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.

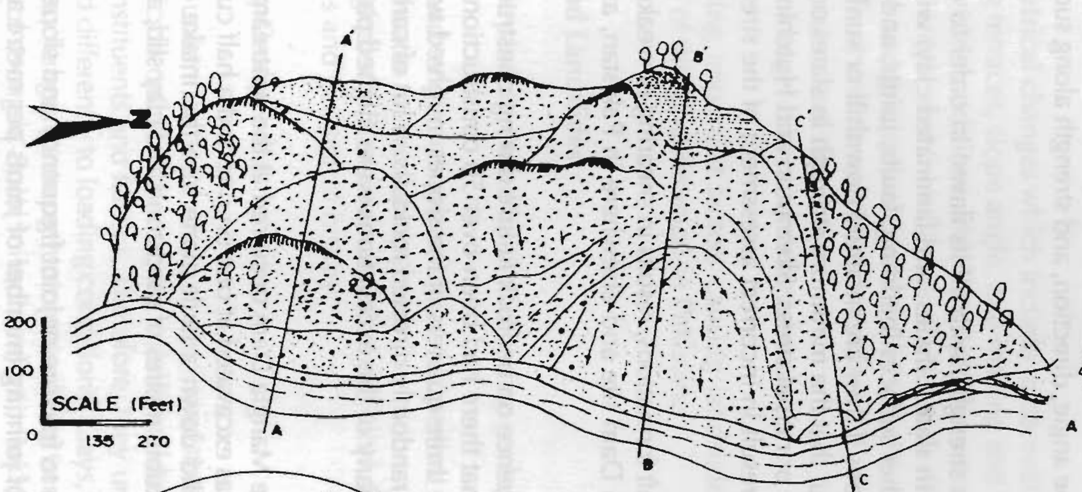
Similarly, folding, particularly in alternate hard and soft formations, results in shearing of weaker materials as can be seen at Mangla Dam and at the Kalabagh Dam site and elsewhere in Pakistan, as described earlier.

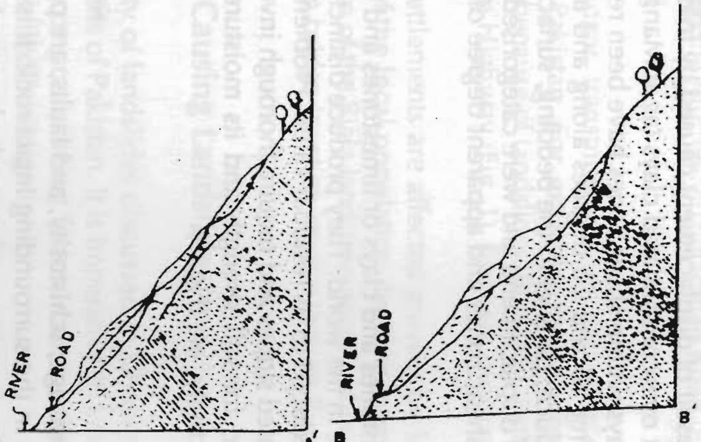
Such geological discontinuities had an important influence on bedrock failure during construction of the Mangla Dam in Pakistan. Fookes (1966) estimates that there had been over 50 construction failures on slopes involving large volumes of material. Of these, three quarters of the slopes involved were 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.

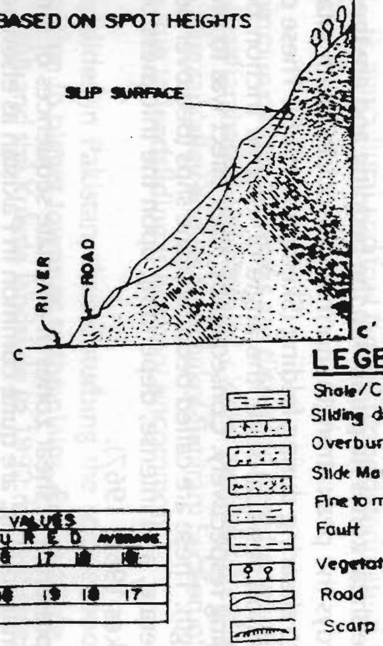
The most important failure during construction of the Mangla Dam occurred at the upstream end of the diversion tunnel where a temporary bedrock slope was excavated at one on one and a half cubic metres. About 2,000 cubic metres of sandstone and clay slid down a fault plane into the intake excavation. 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

TEST RESULTS OF OVERBURDEN SOIL

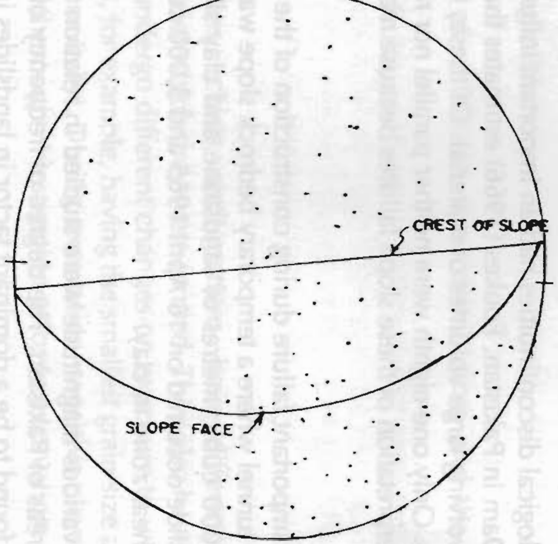
Sample No.	Location	M/C	Particle Size Distribution mm Clay	mm Silt	mm Sand	mm Gravel (75·0)	mm Cobble (300·00)	Atterberg Limits LL	PL	PI	Density PCF rb	M.C	rd	Shear Box Test C Psi	φ Deg	Gs
1		23·15	21	34	14	6	6	26	22·6	4·8	121·6	23·15		2·0	29·5	2·63
2		20·42	19	48	16	7	10	24	[illegible]	4·5	119·9	20·42		1·5	30	2·61
3		19·72	22	44	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	[illegible]	7				118·8	14·21		1·5	31·0	2·59

Samples were taken from slide Material

Direct shear tests performed on soil excluding gravels and cobbles.

Roughness	Traces A Profile	Gouge	JRC assumed
			9
			7

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



STEREO PLOT SHOWING POLES OF JOINTS & SLOPE FACE 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)

