

### 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,  $P = \text{rating for state of nature} \times \text{rating for rainfall} = 0.8 \times 0.5 = 0.40$ .

#### 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°	0.17
			> 45°	0.19
2	Relative relief	Very low	0 - 50 m	0.00
		Low	51 - 100 m	0.01
		Medium	101 - 150 m	0.04
		High	150 - 200 m	0.09
		Very high	> 200 m	0.12
3	Drainage	Single	< 3m deep	0.00
		Active	3-10m deep	0.04
		Very active	> 10m deep	0.08
4	Climatic condition	Dry		0.00
		Wet		0.04
		Flooding (spring)		0.09
5	Land use	Thickly vegetated		0.00
		Moderately vegetated		0.03
		Sparsely vegetated		0.06
		Bare land, dry cultivated land,		0.09

S/N	Attribute	Description	Subdivision	Rating
4	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 artificial 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 (where 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	Cracked 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
		Closo	50cm-10cm	0.06
		Tight	< 10 cm	0.04
12	Rock structure: Orientation of fractures	Slope oblique to joint/ bedding for more than 30°		0.00
		Dip slope of joints ( $\pm 15^\circ$ )		0.04
		Dip slope of bedding ( $\pm 15^\circ$ )		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/diamicton/ 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

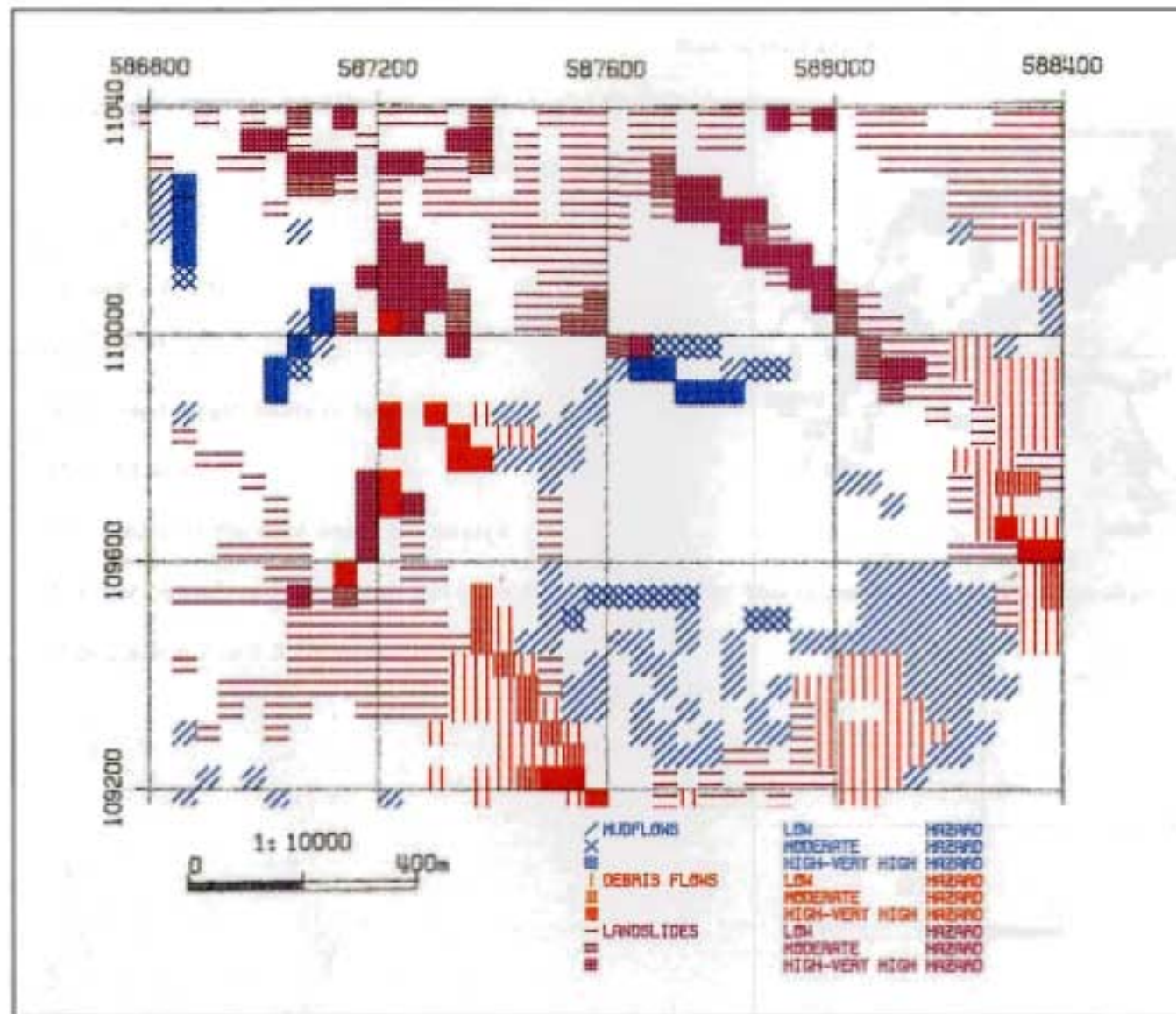
Average annual rainfall, mm	Meam annula maximum 24 hr rainfall, mm	Rating
1000	Less than 50	0.3
	50 to 100	0.5
	101 to 140	0.8
	141 to 170	1.0
	More than 170	1.0
2000	Less than 80	0.4
	81 to 120	0.6
	121 to 140	0.8
	141 to 170	1.0
	More than 170	1.0
3000	Less than 130	0.5
	131 to 150	0.8
	151 to 190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

