Incipient Landslides in the Jhelum Valley, Pakistan Following the 8th October 2005 Earthquake

David Petley,[1)] Stuart Dunning,[1)] Nicholas Rosser[1)] and Allah Bahksh Kausar[2)]
1) : International Landslide Centre, Department of Geography, University of Durham, DH1 3LE, United Kingdom. (d.n.petley@dur.ac.uk)
2) : Geological Survey of Pakistan, Plot No. 84, H-8/1, Islamabad, Pakistan. (kausar_20001@yahoo.com)

Abstract

Extensive landsliding was a notable feature of the 8th October 2005 earthquake in India and Pakistan. The landslides ranged in size from small cut-slope failures to a rock avalanche with an estimated volume of about 80 million m^3. In this paper we examine two key aspects of the landslides associated with the earthquake. First we attempt to estimate the number of fatalities associated with landsliding. We suggest that this is of the order of 26,500 people including 300 in India. As such this represents probably the third largest landslide disaster in recorded history. In the second part of the paper we examine the widespread occurrence of cracked slopes the Kashmir area of Pakistan. We attempt to explain this phenomenon by showing that prior to the earthquake the precipitation input was unusually low, resulting in slopes that were essentially dry at the time of the event. We suggest that these slopes are extremely vulnerable to reactivation during forthcoming wet seasons. As a result, there is a high level of threat to the population of Kashmir, and the landslides represent a significant potential source of problems during the rehabilitation phase in Pakistan.

Keywords: Keywords: landslide, earthquake, Pakistan, cracking, deformation

Introduction

The 8th October 2005 earthquake in northern Pakistan and northwest India represents a disaster on a massive scale. At the time of writing the estimated number of fatalities is 87,350 in Pakistan, and 1,300 in India (Hussain *et al.* 2006), although some estimates put the total number of fatalities at approximately 100,000. Although not the largest in terms of energy release, the Kashmir earthquake represents the most devastating earthquake in South Asia in recorded history. As would be expected in a mountainous, tectonically-active area the earthquake triggered extensive landsliding. These landslides were responsible for a considerable proportion of the fatalities in both India and Pakistan.

As the reconstruction and rehabilitation of the earthquake affected areas proceeds there has been increasing awareness in Pakistan of the threat posed by the landslides. In other mountainous areas affected by earthquakes landslides have posed a threat to the local population and to infrastructure for years after the event. In this context, this paper provides a brief review of the landslides triggered by the earthquake. We then seek to examine the impact of the landslides expressed in terms of the number of fatalities, and to compare this with other large-scale landslide events. We show that this is one of the most deadly landslide triggering events in recorded history. Thereafter we focus on the ongoing issues associated with the extensive ground cracking initiated by the Kashmir earthquake.

Overall, in the paper we have attempted to show that this slope cracking phenomenon might be associated with the hydrological status of the slopes at the time of the failure. Finally, we discuss the likely implications of this extensive cracking for the medium-term safety of the people in Kashmir.

The 8th October 2005 Earthquake

A full description of the geological aspects of the earthquake itself is given in Purnachandra Rao *et al.* (2006), and hence we only provide an outline overview here. The earthquake itself occurred on 8th October 2005 at 03:50:40 UTC (08:50:40 local time). The hypocentre of the earthquake was located at about 34.493° N, longitude 73.629° E and a focal depth of c. 20 km (Purnachandra Rao *et al.* 2006). The earthquake was succeeded by a long, intense aftershock sequence. The magnitude of the main event was $M_L = 7.6$ (USGS 2006), and of the largest aftershock was $M_L = 6.3$. The earthquake occurred as a result of an approximately 100 km long rupture of the previously-mapped Balakot-Bagh fault (now often termed the Muzaffarabad fault), which is a NNW-oriented thrust fault, dipping at an angle of 29°. The maximum displacement on the fault was about 5 m (Hussain *et al.* 2006).

The estimated intensity distribution is closely associated with proximity to the surface expression of the rupture zone. Within about 5 km of the fault trace the level of destruction is very high, but beyond this signs of damage are surprisingly minor, apart from the inevitable anomalous impacts of local effects. Unfortunately, the intensity of shaking cannot be empirically verified as there were no strong motion instruments recording in the Kashmir area at the time of the earthquake. However, eye-witness reports indicate that strong shaking lasted for approximately 40 seconds, with high vertical accelerations in particular.