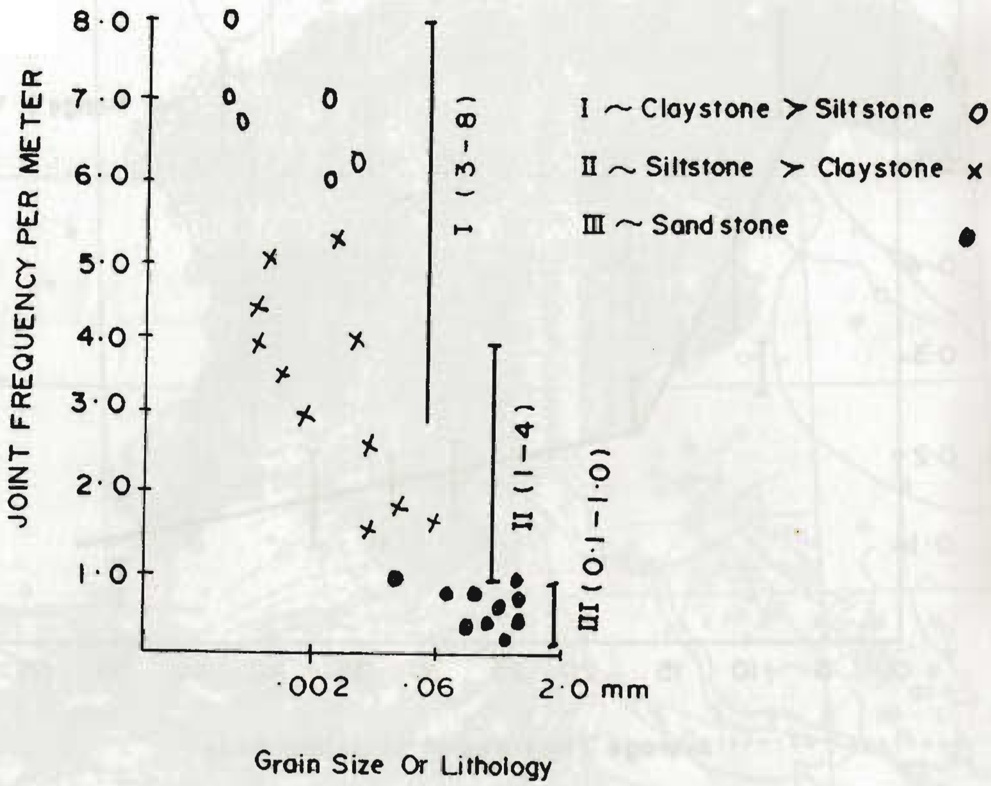


Figure 11: Joint Frequency vs Clay Fraction in Claystone Beds

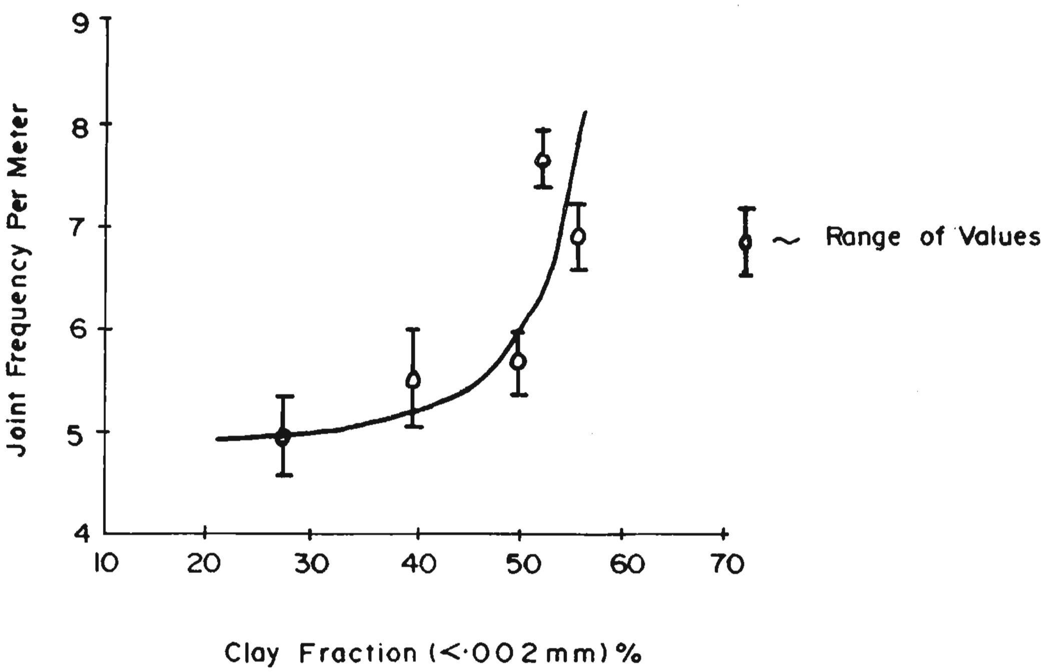


Figure 12: Joint Frequency vs Bed Thickness

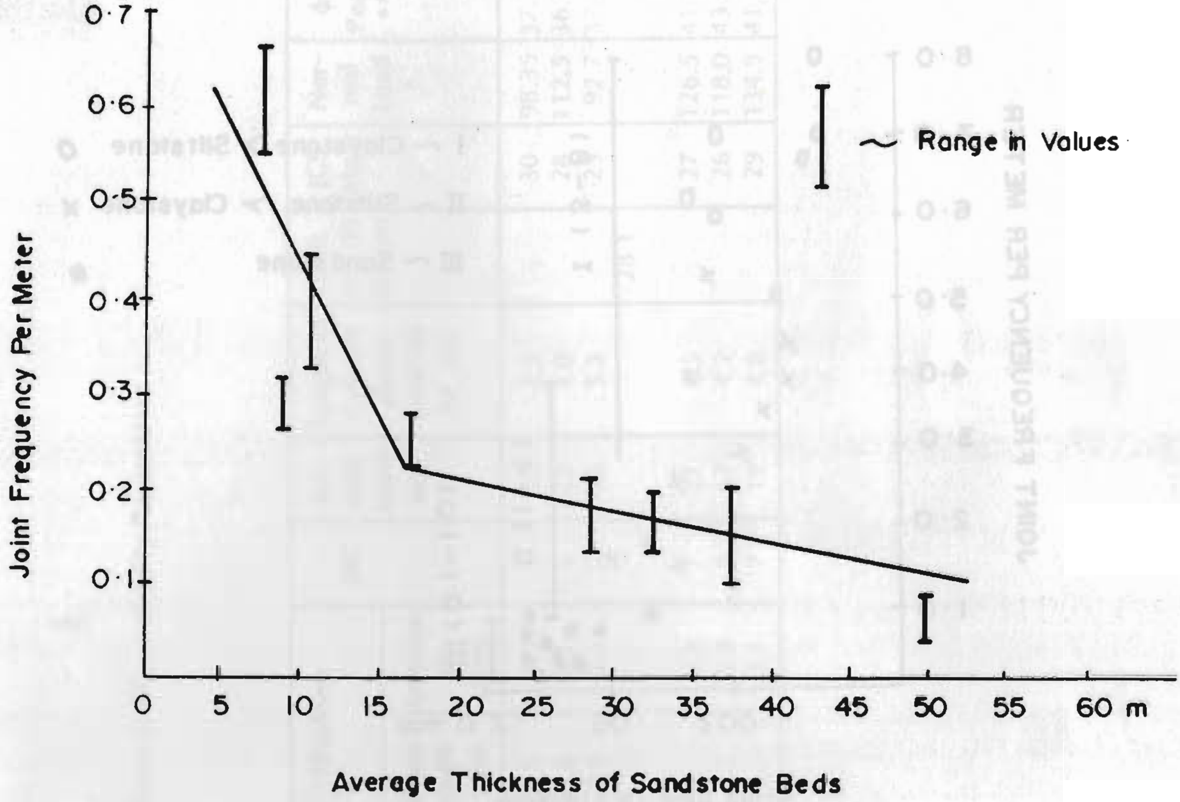


Figure 13: Average Joint Frequency vs Distance from a Small Fault