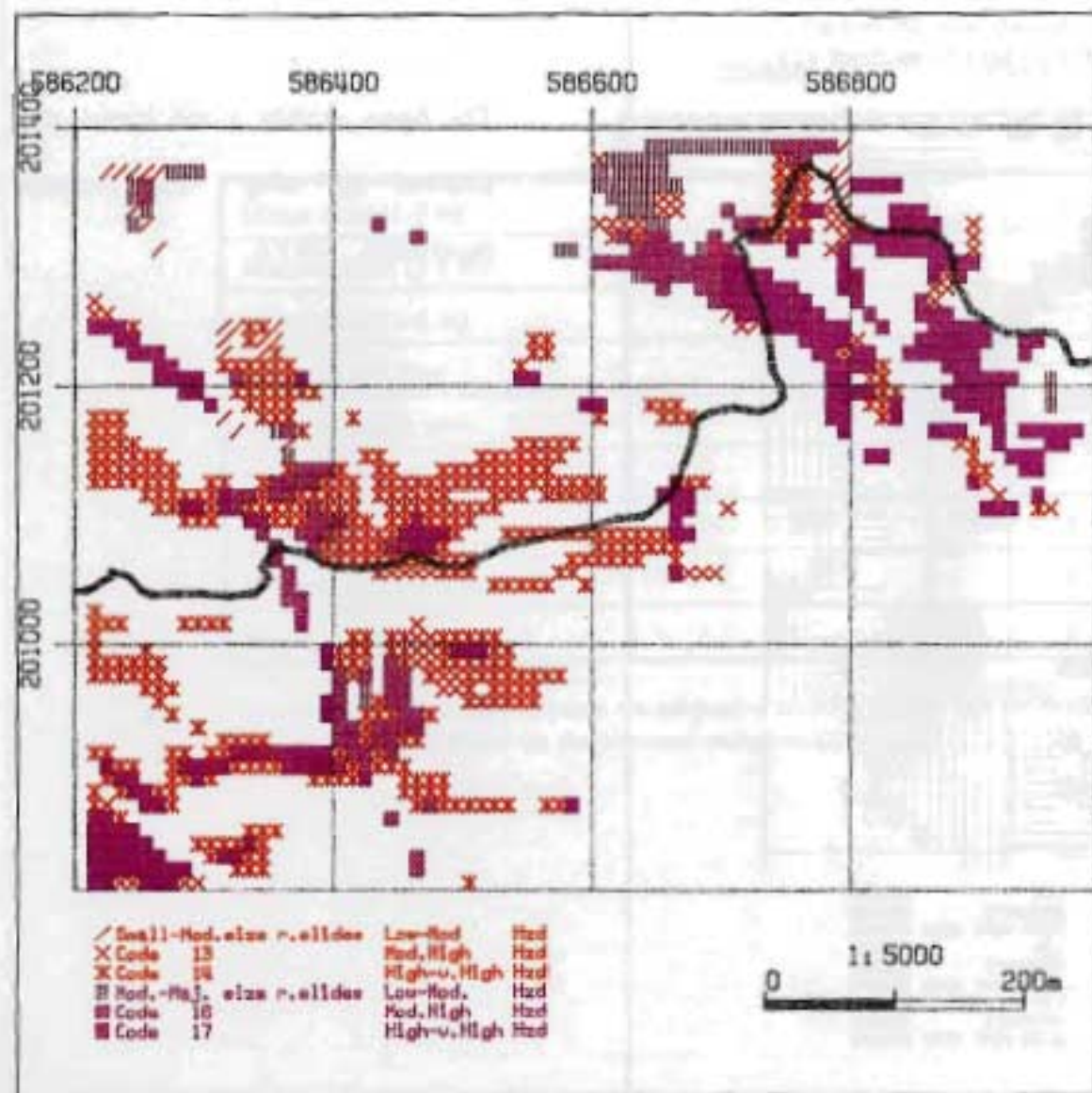
# Soil hazard map of the Prarion Region, Wallis, Switzerland



