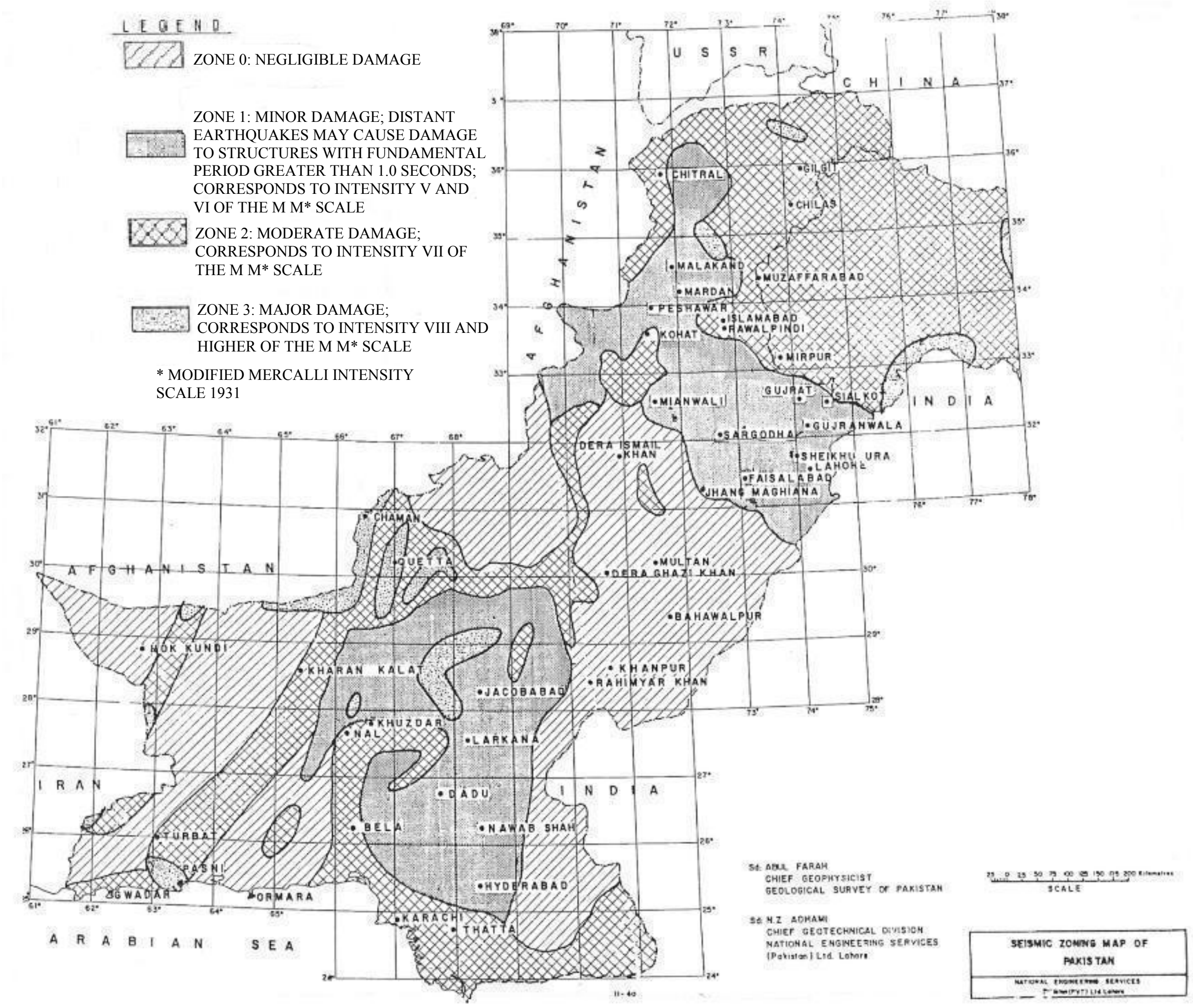

Figure 6.1: The Pakistan seismic zoning map (as per 1986 Pakistan Seismic Code)

From Figure 6.1 it can be seen that all the areas in Jammu Kashmir and North West Frontier Province that were affected by the October 8, 2005 earthquake lie in Seismic Zone 2. According to Table 6.1, these areas are likely to be subjected to moderate damage, corresponding to Intensity VII. In fact the affected areas i.e. Balakot, Muzaffarabad, etc were observed to have Intensities ranging from VIII to X, which greatly exceed that defined for Zone 2, and would place the epicentral region in Zone 3 (as defined in Table 6.1).

Table 6.1: Summary of the seismic zones defined in the Pakistan Seismic Code

Zone	Description of likely intensity	Z-value
0	Negligible damage MMI[1] ≤ IV	3/32
1	Minor damage. Distant earthquakes may cause damage to structures with T > 1s. MMI = V to VI.	3/16
2	Moderate damage. Corresponds to MMI = VII	3/8
3	Major damage. MMI ≥ VII	3/4[2]

[1] *Modified Mercalli Intensity of 1931*
[2] *In locations in Zone 3 that are near known faults Z should be taken to equal 1*

The statement made that in drawing the maps, "the recurrence intervals of different magnitude earthquakes were neglected", means that a probabilistic seismic hazard analysis was not used in delineating the seismic zones. Hence, the zone factor (which represents the ground motion) in each location is associated with a different (and non-quantified) exceedence probability. This means that structures in different locations are being designed for different (and unknown) levels of risk. This is a serious problem for engineers using the Pakistan Seismic Code.

