Landslide Hazard Management and Control in Pakistan
A Review

M.H. Malik
and
S. Farooq

International Centre for Integrated Mountain Development
Kathmandu, Nepal
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Cover Photograph: Plane failure in schists at Lower Gali, Muzaffarabad

Inset: Movement of scree slope blocking the road between Muzaffarabad and Garhi Habib Ullah.

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Preface

The inherently unstable nature of mountain areas of the Hindu Kush-Himalayas is well recognised. The steep slopes, unstable geology, and intense monsoon rains combine to make the Hindu Kush-Himalayas one of the most hazard-prone areas in the world. Although natural hazards of varying intensity have occurred frequently in the past in Hindu Kush-Himalayan countries, more recently there has been an increase in human settlement of hazard-prone areas as a result of population pressure, as well as improvements in accessibility by road and the onset of other infrastructural developments. Consequently, natural and man-made disasters are on the increase and each event affects an even greater number of people than before. Floods and landslides during the monsoon season are the most common natural disasters affecting this region, often resulting in substantial economic and environmental losses and causing great suffering to many people.

Despite all this the present levels of understanding and systematic analysis of these disastrous events are very poor and data bases are non-existent. No monitoring activities are carried out even in cases where such monitoring can be of direct benefit to project-related management activities. Investments in developing practical guidelines for managing such events as well as in forecasting them have been inadequate.

Since its inception, ICIMOD has been promoting the development of a better understanding of natural hazards. Various activities have been undertaken so far. These include several training programmes dealing with mountain risk engineering, focussing on improving road construction along unstable mountain slopes, a review of landslide hazard management activities in China, and field assessment of landslides and flood events in south central Nepal following the extreme climatic events that took place in July 1993.

One of the goals set by ICIMOD in its Mountain Natural Resources' programme is to "Improve the conditions of mountain resources and environments by halting and eventually reversing their degradation." Programme activities envisaged to achieve the above goal are directed to:

- identification of measures to mitigate different types of natural hazards which result in the loss of natural resources;
- promotion of skills and methodologies for natural hazard assessment; and
- improvement of public awareness for better disaster preparedness in mountain areas.

ICIMOD's programme on "Landslide Hazard Management and Control" focusses on these concerns to help protect valuable natural resources from different types of natural hazards. This programme is based on activities already introduced at ICIMOD in 1994 with support from the Government of Japan.

This programme is concerned not only with examining the types and extent of landslide events but also with measures for their mitigation and control; and in addition the skills and methodologies needed for natural hazard assessment.

To improve the knowledge base on Landslide Hazard Management and Control, state-of-the-art reviews were commissioned in four countries of the Hindu Kush-Himalayan Region. These countries are China, India, Nepal, and Pakistan.

Suresh Raj Chalise of the Mountain Natural Resources' Division at ICIMOD coordinated the work carried out on these reviews and the current document entitled "**Landslide Hazard Management and Control in Pakistan : A Review**" was prepared by M.H. Malik, and Saeed Farooq of the Institute of Geology, Punjab University. Mr. Malik and Mr. Farooq have produced a comprehensive document on a topic that is crucial to the development of mountain areas and the well-being of mountain inhabitants.

Abstract

This country review on landslides in Pakistan deals with all the aspects of landslides, their types; causative factors; their relation to geology, earthquakes, monsoons, and deforestation; their impact; and possible studies to overcome disasters and control. This paper systematically identifies the problem areas and gives details of the historical background clearly establishing the connection with certain natural (earthquakes, lithology) and man-made (excavations and indiscriminate construction) causative factors.

The northern parts of Pakistan, i.e., the mountainous regions of the Himalayas, the Karakoram, and the Hindu Kush, have a high incidence of landslides. Though this part of the country is not highly-populated, nevertheless, the impact of landslides is felt severely. More so, because this part of the country is bordered by China, India, and Afghanistan and is, therefore, of considerable strategic importance.

The extent of the impacts of landslides depends upon various factors such as the depth and rate of movement, stresses from the environment, volume of materials involved, and, most importantly, the proximity to settlements and structures. The author quotes instances where more than half a village has been wiped out or where powerhouses/dams have been damaged.

Dealing with the diversity of causes, the author scientifically enumerates aspects of geology, such as lithological distribution, bedding, joints, foliation, and schistosity, that lead to landslides. Causative factors relating to surface and groundwater and the effect of saturation on strength, temperature variations, earthquakes and vibrations, and effects of vegetation and deforestation have been dealt with in the context of Pakistan.

The text is further substantiated with figures, tables, and photographs.

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Acronyms

K.K.H.	Karakoram Highway
C	Cohesion
MC	Moisture Content %
LL	Liquid Limit
PL	Plasticity Limit
PI	Plasticity Index
rb	Bulk Density
rd	Dry density
_	Angle of Internal Friction
Gs	Specific Gravity
p	Density
JRC	Joint Roughness Coefficient
JCS	Joint Wall Compressive Strength
_r	Angle of Residual Friction
n	Normal Load

Introduction

Landslides are a natural phenomenon involving movement of earth materials (soil/rock) on different scales, varying from small insignificant rockfalls to huge movements of materials producing catastrophic effects. Landslides, involving materials from the mountainous regions of the outer Himalayas, the Karakoram, and the Hindu Kush, occur frequently in the northern areas of Pakistan. This part of the country is bordered by China, India, and Afghanistan and therefore is of considerable strategic importance.

This study of landslide types or classification, causes, analysis, and remedial measures has been undertaken keeping in mind the significance of hazards caused by landslides.

Various important routes (highways) in northern Pakistan (Fig. 1) were selected for detailed slope stability studies. Detailed geological mapping was carried out on different scales, emphasising the role of lithology in slope stability. Landslide inventory maps were prepared to identify the stability conditions of slopes in different areas (Fig. 2). Slopes were initially broadly categorised as 'stable', 'unstable', and 'potentially unstable' on the basis of geological and geotechnical studies.

The critical areas termed 'unstable' or 'potentially unstable' were considered for qualitative and quantitative evaluation. On the basis of these evaluations, different relationships were established.

i) Lithology and structure versus landslides
ii) Earthquake activities and slope movements
iii) Precipitation (during monsoon) and number of landslides
iv) Types of landslide and their frequency in different climatic and lithological conditions
v) Geometry of slopes (number of terraces and inclination versus stability)
vi) Vegetation and its effects

Wherever suitable, relevant data have been presented in the form of tables, graphs, plots, and other illustrations. Appropriate landslide warning and monitoring systems have been carried out and recommended on the basis of quantitative evaluation. Different prevailing remedial measures to control landslides have also been critically studied for their effectiveness and, in the light of these studies, more suitable and justifiable methods have been suggested.

The significance and role of different government and non-government organisations have been highlighted at the end. Keeping in mind the varying conditions in different parts of the country, relevant findings and appropriate recommendations are presented.

The Landslide Issue

Description and Types

The word landslide is used to denote the movement of earth or displaced mass (Lundgren 1986). Various movements of earth are designated in different terms by different authors, for example, rockfall, earth flow, slip, mass movement, subsidence, and so on. They can all be grouped as landslides (Fig. 3a - g).

Zaruba and Mencl (1969) broadly classify landslides as 'recent', 'ancient', and 'fossil' on the basis of their ages. Similarly, slopes have been classified as 'active' or 'inactive' depending on the evidence of movement within the last seasonal cycle. Blyth and deFreitas (1984) point out that landslides or slope movement can occur in the following ways, either separately or together.

i) By detachment of rock as rockfalls and topples
ii) By shear failure on existing large-scale geological surfaces
iii) By shear failure of rock and soil materials often using weak horizons
iv) By gradual adjustments on a microscopic scale as in creep

Figure 1: Road Map of Northern Pakistan

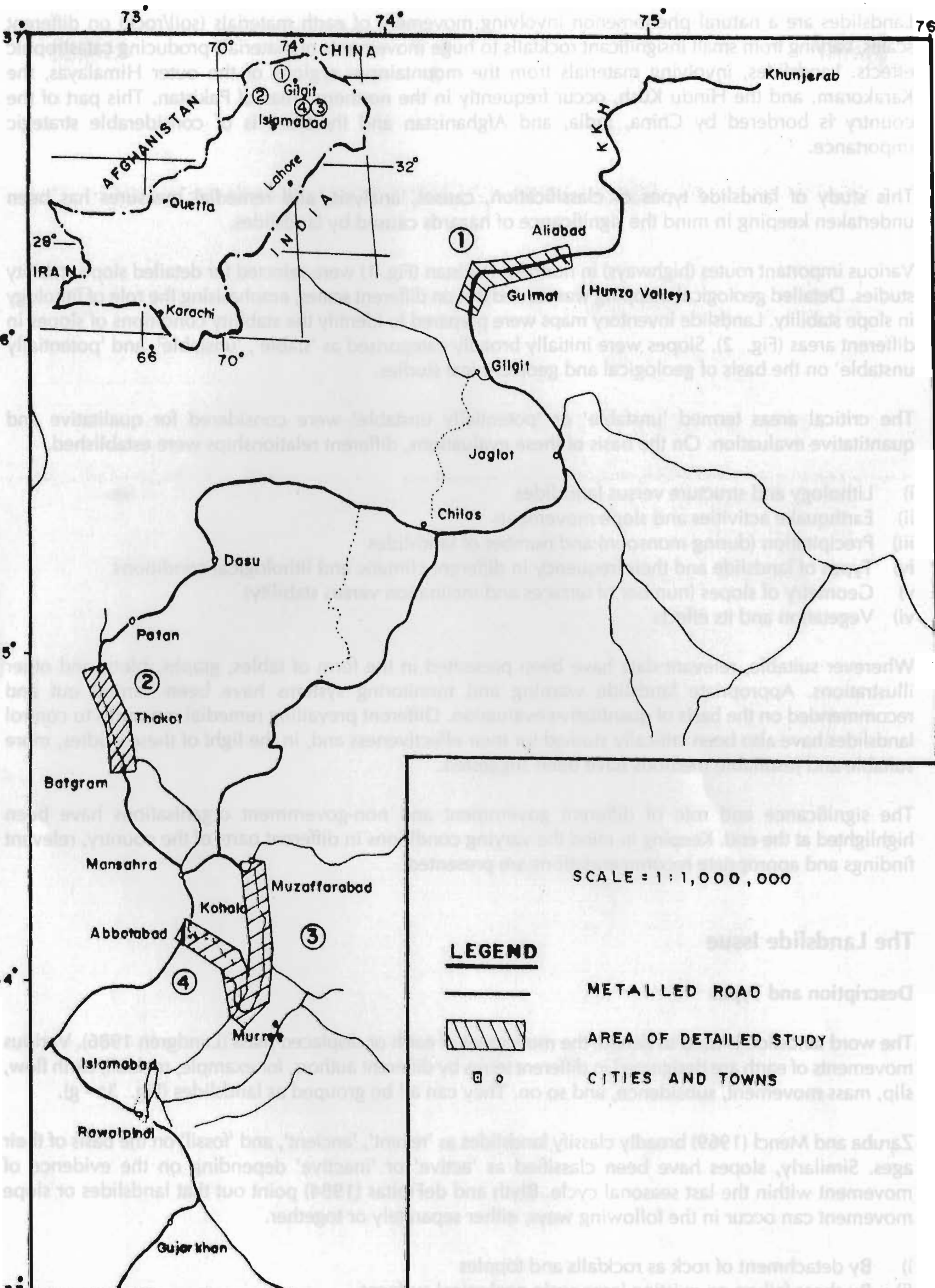


Figure 2: Geological Map of Kohala-Muzaffarabad Area (Kohala to Dulai) Showing Landslide Risk Zones

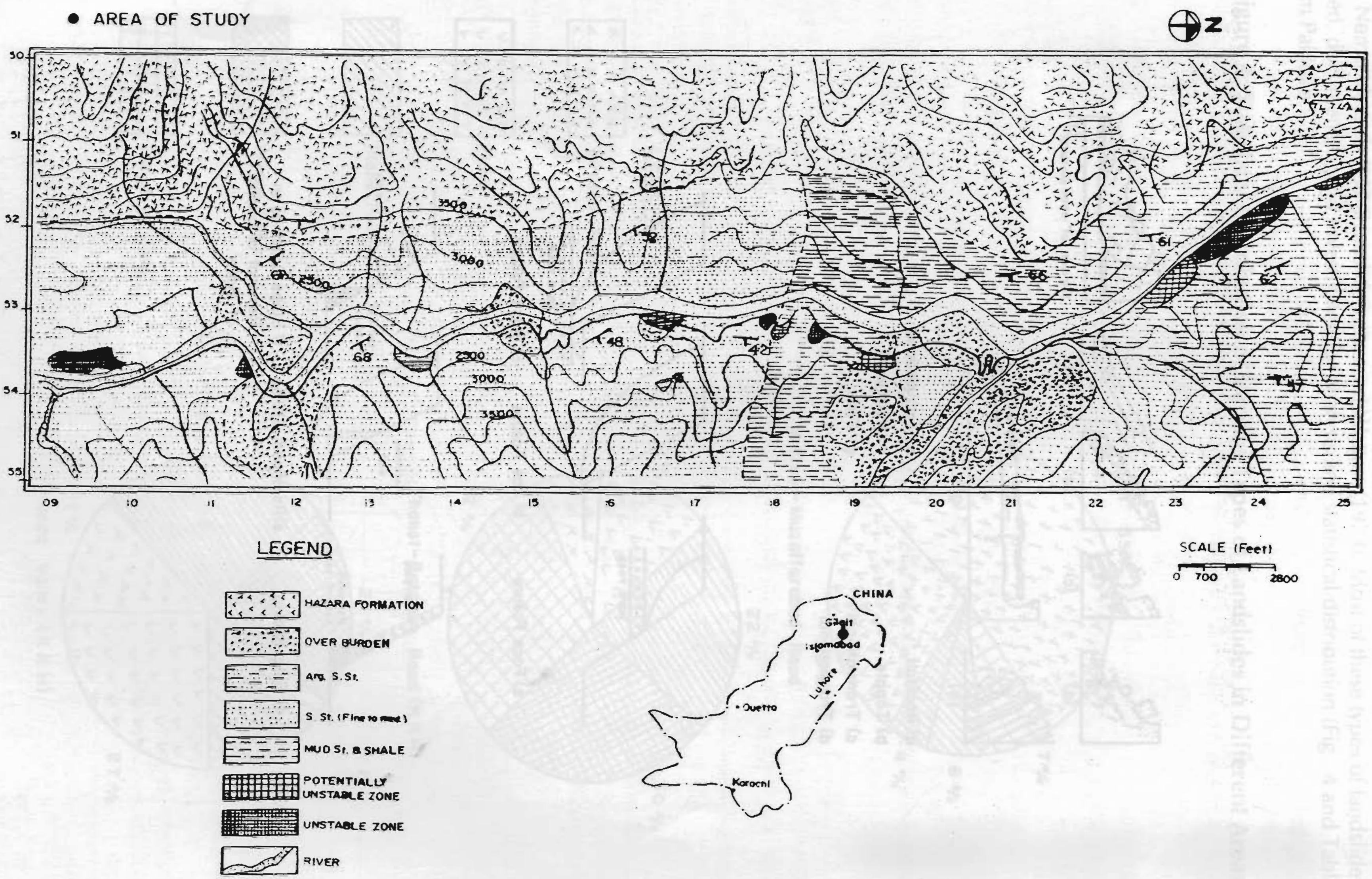
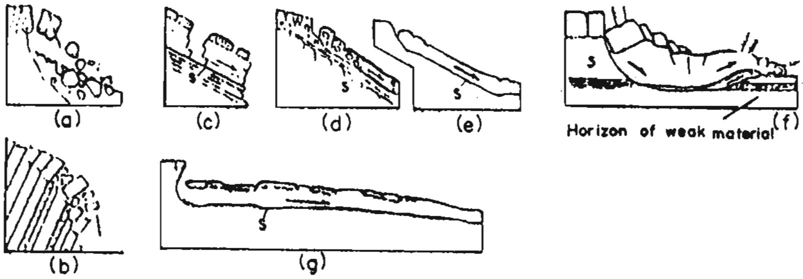
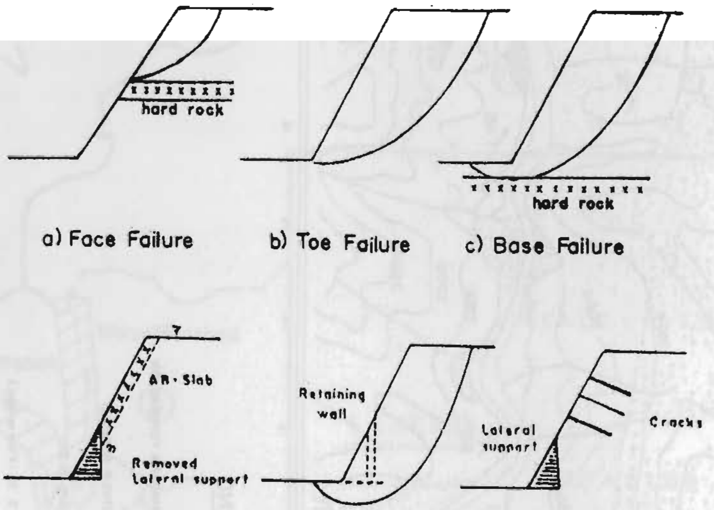


Figure 3: Different Types of Landslides and Slope Failures



a) Rockfall
b) Topple
c) Translational
d) Translational
e) Translational
f) Rotational
g) Flow



a) Face Failure
b) Toe Failure
c) Base Failure
d) Slab Sliding
e) Rotational Sliding
f) Slope Cracking on Removal of Support of Base

Six basic types of slope movement, i.e., falls, topples, slides (translational and rotational), lateral spreads, flows, and complex (combination of two or more principal types of movement) have been referred to by Varnes (1978). This classification is most commonly used (Table 1) and is based on Sharpe (1938), supplemented by other sources Zischinsky (1966), Zaruba and Mencl (1969), Skempton and Hutchinson (1969), Nemcock et al. (1972), and deFreitas and Watters (1973). Most of these types of landslides were identified, documented, and investigated for analysis and statistical distribution (Fig. 4 and Table 2) in northern Pakistan.

Figure 4: Statistical Distribution of Various Types of Landslides in Different Areas

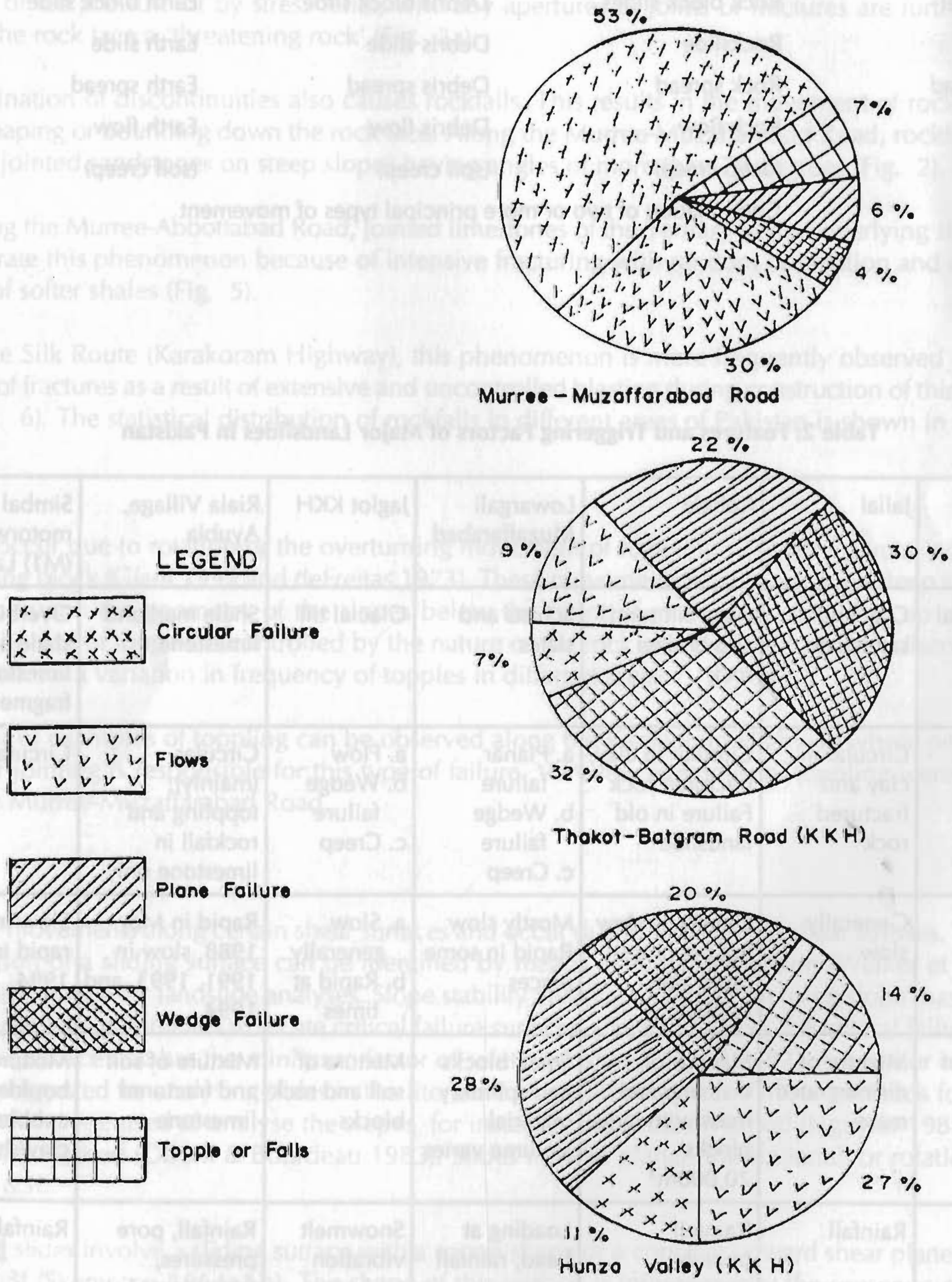


Table 1: Abbreviated Classification of Landslides (After Varnes 1978)

Type of movement	Bedrock	Predominantly coarse	Type of material (Unconsolidated material predominantly fine)
Falls	Rockfalls	Debris fall	Earth fall
Topples	Rock topple	Debris topple	Earth topple
Slides:			
Rotational	Rock slump	Debris slump	Earth slump
Translational	Rock block slides	Debris block slide	Earth block slide
	Rockslide	Debris slide	Earth slide
Lateral spread	Rock spread	Debris spread	Earth spread
Flows	Rock flow	Debris flow	Earth flow
	(deep creep)	(soil creep)	(soil creep)
Complex	Combination of two or more principal types of movement		

Table 2: Features and Triggering Factors of Major Landslides in Pakistan

Features	Jalial	Kohala	Lowargali Muzaffarabad	Jaglot KKH	Riala Village, Ayubia	Simbal motorway (M1) Lahore
Slide material	Clay and sandstone	Clay, silt sand and broken rock	Schists and slates	Glacial till	Shale marl and limestone	Overburden of shale and limestone fragments
Slip surface	Circular in clay and fractured rock	Circular in clay, fractured rock Failure in old landslide	a. Planar failure b. Wedge failure c. Creep	a. Flow b. Wedge failure c. Creep	Circular (mainly), toppling and rockfall in limestone only	Circular
Rate of movement	Generally slow	Generally slow but becomes rapid after rainfall	Mostly slow Rapid in some places	a. Slow generally b. Rapid at times	Rapid in May 1988, slow in 1991, 1993, and 1994	Slow in 1993, rapid in Aug. 1994
Behaviour of mass movement Volume displaced	Mixture of disintegrated mass	Mixture of disintegrated mass with large blocks $70,000m^3$	Small blocks and splintery material Volume varies	Mixture of soil and rock blocks	Mixture of soil and fractured limestone	Mixture of boulders, cobbles, and clay/shale
Triggering factors	Rainfall	Rainfall (mainly) Earthquake 1992	Loading at head, rainfall and mass wasting	Snowmelt vibration and earthquake	Rainfall, pore pressures, fracturing of limestone	Rainfall

Brief descriptions of the types of landslide are given below. Figures illustrating the different landslide types are referred in the relevant passages.

Rockfalls

Rockfalls occur due to loss of support, sliding, fracturing, or rotation of small rock units forming a part of the free face. They involve free falling of rock blocks of different sizes detached from rock slopes in the form of rolling or sliding downwards with a velocity of more than 28m/sec. When rock blocks, which are detached but perched on steep slopes, fall, they are categorised as 'secondary falls' (Hutchinson 1988). Rockfalls are small-scale displacements, involving a direct downward movement, resulting from lack of support from below due to differential weathering of softer materials or to physical undercutting of a rock face (Knill 1967). Rock faces marked by vertical or subvertical fractures fall as a result of slab failure due to water or ice pressure or by stress relief, whereby apertures of joints or fractures are further opened leaving the rock face a 'threatening rock' (Fig. 3a).

The inclination of discontinuities also causes rockfalls. This results in the movement of rock debris by freefall leaping or bounding down the rock face. Along the Murree-Muzaffarabad Road, rockfalls mostly occur in jointed sandstones on steep slopes having angles of more than 70 degrees (Fig. 2).

Also along the Murree-Abbottabad Road, jointed limestones of the Tertiary period overlying shales often demonstrate this phenomenon because of intensive fracturing with random orientation and differential erosion of softer shales (Fig. 5).

Along the Silk Route (Karakoram Highway), this phenomenon is more frequently observed due to the opening of fractures as a result of extensive and uncontrolled blasting during construction of this important road (Fig. 6). The statistical distribution of rockfalls in different areas of Pakistan is shown in Figure 4.

Topples

Topples occur due to rotation or the overturning movement of rock (Fig. 3b) on a pivotal point below the toppling block (Giani 1992 and deFreitas 1973). These movements usually occur on steep slopes and, depending upon the geometry of the slopes below the point of movement, may end up as 'falls' or 'slides'. The size of topples is controlled by the nature of the rock and the orientation of discontinuities. Figure 4 shows a variation in frequency of topples in different areas.