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



Kalang Section rock slide hazard map, Lamosangu-Jiri Road, Nepal



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 Feasibility Assessment of Mountain Roads

#### 3.3.1 Example of Alternative Alignments, Hazards, and Risks

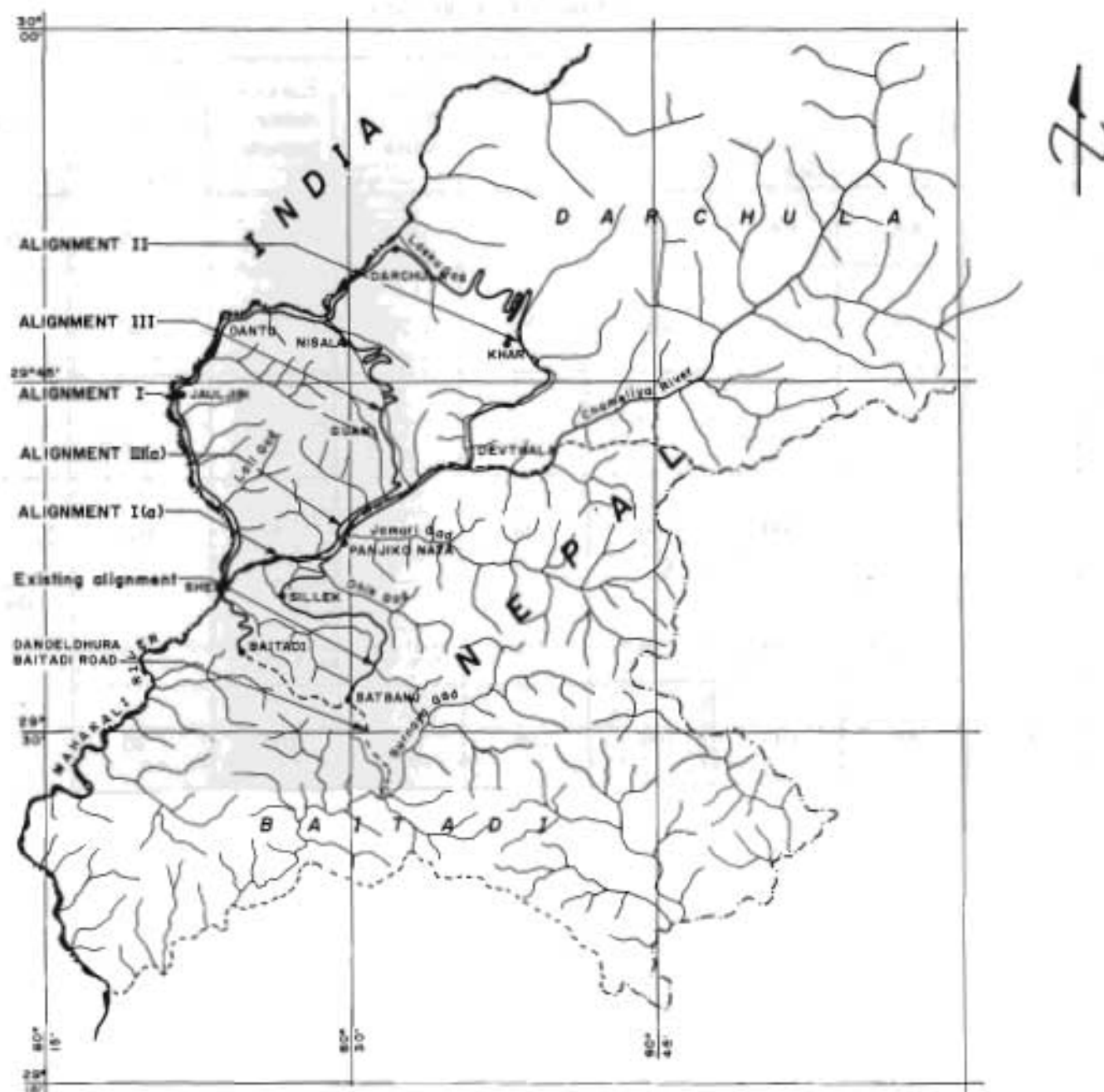
Comparative Hazard Ratings

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%	
Align ment 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		
Align ment 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		
Align ment 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				REMARKS
		VF	VG	CS	RS	VF	VG	CS	RS	VF	VG	CS	RS	VF	VG	CS	RS	
1) DESIGN SPEED, KPH		60	50	40	30	50	40	40	30	50	40	30	40	40	30	30	20	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 MIRRORS OR SLOW HORN. 2) FOR TRAFFIC LESS THAN 200 AADT AND AT SECTIONS OF LESS THAN 5% LONG-GRAD, AND PAVED AND SEALED AREAS, OUTSLOPING OF ROAD AT 5-4% MAY BE FOLLOWED TO REDUCE FORMATION WIDTH AND CUT VOLUME
2) TRAFFIC LANES, NO		2	2	2	2	2	2	2	2	2	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	
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	
5) GRAIN, 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	
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	