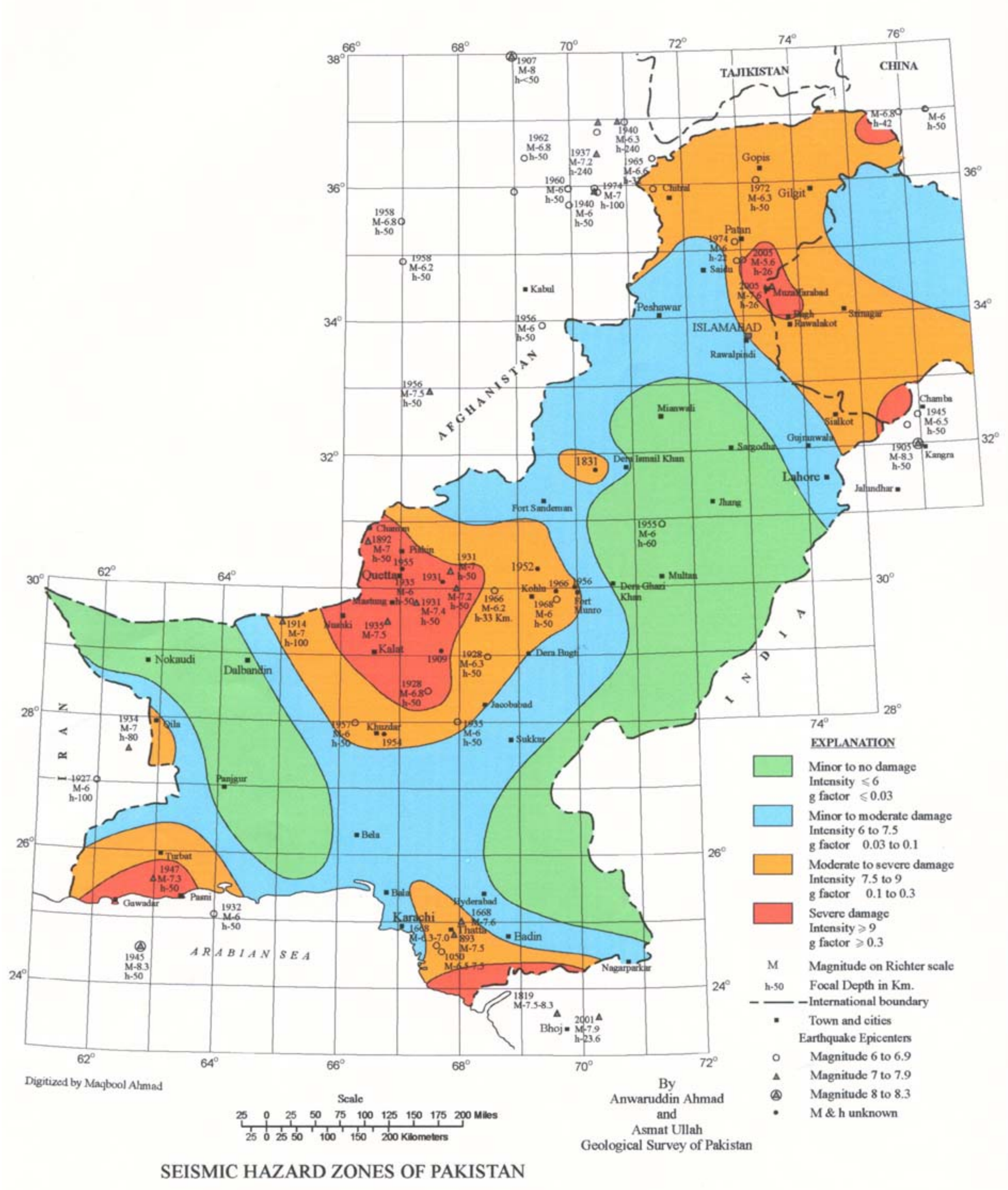

Figure 6.2: The revised Pakistan seismic zoning map, published by the Geological Survey of Pakistan following the October 8, 2005 Kashmir earthquake.

Following the October 8, 2005 event a new version of the Pakistan seismic hazard map was released by the Geological Survey of Pakistan (see Figure 6.2). A significant change can be observed in the contours of the zones which arise from the inclusion of historical records (large events dating back to the 17th century are recorded on the map). One obvious difference is that the area around Muzaffarabad has been assigned to the highest zone. Furthermore, all zones have been upgraded and Seismic Zone 0 has been eliminated, even though the descriptions of the zones in terms of intensity are virtually unchanged. In this map, ranges of PGA are presented for each seismic zone (see Figure 6.2 and Table 6.2). Although the new map may be an improvement on the old seismic zone map in terms of the additional earthquake data used, it also neglects the recurrence intervals of different magnitude earthquakes. The PGA values are therefore most likely extrapolated from strong ground motion, either recorded or derived from ground motion prediction equations, for large events in the past. Thus it poses the same problem to engineers of non-uniform and unknown seismic risk for their structure designs.

The values of PGA presented in the new version of the Pakistan zoning map are however seen to be significantly higher than those implied by the old code zone factors. This means that designs carried out following the 1986 code may be unsafe in view of the new "improved" hazard assessment. GSHAP assigns 500year return period PGA values to the Kashmir region in Pakistan ranging between 0.24g to 0.32g, with some areas in the NWFP being in the range 0.32g to 0.4g. These values tie in fairly well with the new seismic zoning map for Pakistan, but are three times larger than the PGA values assigned to the area by the old zoning map.

From this discussion it is clear that the Pakistan Seismic Zone map of 1986 in the Pakistan Seismic Code is inadequate for use in the seismic design of structures. The new map is an improvement but should be based on a probabilistic seismic hazard assessment rather than on past earthquake observations and their effects.

6.3 Comparison of Base Shear Prediction in Pakistan Seismic Code with Eurocode 8 and UBC 1997

A further problem in the Pakistan Seismic Code is that the zone factors, *Z*, associated with each area do not directly represent the value of peak ground acceleration being designed for, which makes it difficult for the engineer to compare the seismic provisions with those implemented in locations with similar tectonic settings and seismic activity. A back-analysis of the normalized base shear (V/W, that is representative of the spectral acceleration response) equations of the 1986 code was therefore carried out in order to find the PGA values implied by the zone factors. This back-analysis consists of plotting the variation in V/W with T given by the Pakistan Seismic Code for the different zones and matching the constant plateaus with those of similar plots derived from Eurocode 8 (EC8) (see Figure 6.3). The comparison, carried out for ordinary importance (I = 1, γ_I = 1), ductile and non-ductile moment resisting frames (K = 1.0 and 0.67, q = 3.6 and 5.4), for rock and soft soil site conditions (T_s = 0.08s and 0.67s, Soil class A and D). Two examples of the resulting plots are shown in Figure 6.3. All the plot comparisons concur to give the values of PGA shown in Table 6.2.

