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.

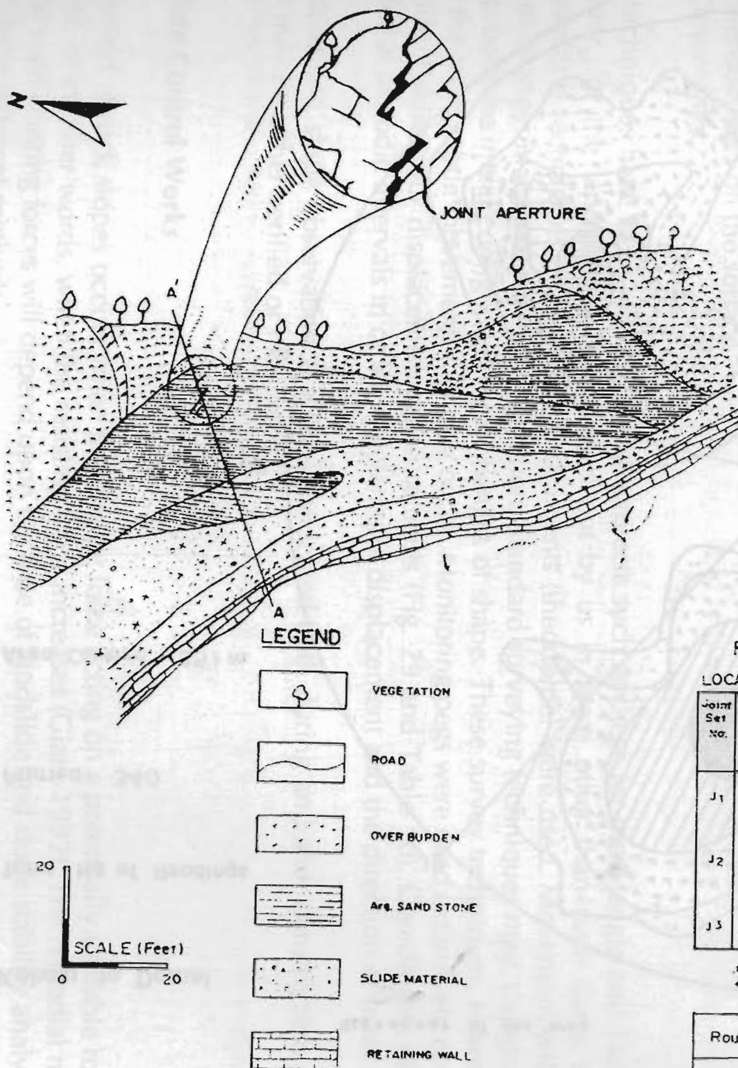
Landslide inventory maps of different areas were prepared to mark areas with different degrees of stability (Saeed & Malik 1990). Demarcation of areas as stable, unstable, and potentially unstable zones (Fig. 2) was carried out along different important routes on the Murree-Muzaffarabad Road and the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

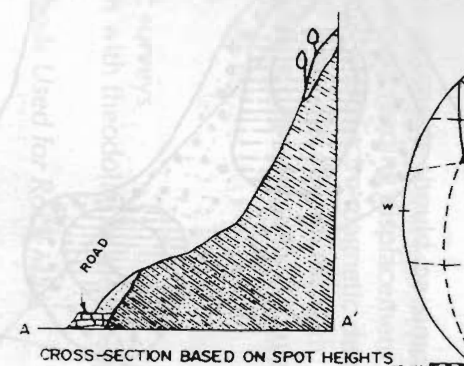
Detailed maps, sketches, and profiles of these unstable zones were prepared for qualitative and quantitative assessment, and these are presented in tabulated form (Fig. 27). In order to map a cross-section of landslides in these unstable zones, spot heights along appropriate lines were taken for evaluation 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.

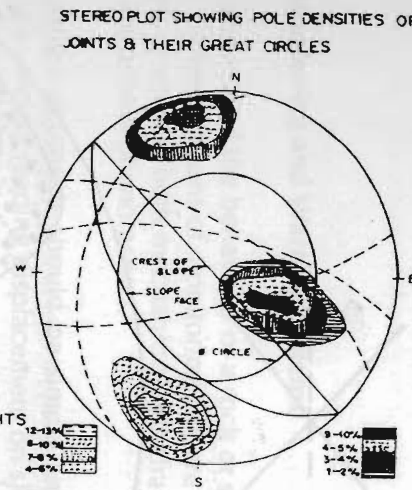
Keeping in mind these facts, the discontinuity survey was carried out (Table 3), and this included various parameters for rock mass characterisation such as joint sets and their orientation, spacing, aperture, persistence, roughness, joint wall strength, filling, and seepage.

