Slope failure and landslide mechanism, Murree area, north Pakistan

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ABSTRACT: *The area around Murree town is inherently vulnerable to mass movement processes, most commonly due to landsliding. It is characterized by high degree of erosivity and erodibility due to both natural and man induced factors. The area is part of a young orogenic belt that is experiencing one of the world's most rapid uplift rates, and is located in the near vicinity of major thrust faults. Shear zones associated with still active faults, such as Murree Thrust and also the folding generated due to thrusting induce an inherited weakness and natural instability in the rocks of the area. This compounded with ever increasing population pressure, deforestation, large-scale construction work in the form of residential and commercial buildings and road network have further aggravated the problem. Lithologically the area is comprised of shale, siltstone and sandstone belonging to the Oligocene-Miocene Murree and Kuldana formations.*

In order to study the landslides and other mass movement problems in Murree, an area around the main town and along the Murree-Kashmir Highway is selected for detailed analysis of the problem. The eastern slopes of the Murree ridge, and the road section between Jhika Gali and Aliot village are worst affected by the landsliding. Around Murree town, major landslides such as Shifang Hotel, Midway and MIT landslides, located on the upslopes of the Jhika Gali-Lawrence College Bypass road are caused by inadequate drainage system from the city centre (Murree ridge). In most part of the area around Murree ridge, creep is a common phenomenon in thick colluvium cover due to obvious loss of vegetation. The area between Jhika Gali and Aliot village is also affected by landsliding, and some of the largest landslides such as Aliot, Birgran and Kasseri landslides have inflicted great damage to farm and forest land. This area is located in the footwall of the MBT and is deformed by folding and termination splays associated with it. Most of the landslides initiated at the colluvium-bedrock interface, but once initiated the tension cracks spread into the bedrock and therefore causing the failure in it. Major landslides in the area exhibit a complex array of joint/fracture pattern both parallel and perpendicular to the bedding, and in various ways contribute to the mass movement.

INTRODUCTION

The town of Murree in Himalayan foothills lies about 50 km to the northeast of Islamabad, the capital of Pakistan (Fig. 1), at an elevation of approximately 2200m. The Himalaya was created by the collision of the Indian plate with the Eurasian plate during Eocene time along a suture zone known as the Main Mantle Thrust (MMT) (Tahirkheli et al., 1979; Coward et al., 1986), and is one of the world's most rapidly uplifting region on earth (Zeitler, 1985). The deformation progressively migrated

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southward away from the Early Eocene collision zone at the MMT and reached the Himalayan foothills by Miocene time. The Himalayan foothills, commonly known as the sub-Himalayas (Gansser, 1964) are defined as a set of rocks which are bounded by major thrust faults such as Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT) to the north and south respectively (Fig. 1). The Murree area lies in a seismically active zone due to its proximity with the active Murree Thrust (local name for MBT) along which magnitude 4.5 to 5.0 earthquakes on the Richter scale have been recorded as recently as 1977. Nevertheless, earthquakes of magnitude 6 and more can be expected along this zone.

The molasse sediments (siltstone and sandstone) of the Murree and Kuldana formations (Oligocene-Miocene) constitute most part of the Murree Hills. The sandstone of the Murree Formation is red to reddish gray in colour, multistoried, fine to medium grained, cross-bedded, hard and compact constitutes 4-6m thick sequences that occasionally attain thickness of over 10m. The sandstone sequences are interbedded with red colour, 10's of meters thick siltstone and shale. These fine-grained facies constitute most part of the formation and provide a week zone for most of the faults to propagate through it. Landsliding and other mass movement phenomenon are inherited to the area due to weak component lithologies, complicated and intense deformation compounded in recent times by anthropogenic factors like deforestation, construction and over-population etc (Neiderer and Schaffner, 1989).

This paper describes landslide prone areas around the Murree town, especially along major road sections, i.e., Bansra Gali-Jhika Gali-Lawrence College ring road, Jhika Gali-Aliot, and the Jhika Gali-Bhurban road sections along the Kashmir Highway (Fig. 2). It describes some selected landslides from the area with special emphasis on the geological processes that contributed in the initiation of the mass movement processes. Detailed geotechnical analyses were conducted to understand the mechanism of failure in the landslide prone parts of the area. The study was conducted with the help of Survey of Pakistan topographic maps, interpretation of digital SPOT panchromatic image, and extensive fieldwork.

STRUCTURAL GEOLOGY

Structurally the area around Murree is complexly deformed by MBT and folding associated with it (Fig. 2) (Chambers, 1992; Iqbal and Bannert, 1998). The Murree Thrust trending NE-SW, is an emergent fault passing close to Bansra Gali, Chitta Mor, Sunny Bank and Kuldana (Fig. 2). Most part of the central ridge on which the Murree Town is located is a SW plunging syncline with the Murree Formation lying in the core of the syncline, and the beds dipping inwards towards the core of the ridge. This structure provides a degree of structural stability to the ridge. At the same time, combined with a lithological setup of alternating sandstone-siltstone-claystone layers, this structure makes the Murree ridge a major reservoir of water. This is evident from the presence of many springs and seepages at the toes of major sandstone horizons (Rafiq et al., 1989). This seepage often facilitates slippage of the rock and soil bodies at slopes and thus contributes to mass movement.