A number of examples of toppling can be observed along the Karakoram Highway where near vertical columnar jointing is responsible for this type of failure. Very few examples of toppling were observed along the Murree-Muzaffarabad Road.

Slides

Slides are movements along certain shear surfaces and occur due to unbalanced shear stresses. The shape and position of a sliding surface can be identified by means of site investigation (Walker et al. 1987), which is imperative for landslide analyses. Slope stability analysis is carried out using slope mass strength and pore pressure parameters to locate critical failure surfaces. On a soil slope, the critical failure surface may be the surface that has the minimum factor of safety (Mostyn & Small 1987). A number of methods has been suggested for analysing slides in the literature on soil mechanics. Various methods for locating critical surfaces are used to analyse the slopes, for instance, the Secant Method (Nguyen 1985) and the Probablistic Method (Oboni & Bourdeau 1983). Slides may be planar (translational) or rotational (Figs. 3c,3d,3e &3f).

<u>Rotational</u> slides involve a sliding surface with a spoon shape or a concave upward shear plane as shown in Figure 3f (Skempton 1964a&b). The shape of this surface is influenced by the presence of bedding joints and faults (Bishop 1955). These are also called 'slumps' and are generally deep in comparison to their length (Figs. 7a & b). The failed material generally remains intact, only a few discrete blocks are likely to be produced. The rate of movement ranges from mm/year, m/day, to rapid or quick. For instance,

the rate of movement (54m/day) recorded on 10 August, 1994, at the Simbal Slide in colluvium on Motorway M1 (Lahore to Islamabad) is moderate compared to the Kohala landslide shown in Figure 2, where rapid movements proved hazardous and catastrophic.

Figure 5: Geological and Landslide Inventory Map of Abandoned Road between Khera Gali and Changla Gali (Hazara)

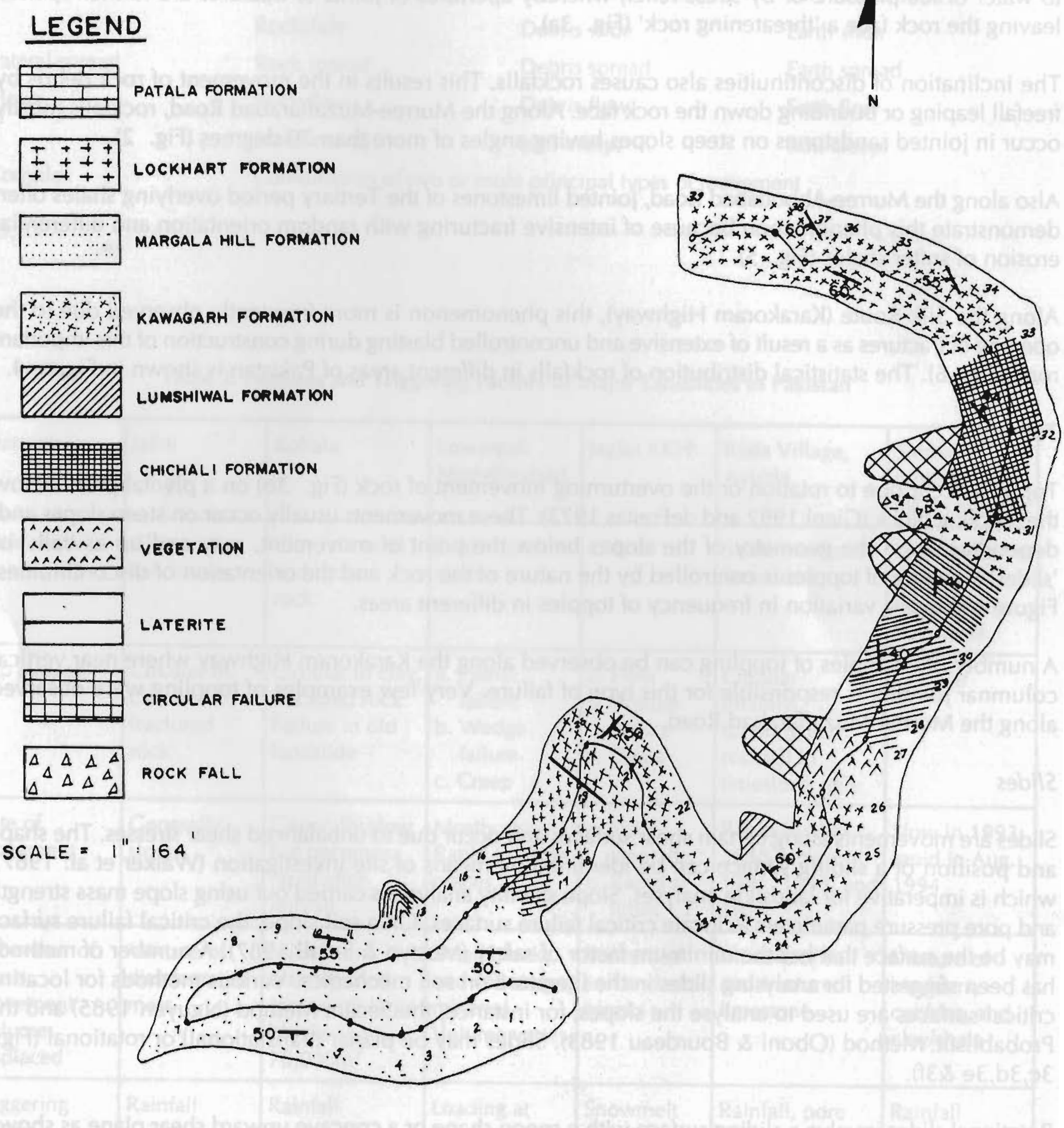


Figure 6: Stability Assessment along part of the Karakoram Highway from Thakot to Batgram (28km) Using the Stereoplotting Technique

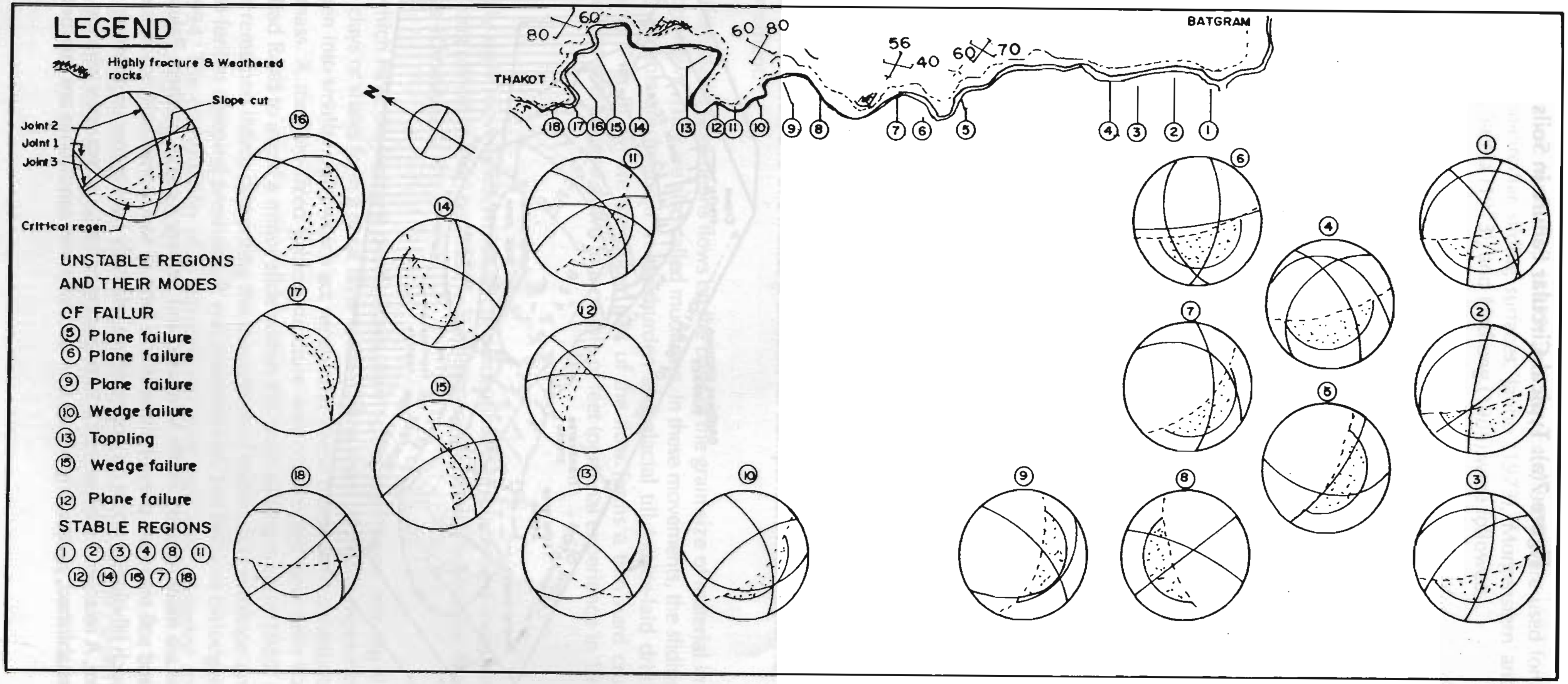


Figure 7(a): Typical Circular Failure in Soils

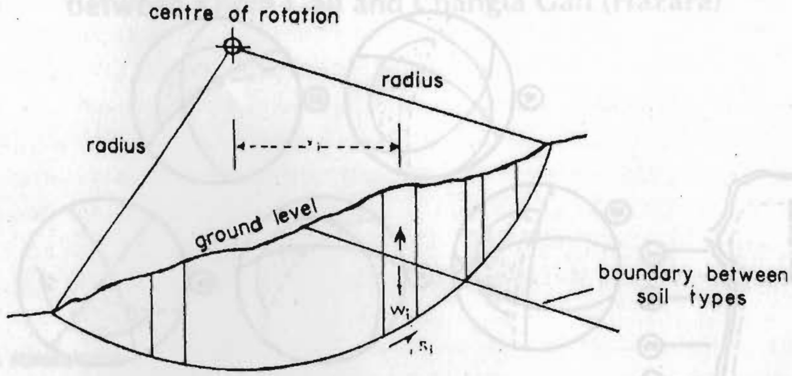
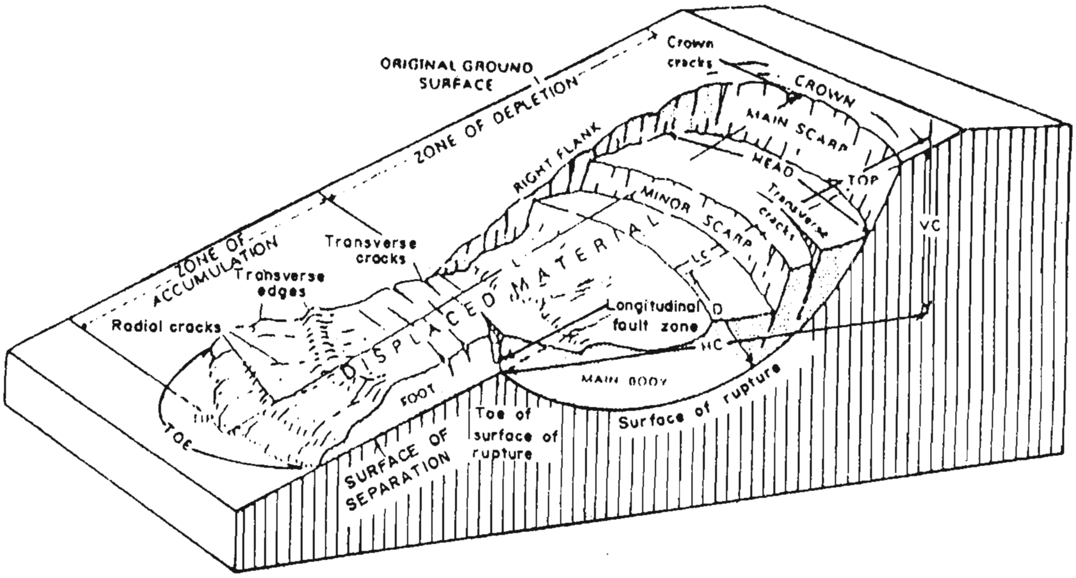


Figure 7(b): Nomenclature Used to Describe Landslides (Varnes 1978)



Rotational slides are more frequent in the Mesozoic and Tertiary rocks of northern Pakistan (Fig. 4) where alternate hard and soft materials prevail either in the form of sandstone/shale or limestone/shale lithologies. Slides in such lithologies occur on slopes where relatively homogeneous materials or closely jointed rocks are present. A relationship between fracture spacing or fracture frequency with the sliding phenomenon has been established, particularly where thin and fractured sandstones are interbedded with shales.

Unit equilibrium methods given by Bishop (1955) and Spencer (1967) were used for circular sliding surface cases, while for non-circular sliding surfaces, Janbu (1973), Morgenstern and Price (1965), Fredlung and Krahn (1977), Sarma (1973), and Fredlung (1984) were followed.

Translational Slides occur when shear failure takes place on a planar surface, or close to bedding planes, joints, faults, or foliation (Hutchinson 1988) and (Morgenstern & Price 1965). These slides were further divided into Plane or Wedge Failures depending upon the discontinuity number and orientation (Hoek and Bray 1981). In northern parts of Pakistan, the frequency of planar or translational slides varies from six to 28 per cent (Figs. 3 & 4).

The effect of pre-existing geological structure as faults or joints is not so prominent in altered, weak, or partly cemented rocks. These may be included in a category known as 'composite slides'.

Debris Slides involve the movement of unconsolidated materials along a bedrock or along more consolidated debris material (Fig. 3g). The movements can lead to a high-velocity flow of rock debris or debris avalanches, which occur more frequently in the upper reaches of the Karakoram Highway than in the rest of the country and which also travel considerable distances. In the lower reaches, i.e., from Mansehra to Thakot (Fig. 1), these slides tend to travel short distances and involve either rockfalls or movement along some discontinuities in the rock.

Flows

This type of movement involves an aspect of flow in unconsolidated materials with low or high rates under saturated or drained conditions. Flows are characteristic features of movement in unstable areas (lying between Kohala and Muzaffarabad) as shown in Figure 2.

Rock Flows refer to displacements due to large or small or even micro-fractures. These movements are usually slow. Flow movements may result in folding, bending, and bulging. It is difficult to assess rock mass parameters in such cases, and this makes it difficult for comparison with numerical results used in other types of movement.

Earth Flows are differentiated from debris flows on the basis of the grain size of material involved, which is finer than in debris flows. They are also called mudflows. In these movements, the sliding surface is not visible. These movements are frequent in overburden and glacial till (or ice-laid drift) near Hunza, Karakoram Highway (Fig. 8), where the upper part of the flow forms a thin hard crust and is very deceptive: a single step gets bogged down to a couple of feet (personal experience in 1974).

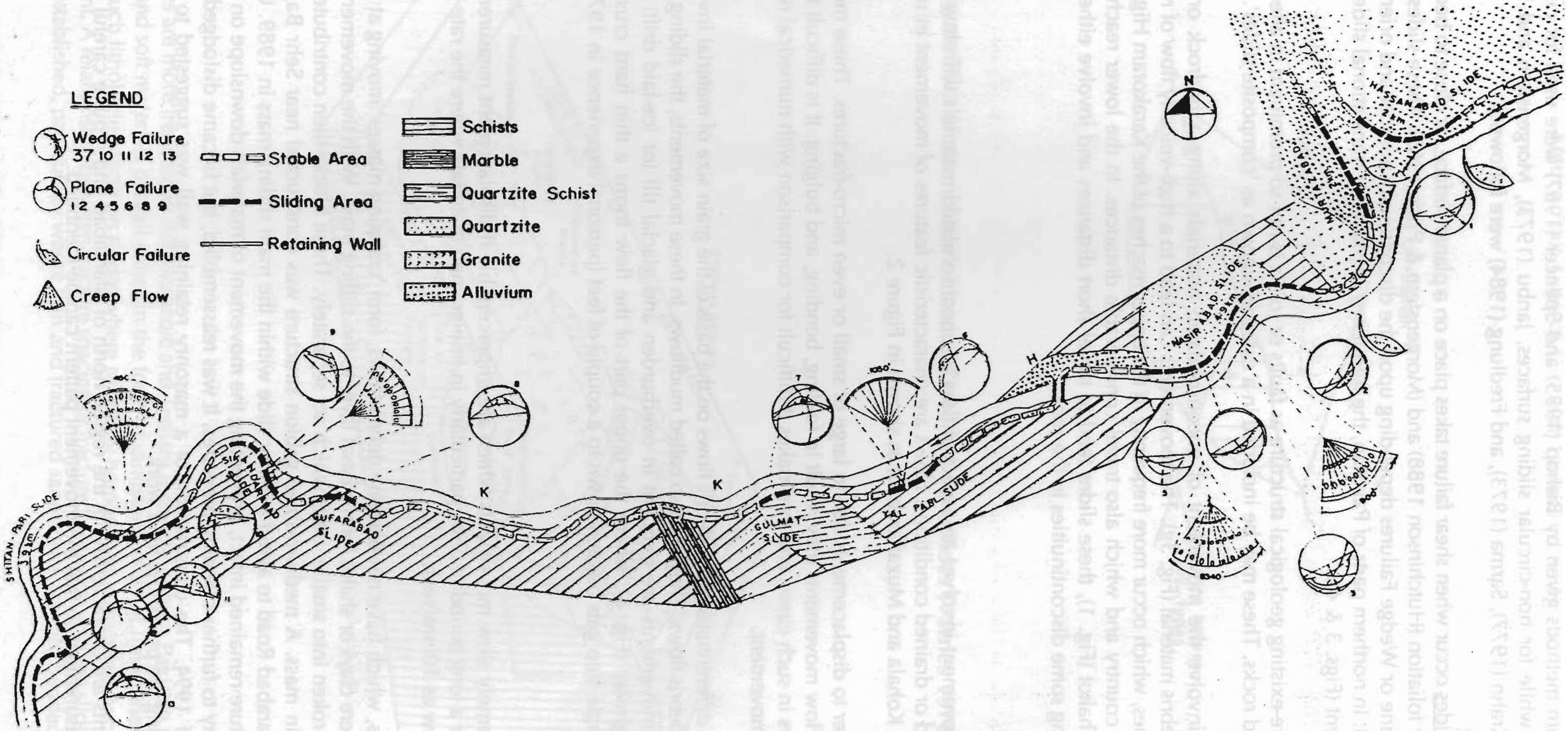
Creep

These are extremely slow movements which are imperceptible if displacement measurements are not carried out over a long period of time, particularly in fine-grained materials where the rate of movement could be as slow as 10mm/year.

Most rockslides, which have not become debris flows, form 'creeping masses' moving at varying rates, particularly where clays or shales form a basal layer to the sliding mass. With the movement, the mass is progressively broken into smaller units which act separately. These blocks then contribute minor slides within the main mass. A medium-sized gabion structure was constructed near Sehr Bagla along the Murree-Muzaffarabad Road to avoid a minor slide within the main sliding mass in 1989. Until October 1993, the structure remained intact, preventing the movement of materials downslope on the highway, then it gave way to further creeping pressures. It was reassembled, but became dislodged again during the summer of 1994. The construction of a masonry retaining wall was suggested to the highway authorities during the prevailing field work.

Such movements are characteristic of the region north of Islamabad and require careful mapping and systematic measurement so that the movement pattern can be identified.

Figure 8: Wedge Failure, Plane Failure, Circular Failure, Creep Flow - Shetan Pari to Aliabad Hunza (65km), Karakoram Highway



Impact of Landslides

The word landslide has been used for a very long time to denote the movement of earth materials varying in origin and magnitude. Landslides also range from near surface disturbances of weathered zones to deep-seated displacements of large rock masses. Their impact, therefore, will depend upon their type, depth of movement, rate of movement, stresses from environments, volume of materials involved, and the proximity of these slides to important structures such as towns, highways, dams, and powerhouses. For instance, movements that are limited to surface layers are generally controlled by stresses produced by surface or near surface environments such as rainfalls or rainstorms and temperature variations, while movements at depth are due to mobilising stresses at depth such as earthquakes and so on. The movements and their effects, therefore, range from slow displacement such as 'creep' to rapid and large catastrophic slides such as the Vajont slide in Italy in 1963, the Jaglot landslide on the Karakoram Highway, the Kohala landslide along the Murree-Kashmir Road, the Riala (Ayubia) landslide in 1988, the landslide near the Powerhouse of the Tarbela Dam, and the Simbal slide on the M1 Motorway in Pakistan. The significance of their impacts is further enhanced if one considers the occurrence of landslide phenomena related to natural or man-made activities, e.g.,valley slides, road cuts, or excavations for engineering work.

As mentioned earlier, landslides range in size from small 'rockfalls' to huge movements involving thousands of cubic metres of earth materials, which may destroy structures, human settlements, and agricultural land; cut off transport and communication systems; block highways of strategic value; and modify landscape. All these points mentioned here are in context with the impact of the landslides occurring in Pakistan. It is appropriate to cite the example of the Riala landslide near Ayubia Pakistan (Malik et al.1989) which occurred in 1988 destroying more than half of the Riala village. An estimated 100 houses and 25 acres of agricultural land were swept down the slope. As a matter of fact, our subsequent visits in 1991, 1993, and 1994 have revealed that the landslide is still active and that more land and houses are being consumed. Already a large number of families has migrated and settled in or around Islamabad, while others have settled in more stable nearby villages. The inhabitants of the remaining so-called stable part of the village apparently feel unaffected temporarily, but they are conscious of the danger that may come in future. This sense of insecurity has led to socioeconomic problems. Developed countries may not have experienced such impacts of landslides to their fullest extent, but it is an absolute reality for the people of affected areas in developing countries like Pakistan.

Small-scale landslides, on the other hand, may affect local structures, individual houses, and small terraced farms in the hills. The magnitude of damage from these landslides, although not catastrophic, should not be underestimated. Landslides lead to serious problems if they are more closely spaced or occur more frequently, as along the Murree-Muzaffarabad (Kashmir) Road. The intensity and frequency of landsliding along this important route, which is a vital link between Pakistan and Independent Kashmir, is a constant problem (even more so during monsoon). The main zones of landslides have been marked, and, on the basis of geotechnical studies, the entire length of this highway is divided into stable, unstable, and potentially unstable regions (Saeed and Malik 1990). Since 1967, these slopes have been studied and documented and, ironically enough, almost every year new slides occur along this route, disrupting transportation, communications, and trade (Malik 1972) and Malik et al. (1989).

Similarly, the impact of landslides on the Karakoram Highway is no less significant. Several landslides (Figs. 5 & 8) have been studied, recorded, and analysed since 1973/74. This route, linking Pakistan with China, is of great national and international importance. Blockage of this strategic route, due to landslides, not only affects settlements and communications but also tourism.

Generally, landslides are considered to be a natural phenomenon triggered by natural factors. However, many landslides are a result of human activities which are initially intended for and oriented towards development of an area for settlement, reclamation of cultivable land, construction of roads, widening of existing roads, or excavation for other civil engineering purposes.

The inevitable pressure of population in mountainous regions in developing countries may indirectly be contributing a great deal to the instability of slopes. There should, therefore, be some balance between the anticipated loss due to induced landslides by human activities and the ultimate achievable goal for development of land use for agriculture or settlements. Farming in northern Pakistan is mainly on terraces, the slopes of which become very steep, particularly in the extreme northern parts. The instability of these slopes affects the cultivated areas and consequently the agricultural produce. For instance, at Jalial landslide on the Murree-Muzaffarabad Road (Fig. 1), agricultural and fruit (apple) farms deteriorate almost every year.

Roads, bridges, transmission lines, and other communication networks are disrupted very frequently in northern Pakistan. For example, the Murree-Muzaffarabad Road remains closed periodically during monsoon because of landslides. Similarly, in the Hunza Valley and on the Thakot-Batgram Section of the Karakoram Highway (Fig. 1), frequent blockage due to landsliding is not very uncommon.

Human settlements are affected gravely by landslides in Pakistan, thus disturbing the socioeconomic patterns of the local population, leading to migration to bigger towns or to the plains. For instance, the occurrence of the Riala landslide near Ayubia in 1988 and the Kohala landslide in 1992 made it essential to shift the bridge location on the Jhelum River.

Factors Causing Landslides

The variety of landslides discussed in Chapter 2 reflects the diversity of causes leading to landslides in various parts of Pakistan. It is imperative to know the susceptibility of an area in terms of sliding and the triggering or precipitating factors causing them. The following principal causes have been identified during detailed investigations.

- **Geometrical changes** which include undercutting, erosion, surface erosion, man-made excavations, sloping terraces, slope angle, and loading and unloading
- **Geological conditions** which include the nature of materials (soils/rocks), lithological distribution, their strength, and their flaws as fractures or discontinuities
- **Surface and groundwater** which include the effect of saturation on strength
- **Permafrost and temperature variations**
- **Earthquakes and vibrations**
- **Effect of vegetation and deforestation**

The following important factors causing landslides were considered in detail with reference to the occurrence of this phenomenon in Pakistan.

Geology and Landslides

Slope stability is influenced by the following geological factors.

- Type and engineering-geological properties of soils/rocks, their distribution, and the effect of groundwater on these properties
- Geological structure such as cleavage, joints, faults, and folds
- Stresses and geological history

Engineering-Geological Properties

Lithologic units, such as clay, shales, sandstones, schists, and granites, have different strength characteristics because of the varying conditions under which they were formed. They also have different mineral constituents and fabrics. Therefore, they undergo different changes on exposure to weathering and respond differently to loading conditions. Clays, for example, having the smallest grain size and fabric and undergo changes in strength on remoulding (sensitivity). During excavation, sensitive clays undergo a great loss of strength. Such soils, therefore, need thorough investigation prior to excavation.

Similarly, the presence of small (a few millimetres thick) shear zones in clays (as in the Siwalik Group) at Mangla Dam, Kalabagh Dam, and in the Murree formation along the Murree-Muzaffarabad Road reduces the strength, which is crucial for slope stability, as it then acts as a sliding surface.