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

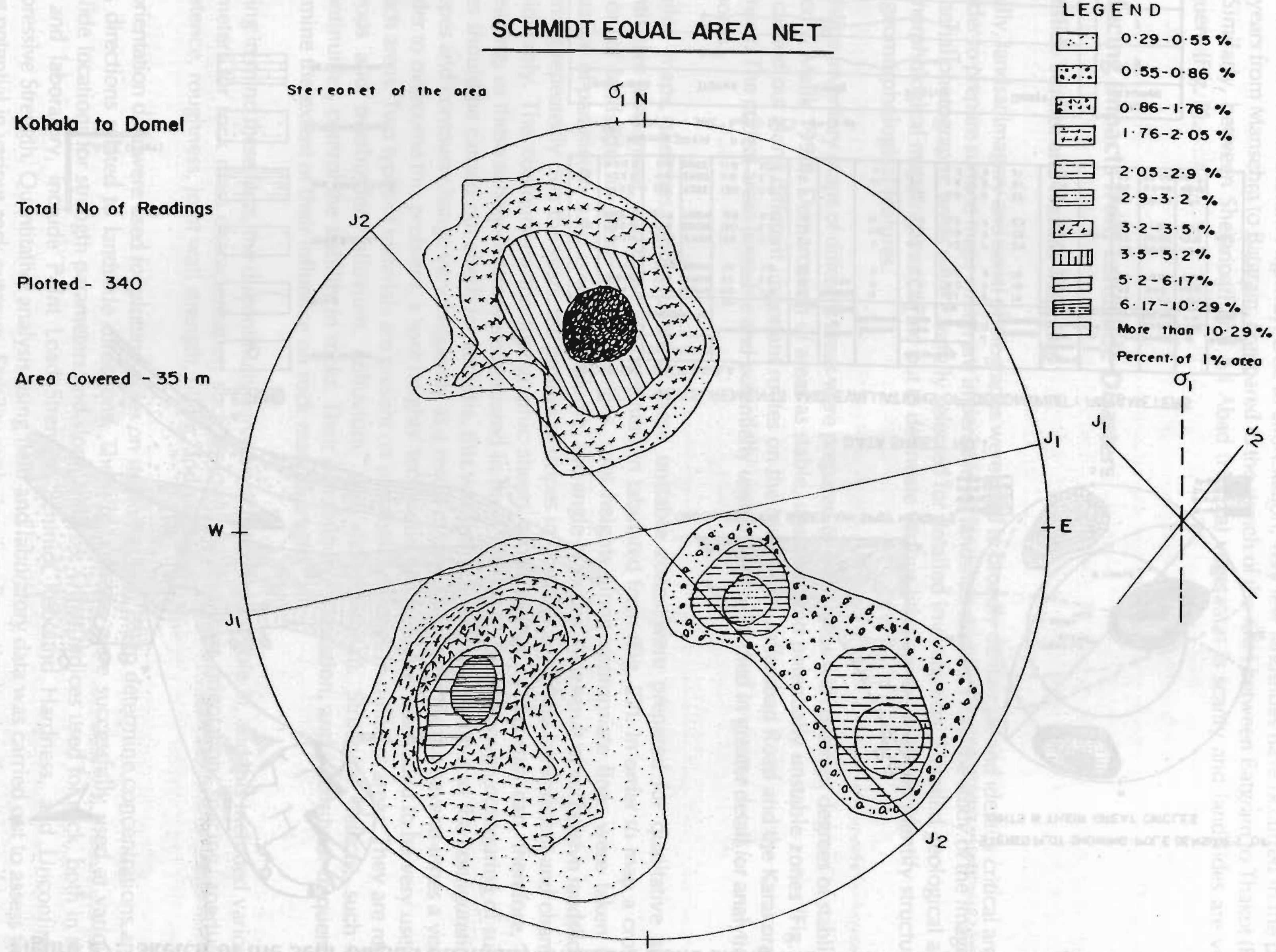
Joint Set No.	Strike	Orientation: Dip Direction	Orientation: Dip	Spacing (cm)	Persistence (m)	Aperture (mm)	Nature of infilling	Surface Roughness	Waviness: Wave Length (cm)	Waviness: Amplitude cm	JRC	Schmidt Hardness	Length of Column above Joint set (h) (m)	Unit Wt. (P) KN/m³	JCS MPa	Normal Stress KN/m²	Ø Peak **	Average Peak
J1	N74E	344	80NW	110	2·4	35	Swelling	IV	3·2	2.1	9	19	2.5		26	70·25	48·1	
	N80E	350	67NW	42	1.6	18	Clays	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	78.63	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 = $p \times h$