The topographic high of the Pindi Point is in the core of a major anticline in which over 2km thick section of the Murree Formation molasse is exposed. The bedding youngs towards north and dips range from 20-60° to almost vertical across the fold axis. Near Bansra Gali steeply dipping strata becomes older, transitionally passing from the Kuldana Formation into the Chor Gali Formation (late Eocene age), characterized by platy, nodular, nummulitic limestone and interbedded greenish marls. In this area the Murree Thrust is SE verging and brings the Chore Gali Formation over the Murree Formation indicating a main SE transport direction along the Murree Thrust. Kashmir point lies to the southeast of the axis of the major syncline with NW dipping (50-60°) outcrops. The area between Kashmir Point and Jhika Gali appears to have been folded by a series

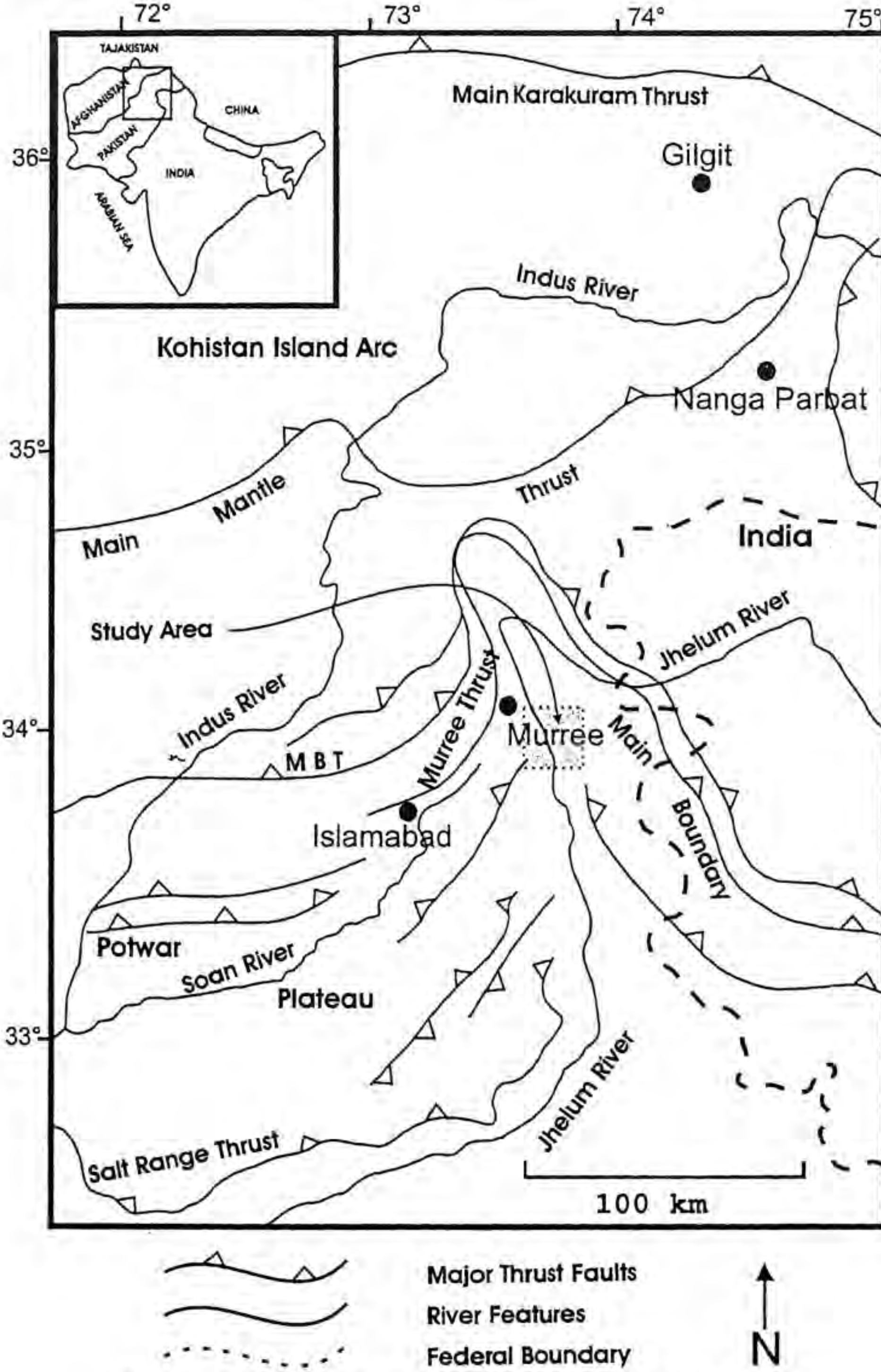

Fig. 1. Generalized map of N. Pakistan with study area around Murree as inset.

