RISK ENGINEERING IN THE HINDU KUSH-HIMALAYA

RISK ENGINEERING

IN THE

HINDU KUSH - HIMALAYA

Introduction To Geological Processes,
Impacts To and From Mountain Roads,
and
Mountain Risk Engineering Approaches

INTERNATIONAL CENTRE FOR INTEGRATED MOUNTAIN DEVELOPMENT

Cover Photograph by B. B. Deoja: Pokhara-Baglung Road, March 1991

Risk Engineering in The Hindu Kush-Himalaya

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FOREWORD

Building linear infrastructures; e.g., roads and canals in the mountainous areas of the *Hindu Kush-Himalaya*, where natural processes, such as geological processes, and climatic severity, such as heavy monsoon precipitation, have resulted in serious instability problems; is not simple.

Infrastructural projects need to be planned,designed,constructed, and maintained taking into due consideration the hazards and risks both to and from the environment.

This work on mountain risk engineering is an illustrative version of the two part Mountain Risk Engineering (MRE) Handbook published by ICIMOD in June 1991. Hopefully, this will help to bring more awareness to the decision-makers and practitioners of infrastructural agencies, in mountainous regions of the *Hindu Kush-Himalaya* and other developing mountainous countries, on the criticality of the problems and the need for adapting MRE approaches and techniques.

Dr. E. F. Tacke

Director, ICIMOD

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B. B. Deoja

MRE Project Coordinator

OBJECTIVES

This document is a complementary version of the Mountain Risk Engineering Handbook published by ICIMOD in June 1991, and it is hoped that it will:

- improve the awareness of the decision-makers of infrastructural agencies / departments, concerning mountainous areas in the developing countries, in order that they may be able to plan and implement the construction of mountain infrastructures; giving due consideration to inherent slope instabilities, human activities accelerating the natural instabilities of mountain slopes , and minimization of risks to and from the roads; through adoption of mountain awareness-specific technologies, and

- create the interest and awareness among academic and practising engineers and geologists concerned with the investigation ,design, and construction of mountain infrastructures , in order that they may adopt the detailed approaches suggested in the MRE Handbook.

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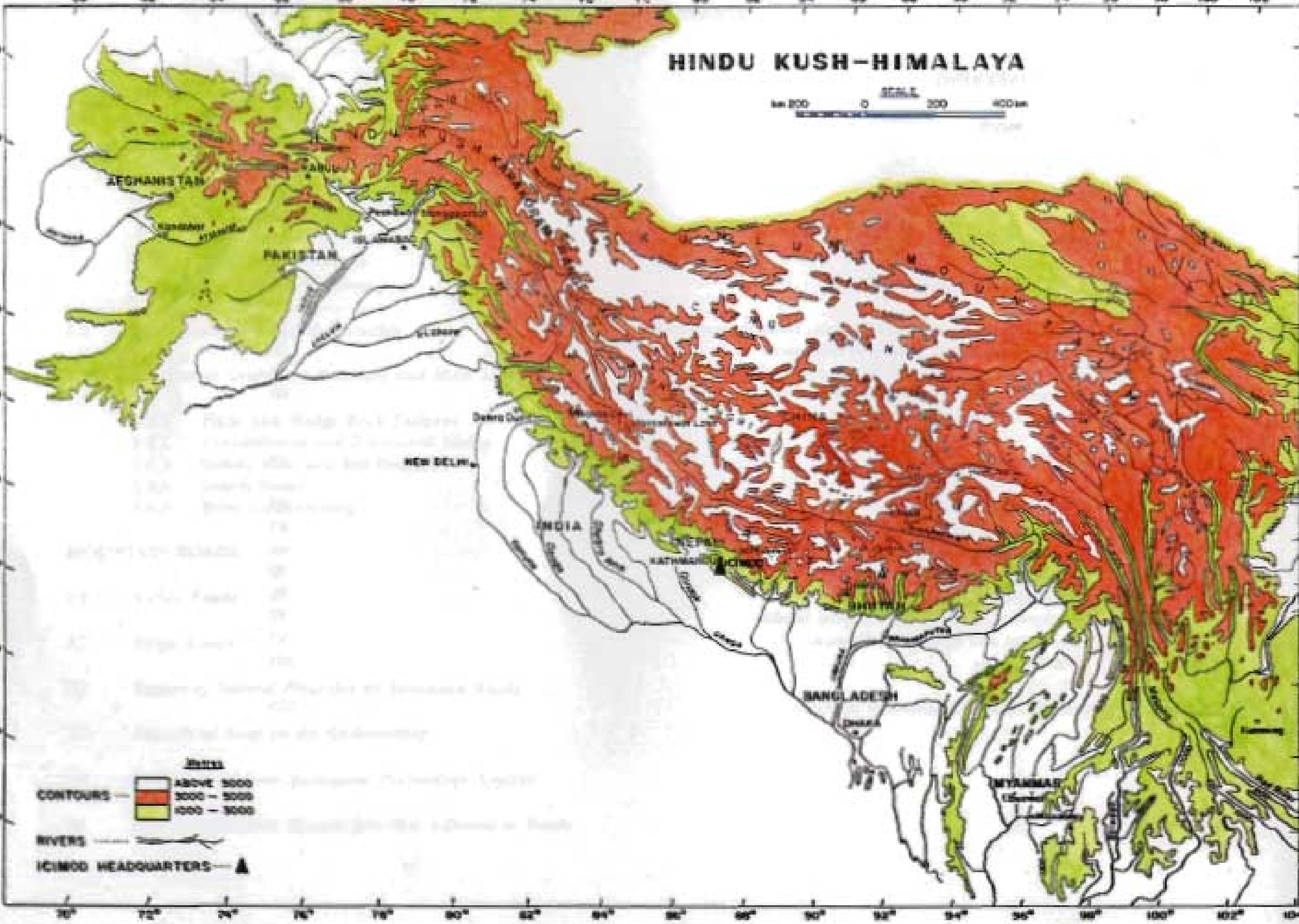
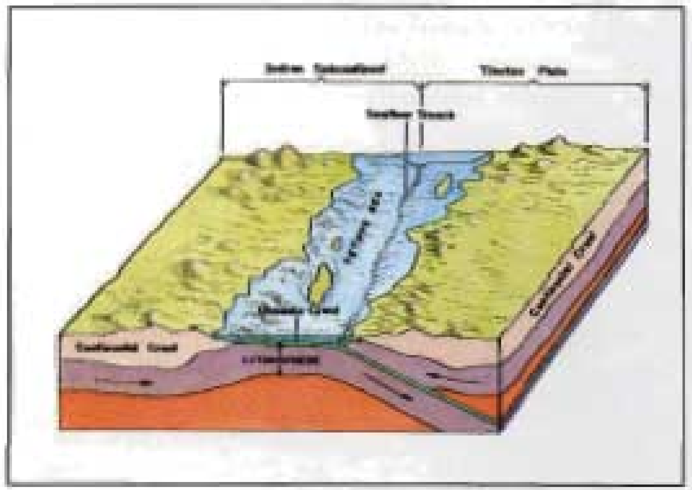
Map of the *Hindu Kush-Himalaya*



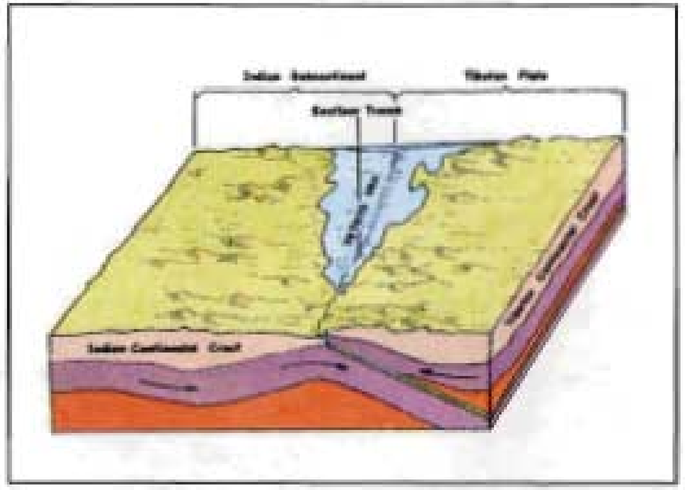
1. GEOLOGY

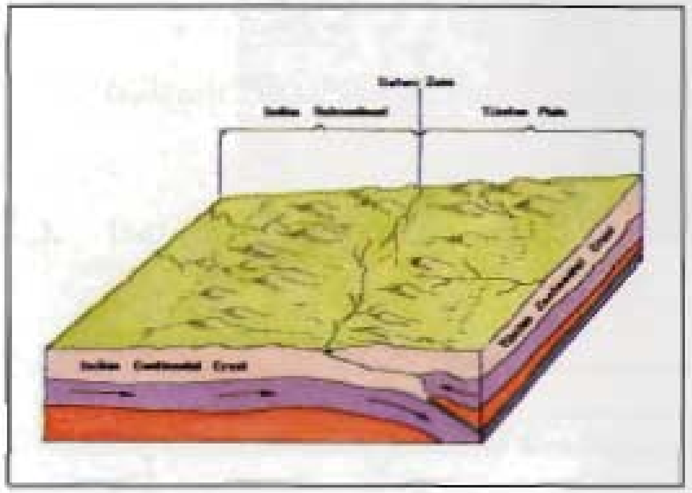
1.1 Origin of the Himalaya



Prior to forty million years ago, there was a sea (called the Tethys) between the Indian Subcontinent and the Tibetan Plate. The Indian Subcontinent was moving gradually towards the Tibetan Plate.

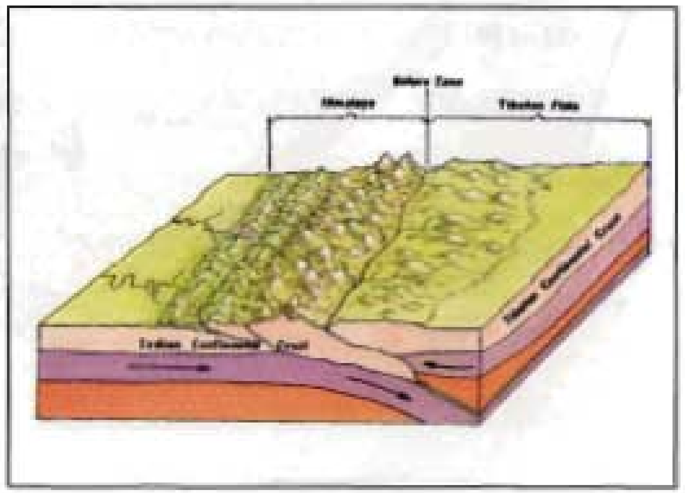
About 40 million years ago, the Indian Subcontinent came into contact with the Tibetan Plate and the Tethys Sea retreated gradually.

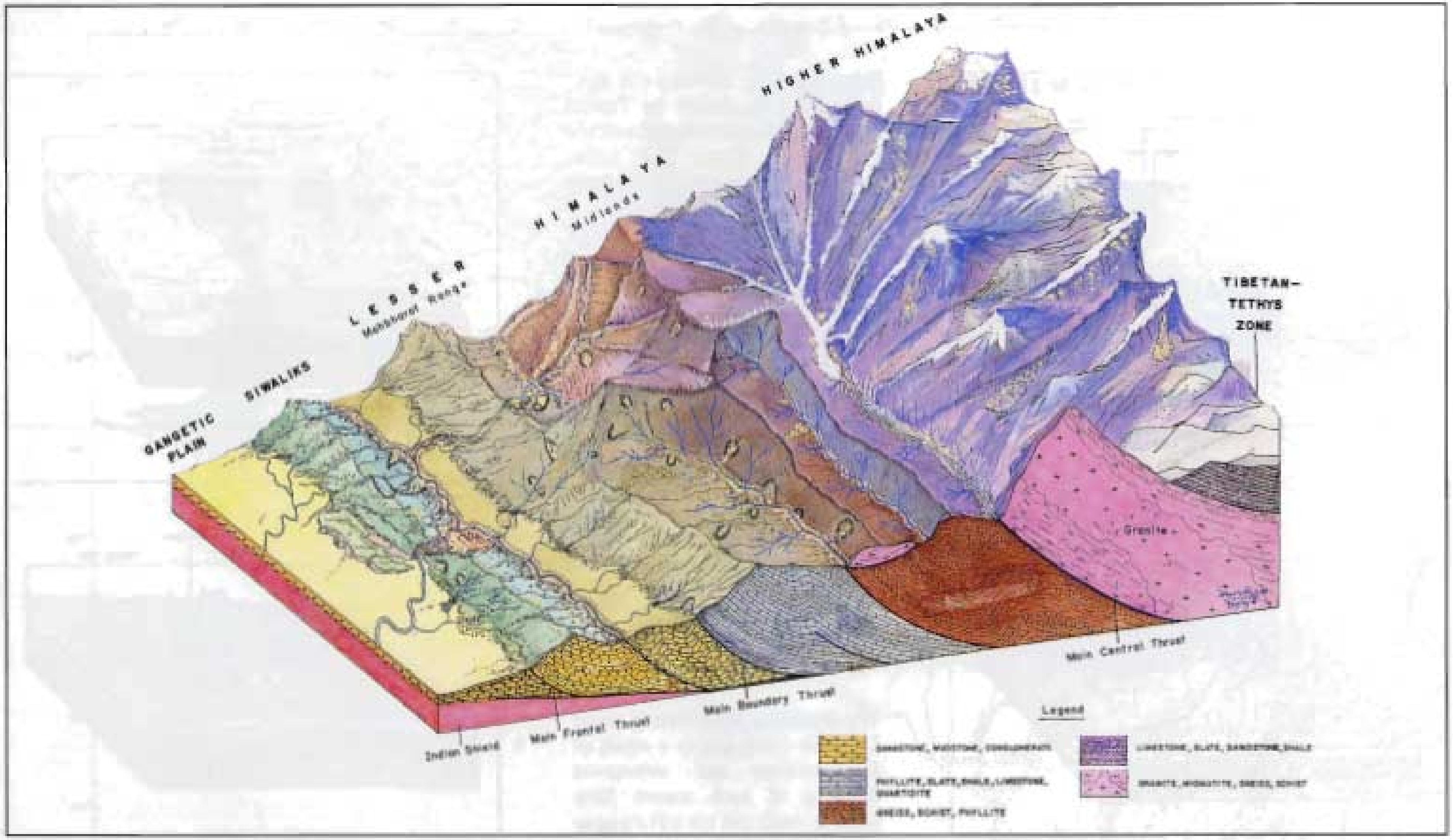




The Indian Continental Crust, being lighter than the Tibetan Oceanic Crust, could not sink into the mantle and remained beneath the Tibetan Continental Crust. Twenty million years ago, there was no Himalayan Chain nor was there a Tibetan Plateau.

The *Himalaya* were formed about 2 million years ago as a result of the collision and subsequent thrusting of rock masses from north to south and are still rising at a rate of 2-5 mm per year.





Block diagram of the *Himalaya*

1.2 Geological Subdivisions of the Himalaya

The process of collision of the Indian Subcontinent with the Tibetan Plate and the subsequent folding, faulting, and upheaval of rock masses led to the formation of the world's highest and one of its most active mountain ranges - the *Himalaya*. The Himalayan Range can be subdivided into the following zones from south to north, respectively:

1. The Gangetic Plain, formed on the Indian Shield as a result of the accumulation of sediments transported by rivers and streams from the Himalaya, is followed northwards by the Sub *Himalaya* or the Siwalik Foothills. The boundary between the Gangetic Plain and the Siwaliks is occasionally a fault called the Main Frontal thrust (MFT).

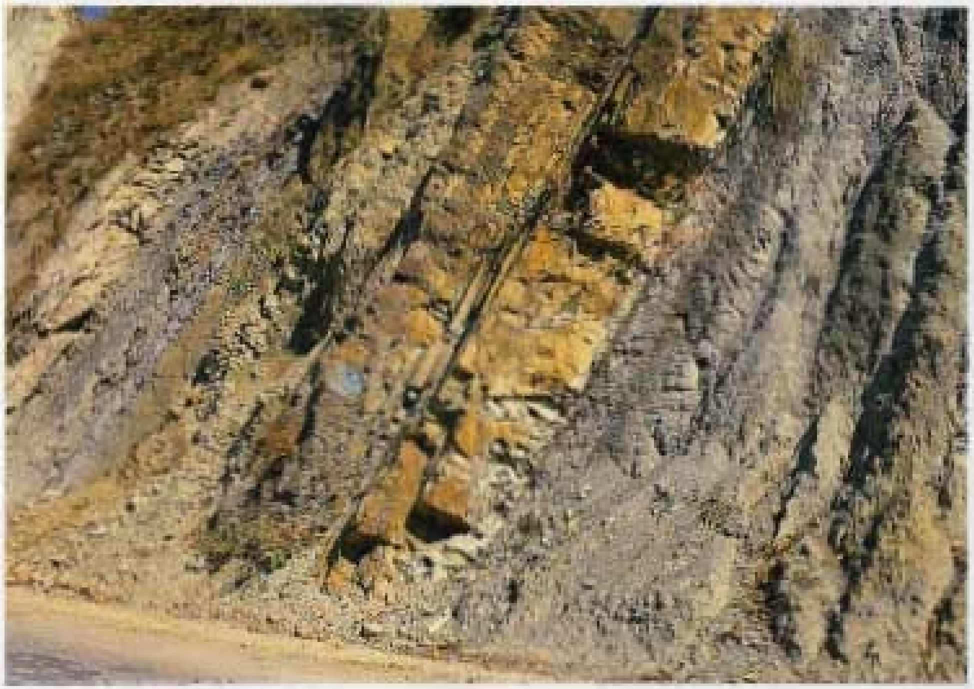
2. To the north of the Sub *Himalaya* lie the Lesser *Himalaya* which are separated from the former by the Main Boundary Thrust (MBT). The Lesser Himalaya can be further divided into the southern mountain belt, called the Mahabharat Range, and the inner zone of the Midlands.

3. The Lesser Himalaya are followed further northwards by the Higher *Himalaya*, and the boundary between the two zones is the Main Central Thrust (MCT).

4. The Higher *Himalaya* gradually pass into the sedimentary belt of the Tibetan - Tethys Zone.

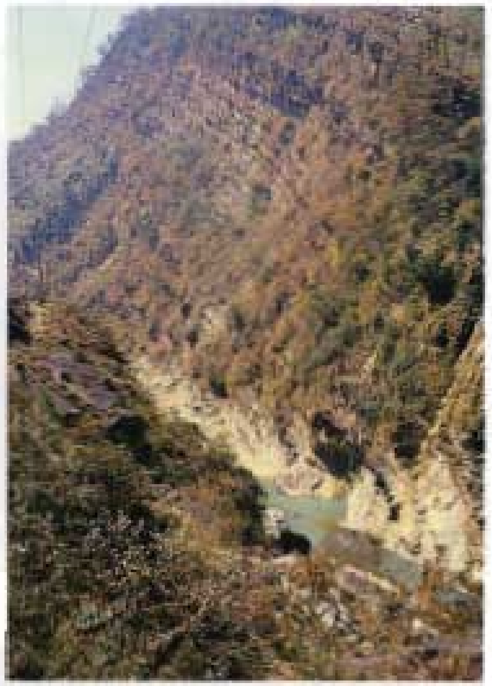
1.2.1 Sub *Himalaya* or Siwaliks

The Siwaliks are the youngest rocks in the *Himalaya*. They are from 40 to 2 million years old (Neogene Period) and are made up of mudstone, sandstone, and conglomerate. They are further classified into the Lower, Middle, and Upper Siwaliks.

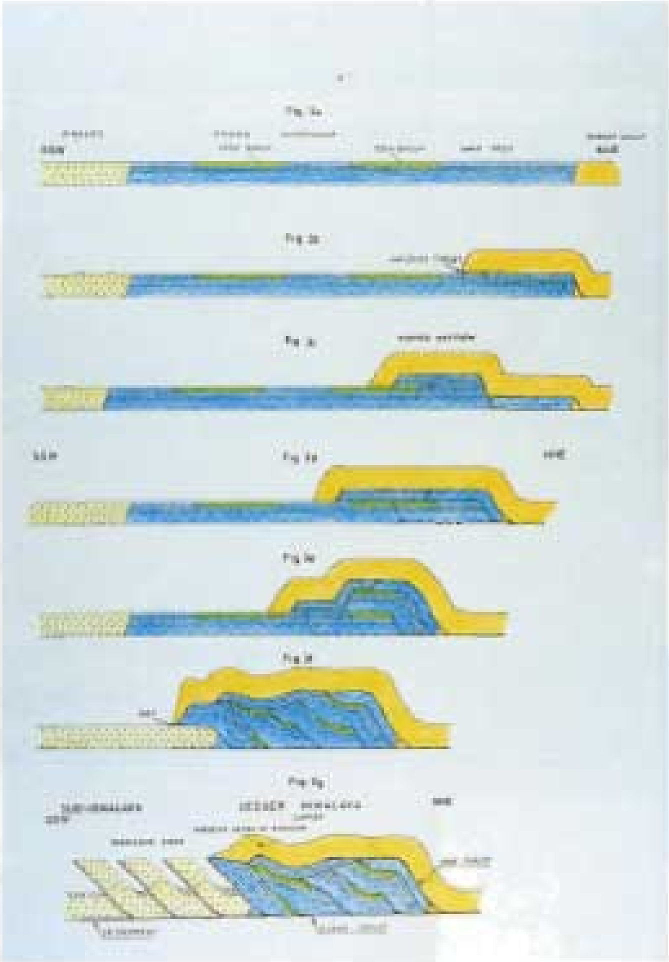


◂ The lower Siwaliks are represented by interbedded soft mudstone and sandstone. They are occasionally faulted and override the younger Middle and Upper Siwaliks.

The Middle Siwaliks, comprised of thick-bedded sandstone and mudstones, are generally soft, but may constitute steep river gorges such as the Tinau Khola of West Nepal.

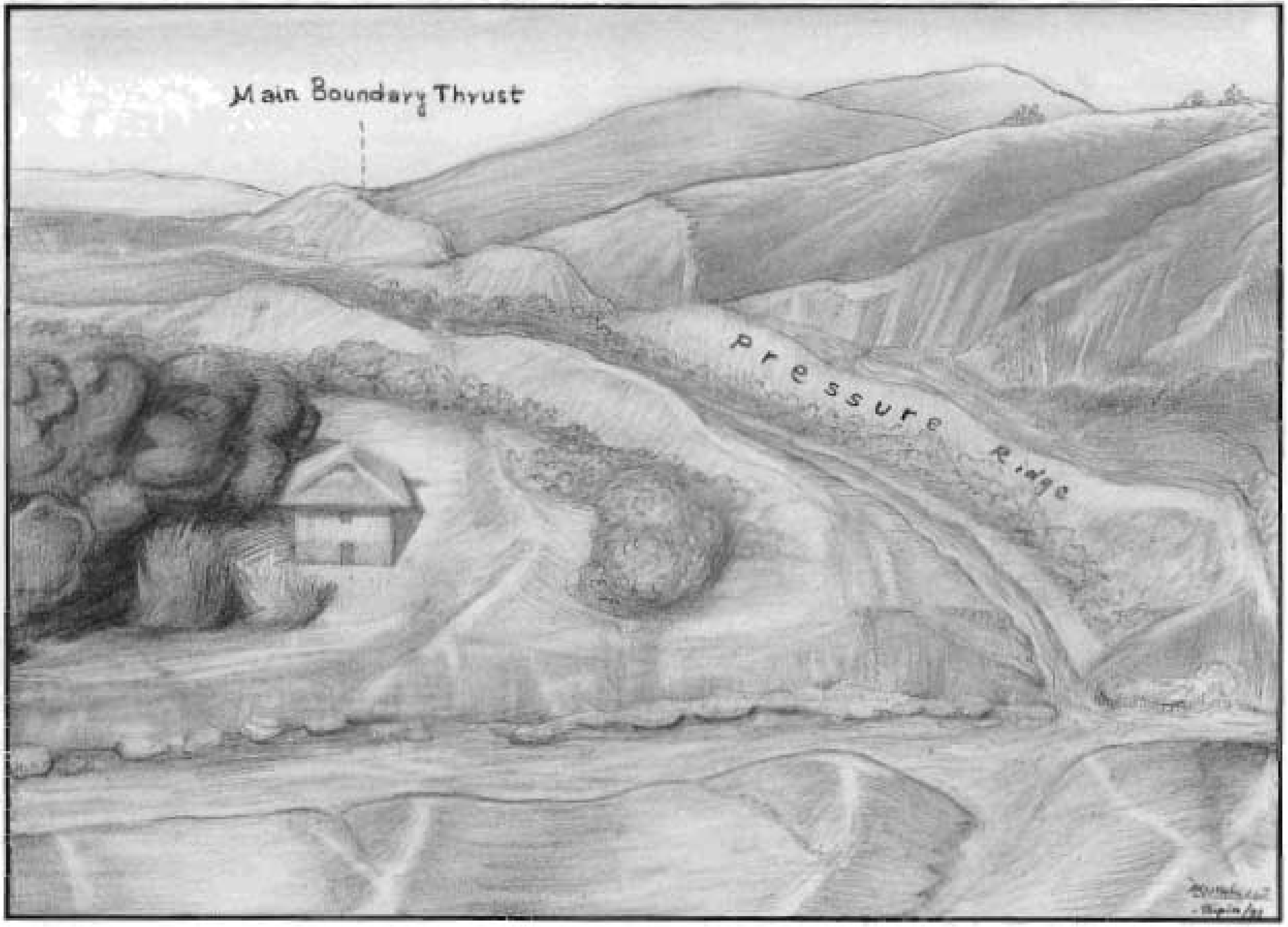


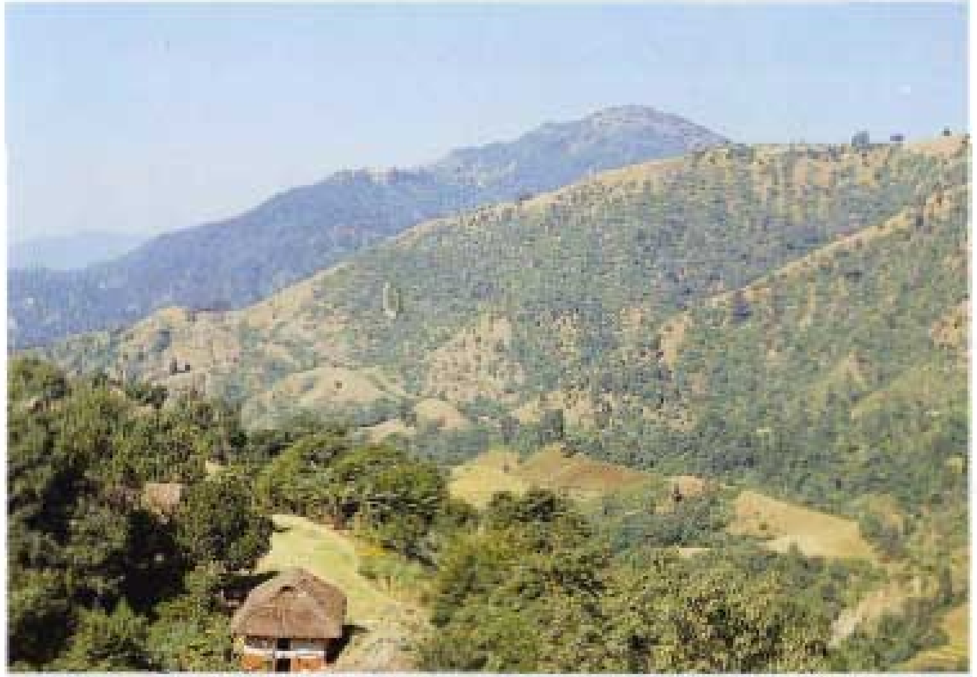
◂ Gravels and conglomerates of the Upper Siwaliks have also experienced tectonic movement, and, therefore, the beds are tilted. Most of the pebbles and boulders seen on the river bed are derived from Upper Siwalik conglomerate.