These shear zones lie parallel to the bedding and are the result of displacement caused by folding. This destroys the peak strength, normally associated with intact overconsolidated clays (as at Mangla Dam), due to shearing during folding (Skempton 1966). These clays within shear zones have been reduced to an almost residual state; the angle of internal friction being 18 and 26 degrees along and across the bedding respectively. Consequently, their effect was to produce, parallel to the bedding, surfaces of low strength. These are called bedding plane slips (bed over bed displacement) and were categorised as slight, moderate, and intense, depending upon the thickness of shear zones and apparent degree of shearing (Fookes 1966, 1967).

The presence of shear zones in alternate sequences of sandstones and clays or limestones and clay, due to gentle folding, are quite common in Pakistan as elsewhere in the world. They produce distinct horizons of significantly low strength: the strength being invariably reduced to its residual value. Problems related to such shear zones involve potential slip surfaces in excavated slopes and require thorough investigation prior to designing slopes. Other indices commonly used for soil strength and its moisture content variations are the Atterberg Limits, Liquidity Index, and Activity, etc (Fig. 9).

Geological Structure

Geological structures, such as bedding, joints, foliation, cleavage, schistosity, and faults, are potentially weak planes in a slope. Their strength is generally less than in the surrounding intact rock. It is therefore imperative to know their orientation in relation to slope angle, direction, and strength along such potential weak planes (discontinuities).

Rock should be assessed on a larger scale (rockmass strength, with all its flaws) in order to evaluate its effect on slope stability. For example, anisotropy (as in slates, shales, and laminated clay) will show the lowest strength in a direction parallel to the fabric. Other surfaces (bedding, faults, joints, and fissures) in overconsolidated clays can affect the stability of slopes if they are inclined downhill or sunlight on the slopes facilitates movement. Donath (1961) points out that the minimum strength in slates occurs when the inclination of cleavage is 30 degrees to the major principal stress. Skempton and Hutchinson (1969) emphasise that orientation of a specimen tested can result in incorrect assessment of the strength of soil or rock in a slope.

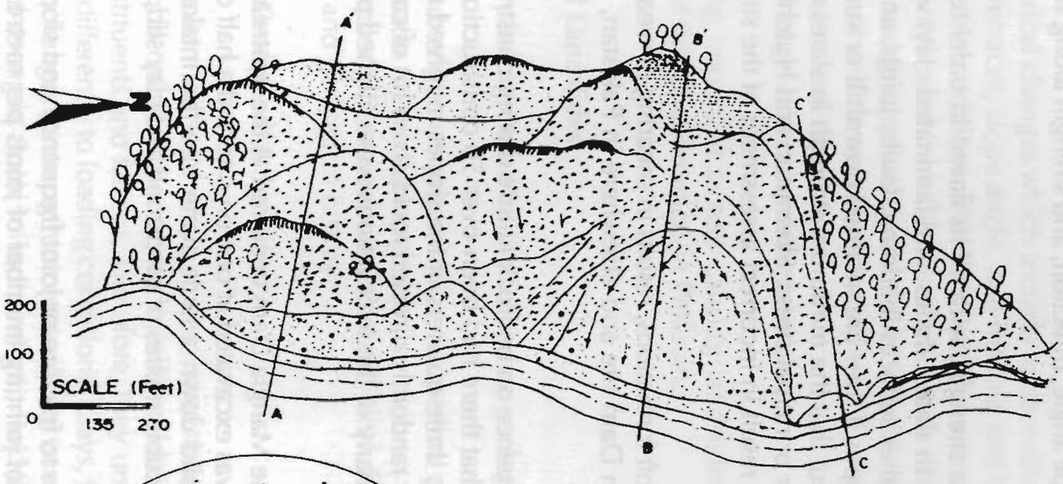
Similarly, folding, particularly in alternate hard and soft formations, results in shearing of weaker materials as can be seen at Mangla Dam and at the Kalabagh Dam site and elsewhere in Pakistan, as described earlier.

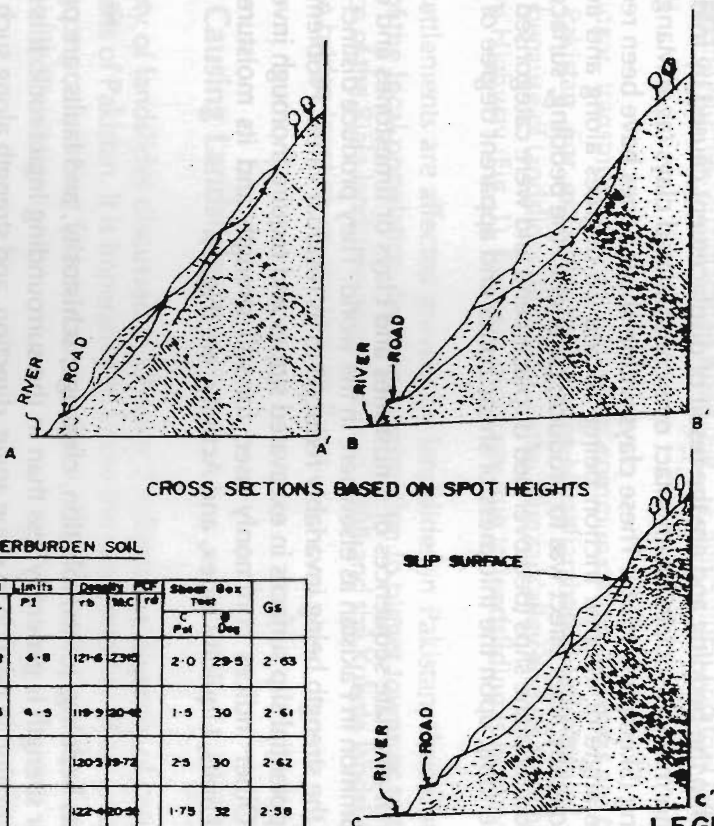
Such geological discontinuities had an important influence on bedrock failure during construction of the Mangla Dam in Pakistan. Fookes (1966) estimates that there had been over 50 construction failures on slopes involving large volumes of material. Of these, three quarters of the slopes involved were parallel to the dip. Only one-eighth were neither parallel nor randomly directed rockfalls. A lot of care was taken in the interpretation of these slope failures because many of the excavations were aligned parallel to the strike.

The most important failure during construction of the Mangla Dam occurred at the upstream end of the diversion tunnel where a temporary bedrock slope was excavated at one on one and a half cubic metres. About 2,000 cubic metres of sandstone and clay slid down a fault plane into the intake excavation. Another slide occurred on 16 April 1965 and 3,000 cubic metres of sandstone and clay slid, after rainfall, along a shear zone in clay.

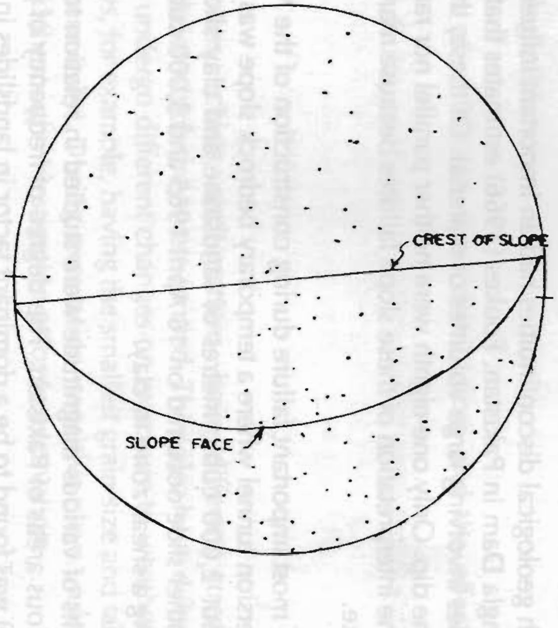
Faults of various magnitude were studied in relation to fracture or joint frequency and slope stability in various areas of Pakistan. The degree of frequency of jointing (number of joints per metre along a scan line) was found to be a dominant factor in landslides in the alternate sandstones and clays of the Murree

Figure 9: Sketch of Kohala Landslide along with Cross-sections, Stereoplot and Test Results





CROSS SECTIONS BASED ON SPOT HEIGHTS



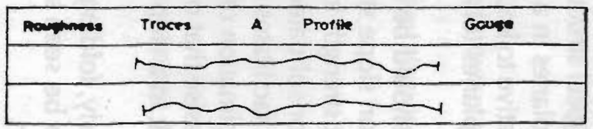
STEREO PLOT SHOWING POLES OF JOINTS & SLOPE FACE

TEST RESULTS OF OVERBURDEN SOIL

Sample No.	Location	M/C	Particle Size Distribution: mm Clay	mm Silt	mm Sand	mm Gravel	mm Cobble	Atterberg Limits: LL	PL	PI	Density PCF: rb	M/C	rd	Shear Box Test: C Psi	ϕ Deg	Gs
1		23·15	21	[illegible]	14	6	[illegible]	[illegible]	[illegible]	4·8	121·6	23·15		2·0	29·5	2·63
2		[illegible]	19	[illegible]	[illegible]	7	10	24	[illegible]	4·5	119·9	[illegible]		1·5	30	2·61
3		19·72	22	[illegible]	19	9	6				120·5	19·72		2·5	30	2·62
4		20·55	17	56	22	5	-				122·4	20·55		1·75	32	2·58
5		14·21	14	50	18	11	7				[illegible]	14·21		1·5	31·0	[illegible]

Samples were taken from slide Material

Direct shear tests performed on soil excluding gravels and cobbles.



JRC assumed
9
7

HARDNESS VALUES MEASURED					AVERAGE
19	18	16	17	18	18
16	18	18	19	18	17

LEGEND

formation along the Murree-Muzaffarabad (Independent Kashmir) Road and in the Tertiary rocks (mostly alternate limestone and shales) of Hazara (outer Himalayas). Structural patterns, including faults, joints, cleavage, and schistosity, are playing a dominant role in producing landslides in the Hindu Kush-Himalayan region (as evidenced by the frequency of landsliding along the Karakoram Highway (KKH) (Fig. 4). The stability analysis using discontinuity data (Figs. 6 and 8) along the KKH indicates the structural control in landslide phenomenon.

Keeping in mind the importance and influence of geological discontinuities on slope stability, a 'discontinuity survey' was carried out to study various detrimental parameters. For this purpose, a data sheet (Table 3) was especially prepared to cover various parameters on any sliding area, e.g., geological structure, orientation, spacing, roughness, and strength of joint wall. These data sheets were used to evaluate rock mass strength and stability analysis (including stereonet plotting).

The different relationships of joint frequency with lithology, clay fraction, bed thickness, and so on, relevant to landslides (directly or indirectly), were established. They are:

i) joint frequency versus lithology or grain size (Fig. 10),

ii) joint frequency versus clay fraction ($<.002mm\%$) (Fig. 11),

iii) joint frequency versus bed thickness (Fig. 12), and

iv) joint frequency versus distance from fault (Fig. 13).

Although our studies on the effect of major structural features, such as thrusts, e.g., the Main Boundary Thrust (MBT) (Fig. 14), are not yet complete, it has been observed without any doubt that the occurrence of landslides increases considerably with proximity to such faults, rendering instability to slopes along a large stretch of road between Kohala and Muzaffarabad (Fig. 2).

It is concluded from these relationships that the spacing in fractures, or indirectly the joint frequency, is affected by faults. The joint frequency generally decreases with an increase in distance from faults, attaining a minimum value of about 30m from the fault, caused by fracturing due to regional tectonics (Fig. 13).

The joint or fracture frequency is also affected by grain size or lithology. Generally, it increases with a decrease in grain size (Fig. 10). The thin beds show greater joint frequency than thick beds (Fig. 12). The joint frequency increases with an increase in clay fraction ($<.002mm\%$). Beyond a 50 per cent clay fraction, the increase in fracturing seems to be due to dessication of clays.

Stresses and Geological History

In addition to geological structure and lithology, weathering plays an important role, e.g., along the Karakoram Highway weathering has led to huge accumulations of scree on slopes. Even hard rocks like granites have undergone extensive weathering, turning the rock into soil-like materials where slump failures can be observed (Fig. 8).

Geological history is also an important factor in determining the response of materials to excavations or landslides. High horizontal stresses in overconsolidated clays of the Siwalik Group cause landsliding, as the stresses stored in them may not have been completely released at the time of slope formation (by unloading). This results in an outward movement at the base of the slope. Examples of this phenomenon were recorded during construction of the Mangla Dam and during road widening along the Jhelum River between Muzaffarabad and Garhi Dupatta, Independent Kashmir where, in places, excavations were being carried out on buried surfaces of ancient landslides, rendering the existing slopes more unstable.

Table 3: Field Measurements and Evaluations of Discontinuity Parameters

LOCATION: NARE GOLI Z-35

Joint Set No.	Strike	Orientation		Spacing (cm)	Persist-ance (m)	Aper-ture (mm)	Nature of infilling	Surface Rough-ness	Waviness		JRC	Sch-midt Hard-ness	Length of Column above Joint Set (h) (m)	Unit Wt. (P) (KN/m)	JCS (Mpa)	Nor-mal Load *	ϕ Peak **	Avera-ge ϕ Peak
		Dip Direction	Dip						Wave length (cm)	Amplitu-de (cm)								
J1	N84E	354	70NW	1.6	2.5	26	Swelling	IV	4.3	3.5	5	18	3.5		30	98.35	37.4	
	N82E	352	57NW	2.4	3.2	28	Clays	III	3.8	3.1	5	22	4.0		28	112.5	36.9	
	N60E	330	48NW	2.7	3.3	23		II	2.9	2.6	5	15	3.3		25	92.7	37.2	
														28.1				36.03
J2	N12W	078	58NE	4.2	3.8	19		II	2.1	2.9	7	21	4.5		27	126.5	41.3	
	N30W	060	39NE	3.2	3.4	33		IV	3.2	3.9	9	17	4.2		26	118.0	43.7	
	N25W	065	31NE	3.5	2.3	26		V	3.3	3.1	7	19	4.8		29	134.9	41.3	

* = Normal Load = p x h

** = ϕ Peak = JRC * log 10 (JCS * σn) ÷ ϕr

JRC - Joint Roughness Coefficient

JCS - Joint Wall Compressive Strength

ϕr - Angle of Residual Friction

Figure 10: Joint Frequency vs Lithology

(Values in Brackets [Range in Frequency] Show Same Overlap - General Increase in Joint Frequency with Decrease in Grain Size is Prominent)