The earthquake occurred south of the Main Boundary Thrust (MBT), at a location in which it makes an inverted "U-turn". This area is often referred to as the Hazara Kashmir Seismic Zone (HKSZ), representing a part of the Hazara Kashmir Syntaxis. This is an area in which a large earthquake has long been considered to be overdue, but unfortunately it is unlikely that the 8th October 2005 event has significantly reduced the probability of a very large event (Bilham *et al.* 2001), and indeed by redistributing the regional stress field it may have increased the likelihood of an forthcoming large earthquake.

The impact of the earthquake event was catastrophic. In addition to the fatalities outlined above, approximately 38,000 people were injured and in excess of 3.5 million were made homeless. In Kashmir many building performed poorly, with 780,000 structures being damaged beyond repair. In particular almost all governmental structures were seriously damaged or collapsed. Combined with the timing of the earthquake this resulted in the tragic deaths of a very large number of children, estimated at over 19,000, primarily because of the collapse of government schools (Hussain *et al.* 2006). It has been calculated by the World Bank that the costs of reconstruction and rehabilitation in Pakistani Kashmir will be in the order of $3.5 billion.

Seismically-induced landslides

Close to the fault rupture there was a high incidence of landslides triggered by the Kashmir earthquake. As would be expected, these include deep-seated failures; shallow, disrupted landslides; rockfalls; and cut-slope failures. The distribution of landslides appears to be very asymmetric, with most of the landslides being located on the hanging wall (north-eastern) side of the fault. The largest landslide occurred close to the town of Hattian Bala, approximately 3 km from the fault trace in a side valley of the Jhelum River valley system. Here a pre-existing landslide has been reactivated, resulting in about 80 million m^3 of material sliding over a total crown to toe distance of about 2 km. The resultant debris avalanche has blocked two valleys to a depth of over 100 m, and two lakes are currently forming on the upstream side of these obstructions. The landslide appears to be structurally-controlled, with the slide plane representing a plunging syncline. Thus, the failure is in effect a complex dip-slope failure.

Essentially the amount of landsliding induced by the Kashmir earthquake is in many ways as would be expected according to previous studies (e.g. Keefer 1984). Perhaps the distribution in terms of the distance from the fault rupture on the footwall side of the fault is atypical, but may in reality map onto the distribution of uplift as implied by radar analysis of crustal deformation.

Fatalities

Estimating the death toll associated with landslides in large seismic events is very problematic (see Petley *et al.* 2005, 2006 for example). In the chaos of the aftermath little attempt is made to differentiate between injuries caused by building collapses and those associated with landslides. In addition, where large landslides have occurred, such as the Hattian landslide, it is rarely possible to recover the bodies of the victims and thus to estimate the true cost of the event. In this context, it is challenging to estimate the death toll associated with landslides in the Kashmir earthquake.

However, there are some potential sources of information. Interestingly, in India an accurate record was kept of the causes of fatalities, which showed that 300 of the 1300 deaths in Indian-controlled territory resulted from landslides. We have also tried to collect information on fatal landslides (Table 1). However, it is certain that this represents only a small fraction of the total number (for example, Table 1 lists 104 landslide fatalities in India out of a total of 300). For Pakistan, a better insight is probably given by the following statement (Bashir 2005):

Table 1. Known landslide fatalities in India and Pakistan resulting from the 8th October 2005 earthquake. Note that this represents only a fraction of the total landslide fatalities.