The Siwalik rocks are gently folded and often dislocated by steep faults which become gentler below the surface and join with each other. They are called imbricate faults. The process of imbricate faulting still continues, and therefore it is seismically the most active region of the *Himalaya*.

The Main Boundary Thrust as seen in the Dang Valley, West Nepal

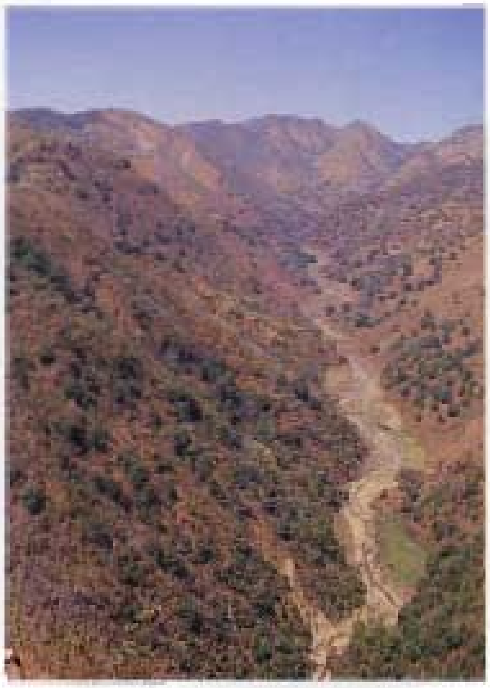




1.2.2 The Lesser *Himalaya*

◄ The Siwaliks are delimited from the north by the Main Boundary Thrust, one of the active faults of the *Himalaya*. Rocks are generally crushed near the fault and the effect dies out gradually away from the fault.

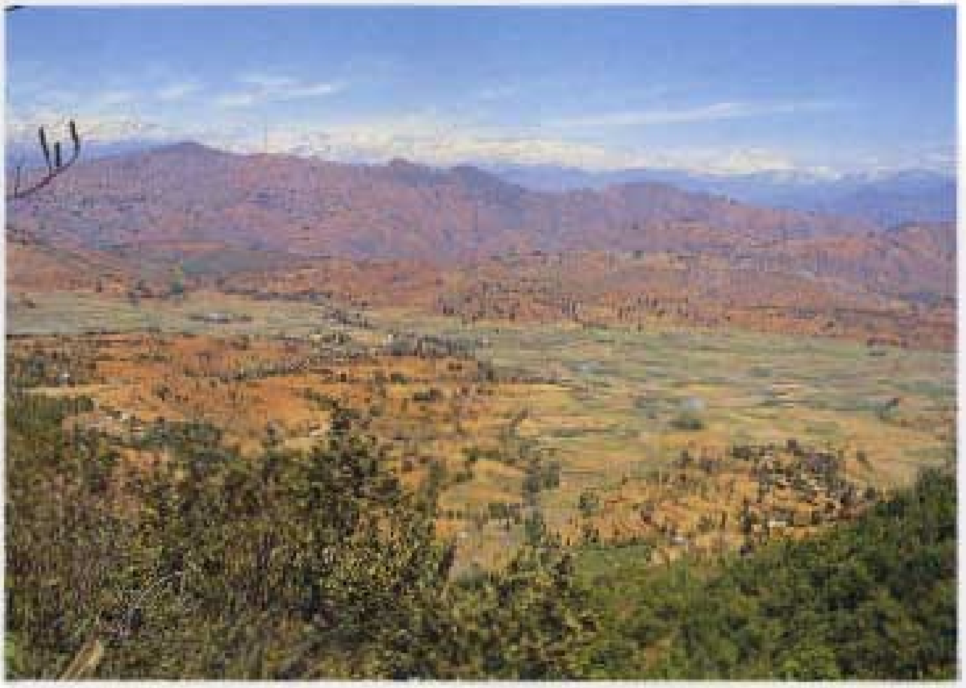
The Mahabharat Range, The outer Lesser *Himalaya* exhibits a young topography with active gullies, steep slopes, and many imbricate faults.



In Pakistan, to the north of the Siwaliks are found soft, red coloured mudstone and sandstone of the Murree Zone.

◂ The steep, dolomite gorge of the Tinau Khola, with vertical beds, is characteristic for the active Mahabharat Range. It depicts the faster rate of upheaval in comparison to the rate of erosion.

The inner Lesser *Himalaya*, called the Midlands, are characterized by the mature topography and wide development of red soil in slate, phyllite, and schist. ·



1.2.3 The Higher *Himalaya*

The Higher *Himalaya*, lying north of the Main Central Thrust,are represented by high-grade metamorphic rocks which gradually become less metamorphosed northwards and pass into the Tibetan-Tethys Zone.

The Tibetan-Tethys Zone is made up of sedimentary rocks ranging in age from Paleozoic to Neogene and are delimited from the north by the Incus-Tsangpo Suture Zone - the boundary of collision of the Indian Subcontinent and the Tibetan Plate.

1.3 Endogenous Geological Processes

Owing to the stresses related to the convergence of the Indian Subcontinent, th sedimentary and metamorphic rocks of the *Himalaya* have undergone intens deformation. The deformation is expressed in the form of folds, faults, joint foliation, and shearing.

◂ This is an example of concentrically folded limestone from the West Nepal Lesser *Himalaya*.

Some of the rock masses have moved hundreds of kilometres from north to south along such faults as the Main Central Thrust and the Main Boundary Thrust. In the process of movement, the rocks adjacent to the fault experienced crushing, shearing, and milling.

The example shown here is a thrust fault with a crushed zone below it which underwent subsequent sliding and gully erosion.

The rocks surrounded by two imbricate faults experienced intense deformation, and in the process of the movement of the thrusts, they were also disrupted.

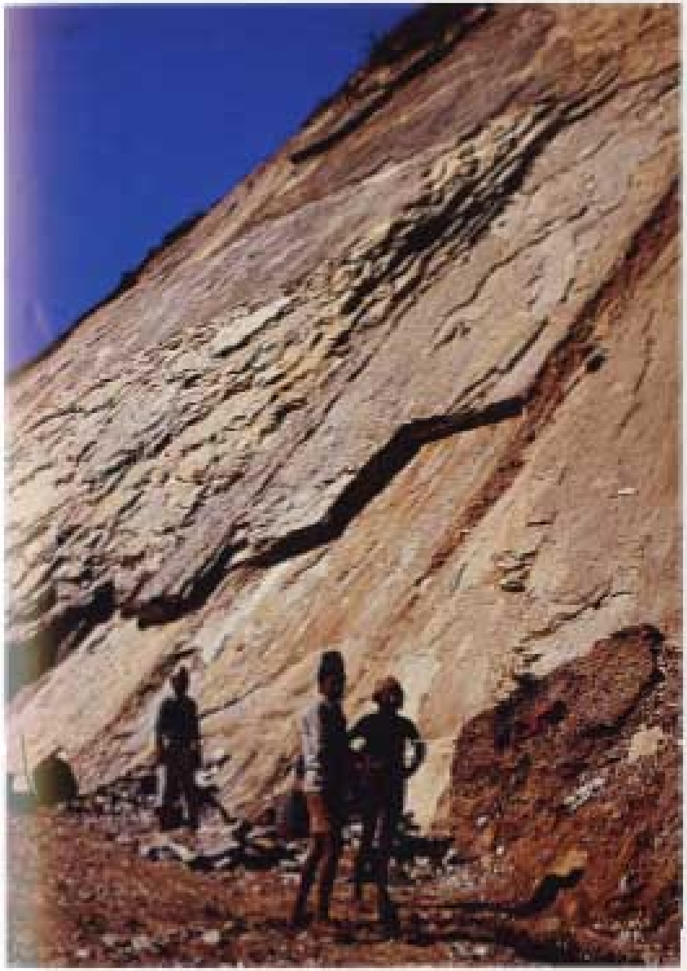
Thinly interbedded limestone and claystone have open joints and small-scale folds are developed in the process of shearing.

An example of very cleaved and folded slate with more than three sets of joints. The rock is unstable and talus slopes occasionally develop.

The high rate of uplift in the *Himalaya* does not permit lateral shifting of the rivers, and the rivers continually cut into the mountains forming steep gorges. The highly foliated and jointed phyllite and schist create talus cones which can slide into the river and create landslide-dams and subsequent outbursts which further steepen the river.

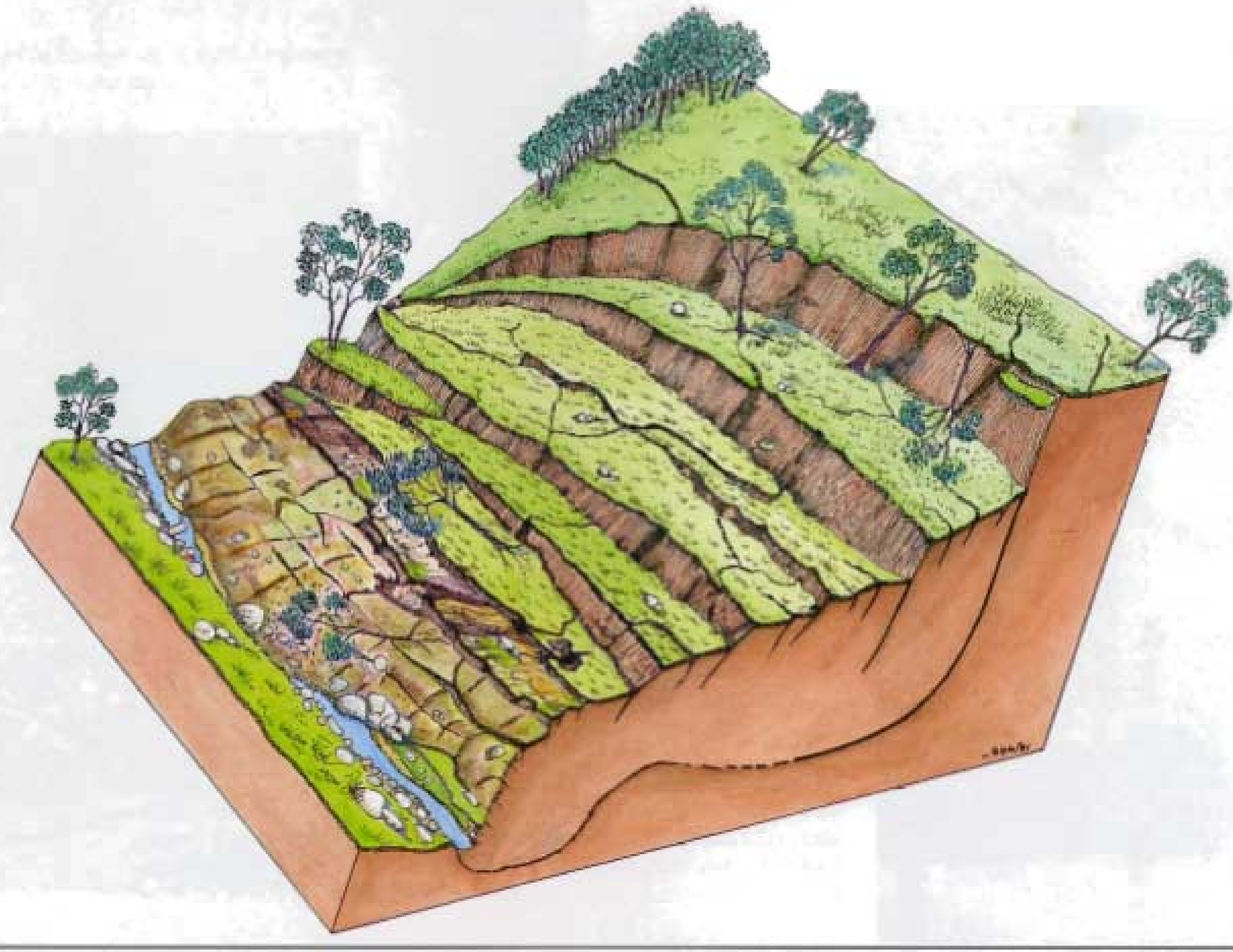
1.4.1 Plane and Wedge Rock Failures

Plane rock failure parallel to the foliation and joints

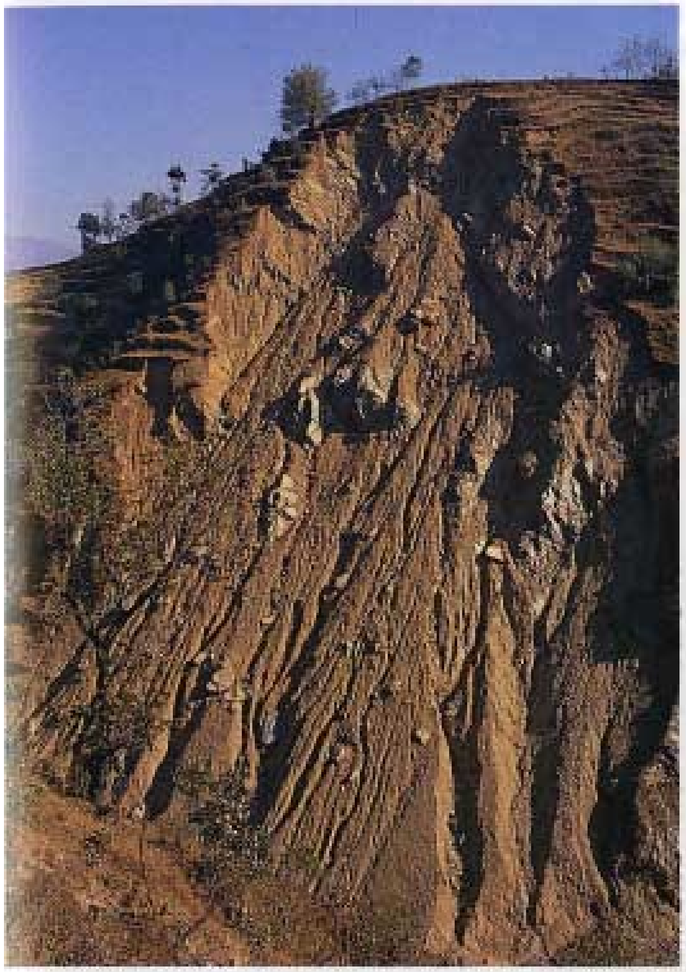


A wedge failure in the weathered rock. Three sets of joints are visible.

A sketch of a rotational slide damming a river



1.4.2 Translational and Rotational Slides

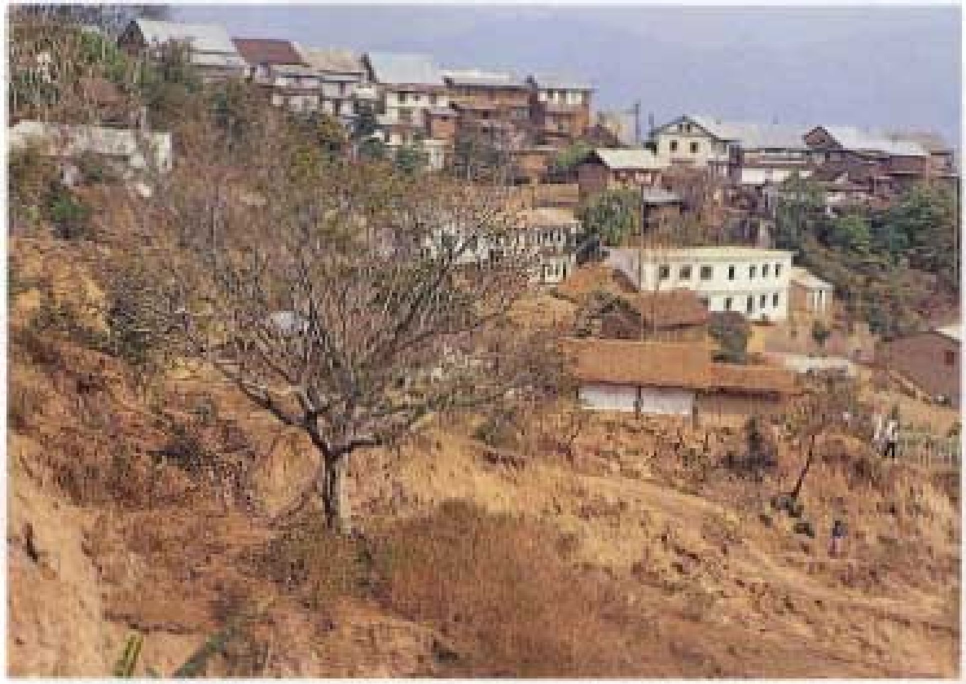


The deeply weathered phyllite underwent sliding and rill erosion.

The deeply weathered area disturbed by faulting in the Siwalik rocks underwent rotational sliding and completely destroyed the bridge near the temple in 1978.

Deep soil cover may be saturated with groundwater and, if stream undercutting takes place, a deep rotational slide may occur.

◄ An old landslide can be inferred from the scar on the upper surface of the green cultivated land.



Rotational slides are also common on slopes covered with residual soil developed from the weathering of rocks. Notice that the tree is taken downslope almost in an intact position, Dhankuta, East Nepal.

1.4.3 Debris Slide and Rill Erosion

◂ Debris slides are common in coarse-grained soil made up of debris from glaciers (i.e. glacier till), or from colluvium resulting from the disintegration of rocks *in situ*, or from soil deposited from past debris flows. Notice the angular fragments.

Rill erosion is common on bare slopes composed of soft rock, soil, or weathered rock. The rill erosion can trigger larger slides.
▾

1.4.4 Debris Flows

◄ The night of the 30th June, 1987, witnessed a cloudburst in the upper catchment of the Sunkosi River, East Nepal. It triggered a huge debris flow which dammed the Bhote Kosi (to the right) and damaged roads and other infrastructures downstream.

A debris flow in China.

A closer view of a small debris fan. The material was brought from the severely fractured slate upstream.

An effect of debris flow triggered by a cloud burst over the Charnawati stream catchment area, East Nepal. Notice the excessive soil thickness (more than 50 m).

The Kalimati Gully, a tributary to the Charnawati Stream, also experienced very high concentration of storm runoff which resulted in deep gullying. More than 17 houses were destroyed overnight.

1.4.5 River Undercutting

◂ Occasionally, landslides are caused by river undercutting in rocks (left) ▸ and in soil (right). Notice that these slides are difficult to stabilize unless expensive mitigatory measures are undertaken.

1.4.7 Badland Formation

Excessive deforestation may lead to badland formation, rill erosion, and gullies and, hence, the environmental degradation.

Idealized cross-section of the *Himalaya* showing valley road and ridge road

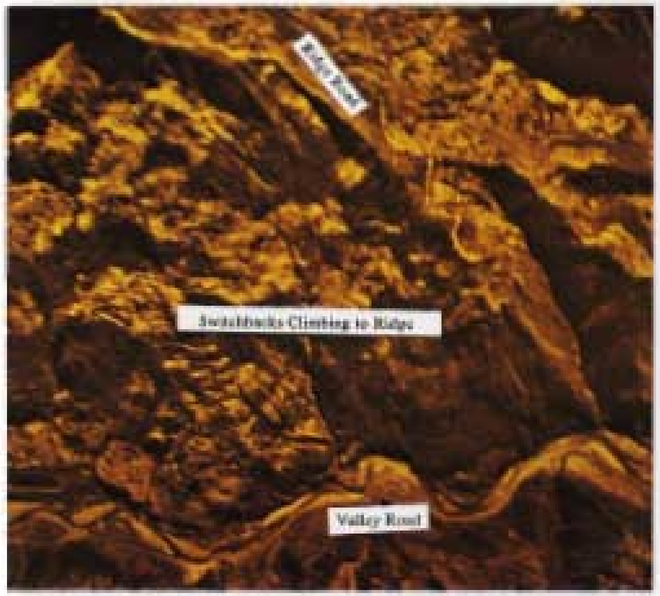
2. MOUNTAIN ROADS

A typical mountain road traverses valleys, mountain passes, and mountain ridges.

Valley road or river road are terms used to describe a mountain road which primarily follows a bank of a river.

A ridge road is one which primarily follows the ridges of the mountains.

Aerial photograph of a mountain road, East Nepal



▲
Ridge Road, an overview

Valley road, an overview
▼

Double lane, paved road

Single lane, paved road

Earthen road (dirt road)

Outsloped roads avoid concentrated runoffs.

Severe undercutting problems exist in valley roads crossing young streams.

2.1 Valley Roads

The number and size of culverts, and the size of side drains, are large since the valley roads are at the bottom of watershed.

▼

A large culvert (right) and causeway (left) on a valley road

Massive landslides are often crossed by river roads.

Debris fans are crossed by valley roads.

A River road sometimes requires massive rock blasting to gain the road width through the almost vertical rock cliff.
▼

▲
Choice among sharp bend, massive rock cut, and tunnelling in this rocky gorge.

2.2 *Ridge Roads*

▲
The magnificent panorama of the landscape is observed from the ridge road.

Low runoff and less drainage (water management) from a road following ridges.
▼

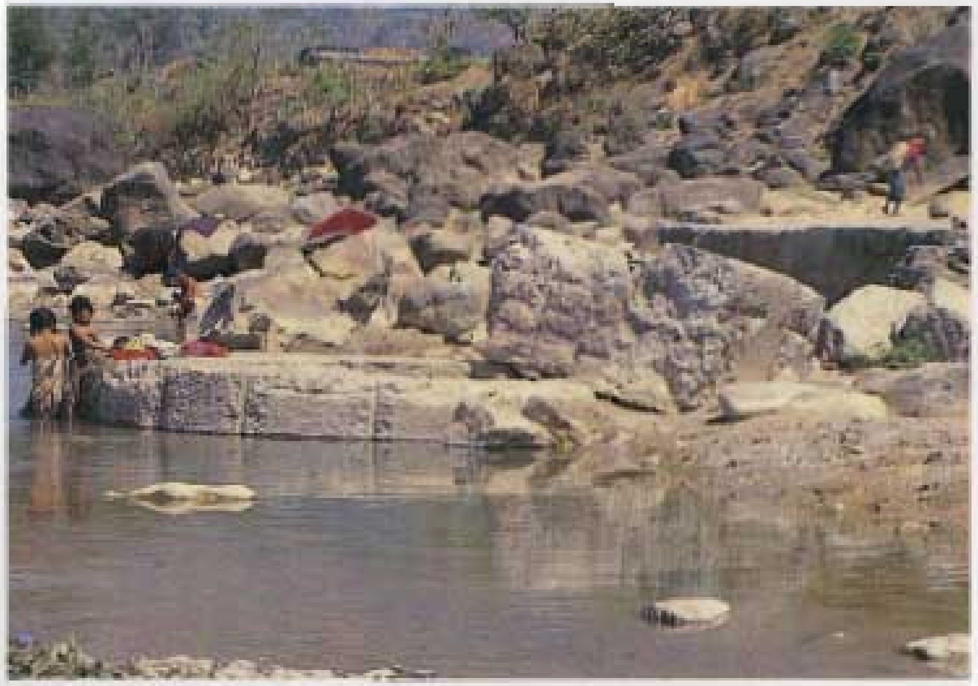
Colluvial terraces of gentler slopes are often favourable for roads through the mid-slope.
▼

▲
Several switchbacks are required on the climb section to quickly get to the ridge from the valley.