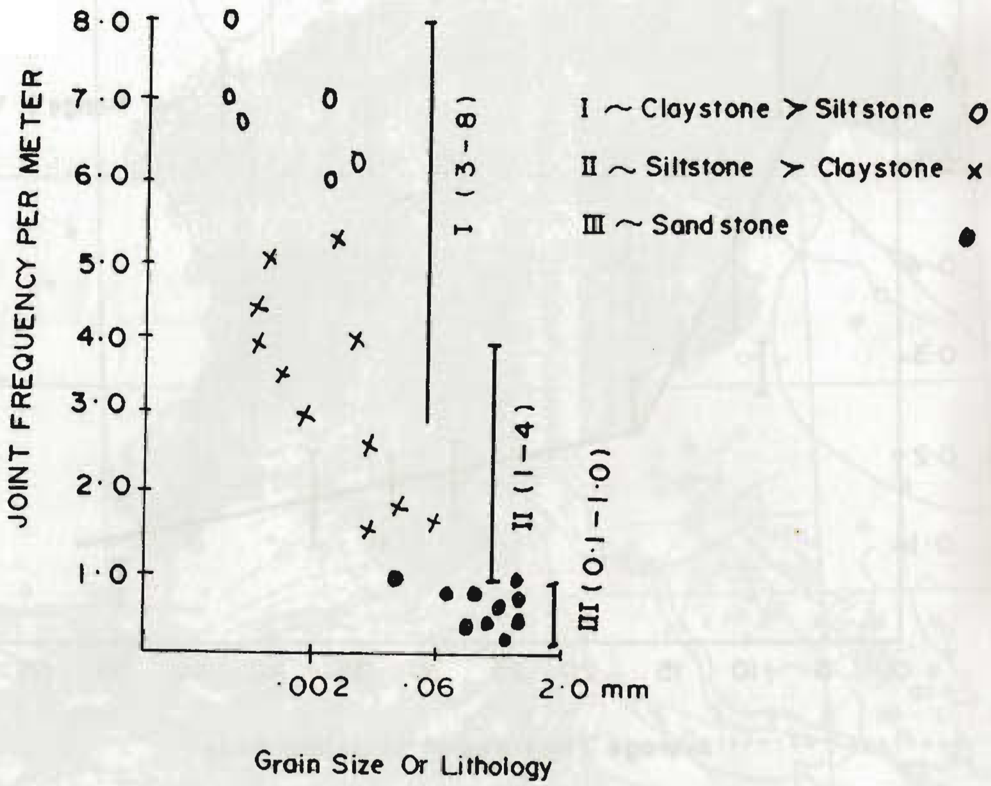


Figure 11: Joint Frequency vs Clay Fraction in Claystone Beds

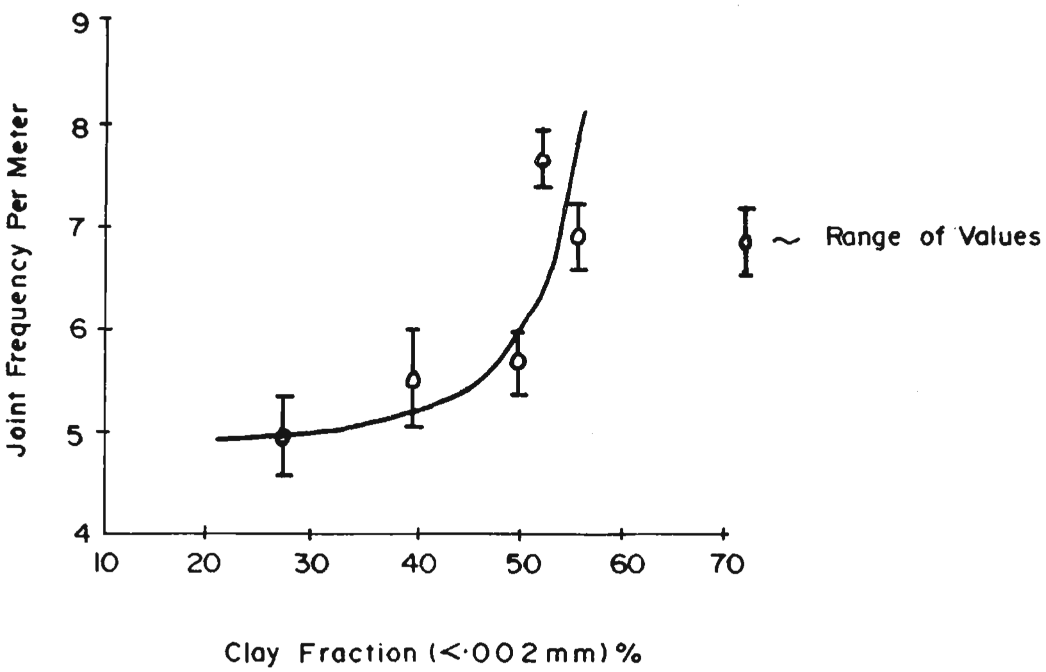


Figure 12: Joint Frequency vs Bed Thickness

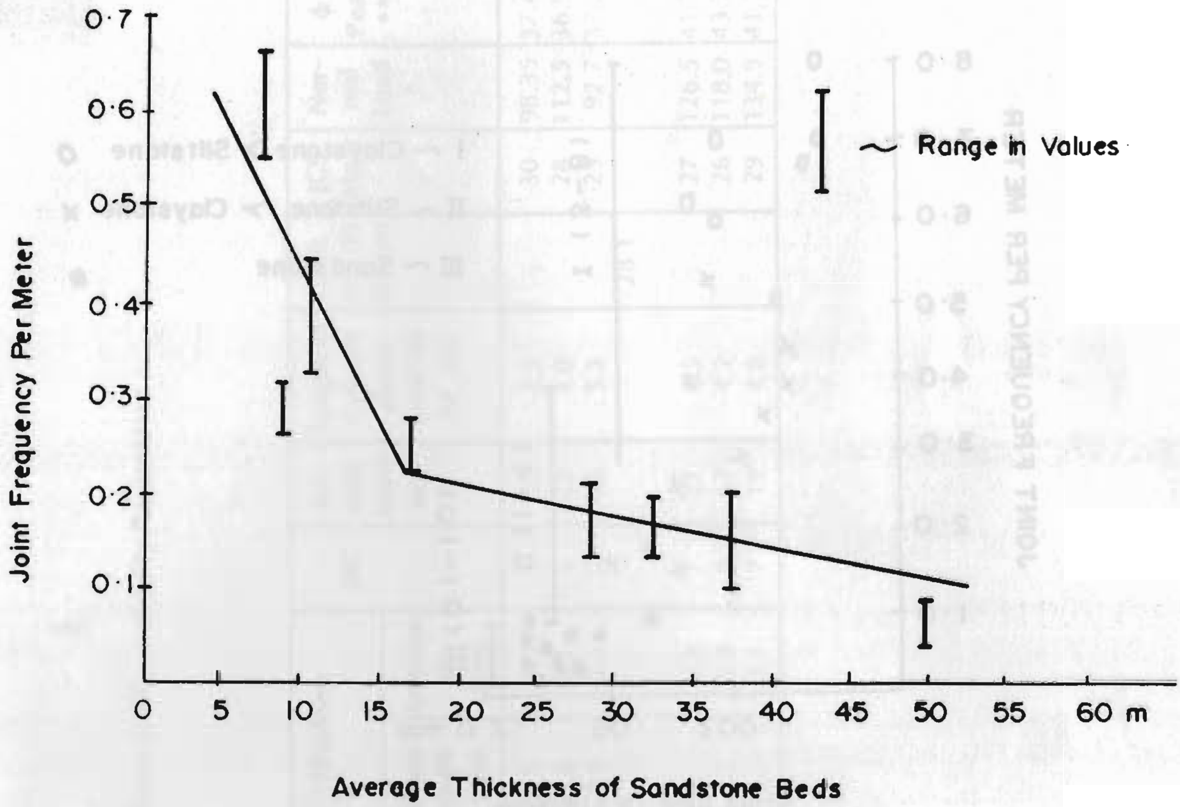


Figure 13: Average Joint Frequency vs Distance from a Small Fault

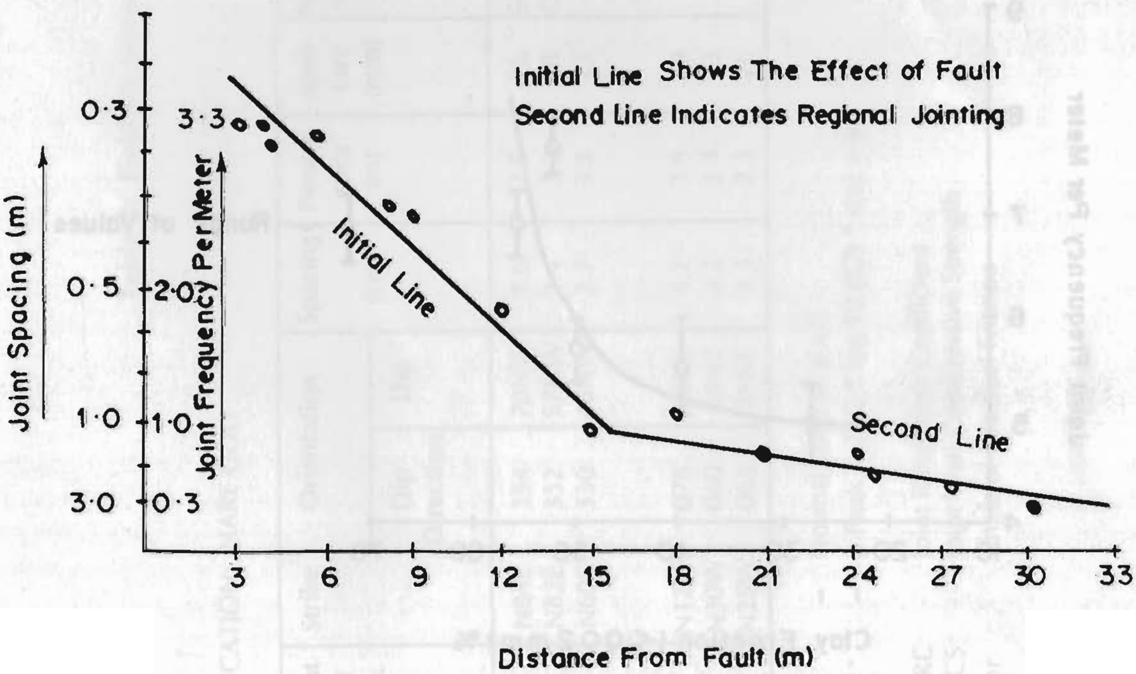


Figure 14: Tectonic Map of Northern Pakistan

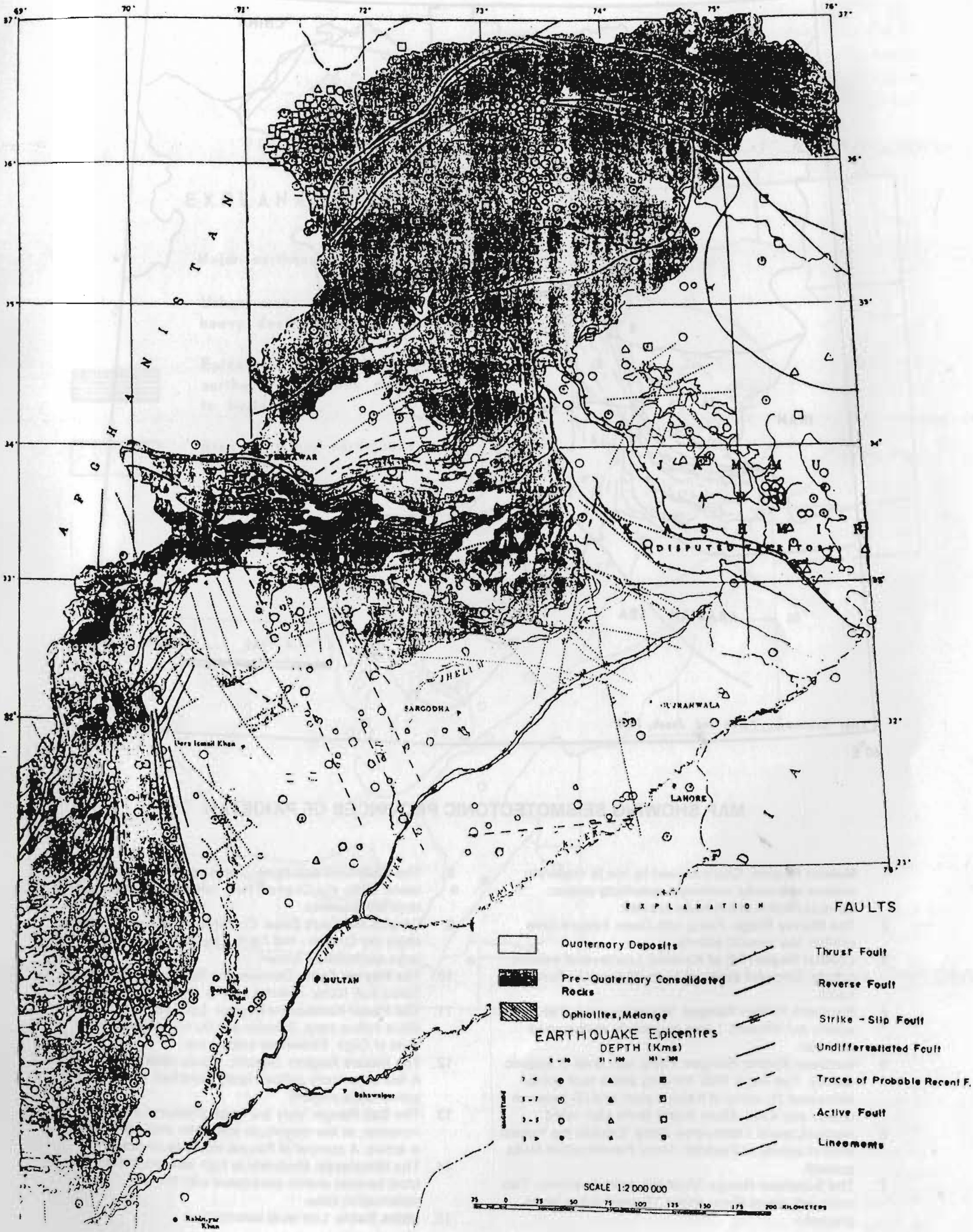
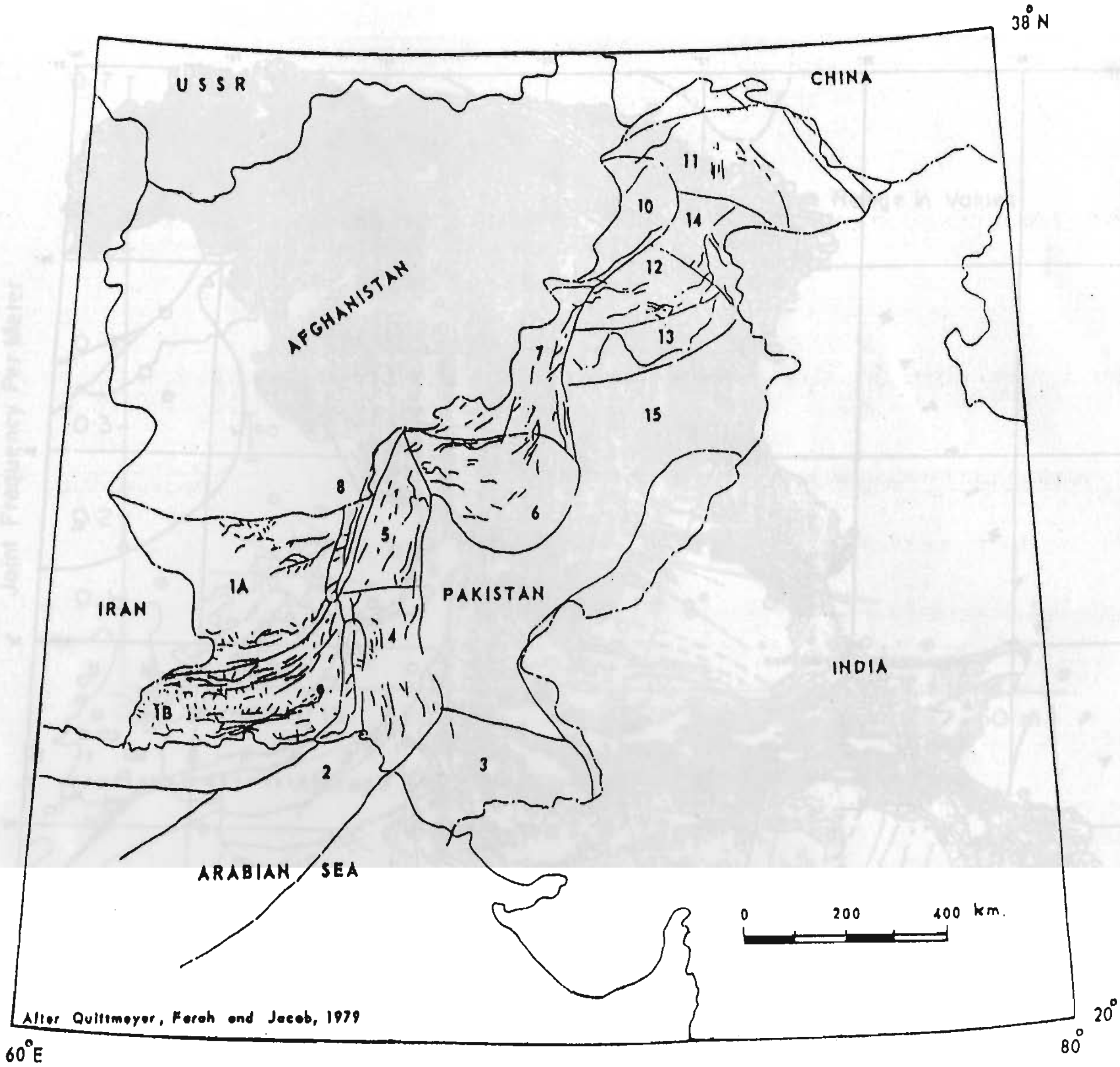


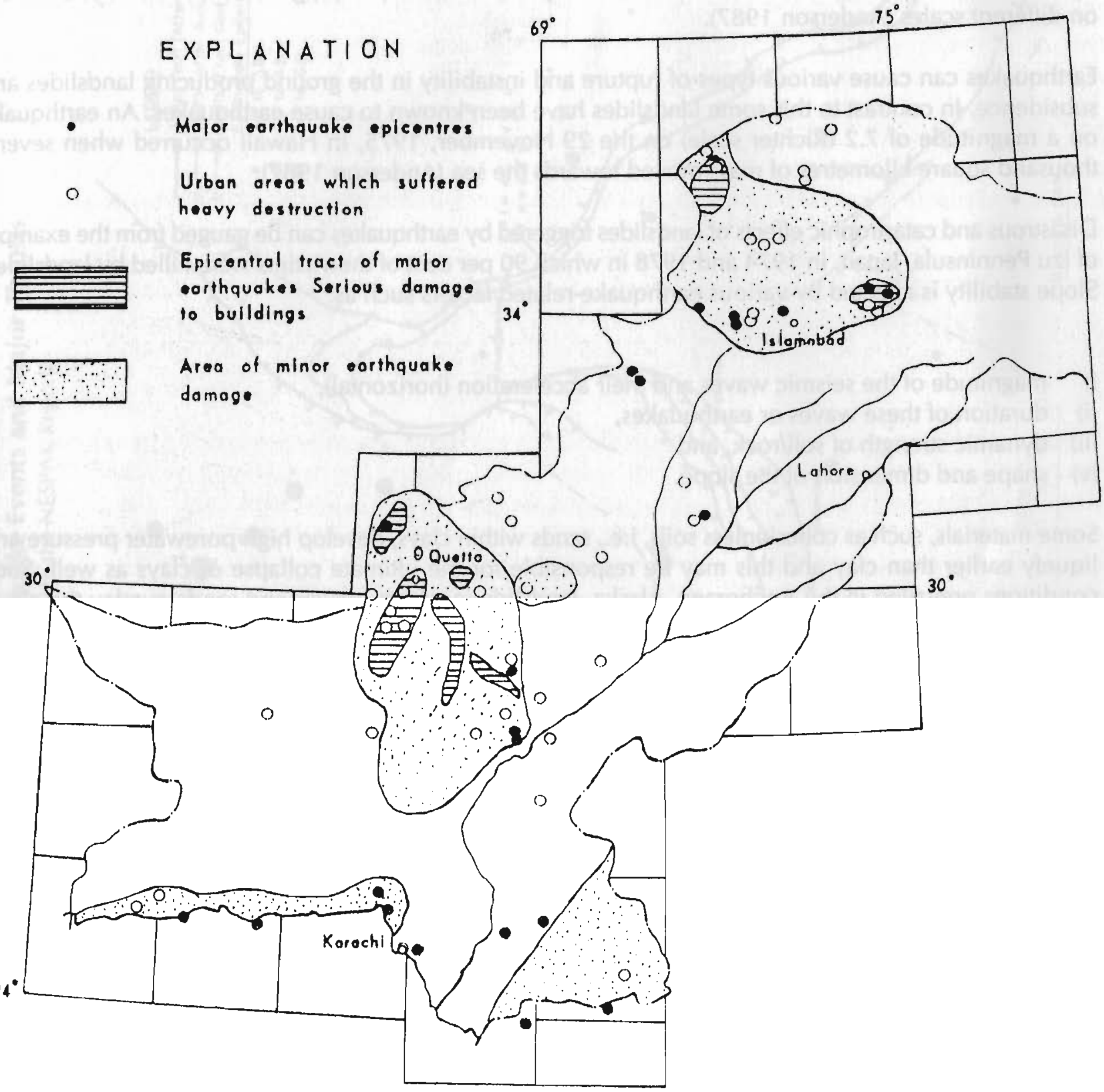
Figure 14(a): Seismotectonic Provinces of Pakistan



MAP SHOWING SEISMOTECTONIC PROVINCES OF PAKISTAN

1. **Makran Region**: Characterised by low to moderate shallow seismicity; northward seismicity deeper. Several Recent active faults present.
2. **The Murray Ridge**: Along with Owen fracture zone exhibits low seismic activity.
3. **Coastal Region SE of Karachi**: Low level of seismic activity. Complex series of faults (Recent) in Runn of Katch.
4. **Southern Kirthar Ranges**: Moderate level of seismic activity but diffused. Large magnitude earthquakes unknown.
5. **Northern Kirthar Ranges**: Fairly high level of seismic activity. Two major NNE trending active fault zones delineated (1) along of Katchhi plain and (2) between Quetta and Kalat. Many recent faults also noted.
6. **Harnai-Loralai Transverse Zone**: Exhibits the highest level of activity in Pakistan. Many Recent active faults present.
7. **The Suleiman Range**: Moderate seismic activity. Two major left lateral shear zones. (Recent active faults present.)
8. **The Chaman Fault Zone**: Contains the active left lateral strike slip Chaman fault. Infrequent moderate to large earthquakes.
9. **Ornach Nal Fault Zone**: Contains the active left lateral strike slip Ornach - Nal Fault. Low level of activity. No large earthquakes known.
10. **The Khyber Fault**: Contains the Gardez, Kunnar and Safed-Koh faults. Seismic activity occurs at high level.
11. **The Pamir-Karakoram Region**: Located north of the Indus suture zone. Seismic activity moderate to high west of Gilgit. Elsewhere activity low.
12. **The Hazara Region**: Seismic activity moderate to high. A few seismically defined faults identified. Many Recent active faults present.
13. **The Salt Range**: Very low level of seismic activity. However, at low magnitude levels the entire Salt Range is active. A number of Recent active faults present.
14. **The Himalayas**: Moderate to high level seismicity. Most seismic events associated with frontal deformation zone.
15. **Indus Basin**: Low level seismicity.

Figure 14(b): Sketch Map Showing Areas which have Suffered Earthquake Damage



Earthquakes and Landslides

Energy in the form of seismic waves is released when an earthquake occurs. These seismic waves, travelling through the ground, accelerate the movement of the ground and produce dynamic loads, increasing porewater pressures and shear stresses in the slopes. This, in turn, causes an imbalance between increasing shear forces and decreasing frictional forces which are meant to resist them. In regions of great seismic activity, the earthquakes affect the geomorphological history of the area. In Patate Valley, there are a number of signs of river diversion as a result of landslides triggered by earthquakes. Similarly, in southern Italy, earthquake-triggered landslides caused major morphologic changes and mass movements. The earthquake at Arizino in the Pre-Alps on 27 March, 1928, generated some 400 landslides on different scales (Anderson 1987).

Earthquakes can cause various types of rupture and instability in the ground producing landslides and subsidence. In contrast to this some landslides have been known to cause earthquakes. An earthquake on a magnitude of 7.2 (Richter scale) on the 29 November, 1975, in Hawaii occurred when several thousand square kilometres of mass moved towards the sea (Anderson 1987).

Disastrous and catastrophic effects of landslides triggered by earthquakes can be gauged from the example of Izu Penninsula, Japan, in 1974 and 1978 in which 90 per cent of the victims were killed by landslides. Slope stability is affected by various earthquake-related factors such as:

i) magnitude of the seismic waves and their acceleration (horizontal),
ii) duration of these waves or earthquakes,
iii) dynamic strength of soil/rock, and
iv) shape and dimension of the slope.

Some materials, such as cohesionless soils, i.e., sands within clays, develop high porewater pressure and liquefy earlier than clay and this may be responsible for the ultimate collapse of clays as well. Such conditions prevailed in the Anchorage, Alaska, landslide in which gravels and sands overlay the clays. The earthquake on March 27,1964, measuring 8.5 on the Richter scale and lasting for four minutes, liquefied sand lenses about one minute before the clay itself failed. A huge landslide triggered by an earthquake at Kohala, Pakistan (Fig. 5) occurred in 1993 mobilising silts, sands, and clays, destroying a one kilometre strip of road and dislodging about 70,000 cubic metres of material towards the River Jhelum. Materials with high porosity (silts and sands), if they are free of clay, have a high liquefaction potential during an earthquake.

Landslides triggered by earthquakes disrupt communication systems; destroy settlements; and, depending upon their magnitude and distance from the source, can prove to be highly catastrophic. The 1991 earthquake in Chitral, Hindu Kush, Pakistan, claimed hundreds of lives and damaged as many houses.

Seismic hazards close to major tectonic zones are not uncommon (Figs. 14 a & b): The Hazara Thrust faults in Pakistan, shown in Figure 15, happen to be located in a seismically active zone. The extinction of the Indus Valley Civilization (the well-known prehistoric city of Mohenjodaro) was caused by a major earthquake in the lower Indus plain. The historic city of Taxila was ruined in 25 A.D. In more recent years (1935), the Quetta (Baluchistan) earthquake claimed 30,000 lives. The Pattan earthquake on the Karakoram Highway (Ambraseys et al. 1974) in December, 1974, killed about 5,000 people. In February 1977, 20 villages were seriously damaged a few kilometres northeast of Islamabad, capital of Pakistan.

Keeping in mind the above facts and seismic events, the stability of slopes, particularly those close to major structures or settlements cannot be ignored. Seismic risk evaluation, therefore, has gained in importance with the rapid pace of urbanisation and construction of modern communication links; natural and artificially excavated slopes near powerhouses, dams, and highways; and underground bases of strategic importance. Therefore, it is essential to know the seismic history and prepare basic seismic zoning maps supplemented with detailed seismic factors.

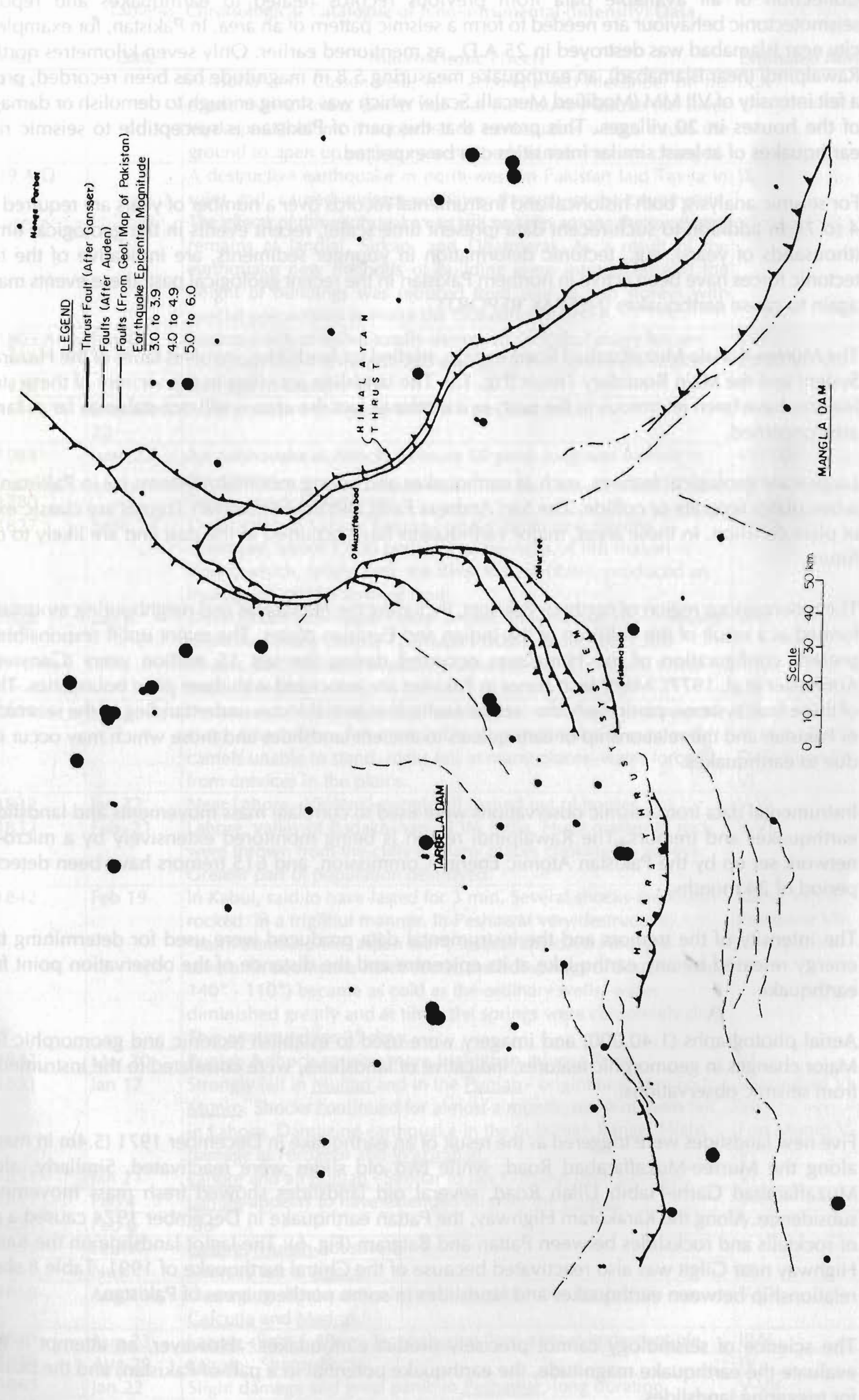


Figure 15: Macro-Earthquake Events and Major Thrusts
(Reproduced from the NESPAK Report)

Collection of all available data from previous records related to earthquakes and reports and seismotectonic behaviour are needed to form a seismic pattern of an area. In Pakistan, for example, Taxila city near Islamabad was destroyed in 25 A.D., as mentioned earlier. Only seven kilometres northeast of Rawalpindi (near Islamabad), an earthquake measuring 5.8 in magnitude has been recorded, producing a felt intensity of VII MM (Modified Mercalli Scale) which was strong enough to demolish or damage most of the houses in 20 villages. This proves that this part of Pakistan is susceptible to seismic risk, and earthquakes of at least similar intensities can be expected.

For seismic analysis, both historical and instrumental records over a number of years are required (Tables 4 to 7). In addition to such recent data (present time scale), recent events in the geological time scale (thousands of years), e.g., tectonic deformation in younger sediments, are indicative of the fact that tectonic forces have been active in northern Pakistan in the recent geological past: these events may occur again to cause earthquakes (NESPAK REPORT).

The Murree-Kohala-Muzaffarabad Road section, studied for landslides, involves faults of the Hazara Thrust System and the Main Boundary Thrust (Fig. 15). The landslide activities in the vicinity of these structural features have been enormous in the past, as a matter of fact the area is still not stable as far as landslides are concerned.

Large-scale geological features, such as earthquakes and young mountain systems (as in Pakistan), occur when plates separate or collide. The San Andreas Fault and the Himalayan Thrusts are classic examples of plate collision. In these areas, major earthquakes have occurred in the past and are likely to occur in future.

The mountainous region of northern Pakistan, including the Himalayas and neighbouring mountains, was formed as a result of the collision of the Indian and Eurasian plates. The major uplift responsible for the present configuration of the Himalayas occurred during the last 15 million years (Gansser 1964, Armbuster et al. 1977). Major fault zones in Pakistan are associated with these plate boundaries. The study of these fault systems, particularly the 'active' faults, is essential for an understanding of the seismic zoning of Pakistan and the relationship of earthquakes to ancient landslides and those which may occur in future due to earthquakes.

Instrumental data from seismic observations were used to correlate mass movements and landslides with earthquakes and tremors. The Rawalpindi region is being monitored extensively by a micro-seismic network set up by the Pakistan Atomic Energy Commission, and 615 tremors have been detected in a period of 24 months.

The intensity of the tremors and the instrumental data produced were used for determining the total energy released by any earthquake at its epicentre and the distance of the observation point from the earthquake.

Aerial photographs (1:40,000) and imagery were used to establish tectonic and geomorphic features. Major changes in geomorphic features, indicative of landslides, were correlated to the instrumental data from seismic observations.

Five new landslides were triggered as the result of an earthquake in December 1971 (5.4m in magnitude) along the Murree-Muzaffarabad Road, while two old slides were reactivated. Similarly, along the Muzaffarabad Garhi-Habib Ullah Road, several old landslides showed fresh mass movements and subsidence. Along the Karakoram Highway, the Pattan earthquake in December 1974 caused a number of rockfalls and rockslides between Pattan and Batgram (Fig. 6). The Jaglot landslide on the Karakoram Highway near Gilgit was also reactivated because of the Chitral earthquake of 1991. Table 8 shows the relationship between earthquakes and landslides in some northern areas of Pakistan.

The science of seismology cannot precisely predict earthquakes. However, an attempt is made to evaluate the earthquake magnitude, the earthquake potential in a part of Pakistan, and the possibilities for triggering landslides.