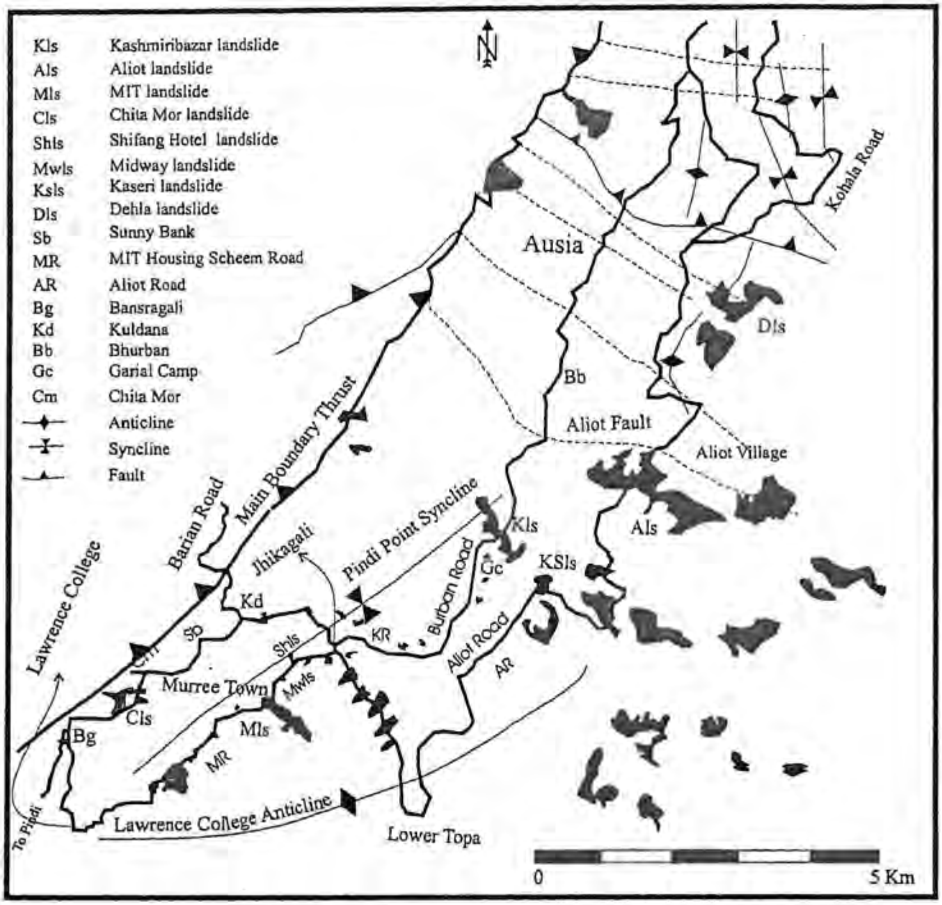

Fig. 2. Detailed location and landslide distribution map of Murree town and surrounding area. Most of important landslides especially those along the Bansragali-Jikagali-Lawrence College ring road, and Jikagali-Bhurban, Jikagali Aliot road sections are marked. Main Boundary Thrust (MBT) is oriented NE-SW direction. Localized faults are marked as broken lines.

of isoclinal folds. A large number of inter-molasse faults may be present in this area but are difficult to recognize in the field. The shear zones associated with still active Murree Thrust and also the folding generated due to thrusting induce an inherited weakness and natural instability potential in the strata of the Murree hills. These are potentially weak zones in a slope and their strength is less than the surrounding intact rock. Presence of small shear zones in shale beds further reduces its strength that is crucial for its stability. Deformation due to faulting and orientation of rock discontinuities (joints and bedding planes) behind the slope face is a determining factor for slope instability. In most of the studied area, particularly in major landslide areas such as Kashmiri Bazar and Chitta Mor landslides a detailed survey of the joint orientation was carried out.

LANDSLIDE PROCESSES AND MECHANISM

In order to understand the processes and mechanism involved in the landslide activity in the area, two major landslides are selected for detailed studies, one at Chitta Mor and other at Kashmiri Bazar

(Fig. 2). These slides are mapped at 1:500 on topographic maps prepared with the help of theodolites and plane tabling.

KASHMIRI BAZAR LANDSLIDE

This landslide is located about 5 km NE of Murree, on the Murree-Kashmir road (Fig. 2). Locally this road connects Murree with the prime hotel resort at Bhurban, and ultimately to Kashmir valley reflecting its strategic and tourist importance. A topographic base map at a scale of 1:500 has been prepared for this purpose, which has also been used for detailed geotechnical analysis (Fig. 3).

The landslide occurred in a section of the road between Garial Camp and the Kashmiri Bazar (Fig. 2). The slide involves the rocks of the Murree Formation, including siltstone, shale and sandstone. These lithologies are prone to mass-movement upon excessive saturation. The general trend of outcrops in the slide area is N12°W/40°NE, almost at right-angle to the local slope. Sandstone beds are exposed in parts of the escarpment, particularly in its SE part above the road. Thin, 1-2m thick sandstone beds are exposed in the upper part or crown of the escarpment (Fig. 3). About one metre thick sandstone bed lies in the lower part of the escarpment that is underlain by a sequence of alternating siltstone and shale. The sandstone beds are laterally inconsistent and their thickness changes even on the outcrop scale. The sandstone is fine to medium grained, thin to medium bedded, hard and fractured. Most part of the slide area (above the road), however, is comprised of shale and siltstone. There is a thin layer of colluvium in this area. A number of sandstone ridges are partially exposed upslope of the landslide. The upslope of the landslide is moderate to high, whereas, the downslope is generally moderate. The upslope area is covered with fairly thick pine forest. A number of local streams (nullahs) from the upslope military camp used to drain through the landslide zone. New channels have now been constructed around the landslide to direct the water from these nullahs into the channels.

Field observations

The landslide is typically a translational type with a complex nature of displacement (Figs. 3). The escarpment of the slide is clear on the hillside face and is irregular in shape (Fig. 3). The maximum width of the unstable area measures to be about 100 meters along the road section, but is substantially reduced to about 20m in the downslope of the road (Fig. 3). The total length of the landslide is about 350m, 35m on the hillside and rest below the road. The direction of movement of the slide is at right angle to road alignment that runs in the direction of NE. The main body of the slide is lying below the road but has been leveled by extensive engineering work.

The main escarpment towards the hillside is composed of bedrock in which the major movement took place (Fig. 3). Within the bedrock, a number of new weak horizons are developing, such as just below the main escarpment towards the northern margin of the slide. These surfaces are future's potential sliding surface. Similar weak horizons or tension cracks are developing in the colluvium cover just above the crown of the slide. These cracks are up to 10cm wide and fairly unstable. Downslope the road, the movement is probably located at the interface between the colluvium and the bedrock. The bedrock is also exposed on the sides of the slide.