7) TOTAL FORMATION WIDTH IN M		10-15	10-15	10-15	10-15	10-15	9-15	9-15	9-15	10-15	9-10	9-10	9-10	6.25-7	5.5-9	5.5-9	5.5-9	
8) RULING GRADIENT %	HIGH STANDARDS, MY JUSTIFY TUNNELS,	3	4	5	5	4	5	5	5	4	5	5	5	4	7	7	5	
9) MAXIMUM GRADIENT %		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
10) EXCEPTIONAL GRADIENT %		-	10	10	10	-	10	10	10	-	10	10	10	-	12	12	12	
11) GRADE COMPENSATION AT CURVE %	CROSSING A RIVER MORE THAN ONCE, ETC. EXTENSIVE STUDY REQUIRED	100	100	100	100	100	80	80	80	100	80	80	80	100	80	80	80	
12) MAXIMUM LENGTH OF MAXIMUM GRADIENT, M		200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	
13) MAXIMUM LENGTH OF EXCEPTIONAL GRADIENT, M		200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	
14) MINIMUM LENGTH OF RECOVERY, AFTER MAXIMUM OR EXCEPTIONAL GRADE, AS SPECIFIED		200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	200-150M	
15) MINIMUM STOPPING SIGHT DISTANCE, M		90	60	45	30	60	45	45	30	60	45	30	45	45	30	30	20	
16) MINIMUM OFFSET FROM CENTRE LINE TO INSIDE EDGE OF CUT AT 1.2 M HT		14	5.5	3.5	2.5	6.5	3.5	3.5	2.5	6.5	3.5	3.5	2.5	20	15	15	10	
17) SUPER-ELEVATION, M																		
18) VERTICAL CURVE MINIMUM RADIUS OF HORIZ. CURVE, M		120	75	45	30	75	45	45	30	75	45	30	45	45	30	30	20	
19) EXTRA WIDENING OF PAVEMENT AT CURVES, M		-	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	