▲
The hill slopes adjacent to a fault are highly crushed and susceptible to severe instability. This road crossing a fault zone has subsided for more than 5 m. Notice the tilted houses to the right of the road, the Illam-Taplejung Road, Nepal.

Hill slope adjacent to the Main Boundary Thrust, the Pokhara-Butwal road in Nepal
▼

Huge slumping and bridge collapse after heavy rainfall (Butwal-Nepalganj Road, West Nepal).



Massive damage to railway track by a large-scale debris flow in China

▲

About one fourth of this road was severely damaged by a glacial lake outburst flood (GLOF) in 1981, Arniko Highway, Nepal.

Slope failure from earthquake and heavy rainfall in 1988, Dharan-Dhankuta Road, Nepal)

▼

Massive landsliding, the Karakoram Highway, Pakistan
▼

▲
River undercutting, the Karakoram Highway, Pakistan

▲

Massive gullying after heavy rainfall in this more than 50m deep colluvium/till washed out several houses, killing their occupants, in 1987; the Lamosangu-Jiri Road, Nepal.

Cloudburst and heavy rainfall (150 mm in one and a half hours) discharging 160 cumecs from this tiny stream in 1987 destroyed the bridge and created landslides; The Lamosangu-Jiri Road, Nepal.

▼

A deep seated rotational slide damages the road.

A landslide cutting off the traffic.

Washouts at several stretches closes the road, forcing transportation of goods by porters.

A complete washout of the road by the river

Devegetation and scars from indiscriminate side casting

Landslide from indiscriminate cutting into mountain slope

▲
High runoff discharging onto unstable slope triggers a major landslide.

Careless discharge from the side drain into the highly erodible slope creates severe instability.
▼

A culvert outlet is directed towards an existing building, flooding the latter.

Side casting during construction

Indiscriminate bulldozing, apparently the easiest method of quick road opening, destroys downhill slope.
▼

▲
Indiscriminate blasting triggers major rockslides.

2.5 *Risk to Road from Inadequate Technology Applied*

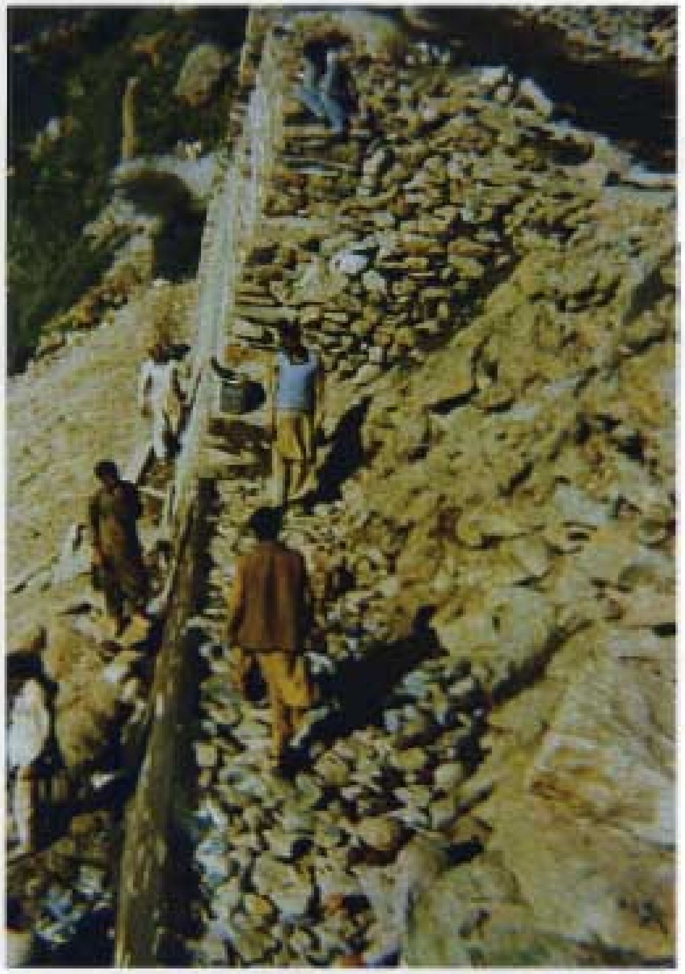
▲
Gabion spur failures, first by scour and then by rupture of wires

Revetment wall failure due to inadequate foundation
▼

▲
Breast wall failure from hydrostatic pressure

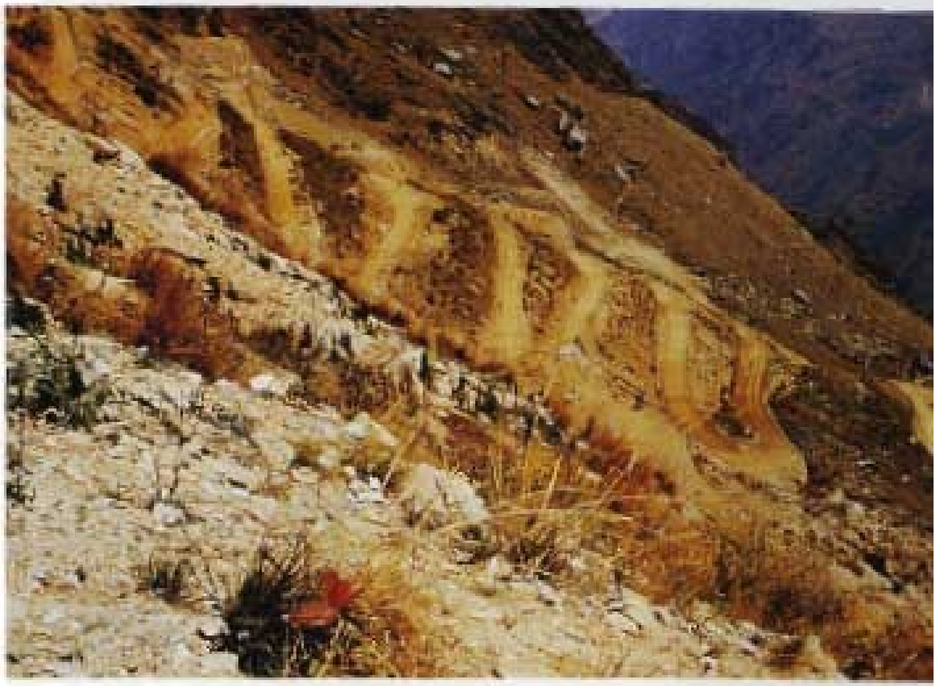
Dry stone masonry without proper bonding leads to early failure of the wall.

▼



Lack of protection at the outfall of drainages undercut the road.

▼



▲

Stacks of parallel switchbacks offer no scope for widening, are extreme difficult to maintain, and are stressful for drivers.

Daylighting of dip slope leads to planar rock failure.

2.6 Risk to Road from Human Activities Adjacent to Roads

▲
Agricultural farming at the edge of road slopes

Irrigation canal above the cut slope
▼

Indiscriminate quarrying for the cement factory has caused aggradation by more than 2m in one year and damaged the road.

Spurs deflecting the flow from the left bank to save the power plant threatens the road on the right bank.

3. MOUNTAIN RISK ENGINEERING

3.1 Purpose and Approach

PURPOSE: To minimize risk to infrastructure and environment from natural processes and human activities.

APPROACH: Avoid hazardous areas and select least risky alignment.

Adopt matching design based on hazards and risks.

Adopt construction controls to avoid accelerated hazards.

3.2 Hazards and Risks

3.2.1 Hazards

Hazard is the probability of occurrence of a particularly damaging phenomenon.

EXAMPLE: There is a 0.4 probability that a deep-seated soil slide will occur within 5 years after the road construction on a 200 m road length between stations 10 + 300 to 10 + 500.

Hazard assessment involves assessment of:

the state of nature (soil and rock type and their thickness, rock structure, slope, relief, rivers and streams, vegetation, water table),

triggers (rainfall, earthquakes, and land use), and

dangers (past and present landslides, river undercutting, glacial lake outburst floods, landslide dams, and debris flows).

Ratings for hazard assessment based on subjective judgement

Example of hazard calculation:

Probability of occurrence of a deep-seated soil slide, P= rating for state of nature x rating for rainfall = 0.8 x 0.5 = 0.40.

Prefeasibility stage ratings for state of nature

S/N	Attribute	Description	Subdivision	Rating
1	Slope angle	Very gentle	0 - 5°	0.00
		Gentle	6 -15°	0.05
		Moderately steep	16 - 25°	0.10
		Steep	26 - 35°	0.14
		Very steep	36 - 45°	0.12
			> 45°	0.10
2	Relative relief	Very low	0 - 50 m	0.00
		Low	51 - 100 m	0.03
		Medium	101- 150 m	0.06
		High	150- 200 m	0.09
		Very high	> 200 m	0.12
3	Drainage	Simple	< 3m deep	0.00
		Active	3-10m deep	0.04
		Very active	> 10m deep	0.08
4	Groundwater condition	Dry		0.00
		Wet		0.04
		Flowing (spring)		0.08
5	Land use	Thickly vegetated		0.00
		Moderately vegetated		0.03
		Sparsely vegetated		0.06
		Barren land, dry cultivated land,		0.09

S/N	Attribute	Description	Subdivision	Rating
6	Major fault		Up to 50 m on both sides	0.16
			Onwards for 50 m	0.08
			Further onwards for 100 m	0.04
7	Major anticlinal zone		Up to 50 m on both sides	0.08
			Onwards for 50 m	0.04
			Further onwards for 100 m	0.02
8	Major synclinal zone (when the hinge is plunging out of the slope)		Up to 50 m on both sides	0.04
			Onwards for 50 m	0.02
			Further onwards for 100 m	0.01
9	Rock type	Massive, resistant	Limestone, quartzite	0.00
		Soft rock	Shale, mudstone	0.02
		Alternating /interbedding of soft and hard rock	Phyllite + quartzite	0.04
		Weak rock in general	Crushed rock	0.06

Continued:

Prefeasibility stage ratings for state of nature, continued

S/N	Attribute	Description	Subdivision	Rating
10	Rock weathering grade	Fresh/slightly weathered		0.00
		Moderately weathered		0.02
		Highly weathered		0.04
		Completely weathered		0.03
11	Rock structure: Joint spacing	Wide	> 1m	0.00
		Medium	1m - 51 cm	0.03
		Close	50cm-10cm	0.06
		Tight	< 10 cm	0.04
12	Rock structure: Orientaion of fractures	Slope oblique to joint/ bedding for more than 30°		0.00
		Dip slope of joints (±15°)		0.04
		Dip slope of bedding (±15°)		0.08
13	Soil type	Compacted alluvium		0-0.04
		Colluvium/ eluvium		0.04-0.08
		Loose alluvium		0.04-0.12
		Talus deposit		0.04-0.12
		Till/diamiton/ debris		0.06-0.12
14	Soil depth	Very shallow	< 1 m	See rock ratings
		Shallow	1 - 3 m	0.06
		Deep	3 - 10 m	0.12
		Very deep	> 10 m	0.08

Rainfall factor for hazard assessment

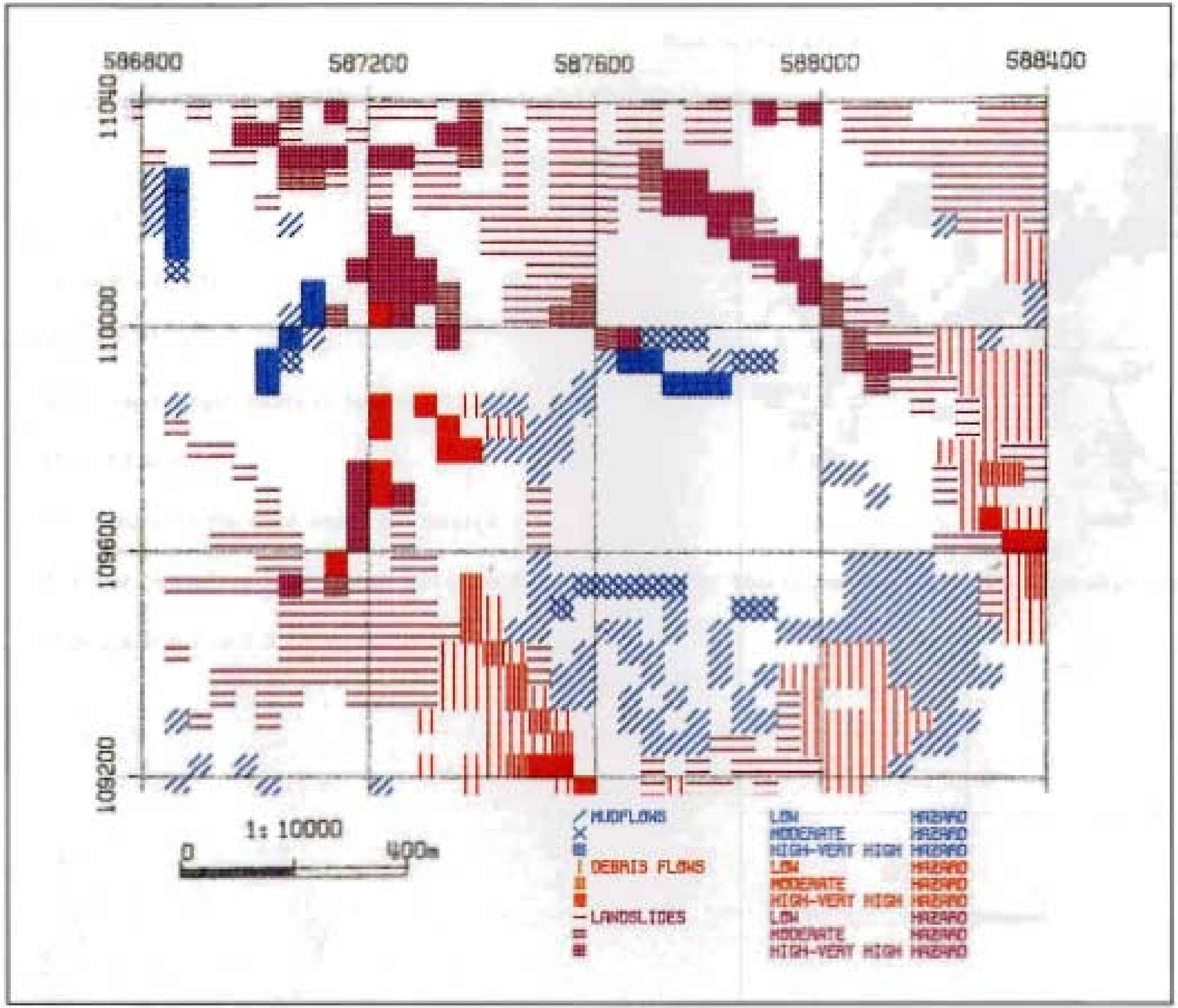
Average annual rainfall, mm	Meam annula maximum 24 hr rainfall, mm	Rating
1000	Less than 50	0.3
	50 to 100	0.5
	101 to 140	0.8
	141 to 170	1.0
	More than 170	1.0
2000	Less than 80	0.4
	81 to 120	0.6
	121 to 140	0.8
	141 to 170	1.0
	More than 170	1.0
3000	Less than 130	0.5
	131 to 150	0.8
	151 to 190	1.0
	More than 190	1.0
4000	Less than 160	0.6
	161 to 190	0.9
	191 to 220	1.0
	221 to 260	1.0
	More than 260	1.0

Factors for road damage
(in fractions of road length)

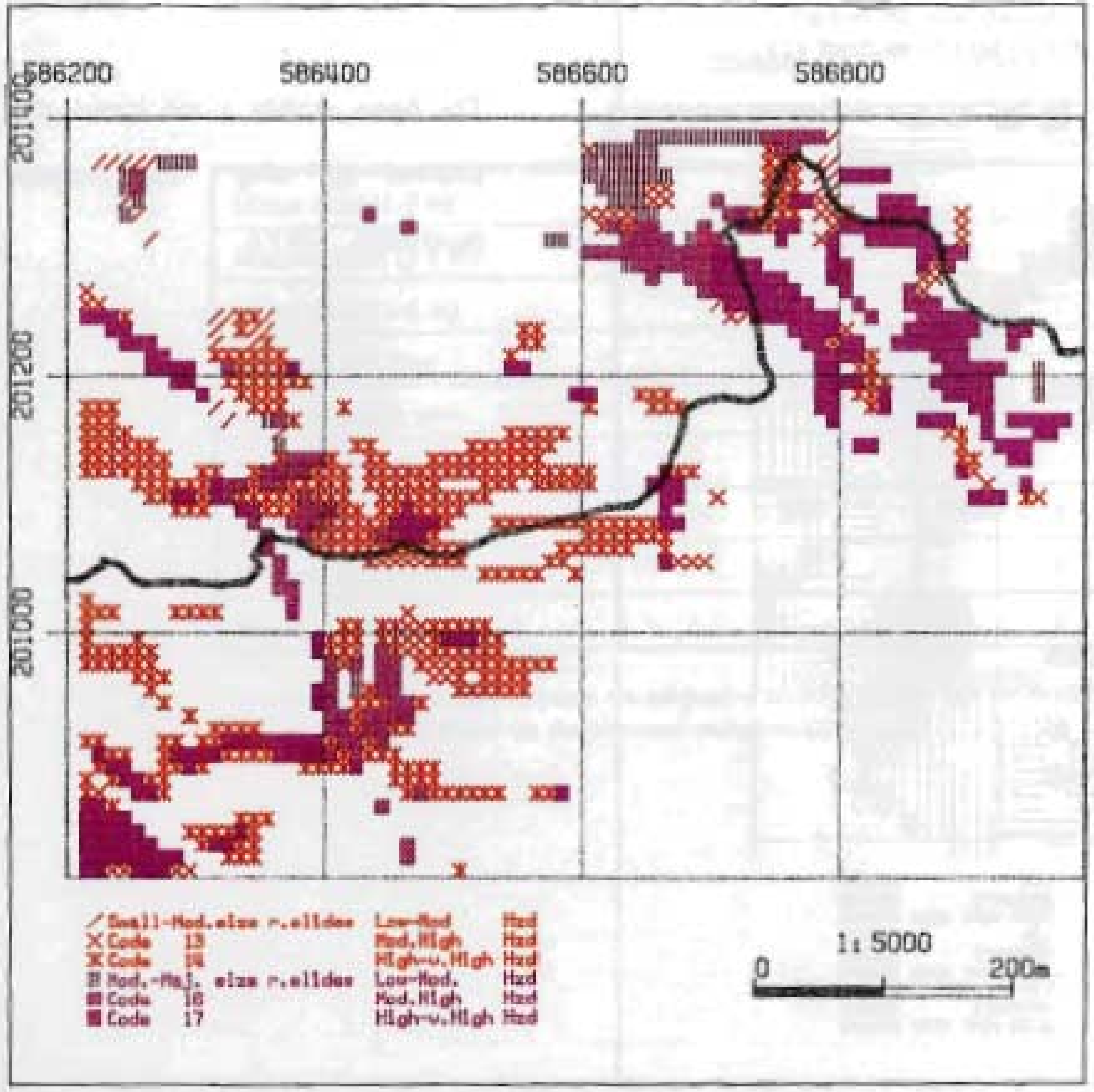
	Soil	Rock	Soil and rock
Minor slide (1-3 m)	0.2	0.3	-
Medium slide (3-6 m)	0.5	0.6	-
Major slide (>6 m)	0.9	1.0	-
Minor debris flow	-	-	0.2
Medium debris flow	-	-	0.4
Major debris flow	-	-	0.9
Minor undercutting	0.3	0.1	-
Medium undercutting	0.5	0.2	-
Major undercutting	0.9	0.5	-

The per cent of damage is based on subjective assessment and can be modified for specific situations based on the personal experience.

Soil hazard map of the Prarion Region, Wallis, Switzerland



The figure exhibits a soil hazard map prepared by using the computer programme, SHIVA.



The figure shows a rock slide hazard map executed by the computer programme, SHIVA.

3.2.2 Risks

Risk is the hazard times worth of loss

Example:

$$R = P \times (l \times f)$$

where,

R = road length likely to be lost

P = hazard

l = length of the road under the hazard

f = per cent of road likely to be lost should the hazard occur. This factor to be established by subjective judgement from past experiences. f = 1 for major slides, and 0.2 to 0.9 for minor to medium slides.

3.3.1 Example of Alternative Alignments, Hazards, and Risks

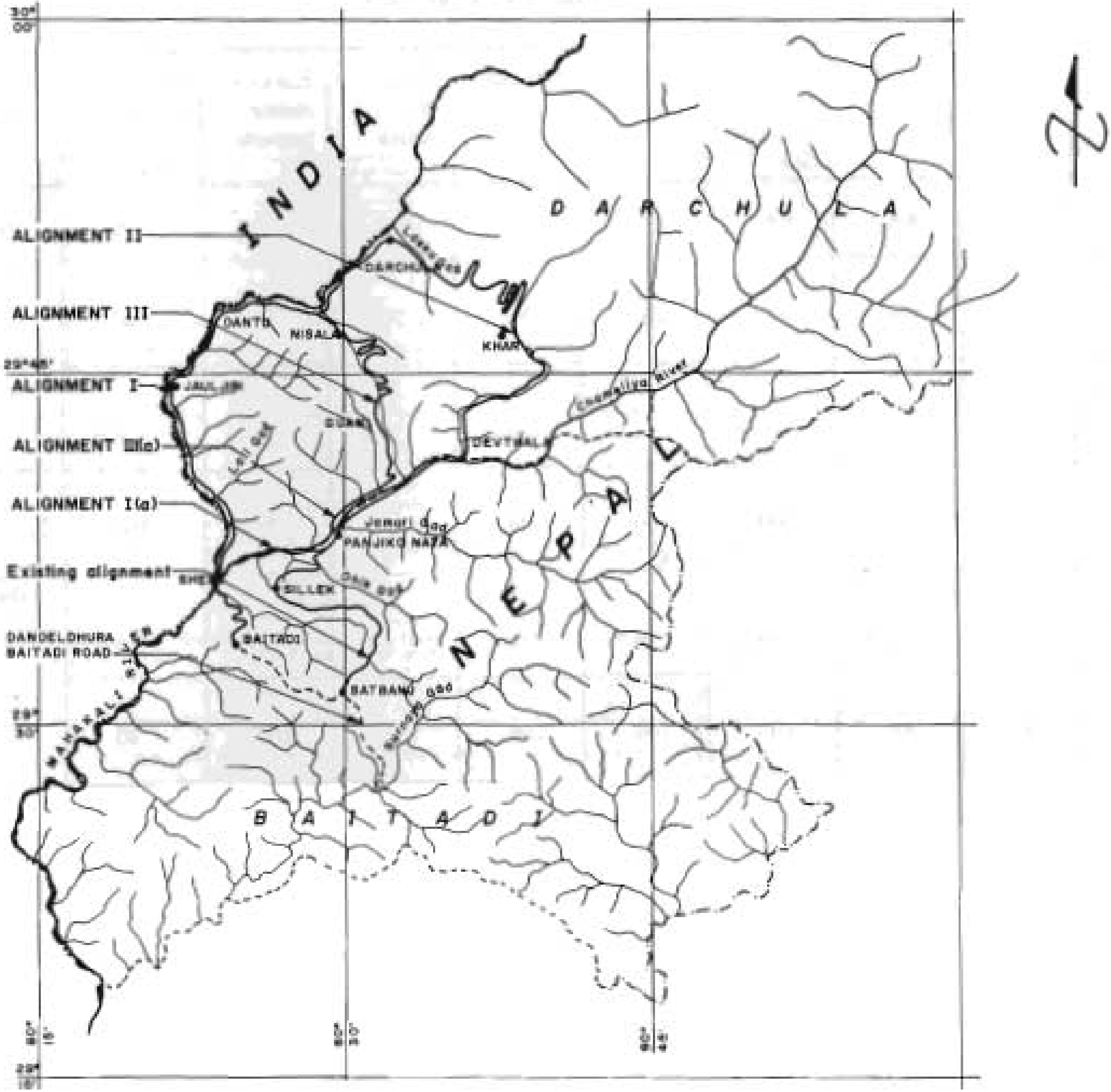
Comparative Hazard Ratings

Alignment	Total length (km)	Total hazard level					
		Low hazard		Medium hazard		High hazard	
		Length (km)	Length in %	Length (km)	Length in %	Length (km)	Length in %
I	64.5	37.7	58.5	11.7	18.1	15.1	23.4
Ia	7.5	3.8	49.6	1.4	18.6	2.4	31.8
II	71.5	25.5	35.7	24.6	34.4	21.4	29.9
III	72.7	48.8	67.0	14.2	19.5	9.7	13.3
IV (Existing Road)	46.9	15.7	33.4	26.1	55.7	5.1	10.9

Summary of Preliminary Risk Assessment

Alignment	Total road length (km)	Total expected loss of length (km)	Expected cost per km (million Rs)	Total expected risk (million Rs)
I	64.520	18.14	12.42	225.32
II	72.461	19.56	13.13	256.84
III	72.725	11.97	9.07	108.53