Table 6.2: PGA values for the Pakistan seismic zones derived from comparison with EC8 and those stated in the new seismic zone map of Pakistan

Zone (1986 code)	Z-value	PGA (g), EC8	Zone (2005 map)	PGA (g), (2005 map)
0	3/32	0.016	1	≤ 0.03
1	3/16	0.033	2	0.03 – 0.1
2	3/8	0.065	3	0.1 – 0.3
3	3/4[2]	0.130	4	≥ 0.3

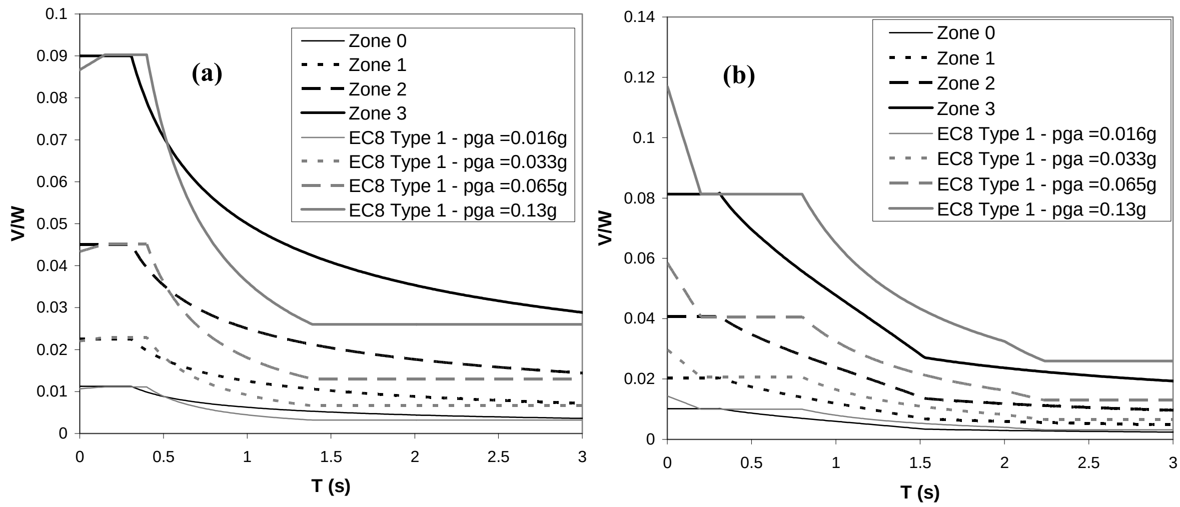

Figure 6.3: Examples of the plots of normalized base shear vs building fundamental period given by the Pakistan 1986 Seismic Code and Eurocode (EC) 8 used to find the PGA corresponding to each seismic zone: (a) Normal importance, non-ductile frame and rock-site conditions, (b) Normal importance, ductile frame and soil conditions

Figure 6.3 compares the plots of normalized base shear (representative of the spectral acceleration) versus structural period given by Eurocode 8 (EC8) and the 1986 Pakistan Seismic Code for the same PGA values, for soil and rock site conditions. It is observed that for soil site conditions EC8 assigns a greater base shear than the Pakistan Seismic Code for structures with fundamental periods between 0.6s to 2.0s. The opposite is true in the case of the rock site, although the difference is not as large in this case. This would seem to suggest that the 1986 Pakistan Seismic code under-predicts the seismic actions on flexible structures. A similar trend is seen in the comparison between the Pakistan code and UBC 1997 below.

Table 6.3: Normalised base shear (V/W) values for 3-storey and 5-storey ductile and non-ductile reinforced concrete moment resisting frames founded on soft soil and rock sites calculated according to UBC 1997 and the 1986 Pakistan Seismic Code

Building Type	Soft Soil			Rock		
	PK 1986 Zone 2	UBC1997 Zone 1	UBC 1997 Zone 4	PK 1986 Zone 2	UBC1997 Zone 1	UBC 1997 Zone 4
3-storey non-ductile MRF	0.061	0.136	0.257	0.045	0.043	0.229
3-storey ductile MRF	0.061	0.133	0.257	0.045	0.031	0.164
5-storey non-ductile MRF	0.040	0.056	0.106	0.030	0.018	0.094
5-storey ductile MRF	0.035	0.055	0.106	0.024	0.013	0.068