Country	Location	Description	Fatalities
India	Srinagar-Muzaffarabad highway between Uri and Aman Setu	Indian Border Roads personnel buried in a bus by rockfalls	68
India	Eagle Picket, Tangdhar	Soldiers hit by a rockslide	12
India	Qazi Nag, Kalakote	Villagers hit and killed by a rockslide	24
Pakistan	Bandhi Thanoliya	Destruction of complete village in mudslide	30
Pakistan	Hattian landslide	Villages of Lodhiabad, Bail, Cholian, Naina and Bat Shair all buried by massive rockslide	600
Pakistan	Jabla	50% of the 196 buildings in the village buried by a landslide	17
Pakistan	Pahl, Jhelum Valley	Burial in landslides of every house in village of 600 people	250
Pakistan	Chalapani (10 km from Muzaffarabad)	Bus buried by rockfalls	13

> *"The severe October 8 earthquake rattled mountains where slopes were already destabilized by years of deforestation. Officials in the wildlife and forest department of Azad Jammu and Kashmir, (AJK) are of the view that an estimated 30% of the people who died in the magnitude 7.6 earthquake could have been saved if there had been fewer landslides...Some 100 villages fell from mountains, many of them into rivers, causing huge casualties... The AJK officials said that the landslides also buried vehicles and killed many people on the spot. "It was unfortunate to see that all the debris and vehicles, including the bodies of unfortunate souls that were blocking roads, had to be shoved into the river in order to reopen the road," they said."*

Assuming that this figure of 30% of fatalities occurring as a result of the direct or indirect impact of landslides, the death toll associated with the landslides would be about 26,200, plus 300 in India, i.e. 26,500 in total. If it is true that approximately 100 villages were destroyed totally by landslides then such an estimate might well be realistic. At present this is the best available estimate. Interestingly, a figure of 30% of fatalities being the result of landslides agrees broadly with the figures for Indian Kashmir, where the 300 landslide fatalities represent 23% of the total.

Table 2 details the largest known landslide disasters, based upon Alexander (1989) and the International Landslide Centre database (see Petley *et al.* 2005 for details). Based upon this still-evolving list, the Kashmir earthquake may represent the fourth largest landslide-triggering event in terms of fatalities known to date. Clearly however further work is needed both to refine this list and to improve our understanding of the fatalities in the Kashmir earthquake. Certainly the Kashmir earthquake represents the largest fatality-inducing slope failure event in recorded history in South Asia.

Slope cracking in the Kashmir earthquake

Perhaps the most notable landslide aspect of the Kashmir earthquake is the very large extent of slope cracking in areas within 5 km of the fault. In most cases these appear to represent incipient landslides that have not developed to the point of full failure. As with the occurrence of landslides, the distribution of these features is limited to locations within about 5 km of the fault rupture, and in most (but not all) cases they are limited to slopes on the hanging wall block.

Two main types of cracked slope have been observed:

1. **Cracked slopes at the top of bedrock slopes**. A small proportion of the cracked slopes (perhaps 20–25%) occur at the top of rock cliffs formed from in situ bedrock, primarily the Precambrian materials. Here, multiple arrays of arcuate cracks are observed behind the crown of the cliff (Figure 1). In many cases these cracks define blocks with a down slope length of 50 m or more, and a cross slope extension of over 100 m. The lateral shears of the defined slide blocks often follow existing topographic features (Figure 1), such as gullies. In many cases the crack systems define a complete block. The cracks are often up to 1 m in width, with steps of 50 cm or more. In some cases the crack arrays even traverse reverse slopes (Figure 2).
2. **Cracked slopes in colluvium.** The majority of the cracked slopes appear to represent partially

Table 2. Recorded large-scale landslide events in terms of numbers of fatalities, compiled from Alexander (1989) and the ILC database (see Petley *et al.* 2005). Based on this dataset the Kashmir earthquake may be the fourth largest fatality-inducing landslide event in recorded history.