The slope above and below the road section is distinctly different. The slope above the road varies from 30-35°, whereas the slope below the road is only about 20°. The slope above the landslide on the hillside gradually flattens to a minimum towards the ridge top. The forest cover is fairly thick above and on sides of the landslide. The colluvium cover is about 4 meters thick upslope of the landslide but thins out to only about 2m around the landslide. The colluvium cover has been more or less completely removed from the landslide escarpment. The bedrock is generally at shallow depth. On the hillside, the depth of the bedrock is estimated to be about 2 metres, while on the valley side it could be 4-6 metre deep.

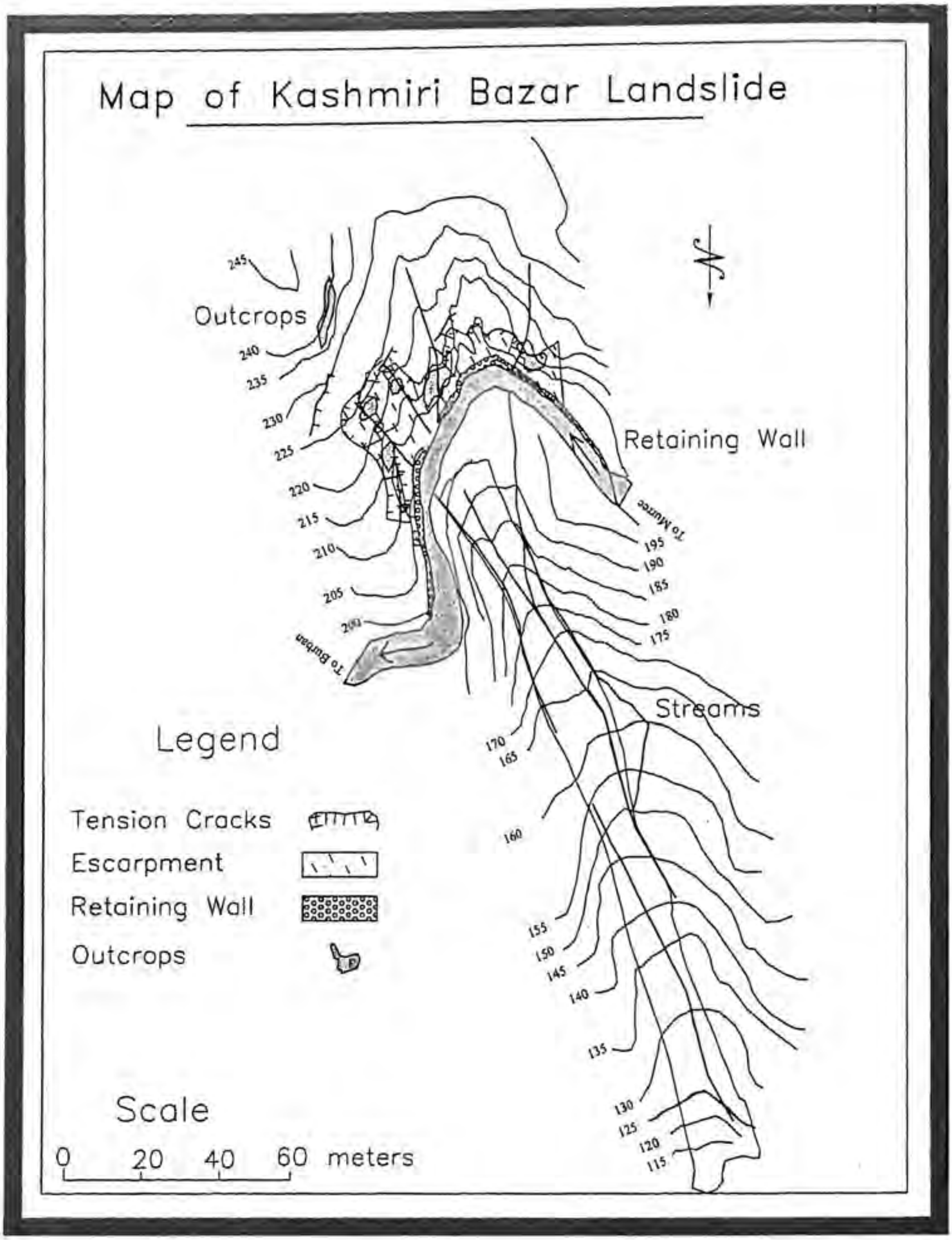

Fig. 3. Kashmiri Bazar landslide map. The landslide is mapped on 1:500 scale in order to show tension cracks developed along the scarp of the landslide. The landslide body is removed through civil work and a network of channels is constructed to stabilize it.

The landslide is generally dry for most part of the year, but during monsoon rain bursts a number of small streams (nullahs) start flowing through the unstable area. Nullahs on both sides of the landslide drain water from the upslope and also from the settlement on top of the ridge into the major stream downslope. There is an extensive network of channels built to drain this water away from the unstable zone.

Geotechnical analysis (joint and fracture data)

The escarpment of the Kashmiri Bazar slide exposes a number of outcrops of the bedrock. Several sets of joints and fractures are noticed in the bedrock particularly in the sandstone. Figure 4, shows that poles to the joint/fracture planes are distributed mainly in the NE, SE, and SW quadrants of the equal-area net. Within this general distribution there is a greater concentration of the poles in the SE quadrant suggesting preponderance of joints/fractures oriented NE-SW and dipping moderately to steeply towards NW i.e., the facing direction of the slide. In most cases the surfaces of these joints are marked with striations and slickensides. These striations/slickensides are marked with a direction of movement ranging from NNW to ENE, with a great majority in the direction of NE. The sense of slip indicated by these linear structures varies from dip-slip to a combined strike-slip and dip-slip component. In addition to this predominant set of joints, two sets with a relatively moderate density of distribution are noticed. One of these sets comprises joints oriented NW-SE and dipping steeply to the NE or SE with most being almost vertical. Third of the sets is least frequent and is oriented NS with steep dips to the west.