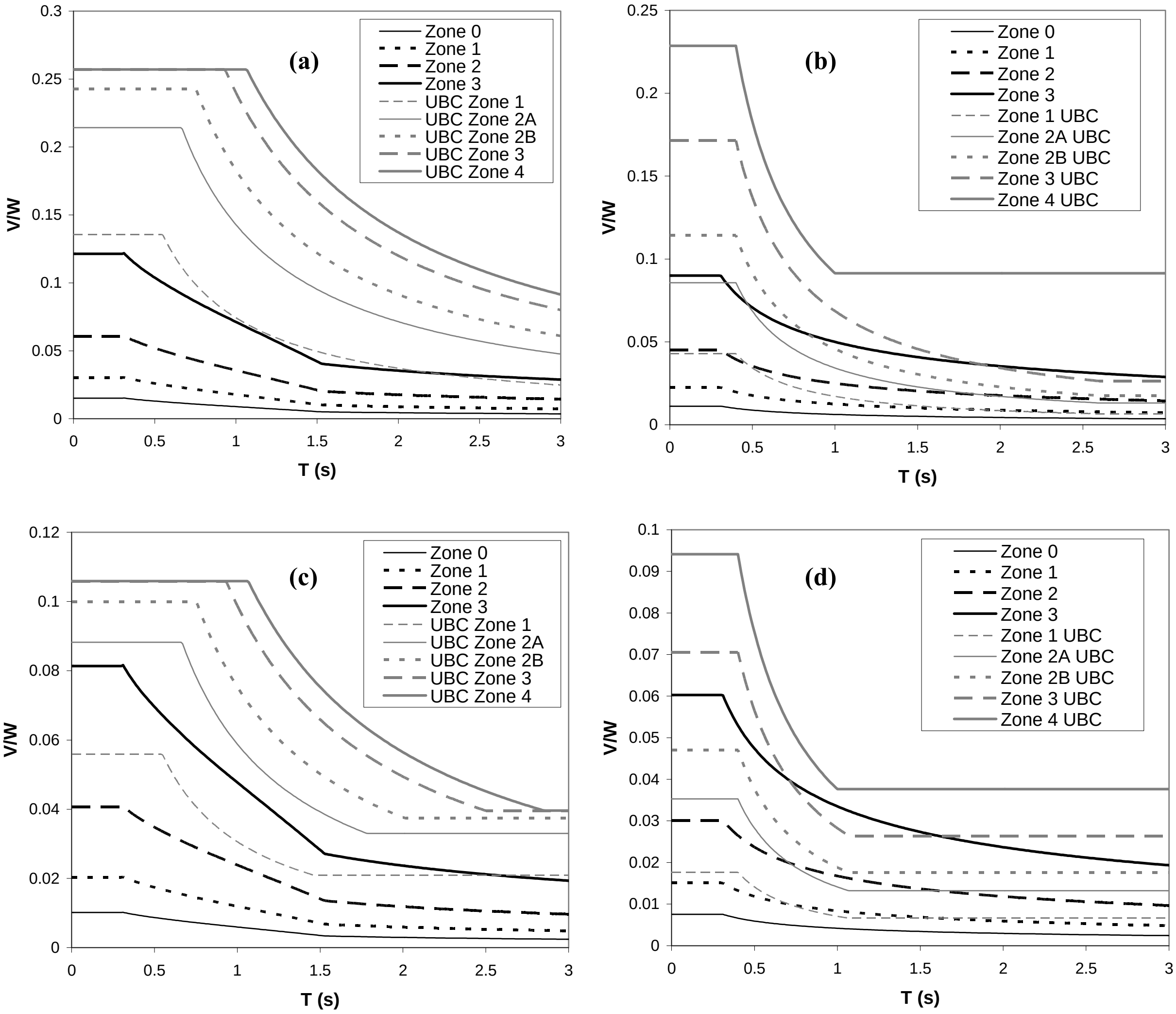

Figure 6.4: Examples of the plots of normalized base shear vs building fundamental period given by the Pakistan 1986 Seismic code and UBC 1997: (a) Normal importance, non-ductile MRF and soft-soil site conditions, (b) Normal importance, non-ductile MRF and rock site conditions, (c) Normal importance, ductile MRF and soft-soil site conditions, (d) Normal importance, ductile MRF and rock site conditions

Figure 6.4 compares the plots of normalized base shear versus structural period obtained from UBC1997 and the 1986 Pakistan Seismic Code for ductile and non-ductile reinforced concrete moment resisting frames for both soft soil and rock site conditions. From the plots it is clear that the base shear prescribed by the 1986 Pakistan seismic code for the design of buildings in its highest zone, is often less than that prescribed by UBC 1997 for its second lowest seismic zone (Zone 2A). The base shear given for Zone 2 in the Pakistan seismic code, which applies to the Kashmir Region, is in most cases seen to be less than that for Zone 1 in UBC 1997. The difference in magnitude of the prescriptions for base shear is further illustrated in Table 6.3. These observations strongly contradict the UBC 1997 recommendation that Pakistan be assessed as if it is in UBC Zone 4.

6.4 Conclusions

The static lateral force procedure presented in the 1986 Pakistan Seismic Code is not an unreasonable basis on which to build a new seismic code for Pakistan. However, a revision of the Pakistan seismic code should be made to include capacity design principles and modern developments in terms of seismic analysis and design. Major flaws have however been identified in the seismic zone map, which needs to be revised to include both recent and historical seismic events and a probabilistic seismic hazard evaluation. In light of the new seismic zone map proposed by the Geological Survey of Pakistan, which takes a first but insufficient step in the right direction, and from comparisons with EC8 and UBC 1997 it is expected that the hazard map revision will result in substantially higher seismic design forces.

6.5 References

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7 Socio-Economic Impact and Recovery

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The October 8, 2005 Kashmir Earthquake destroyed over 270,000 buildings and partially damaged about 180,000 buildings in the affected districts of North West Frontier Province (NWFP) and the Pakistan administered Kashmir (AJK). The number of casualties as at January 1, 2006 was 72,763 deaths and 68,679 injuries making this earthquake the 5th most fatal in the world since 1900. Pakistan is a developing nation with an economic ranking of 43 in the world in terms of economic output and GDP per capita (World Bank data). The affected region has the highest incidence of poverty (headcount index of 42.6%) in Pakistan. This chapter discusses the societal impact (casualties, housing, health and education) and the economic impact to the region and to the country from the Kashmir Earthquake.

7.1 Societal Impact

7.1.1 Casualties

Initial estimates suggest that the earthquake resulted in about 80,000 deaths and 70,000 injuries in the earthquake affected North West Frontier Province (NWFP) and Azad Jammu Kashmir (AJK) Province, leaving more than 2.8million people without shelter. These figures were expected to rise as more of the remote areas are accessed in time. Table 7.1 summarizes the number of deaths and injuries by district in the affected NWFP and AJK provinces at November 12, 2005. The largest recorded deaths were in the Muzaffarabad district at 33,724 and the Muzaffarabad city (capital of AJK) with a population of about 80,355 recorded about 23,000 fatalities (29% of the city's population was killed).

Table 7.1: Casualties in the affected districts of NWFP and AJK provinces

District	Deaths	Injuries
North West Frontier Province (NWFP)		
Shangla	423	957
Mansehra	24,511	30,585
Kohistan	661	639
Abbottabad	515	1,730
Batagram	3,232	3,279
Sub Total	**29,342**	**37,190**
Azad Jammu Kashmir (AJK)		
Neelum	447	1,013
Muzaffarabad	33,724	21,374
Bagh	8,157	6,644
Rawalakot	1,025	1,909
Sudhnoti	4	16
Mirpur	6	11
Sub-Total	43,363	30,967
Total	**72,705**	**68,157**

Source: www.ajk.gov.pk, ADB-WB (2005), data at Nov 12, 2005

The victims were from already vulnerable groups, living in comparatively inaccessible mountain areas with lower levels of income compared to the national average (ADB-WB, 2005). Many of the victims were women and children since many women were caught unaware in houses when the earthquake occurred and the collapse of school buildings resulted in deaths of many school children. Among the injured, many will be permanently disabled due to spinal cord injuries, severe head injuries and injuries to limbs, resulting in a high proportion of amputations. Many victims succumbed to their injuries in the absence of medical treatment as the victims could not be rescued in time due to access difficulties.