Table 4: Chronological Catalogue of Non-intrumental (Intensity) Data

S.No.	Year	Date	Macroscismic Effects	Estimated MM
1.	4 B.C.		Aristobulus of Cassandreia, who accompanied Alexander on his expedition to India, points out that the country above the River Hydaspes (Jhelum) is subjected to earthquakes which cause the ground to open up so that even the beds of the river are changed.	IX.X
2.	29 A.D.		A destructive earthquake in north-western Pakistan laid Taxila in ruins and caused widespread havoc throughout the countryside. The effects of this earthquake can still be seen among the excavated remains at Jandial, Sirkap, and Dharmaraj. As a result of the earthquake new methods of building were introduced and the height of buildings was reduced from four to two storeys with special precautions to make the foundations secure.	IX
3.	1505 A.D.	July 6	Region north of Kabul totally destroyed. In Kabul many houses collapsed and the fortress was damaged. Felt up to Agra (India).	VIII Kabul VII VIII
4.	1552		Damage in Kashmir	V
5.	1669	June 4 or 22	A very violent earthquake felt all over Kashmir.	VI-VII
6.	1969	June 23	An earthquake at Attock, a fissure 50 yards long was formed in the ground.	VIII-IX
7.	1780		Severe shock in Kashmir	V-VII
8.	1827	Sept. 24	Destruction in Lahore Region-Fort Kolitaran near the city destroyed, about 1,000 perished in the ruins. A hill shaken down, which, falling into the River Rowee (Ravi), produced an inundation of 100 acres of land.	VII-IX
9.	1828	Jun 6	Destruction in Srinagar - very severe, shook down many houses and killed many people - perhaps 1,000 people and 1,200 houses. Earth opened in many places about the city and water became foetid.	IX-X
10.	1831		Peshawar & Valley of Indus - Severe, extended from Peshawar to Dera Ghazi Khan, felt most at Dera band (Deraban); men and camels unable to stand, rocks fell in many places, water forced from crevices in the plains.	Daraban VIII-IX Peshawar & D.G. Khan IV-VI
11.	1832	Jan 22	Near Lahore - Violent - people all rushed out of houses	V-VI
12.	1832	Feb. 21	Lahore, valley of Badakhshan, N.W. India. Huge masses of rock were thrown from the cliffs in many places choking up valleys. Greater part of population destroyed.	V-VI
13.	1842	Feb 19	In Kabul, said to have lasted for 3 min. Several shocks-the fourth rocked in a frightful manner. In Peshawar very destructive, "earth trembled like aspen leaf", several killed. At Ferozpur severe. In Ludhiyana north-south, the hot springs of Souah (temp. 140° - 110°) became as cold as the ordinary wells, water diminished greatly and at times the springs were completely dry. This continued for 25 days.	Kabul VI-VII Peshawar VII Ferozpur VI
14.	1847	Mar 30	<u>Punjab</u> A shock causing more fright than injury - Perry.	VI
15.	1851	Jan 17	Strongly felt in <u>Multan</u> and in the <u>Punjab</u> - originating from <u>Fort Munro</u>. Shocks continued for almost a month, some of them felt in <u>Lahore</u>. Damaging earthquake in the Suleiman Range. Slight damage at Ferozpur and <u>Wazirabad.</u>	Wazirabad VI-VII Fort Munro V-VI
16.	1851	Jan 21	<u>Lahore</u> and all <u>Punjab</u> - Similar to Jan 17th but even stronger.	VI
17.	1851	Feb 4	<u>Lahore</u>-appears to have extended all over the <u>Punjab</u>.	V-VI
18.	1851	Feb 6	-do-	V-VI
19.	1851	Feb 17	<u>Lahore</u>, <u>Multan</u> not severe	V
20.	1853	Nov	Strongly felt at <u>Attock</u>	VI
21.	1858	Aug 11	Damaging shocks at Simla felt throughout the <u>Punjab</u>, in <u>Calcutta</u> and <u>Madras.</u>	V-VI
22.	1858	Aug 23	<u>Lahore</u>-slight 6:30pm, <u>Jacobabad</u> at 2pm almost imperceptible.	III-V
23.	1858	Aug 29	<u>Lahore</u> - Sharp shocks.	IV
24.	1865	Jan 22	Slight damage and great panic in <u>Peshawar</u>, long duration.	V-VII
25.	1865	Dec 4	<u>Lahore</u> - two sharp shocks	III-V

S.No.	Year	Date	Macroscismic Effects	Estimated MM
26.	1867	Nov 10	Damage in Bannu.	VII-VIII
27.	1868	Aug 11	Damage in Peshawar, a portion of the fort was shaken down (official record).	VII-VIII
28.	1868	Nov 12	Violent shock felt in Lahore, Dera Ismail Khan and Attock, followed by many after shocks which were felt throughout the Punjab.	Attock IV-VI
29.	1869	Mar 24	Severe shock in the upper reaches of the Jhelum	V-VII
30.	1869	Mar 25	A large earthquake in the Hindu Kush, strongly felt at Kohat, Lahore, Peshawar and at Khojend and Tashkent; shocks lasting 20 seconds.	Kohat & Peshawar V
31.	1869	April	Peshawar - Part of fort shaken down (official record)	VII-VIII
32.	1869	Dec 20	Rawalpindi - Shock said to have lasted for ½ a minute, cracked walls and caused all people to run out of houses. Attock - A series of shocks at intervals of about 20 sec. Lawrencepur - 1st shock 15 sec others at 5 sec. intervals. Campbellpur - For half an hour; building much damaged Talagang - Not felt	VII-VIII
	1869	Dec 24	Rawalpindi - Murree some very heavy claps of thunder preceded.	VII-VIII
33.	1871	April	Severe at Rawalpindi and Murree originating from Kashmir	Rawalpindi & Murree VI
34.	1871	May 22	Damaging shock at Gilgit; strongly felt in Meerut, Agra, Landur many aftershocks.	Gilgit VII-VIII
35.	1875	Dec 12	Damage in villages between Lahore and Peshawar where a number of people were killed.	VII-VIII
36.	1878	March 2	Damaging earthquake in the Punjab. At Kohat several houses, public buildings, and a portion of the wall of the fort fell. At Peshawar it caused damage to houses and city walls. Damage at Attock, Abbottabad, Rawalpindi, Jhelum, Murree. Strongly felt at Bannu, Nowshera, Mardan, Lahore and Simla. Many after shocks.	Peshawar, Kohat VII-VIII Rawalpindi, Attock VI-VII
37.	1883	April	Damaging shock at Peshawar.	VI-VII
38.	1885	May 30	Destructive shock in Kashmir. Sopot, Gulmarg and Srinagar about totally ruined and 3,000 people killed. Heavy damage at Gurais and Punch; Muzaffarabad heavily damaged. Felt in Peshawar , Lahore, Simla, Leh, Kanpalu, and Gilgit. Radius of perceptibility about 650km. Many after shocks.	Kashmir IX Muzaffarabad VII Peshawar IV
39.	1893	Nov 3	Slight damage at Peshawar, Nowshera; felt throughout the Punjab.	VI-VIII
40.	1902	Jan 20	Large earthquake, damage in the Chitral area; felt widely in the Punjab and Simla.	Punjab IV
41.	1905	April 4	Kangra earthquake. In Rawalpindi a few lofty buildings cracked.	Rawalpindi V-VI
42.	1919	Sept 5	Strongly felt in Lahore.	V
43.	1929	Feb 1	Destructive earthquake, perhaps shallower than calculated, ruin of Skorzor and Drosh. Damage was equally heavy in the USSR at Kulyab. It caused substantial damage in Abbotabad, Peshawar, Cherat, Gurez, Chitral and Dushambe. It was felt within a radius of 1,000km.	Abbotabad & Peshawar VI-VII
44.	1939	Nov 21	Destructive in the Badakhshan area, the damage extending to Srinagar, Rawalpindi and Kargil Drosh was seriously damaged. Felt within a radius of 600km.	Rawalpindi V-VI
45.	1940	May 27	Felt in Peshawar.	IV
46.	1945	June 22	Destruction in Chamba and parts of Kashmir. Strongly felt at Rawalpindi, Peshawar, Lahore, and Simla.	Rawalpindi V
47.	1952	Jul 10	Damage in Bhadrawal; strongly felt at Gulmarg, Srinagar, Dalhousie, Simla, and in the Kumaon hills. Felt all over Kashmir and in some parts of the Punjab, as well as in the NWFP Followed by many after shocks.	Punjab & NWFP IV
48.	1953	May 11	Felt in the Punjab.	
49.	1956	Mar 1	Slight damage in Campbellpur.	V-VI

S.No.	Year	Date	Macroscismic Effects	Estimated MM
50.	1956	Sept 16	Destruction in the Ghazni district of Afghanistan where many villages were destroyed and animals lost. The damage was equally serious at Said Karem. Caused panic in Kohat, strongly felt at Parachinar, Parwan, Loger, Ghazni, Nazerajat, Behsud, Makur, Rawalpindi, and Srinagar. Radius of perceptibility about 450km.	Rawalpindi V
51.	1962	Aug 2	Felt at Rawalpindi.	IV
52.	1966	Jan 11	Felt at Risalpur.	IV
53.	1966	Feb 2	Strongly felt around Abbotabad where it caused minor damage at Havelian. Felt at Rawalpindi, Islamabad, Abbotabad, Taxila. The shock was felt at Muzaffarabad and Gujjar Khan.	Abbotabad VI Islamabad V
54.	1977	Feb 14	About 7km northeast of Rawalpindi, caused damage in 20 villages. In the villages of Kuri, Malot and Pindi Begwal around Nilour most of the '*Katcha*' houses either collapsed or were damaged. A few houses built with dressed blocks of sandstone and sand-cement mortar also developed extensive cracks.	VII

Table 5: Instrumental Data List of Macro-earthquakes (1904 - 1977)

Date			Latitude	Longitude	Magnitude	Depth	Source
Year	Month	Day					
1	2	3	4	5	6	7	8
1994	7*	27	33.00	72.00	5.0	-	MW
1924	9	12	33.20	71.40	5.0	-	MW
1927	6	29	34.00	73.00	5.0	-	MW
1928	1	14	35.00	72.00	6.0	110	MW
1937	1	07	35.00	73.00	5.7	100	MW
1962	8*	02	34.00	3.50	5.0	-	MW
1963	9	02	33.90	74.70	5.4	44	MW
1964	7*	03	34.15	74.91	4.0	33	MW
1965	7*	13	34.20	74.30	3.0	178	MW
1968	7*	03	34.80	74.60	3.9	88	MW
1970	7*	26	34.80	73.22	5.0	33	MW
1972	9	27	33.91	72.72	4.5	46	MW
1973	9	27	33.85	72.15	4.5	35	MW
1974	7*	30	35.5	71.5	5.3	-	GCQ
1977	7*	10	32.773	71.379	4.4	5.00	NMSNW
	MW	-	Willmore Earthquake Data Files				
	AMB	-	Ambrassey et al. 1974				
	GC	-	Geophysical Centre, Quetta				
	NMSNW	-	Nilore Microseismic Network PAEC				
	*	-	During Monsoon				

Table 6: Instrumental Data

List of Earthquakes with Magnitudes Greater than 2.0 (Richter Scale) Recorded by the Microseismic Network, Nilore (May 1976 - April 1978) during Rainy Season and Some Significant Earthquakes Recorded in a Year

Date			Latitude	Longitude	Magnitude	Depth (km)
Year	Month	day				
1	2	3	4	5	6	7
1976	7 *	19	3237.10	7122.72	0.8	6.70
1976	7 *	27	3338.89	7147.17	2.4	7.60
1976	8 *	23	3337.46	7119.21	2.7	10.00
1976	10	23	3246.18	7318.72	4.3	10.00
1977	2	14	3337.46	7312.61	5.8	14.53
1977	7 *	10	3246.39	7122.76	4.4	5.00
1978	4	27	3411.16	7232.50	5.0	7.62
	*	During Monsoon				

Table 7: Earthquakes Felt at the Tarbela Dam Project

DATE	LAT-N	LON-E	KM.	MAGNITUDE
16/12/82	36.1	69.0	036.0	6.6
26/01/83	36.4	70.9	184.0	5.0
12/09/83	36.5	71.7	208.8	6.1
30/10/83	36.4	71.4	132.0	5.6
31/12/83	36.3	71.1	150.0	7.0
02/01/84	36.5	70.7	205.0	5.0
27/01/84	36.7	71.3	175.0	6.0
01/02/84	36.6	70.4	033.0	5.7
16/02/84	36.4	70.8	208.0	6.1
24/02/84	36.4	70.4	212.0	5.0
19/04/84	36.4	70.9	202.0	5.7
15/05/84	36.5	69.7	100.0	5.0
01/07/84	36.5	70.9	204.0	5.8
22/08/84	36.1	70.5	141.0	5.3
20/12/84	36.2	70.1	125.0	5.2
23/1284	36.6	70.9	110.0	5.5
27/04/85	36.7	71.5	150.0	5.1
29/07/85	36.3	70.9	011.0	6.7
02/08/85	36.2	70.9	033.0	6.2
19/08/85	36.1	70.2	033.0	5.2
23/08/85	39.8	75.5	033.0	7.6
26/04/86	36.5	71.1	187.0	57
17/07/86	36.6	71.3	047.0	5.3
15/09/86	36.7	71.4	189.0	5.8
17/09/86	37.3	71.7	120.0	5.5
13/10/86	36.1	70.9	117.0	5.4
02/04/86	36.2	71.2	095.0	5.9
05/05/87	36.5	70.6	210.0	5.6
03/10/87	36.5	71.5	080.0	6.2
09/01/88	36.1	70.1	100.0	5.2
14/01/88	36.2	70.1	090.0	5.4
06/08/88	36.1	69.1	080.0	5.9
06/08/88	36.2	69.8	090.0	6.1
24/07/89	35.8	71.8	010.0	5.0
21/12/89	33.6	74.9	014.8	6.0
08/01/90	35.8	72.4	475.0	5.2
05/02/90	36.4	71.4	280.0	5.2
15/05/90	36.0	70.0	200.0	5.4
17/05/90	37.3	73.8	034.0	5.0
13/07/90	36.6	70.5	114.0	5.9
25/10/90	35.1	70.6	118.0	6.0
12/11/90	36.5	71.0	120.0	5.2
01/02/91	36.2	70.2	125.0	6.8
23/02/91	36.3	71.2	150.0	5.1
16/04/91	36.5	71.0	150.0	5.0
14/07/91	36.6	70.6	150.0	6.0
20/10/91	About 500km ESE			6.0
20/05/92	33:40.56 71:15.00 10.0			5.5
13/11/92	About 250 NW of Tarbela			5.0
04/12/92	About 250 NW of Tarbela			5.0

Table 8: Landslides Related to Major Earthquakes

Date of earthquake	Magnitude (Richter scale)	No. of new slides occurring	No. of old slides reactivated	Areas of landslide activity	Remarks
18/12/82	6.6	2	3	Murree-Muzaffarabad road and Ghari Habib Ullah road	During moderate rains
12/9/83	6.1	6	8	Murree-Kohala road and Karakoram Highway	After heavy rains
16/2/84	6.1	1	2	Hunza Valley, Karakoram Highway	Dry season
29/7/85	6.7	5	9	Murree-Kohala Muzaffarabad road and Karakoram Highway	During monsoon
3/10/87	6.2	3	3	Karakoram Highway	Dry season
24/7/89	5.0	7	6	Kohala-Muzaffarabad-Garhi Habib Ullah road and Karakoram Highway (Hunza Valley)	During monsoon
25/10/90	6.0	2	2	Hunza Valley and Batgram-Thakot road section (Karakoram Highway)	Dry season
16/7/91	6.0	5	7	Various sections of Karakoram Highway and Murree-Kohala road	During heavy rains
4/12/92	5.0	1	2	Abbotabad-Nathiagali and Lowargali and Kohala road	Rains negligible

Earthquake Magnitude (Richter Scale)	Recurrence Interval (years)
4	2
5	12
6	66
7	380
7.5	912

From the records, the average value of horizontal acceleration computed ranges from 0.16 to 0.24g, giving an average of 0.2g (Adhami & Mansur 1977).

In the Rawalpindi region, earthquakes of magnitudes ranging from 4.5 to 5.0 on the Richter scale have occurred since 1904, with the exception of an earthquake in 1977 (5.8m in magnitude) having an epicenter seven kilometres northeast of Rawalpindi. The possibility of recurrence of an earthquake of similar magnitude, therefore, exists after short intervals. Ground motions associated with earthquakes (Orphal and Lahoud 1974) can be determined for maximum or likely occurrence.

Similarly, the recurrence intervals of major earthquakes can be estimated from historic or instrumental seismic records. The following details give the recurrence intervals for the Rawalpindi area and their earthquake magnitudes.

For important structures, including excavations and slopes, seismic risk evaluation is imperative. Generally, the alluvial deposits and weak rocks tend to amplify the rock motions. Soils, e.g., sands, with high porewater pressure liquefy with an increase in dynamic load, as mentioned earlier.

Slopes along important and strategic highways like the Rawalpindi-Murree-Muzaffarabad Road should be constructed or designed to resist a 0.2g acceleration. The distance of the slopes from the earthquake potential of nearby active faults is important in this respect.

From the statistical data given (Table 8), it is evident that landslide activity has a definite relationship to earthquakes. It is also inferred that earthquakes which occurred during rainy seasons caused more sliding as a result of the added effect of slope saturation. The granular materials in scree accumulations on slopes in various parts of the KKH caused more landslides than in other parts of the country, perhaps because of liquefaction.

Monsoon Rains and Landslides

Landslide activity rises in the years with heavy rainfall during monsoon. In northern Pakistan, the blockage of some important routes due to landslides after heavy rainfalls is not an unusual phenomenon. The onset of monsoon does not trigger landslides in early or mid July in Pakistan; instead landslide activity increases in the latter part of July or even August as the successive rains first wet the dry slopes and then saturate the materials in their depths. A number of landslides have been reported and documented along some important roads, only after heavy rainfall or rainstorms, e.g., the Simbal landslide along the M1 Motorway which was triggered during different periods of heavy rainstorms in August 1992 and September 1994, recording displacement along slip surfaces of 40m and 45m respectively.

A heavy storm during the 1992 monsoon was characterised by immense landslide activities in most parts of northern Pakistan. Rainfall on rock slopes created different activities such as seepage, weathering, swelling, and reduction in strength. Alternate soft and hard rocks like limestone/shales or sandstone/clays were abundant sedimentary rocks in Pakistan, as elsewhere in the Mesozoic and Tertiary sequences. These proved problematic due to the differences in lithology and strength reduction brought on by saturation after heavy rains. These alternate sequences control drainage patterns; weak clays and shales showed differential erosion due to surface runoff, leaving harder sandstones or limestones unsupported from underneath, causing slope collapse. Other effects, e.g., seepage forces generated towards slope faces, weathering of soluble rocks, swelling of expansive clays, and the removal of fine particles from weakly-cemented rocks (e.g., in the Siwalik sandstones of Pakistan) contributed to landsliding as a result of rainfall.

Tests, both *in situ* and laboratory, on soils and rocks were carried out at different locations in unstable and potentially unstable zones. Their values in relation to moisture variations show a remarkable decrease in the strength of marls, sandstones, and shales/clays on saturation.

Stability analysis of dry and saturated slopes, using the 'Circular Failure Chart' method (Hoek and Bray 1981), shows a substantial difference in the safety factor or the stability conditions. Relevant details of stability analysis are given in Chapter 4. At a number of locations along the Murree-Muzaffarabad Road, the retaining walls gave way due to increased saturation load.

Tension cracks filled with rainwater increase hydraulic forces which generate sliding surfaces. Similarly, slopes of porous materials, such as sands, are affected by seepage forces, as has been seen near Kohala.

The laboratory study of slope materials consisting of old landslide materials revealed that the natural moisture content in saturated conditions during the monsoon is very close to liquid limits. When this moisture content exceeds the liquid limits, these materials turn into mudflows. Such mudflows are frequent between Kohala and Muzaffarabad and cause road blockages very often during the monsoon. The presence of a number of bulldozers for road clearance during the months of July and August in this region is a perpetual phenomenon.

An increase in moisture content on a potential sliding surface plays the deciding role in rendering the slope unstable by decreasing the shear strength of existing materials (this happens because the rainwater decreases normal stress on potential slip surfaces).

Several landslides attributed to heavy rainfalls or rainstorms during monsoon have been recorded and documented. Their occurrence and frequency have been related to precipitation data collected from metereological stations (Figs. 16 to 25). These relationships show an increase in landslide activities during heavy precipitation periods. Data collected over a period of 30 years, i.e., from the 1960s to the 1990s, were used for this purpose. Both month-wise and year-wise data were plotted to assess the cumulative effects of precipitation. Unfortunately, such data cannot be presented for remote areas (about landslide phenomena or rainfall record), because they are restricted to major towns or cities only. Similar studies carried out by many other workers suggest a pore pressure 'threshold' associated with rainfall, which must be exceeded before landslides occur.

Siwalik sandstones (friable) show a reduction in strength from 70 to 100 per cent, whereas sandstones in the Murree formation, being well cemented, show a decrease of 10 to 20 per cent. Similarly, in clays, there is a reduction in strength due to remoulding.

Sloping Terraces and Landslides

An increase in steepness or slope gradient leads to an increase in shear stress on the potential failure plane and a decrease in normal stress on both natural and man-made slopes. On the other hand, gentler slopes, particularly with pervious soil covers, are more prone to absorption and percolation of water than steep slopes.

A study was carried out to assess the relationship of terraces to the instability of slopes in some of the study areas. Three types of terrace were found in the mountainous regions of Pakistan. They are: natural terraces with steep slopes (above 30°) having little vegetation and cultivation; natural terraces with gentler slopes (generally less than 30°); and man-made terraces for cultivation and housing.

Natural terraces with steep angles and less vegetation, having pervious soil cover, proved to be the most unstable areas. About 80 per cent of slope failures along the Murree-Muzaffarabad Road fall into this category and have been studied in detail. The relationship of slope angles to the factors of safety of such terraces is given in Figure 26. It is clear from this figure that there is a substantial decrease in factors of safety of slopes where there are increases in the water content of terrace materials. Similarly, the safety factor decreases with an increase in slope angles. Natural terraces where there is a lot of cultivation are found to be stable, but ploughing these terraces causes some degree of instability. For instance, cultivated terraces behind the head of the Jalial landslide along the Murree-Muzaffarabad Road are destabilising the downslope areas due to poor drainage. Similarly, extensive cultivation on the terraces from Kohala to Muzaffarabad are destabilising the downslopes, resulting in sliding of the road.

Man-made cultivated terraces and housing, along with their approach roads, are contributing to slope instability due to changes caused in the geometry and configuration of the morphological features. Such terraces also change the surface and groundwater conditions.

Deforestation and Landslides

Slope movements increase due to deforestation, as the tree roots provide some reinforcement and also remove groundwater. On the other hand, addition of vegetation to slopes can cause slope movement, because the vegetative mass increases the weight of the slope in terms of moisture content.

Vegetation growing on slopes has traditionally been considered to have an indirect or minor effect on stability, and it is usually neglected in stability analysis. This assumption is not always correct, as proved by commercial harvesting activities in mountainous regions of the U.S.A., Canada, and Japan, which resulted in an increase in landslide problems.

Figure 16: Slides Recorded on Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Murree 1988)

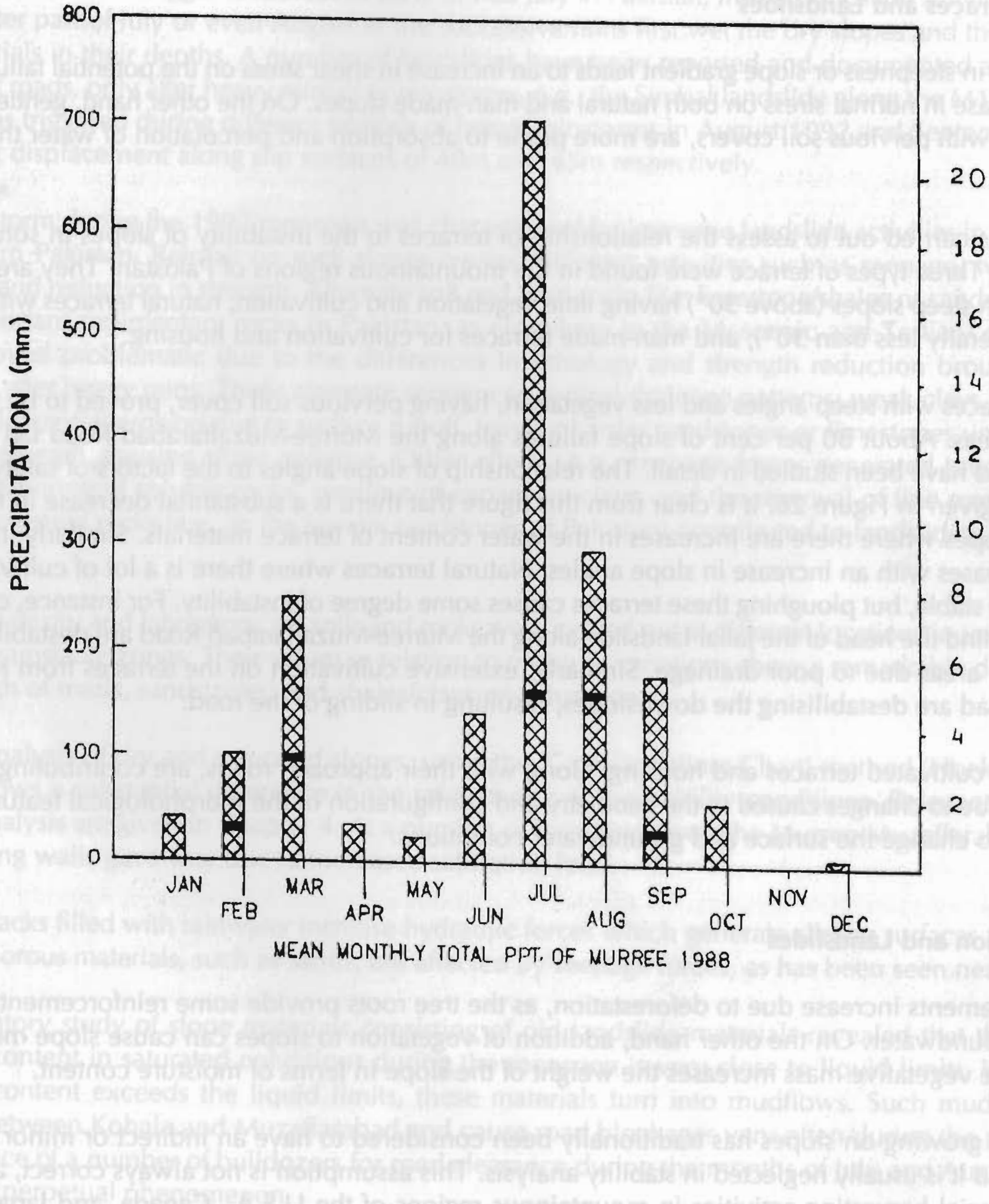


Figure 17: Slides Recorded on Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Murree 1989)

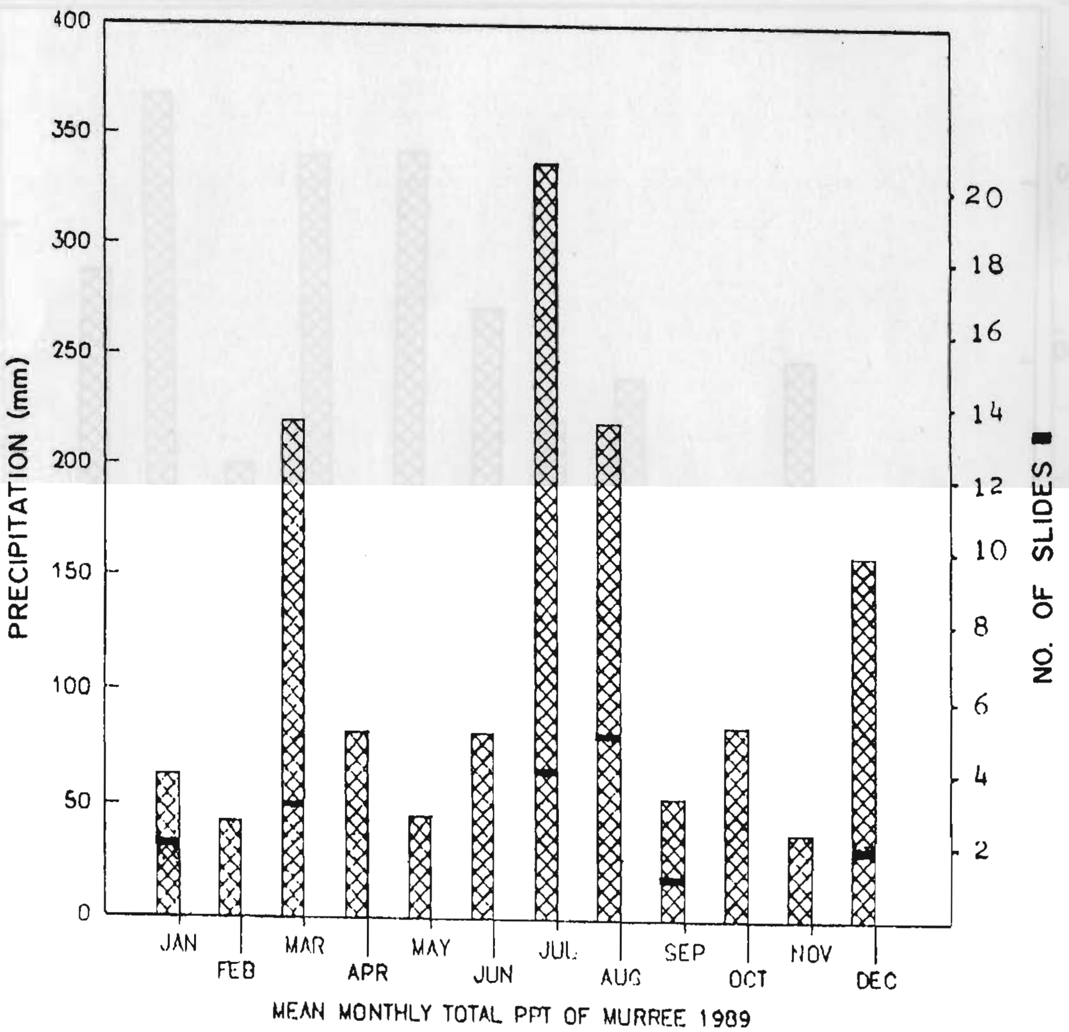


Figure 18: Slides Recorded on Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Murree 1990)