It is clear from the Fig. 4 that the most predominant set of joints/fractures is oriented parallel to or at angles less than 30° to the escarpment of the slide. Furthermore, the NE direction of slip and a normal to strike-slip sense of movement is in parallelism with the mass-movement direction of the landslide. This compatibility between the kinematic attributes of the landslide and those of the joints/fractures in the bedrock suggest that the latter are genetically related with the landslide phenomenon and not to the regional tectonics. We interpret that the predominant set of joints in the bedrock in the landslide area, particularly those exposed in the escarpment area, are tension joints/fractures induced by the slope-instability. The gravity sliding of the blocks

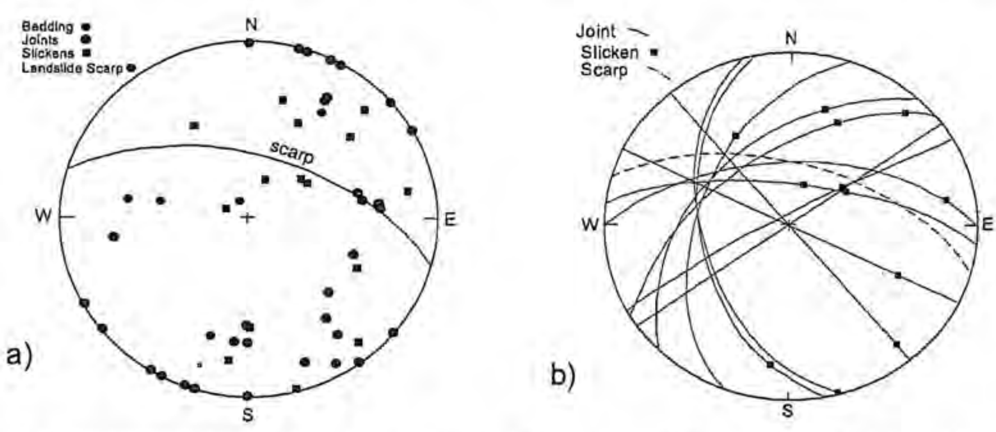

Fig. 4. Joint/fracture plot of Kashmiri Bazar landslide. a) Pole plot showing NNE slip direction, b) Joint and fracture planes with slickensides.

down-dip or oblique to dip-direction resulted in the development of striations/slickensides at the joint/fracture surfaces of the intact blocks. The observed genetic relation between the joints and the landslide has important bearings on the mechanism of the landslide.

Slide mechanism

The road through Kashmiri Bazar is an old link between Kashmir and other parts of the country. Since past many years it also became significant due to its touristic importance as it connects a number of tourist resorts and scenic countryside. Due to ever increasing visitors each year, the road was widened by excavating the hillside. The current site of the Kashmiri Bazar landslide has been unstable since long and the mass movement activity has been common. Road excavation work further compounded the problem and the road now runs in a U-shape. The road cut appears to be the triggering mechanism, which then continued due to the rain and sewerage water on the surface and weathering of *insitu* soft rocks. There is a great probability that the initial slip occurred along the colluvium-bedrock interface due to excavation at the toe of the slope during the widening of the road. Much of the later landslide activity, however, involved formation of tension cracks that penetrated through the colluvium as well as the underlying bedrock as joints and fractures. Much of the landslide body is thus a mixture of colluvium, shale, silt and sandstone blocks slipped along favourably oriented set of joints.

CHITTA MOR LANDSLIDE

The landslide occurs on the Rawalpindi-Murree Highway and is located between Chitta Mor and Bansra Gali (Fig. 2), about 6km short of Murree. It has a long history of instability and has been disrupting the road since 1965 (Khan et al., 1987). As shown in Fig 2, much of the 2 km strip of the Murree-Islamabad road between Chitta Mor and Bansara Gali is classified as an unstable zone, and therefore vulnerable to mass movement. The Chitta Mor landslide being described here is part of this active unstable zone.

The instability of the area can be attributed to complex geology. The Murree Thrust (MBT) outcrops in the near vicinity of the landslide, bringing the Chore Gali Formation of the Eocene age over the rocks of the Kuldana and Murree formations (Oligocene-Miocene age). The unstable zone also lies at the contact of the Kuldana Formation with that of the Murree Formation, in the core of a major syncline. Severe tectonic activity in the area has led to the development of a network of joints and fractures.

The landslide is mapped at 1:500 scale topographic map, with contours at 1 metre interval (Fig. 5). The activity map of the landslide was prepared by demarcating stable and unstable zones, tension cracks, landslide escarpment and bedrock outcrops.

Field observations

The landslide has taken place in colluvium, also involving some bedrock belonging to the rocks of the Murree Formation. Colluvium is thick and supports thick vegetation (pine trees) around the landslide area. Creep is common in unstable colluvium. The bedrock involved in the mass movement includes shale and siltstone with interbeds of sandstone (Fig. 5). About 2m thick sandstone body is located in the centre of the escarpment, and is laterally inconsistent in thickness. Sandstone is the most resistant lithology, but it is only about a metre thick towards the Murree end of the slide. The sandstone is fine to medium grained, greyish brown to brown in colour, multistoried, thin to medium bedded, highly fractured and jointed. Major part of the landslide, both on the hillside as well as on the valley side is comprised of shale and siltstone, however, on the valley side, major part of the slide zone is now occupied by the dumped material.