Location	Date	Fatalities	Description
Gansu, China	16/12/1920	200,000	Earthquake triggered flow slides
Sichuan, China	10/06/1786	100,000	Collapse of landslide dam
Vargas, Venezuela	15/12/1995	30,000	Debris flows
N. Pakistan and India	08/08/2005	26,500	Earthquake triggered landslides and rockfalls
Nevado del Ruiz, Colombia	31/05/1970	22,000	Lahars
Nicaragua & Honduras	30/10/2005	19,600	Debris flows triggered by Hurricane Mitch
Nevados Huascaran, Peru	31/05/1970	18,000	Earthquake triggered landslide
Shimbara, Japan	1792	15,000	Debris avalanche and wave
TienShan, Tajikistan	1949	12,000	Earthquake triggered landslides
Mount Kelut, Indonesia	1919	5,000	Lahar
Huaraz, Peru	01/12/1941	5,000	Debris flow
Nevados Huascaran, Peru	10/01/1962	4,500	Earthquake triggered landslide
Gonaives, Haiti	19/09/2004	3,006	Mudflows triggered by Hurricane Jeanne
Cholima, Honduras	20/09/1973	2,800	Landslide
Sichuan, China	08/10/1933	2,500	Collapse of landslide dam
Vaiont, Italy	09/10/1963	2,100	Landslide into reservoir created wave
Fonds-Verettes, Haiti	24/05/2004	1,500	Mudflows
Guinsaugon, Leyte, Philippines	17/02/2006	1,450	Debris avalanche
Kure. Japan	1945	1,000	Mudflows and slides
Bihar, Bengal, India	01/10/1968	1,000	Landslide
Revantador, Ecuador	05/03/1987	1,000	Earthquake triggered landslides

developed landslides in colluvial materials (Figure 3). Here, multiple arrays of large, arcuate cracks are seen traversing slopes with gradients in the range 20–45° (Figure 4). In many cases these define completely potential landslide blocks, some as large as 200 m in length and 500 m in width, with fully developed lateral shear systems. Extension across the cracks is in places as much as 2 m horizontally and 1.5 m vertically. In many locations graben structures appear to have developed in the crown area of the incipient landslides, and there is clear evidence of changes to the slope hydrogeology, with large, well-established springs having disappeared at the time of the earthquake. There are however almost no reports of new areas of seepage across the affected hillslopes.

This extensive occurrence of slope cracking is unusual for seismically-triggered landsliding. In other areas slope cracks have been observed, but generally speaking they are not as extensive as in this case. It appears that many slopes have effectively failed during the ground shaking, but have not been able to transition into full runout landslides, even on quite steep slopes. The slope gradients and lithologies involved are not exceptional in any way, suggesting that this behaviour is not the result of a material control on movement. The probable explanation for this phenomena lies with the precipitation that had been deposited in the area in the period preceding the earthquake. Figure 5 shows the rainfall record for the grid square 73–74°E 34–35°N, in which the Muzaffarabad area lies. These data have been obtained from the monthly monitoring data for precipitation produced by the Global Precipitation Climatology Centre (GPCC) (see Rudolf *et al.* 2005). This is based upon rain gauge records for 7000 surface stations. The gauge error in this area is estimated to be ±5%, and in general the GPCC dataset consistently underestimates slightly the true level of precipitation (Rudolf *et al.* 2005). These data suggest that in the months leading up to the earthquake the precipitation level was anomalously low. In fact, in the period between March and September 2005 the recorded precipitation in this grid square was just 54% of its long term mean. In the Kashmir area, 44% of annual precipitation occurs as a result of the SW Monsoon between July and September. In 2005 the precipitation during this monsoon period was 55% of the long term mean. Thus, prior to the earthquake the Kashmir region effectively suffered the effects of a severe drought. It is likely that as a result groundwater levels were unusually low, and thus that the slopes were in effect dry. Unfortunately no piezometer data are available for the Kashmir area to verify this observation.

Hence, it seems probable that the extensive slope cracking observed in the earthquake affected area was the result of landslides that were triggered by the earthquake, but could not transition to full failure due to the lack of groundwater. Interestingly, at the time of writing (July 2006) these slopes had remained