Various researchers have investigated the relationship between casualties and building damage due to earthquakes, given that it is the damage to buildings that largely leads to earthquake casualties (Coburn and Spence (2002), FEMA (2006)). Chapter 3 discusses the performance of various occupancy types; residential, commercial, government and educational institutions. It is clear that the performance in the above occupancies, apart from commercial buildings, was worse than life safety and collapse prevention performance levels (FEMA 356), hence the consistency with the high rate of casualties particularly among school children since the earthquake occurred on a school day.

7.1.2 Housing, Health and Education

The damage to housing, health and education infrastructure had a profound social impact on the affected region. Table 7.2 lists the damage statistics for housing and other institutions by district in the affected NWFP and AJK provinces. In total over 272,019 buildings was totally destroyed and 182,886 buildings suffered partial damage. More buildings were fully damaged than partially damaged in AJK and the trend is reversed in NWFP. Housing constituted the largest proportion of destroyed (96%) and partially damaged (97%) buildings in the affected districts. According to the 1998 population census, a typical house is occupied by 7 people in urban areas and 6 people in rural areas. The damage to housing therefore resulted in more than 2.8million people without proper shelter. Shelter was provided by the Government of Pakistan, United Nations agencies, NGOs and donors in terms of supply of tents and other material to repair partially damaged homes to survive the advancing winter.

Table 7.2: Damage statistics in the affected districts of NWFP and AJK provinces

District	**Housing**		**Medical Facilities**		**Educational Institutions**		**Other Govt. Buildings**		**Misc. Structures (Shops, Mosques, etc)**		**Sub-Total**	
	Full*	Partial*	Full	Partial	Full	Partial	Full	Partial	Full	Partial	Full	Partial
North West Frontier Province (NWFP)												
Abbottabad	6961	27051	11	26	295	736	-	-	-	-	7267	27813
Batagram	28712	8656	35	5	268	180	-	-	-	-	29015	8841
Kohistan	4350	18395	-	22	154	320	-	-	-	-	4504	18737
Mansehra	31323	43282	35	19	935	624	-	-	-	-	32293	43925
Shangla	15661	10281	13	19	206	247	-	-	-	-	15880	11087
Sub-Total	**87007**	**108205**	**94**	**91**	**1858**	**2107**	**-**	**-**	**-**	**-**	**88959**	**110403**
Azad Jammu Kashmir (AJK)												
Neelum	3692	7215	0	9	0	75	0	2	0	1690	3692	8991
Muzaff.	108157	17120	103	0	929	0	77	89	5945	0	115211	17209
Bagh	47619	18226	49	40	511	240	186	76	0	154	48365	18736
Rawalakot	15086	25405	16	19	125	275	78	71	57	0	15362	25770
Sudhnoti	429	1719	0	2	1	54	0	0	0	2	430	1777
Mirpur	0	0	0	0	0	0	0	0	0	0	0	0
Sub-Total	**174983**	**69685**	**168**	**70**	**1566**	**644**	**341**	**238**	**6002**	**1846**	**183060**	**72483**
Total	**261990**	**177890**	**262**	**161**	**3424**	**2751**	**341**	**238**	**6002**	**1846**	**272019**	**182886**

Source: www.ajk.gov.pk, ADB-WB (2005), data for Nov 12, 2005

**Full implies fully damaged structure defined as a structure damaged in excess of 40%. Partial implies partially damaged defined as a structure damaged to an extent 40% or less.*

The damage to health infrastructure has been widespread with 423 health facilities fully damaged or partially damaged (Table 7.2). Almost 75% of the first level care facilities have been either fully damaged or suffered partial damage (ADB-WB, 2005). Additionally, there were deaths and injuries among the health care staff and particularly among female health workers. These physical and human losses resulted in a complete breakdown of the health system, with disruption to both primary and secondary care services. In addition the health management in the AJK province at the central level, district level and at facility level was paralyzed due to loss of information records and systems. Health care was being provided by medical teams through the establishment of 11 field based hospitals with support from the Pakistan Army, Ministry of Health, UN agencies, NGOs and local people.

Substantial damage occurred to the education infrastructure where 95% of the buildings were either fully or partially damaged in AJK and the percentage was 53% in NWFP (Table 7.2). In addition to physical damage, about 18,095 students and 853 teachers have died in both AJK and NWFP. The loss of teachers meant the loss of teaching force and the government's investment in teacher training capacity. The most urgent requirement was to resume classes at all levels in order to introduce some normalcy to the lives of affected people. This required setting up temporary and semi-permanent learning spaces, e.g. tents and semi-permanent structures and provision of school equipment.

7.2 Economic Impact

The economic impact of the earthquake includes the estimation of direct and indirect losses and reconstruction costs, and the determination of the macroeconomic impact due to earthquake induced losses. The direct loss is the monetary value of the fully or partially damaged assets such as social, physical and economic infrastructure. Indirect loss arises from the disruption to the flow of goods and services resulting in increased expenses, reduced production and revenue. Reconstruction costs measure the cost of rebuilding the lost assets and restoring the lost services. Table 7.3 summarizes the preliminary estimates of direct and indirect losses from the October 8, 2005 earthquake and reconstruction costs from the preliminary damage and needs assessment carried out by ADB-WB (2005).