The unstable zone is about 120 m wide, while the major landslide with clear escarpment is 80m

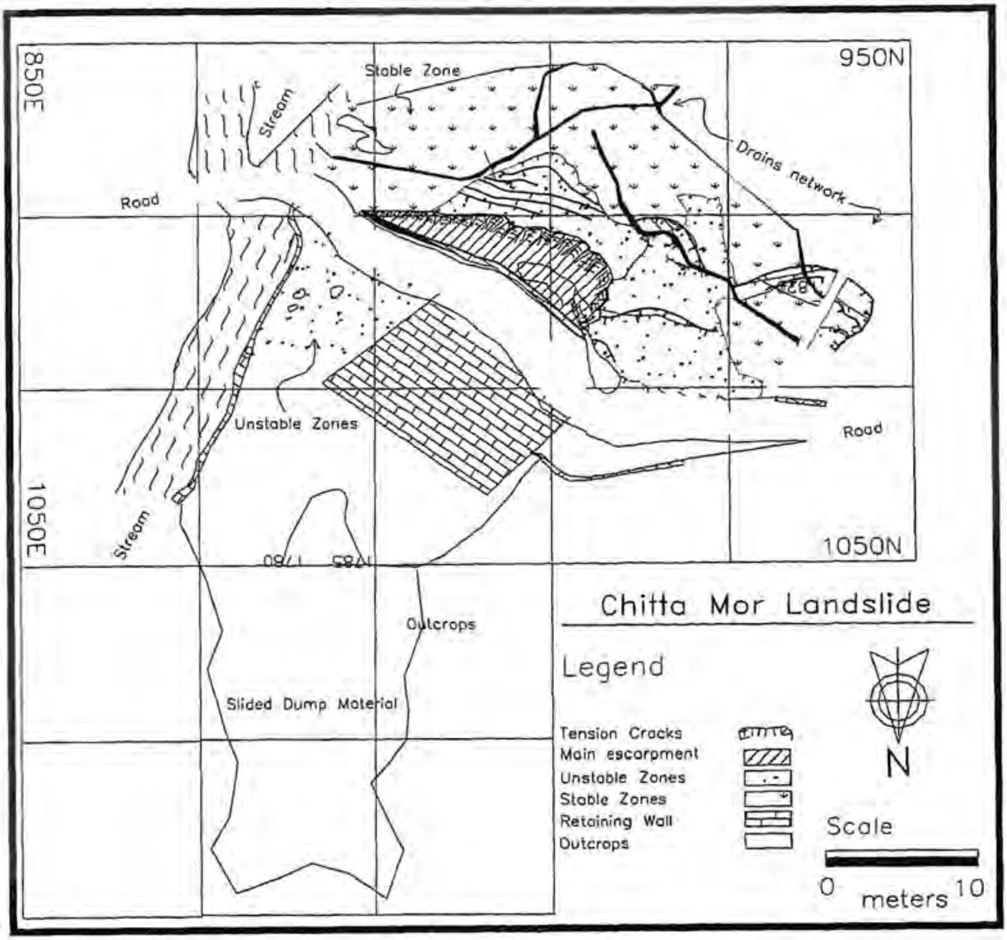

Fig. 5. Detailed map of Chitta Mor landslide at 1:500 scale. The landslide (Cls on Fig. 2) is located halfway between Bansragali and Chitta Mor. The landslide has been stabilized through engineering work but new tension cracks are developing close to the escarpment.

wide. The road is oriented in SEE-NWW direction, which also is direction of the escarpment (Fig. 5). On Bansra Gali end of the escarpment, another potential unstable zone is also threatening the road, and is therefore included in the active landslide. The landslide is about 150m long, about 20m on the hillside (up to the escarpment) and the rest on the valley side. On the valley side most of the landslide material has been leveled for the engineering remedial work by the Highway Department.

The movement direction along the main landslide is towards N20°E at right angle to the road orientation. The escarpment is very steep to vertical but flattens to only about 20°-25° above the escarpment. On the valley side the downslope is also about 20°. There is a thick forest cover on the sides of the landslide, particularly on the hillside. There is a perennial stream flowing on the Murree end of the slide. On the valley side, the stream banks are unstable and are sliding into stream bed. The Highway Department has constructed a network of channels in order to regulate the rainwater away from the unstable zones, however, these drains are now broken and disrupted due to unstable nature of the colluvium.

The colluvium cover is over 2m thick close to the landslide upslope of the road. Large tension cracks are developing in the colluvium cover and a number of unstable zones can be recognized (Fig. 5). The colluvium cover can therefore be divided into stable and unstable zones. These unstable zones may become potential landslides during next rainy seasons. One such large unstable zone is located on the Bansra Gali side of the landslide (Fig. 5). It has a well-developed scarp which is gradually increasing, laterally joining with the escarpment of the major landslide. The colluvium within the zone is highly fractured with a series of tension cracks indicating movement within the body. A small rain water channel constructed through the colluvium has been badly disrupted and broken at a number of places. The zone is oriented NNW, at right angle to the road and is threatening the retaining wall.

A similar unstable zone occurs upslope of the main escarpment with a fairly regular outline (Fig. 5). The colluvium in the zone shows strong creep and even movement as reflected by abundant tension cracks. This zone is highly unstable and will ultimately join the main escarpment. On the valley side, just below the road, another zone of unstable colluvium occurs towards the Murree end.