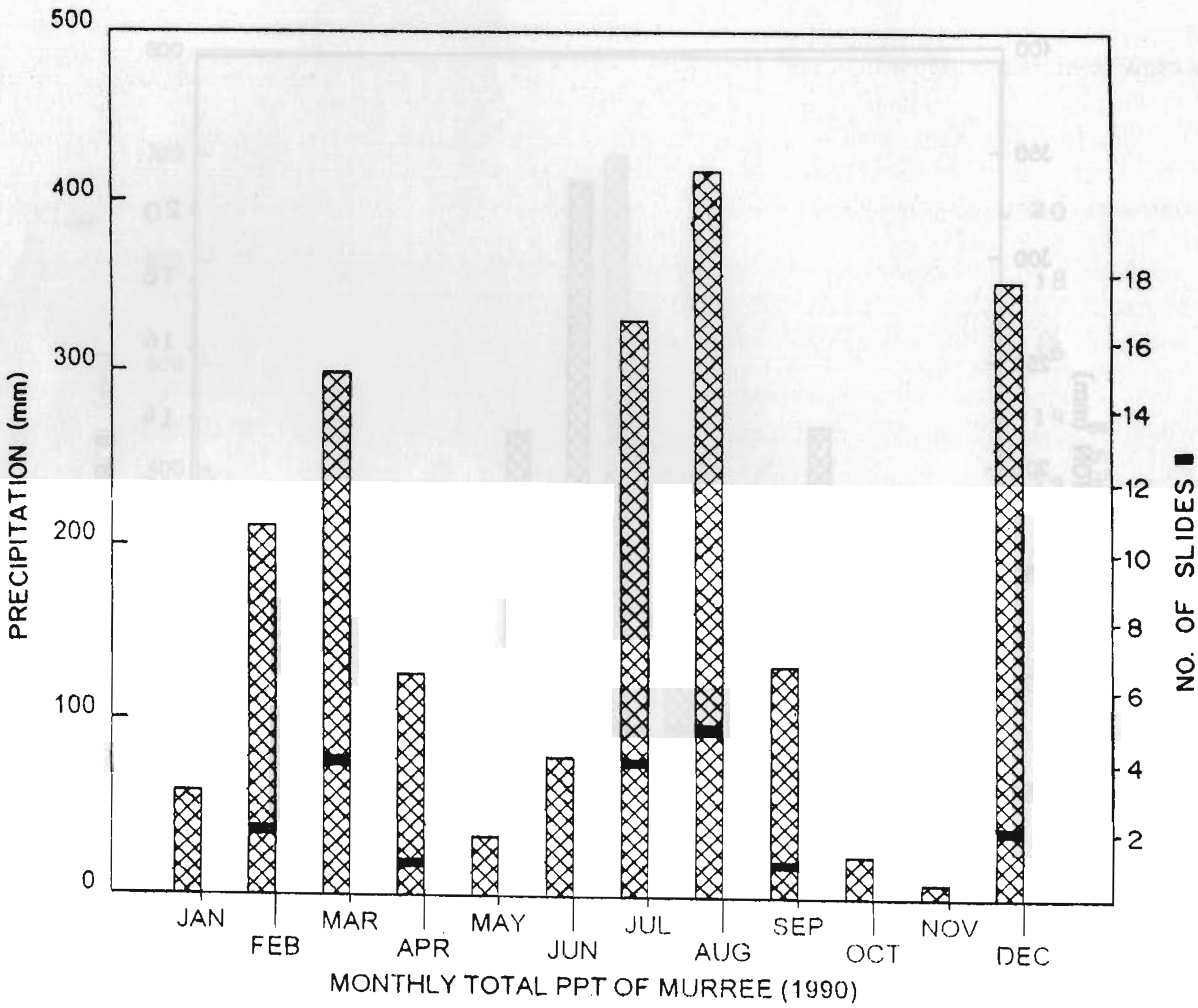


Figure 19: Slides Recorded on Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Murree 1991)

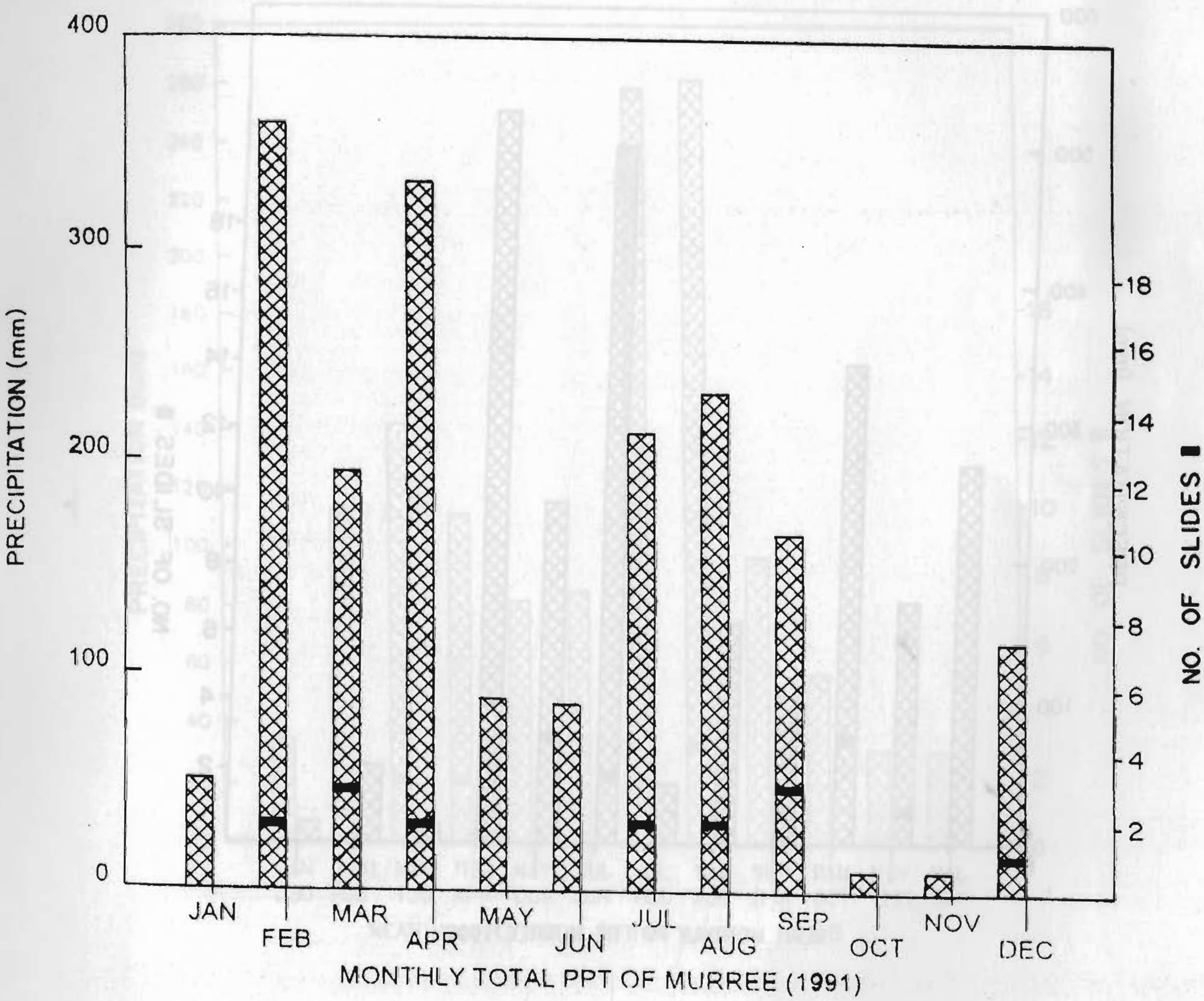


Figure 20: Slides Recorded on Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Murree 1992)

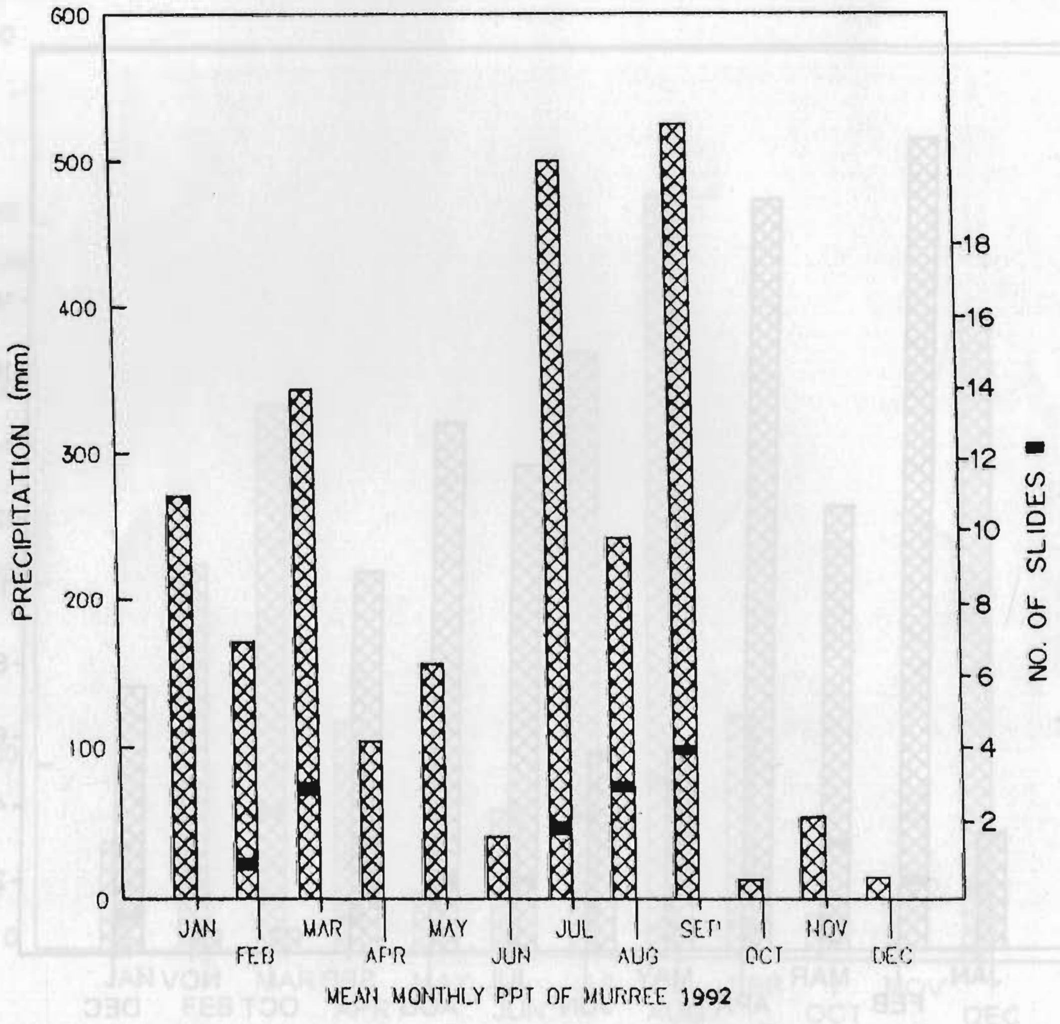


Figure 21: Slides Recorded on Murree-Abbottabad and Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Kakul 1988)

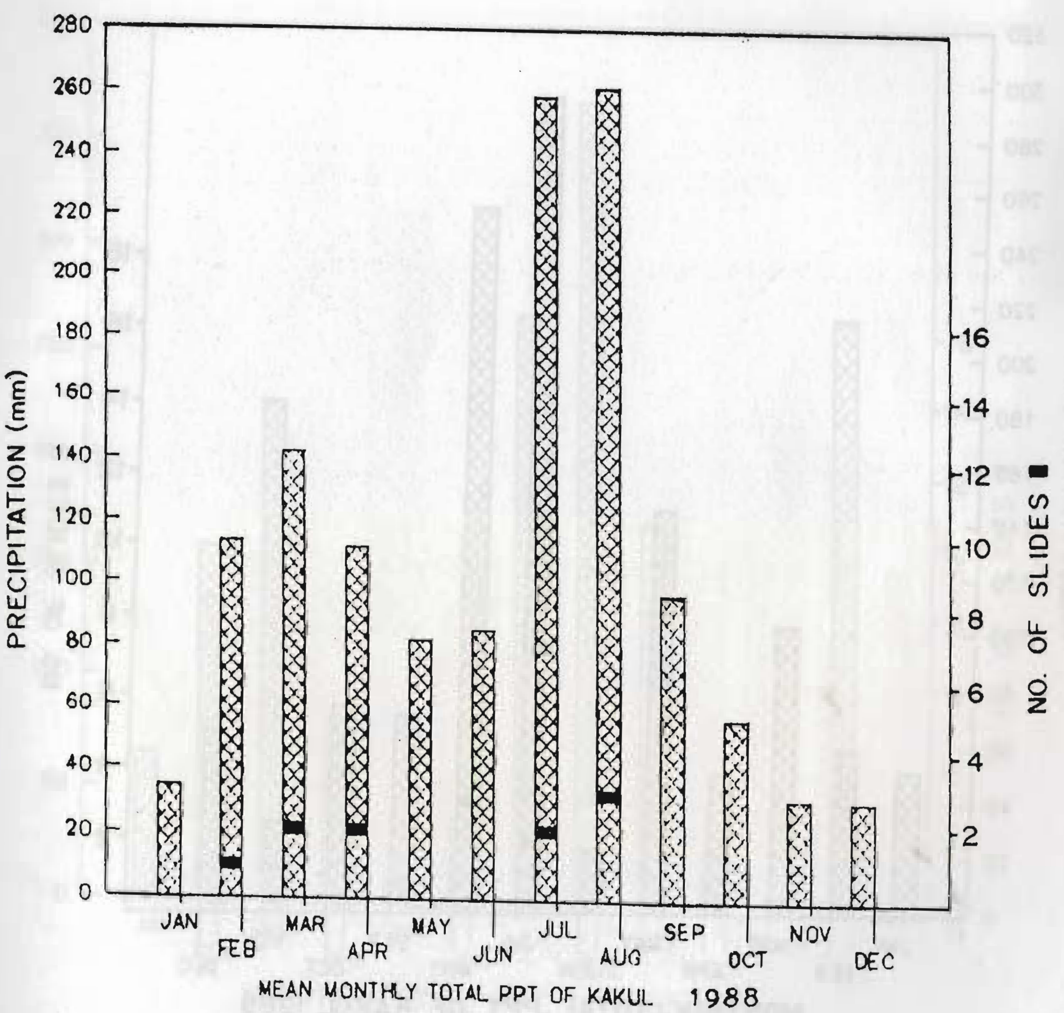


Figure 22: Slides Recorded on Murree-Abbottabad and Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Kakul 1989)

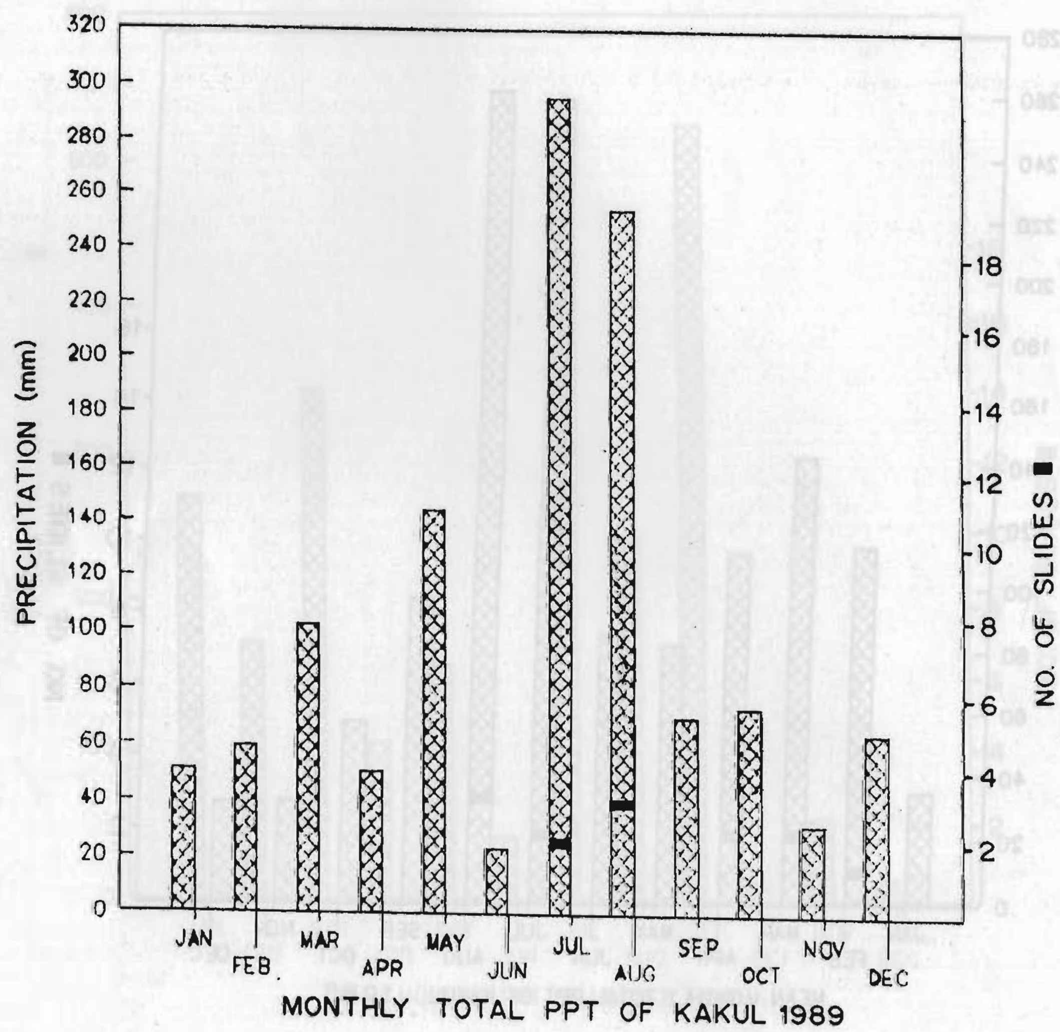


Figure 23: Slides Recorded on Murree-Abbottabad and Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Kakul 1990)

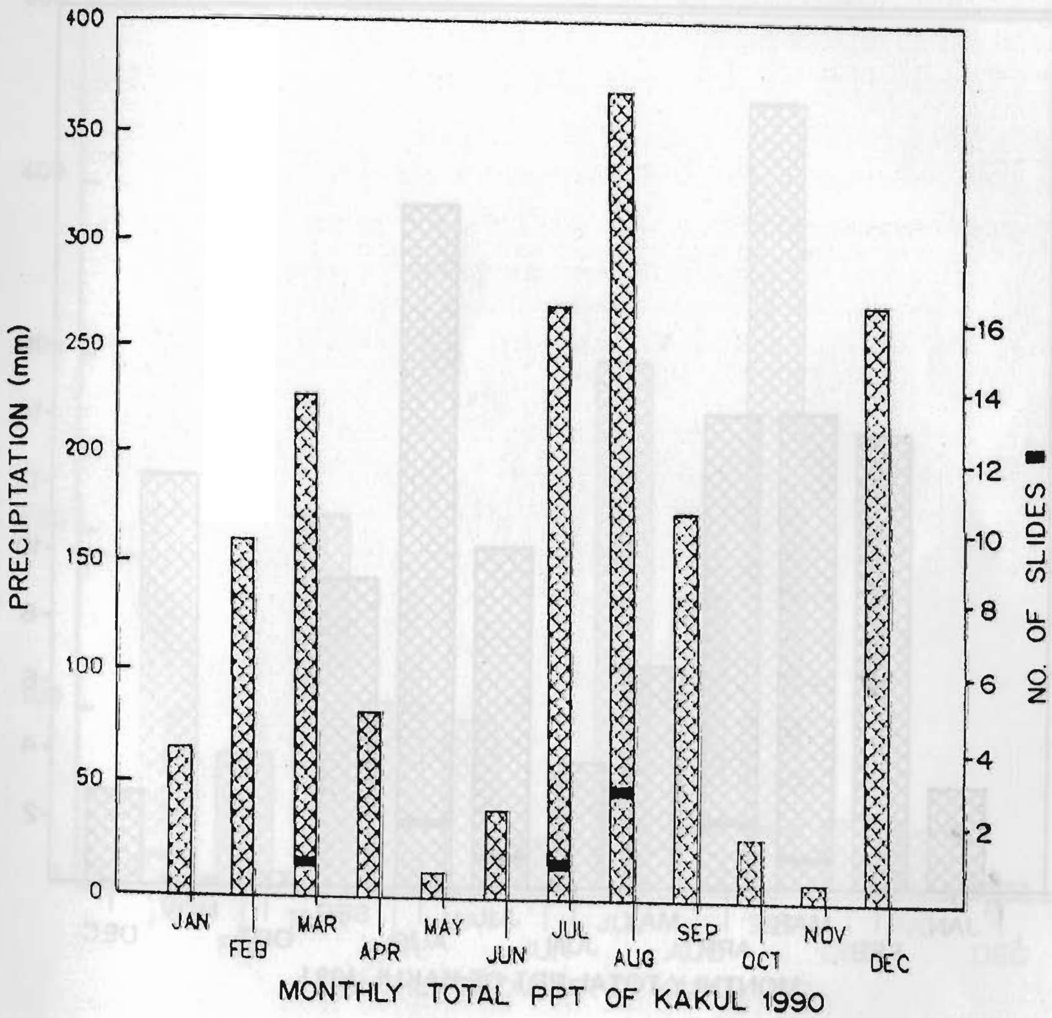


Figure 24: Slides Recorded on Murree-Abbottabad and Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Kakul 1991)

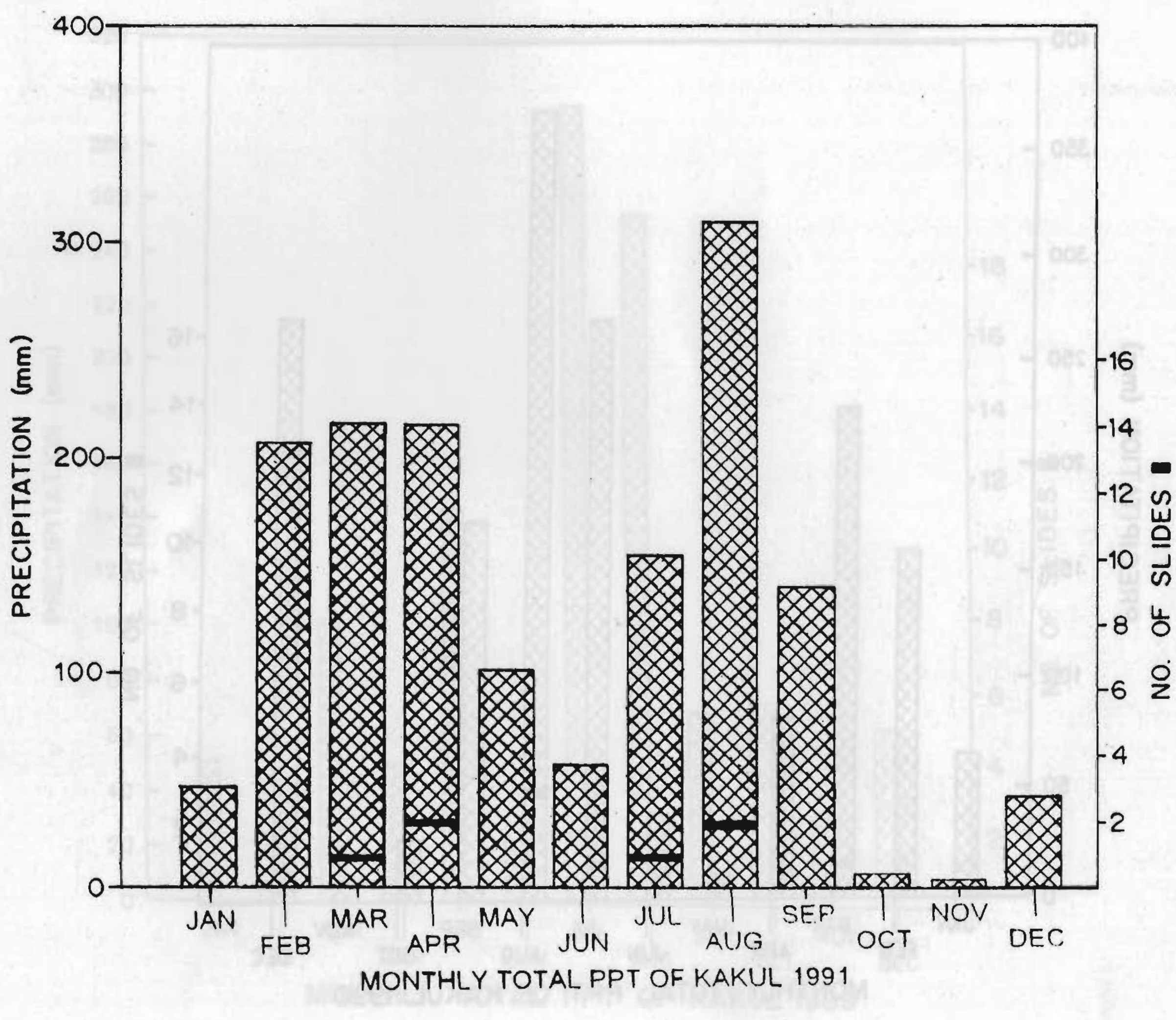


Figure 25: Slides Recorded on Murree-Abbottabad and Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Kakul 1992)