Table 7.3: Preliminary estimates of losses and reconstruction costs as of November 10, 2005 (ADB-WB, 2005)

Sector	Direct Damage (Rs. mill.)	Indirect Losses (Rs. mill.)	Reconstruction Costs* (Rs. mill.)	Reconstruction Costs* (US$ mill.)	Share of Total Reconst. Costs (%)
1. Social Infrastructure					
Private Housing**	61,200	7,218	92,160	1,552	44
Health	7,114	1,378	18,012	303	9
Education	19,920	4,133	28,057	472	13
Environment	12		8,985	151	4
Public Administration	2,971	687	4,254	72	2
2. Physical Infrastructure					
Transport***	20,165	4,061	24,699	416	12
Water Supply and Sanitation	1,165		1,900	32	1
Irrigation	324		623	10	0
Energy, power and fuel	744	1,561	2,377	40	1
3. Economic Sectors****					
Agriculture and livestock	12,933	6,770	17,846	300	9
Industry and services	8,578	8,379	9,178	155	4
4. Total = 1+2+3 (in Rs. million)	**135,146**	**34,187**	**208,091**	**3,503**	**100**
O/w: AJK	76,735	17,671	116,625	1,963	56
: NWFP	58,771	16,516	91,467	1,540	44
O/w: Public Assets	48,131	12,175	82,187	1,384	39
: Private Assets	87,015	22,012	125,904	2,120	61
O/w: Urban Areas	26,490	13,675	46,163	777	22
: Rural Areas	108,656	20,512	191,928	2,726	78

Source: ADB-WB (2005), data for Nov 12, 2005

**Includes cost of reconstruction of both immovable and movable assets and restoration of public services.*
***Includes value of household contents such as consumer durables; reconstruction cost excludes replacement of these assets.*
****Includes roads and bridges.*
*****Total losses and reconstruction cost in agriculture, industry and services are over and above what is accounted for by the sectors listed above.*

The earthquake has resulted in a direct damages amounting to Rs.135.1 billion (US$2.3 billion). The largest proportion of damage is in the housing sector at Rs.61.2 billion (US$1.0 billion) followed by transport sector at Rs.20.2 billion (US$343.0 million). The level of direct damage is higher in AJK at Rs.76.4 billion (US$1.3 billion) than in NWFP at Rs.58.7 billion (US$1.0 billion). The reconstruction cost of all assets is estimated at Rs.208.1 billion (US$3.5 billion), which considers the replacement cost of the damaged assets and the additional cost to be incurred due to seismic resistant design.

The economic sectors impacted by the earthquake are agriculture and livestock, and industry and services (ADB-WB, 2005). Agriculture and livestock accounts for 34% of the employment in AJK and 47% in NWFP. Most of the rural population in the affected provinces engages in subsistence agriculture. The damage to agricultural assets worth Rs.12.9 billion (US $220 million) is substantial to this sector where the decline in the production capacity could further impair the food security and livelihoods generating severe social consequences. The service sector, which also provides employment for 35% in AJK and 24% in NWFP could also lead to similar social problems. The severe social consequences are due to high levels of poverty in the affected provinces, particularly in rural areas. For instance the NWFP has recorded the highest percentage of people considered poor (headcount index of 43%) in both urban and rural areas (Zaidi, 2005).

The overall cost of the earthquake has been estimated to be at US $5.2 billion by ADB-WB (2005). This estimate includes the reconstruction cost of US $3.5 billion and the cost of relief and early recovery of US $1.7billion as summarized in Table 7.4.

Table 7.4: Overall cost of the earthquake

Category		US$ million
Relief		1,092
Death and injury compensation		205
Early recovery		301
Restoration of livelihoods		97
Reconstruction		3,503
Of which short term reconstruction	*450*	
Of which medium/long term reconstruction	*3,053*	
Total		**5,198**

Source: ADB-WB (2005), data for Nov 12, 2005, excludes indirect losses (income) of US$576 million

The macroeconomic impact was assessed in terms of the impact on the Gross Domestic Product (GDP) of the affected provinces and the country from the earthquake. It has been estimated that the impact of the earthquake on Pakistan's official GDP, which excludes GDP from AJK is expected to be relatively small at about 0.4%. This is due to the affected districts in AJK and NWFP accounting for only 0.8% and 1.5% of the national GDP respectively. Figure 7.1 illustrates the macroeconomic impact from the Kashmir Earthquake (ADB-WB, 2005).

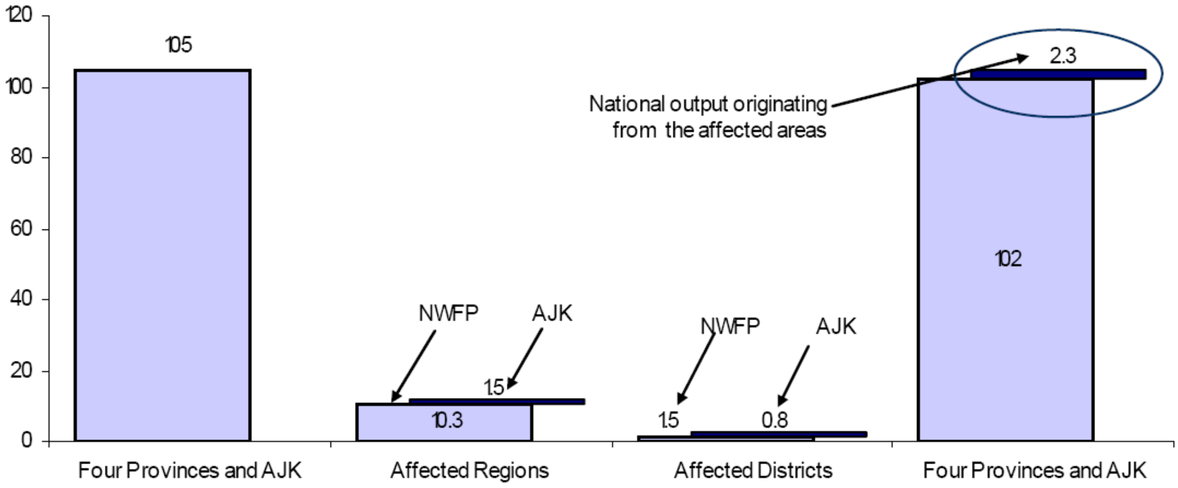

Figure 7.1: Output originating from the affected regions and districts, US$billions (ADB-WB, 2005)

7.3 Emergency Relief and Recovery

7.3.1 Emergency Relief

The October 8, 2005 Kashmir earthquake presented many challenges to those involved in the emergency relief. Firstly there were about 2.8million people displaced due to damage to some 455,000 homes, which were the most vulnerable of all the building stock. Secondly the locations where the relief was needed were scattered in the mountainous areas and at some distance from a major route as shown in Figure 7.2 (Risepak, 2005) where locations of villages requiring medical assistance are plotted as distance from a major route (a measure of remoteness) vs epicentral distance. Some locations needing help are not readily accessible due to altitude and lack of proper roads for vehicular access. These already difficult conditions were exacerbated by routes being blocked due to landslides and slope failures (see Chapter 4). Furthermore the advancing winter meant that the relief must reach those at higher altitudes before the advancing snow line prevents safe access to these areas.