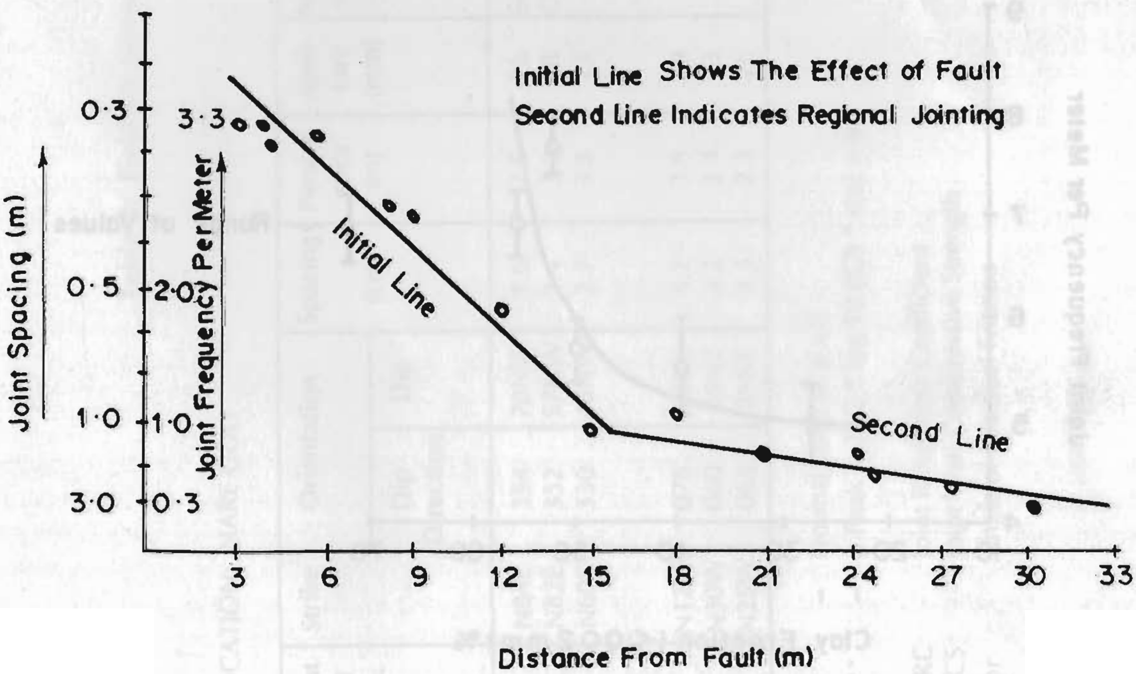


Figure 14: Tectonic Map of Northern Pakistan

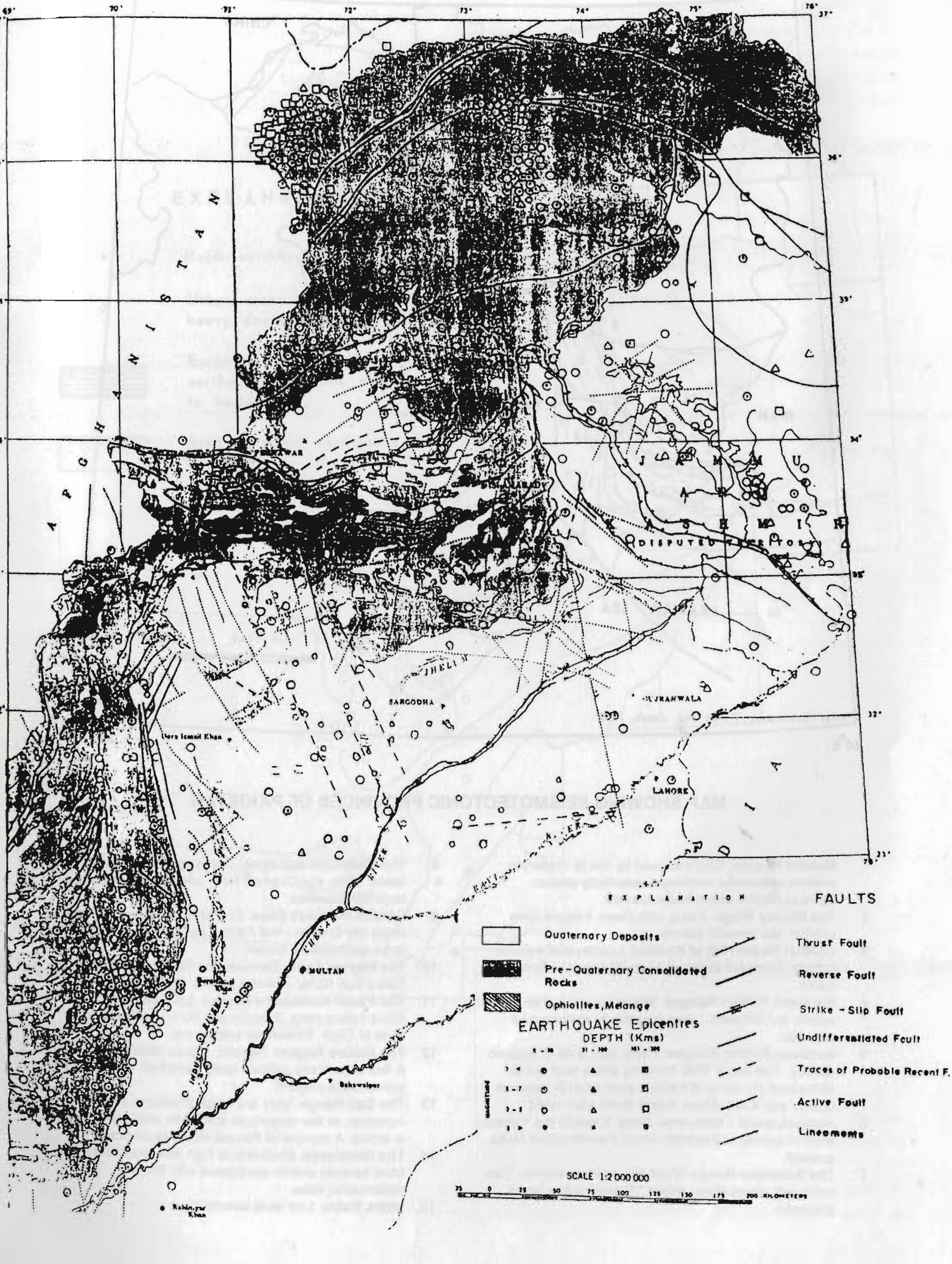
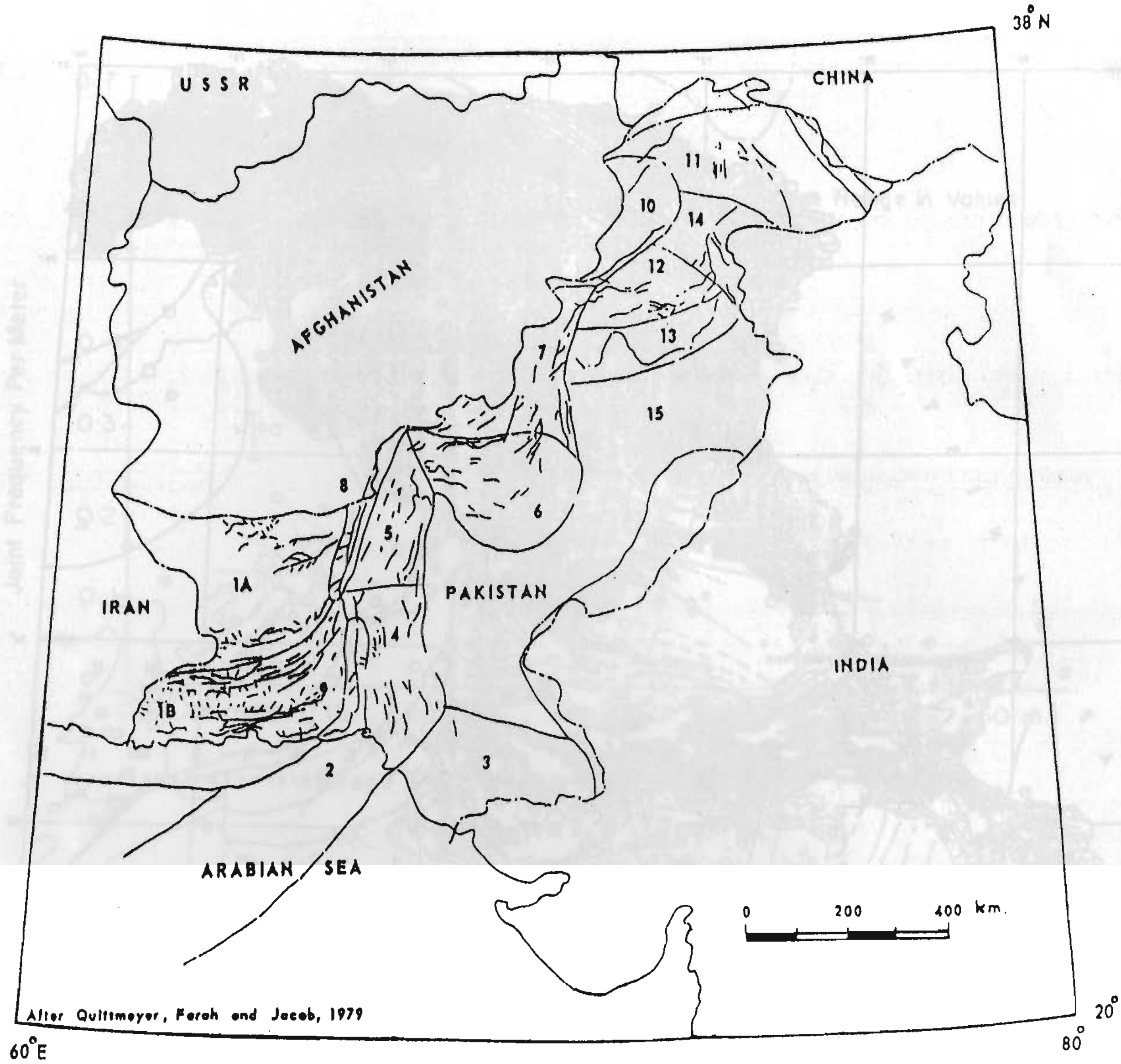


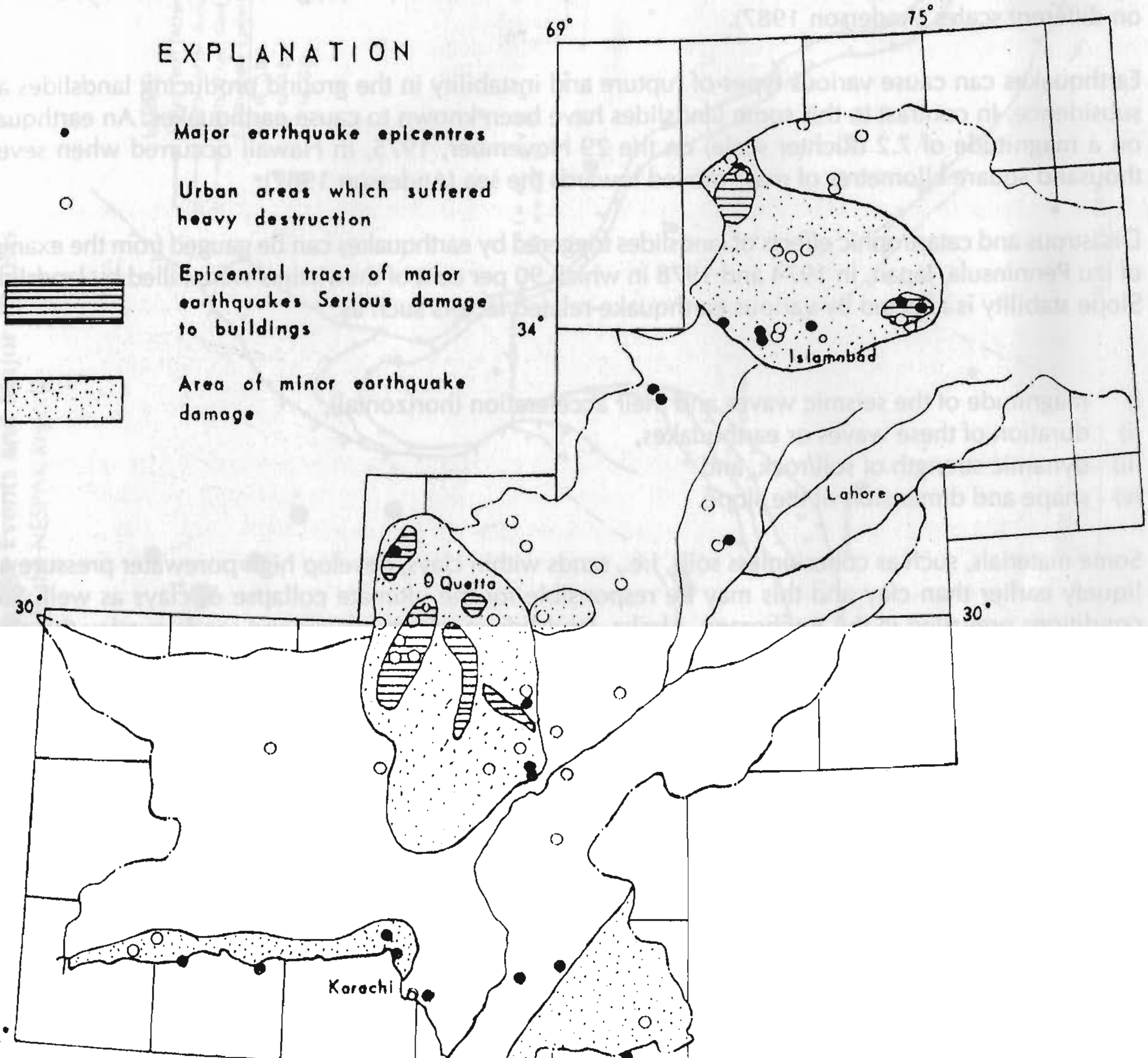
Figure 14(a): Seismotectonic Provinces of Pakistan



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.