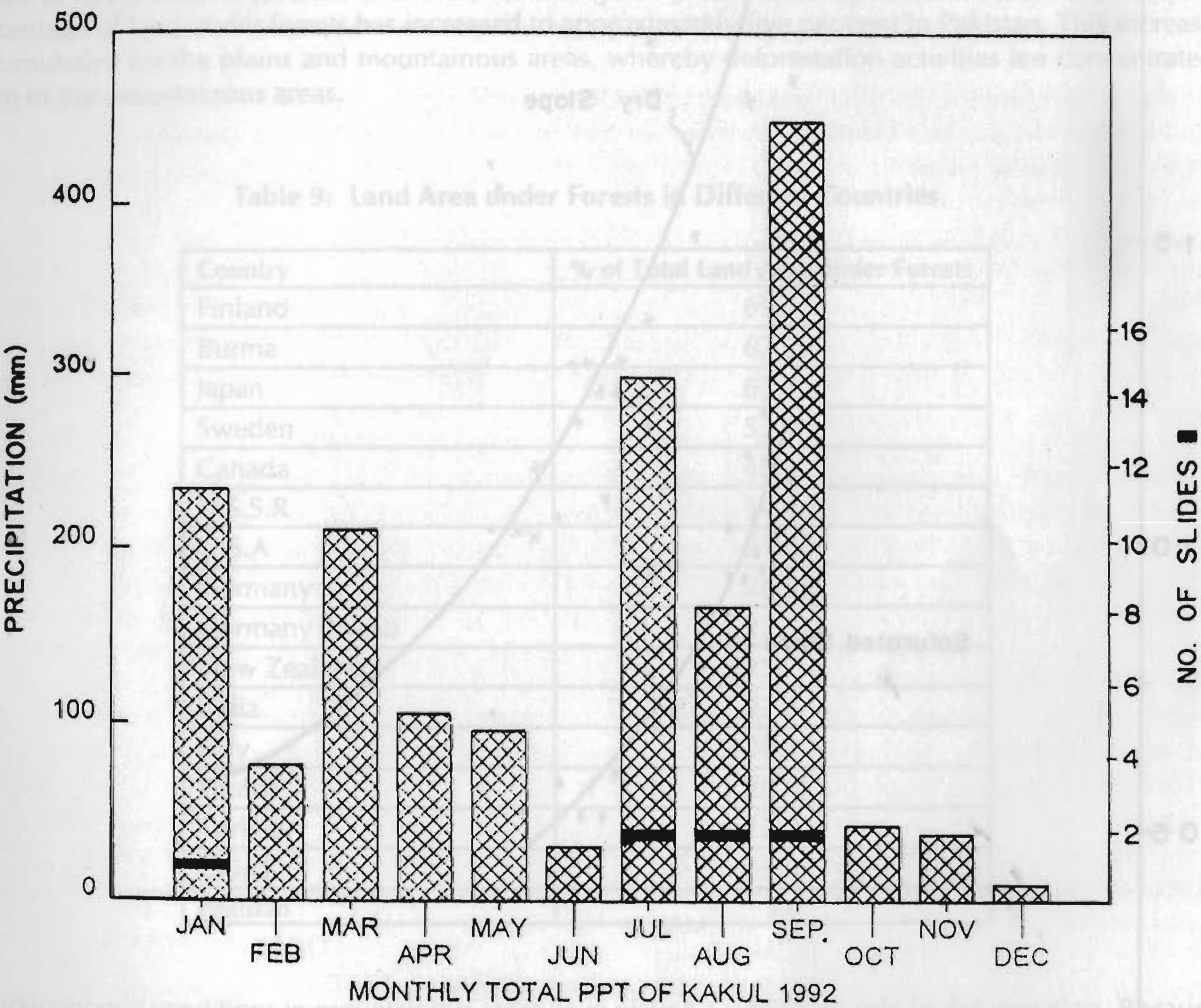
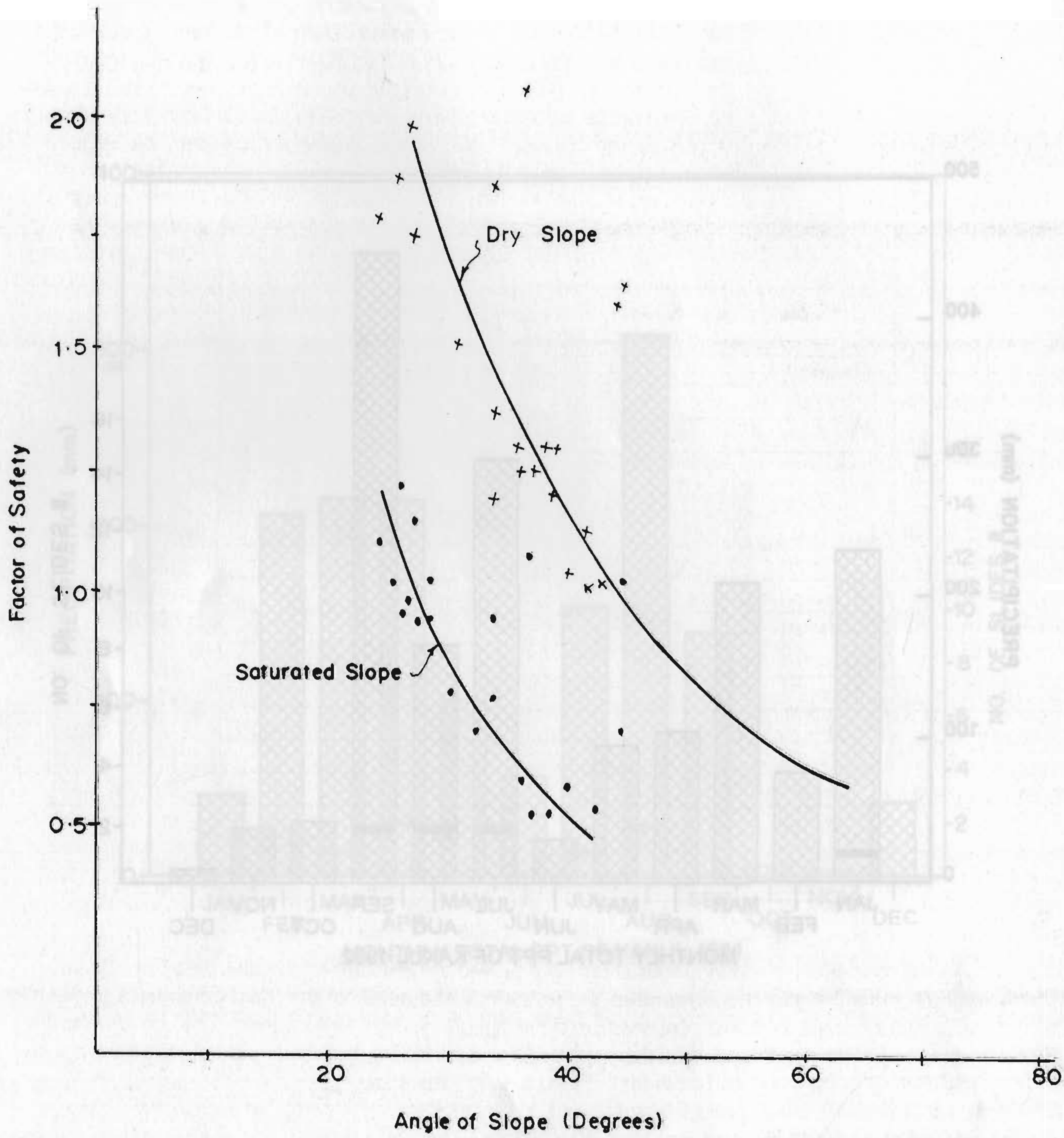


Figure 26: Relationship of Angle of Slope (Terraces) with Stability Number



The following effects of vegetation should be considered for assessing its impact on slope stability:

- evaporative and absorptive losses reduce infiltration,
- roots absorb water from soil for transpiration and reduce porewater pressure,
- roots reinforce the soil increasing its shear strength,
- tree roots may also anchor into firm strata providing support to the slope, and
- roots and soil particles on ground surfaces reduce their susceptibility to erosion.

On the basis of available information and data regarding vegetation and deforestation, an attempt has been made to correlate it with the landslide phenomenon in the northern parts of Pakistan. To date only five per cent of the country is covered with forests, compared to the 25 to 30 per cent forest area required.

According to the 1977 records of the Pakistan Forest Institute, Peshawar, the following Table 9 shows the extent of forest area in different countries, including Pakistan. According to more recent statistics the percentage of land under forests has increased to approximately five per cent in Pakistan. This increase is cumulative for the plains and mountainous areas, whereby deforestation activities are concentrated more in the mountainous areas.

Table 9: Land Area under Forests in Different Countries

Country	% of Total Land Area under Forests
Finland	69.3
Burma	67.3
Japan	63.9
Sweden	53.4
Canada	45.6
U.S.S.R	34.4
U.S.A	31.8
Germany	28.5
Germany (West)	25.5
New Zealand	23.7
India	22.3
Italy	20.5
France	20.0
Turkey	13.7
China	9.9
Pakistan	3.6

Socioeconomic conditions in mountainous areas have played a significant role in deforestation. Because of the agricultural and pastoral communities in these areas, the needs of the local inhabitants and the pressures or requirements of forest conservation departments have always clashed. The rights given to these people about 100 years ago (when the population was much less than today) permit grazing, grass-cutting, and storing of firewood and trees for their houses at concessional rates. Due to faulty agricultural practices, e.g., excessive grazing and felling of trees, soil erosion and landslides have increased. Because of illiteracy, ignorance, and the tendency to stick to old traditions and convictions, they still seek to make a living from their limited agricultural and pastoral resources. Because of their limited resources, which last for only three months, they either move down to the plains or bigger cities to look for work or remain behind and indulge in illicit damage to forests. Due to deforestation and loss of grazing grounds, soil erosion increases, resulting in slope instability or landslides.

Legal deforestation for timber production and use in industry also adversely affects slope stability because of poor planning, creating an imbalance. In 1973, the northern parts of Pakistan produced 134,000 cubic metres of timber; this does not include unrecorded production. Presently, the need for more timber for industry is causing deforestation and landslides.

Due to thick vegetation, from Murree to Jalial the frequency of landslides is remarkably less than in the area between Jalial and Muzaffarabad where a thin vegetation cover exists. A similar relationship is observed on the Karakoram Highway. Due to afforestation, very few landslides have occurred in the past ten years from Mansehra to Batgram, compared to the stretch of the KKH between Batgram to Thakot (Fig. 6). Similarly, between Shetanpari and Ali Abad (Hunza) vegetation is scanty and landslides are very frequent (Fig. 8).

Reducing Impacts from Landslide Disasters

Landslide Studies and Hazard Mapping

Initially, landsat imagery and aerial photographs were used to broadly demarcate and identify critical areas in order to prepare surface maps which are imperative for landslide studies. From the study of the imagery and aerial photographs, areas were carefully selected for detailed investigation. Detailed geological and geomorphological mapping was carried out to delineate various lithological units and identify structural and geomorphological features.

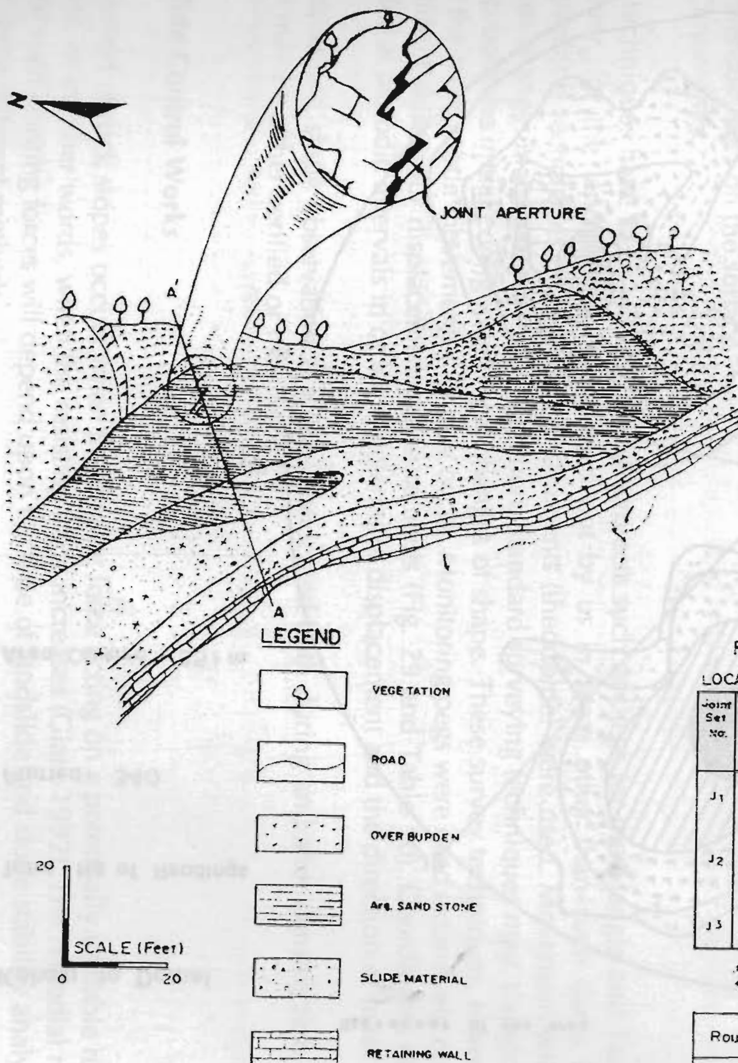
Landslide inventory maps of different areas were prepared to mark areas with different degrees of stability (Saeed & Malik 1990). Demarcation of areas as stable, unstable, and potentially unstable zones (Fig. 2) was carried out along different important routes on the Murree-Muzaffarabad Road and the Karakoram Highway. The critical areas (unstable and potentially unstable) were studied in greater detail for analytical purposes.

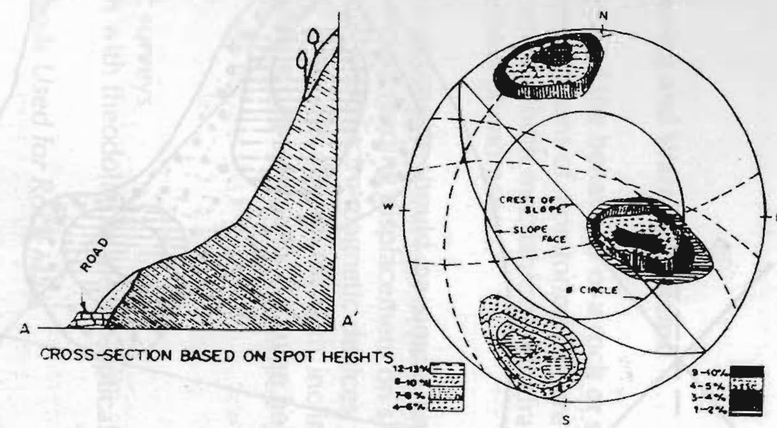
Detailed maps, sketches, and profiles of these unstable zones were prepared for qualitative and quantitative assessment, and these are presented in tabulated form (Fig. 27). In order to map a cross-section of landslides in these unstable zones, spot heights along appropriate lines were taken for evaluation of parameters such as weight, volume, and angle of slopes. As a result of successive landslides occurring repeatedly over the years, the profiles of slopes in unstable zones are inconsistent and change considerably. The contours on the topographic sheets of the Survey of Pakistan can, therefore, be misleading, as these survey sheets were prepared in the 1920s or 1930s. Although contouring of such slopes should be carried out afresh for analysis, this was purposely not carried out as the configuration of slopes and contours change very frequently as a result of landslides which occur several times a year. In order to overcome this problem, a spot heights' technique was used and was found to be very useful for such areas. Two types of materials are present on problematic slopes in different areas. They are rock outcrops and overburden (alluvium, colluvium, and slide material). Structural defects, such as discontinuities, control the stability in rocks. Their distribution, orientation, and intensity or frequency determine the extent of their influence on rock mass strength.

Keeping in mind these facts, the discontinuity survey was carried out (Table 3), and this included various parameters for rock mass characterisation such as joint sets and their orientation, spacing, aperture, persistence, roughness, joint wall strength, filling, and seepage.

The orientation data were used for plotting poles on stereonets (Fig. 28) to determine concentrations and stress directions related to landslide directions. These data sheets were successfully used at various landslide locations for strength parameters and slope analysis. Other indices used for rock, both in the field and laboratory, include Point Load Strength, Schmidt Rebound Hardness, and Unconfined Compressive Strength. Quantitative analysis using field and laboratory data was carried out to assess the sliding potential in various rock outcrops. Stability analysis using discontinuity data for plane and wedge failure gave values for factors of safety ranging from 0.3 to 1.0 indicating the likelihood of failures on widening or excavating of these slopes, because the excavations made at steeper angles will cause the discontinuities to daylight on slopes.

Figure 27: Sketch of the Sehr Bagla Potentially Unstable Zone along with Cross-section, Stereoplot and Test Results





DATA SHEET NO. 1

FIELD MEASUREMENTS AND EVALUATIONS OF DISCONTINUITY PARAMETERS

LOCATION: SHER BAGLA

Joint Set No.	Strike	Orientation: Dip Direction	Orientation: Dip	Spacing (cm)	Persistence (m)	Aperture (mm)	Nature of infilling	Surface Roughness	Waviness: Wave Length (cm)	Waviness: Amplitude cm	JRC	Schmidt Hardness	Length of Column above Joint set (h) (m)	Unit Wt. (P) KN/m³	JCS MPa	Normal Stress KN/m²	Ø Peak	Average Peak
J1	N74E	344	80NW	110	2.4	35	Swelling Clays	IV	3.2	2.1	9	19	2.5		26	70.25	48.1	
	N80E	350	67NW	42	1.6	18		V	4.8	3.0	9	18	3.0		23	84.3	46.9	
	N70E	340	50NW	30	0.8	15		V	2.4	0.9	9	19	2.9		29	78.68	48.1	
J2	N40W	230	67SW	116	2.0	27		V	4.0	1.3	7	24	1.9		38	50.55	45.2	
	N36W	224	89SW	110	3.2	25		VII	3.2	1.9	7	22	2.0	28.1	27	56.20	43.8	46.7
	N42W	228	78SW	96	1.2	19		IV	2.9	2.3	7	23	2.2		36	61.81	44.3	
J3	N16E	106	32SE	130	0.5	13		VI	2.3	2.2	9	22	3.2		26	89.92	47.1	
	N22E	112	28SE	116	2.1	11		VI	3.1	1.6	9	21	2.4		24	57.44	48.0	
	N20E	110	28SE	110	1.7	27		V	1.7	1.2	9	21	2.5		32	73.06	48.7	

* = Normal Stress = p x h

** = Ø Peak = JRC* log10 (JCS / σn) + Ør

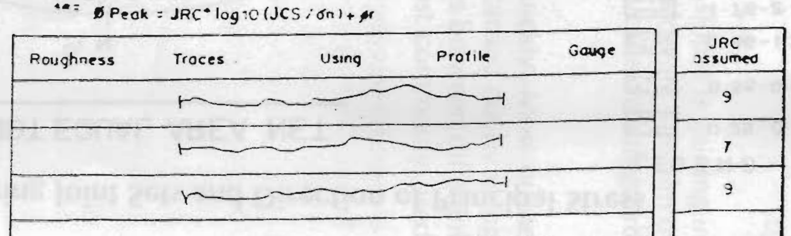
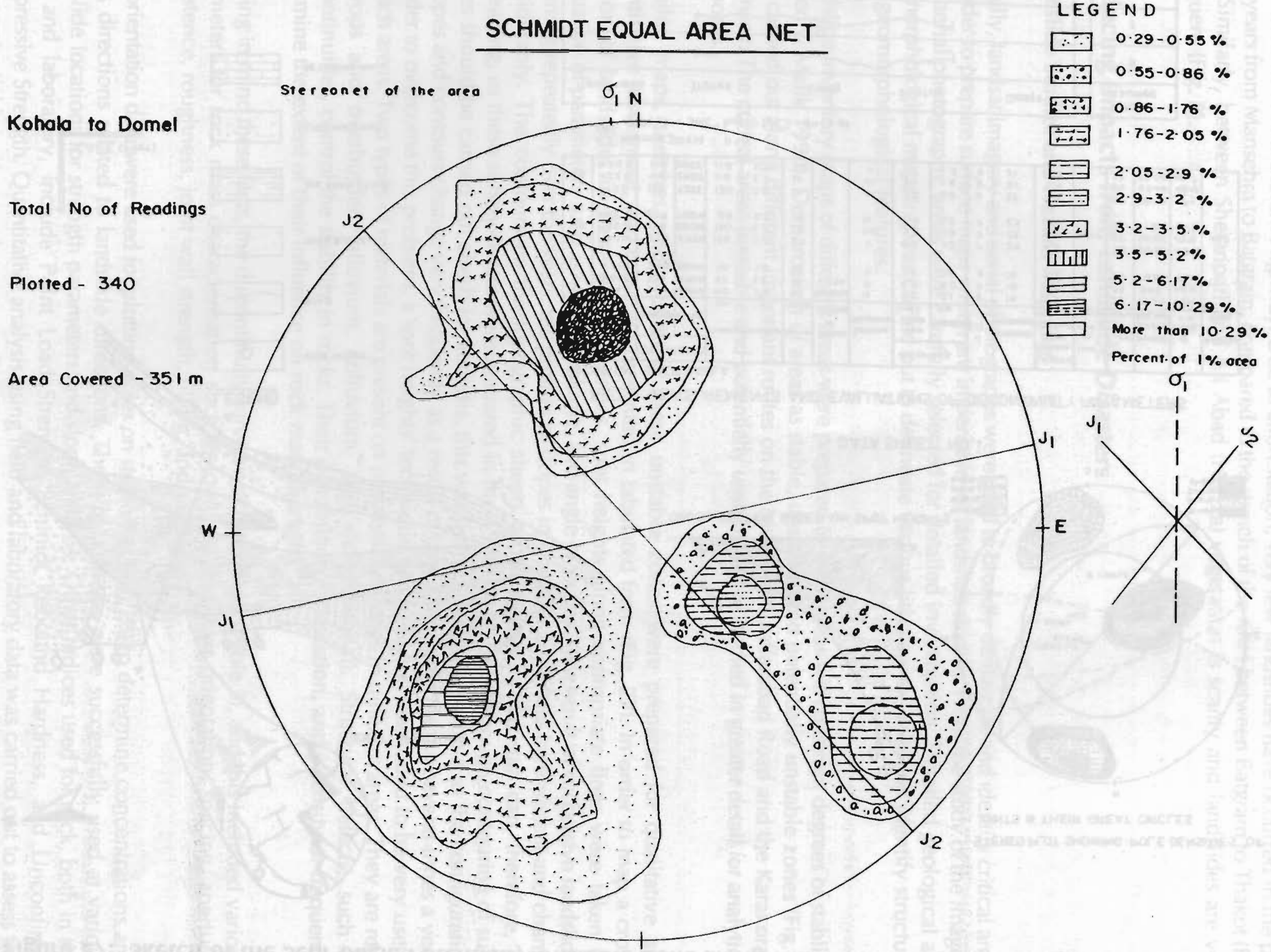


Figure 28: Stereoplot Showing Joint Sets and Direction of Principal Stress



For the stability analysis of overburdened slopes, or slopes consisting of heavily fractured and sheared rocks, various field and laboratory tests were performed to establish strength parameters. These tests included moisture content, particle size distribution, Atterberg limits, field density, specific gravity, and shear box tests (Fig. 9). Different methods for the analysis of such slopes were used. However, the circular failure chart method (Hoek & Bray 1981) was more successfully used for the determination of safety factors. On the basis of the above-mentioned studies areas of hazardous potential were highlighted (Figs. 2, 6 & 8).

Landslide Monitoring and Warning Systems

In order to understand the behaviour of a rock or slope, monitoring landslides and slopes is gaining in importance. Different means of monitoring that are suitable to local conditions are adopted. The aim of monitoring is to analyse both mechanic and hydraulic conditions in a rock mass, in order to safeguard against this hazardous phenomenon.

The monitoring instruments should be simple and should take measurements quickly. Most of the instruments are used for reading displacement on slopes. Measurement of slopes is carried out by using mechanical, optical, and electro-magnetic devices, mainly used for varying distances between different points on slopes. Borehole deflections with inclinometers are also used. The most commonly used methods for measuring displacements are given below.

Optical Methods

a) Topographic surveys
b) Triangulation with theodolite or electro-optical instruments (e.g., tellurometers)

Mechanical Methods Used for Rock Mass

a) Extensometers (wires or rods in boreholes)
b) Extensometers on the surface
c) Clinometers

Such techniques have been widely used in projects such as these for the Mangla and Tarbela Dams. However, for the landslide studies carried out by us in areas other than such dams in Pakistan, topographical techniques using optical instruments (theodolite) were used. Movement within a slope involves changes in its geometric configuration. Standard surveying techniques may, therefore, be used to map both the initial configuration and changes of shape. These survey techniques, however, do not detect the more subtle movements that may occur. Monitoring pegs were used extensively on the Simbal landslide, Pakistan for displacement measurements (Fig. 29 and Table 10). Coordinates of pegs were recorded at periodic intervals in order to determine displacement and the direction of mass movement.

In excavations, slope observation is mostly condcuted both during and after construction, so that the design may be either verified or modified.

Landslide Control Works

Stabilisation of rock slopes occurs when the driving force acting on a potentially unstable rock slope is reduced, or in other words, when the resisting force increases (Giani 1992). The remedial measures to increase such resisting forces will depend upon the type of landslide and slope stability analyses carried out by using different methods.