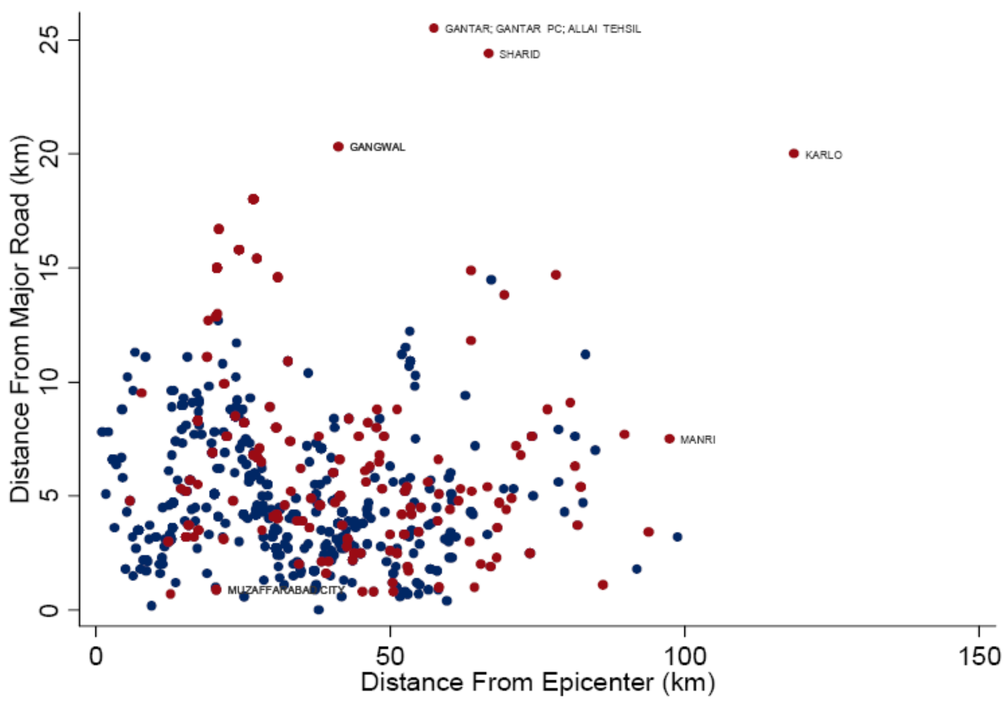

Figure 7.2: Locations of villages requiring medical assistance (blue; <100 people, Maroon; 100+ people, Risepak, 2005))

The initial emergency phase consisted of rescue and relief missions. The government created the Federal Relief Commission (FRC), whose responsibility is to coordinate the relief effort working with the Pakistan military, UN and other civil organizations. Various international rescue teams arrived at the affected areas to work with the Pakistan military to rescue those trapped under the rubble and evacuate the injured. The relief missions were involved in supply of food, water and shelter to those displaced and those who had no proper access to essentials since the earthquake damaged the food supply network. Displaced personnel were transferred to camps run by the United Nations (UN) and Non-Governmental Organizations (NGOs). Those who could not access these camps were supplied winterized tents, which was a priority since many conventional or makeshift tents put up by locals would not be sufficient to survive the winter snow and the snow melt and rain following the winter. The supply of relief was done though a combination of helicopter flights and local distribution networks in the remote areas. Another challenge in the relief phase was the provision of health care to those injured since many of the hospitals were damaged from the earthquake and medical personnel were also among the casualties. Various field hospitals were set up by the UN and NGOs to provide health care to the displaced and local population. For an effective relief distribution system to function, it is imperative that data on affected people are collected in a manner that represents the actual conditions on the ground. Several discrepancies arose in the data collected by the Pakistan Army and those by the local administration officials working with the UN and NGOs.

This led to relief not reaching some of those who needed it most, particularly in the remote mountainous areas (Zaidi, et al., 2006).

7.3.2 Recovery

While the FRC dealt with the emergency relief phase, the Earthquake Reconstruction and Rehabilitation Agency (ERRA) was set up to handle the reconstruction and recovery phase. ERRA together with the United Nations drafted the “ERRA – UN Early Recovery Plan” in May 2006 (ERRA, 2006) in order to bridge the transition period from relief to reconstruction. The plan covers a 12month period from May 2006 onward to lay the groundwork for a successful long term reconstruction. Unlike the relief phase, which was federally administered, the provincial and local authorities were given greater control over the planning and implementation of the early recovery plan. The plan was intended to draw on the strength and resilience of local communities covering the following sectors; education, health, livelihoods, water and sanitation, housing, shelter and camp management, support for vulnerable groups, governance and disaster risk reduction, and coordination and common services.

Despite the expectations, there were difficulties in implementing the early recovery as it took ERRA some months to set up the local administration vital for the coordination and implementation of the plan. This has led to many living in difficult conditions in camps and temporary accommodation in the winter of 2006. The government started the compensation payments almost immediately after the earthquake during the relief phase. The compensation payments were made for families with fatalities, injured and those who lost their homes. In the latter case, a reconstruction grant of about Rs. 175,000 was handed out to home owners during the relief phase before the early recovery plan was implemented (Zaidi, et al., 2006). Many used this money to start rebuilding their homes without considering the need to provide some form of seismic protection, which was intended by ERRA as part of the relief and recovery plan. Kubilay Hyicilmaz of Arup, who spent 3-months working with the Irish NGO, GOAL experienced these difficulties working to the ERRA plan. His primary responsibility was advising the implementation of seismic resistance construction practices to the NGOs in the field and most importantly the local builders trying to rebuild the damaged homes.