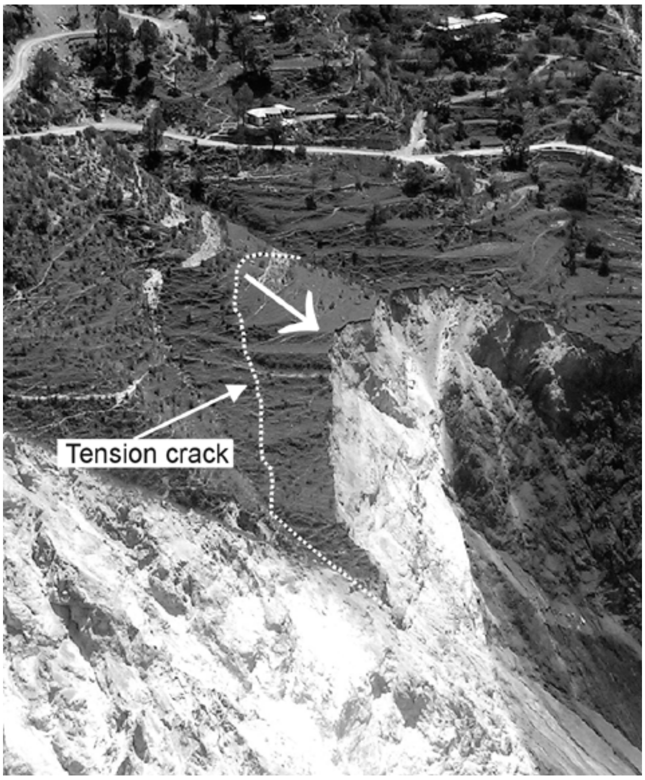

Fig. 1. A cracked slope in unweathered Precambrian dolomite at Mukree. Here a block about 50 m in length is sliding forward. At the time of the photograph the tension crack was about 50 cm in width

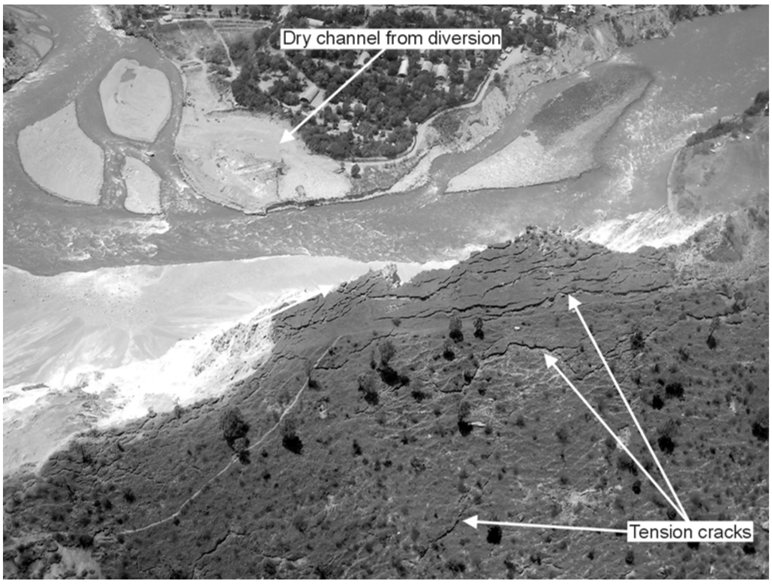

Fig. 2. A cracked slope in unweathered Precambrian dolomite above the Nisar camp upstream on the Neelum river from Muzaffarabad. The cracks daylight on a reverse slope at the top of a ¿200 m cliff. A large failure here during the earthquake blocked the river, causing the labeled change in the drainage.

effectively stable. However, the period since the earthquake was also marked by warm temperatures and, more importantly, dry conditions. In the period October 2005–May 2006 only 72% of the long term average precipitation was deposited. Thus, at the time of writing the slopes remain unseasonally dry.