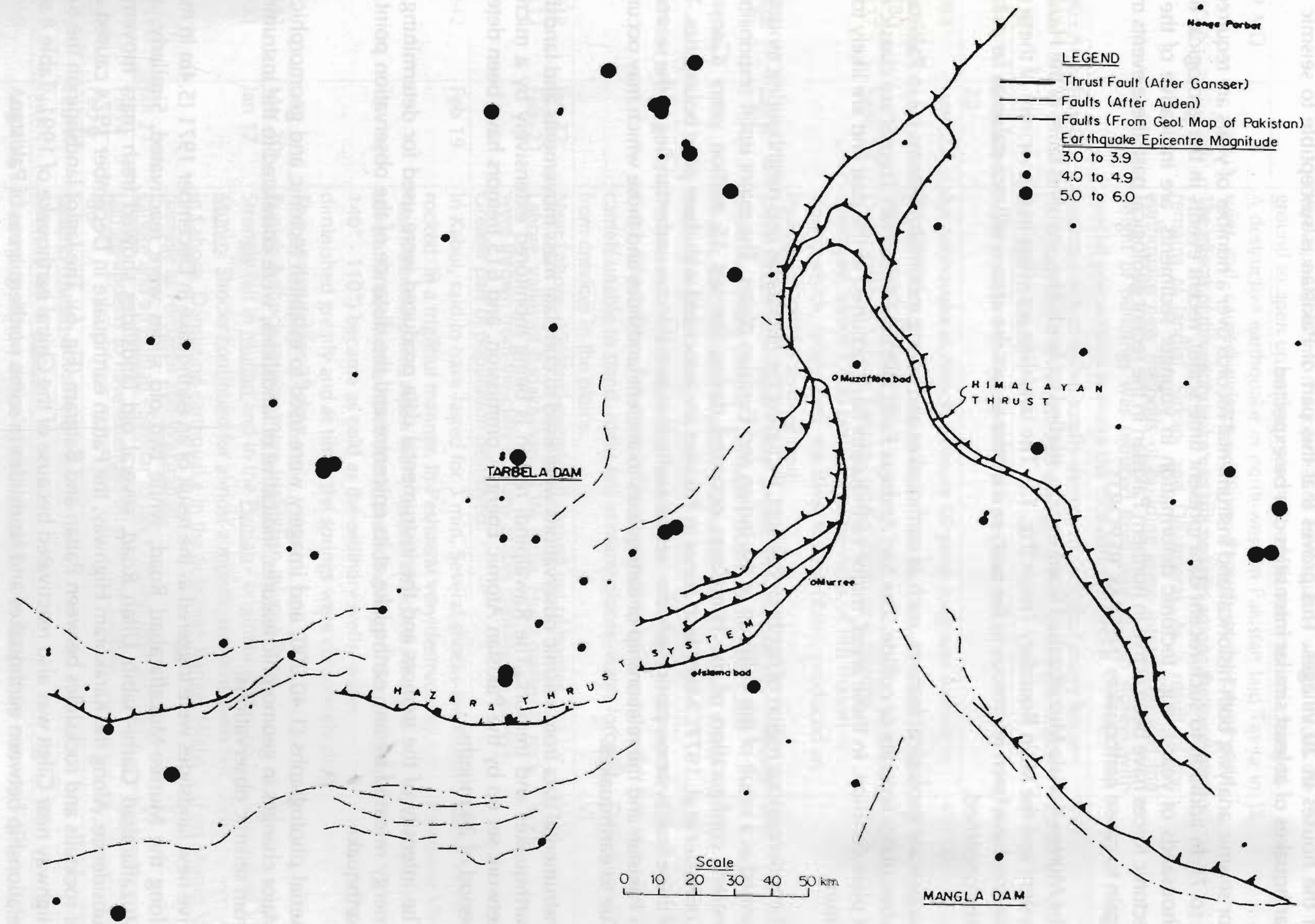
Landslides triggered by earthquakes disrupt communication systems; destroy settlements; and, depending upon their magnitude and distance from the source, can prove to be highly catastrophic. The 1991 earthquake in Chitral, Hindu Kush, Pakistan, claimed hundreds of lives and damaged as many houses.

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	Punjab A shock causing more fright than injury - Perry.	VI
15.	1851	Jan 17	Strongly felt in Multan and in the Punjab - originating from Fort Munro. Shocks continued for almost a month, some of them felt in Lahore. Damaging earthquake in the Suleiman Range. Slight damage at Ferozpur and Wazirabad.	Wazirabad VI-VII Fort Munro V-VI
16.	1851	Jan 21	Lahore and all Punjab - Similar to Jan 17th but even stronger.	VI
17.	1851	Feb 4	Lahore-appears to have extended all over the Punjab.	V-VI
18.	1851	Feb 6	-do-	V-VI
19.	1851	Feb 17	Lahore, Multan not severe	V
20.	1853	Nov	Strongly felt at Attock	VI
21.	1858	Aug 11	Damaging shocks at Simla felt throughout the Punjab, in Calcutta and Madras.	V-VI
22.	1858	Aug 23	Lahore-slight 6:30pm, Jacobabad at 2pm almost imperceptible.	III-V
23.	1858	Aug 29	Lahore - Sharp shocks.	IV
24.	1865	Jan 22	Slight damage and great panic in Peshawar, long duration.	V-VII
25.	1865	Dec 4	Lahore - 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 as 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)

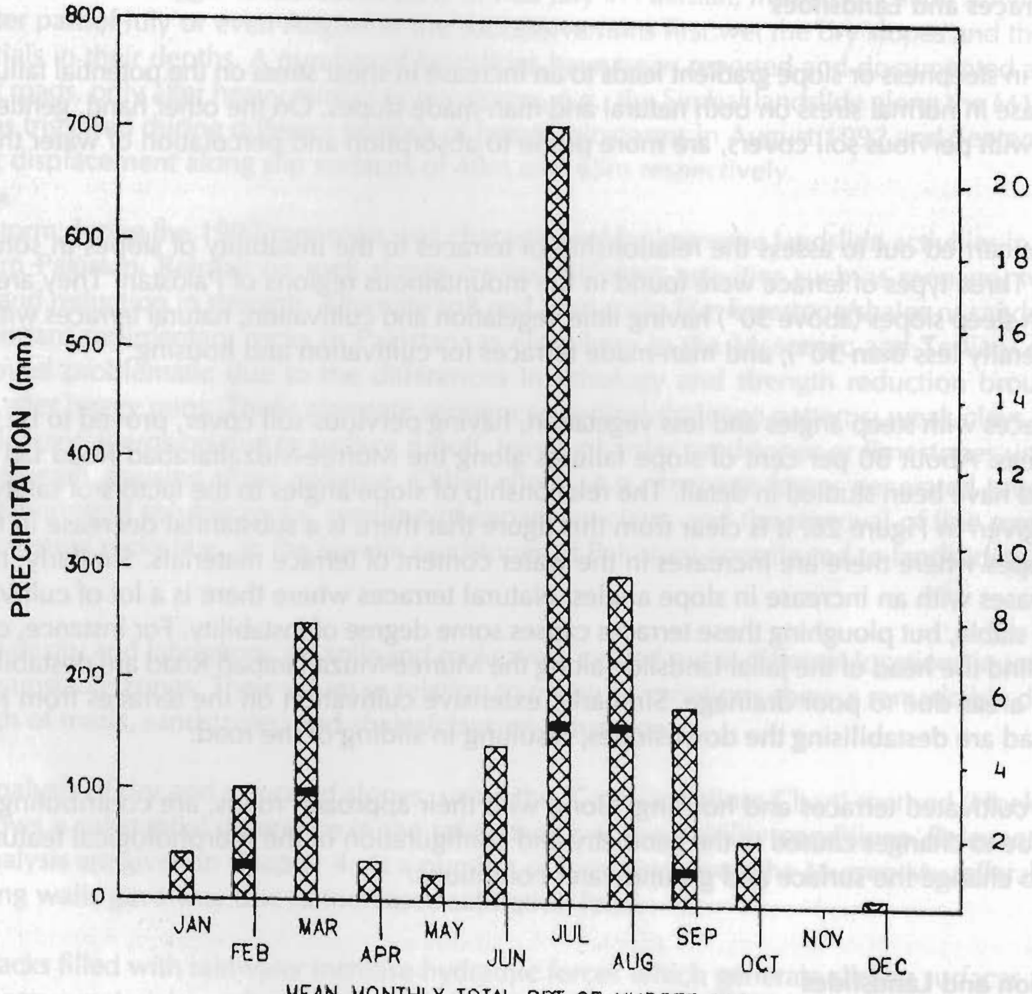


Figure 17: Slides Recorded on Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Murree 1989)