Alternative Road Alignments



3.3.2 Decision Making on choice of Alignment

Final selection of best alternative

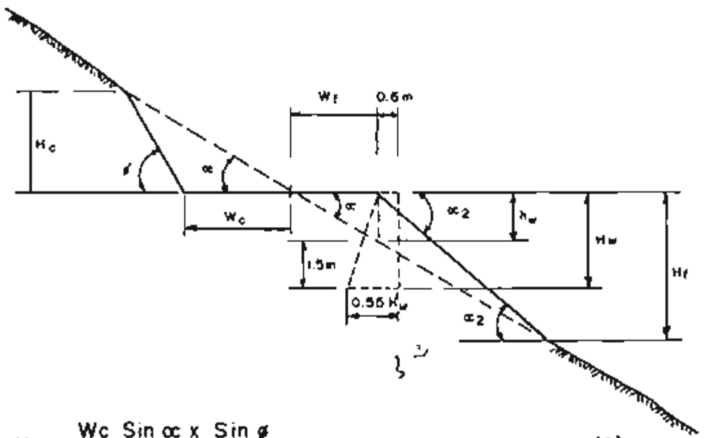
Attributes		Initial cost	Maintenance cost	Duration of construction	Design life	Hazards and risks	Economic return	Environmental impacts	Strategic or other considerations	Total Rating	Rank
Relative importance		10%	10%	10%	10%	20%	15%	15%	10%	100%	
Alignment I	Relative rating	82	100	100	100	50	79	89	60	79.5	2
	Weighted rating	8.2	10.0	10.0	10.0	10.0	11.9	13.4	6.0		
Alignment II	Relative rating	70	90	100	100	44	56	73	100	74.2	3
	Weighted rating	7.0	9.0	10.0	10.0	8.8	8.4	11.0	10.0		
Alignment III	Relative rating	100	88	100	100	100	100	100	80	96.8	1
	Weighted rating	10.0	8.8	10.0	10.0	20.0	15	15	8.0		

3.3.3 Recommended Geometric Standards for Mountain Roads

DESIGN PARAMETERS	AADT > 2000 VF VG CS RS	AADT 1000 - 2000				AADT 500 - 1000				AADT 200 - 500				AADT 50 - 200				AADT < 50				REMARKS
		VF	VG	CS	RS	VF	VG	CS	RS	VF	VG	CS	RS	VF	VG	CS	RS					
1) DESIGN SPEED, KPH		60	50	40	50	50	40	40	50	50	40	30	40	40	30	30	40	40	25	25	30	1) * ALMOST IMPOSSIBLE TO PROVIDE REQUIRED SIGHT DISTANCE FOR SINGLE-LANE ROAD IN THE HILLY AREAS. EITHER PROVIDE DOUBLE-LANE AT CURVES OR DRASTICALLY REDUCE THE SPEED, PROVIDE MIRROS OR BLOW HORN.
2) TRAFFIC LANES, NO		2	2	2	2	2	2	2	2	2	1+	1+		1	1	1	1	1	1	1	1	
3) CARRIAGE WAY WIDTH M		7	7	7	7	7	6	6	6	7	4-6	4-6	4-6	3.75	3.75	3.75	3.75	3.5	3.5	3.5	3.5	
4) SHOULDER WIDTH,ON EACH, SIDE, M		1	1	1	1	1	1	1	1	1	0.75	0.75	0.75	0.75	0.50	0.50	0.50	0.5	0.5	0.5	0.5	
5) DRAIN, M		1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	
6) MINIMUM ROADWAY WIDTH AT APEX OF SWITCH BACKS/HAIR PIN BENDS		—	11.5	11.5	11.5	—	11.5	11.5	11.5	—	9	9	9	—	7.5	7.5	7.5	6.5	6.5	6.5	6.5	
7) TOTAL FORMATION WIDTH IN M		10-10.5	10-13	10-13	10-13	10-10.5	9-13	9-13	9-13	10-10.5	8.5-10	8.5-10	8.5-10	6.25-7	5.5-9.0	5.5-9.0	5.5-9.0	5.5-6.0	5.0-6.0	5.0-6.0	5.0-6.0	
8) RULING GRADIENT %	HIGH STANDARDS, MAY JUSTIFY TUNNELS, CROSSING A RIVER MORE THAN ONCE, ETC. EXTENSIVE STUDY REQUIRED	3	4	6	5	4	5	6	4	4	5	6	5	4	7	7	6	4	7	7	6	
9) MAXIUM GRADIENT %		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	
10) EXCEPTIONAL GRADIENT %		—	10	10	10	—	10	10	10	—	10	10	10	—	12	12	12	—	12	12	12	
11) GRADE COMPENSATION AT CURVE %																						
12) MAXIUM LENGTH OF MAXIUM GRADIENT, M		100	100	100	100	100	60	60	60	100	60	60	60	100	60	60	60	100	60	60	60	
13) MAXIUM LENGTH OF EXCEPTIONAL GRADIENT, M																						
14) MINIMUM LENGTH OF RECOVERY, AFTER MAXIMUM OR EXCEPTIONAL GRADE, AS SPECIFIED		200 M @ — 150M @ 4%				200 M @ 3% — 150M @ 4%				150 M @ 4%												2) FOR TRAFFIC LESS THAN 200 AADT AND AT SECTIONS OF LESS THAN 5% LONG. GRADE, AND PAVED AND SEALED AREAS, OUTSLOPING OF ROAD AT 3 - 4% MAY BE FOLLOWED TO REDUCE FORMATION WIDTH AND CUT VOLUME
15) MINIMUM STOPPING SIGHT DISTANCE, M		80	60	45	60	60	45	45	60	60	45	30	45	45	30	30	45	45	25	25	30*	
16) MINIMUM OFFSET FROM CENTRE LINE TO INSIDE EDGE OF CUT AT 1.2 M HT		14	6.5	3.5	6.5	6.5	5.5	5.5	6.5	6.5	5.5	4.5	5.5	20	16	16	20	20	13	13	16	
17) SUPER-ELEVATION, M		$e = \frac{V^2}{127R}$ (max)								10% ; f 0.14 for 60 KPH to 0.19 for 20 KPH												
18) VERTICAL CURVE		FORMULAE																				
19) MINIMUM RADIUS OF HORIZ. CURVE, M		120	75	45	75	75	45	45	75	75	45	25	45	45	25	25	45	45	20	20	25	
20) EXTRA WIDENING OF PAVEMENT AT CURVES, M		—	0.9	0.9	0.9	0.9	0.6	0.6	0.6	0.9	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	

ADDT = Average Annual Daily Traffic
VF = Valley-flat
VG = Valley-gorge
CS = Climb Section
RS = Ridge Section

3.3.4 Indicative Quantities of Some Items of Mountain Road Works for Preliminary Estimating



$$H_c = \frac{W_c \sin\alpha \times \sin\phi}{\sin(\phi - \alpha)} \quad \cdots\cdots (1)$$

$$h_w = W_f \tan\alpha$$

$$H_f = \frac{W_f \times h_w}{W_f + 2h_w}$$

$$= \frac{W_f^2 \tan\alpha \tan\alpha_2}{W_f \tan\alpha_2 - W_f \tan\alpha}$$

$$= \frac{W_f \tan\alpha \tan\alpha_2}{\tan\alpha_2 - \tan\alpha} \quad \cdots\cdots (2)$$

$$H_w = W_f \tan\alpha + 0.6 \tan\alpha + 1.5 \quad \cdots\cdots (3)$$

Cut area $A_c = 0.5\, H_c \times W_c \quad \cdots\cdots (4)$

Fill area without wall $A_f = 0.5\, H_f \times W_f \quad \cdots (5a)$

Fill area with wall, A_{fw}

$$= W_f \tan\alpha \left[0.5\, W_f - \frac{0.25\, W_f \tan\alpha}{1 + 0.5 \tan\alpha} \right] \cdots$$

$$= 0.5\, W_f^2 \tan\alpha - \frac{0.25 (W_f \tan\alpha)^2}{1 + 0.5 \tan\alpha} \quad \cdots (5b)$$

Quantity of retaining wall,

$$Q_R = \frac{0.6 + 0.55 \times (W_f \tan\alpha + 0.6 \tan\alpha + 1.5}{2} \times (W_f \tan\alpha + 0.6 \tan\alpha + 1.5) \quad \cdots (6)$$

Quantity of breast wall,

$$Q_B = (0.5\, H_c + 0.15\, H_c^2) \quad \cdots\cdots (7)$$

Indicative Quantities of Major Items of Hill Road for Height of Cut Limited to Less Than 12 m and Low Risk Design of Coss Sections

HILL SLOPE deg.	AV. SLOPE deg.	CUT SLOPE deg.	H:V	ROAD WIDTH m.	RATIO CUT	FILL	CUT HT. m.	FILL HT.	HT.OF RTG. WALL m.	PER KM. QUANTITIES CUT VOL. 1000 cu.m.	FILL VOL. 1000 cu.m.	RETG. WALL VOLUME 1000 cu.m.	BREAST WALL VOLUME 1000 cu.m.	CULVERT No./Type	REMARK
LOW HAZARD AREAS															
0-14	7	45	1:1	6.50	.60	.40	.55	.42		1.06	.55			5/HP + 2/Box	HP = Hume Pipe
15-24	20	45	1:1	6.50	.60	.40	2.23	3.48		4.35	4.53			5/HP + 1/Box	
25-34	30	56.30	1:1.5	6.50	1	0	6.10		1.78	19.84	0			7/HP + 1/Box	
35-44	40	63.40	1:2	6.50	.90	.10	8.47		2.34	24.77	.12	2.20		7/HP + 1/Box	
45-54	50	76	1:4	6.50	.70	.30	7.72		3.82	17.55	1.42	5.16		6/HP + 1/Box	Rock or hard soil
55-64	60	80.50	1:6	6.50	.70	.30	11.10		4.62	25.25	1.77	7.26		6/HP + 1/Box	Rock or hard soil
0-14	7	45	1:1	10	.60	.40	.84	.65		2.52	1.30			5/HP + 2/Box	
15-24	20	45	1:1	10	.60	.40	3:43	5.36		10.30	10.72			5/HP + 1/Box	
25-34	30	56.30	1:1.5	10	1	0	9.39		1.78	46.95	0			7/HP + 1/Box	
35-44	40	63.40	1:2	10	.90	.10	13.03		2.57	58.62	.30	2.59		7/HP + 1/Box	
45-54	50	76	1:4	10	.70	.30	11.87		4.77	41.54	3.36	7.70		6/HP + 1/Box	Rock or hard soil
55-64	60	80.50	1:6	10	.60	.40	14.63		7.13	43.90	7.43	16.11		6/HP + 1/Box	Rock or hard soil
MEDIUM HAZARD AREAS															
0-14	7	45	1:1	6.50	.60	.40	.55	.42		1.06	.55			5/HP + 3/Box	
15-24	20	45	1:1	6.50	.60	.40	2.23	3.48		4.35	4.53			5/HP + 3/Box	
25-34	30	56.30	1:1.5	6.50	.90	.10	5.49		2.09	16.07	.09	1.83		8/HP + 1/Box	
35-44	30	71.60	1:3	6.50	.80	.20	6.05		2.77	15:74	.50	2.95	8.52	8/HP + 1/Box	
45-54	50	76	1:4	6.50	.60	.40	6.61		4.41	12.90	2.53	6.67	9.87	8/HP + 1/Box	
55-64	60	80.50	1:6	6.50	.50	.50	7.93		6.21	12.88	4.90	12.47		8/HP + 1/Box	
0-14	7	45	1:1	8	.60	.40	.67	.52		1.61	.83			5/HP + 3/Box	
15-24	20	45	1:1	8	.60	.40	2.75	4.29		6.59	6.86			5/HP + 3/Box	
25-34	30	71.60	1:1	8	.80	.20	4.57		2.54	14.64	.57	2.54	5.43	8/HP + 1/Box	
35-44	40	71.60	1:3	8	.70	.30	6.52		3.51	18.25	1.70	4.44	9.63	8/HP + 1/Box	
45-54	50	76	1:3	8	.50	.50	6.78		5.68	13.57	5.98	10.59	10.29	8/HP + 1/Box	
55-64	60	80.50	1:6	8	.50	.50	9.76		7.13	19.51	7.43	16.11		8/HP + 1/Box	

Continued...

Indication Quantities of Major Items of Hill Road for Height of Cut Limited to Less than 12m. and Low Risk Design of Cross Section

HILL SLOPE deg.	AV. SLOPE deg.	CUT SLOPE DEG.	CUT SLOPE H:V	ROAD WIDTH m.	RATIO CUT	RATIO FILL	CUT HT. m.	FILL HT.	HT. OF RTG. WALL m.	PER KM QUANTITIES: CUT VOL. 1000 cu.m.	FILL VOL. 1000 cu.m.	RETG. WALL VOLUME 1000 cu.m.	BREAST WALL VOLUME 1000 cu.m.	CULVERT No./Type	REMARK
HIGH HAZARD AREAS															
0-14	7	45	1:1	6.50	.60	.40	.55	.42		1.06	.55			5/HP+3/Box	
15-24	20	45	1:1	6.50	.60	.40	2.23	3.48		4.35	4.53			5/HP+3/Box	
25-34	30	71.60	1:3	6.50	.70	.30	3.25		2.71	7.40	.85	2.83	3.21	9/HP+2/Box	
35-44	40	71.60	1:3	6.50	.70	.30	5.30		3.21	12.05	1.12	3.79	6.86	9/HP+2/Box	
45-54	50	76	1:4	6.50	.40	.60	4.41		5.59	5.73	5.68	10.28	5.12	9/HP+2/Box	
55-64	60	80.50	1:6	6.50	.40	.60	6.34		7.01	8.24	7.06	15.60		9/HP+2/Box	
0-14	7	45	1:1	10	.60	.40	.84	.65		2.52	1.30			5/HP+3/Box	
15-24	20	45	1:1	10	.60	.40	3.43	5.36		10.30	10.72			5/HP+3/Box	
25-34	30	71.60	1:3	10	.70	.30	5.00			17.51	2.02	3.79	6.26	9/HP+2/Box	
35-44	40	71.60	1:3	10	.70	.30	8.15			28.52	2.66	5.38	14.04	9/HP+2/Box	
45-54	50	76	1:4	10	.40	.60	6.78			13.57	13.45	17.73	10.29	9/HP+2/Box	
55-64	60	80.50	1:6	10	.40	.60	9.76			19.51	16.72	28.09		9/HP+2/Box	

Notes:

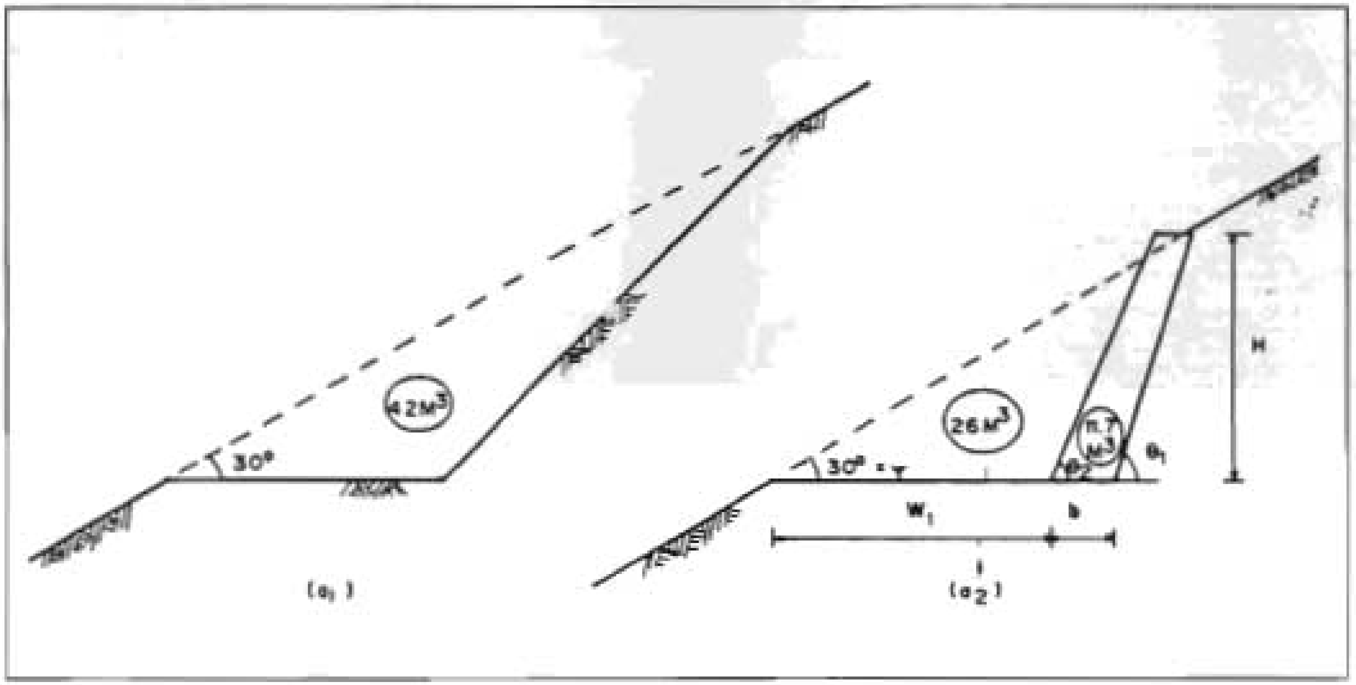
1. Provide vegetative measures for erosion controls in Low Hazard Areas.
2. Provide biotechnical and engineering works for erosion, gully, and minor slides in Medium Hazard Areas.
3. Provide specific landslide stabilization measure based on detailed investigation and analysis for High Hazard Areas.

3.4 *Design Considerations*

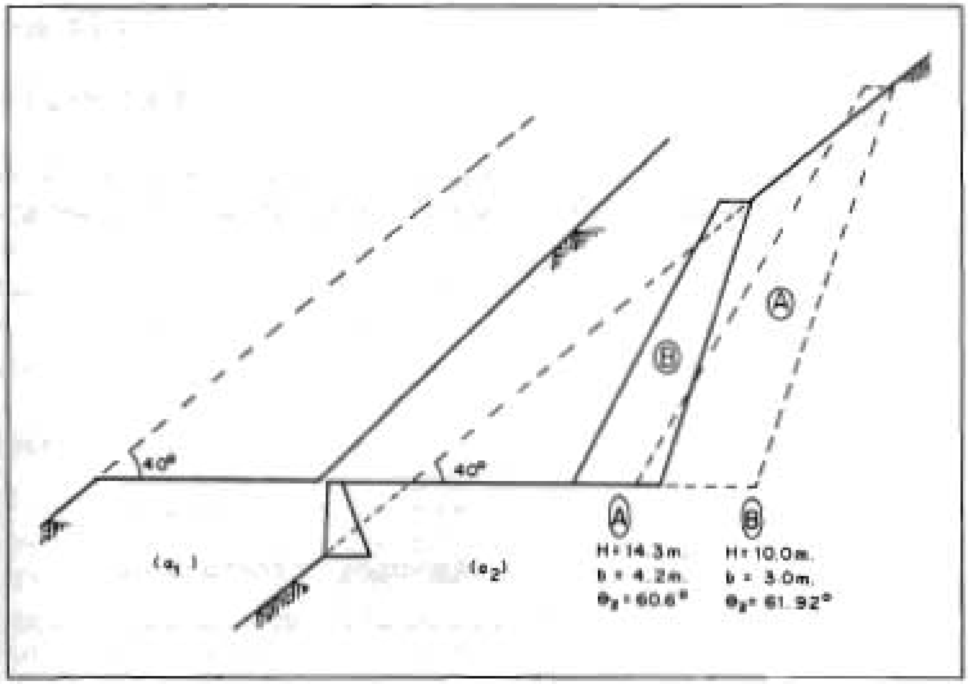
3.4.1 Road Formation Design

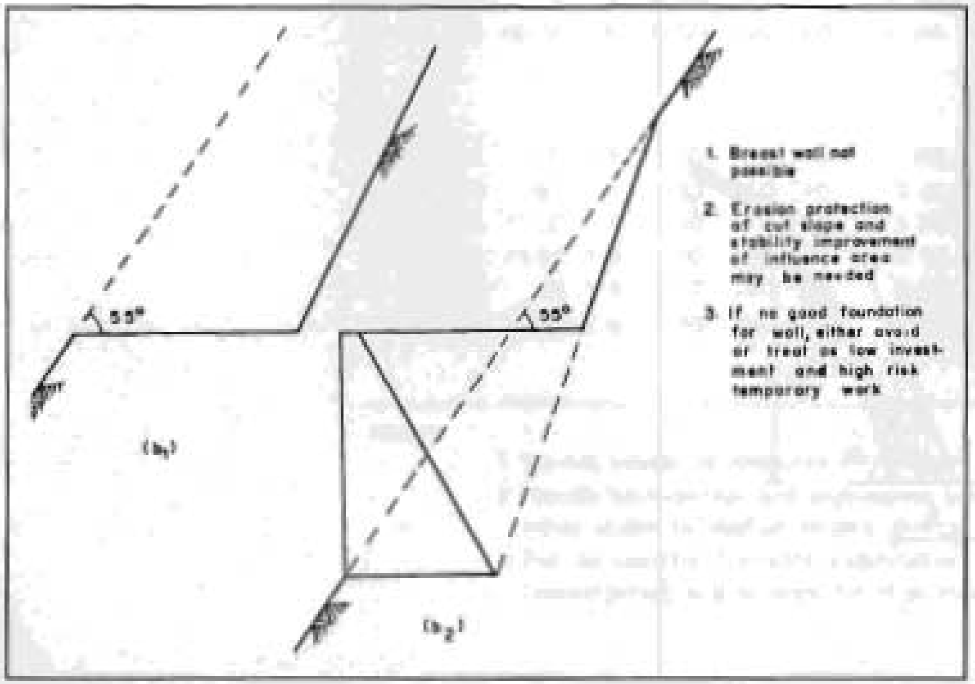
Cross-section design of mountain roads plays an important role in reducing hazards and enhancing long term economy. Designs that slightly shift the centre line horizontally, and sometimes vertically as well, and provide breast walls can greatly reduce the height of cut, cut volume, and, in many instances, the cost of roads.

Minimizing cut heights in soils



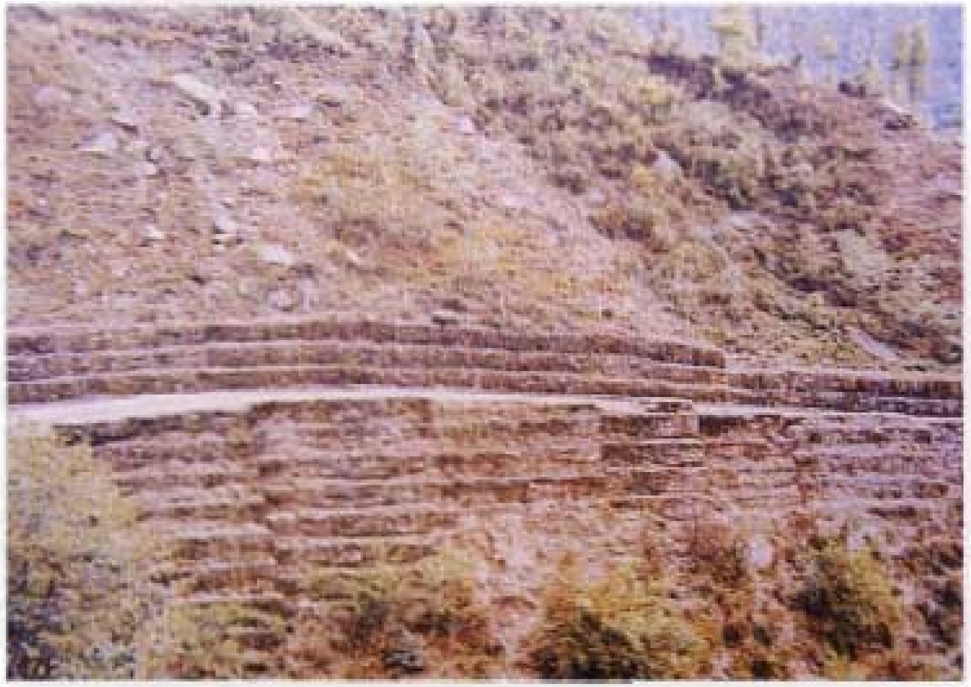
Minimizing height of cut on steep slopes is possible by providing breast walls and shifting the centre line horizontally as shown in the figure to the right.





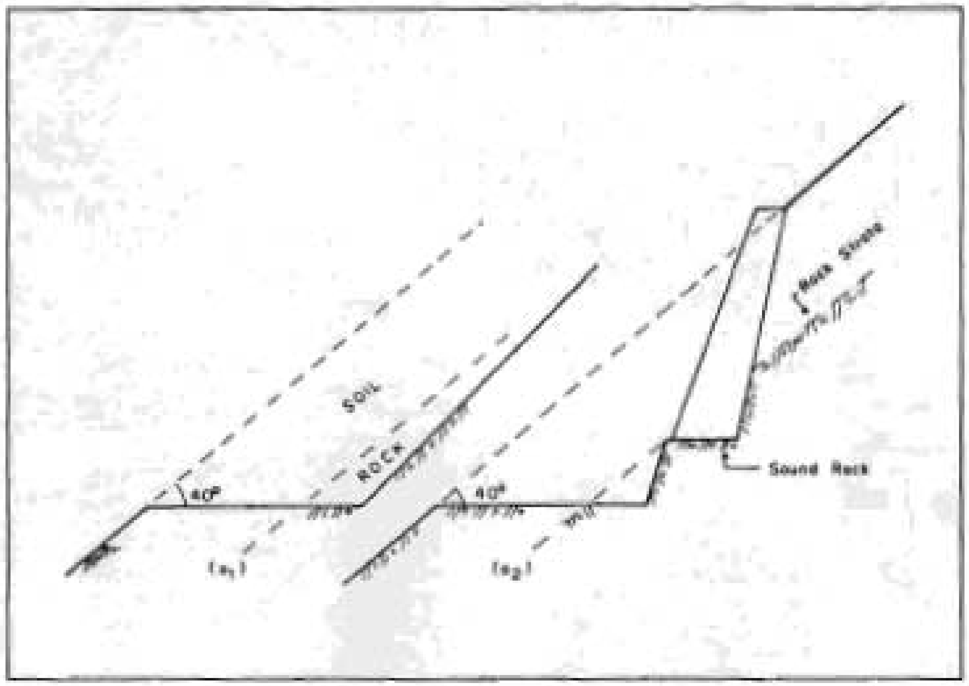
◂ On very steep slopes, breast wall construction is not feasible. By shifting the centre line horizontally and providing a back-battered retaining wall towards the downhill side of the road, the volume of excavation is reduced drastically.