Generally, for controlling landslides, techniques such as rock bolting, drainage, retaining walls, shotcreting or guniting, stepping, rock anchoring vegetation, piling and gabions are used. Almost all of these techniques have been used in Pakistan.

Figure 29: Brief Sketch of the Simbal Slide (Motorway M1) Showing Monitoring Pegs

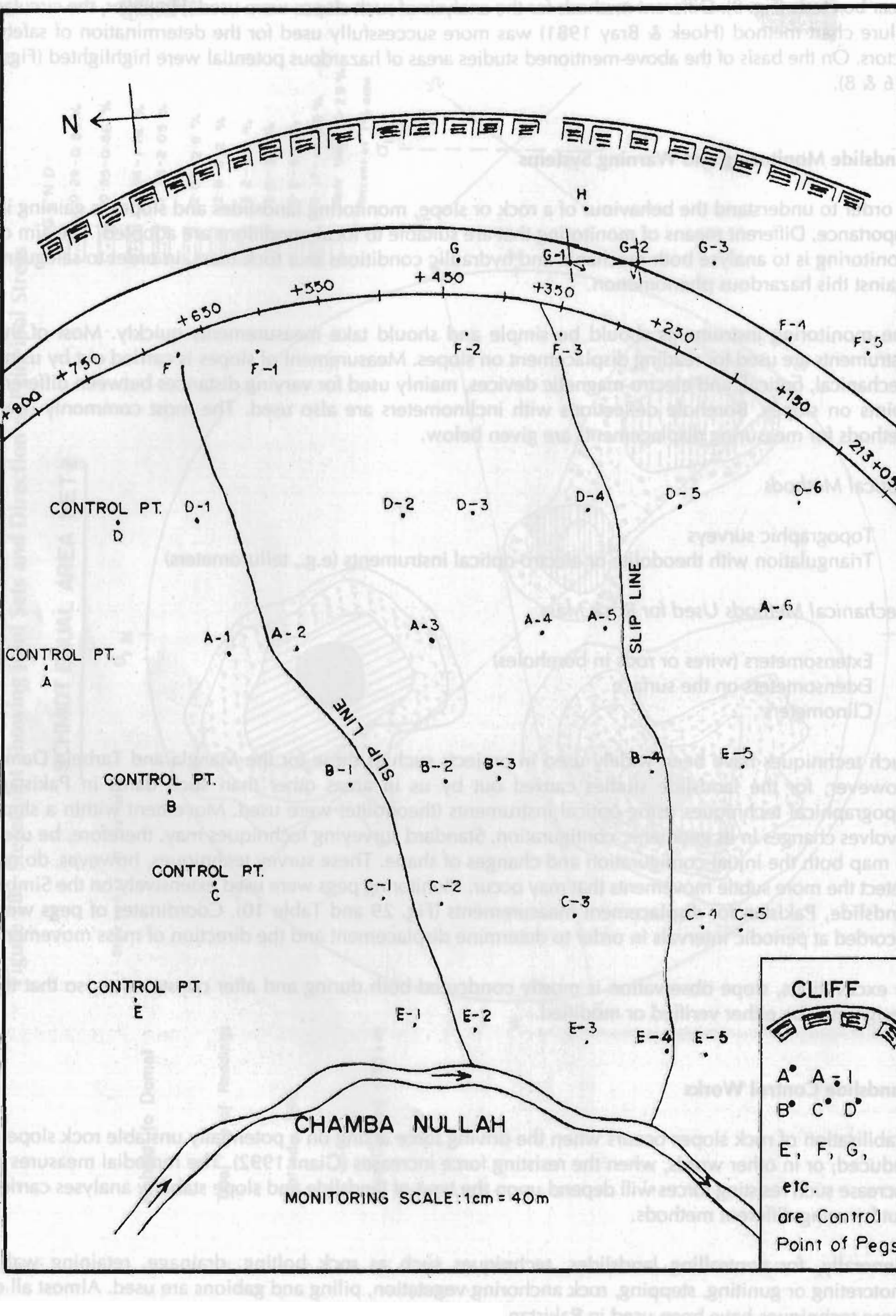


Table 10:Monitoring Data of Simbal Landslide on the M1 Motorway between Lahore and Islamabad - June 1994

PEG. NO	DATE: 17-05-1994			DATE: 16-06-1994			MOVEMENT			3D DIFF	REMARKS
	ELEVATION	NORTHING	EASTING	ELEVATION	NORTHING	EASTING	ELEVATION	NORTHING	EASTING		
A	680.446	945535.178	3188679.985	680.446	945535.178	3188679.985	0.000	0.000	0.000	0.000	CONTROL POINT
A-1	646.560	945479.006	3188692.617	646.560	945479.006	3188592.617	0.000	0.000	0.000	0.000	***
A-2	631.314	945438.170	3188701.790	631.310	945438.162	3188701.783	-0.004	-0.009	-0.007	0.012	***
A-3	630.134	945370.954	3188716.915	630.134	945370.946	3188716.913	0.000	-0.008	-0.002	0.008	***
A-4	627.390	945300.898	3188732.615	627.379	945300.890	3188732.597	-0.011	-0.008	-0.018	0.023	***
A-5	627.888	945209.507	3188753.179	627.880	945209.489	3188753.167	-0.008	-0.018	-0.012	0.023	***
A-6	646.505	945080.420	3188782.249	646.505	945080.420	3188782.249	0.000	0.000	0.000	0.000	***
B	659.081	945499.078	3188602.439	659.081	945499.078	3188602.439	0.000	0.000	0.000	0.000	CONTROL POINT
B-1	622.712	945417.091	3188603.885	622.712	945417.090	3188603.885	0.000	-0.001	0.000	0.001	***
B-2	616.400	945366.679	3188604.760	616.400	945366.676	3188604.760	0.000	-0.003	0.000	0.003	***
B-3	616.627	945310.490	3188605.630	616.620	945310.476	3188605.626	-0.007	-0.013	-0.004	0.015	***
B-4	614.180	945216.734	3188607.445	614.178	945216.731	3188607.408	-0.002	-0.003	-0.037	0.037	***
B-5	611.003	945144.953	3188608.625	611.004	945144.953	3188608.622	0.001	0.000	-0.003	0.003	***
C	649.478	945477.219	3188529.937	649.478	945477.219	3188529.937	0.000	0.000	0.000	0.000	CONTROL POINT
C-1	613.612	945358.940	3188514.208	613.612	945358.940	3188514.208	0.000	0.000	0.000	0.000	***
C-2	614.125	945326.114	3188509.820	614.118	945326.087	3188509.796	-0.007	-0.027	-0.024	0.037	***
C-3	601.351	945201.041	3188493.133	601.346	945201.036	3188493.114	-0.005	-0.005	-0.019	0.020	***
C-4	590.353	945139.144	3188484.837	590.353	945139.139	3188484.836	0.000	-0.005	-0.001	0.005	***
C-5	598.365	945099.397	3188479.709	598.365	945099.397	3188479.709	0.000	0.000	0.000	0.000	***
D	674.154	945506.561	3188748.437	674.154	945506.561	3188748.437	0.000	0.000	0.000	0.000	CONTROL POINT
D-1	668.020	945488.696	3188753.223	668.017	945488.692	3188753.224	-0.003	-0.004	0.001	0.005	***
D-2	627.480	945372.557	3188784.319	627.475	945372.549	3188784.317	-0.005	-0.008	-0.002	0.009	***
D-3	637.005	945330.849	3188795.496	637.005	945330.849	3188795.496	0.000	0.000	0.000	0.000	***
D-4	644.045	945242.513	3188819.099	644.036	945242.495	3188819.059	-0.009	-0.018	-0.040	0.045	***
D-5	649.354	945195.789	3188831.676	649.350	945195.783	3188831.666	-0.004	-0.006	-0.010	0.012	***
D-6	653.509	945122.312	3188851.396	653.505	945122.311	3188851.397	-0.004	-0.001	0.001	0.004	***
E	652.146	945528.689	3188440.724	652.146	945528.689	3188440.724	0.000	0.000	0.000	0.000	CONTROL POINT
E-1	575.758	945323.709	3188388.921	575.758	945323.709	3188388.921	0.000	0.000	0.000	0.000	***
E-2	575.629	945288.754	3188380.099	575.630	945288.750	3188380.098	0.001	-0.004	-0.001	0.004	***
E-3	567.575	945210.838	3188360.435	567.575	945210.838	3188360.435	0.000	0.000	0.000	0.000	***
E-4	562.137	945164.631	3188348.763	562.136	945164.631	3188348.763	-0.001	0.000	0.000	0.001	***
E-5	556.693	945121.970	3188337.986	556.693	945121.970	3188337.986	0.000	0.000	0.000	0.000	***
F-2	676.484	945344.823	3188915.613	676.484	945344.833	3188915.610	0.000	0.009	-0.003	0.010	***
F-3	674.664	945287.781	3188943.695	674.664	945287.783	3188943.694	0.000	0.002	-0.001	0.002	***
F-4	653.400	945124.088	3188989.710	653.399	945124.091	3188989.707	-0.001	0.003	-0.003	0.005	***
F-5	666.314	945091.182	3188996.003	666.312	945091.177	3188996.004	-0.002	-0.005	0.001	0.006	***
F-6	677.304	945066.920	3189003.541	677.304	945066.919	3189003.541	0.000	-0.001	0.000	0.001	***
G	675.878	945357.203	3188956.744	675.880	945357.214	3188956.730	0.002	0.010	-0.014	0.018	***
G-1	672.477	945290.716	3189011.142	672.473	945290.501	3189010.990	-0.004	-0.215	-0.152	0.263	MOVEMENT POINT
G-2	674.512	945246.827	3189032.135	674.510	945246.850	3189032.074	-0.002	0.022	-0.062	0.066	MOVEMENT POINT
G-3	689.324	945180.596	3189059.567	689.324	945180.595	3189059.565	0.000	-0.001	-0.002	0.002	***
H	691.795	945281.114	3189053.499	691.795	945281.110	3189053.495	0.000	-0.004	-0.004	0.005	***

*** = No movement (only manual error)

Changing the Geometry or Shape of the Slope

By modifying the geometry of a slope, which includes height of slope, reduction in slope inclination, removal of unstable materials, and creation of benches, slope stability can be increased. This technique was very successfully employed behind the powerhouse and on the sloping sides of the spillways of the Tarbela Dam, Pakistan.

Rock Bolting

The rock bolting technique is applied to tie discrete blocks and weaker rocks on to surface with the intact and firm rocks at depth in order to avoid landslides. Rock bolts were used extensively on slopes near the powerhouse of the Tarbela Dam, while rock anchors were used on the sides of spillways of both the Simly and Tarbela Dams.

Drainage

The presence of water in rock joints has a fundamental influence on rock stability. Therefore, it is important to know the water pressure distribution and measures to dissipate this pressure through drainage (surface and subsurface). For surface drainage, various techniques are used to check infiltration by either diverting the surface water or treating the slope material with impervious protective covers. For subsurface drainage, relief wells or weep holes and drainage galleries have been installed effectively at the Mangla, Tarbela, Khanpur, and Simly Dams. Weep holes have also been used effectively in retaining walls along the Murree-Muzaffarabad Road and the Karakoram Highway.

Retaining Walls

Masonry and concrete retaining walls are frequently constructed along various roads in the mountain areas of Pakistan to provide support against lateral pressure. Most of the retaining walls along these roads have been constructed indiscriminately without proper design and without calculation of likely earth pressures. As a result, most of these walls fail during the rainy season.

Vegetation

Increase in slope movements is caused by the removal of trees as their root systems provide some reinforcement and remove groundwater and absorb much of the rain. Vegetation has been successfully used by the highway department at the Kohala landslide where a part of the slide has been stabilised.

Methods of Preventing Flooding caused by Landslide Dams

Huge landslides in river valleys create natural dams with lakes behind them. These natural dams are overtopped or collapse causing floods in downstream areas. On the other hand, a rise in water level in such lakes, if such natural dams persist or remain for longer periods, causes submergence of agricultural land, settlements, and other infrastructural installations on the upstream side. In order to overcome this difficulty, either diversion works or demolition of the dam should be carried out.

Two examples can be cited here from Pakistan. First, during the construction of the Karakoram Highway in the early 1970s, a huge mass movement took place across the valley of the Hunza River creating a natural dam 85 feet in height at Shishkat. Initially, it was proposed to blast this dam with dynamite in order to keep the location of the KKH unchanged. This proposal was found impracticable, and ultimately it was decided to leave the dam as such and change the route of the KKH around the lake.

The second example of a natural dam created by a landslide occurred along the Neelum River (Kashmir) in 1976/77 (Chelah landslide). This caused an emergency situation because of the excessive flooding of Chelah village. The Pakistan Army Engineering Corps blasted the dam to save the area and the inhabitants of Chelah village from flooding.

Landslide Control in Watersheds

Deforestation on a large scale and increase in population exacerbates soil erosion, leading to landslides. This, in turn, creates another serious problem of silting in dams such as the Mangla and Tarbela (Pakistan). In Tarbela Lake, a huge delta caused by siltation from denuded watershed areas is posing a serious threat not only to the longevity of the dam but also to its stability. It is feared that this delta material may liquefy as the consequence of an earthquake. If it does happen, it will damage the dam seriously and could be catastrophic. Currently, due to lack of proper planning and attention to conservation of soils in the watershed areas, this problem is gaining momentum.

Watershed management in Pakistan came into being in 1959. Its primary objective was to prolong the life of the Mangla Dam reservoir through improvement of land use and implementation of watershed management practices in the catchment area. Subsequent to the construction of Tarbela Dam, similar watershed management practices were introduced. At present, two watershed management projects are functioning in Pakistan, i.e., the Mangla and Tarbela watershed management projects. In light of the serious problems of erosion, landsliding, and silting in watershed areas, watershed management has been reorganised and is now emphasising the following activities.

Planning and Survey

For construction of engineering structures and afforestation, the area has been divided into sub-watershed units. Surveys which include location maps, soil classification, erosion conditions, climate, and so on are carried out.

Afforestation

Afforestation programmes under different schemes are imperative for watershed management. This includes establishment of nurseries for project plantation requirements.

Structural Control

In order to reduce soil erosion and landslides, several engineering structures are constructed in these catchment areas, e.g., checkdams and retaining walls at the toes of steep slopes.

Treatment of Landslides

Landslides contribute greatly to silting as they provide ready-made loose materials for runoff during rains. A number of landslides have been treated and stabilised in the watershed areas by building retaining walls, diversion channels for spring water, gabions, and spurs and by plantation on slopes.

Increasing Public Awareness

Due to lack of communications, inaccessibility in mountainous areas, education, newspapers, and electronic media, it is difficult to make the local inhabitants of mountainous regions of Pakistan realise the impact of landslides on their socioeconomic conditions. Some of the facts referred to previously, i.e., cutting of trees, overgrazing, making terraces for houses and cultivation, and the presence of small paths and improper drainage need to be emphasised, and local people should be educated about the gravity of landslides, their causes, and impacts. Our conversations with local people during field work revealed that they are only concerned about their cultivable land and want to stick to their traditional lifestyles and patterns. We also experienced difficulties in communicating with local people in the far-flung northern areas due to language barriers. It is, therefore, recommended that efforts should be made to educate the local people through village or union councils, local school teachers, and tribal chiefs.

Relevant departments, e.g., Soil Conservation, Highway Authority, Public Works Department, and Tourism, which are directly concerned with the problems caused by landslides, should get technical advice in order to tackle them. Unfortunately, a lack of coordination exists between the above agencies and the relevant experts in Pakistan. Due to the malfunctioning and malpractices prevailing in these agencies, influential and inappropriate experts are normally appointed or consulted, resulting in inadequate corrective measures. Proper technical services should be made available by academic institutions, private consulting firms, and individual researchers.

Insurance Programme

The loss incurred by landslides cannot be fully compensated for due to material loss and the effect of affiliation values of the local people concerning their lands and houses. So far, no programme giving insurance coverage for landslide damage exists in Pakistan. However, whenever landslides of a major catastrophic nature occur, the affected locals in the calamity-stricken area are given compensation by the government. The government should reserve special funds for landslide-damaged areas.

Institutions Dealing with Landslides

Role of Public Agencies

In the hill areas of Pakistan, only union councils or cooperative societies exist. They can contribute to reducing the impact of landslides through public awareness and participation in programmes, if any, giving training about landslides and how to monitor them. These agencies should remain in contact with organisations concerned with research, training, and management of landslides.

Role of Research Institutions

Concerned research intitutions are mainly in the universities or organisations such as the Road Research and Building Research and the National Highway Authority in Pakistan. Although these institutions carry out research on various aspects, very few institutions are really contributing research about landslides. Whatever research is carried out should be disseminated to other government departments and private agencies working on roads, townships, small dams, soil/conservation, and so on. There is a lack of coordination between researchers and decision-making personnel in different government and non-government organisations.

Role of Provincial and Local Governments

In developing countries like Pakistan, local and provincial governments have limited development plans due to lack of funds.

In the case of landslides, particularly ones which disrupt communication systems, emergency measures are taken to reconstruct and restore these routes. Wherever private land or houses are involved, little attention is given by provincial or local governments.

Role of NGOs and Scientific Societies

Developing countries in the Third World suffer from resource constraints. Governments alone cannot possibly promote sustainable development models. Therefore, NGOs have gained immense importance in these countries. Since NGOs are closer to the communities and, therefore, their representatives, they are more effective in providing basic facilities to the common man. They are also considered to be more flexible in terms of modifying their approaches and strategies according to local conditions and requirements. Unfortunately, in Pakistan, the role of NGOs has not been so effective, in spite of their increasing numbers. Initially, in most cases these (NGOs) enter into this field for the sake of earning a name or to cater to certain vested interests.

Scientific societies (e.g., Geological Societies) on the other hand, contribute by organising seminars and lectures on different aspects of geological, geotechnical, and environmental problems, including landslide hazards from time to time.

Overall Conclusions and Recommendations for a Practical Training Programme

Conclusions

The conclusions drawn from this study are summarised below.

1. A diversity of landslide types prevails in Pakistan, and this is attributed to local geological, climatological, and geomorphological conditions. In the northern parts of Pakistan, the landslide phenomenon occurs more frequently than in other parts of the country.
2. Plane and wedge failures on the Batgram-Thakot section of the Karakoram Highway are more abundant than other types of slope failures, while rockfalls and topples are not uncommon on this important route due to steep cutting and blasting. In the Hunza Valley, on the other hand, different types of failure occur, including mudflows.
3. Circular failures and 'flows' are more frequent in the alternate sandstone and clay layers of the Murree Formation along the Murree-Muzaffarabad Road.
4. Heavy rainfalls and rainstorms, 'reduction in strength of materials on saturation, and earthquakes, although of small magnitude, are the major factors contributing to landslides.
5. Very few government and non-government institutions are involved in research on this problem. Difficulties in bringing about coordination and finding funds for such activities prevent detailed and appropriate studies.

Recommendations

The following recommendations have been made in the light of the above conclusions.

1. To overcome the problem of landslides and the consequent disasters and losses, a centre for environmental studies (particularly for landslides) should be set up in institutions concerned with geology.
2. The proposed centre must be very well coordinated with the departments or organisations looking into the landslide problem. Any sliding phenomenon, throughout the country, should be immediately documented and initial studies carried out.
3. Landslide inventory maps of the entire northern parts of Pakistan should be prepared and continually updated.
4. The proposed centre should endeavour to mobilise agencies other than the government to come forward and participate in the efforts to mitigate this catastrophic and hazardous phenomenon.
5. Government and non-government agencies should arrange training courses and workshops frequently and use the media for effective propagation and dissemination of knowledge. Two types of courses for practical training are recommended.
   a) An awareness course for people living in mountain areas (including school children) given by educational institutions and local union councils. The purpose of this training (lasting for 2-4 weeks) should be to identify the problems in the villages and emphasise the need for vigilance and for applying precautionary measures.
   b) A technical course covering geological, geotechnical, and environmental reports should be arranged for a period of four to six weeks by the universities or the concerned authorities, e.g., the National Highway Authority and Communication Works' Department. The trainees should be from research organisations, universities, colleges, and departments concerned with the development of mountainous areas, highways, and others.
6. Since only five per cent of the land area is covered by forests, intensive afforestation programmes should be carried out.

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Plates

Plate 1: Medium-sized gabion structure showing deformation due to creep

Plate 2: Landslide between Muzaffarabad and Garhi Dupatta (Failure is within the ancient landslide)

Plate 3: Downslope failure of the retaining wall due to landslide as a result of saturation

Plate 4: Failure of retaining wall due to slump failure

Plate 5: Reconstruction of retaining wall after landsliding along the Murree-Muzaffarabad Road

Plate 6: Backfilling behind the retaining wall along the Murree-Muzaffarabad Road

Plate 7: Subsidence of metalled road near Kohala

Plate 8: Initiation of failure of downslope due to absence of retaining wall

Plate 9: Landslide due to deforestation

Plate 10: Tilting of trees due to landslide

Plate 11: Plane failure in schists at Lower Gali near Muzaffarabad

Plate 12: Movement of scree slope blocking the road between Muzaffarabad and Garhi Habib Ullah

Plate 13:
Small-scale landslide caused by making a path for a newly-built house

Plate 14:
Widening of road by blasting (may cause threatening slope ultimately)

Plate 15: Plane table mapping in critical areas

Plate 16: Point load testing of rock at site

Plate 17: Landslide activity in Aug. 1994 shows slip surface in background and cracks in displaced material along the M1 Motorway Lahore-Islamabad

Plate 18: Fresh slip surface (Aug. 1994) along the M1 Motorway (Simbal landslide) between Lahore and Islamabad

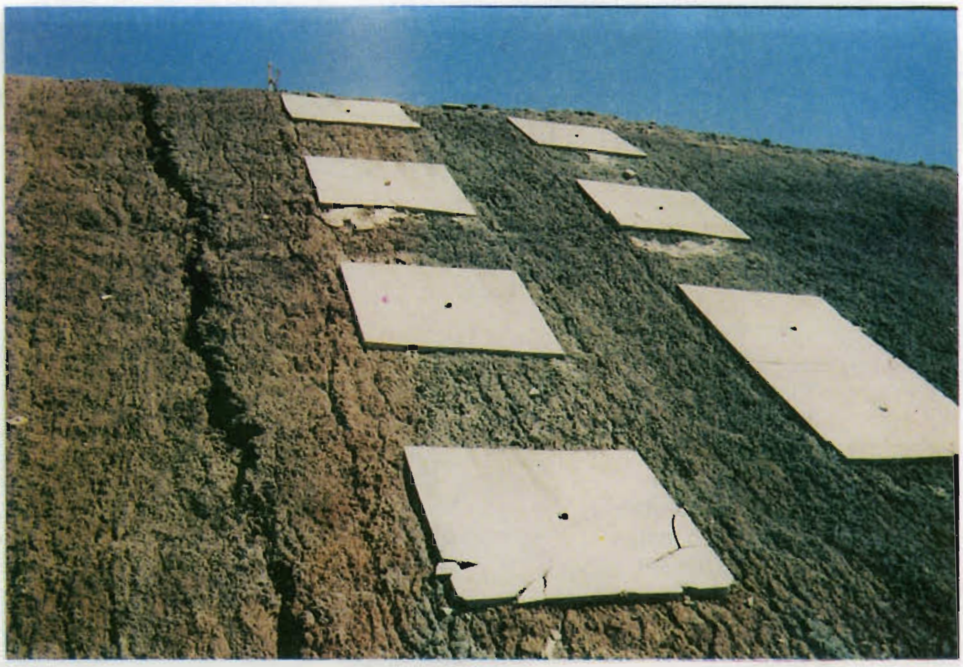

Plate 19: An experiment for protection of excavated slope by plaster covering plates

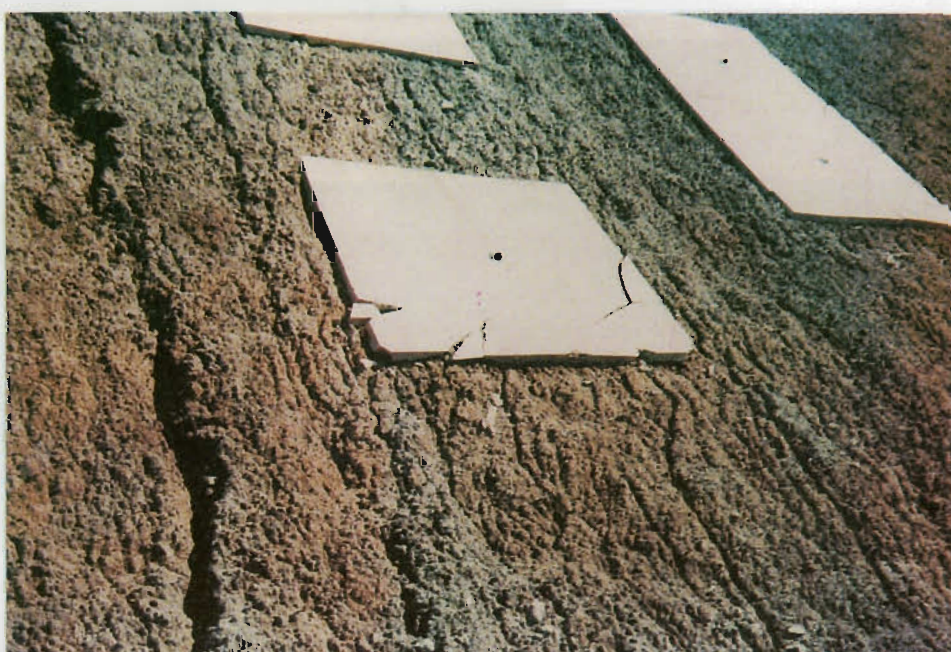

Plate 20: Failure of experimental plaster covering due to swelling of shales

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Other publications on natural hazards are:

- Landslide Hazard Management and Control in India
- Landslide Hazard Mapping and Management in China
- Landslide Studies and Management in Nepal
- Climatic Atlas of Nepal

Participating Countries of the Hindu Kush-Himalayan Region

- Afghanistan
- Bhutan
- India
- Nepal
- Bangladesh
- China
- Myanmar
- Pakistan

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