Geotechnical analysis (fracture and joint data):

The outcrops, particularly the sandstone beds are highly fractured and jointed. We have collected orientation data for the joints in the sandstone outcrops exposed in the escarpment area. Figure 6, shows an equal area projection of measured joint planes, bedding and poles to the both. The poles to the joint planes have a three-fold distribution suggesting presence of three sets of joints. The principal set of joints is oriented ENE-WSW with moderate dips to the NNW. The escarpment of the slide is defined by this set of joints. These joints are commonly associated with the slickensides and striations similar to those observed and described from the Kashmiri Bazar slide (see above). In all the cases, the hanging block has been noticed to have slided down-dip or oblique to dip within the general direction of the mass-movement. The second set of joints is oriented NNW-SSE with steep dips to the NE. This set of joints is at high angle to the first joint set and the plane of the slide, but has a general parallelism with the slip direction in the landslide. It is therefore envisaged that this joint set has important contribution to the mass movement in the landslide area. A third set of minor joints is noticed parallel to the bedding plane. These joints together with the bedding plane are oriented at high angle to slip plane as well as the slip direction and are thus non-contributory to the mass movement in the Chitta Mor landslide.

Slide mechanism

The Chitta Mor landslide on the eastern slope of the Murree ridge is a major landslide which initiated during early 70s. The landslide is part of a major unstable zone close to main Islamabad-Murree road section. This zone is about one km long, which hosts a number of large and small landslides, most of which are under different phases of stabilization. This area is deformed structurally by a major thrust fault in the area, known as the Murree Thrust (also called the Main Boundary Thrust). The fault brings carbonate rocks of the Eocene age on top of the Miocene molasse sediments. Complex sets of joints in the slide area are associated

DISCUSSIONS AND RECOMMENDATIONS

The instability in the Murree area is partly due to its inherited geological characteristics and climatic conditions, and partly due to human factors. It is difficult to overcome the natural causes but it is

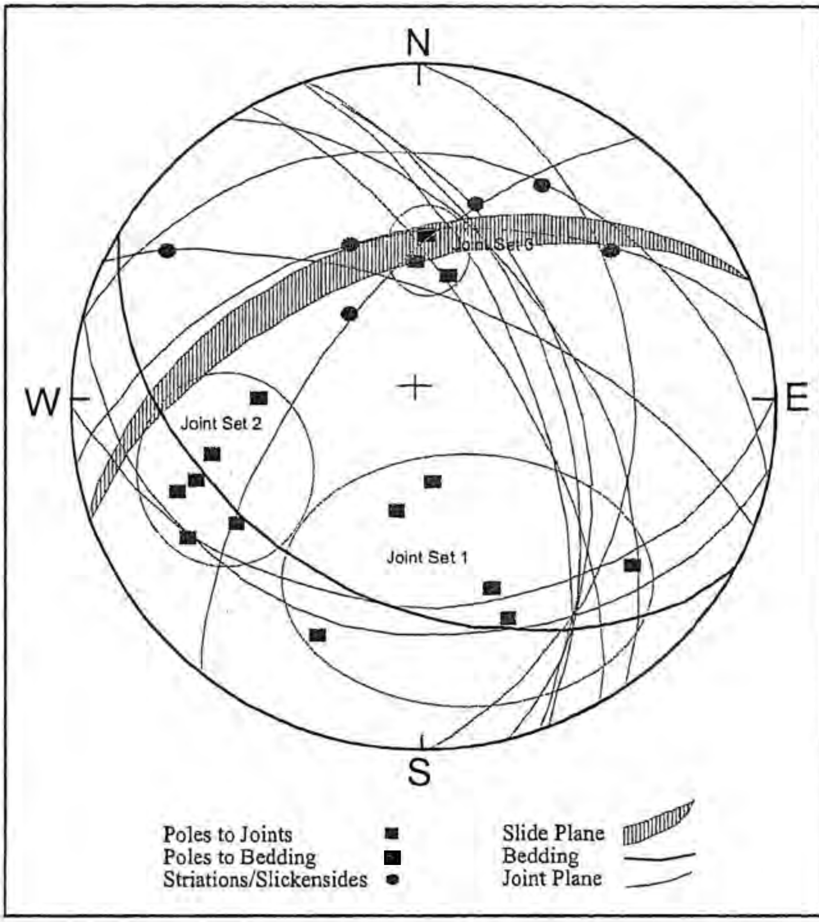

Fig. 6. Joint/fracture plot of Chitta Mor Landslide. The NNW oriented joint plane (joint set 3) that is locally sub-parallel to the escarpment is the principal slip plane. Lineations plunge moderately to the NNE are in the general slip direction of the landslide.

greatly needed to reduce the effects of human activities contributing to landslide problem. The area around Murree is extremely fragile but little work has been done so far to evaluate the risks of erosion and mass movement. Major emphasis has so far been on the engineering base remedies, which have been partially successful but have limited scope. Major engineering work at the Chitta Mor landslide has stabilized the movement for the time being but the enormous load added due to large scale concrete work on the valley side has started showing adverse effects. Large cracks are developing in the retaining walls and most of the channels constructed for diversion of drainage water have been broken. New scarps are developing along major tension cracks on the hillside and movement has started along them. Similarly, large-scale engineering work failed to stabilize the MIT landslide, and major part of the engineering structure is already in disintegration during the first monsoon rains. Engineering methods added with bioengineering techniques is considered effective to control soil erosion and mass movement, such as in the Kashmiri Bazar landslide area. Same techniques should be adopted at other landslide prone areas along with an efficient surface drainage and sewerage system.

A number of major landslides such as the MIT and Shifang Hotel landslides on the Murree Bypass road section appear to be direct result of the poor drainage system from the Forthview Hotel and Shifang Hotel respectively into the slide areas. Major construction work in the Murree Improvement Trust Housing scheme is major strain on the eastern slope of the Murree ridge. The construction work is being carried out without much regard to natural drainage, resulting in excessive undercutting by the water during monsoon rains.