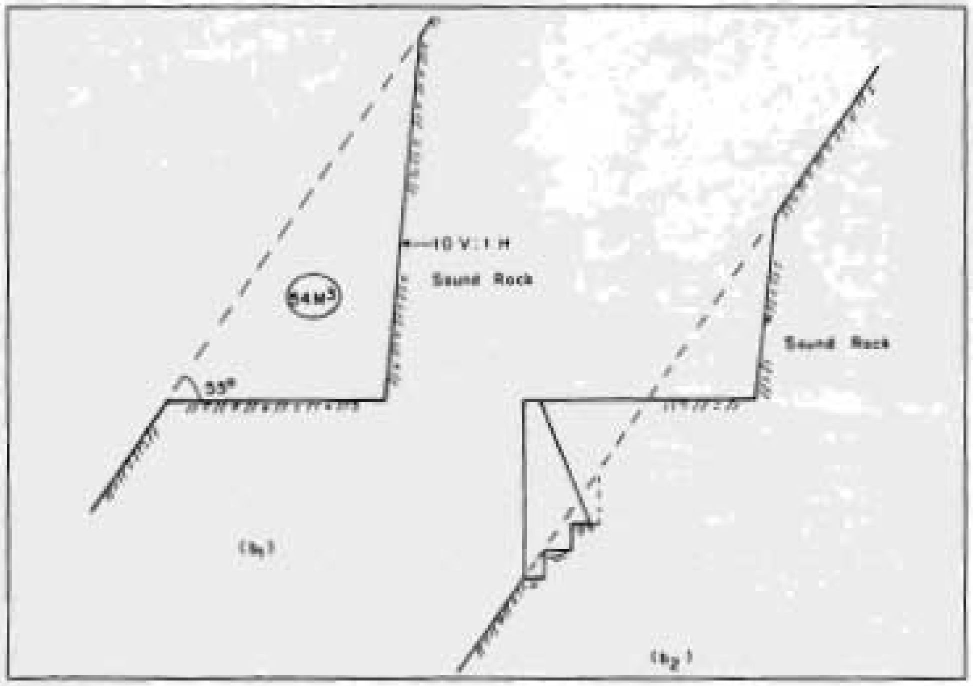
◂ A valley side retaining wall is supporting the fill section.



A breast wall supports a cut slope, while the fill section is supported by a retaining wall on the valley side.

In rocky areas, where excavation is difficult and expensive, the centre line shift towards the valley reduces the height of cut and volume of excavation to a great extent.





A breast wall founded on the sound rock supports cut slope and greatly reduces the amount of excavation. Cut height is much smaller, and hazards and risks are reduced significantly.

3.4.2 Cut Slope Stability

The traditional practice of cut slope design by selecting arbitrary cut slope angles, e.g., 1:1/3 to 1/2 (V:H) for soils and 1:1/15 to 1:1/8 (V:H) for rocks is not satisfactory. It often leads to slope failures and progressive destabilizations.

Preliminary designs can be carried out by using available information from preliminary hazard assessment on the type of soil or rock and on estimate of the height of cut. The table on this page shows stable cut slopes with or without breast walls for the purpose of tentative designs.

Preliminary Design of Cut Slopes for Heights of Cut Less Than 10 m.

SL.	Type of Soil/rock protection work (vertical to horizontal)	Stable cut slope without any breast wall or minor protection work (vertical to horizontal)	Stable cut slope with
1	2	3	4
1.	Soil or soil mixed with boulders		
	(a) Disturbed vegetation	1:1	n:1*
	(b) do-overlaid on firm rock	Vertical for rock-portion and 1:1 for soil portion	Vertical for rock portion and n:1 for soil portion
2.	Same as above but with dense vegetation forests, medium rock and shales	1:0.5	5:1
3.	Hard rock, shale or harder rocks with inward dip	1:0.25 to 1:0.10 and vertical or overhanging	not needed
4.	Same as above but with outward dip or badly fractured rock/shale	At dip angle or 1:0.5 or dip of intersection of joint planes	5:1
5.	Conglomerates/very soft -shale/sandrock which erode easily	Vertical cut to reduce erosion	5:1

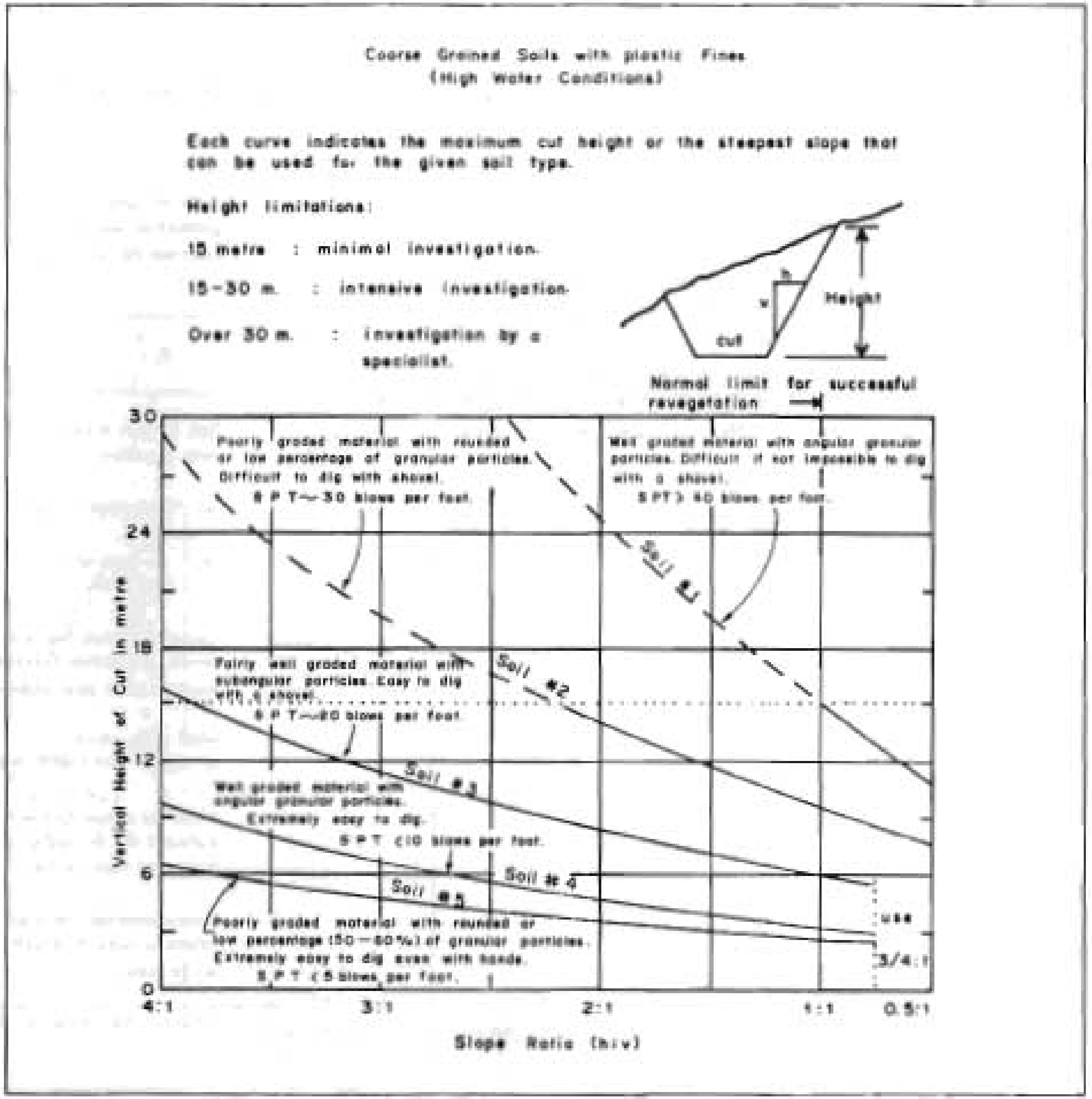
* n is 5 for H 3 m; 4 for H= 3-4 m; 3 for H= 4.6 m

Accuracy of cut slope designs is improved by use of design charts as one shown to the right.

Specialized geotechnical and geological investigations and analyses will be necessary for cut slope design for areas under medium hazards or cut heights ranging from 15 to 30 m.

At high hazard sites, or where cut heights exceed 30 m, specialized slope stability analysis, based on intensive geotechnical and geological investigations, is a must.

During construction, the standard/typical designs for various situations are verified for actual conditions and, if necessary, the designs are revised. Depending on the importance and size of the problem, additional investigations and specialized slope stability analysis are carried out.



3.4.3 Retaining and Breast Walls

Retaining walls are structures to retain the backfill and withstand the earth pressure and surcharge loads and are normally below the road surface.

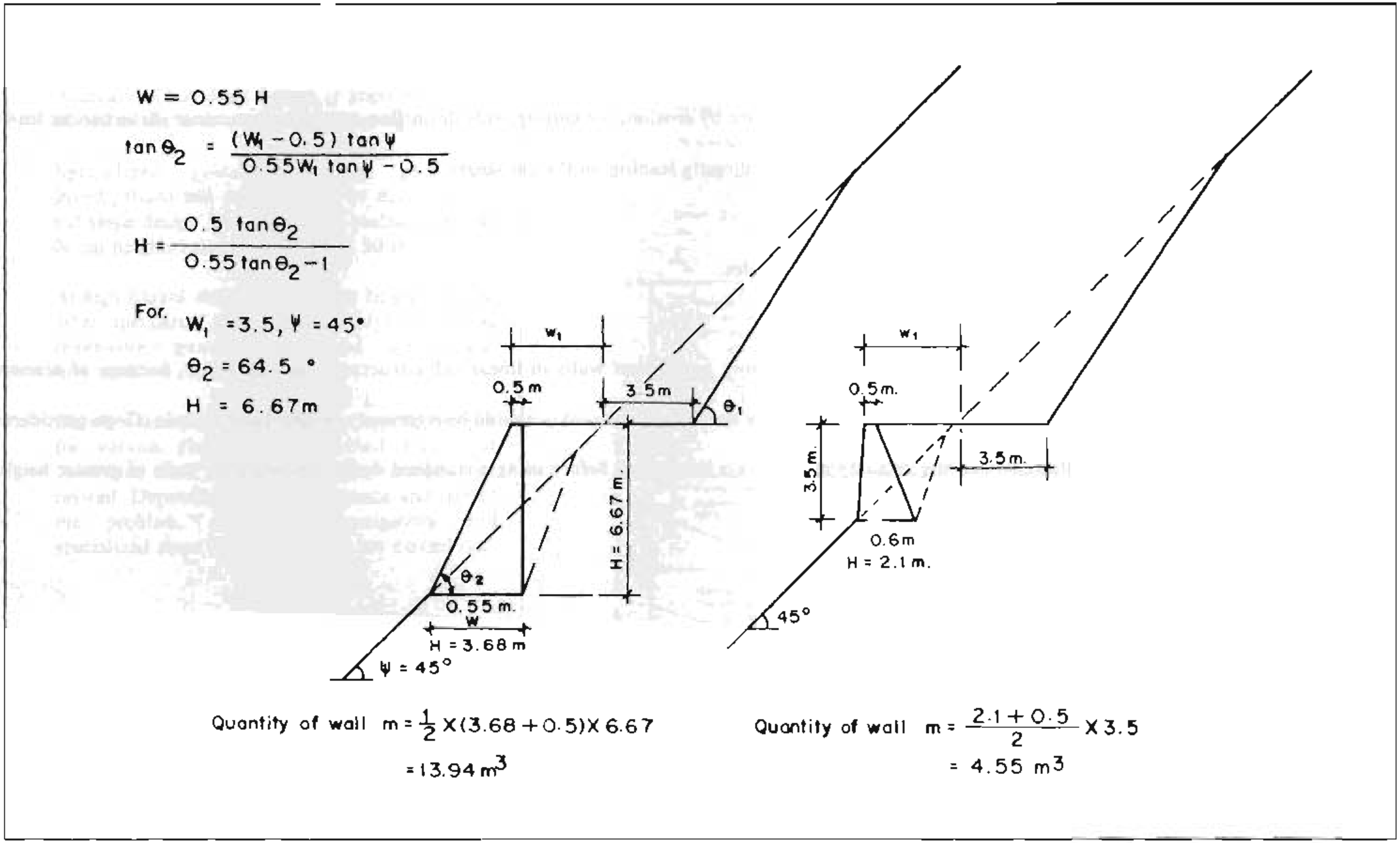
Breast walls are revetment walls meant to buttress the slope against failure by erosion, toe cutting, side drain flow, and by other minor disturbances leading to progressive failure of the cut slopes. Breast walls are generally built directly leaning on the cut slopes.

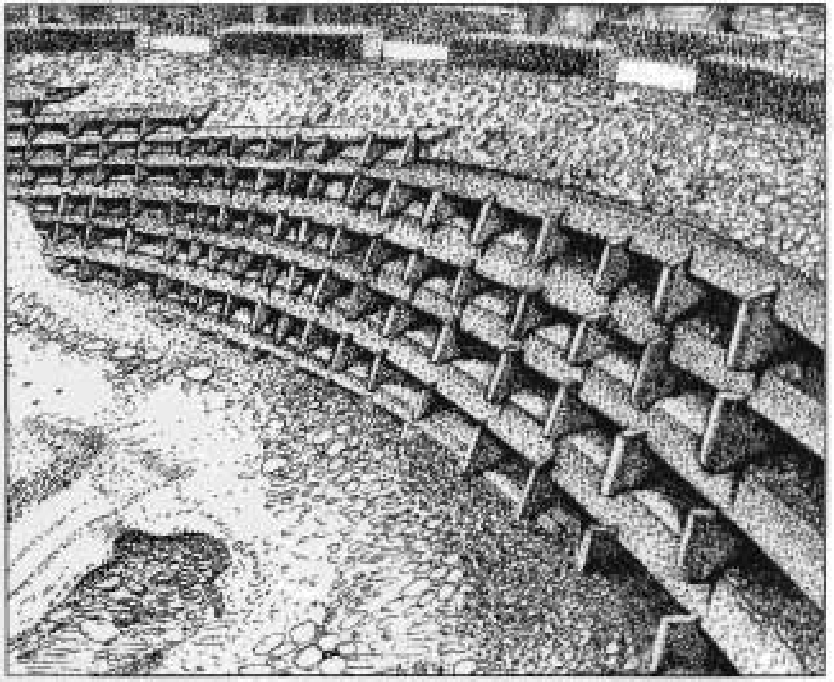
Retaining and breast walls are not normally intended to stabilize landslides.

Seismic considerations are rarely accounted for in the design of retaining and breast walls in linear infrastructures such as roads, because of economic considerations. However, major structures which are likely to entail heavy loss from earthquakes should be rigorously designed and seismic effects considered. Toe pressure from the walls and the allowable bearing capacity must always be verified before using a standard design for retaining walls of greater heights.

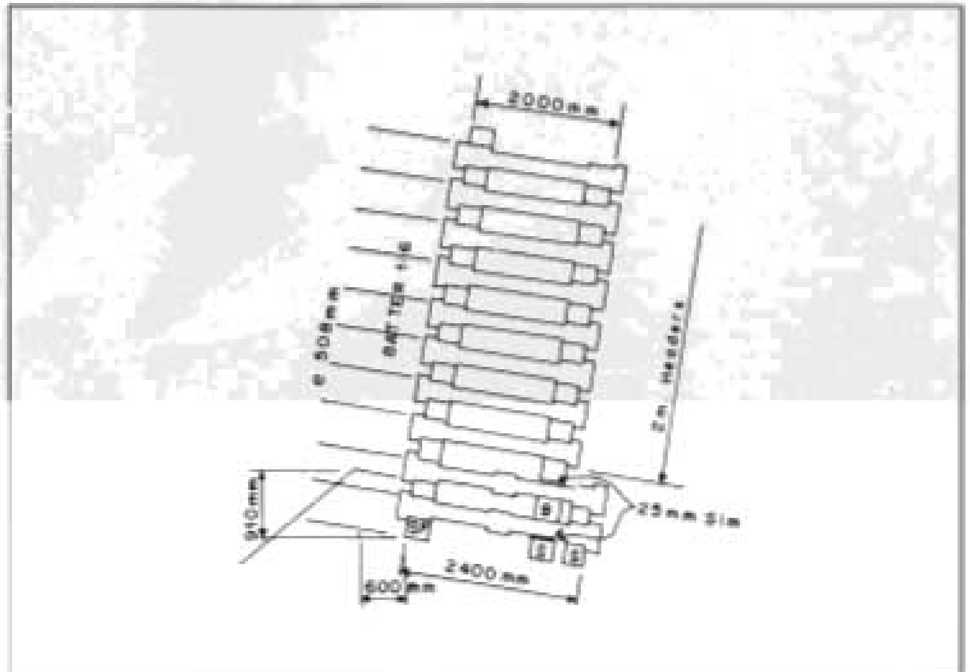
Back-battered retaining walls on a mountain slope can result in cost saving by more than 60% compared to front-battered retaining walls.

Back-battered versus front-battered retaining walls



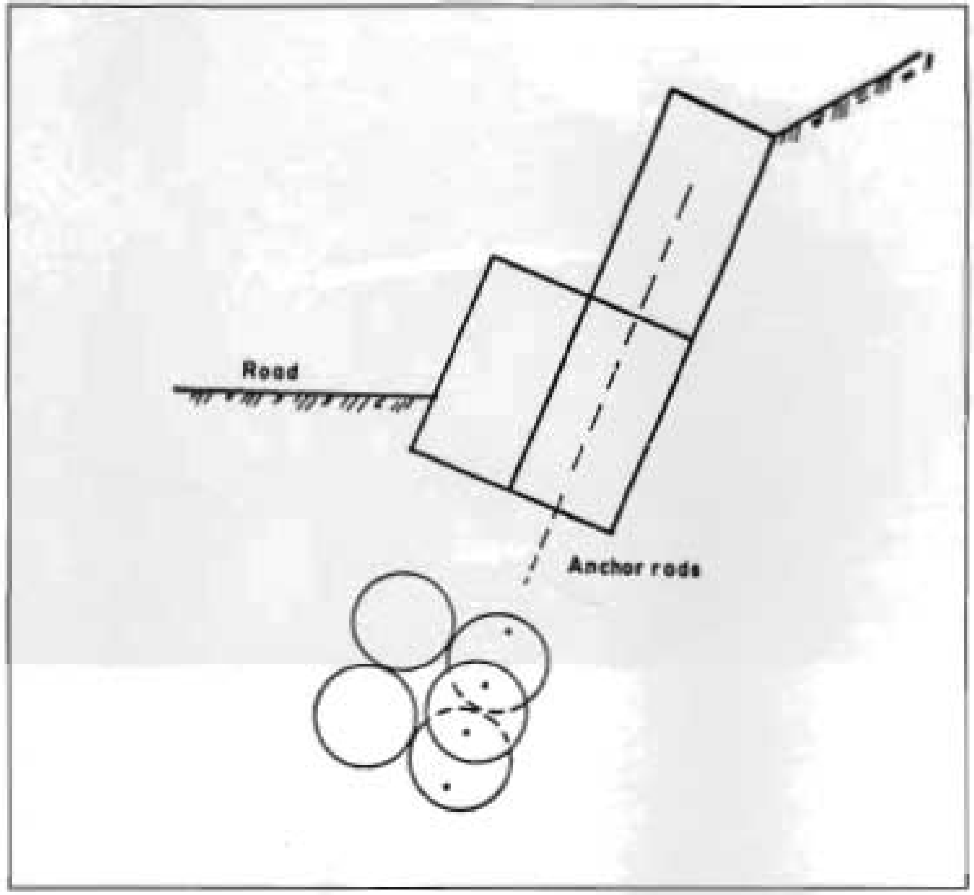


Reinforced concrete crib walls are economical and fast tracking since the volume of wall is less. Precasting and storing can be done during the off season. Quality control in the precasting yard is more assured than in the field.

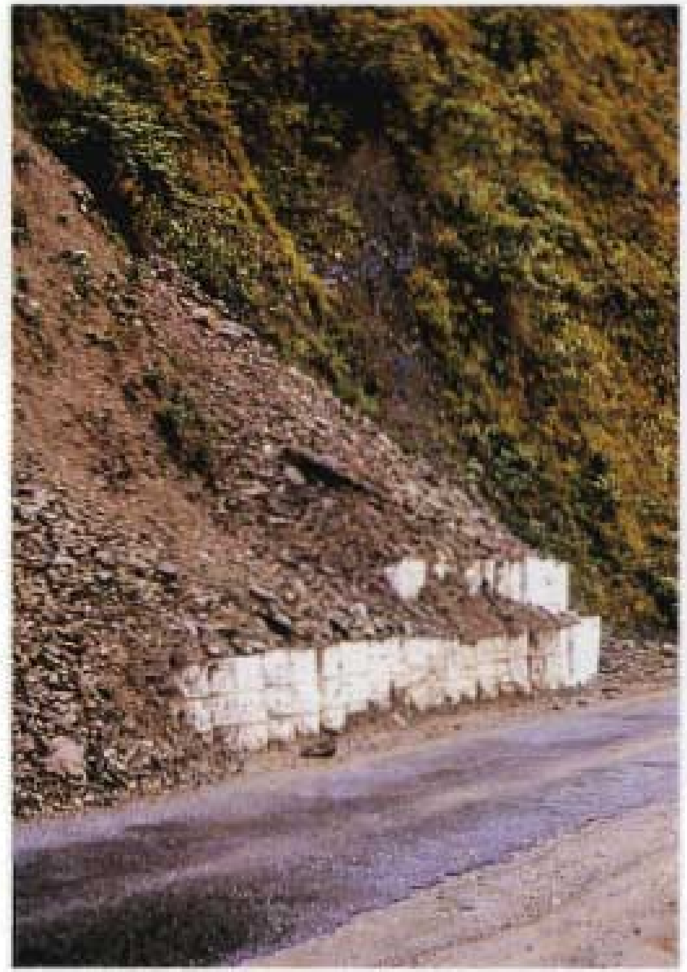


Anchored H-piles can be used for low-bearing capacity foundations and high walls.

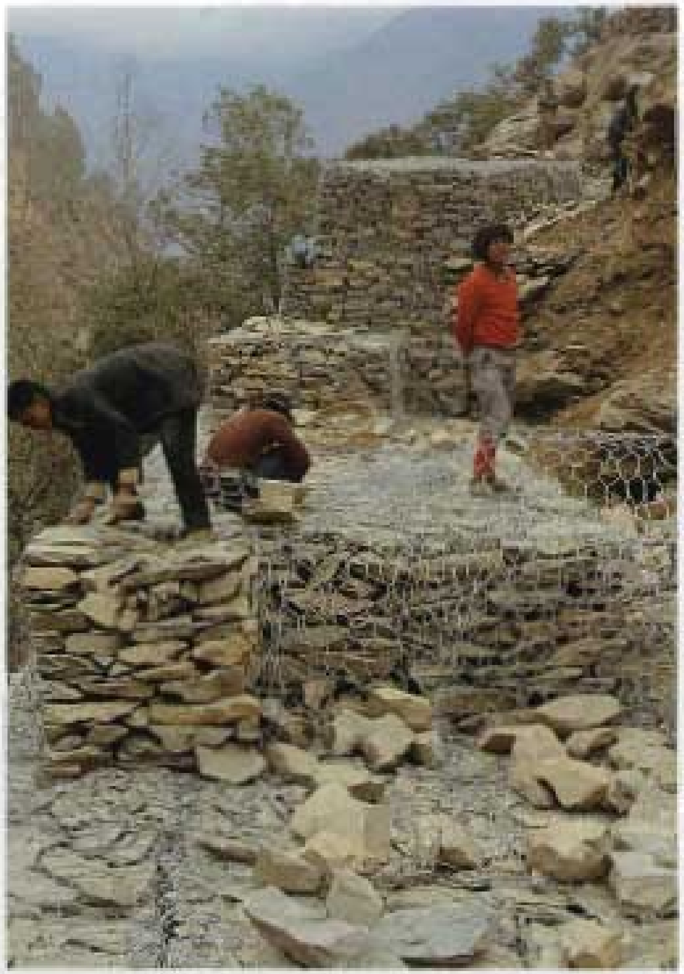
Bin walls of steel are used where steel is easily available.