AADT = Average Annual Daily Traffic

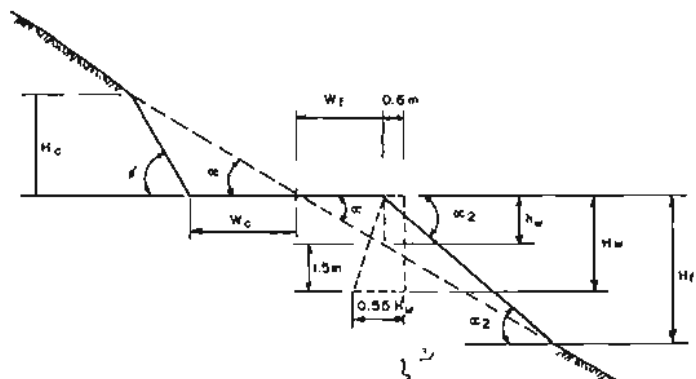
VF = Valley-floor

VG = Valley-gerge

CS = Climb Section

RS = Ridge Section

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



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

$$h_w = W_f \tan \alpha$$

$$\begin{aligned} H_f &= \frac{W_f \times h_w}{W_f + 2 h_w} \\ &= \frac{W_f^2 \tan \alpha \tan \alpha_2}{W_f \tan \alpha_2 - W_f \tan \alpha} \\ &= \frac{W_f \tan \alpha \tan \alpha_2}{\tan \alpha_2 - \tan \alpha} \dots \dots \dots (2) \end{aligned}$$

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

$$\text{Cut area } A_c = 0.5 H_c \times W_c \dots \dots \dots (4)$$

$$\text{Fill area without wall } A_f = 0.5 H_f \times W_f \dots \dots (5a)$$

$$\text{Fill area with wall, } A_{fw}$$

$$\begin{aligned} &= W_f \tan \alpha \left[ 0.5 W_f - \frac{0.25 W_f \tan \alpha}{1 + 0.5 \tan \alpha} \right] \dots \\ &= 0.5 W_f^2 \tan \alpha - \frac{0.25 (W_f \tan \alpha)^2}{1 + 0.5 \tan \alpha} \dots \dots (5b) \end{aligned}$$

$$\text{Quantity of retaining wall,}$$

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

$$\text{Quantity of breast wall,}$$

$$Q_B = (0.5 H_c + 0.15 H_c^2) \dots \dots \dots (7)$$

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

HILL SLOPE deg.	AV. SLOPE deg.	CUT SLOPE deg.	ROAD WIDTH H:V	RATIO CUT FILL	CUT HT.	FILL HT.	HT.OF RTG. WALL m.	PER KM. QUANTITIES				REMARK	
								CUT	FILL	RETG.	BREAST		
								VOL.	VOL.	WALL	WALL		
								1000	1000	1000	1000		
								cu. m.	cu. m.	cu. m.	cu. m.		
----- LOW HAZARD AREAS -----													
0-14	7	45	1:1	6.50	.60	.40	.55	.42	1.06	.55		5/HP + 2/Box	HP = Humc Pipe  Rock or hard soil Rock or hard soil
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		19.84	0		7/HP + 1/Box	
35-44	40	63.40	1:2	6.50	.90	.10	8.47		24.77	.12	2.20	7/HP + 1/Box	
45-54	50	76	1:4	6.50	.70	.30	7.72		17.55	1.42	5.16	6/HP + 1/Box	
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
----- MEDIUM HAZARD AREAS -----													
0-14	7	45	1:1	6.50	.60	.40	.55	.42	1.06	.55		5/HP + 3/Box	8/HP + 1/Box 8/HP + 1/Box 8/HP + 1/Box 8/HP + 1/Box 8/HP + 1/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	
35-44	30	71.60	1:3	6.50	.80	.20	6.05		2.77	15.74	.50	2.95	
45-54	50	76	1:4	6.50	.60	.40	6.61		4.41	12.90	2.53	6.67	
55-64	60	80.50	1:6	6.50	.50	.50	7.93		6.21	12.88	4.90	12.47	
0-14	7	45	1:1	8	.60	.40	.67	.52	1.61	.83		5/HP + 3/Box	8/HP + 1/Box 8/HP + 1/Box 8/HP + 1/Box 8/HP + 1/Box 8/HP + 1/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	
35-44	40	71.60	1:3	8	.70	.30	6.52		3.51	18.25	1.70	4.44	
45-54	50	76	1:3	8	.50	.50	6.78		5.68	13.57	5.98	10.59	
55-64	60	80.50	1:6	8	.50	.50	9.76		7.13	19.51	7.43	16.11	