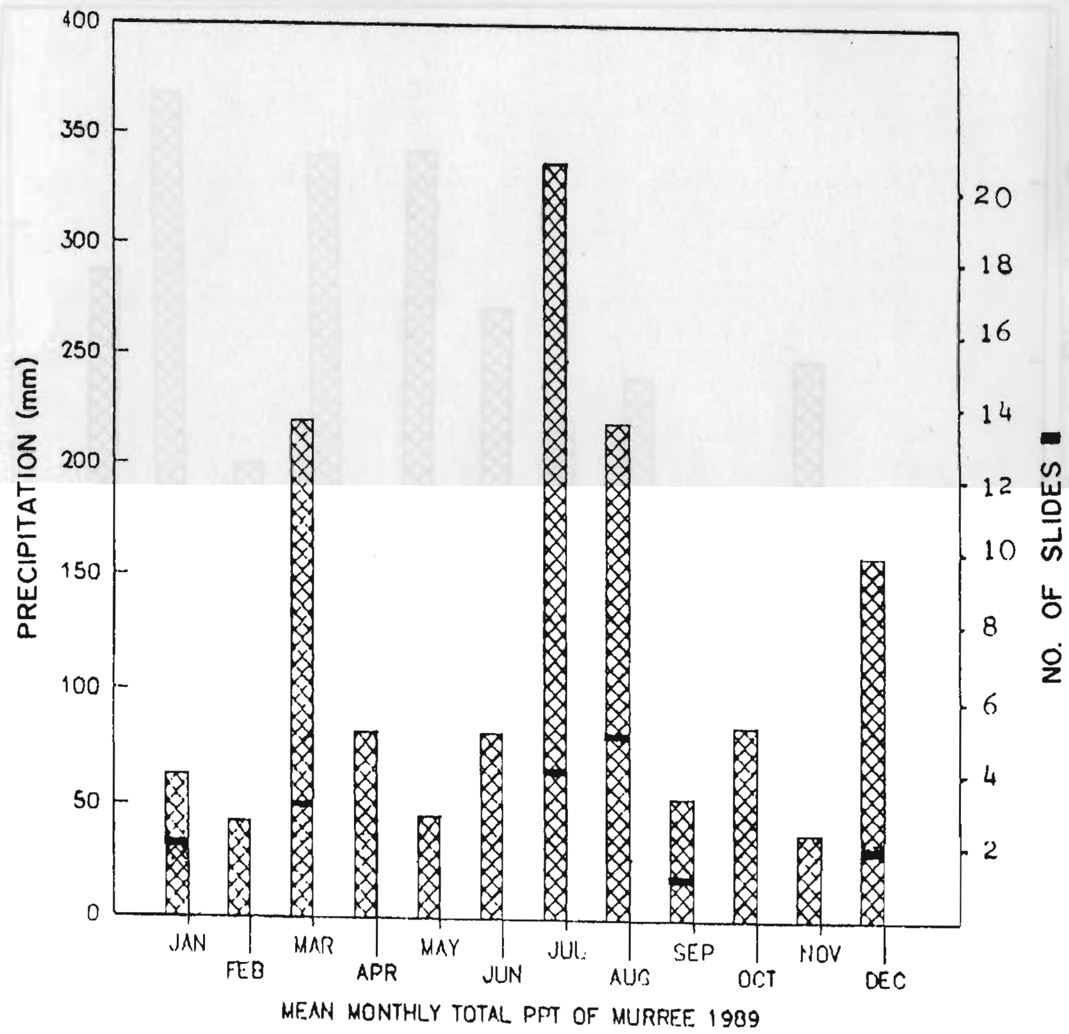


Figure 18: Slides Recorded on Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Murree 1990)

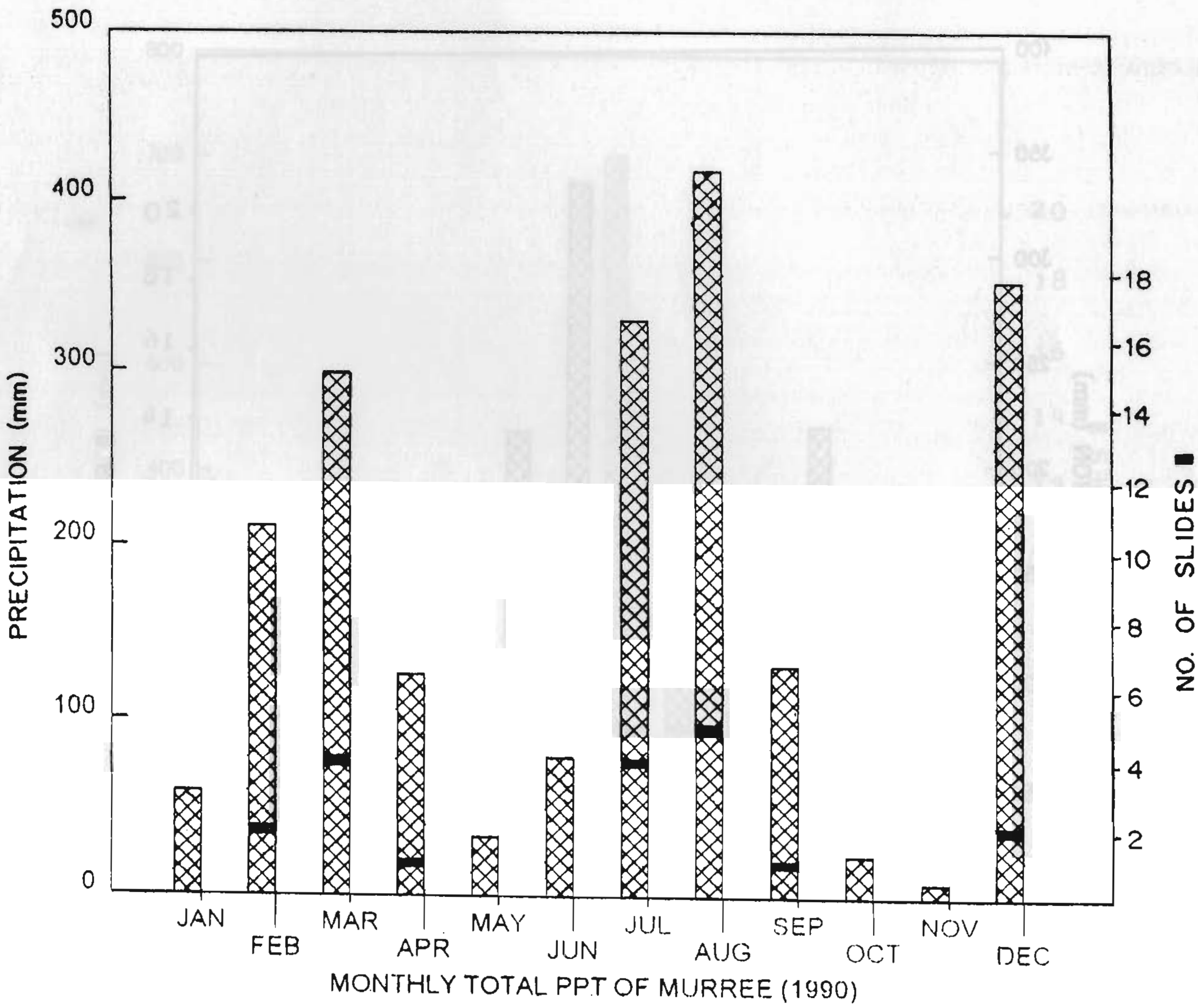


Figure 19: Slides Recorded on Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Murree 1991)