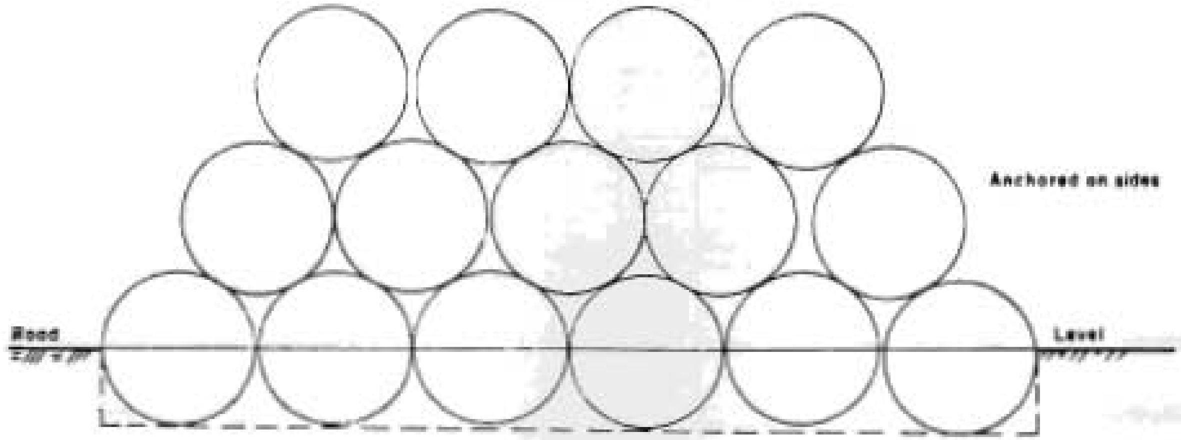
Drum walls from bitumen drums can be used for temporary walls on sections of shallow landslides where there is large road formation width.



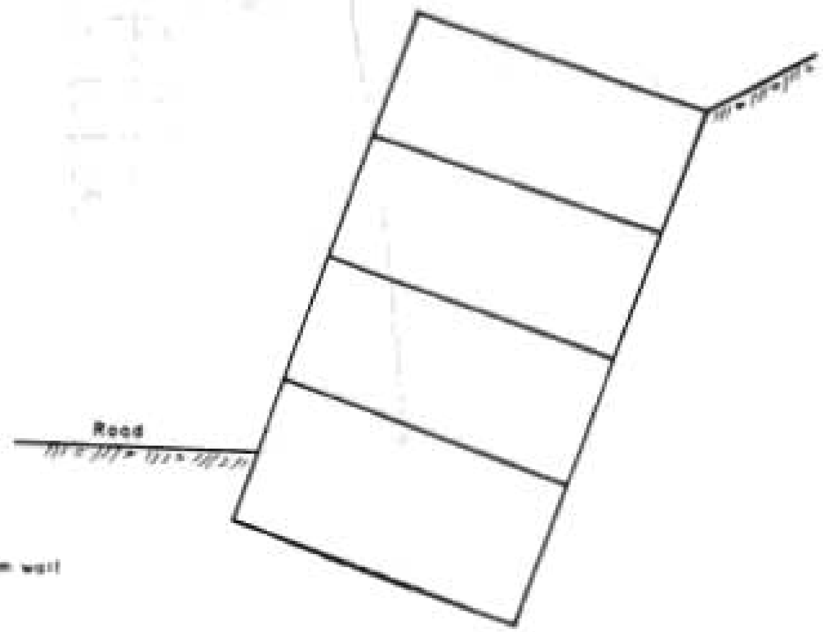
Heavy cylindrical walls are useful for retaining higher earth pressure.



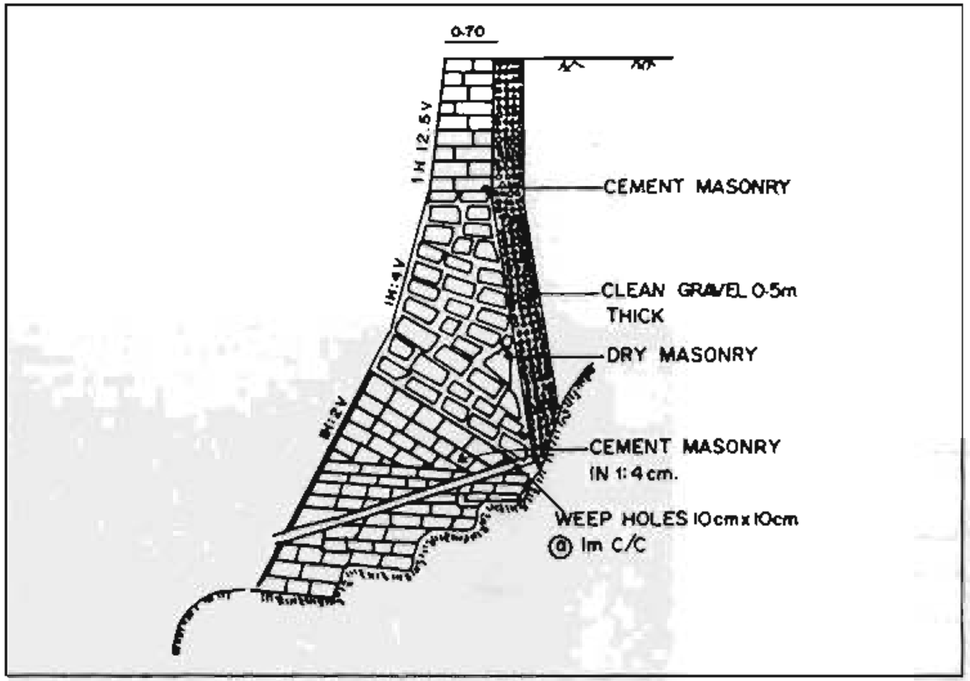
Gabion walls are easy to construct, flexible for yielding foundations, self draining, and do not require cement, sand, and water.



(a) Front view of horizontal drum wall

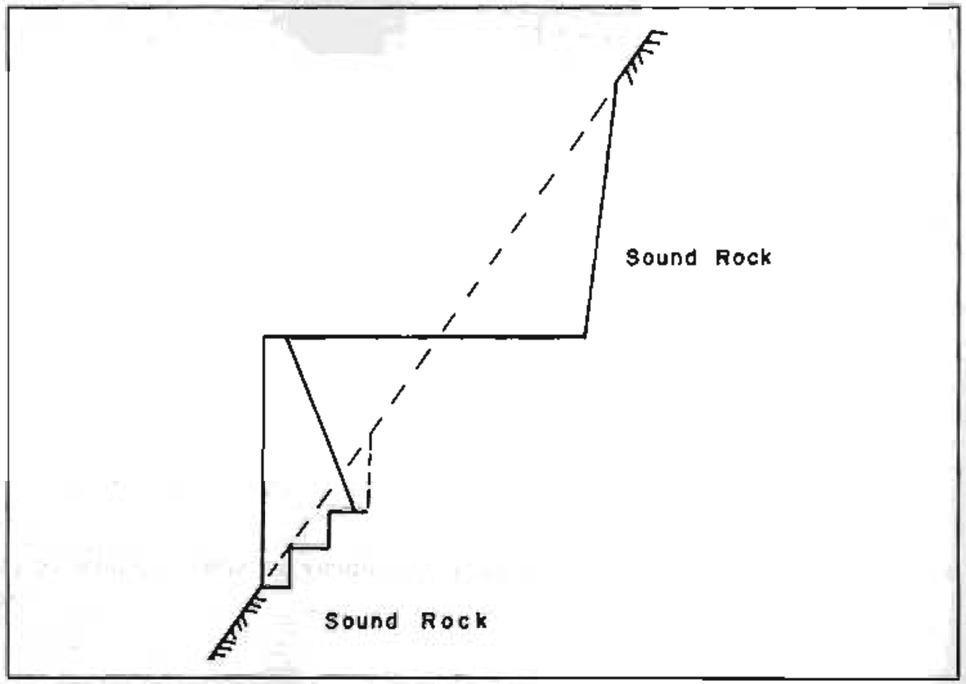


(b) 1.2m high drum wall



Composite wall (consisting of dry masonry and cement masonry) is suitable and economical whenever the foundation is sound.

Cement masonry walls can be constructed economically in rocky areas because benching of the foundation is possible and the backfill wedge may also be smaller.



Selection of the retaining wall type depends upon the height of the wall, hill slope, fill slope, hazard level, construction time, life of the wall, foundation type and material, construction material, equipment, initial cost, and aesthetics.

FINAL SELECTION OF TYPE OF RETAINING WALL

WALL TYPE									CONSTRUCTION MATERIAL				
BY MECHANICS	BY STRUCTURAL MATERIAL	HEIGHT OF WALL M	HILL SLOPE DEGREE	HAZARD LEVEL	FILL SLOPE	CONSTRUCTION TIME	LIFE OF WALL YEARS	FOUNDATION MATERIAL	BACKFILL MATERIAL	STRUCTURE	EQUIPMENT REQUIRED	AESTHETIC REQUIRED	INITIAL COST
GRAVITY	DRYSTONE MASONRY	1-8	<35	L	<35	SHORT	≤20	GOOD	GOOD	HARD, RECTANGULAR STONE BLOCKS	PORTABLE COMPACTER	GOOD	LOW COST
GRAVITY	DRYSTONE MASONRY	1-5	<35	H	<35	SHORT	≤5	FAIR	GOOD TO FAIR	HARD, RECTANGULAR STONE BLOCKS	PORTABLE COMPACTER	GOOD	LOW COST
GRAVITY	GABION	1-10	<60	L,H	<35	SHORT	≤20	FAIR	GOOD TO FAIR	HARD STONE BLOCKS OR BOULDERS, G.I. WIRE	PORTABLE COMPACTER	GOOD	MEDIUM COST
GRAVITY	RCC CRIB	1-10	<35	L,H	<35	SHORT	≤20	FAIR	GOOD TO FAIR	PRECAST RCC CRIBS	PORTABLE COMPACTER	GOOD	LOW COST
GRAVITY	DRUM WALL	≤2.5	<35	L,H	<35	SHORT	<5	FAIR	FAIR	EMPTY BITUMEN DRUMS	TAMPER	POOR	VERY LOW COST
GRAVITY	CEMENT MASONRY	1-10	ANY	L	<35	AS REQUIRED	>20	GOOD	GOOD	CEMENT, SAND, WATER	-	FAIR	HIGH COST EXCEPT FOR BENCHING ROCKS
GRAVITY	DRYSTONE MASONRY WITH BANDS OF CEMENT MASONRY	4-8	<15	L	<20	AS REQUIRED	<20	GOOD TO FAIR	GOOD TO FAIR	PARTIAL CEMENT, SAND, AND WATER	PORTABLE COMPACTER	FAIR	MEDIUM COST
GRAVITY	REINFORCED CONCRETE	>8	<40	L	<35	AS REQUIRED	<20	GOOD TO FAIR	GOOD	CEMENT, SAND, WATER, AGGREGATES, STEEL FORM WORK	CONCRETE MIXER, VIBRATOR, TRUCKS	FAIR	MEDIUM COST
REINFORCED EARTH	GABION MASONRY FOR FACING AND GABION MESH OR GEOTEXTILE FOR EARTH REINFORCEMENT	1-10	<35	L	<35		<20	GOOD TO FAIR	FAIR	STONE, GIWIRE, PROPRIETARY MANUFACTURED PRODUCTS	COMPACTOR	FAIR	MEDIUM COST

Source:

1. Other wall types such as anchored walls may be considered depending on unusual problems, site coditions, and available materials and equipment.
2. Comparative cost calculation and environmental considerations may be required for final decisions in case of major walls.

It is not possible to design each and every wall for a long road. The design approach can be based upon the height of the wall, lenght of the wall, hazard level of the area, and the project cycle.

Design Approach for Retaining and Breast Walls During Different Project Cycles

Design Method	Wall Size Height, m	Wall Size Area, m^2	Type	Hazard level	Project Cycle
Rule of thumb	< 3	< 120	D, CM, G	L	All
	< 3	< 120	G	H	All
	< 3	< 120	D, CM, G	L	PF, F, D, CON.
	< 3	< 120	G	H	PF, F
Standard Drawing	4-8	< 120	D, CM, G	L	All
	4-8	< 120	G	H	PF, F
	4-8	< 120	D, CM, G	L	PF, F
	4-8	< 120	G	H	PF, F
	> 8	< 120	CM, G	L	PF, F
	> 8	< 120	G	H	PF, F
Semi-Empirical	< 3	> 120	D, CM, G	H	CON.
	4-8	< 120	G	H	D, CON
	4-8	> 120	D, CM, G	L	D, CON
	4-8	> 120	G	H	D, CON
	> 8	< 120	CM, G	L	D, CON
	> 8	> 120	G	H	D, CON
	> 8	> 120	CM, G	L	PF, F, D
	> 8	> 120	G	H	PF, F
Theoretical Analysis and Specific Design	> 8	> 120	CM, G	L	CON
	> 8	> 120	G	H	D, CON

TYPE OF WALL
D = Dry stone masonry
CM = Cement stone masonry
G = Gabion masonry

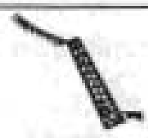
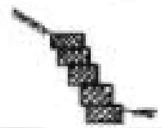
PROJECT CYCLE
PF = Prefeasibility
F = Feasibility
D = Detailed design

HAZARD LEVEL OF THE AREA
L = Low
H = High

OTHER TYPES OF WALL Follow proprietary, semi-empirical or theoretical methods.

Breast walls are useful for minimizing the height of cut on slopes that can stand at steeper slopes in dry conditions but are liable to failure later on due to erosion, toe cutting, and other minor disturbances.

Types of breast wall and their applications

TYPE	Breast Walls/Revetment Walls						
	DRY STONE			HANDED DRY STONE MASONRY	CEMENT MASONRY	GABION	HORIZONTAL DRUM WALLS
Diagrammatic cross-section							
Construction notes: Top width	0.5			0.5	0.5	2	1
Base width	0.25H	0.3H	0.33H		0.23H	2	1
Front batter							
Back batter	3:1	4:1	5:1	3:1	3:1	3 to 5:1	3:1
Inward dip of foundation	1:3	1:4	1:5	1:3	1:3	1:6	1:5
Foundation depth below drain	0.5m	0.5m	0.5m	0.5m	0.5m	0.5 – 1m	0.25m
Range of height	6m	4m	3m	3–8m	1–10m	1–8m	2.2m
Hill slope angle	35 – 60			35–60	35–70	35 – 60	35
Toe protection in case of soft rock/soil	No pitching			No	No	No	No
General	Pack stone along foundation bed. Use bond stones. Specify minimum stone size.			Cement masonry (1:6) bonds of 0.5m thickness at 3m c/c.	Weep holes 15x15 cm at 1.5-2m c/c and grade 1:10. Cement sand mortar (1:6)	Step in front face 20–50 cm wide. Otherwise as for retaining walls.	Use vertical single drum for 0.7 m height. Anchor drum walls on sides. Fill debris material.
	Revetment walls have uniform section of 0.5m/0.75m thickness for batter of 2:1 or more. Section shaped to suit variation and overbreak in rock cut slope.						
Application	Least durable/economical			Little used	Most durable / costly	Quite durable /costlier or Very flexible	Promising/most economical Flexible
	Not ductile structures most susceptible to earthquake damage						
	Revetments are used to prevent only major erosion, rockfall, slope degradation particularly where vulnerable structures are at risk.						

Notes

1. Wall construction requires special skills and practical labour. Curing of masonry walls generally not feasible in hills due to paucity of water.

2. The typical dimensions shown rely both on well–drained backfill and good foundation conditions.

3. Detailed design is necessary in case of soil slopes and walls higher than 6m and poor foundation conditions.

4. Gabion walls should be used in case of poor foundation/seepage conditions. They can take considerable differential settlement and some slope movement.

5. Other measures should also be taken, e.g., check drains, turfing, benching of cut slopes in soft rocks, sealing of cracks, etc. All preventive measures should be implemented in one season. Total system of measures is far more effective than individual measures.

3.4.4 Drainage and Erosion Controls

Side drains

Side drains should be designed to safely carry runoff from the entire watershed above the road and from the road surface between the two culverts.

At least a 5 year return period of rainfall should be considered.

All side drains in high runoff areas, on steep gradients, and in erodible areas should be lined to protect the road from the undercutting of side slopes, from weakening of pavement layers by infiltration of water, and from landsliding caused by pore-water pressure development beneath the road level by the infiltration of water.

Wet areas require surface drains as well as sub-surface drains.

Protections are required at the outfall of side drains, switchbacks, and on bends.

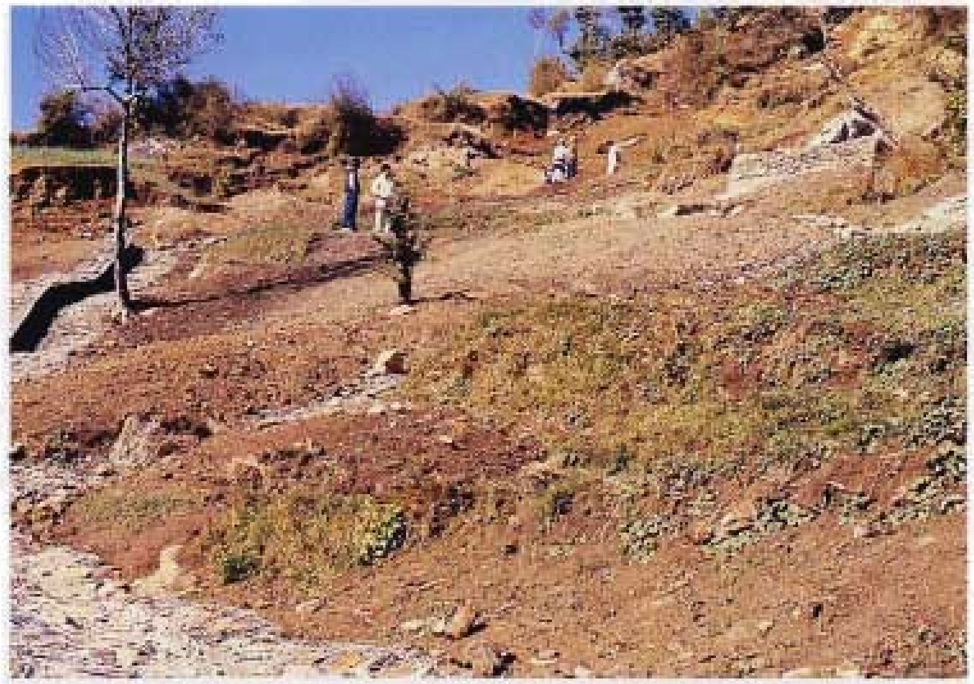
Side drains can sometimes be completely avoided by outsloping the road.

Culverts

Culvert design should be based on hydrological and hydraulic considerations. Culverts should be designed for a 10 year return period for minor culverts and a 25 year return period flood for major culverts.

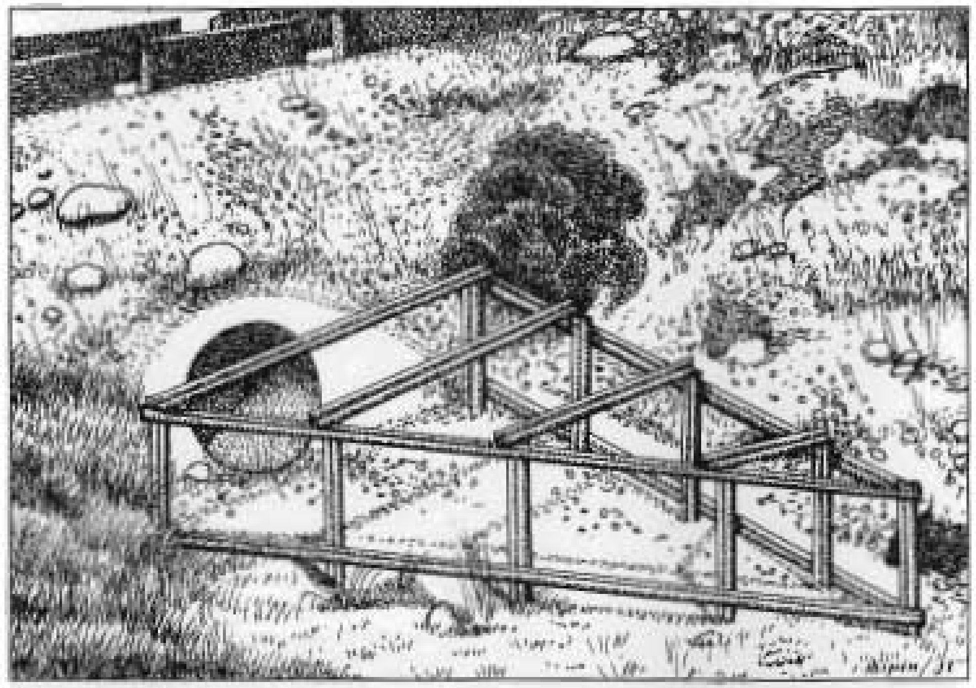
Protections should be designed at the outfall of culverts.

◂ A combination of surface and sub-surface drain is required for wet areas.
▾



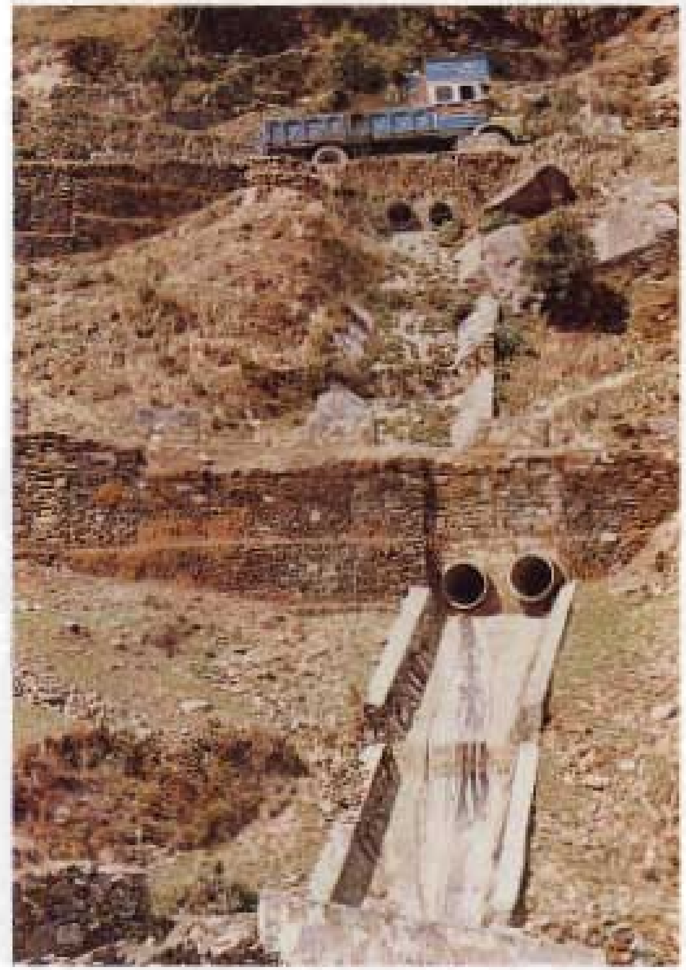
Debris relief riser to relieve water passage in the event of the culvert entrance clogging.

A debris relief riser



Debris deflector to protect the culvert entrance from clogging by large boulders

Culvert with outlet protections



Erosion protection by a series of check dams

A cascade for gully control

Erosion protection at the outfall of a side drain

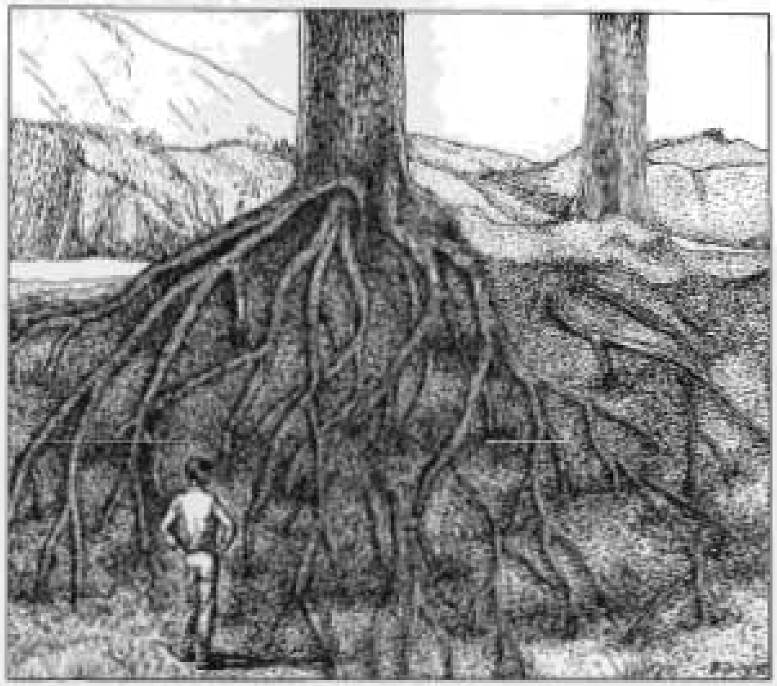
A view of a tea estate (a productive erosion protection for hill slopes

3.4.5 Biotechnical Stabilization

Biotechnical measures help stabilize cut slopes, the watershed influencing the road, and minor landslides by:

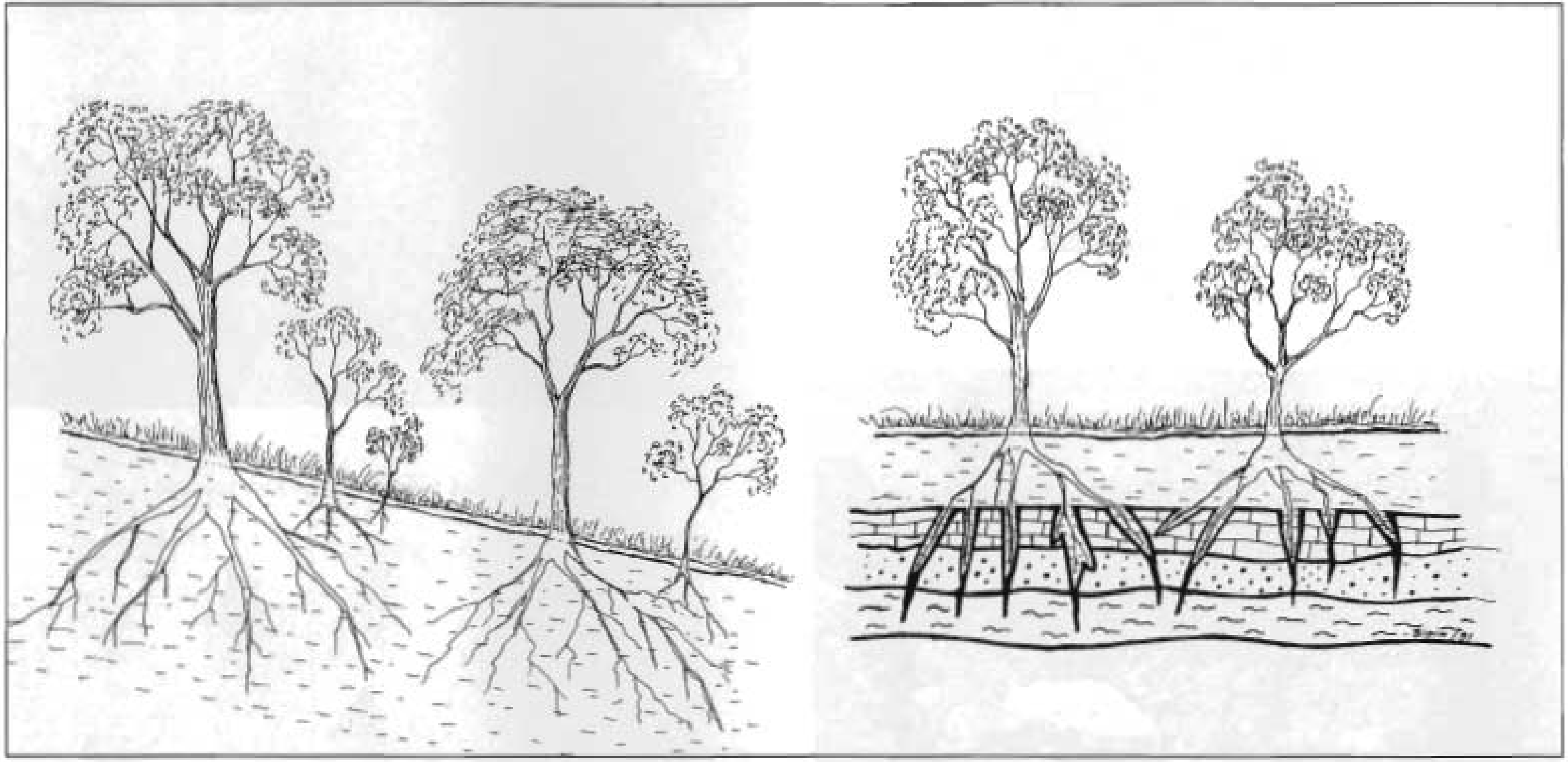
- providing cover against surface erosion,
- increasing soil shear strength, and
- reducing the groundwater table or moisture content.