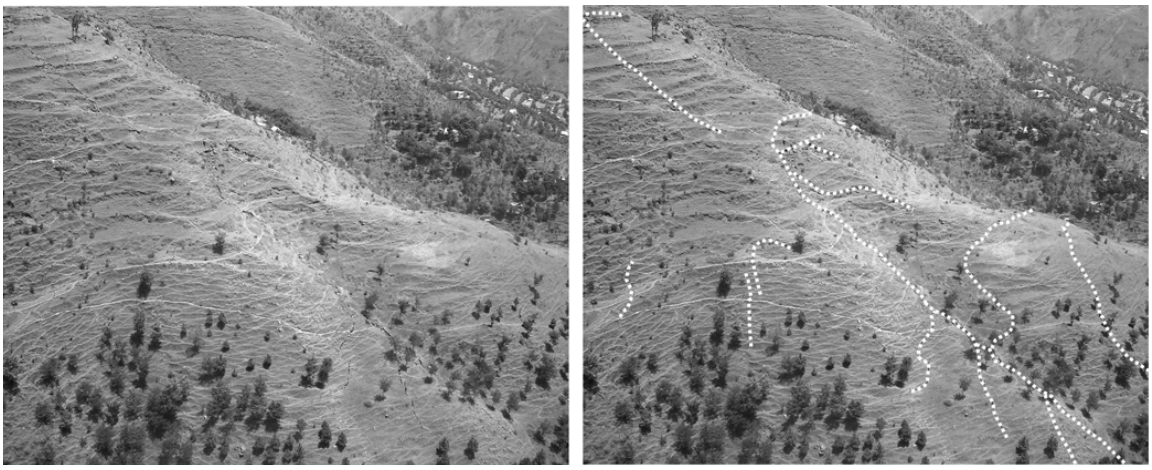

Fig. 3. A cracked slope in colluvium in the Jhelum River valley. The annotated image shows the locations of the main cracks. Note the clearly defined main block, complete with fully developed lateral shears, and less well developed slope failures above and on the margins of the main slide. Crack widths at this location exceed 1 m.

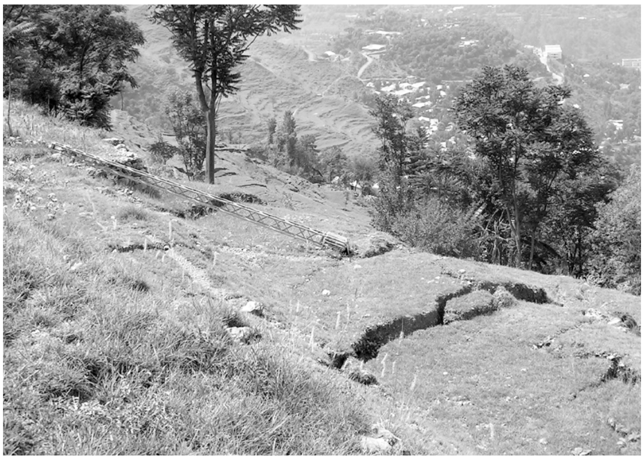

Fig. 4. Ground cracks at Botha, on the colluvium slopes above Muzaffarabad. At this location there are multiple arrays of cracks extending upslope for over 200 m, and across the slope for over 500 m. The orientation of the cracks varies according to local topographic controls.

Long term implications of the cracked slopes

In other steep mountain chains that have been subject to large seismic events the density of landsliding increases dramatically in the rainy periods immediately following the earthquake. For example, Lin *et al.* (2006a) reported that the area of landslides in the Choushui River catchment in Taiwan increased from 35.52 km^2 before the 1999 Chi-Chi earthquake to 57.37 km^2 in early 2000 after the seismic event. However, subsequent rainfall events increased the area of landsliding dramatically, reaching 148.81 km^2 by the middle of August 2001. Thus, whilst the earthquake increased the spatial extent of landslides by about 61%, the area had increased had increased by 260% above the post-earthquake level within 18 months, as a result of the effects of two wet seasons. Chen and Petley (2005) and Lin *et al.* (2006b) provided similar evidence of increases in the occurrence of landslides in other Taiwan catchments in the post-seismic phase. Interestingly though the increase in landslide area was mostly associated with increases in surface area of existing landslides, even during the seismic event. Thus, during the earthquake the area of new (i.e. first time) landslides in the Choushui catchment was only 7.47 km^2. The area of new landslides in triggered by the subsequent rainfall events was only 26.74 km^2 out of an increase in surface area of 91.44 km^2 (Lin *et al.* 2006a).

It seems very likely that in the next few years the area of landsliding in the Kashmir earthquake zone will also undergo a large increase as a result of the effects of rainfall. As many of the cracked slopes are