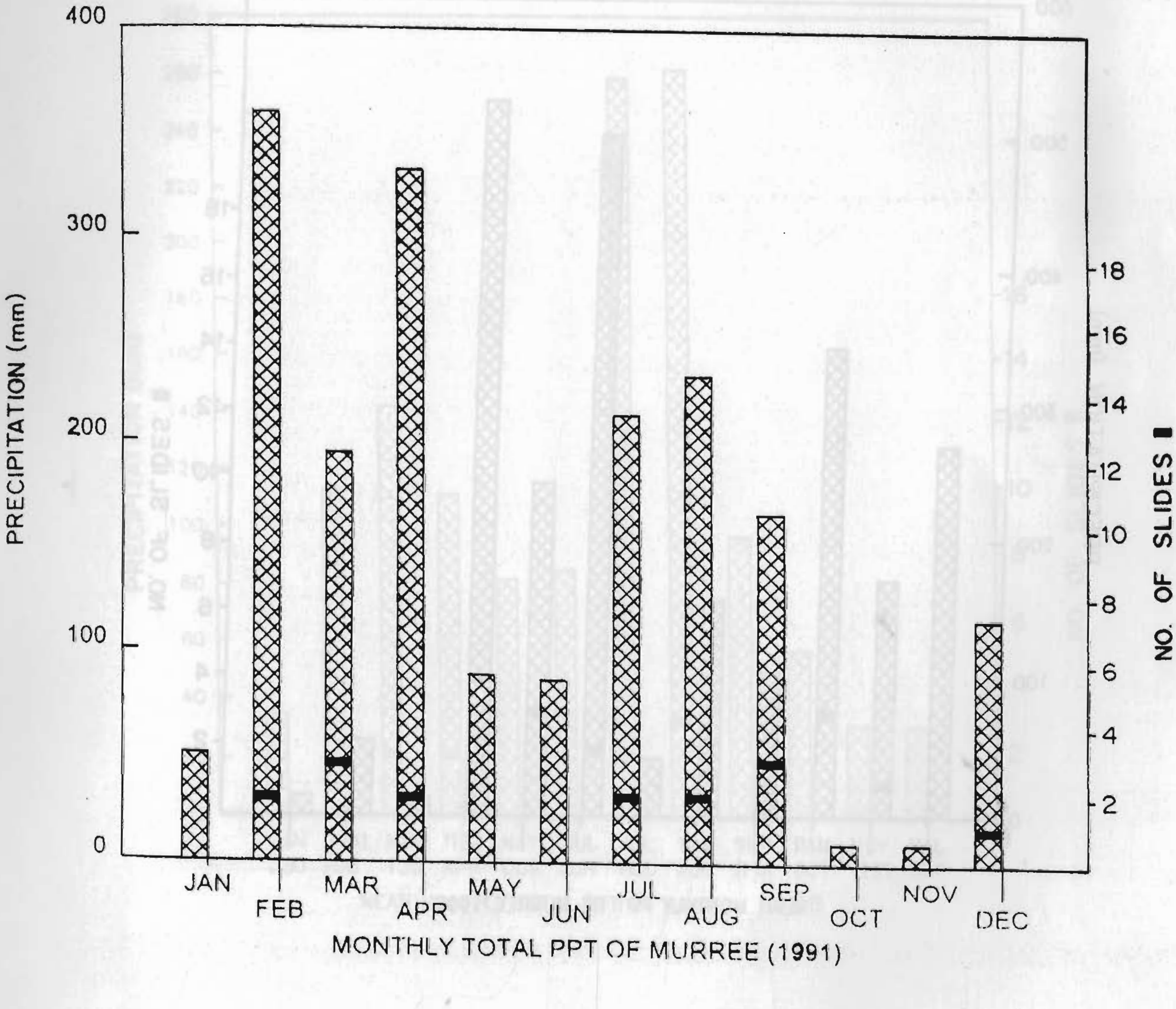


Figure 20: Slides Recorded on Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Murree 1992)

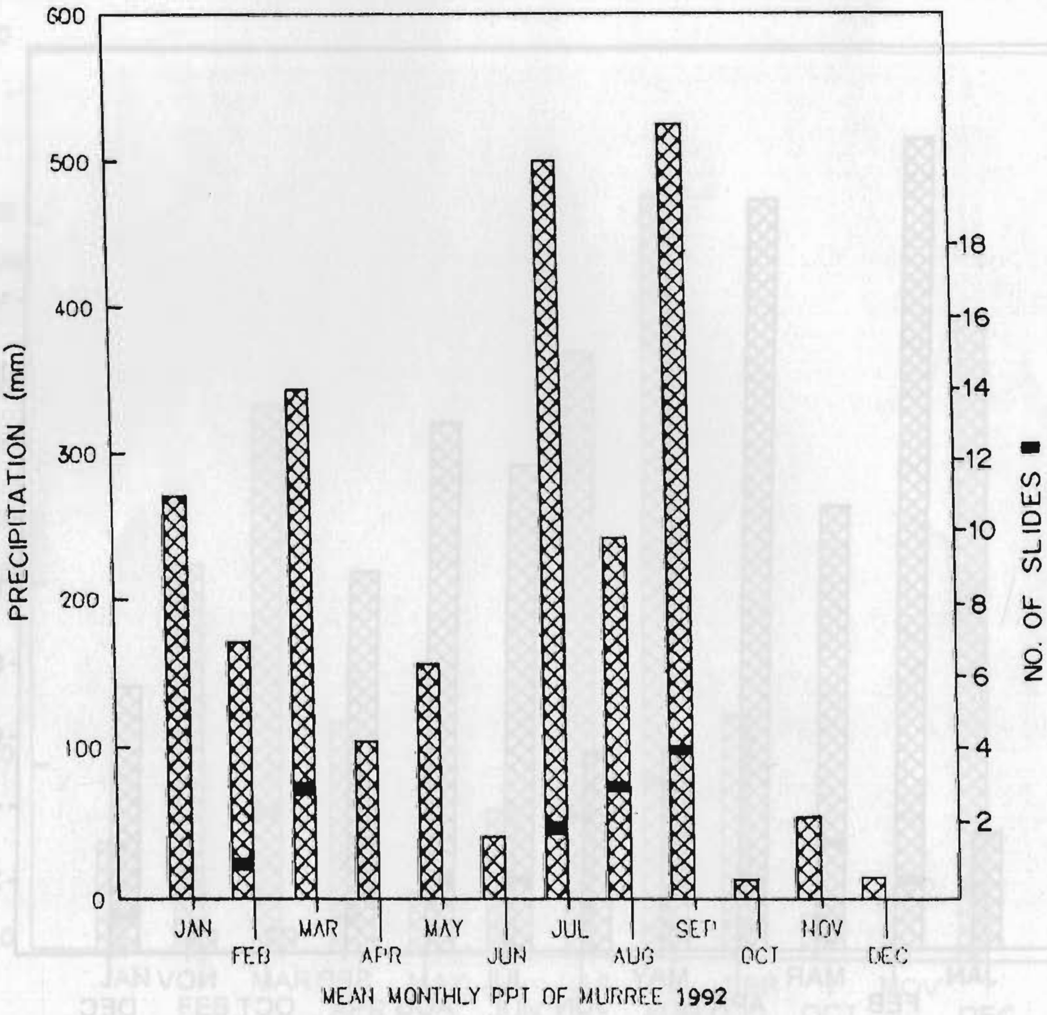


Figure 21: Slides Recorded on Murree-Abbottabad and Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Kakul 1988)

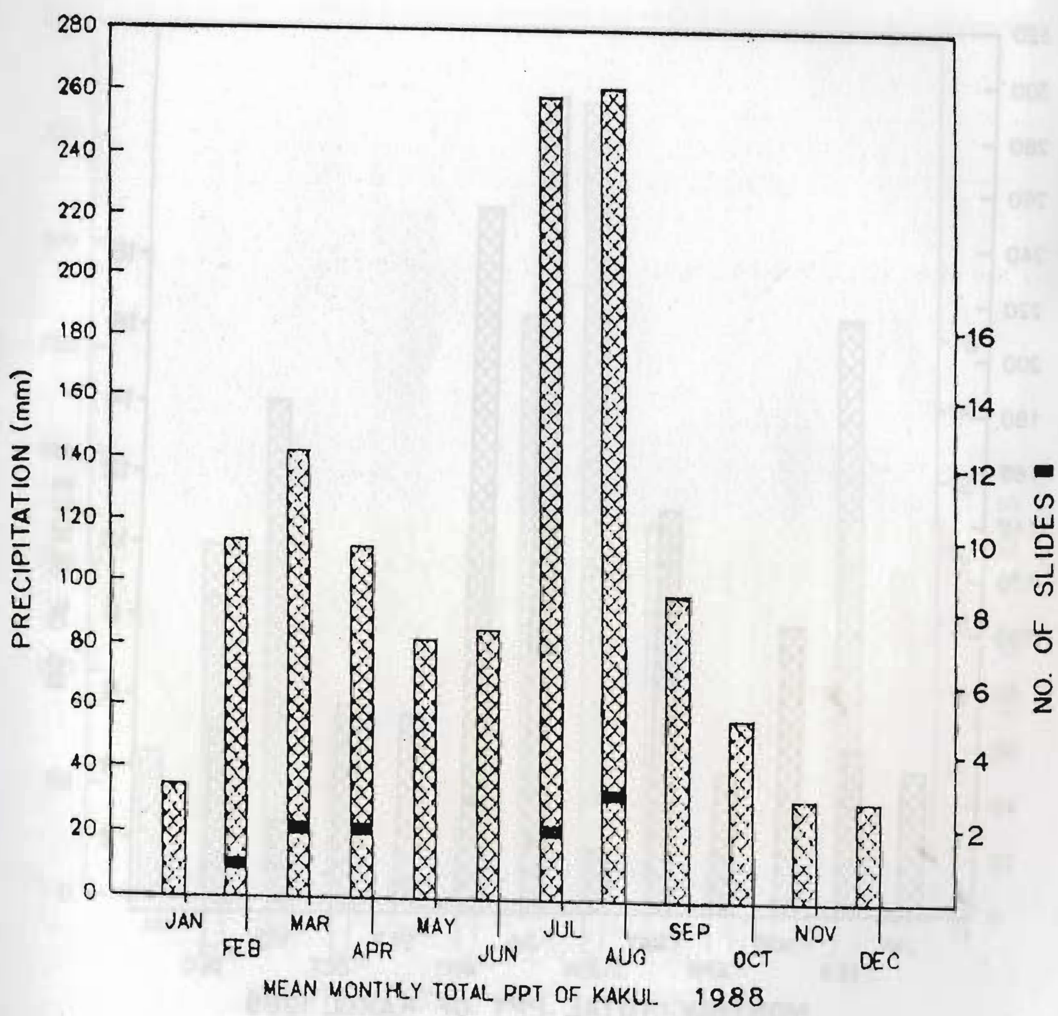


Figure 22: Slides Recorded on Murree-Abbottabad and Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Kakul 1989)