Frictional anchoring of roots embedded in the soil causes the roots to develop tensile resistance to shearing, increasing the shear resistance of soil.



Vegetation cover reduces runoff by interception and increased infiltration. Root binding protects against splash or sheet erosion and prevents the dislodging of soil particles.

Root reinforcement increases the shearing strength of soil through the presence of roots anchored in the soil.



Root reinforcement and anchoring of plant roots develop effectively only when the root can gain sufficient anchoring by penetration into the soil layers or cracks of bedrock.

Root anchoring of shallow layers of soil on steep bedrock with little or no fractures cannot develop effectively to help prevent slides. Similarly, deepseated slides are not affected by root reinforcement.

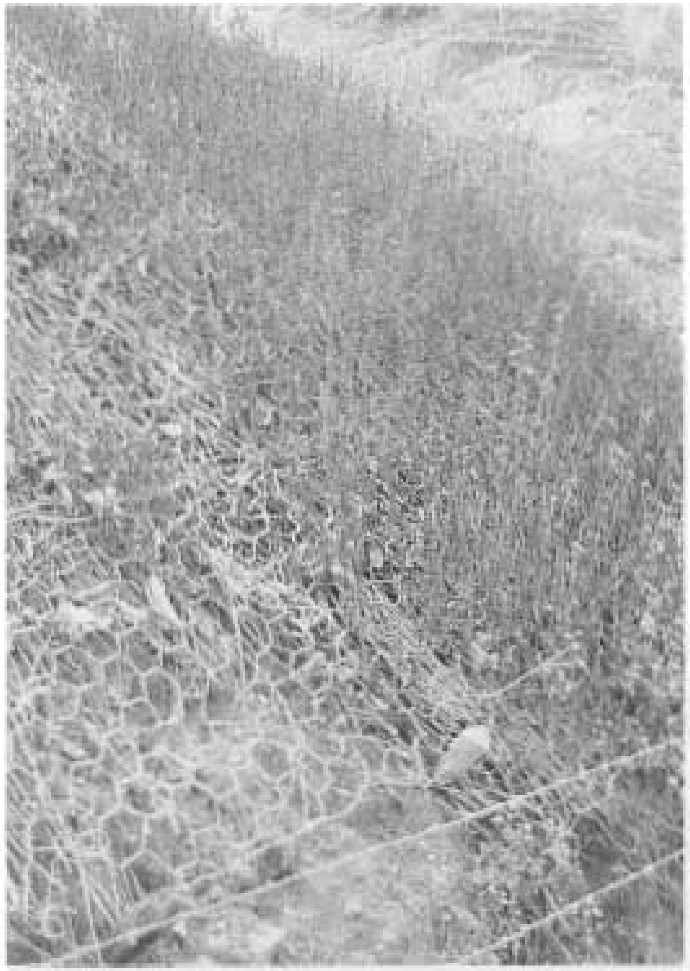
▲
In spite of thick forest, landslips have occurred

The tilted trees on the slope indicate the creep movement of the slope.
▼

Cuttings are fixed with stake and covered by jute net manually.

Cuttings fixed and covered by synthetic fabrics

Completed work on a road slope along the Dharan - Dhankuta Road, Nepal

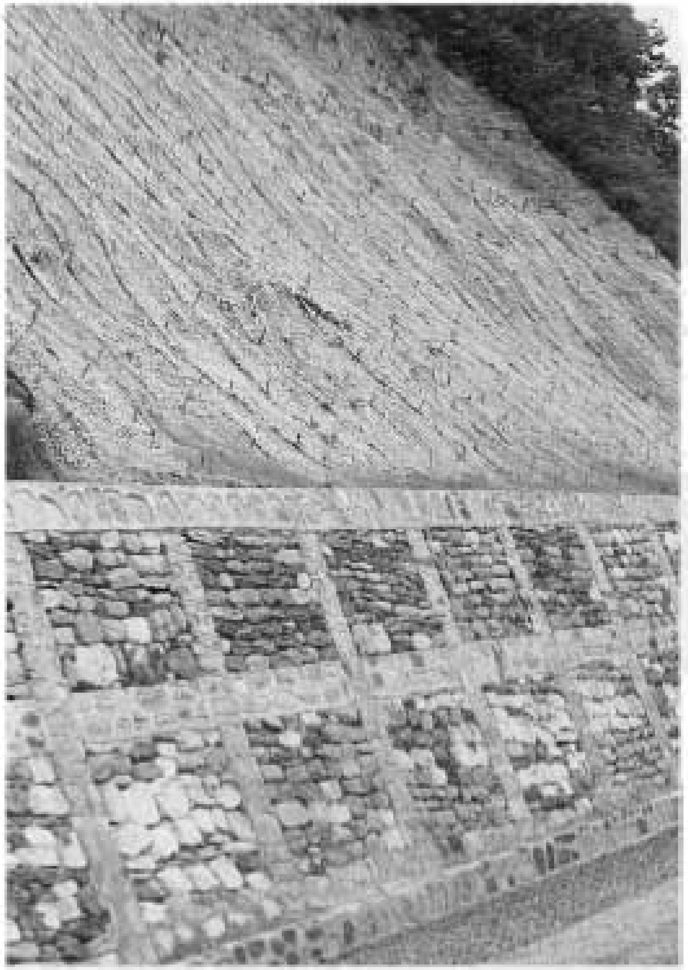


Covering the ground with salvaged gabion net has helped revegetation.

Downslope grass lines planted on the poorly drained Siwalik mudstone.

Diagonal grass lines planted on a steep slope

Terracing of slope below road and grass planting



This cut slope supported by a breast wall is protected by biotechnical measures.

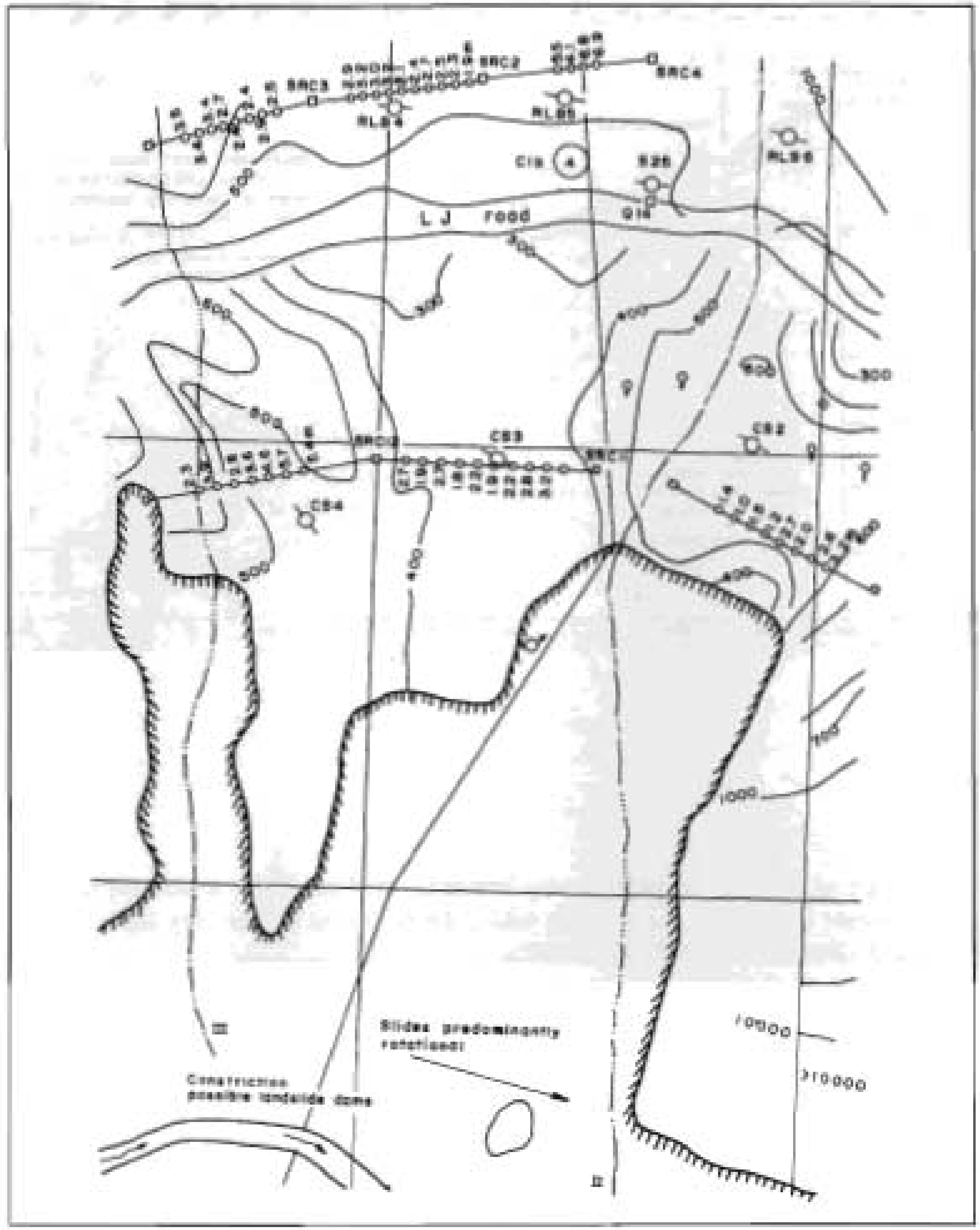
A lined catch drain above the cut slope

A combination of biotechnical and landslide drainage measures stabilize a landslide that damaged the road. The photograph on the left shows the completed works, while the photograph to the right shows the same site under construction.

Seabuckthorn

- a productive method of mountain slope stabilization in China is the use of this plant which is adaptable to a climate range of from 60 m to 5200 m, fast growing and has strong roots. The fruits are used for making jam, wine, and various food products.

Seabuckthorn fruits from the Langtang area, Nepal

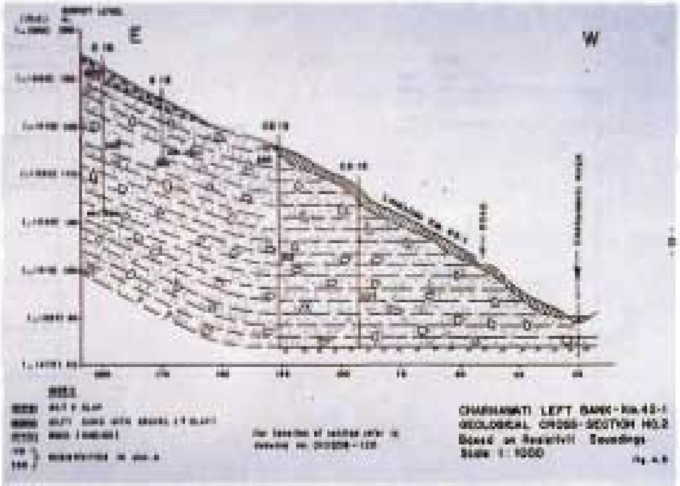


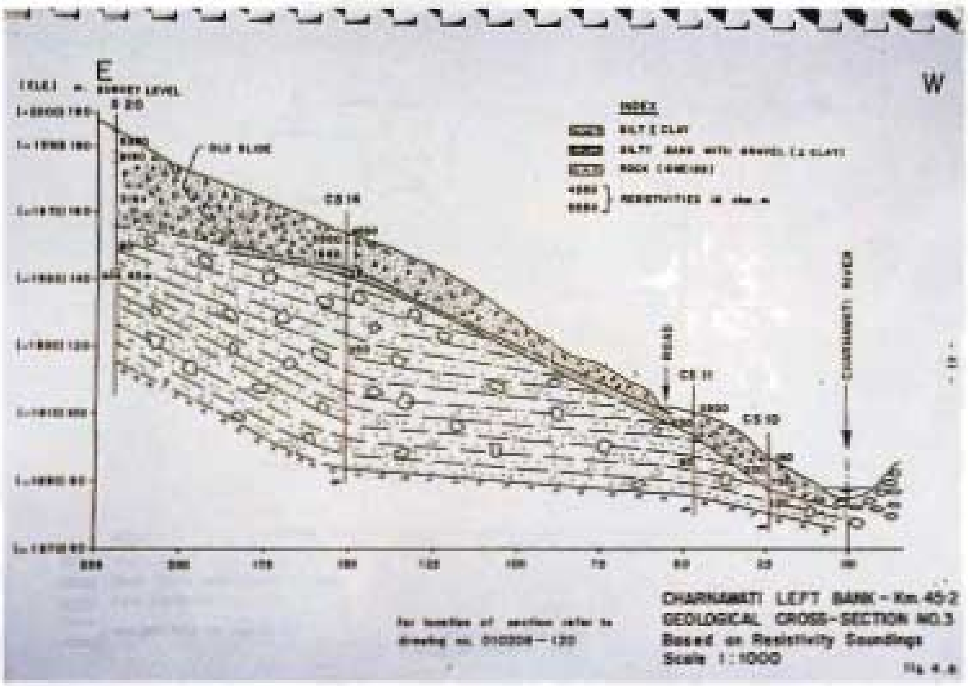
3.4.6 Geophysical Methods for Detailed Studies

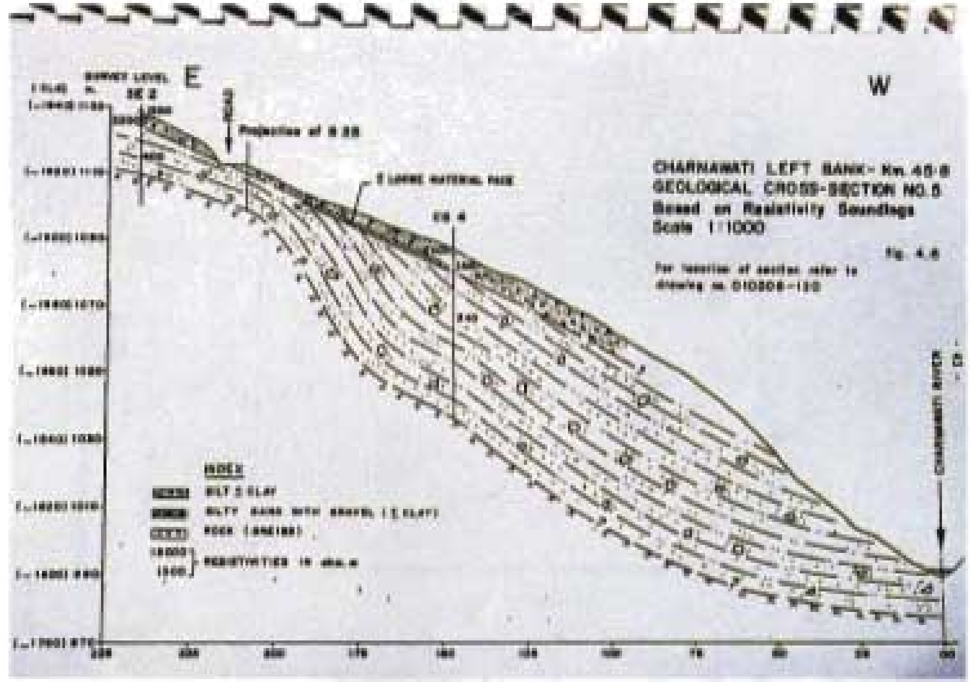
Geophysical methods are very relevant for detailed assessments.

Resistivity and seismic refraction methods are commonly used.

This map shows resistivity contours and seismic refraction shots of a landslide area. While the reisistivity contours permit the identification of the water table (which is close to the ground surface), the seismic shots allow the identification of 2 to 6 m thick unstable, loose material between the two slides. As expected, both slides widened up to the road. The remedial measures applied were landslide drainage by horizontal and surface drains and anchoring of the sliding mass.





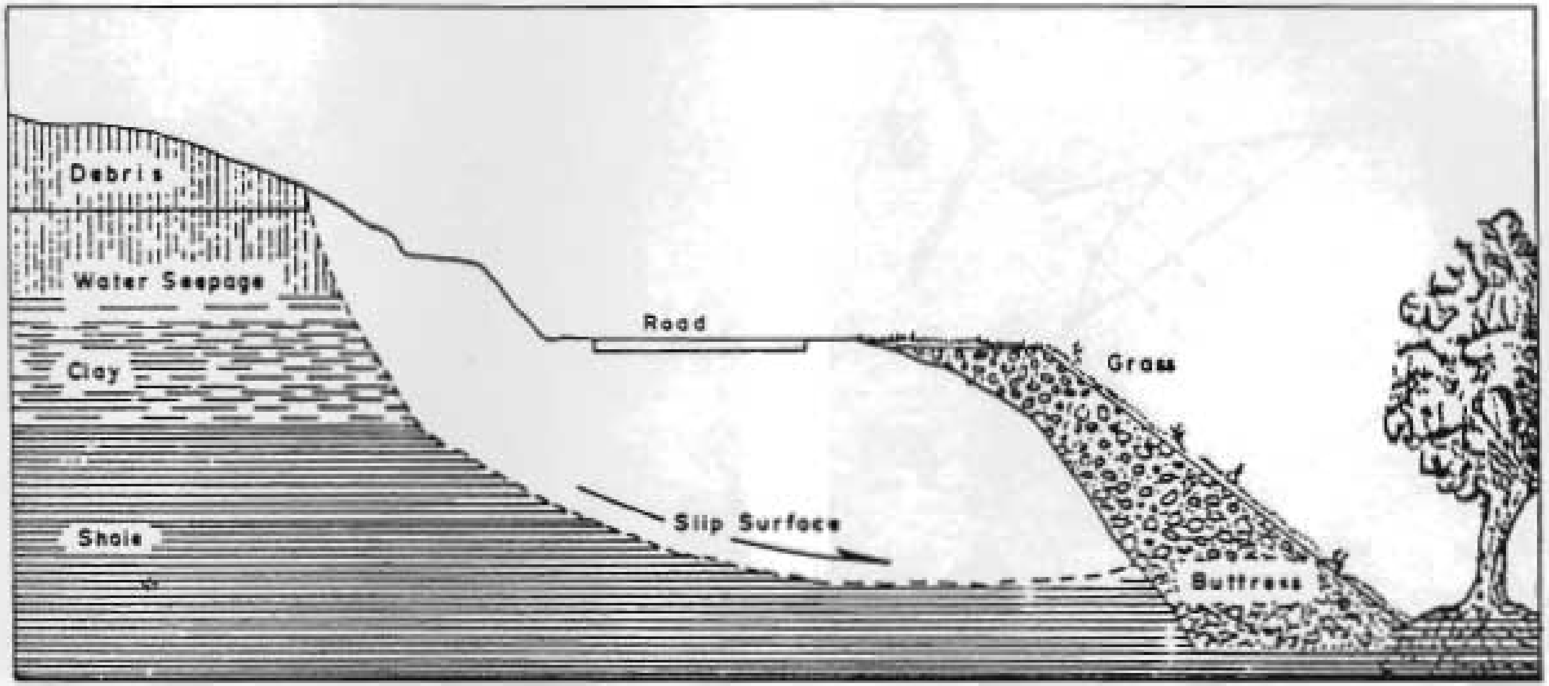


Electrical sounding is another very important method. This method permits one to locate the depth of the water table, the thickness of the clay layer, or the depth of sound bedrock.

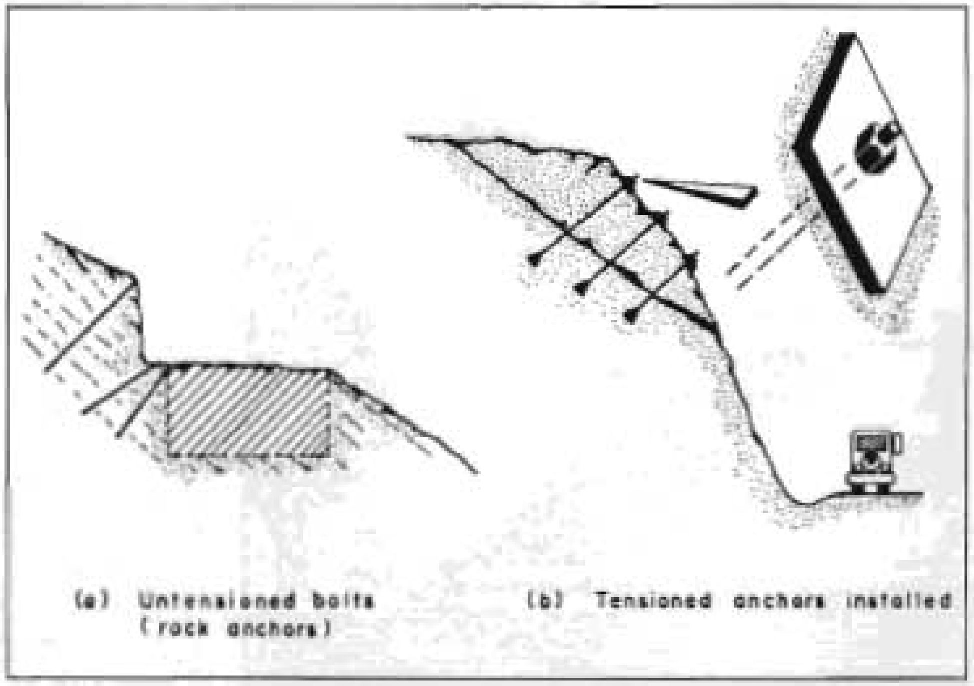
The figures show the results of electrical sounding in the Charnawati Valley, Nepal.

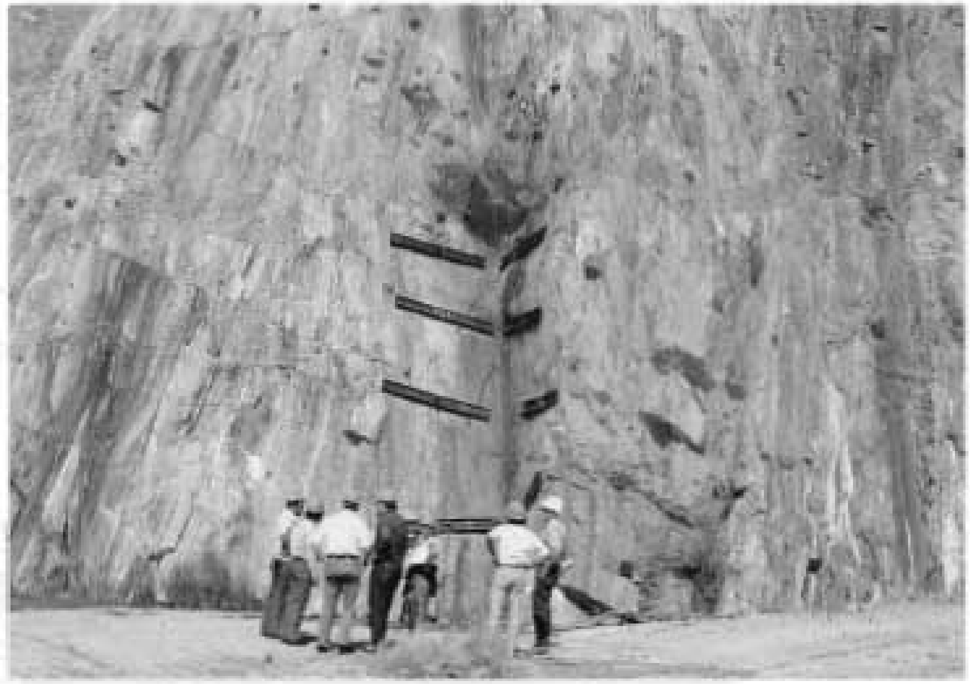
3.4.7 Landslides and Slope Stabilization

Stabilizing berms in the form of rocks, gravel, or sandfills are placed at the toe of the slope, where upward movement of the sliding mass is possible. This buttress



increases resisting forces and at the same time prevents piping of the unstable material. Specially graded filter of stone aggregates or modern synthetic filter fabrics are used to prevent the piping of finer materials. The size of the buttress is roughly one third the volume of the moving mass to be restrained.