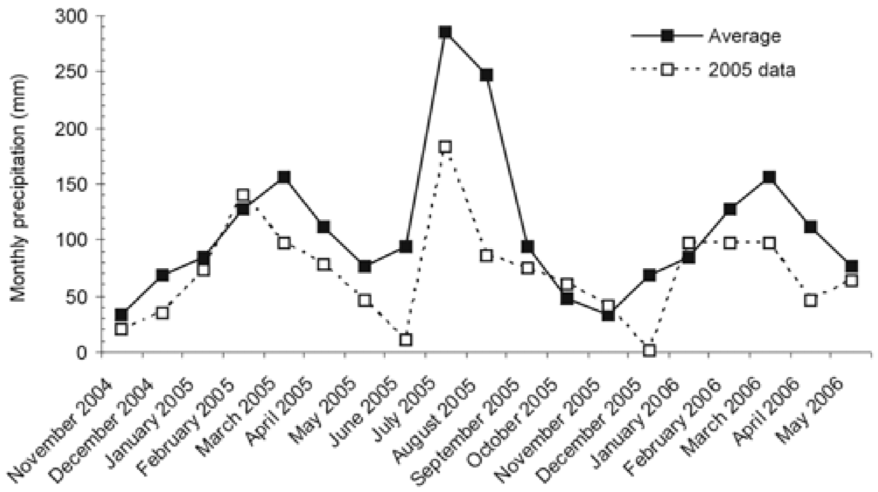

Fig. 5. Rainfall record for the grid square 73-74°E 34-35°N (data from GPCC — see Rudolf *et al.* 2005) for the period November 2004 to May 2006. It is clear that for most of the year before the earthquake in October 2005 the rainfall level was significantly below average. In particular there was a very low level of monsoon rainfall. Interestingly, the period since the earthquake is also marked by low level of precipitation.

probably at residual strength, it is likely that as the groundwater level rises large numbers of slope failures will occur. At the time of writing, which represents the first week of the 2006 monsoon, there is some evidence that this is beginning to occur, with newspaper reports that 13 people had been killed by a landslide on the outskirts of Muzaffarabad in an area of extensively cracked slopes, and widespread disruption to vehicular traffic from landslide and rockfall activity, with one event having killed a road-user. It seems highly likely that this situation will deteriorate in the coming months and years.

Discussion

In this paper we have attempted to examine two aspects of the Kashmir earthquake. First, we have attempted to examine the event in terms of the numbers of lives lost, and in particular to estimate the likely number of fatalities. It is clear that the earthquake event represents one of the largest fatality-inducing events in history, although much more work is needed to gain a reliable estimate of the number of fatalities. We then focus on the future evolution of the Kashmir area, suggesting that there is a high likelihood of many more landslides, and thus a substantial increase in loss of life. There is a need to mitigate this threat through hazard assessment. However, the presence of the cracked slopes also raises some fundamental questions about one of the key techniques for assessing the hazards associated with earthquake-triggered landslides — the Newmark Displacement method. This approach, proposed by Newmark (1965), is based upon the application of a simple model of a landslide, in which the system is considered to act as a block on an inclined plane. The Newmark's method calculates the cumulative displacement of the block resulting from an acceleration time history for the earthquake. Movement of the block is assumed to occur when the calculated sum of the static and dynamic driving forces exceed the shear resistance of the block. Thus, permanent deformation occurs when induced accelerations exceed some critical acceleration (see Miles and Ho 1999 for example). It is assumed that failure of the landslide has occurred when some critical displacement is reached, but this distance is in general very poorly defined (Murphy *et al.* 2002 for example). Indeed, in many cases it appears to be entirely arbitrary. For example, failures occurring in rocky slopes (i.e. disrupted falls and slides) are often assumed to have a critical displacement of 5 cm (Romeo, 2000 for example). On the other hand a critical displacement of 10 cm is often assumed for flows and slides occurring in cohesive soils (Jibson and Keefer, 1993 for example). However, clearly the slides observed in Kashmir, which constitute a combination of rock slopes and cohesive materials, have undergone much greater displacements than this and yet have still to fail. Indeed in some cases the tension crack systems indicate a displacement of in the order of several metres. Therefore, the small critical displacements as are generally used in Newmark analyses appear to be unsupported by field evidence. It is perhaps more logical to work on the basis of a critical strain at failure, rather than a critical displacement.