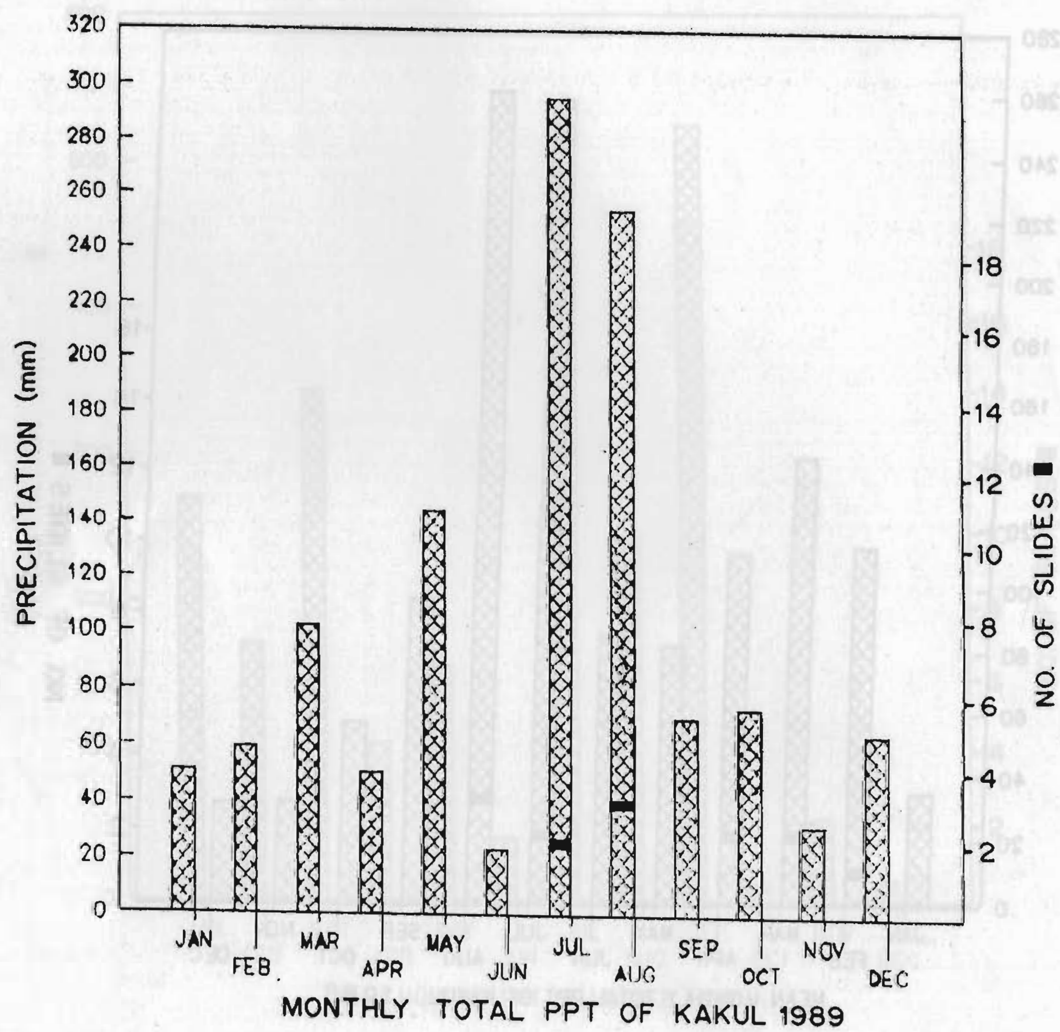


Figure 23: Slides Recorded on Murree-Abbottabad and Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Kakul 1990)

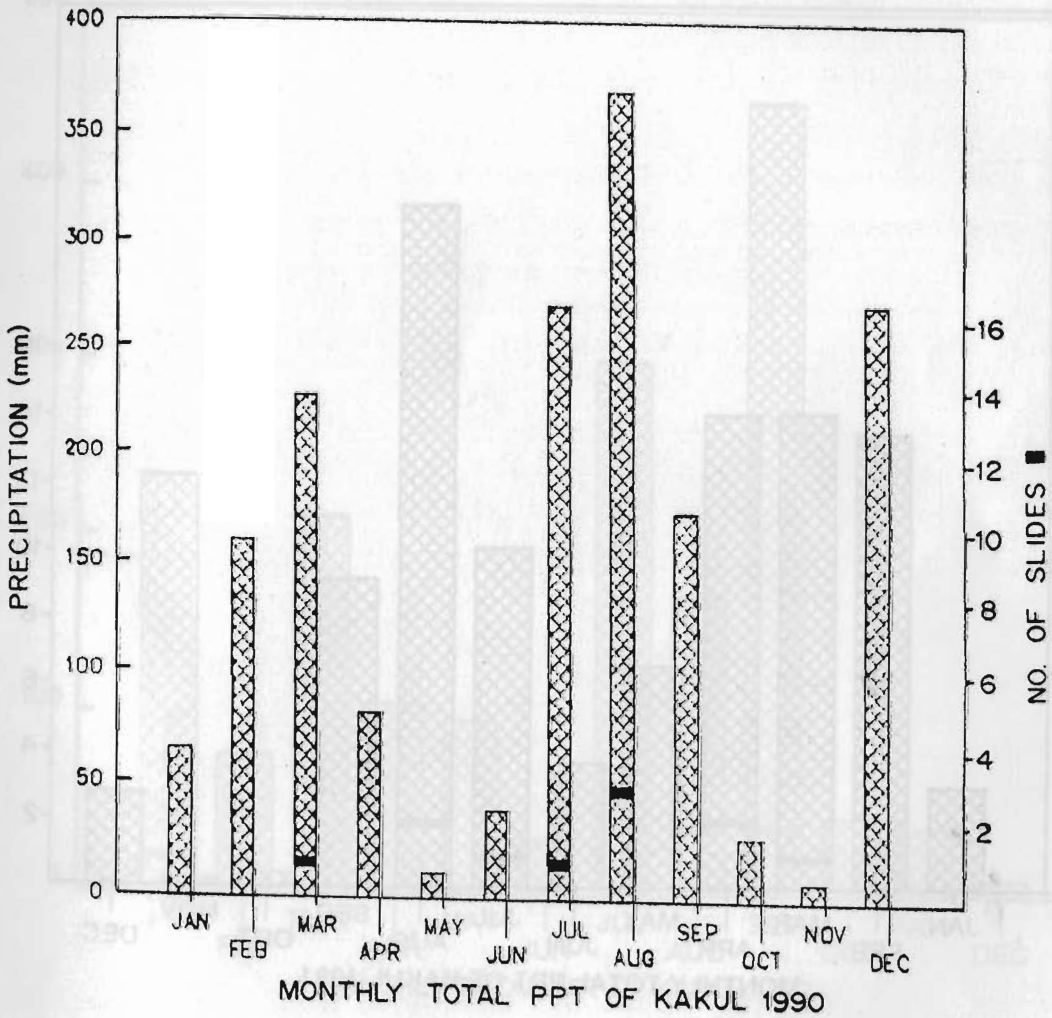


Figure 24: Slides Recorded on Murree-Abbottabad and Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Kakul 1991)