There is also an urgent need to prepare comprehensive landuse and hazard maps not only for the Murree Town but also for the adjoining areas. This requires detailed study of the area over a longer period of time. No attention has been paid to most of the landslides located away from the main roads or highways. Large area is eroded along major steams in the area where people are forced to abandon their houses and valuable land due to landslides. Most of these landslides are not even marked on a proper map.

SUMMARY

- The slopes encircling the Murree ridge, which hosts the old Murree township are generally unstable despite a reasonably thick forest cover. This is mainly due to unmanaged sewerage outlet and excavation work for road and building construction.
- The ring road encircling the Murree ridge is generally unstable. In particular the Jhika Gali-Lawrence College Bypass road section is the unstable zone designated in this study. This is mainly due to a relatively steeper slope on this side of the Murree ridge, as well as a relatively thin vegetation cover, sewerage disposal from the old Murree township on this side and large-scale new construction work, particularly in the area downslope the bypass road in the form of the MIT housing scheme.
- One of the crucial observation of this study is reactivation of apparently stabilised old landslide zones. Excavation in these zones and unmanaged drainage causes these zones to commonly reactivate and trigger major new landslide mass-movement.
- Study of a selected few major landslides demonstrates that the landslides in the Murree area are primarily triggered by the slope failure along the bedrock-colluvium interface mainly in response to excavation for road construction/ widening. Once initiated, the escarpment progressively migrates upslopes engulfing steep tension cracks. At this stage the landslides involve both the colluvium as well as the bedrock. Joint planes, both pre-existing as well as those related with the slope failure facilitate rock sliding leaving behind striations/ slickensides on planar surfaces of the intact bedrock.

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REFERENCES

Abbasi, I. A. 1994. Clay minerals in the Himalayan Foreland-basin sediments indicating an uplifting orogenic belt. In: Geology in South Asia, Proceedings of the Ist. GEOSAS conference (Riaz Ahmed and Arshad M. Sheikh edits.), 280-284.

Chambers, A. F. 1992. Kinematics of the frontal Himalayan thrust belt, Pakistan and the external western Alps, France. Unpubl. Ph.D. dissertation, Imperial College London. 369p.

Coward, M.P., Windley, B.F., Broughton, R.D., Luff, I.W., Petterson, M.G., Pudsey, C.J., Rex, D.C. and

Khan, M.A., 1986. Collision tectonics in the NW Himalayas. *In:* (Coward, M.P. & Ries, A.C. edits) Collision Tectonics, Geol. Soc. London Spec. Publ. No. 19, 203-219.

Fraser, 1998. Structural and metamorphic evolution of the deep crust in the Hunza Karakorum, Pakistan. Abstract, 13 HKT Workshop, NCE Geology, University of Peshawar, Pakistan, 65-66p.

Gansser, A. 1964. Geology of the Himalayas. Wiley, New York, 273p.

Iqbal, M. and Bannert, D. 1998. Structural observations of the Margala Hills, Pakistan and the nature of the Main Boundary Thrust. Pakistan Jour. Hydrocarbon Res. 10, 41-53.

Khan, K.S.A., Fayaz, A., Latif M. & Khan, M.S.Z. 1987. Study of the landslide problems along the Rawalpindi-Murree-Kohala road. Geol. Sur. Pak. Information release, 279, Quetta.

Khan, M. N., Jalloh, S. and Moughtin, C. 1998. Towards an appraisal of landslide hazard reduction programme in Murree, Pakistan. *In:* (Israr-ud-Din edit) Studies in Pakistan Geography, Dept. of Geography, 13-38.

Malik M. H. & Farooq, S. 1996. Landslide hazard management and control in Pakistan: A review. ICIMOD, Kathmandu, Nepal. 68p.

Master Plan Murree Town, 1988 prepared by the office of Deputy Director, Regional Physical Planning Rawalpindi, Director of Physical Planning, Housing and Physical Planning Department, Government of Punjab.

Niederer, S. and Schaffner, R. 1989. Landslide problems and erosion control in Murree and Kahota tehsils of Rawalpindi Distt. Report of the fact finding mission, SDC, Ministry of Foreign Affairs, Govt. of Switzerland, CH-3003, Bern.

National Engineering Services Pakistan (Pvt) Ltd (NESPAK), 1997. Study of landslides in Murree area. Govt. of the Punjab, Commun. And Works Dept.

Rafiq, M., Khan, S.R., Wagner, A. and Stephan, N. 1989. Murree Erosion Control: Results of the Fact Finding Mission. Swiss Dev. Coop. Ministry of foreign Affairs, Govt. of Switzerland, 3003, Bern. 38p.

Schenellmann, M. and Gnehm, F. 1999. A structural analysis of the NW Himalayan fold-and-thrust belt in Hazara, Pakistan. Unpubl. Diploma thesis, Institute of Geology, ETH Zuerich.

Tahirkheli, R.A.K., Mattauer, M., Proust, F. and Tapponnier, P., 1979. The India-Eurasia suture zone in north Pakistan: Synthesis and interpretation of recent data at plate scale, in: "Geodynamics of Pakistan" (edit, A. Farah and K.A. DeJong). Gest. Surv. Pakistan, Quetta, Pakistan, 125-130.

Urs and Schaffner, R. 1998. Landslide management and construction of roads in hilly areas of Murre and Kahuta. Govt. of the Punjab. 22p.

Zeitler, P. K. 1985. Cooling history of N.W. Himalaya, Pakistan. Tectonics, 4 127-151.