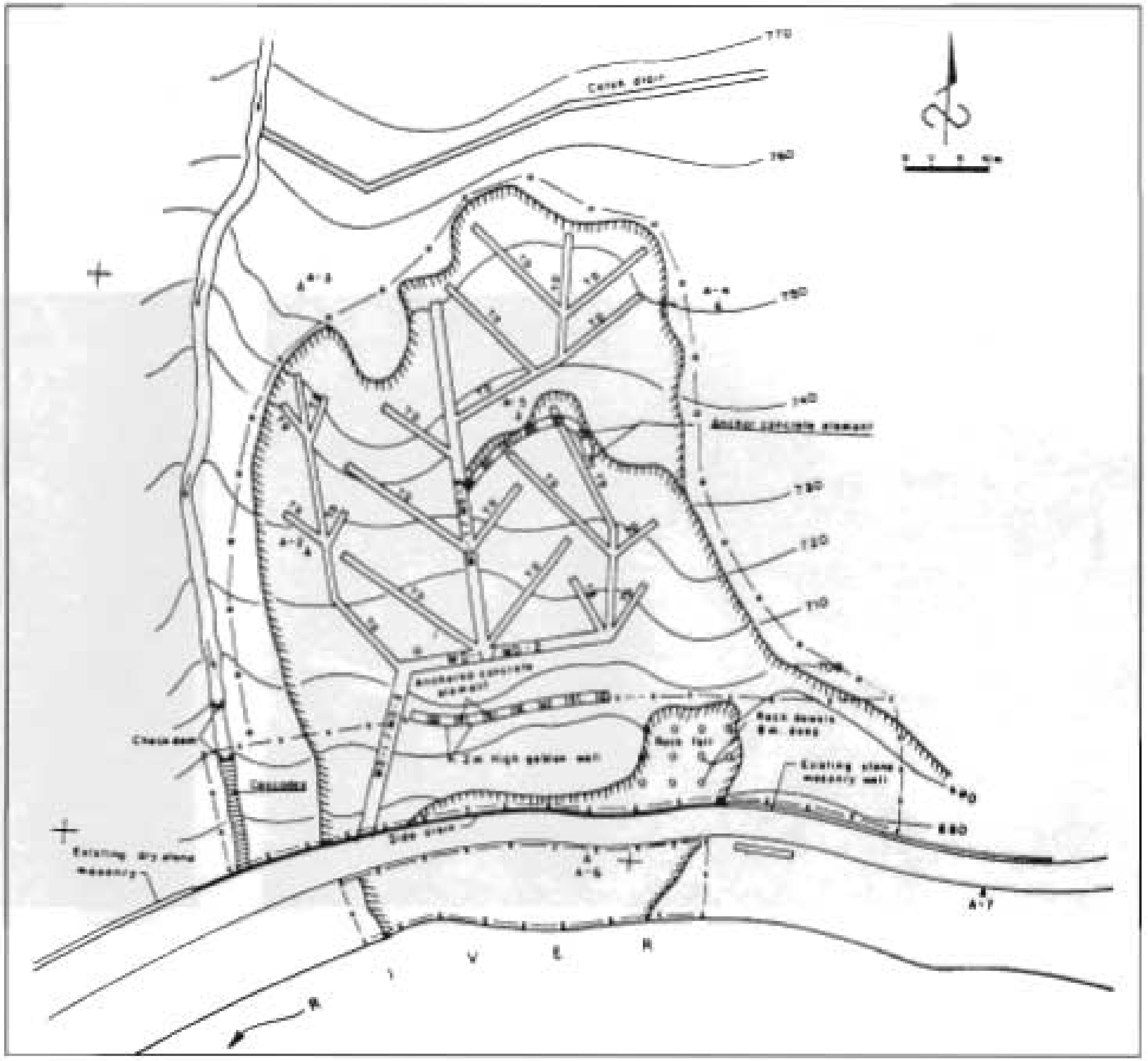




Fractured rock masses can be held together by rock bolts. Sliding rock masses along a joint plane can be stabilized by the installation of rock anchors embedded into sound rock.

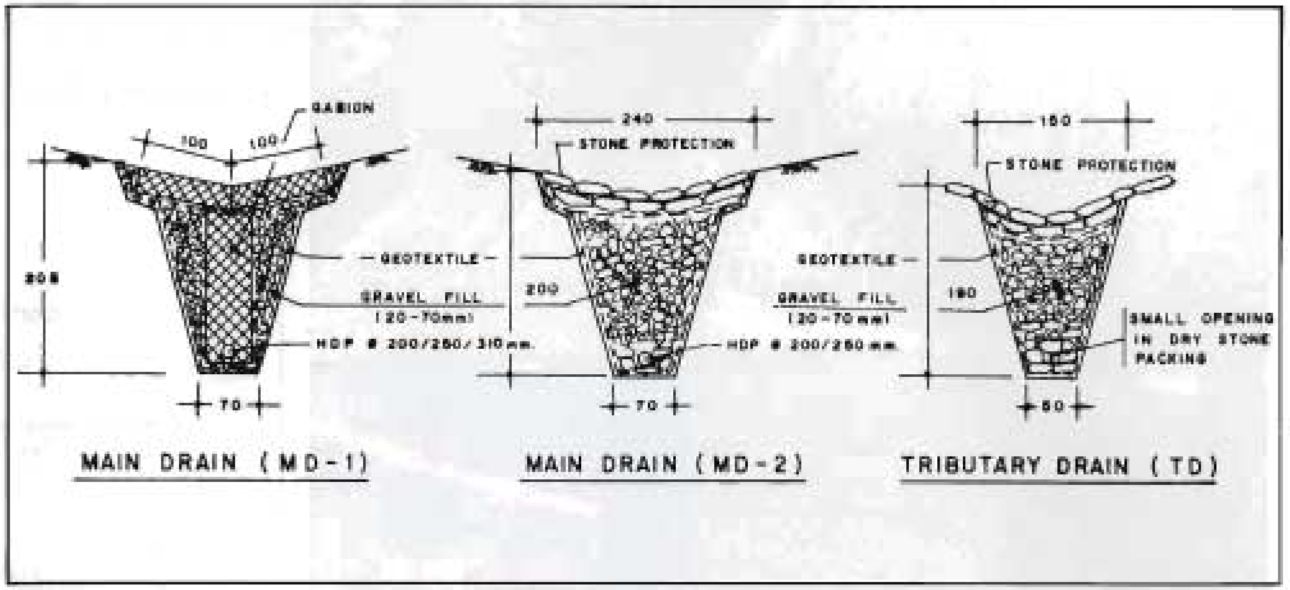
The anchor bars are fixed to a metal base plate which rests on the 1m x 1m reinforced concrete distribution slab 1m to 2m apart.

Landslide stabilized by a sub-surface drainage network



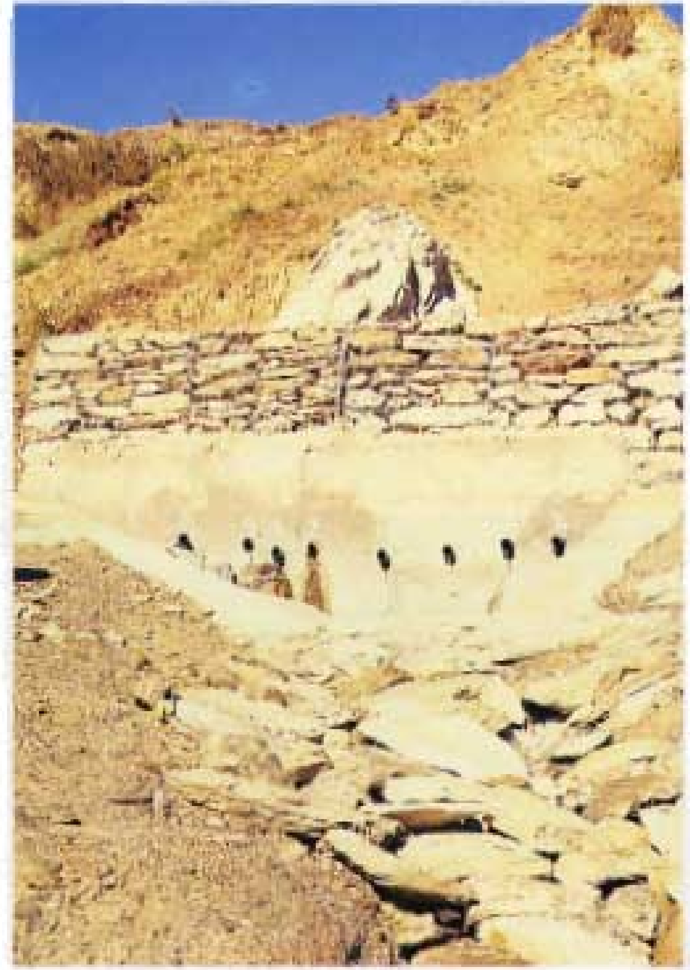
Counterfort drains collect water from tributary drains.

Counterfort Drains (Main Drains) and Tributary Drains



◂ Horizontal drains along a forest road, California, USA

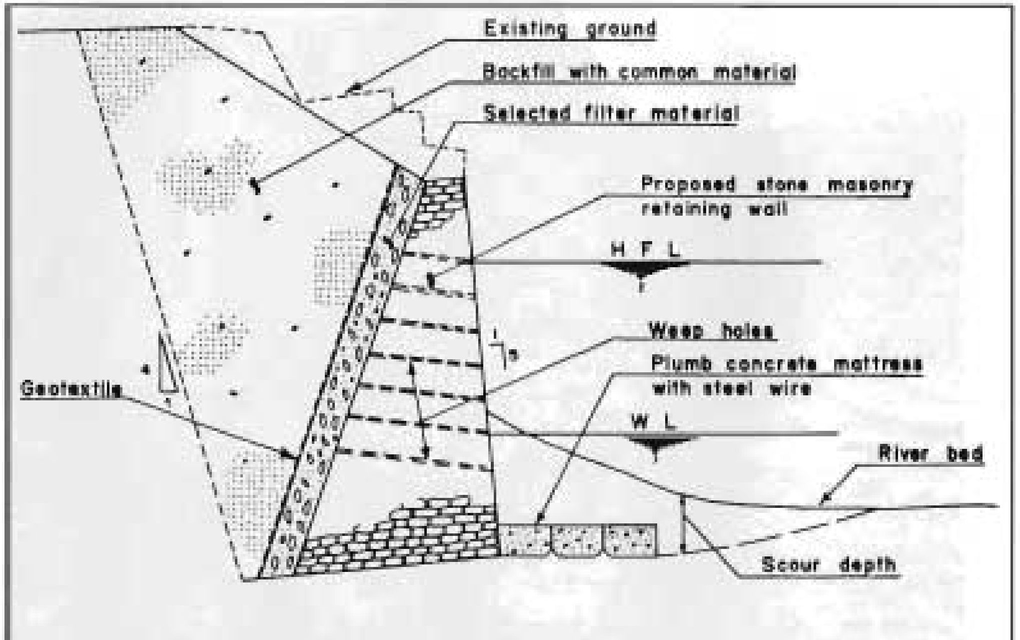
Horizontal drains at the Charnawati,Lamosangu-Jiri Road, Nepal ▾



Horizontal drilling

3.4.8 River Training

Cement masonry revetment wall with gabions above high flood level

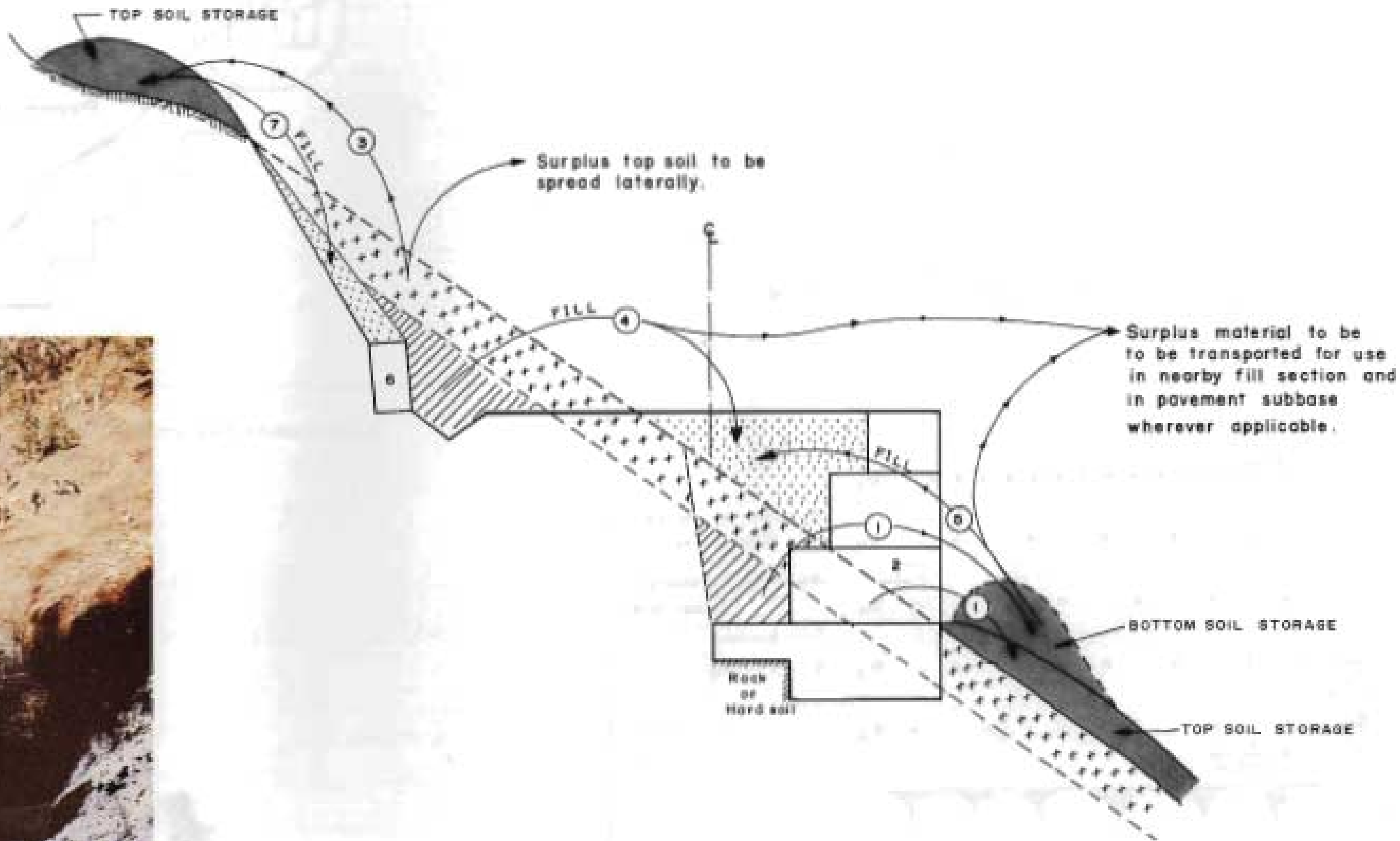


'River Training Work' with type 'B' launching apron

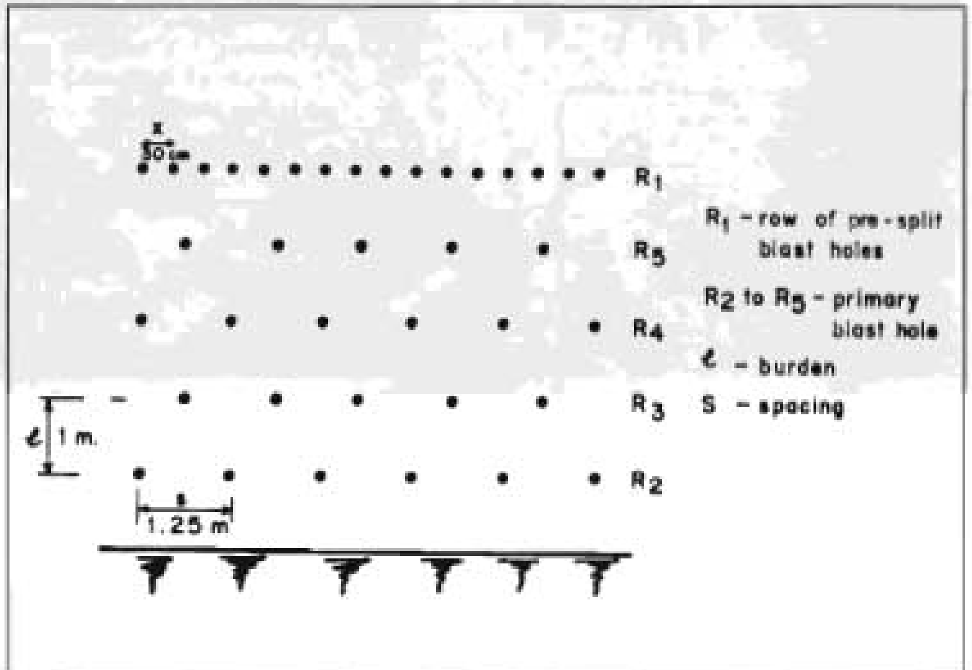
Prevention of bed scour and bank sliding of a steep mountain stream, with thick (more than 30 m) soil cover, by use of concrete armour blocks (tetrapods), along the Charnawati River, Nepal.

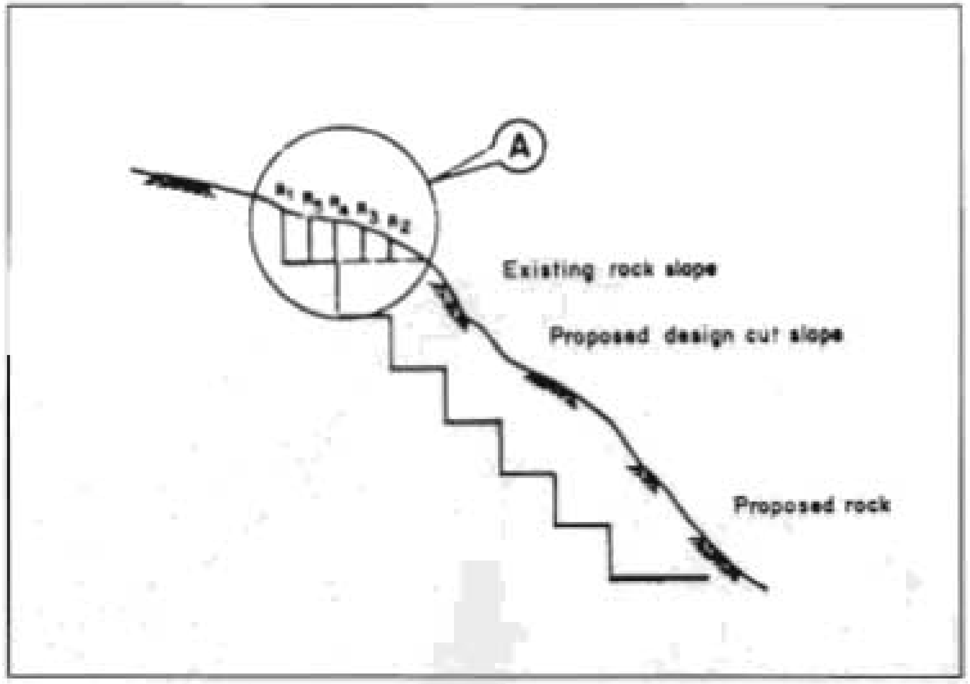
3.5 Environmentally Sound Construction Methods

Construction of a road by building the retaining wall first, saving the topsoil, filling behind the retaining wall, and reusing the topsoil for vegetation minimizes the problem of loss of topsoil and disposal of excavated material.



Plan view of A: a staggered pattern of blasting





An illustrative diagramme for pre-split blasting

Founding of ICIMOD

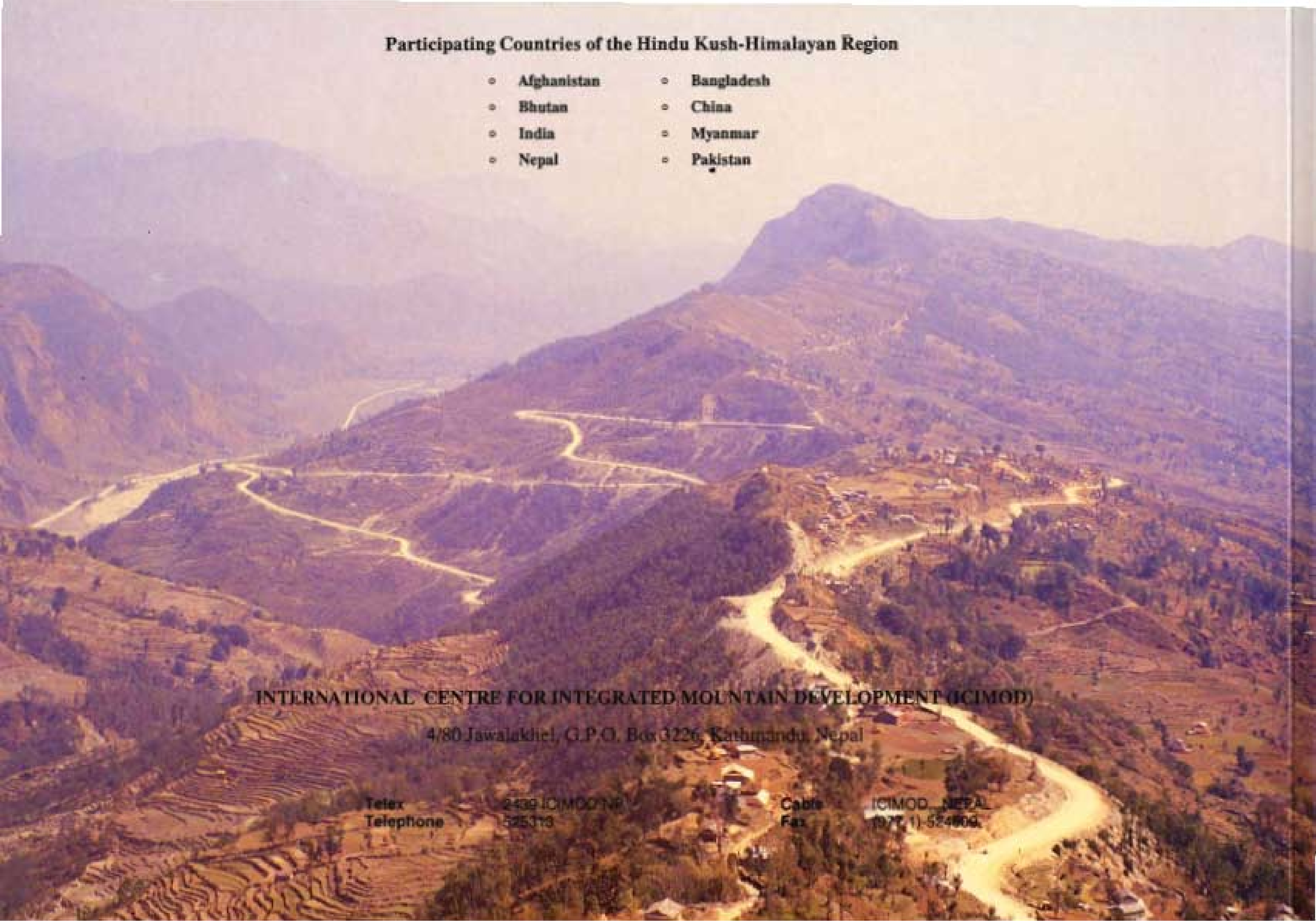
The fundamental motivation for the founding of this first International Centre, in the field of mountain area development, was widespread recognition of the alarming environmental degradation of mountain habitats and the consequent increasing impoverishment of mountain communities. A coordinated and systematic effort on an international scale was deemed essential to design and implement more effective development responses to promote the sustained well-being of mountain communities.

The establishment of the Centre is based upon an agreement between His Majesty's Government of Nepal and the United Nations Educational, Scientific, and Cultural Organisation (UNESCO) signed in 1981. The Centre was inaugurated by the Prime Minister of Nepal in December, 1983, and began its professional activities in September, 1984.

The Centre, located in Kathmandu, the capital of the Kingdom of Nepal, enjoys the status of an autonomous international organisation.

Director : Dr. E.F. Tacke

Deputy Director : Dr. R.P. Yadav



Participating Countries of the Hindu Kush-Himalayan Region

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

INTERNATIONAL CENTRE FOR INTEGRATED MOUNTAIN DEVELOPMENT (ICIMOD)

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