Conclusions

The key conclusions arising from this work are as follows:

1. The Kashmir earthquake represents a remarkable event in terms of landslide fatalities, probably representing one of the largest landslide disasters in recorded history;
2. The occurrence of landslides was probably lower than might have otherwise been expected due to the low rainfall totals in the year preceding the earthquake;
3. The presence of extensive slope cracks in areas on the hanging wall block indicates that there are likely to be many landslides in the next few years. Mostly these are likely to be associated with monsoon rainfall;
4. As such there remains a very high threat to the population of Kashmir and Nothwest Frontier Province in the forthcoming years;
5. The large displacements on these crack systems suggest that the critical displacements used in Newmark displacement analyses are probably incorrect.

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References

Alexander, D.E. (1989) Urban landslides. *Progress in Physical Geography* **13**, 157–191.

Bashir, I. 2005. Earthquake touched off deadly slides in Kashmir's deforested hills. *Environment News Service*, November 30th 2005, 1 pp.

Bilham, R., Gaur, V.K. and Molnar, P. (2001) Himalayan Seismic Hazard, *Science*, **293**, 1442–4.

Chen, H., Dadson, S. and Chi, Y-G. (2006) Recent rainfall-induced landslides and debris flow in northern Taiwan. *Geomorphology*, **77** (1-2), 112–125

Chen, H. and Petley, D.N. (2005) The impact of landslides and debris flows triggered by Typhoon Mindulle in Taiwan. *Quarterly Journal of Engineering Geology and Hydrogeology*, **38** (3), 301–304.

Hussain, S., Nisar, A., Khazai, B., and Dellow, G. 2006. *The Kashmir Earthquake of October 8, 2005: Impacts in Pakistan.* Earthquake Engineering Research Institute Special Paper, 8 p.

Jibson, R.W. and Keefer, D.K., (1993). Analysis of the seismic origin of landslides examples from the New Madrid seismic zone. *Geological Society of American Bulletin*, **105**, 521–536.

Lin, C-W., Liu, S.H., Lee, S-Y. and Liu, C-C. (2006a) Impacts of the Chi-Chi earthquake on subsequent rainfall-induced landslides in central Taiwan. *Engineering Geology*, In Press (available online), Corrected Proof, 15 pp.

Lin, J-C, Petley, D.N., Jen, C-H., Hsu, M-L. (2006b) Slope movements in a dynamic environment — A case study of Tachia river, Central Taiwan. *Quaternary International*, **147** (1), 103–112.

Keefer, D., (1984) Landslides caused by earthquakes. *Geological Society of America Bulletin*, **95** (4), pp. 406–421.

Miles, S.B., and Ho, C.L. (1999) Rigorous landslide hazard zonation using Newmark's method and stochastic ground motion simulation. *Soil Dynamics and Earthquake Engineering*, **18** (4), 305–323.

Murphy, W., Petley, D.N. Bommer, J., and Mankelow, J.W. (2002). Geotechnical and seismological uncertainty in the assessment of slope stability during earthquakes. *Quarterly Journal of Engineering Geology and Hydrogeology*, **35**, 71–78.

Newmark, N.M. (1965) Effects of earthquakes on dams and embankments. *Geotechnique*, **15**, 39–160.

Petley, D.N., Dunning, S.A. and Rosser, N.J. (2005) The analysis of global landslide risk through the creation of a database of worldwide landslide fatalities. In: Hungr, O, Fell, R., Couture, R., and Ebergardt, E. *Landslide Risk Management*, A.T. Balkema, Amsterdam, pp.367–374.

Petley, D.N., Oven, K., Mitchell, W.A., Rosser, N.J., Dunning, S.A., and Allison, R.J. (2006 in press) The role of global and regional precipitation patterns in landslide generation. *Proceedings of the International Conference on Slopes*, Malaysia, 10 pp.

Purnachandra Rao, N., Kumar, P., Kalpna, Tsukuda, T. and Ramesh, D.S. (2006) The devastating Muzaffarabad earthquake of 8 October 2005: New insights into Himalayan seismicity and tectonics. *Gondwana Research*, **9** (4), 365–378.

Romeo, R. (2000) Seismically induced landslide displacements; a predictive model. *Engineering Geology*, **58** (3-4), 337–351

Rudolf, B., Beck, C., Grieser, J. and Schneider, U, (2005) *Global Precipitation Analysis Products.* Global Precipitation Climatology Centre (GPCC), DWD, Internet publication, p.1–8.