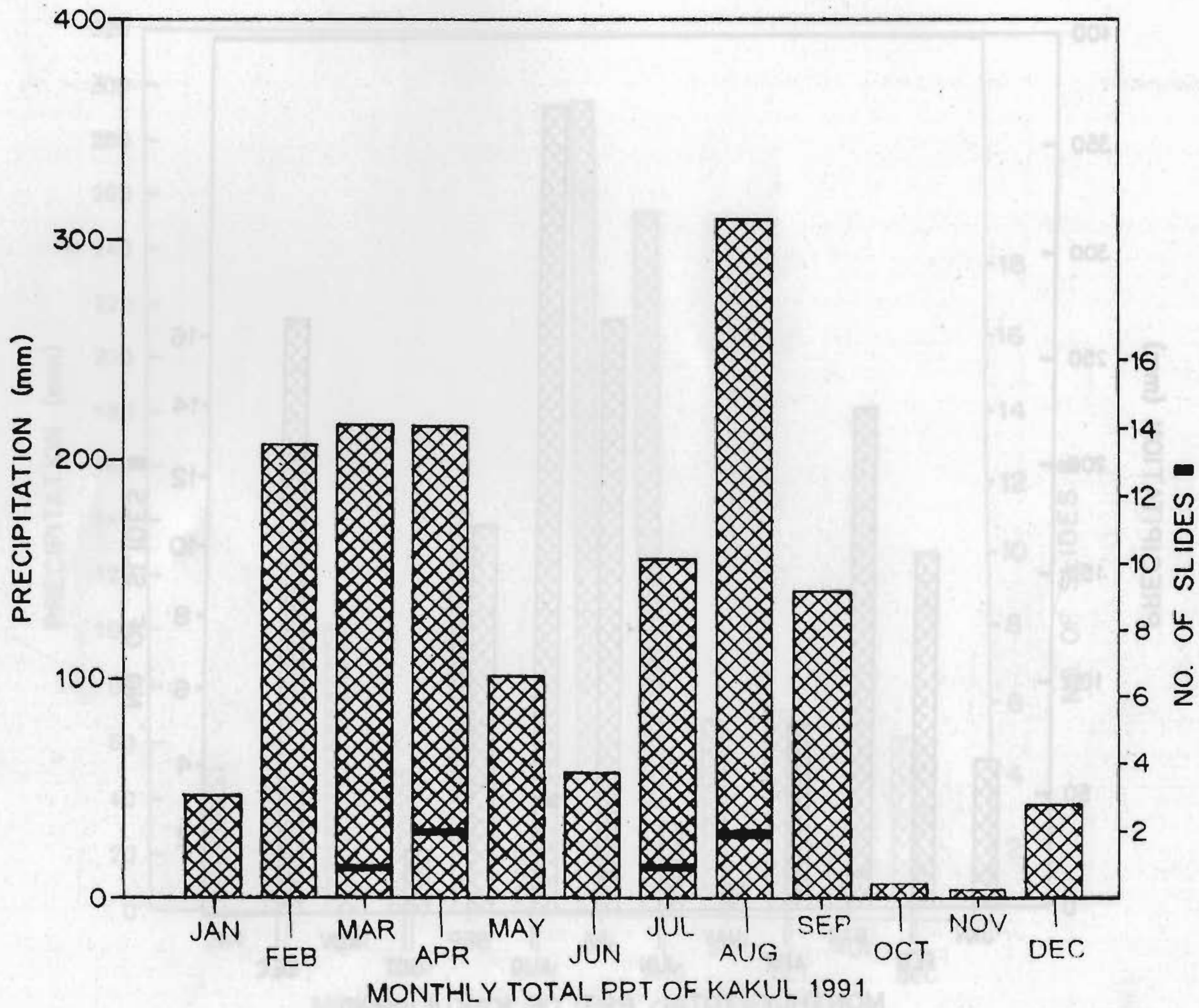


Figure 25: Slides Recorded on Murree-Abbottabad and Murree-Muzaffarabad Road — New Slides and Reactivated Slides (Kakul 1992)

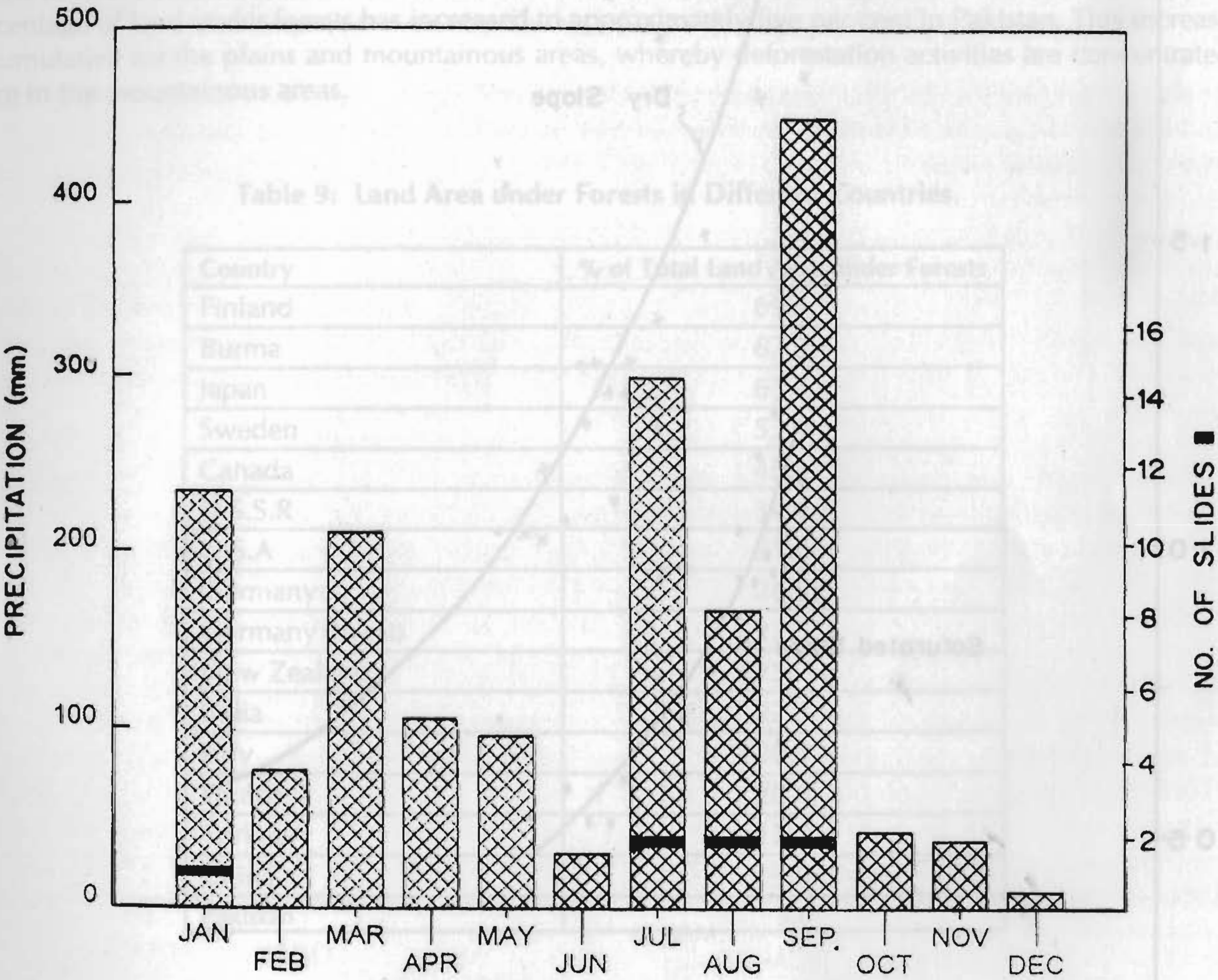
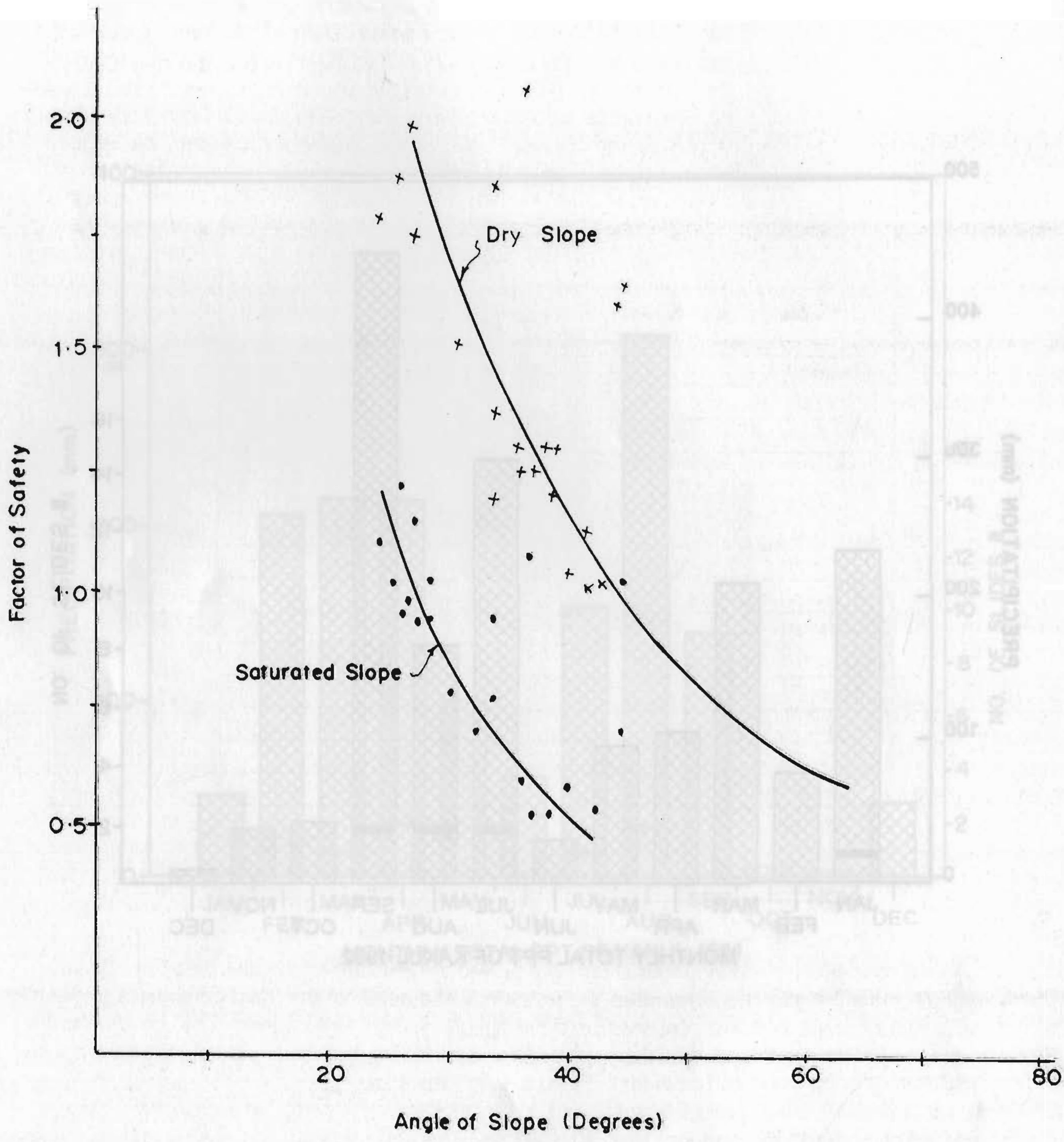


Figure 26: Relationship of Angle of Slope (Terraces) with Stability Number



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).