** = ϕ Peak = JRC* $\log_{10}(JCS / \sigma n) + \phi r$

Roughness Traces Using Profile Gauge	JRC assumed
	9
	7
	9

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

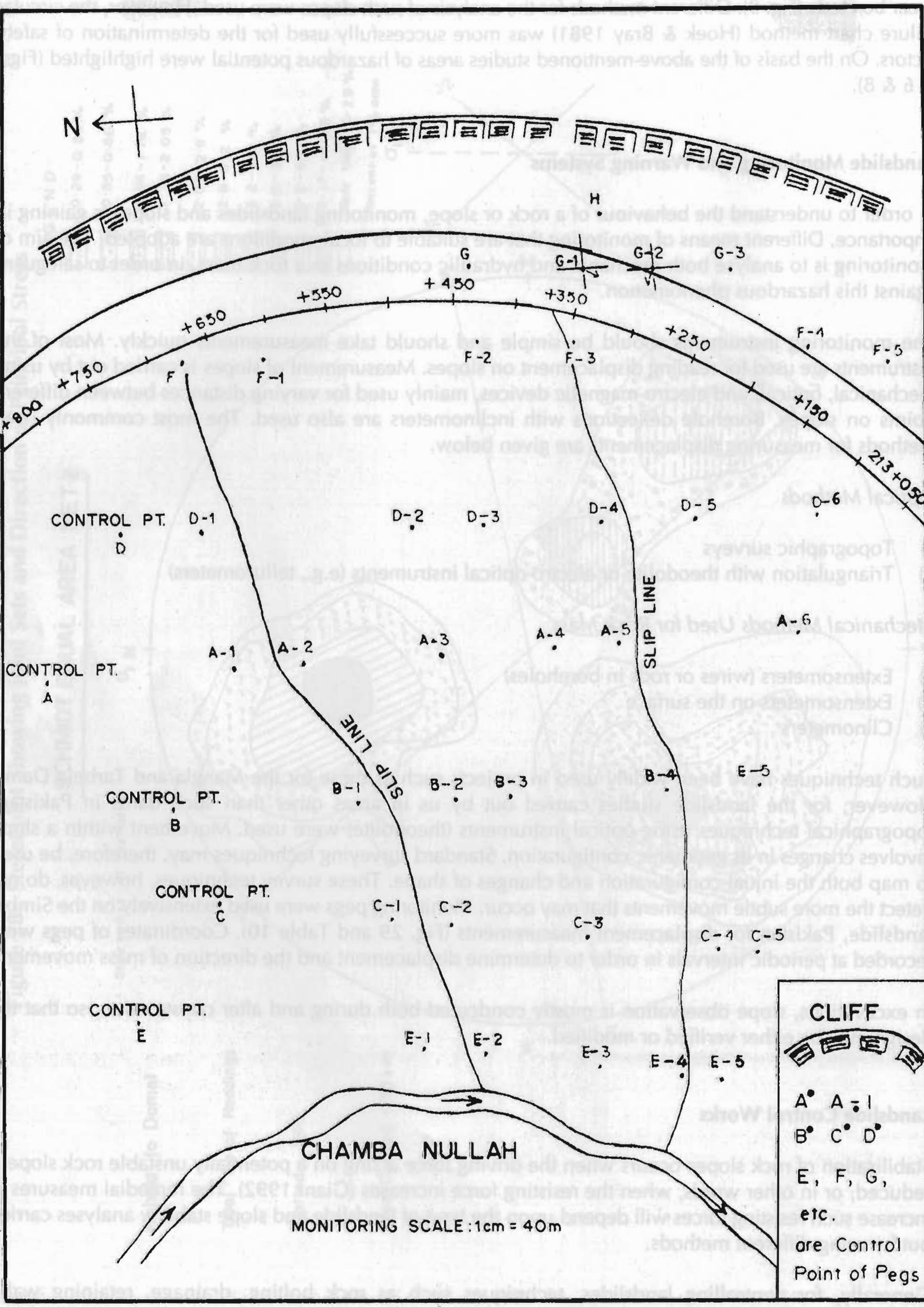


Table 10:Monitoring Data of Simbal Landslide on the M1 Motorway between Lahore and Islamabad - June 1994

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.

Technical Consulting Services

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.