At the time of publication of this report, the government has initiated a programme to construct 585,000 homes in the earthquake affected areas compliant with seismic safety requirements. The funding is largely from ADB, which provided a US$1.0billion loan and aid package to finance the house building as well as infrastructure development and training of local personal. On July 2007, ADB transferred US$200million to the Government of Pakistan to cover the financing of house building already under way with another US$200million released in six months subject to meeting the agreed development targets (Reliefweb, 2007). The loan would help the government achieve its target to complete the house building by May 2008. Hence the winter of 2007 should hopefully be the last with difficult living conditions for those currently living in camps and transitional accommodation.

7.4 Conclusions

The Kashmir earthquake resulted in about 73,000 deaths and 69,000 injuries in the earthquake affected North West Frontier Province (NWFP) and Azad Jammu Kashmir (AJK) Province, leaving more than 2.8million people without shelter. Despite the level of damage, macroeconomic impact was very low given the substantially lower level of contribution to the national output from the earthquake affected areas. However, the biggest impact was on the people affected by the earthquake with a very high social cost for the recovery. This was largely due to the very high incidence of poverty in the affected regions and lack of service provisions.

7.5 References

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8 Conclusions and Recommendations

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Risk Management Solutions

This chapter summarizes the conclusions from the field mission findings described in the preceding chapters and make recommendations for risk reduction from future earthquakes in the region.

8.1 Conclusions

The following preliminary conclusions could be drawn based on the observations made during the field mission.

- The earthquake resulted in substantial damage to the buildings in NWFP and AJK province. Large proportion of damage occurred to residential structures. Commercial buildings, health care facilities, educational institutions and other government buildings also suffered severe damage

- The large proportion of collapsed and damaged residential buildings resulted in significant casualties (72,763 deaths and 68,769 injuries, at January 2006). Given that each house is occupied by 6 or 7 people, the earthquake resulted in about 2.8 million people without proper shelter. Many of the victims were women and children

- The damage to healthcare facilities meant that health care for the injured and those living in the affected areas had to be provided through field hospitals. The problems of healthcare delivery was exacerbated by the loss of healthcare staff due to deaths and injuries, and the loss of information records and systems

- The damage to education institutions resulted in a significant loss of life among school children (18,095). The loss of life among the teachers (853 deaths) meant the loss of teaching force and the government's investment in teacher training capacity. Temporary and semi-permanent structures were erected in order to resume classes for the surviving children

- The performance of buildings was ranked in terms of four major occupancy categories and performance levels stated in FEMA 356. Based on the damage survey observations, the residential buildings performed at a collapse prevention or worse level since they were largely of unreinforced masonry construction and using poor quality material. The commercial (including retail) buildings had a mixed performance. Those of masonry construction performed at a collapse prevention or worse level while RC construction performed at an immediate occupancy or life safety level. Government buildings mostly of concrete block or brick URM performed at a life safety or collapse prevention performance level. Educational institutions made of concrete block or brick URM performed at a collapse prevention or worse level. The performance levels demonstrated the level of vulnerability of the built environment in the affected region

- The surveys identified deficiencies in construction practices as well as the quality of brick, mortar and concrete used for construction. There were visible cracks through the mortar and the brick masonry in many buildings. The presence of a heavy RC slab on unreinforced masonry bearing walls without ties gave meant that during strong ground shaking the walls could not support the weight of the RC slab, which collapsed trapping residents underneath. The damaged reinforced concrete constructions did not have appropriate rebar sizes and arrangements, and the concrete appears to show deficiencies in the mix proportions, which was confirmed by carrying out cube strength test by UET Peshawar where the nominal cube strength was found to be less than $25N/mm^2$

- Landslides were a major secondary hazard if this earthquake. The slides varied from major slides such as that seen to the north of Muzaffarabad to disrupted slides, which pose a danger in future earthquake or during heavy rainfall. It was estimated that landslides may have occurred to a distance of about 200km from the epicenter

- Landslides and geotechnical failures have resulted in damage to buildings and most notably lifelines (roads) hampering the relief effort. This may have had an added impact on the casualties given the relative inaccessibility in many of the mountainous areas

- The earthquake resulted in direct damages amounting to US$2.3 billion resulting in a reconstruction cost of US$3.5 billion. The cost of the earthquake is estimated to be US$5.2 billion, which includes the reconstruction costs and the cost of relief and early recovery.

- It has been estimated that impact on Pakistan's GDP has been minimal given the relatively small contribution to the output by NWFP and AJK. However, the earthquake resulted in severe social consequences given that the affected provinces record the highest level of poverty (43%) in both urban and rural areas

8.2 Recommendations for Earthquake Risk Reduction

The following preliminary recommendations could be made based on the findings from the field mission.

- It is recommended that a detailed seismic hazard assessment is carried out in the affected provinces prior to commencing reconstruction. This study should be comprehensive and should incorporate latest information on geology, tectonics and seismicity in the area. A detailed seismic hazard assessment would allow the ground motion to be estimated in order to be used for seismic design and the evaluation of impact by secondary hazards such as landslides

- The evaluation of the 1986 Pakistan Seismic Code suggests that it is a good basis to form a new seismic code. The current code deals with only the static lateral force procedure whereas a revised code should deal with capacity design given that Pakistan has areas of high as well as low seismicity

- The affected region has landslides and flood hazards in addition to the seismic hazard. It is advisable that a multi-hazard risk assessment is carried before selecting new sites for the reconstruction of the devastated settlements

- The substantial damage to the building stock in the area suggests the lack of seismic resistance design and construction practice in the region. It is therefore important that the reconstruction is carried out in accordance with proven seismic resistance methods, given that the region is frequented with large earthquakes. There is also a need to improve the quality of the construction materials

- Given that a large proportion of buildings damaged were residential and hence their reconstruction will be primarily locally driven, there is an urgent need for a good education program in seismic resistant construction practices using local materials and locally available technologies

- There is a need to properly license engineers in order to ensure that they possess the knowledge to implement and supervise seismic resistant practices in the field

- It is also important to assess the condition of the roads and implement remedial measures as these were largely vulnerable to landslides and geotechnical failures. Roads are important in relief distribution for any future earthquake or other form of natural disaster.