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	AV. SLOPE	CUT SLOPE	ROAD WIDTH	RATIO		CUT HT.	FILL HT.	HT.OF RTG. WALL	PER KM QUANTITIES				CULVERT No./Type	REMARK
				CUT	FILL				CUT	FILL	RETG.	BREAST		
				deg.	deg.				VOL.	VOL.	WALL	WALL		
				deg.	deg.				1000 cu.m.	1000 cu.m.	1000 cu.m.	1000 cu.m.		
----- 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	5.36	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:

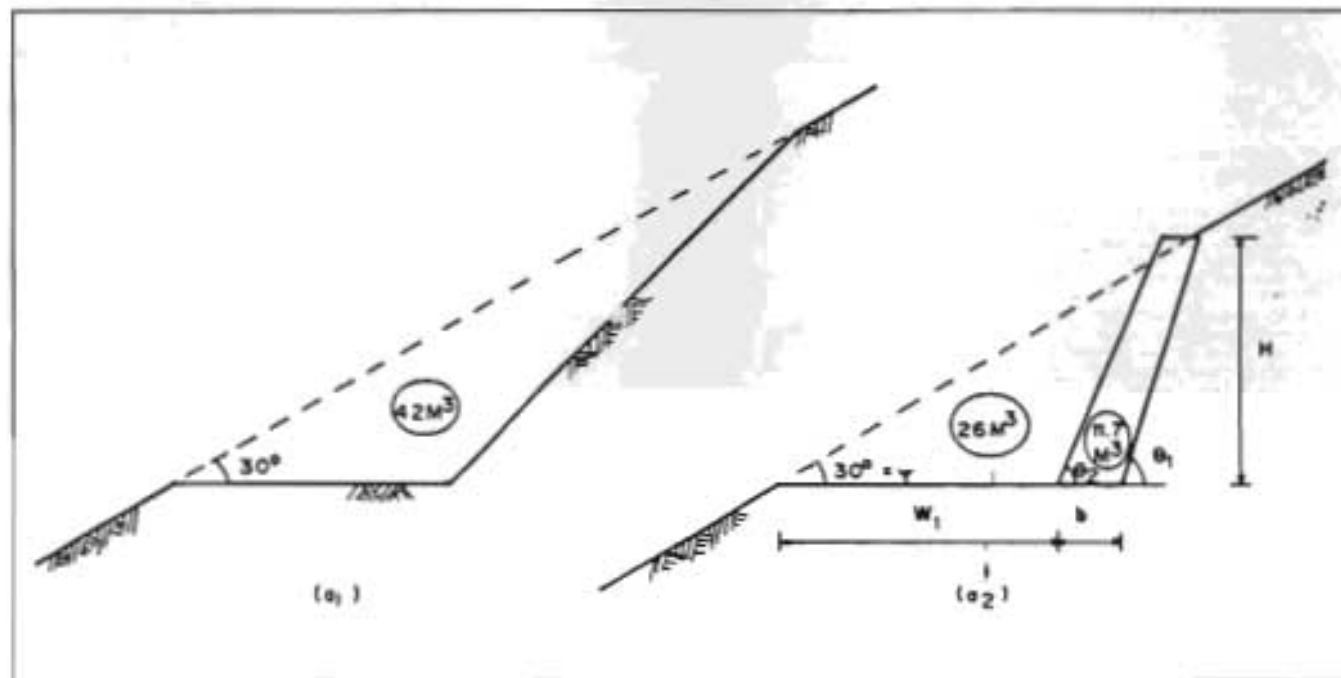
1. Provide vegetative measures for erosion controls in Low Hazard Areas.
2. Provide biotechnical and engineering works for erosion, gully, and minor slides in Medium Hazard Areas.
3. Provide specific landslide stabilization measure based on detailed investigation and analysis for High Hazard Areas.

### 3.4 Design Considerations

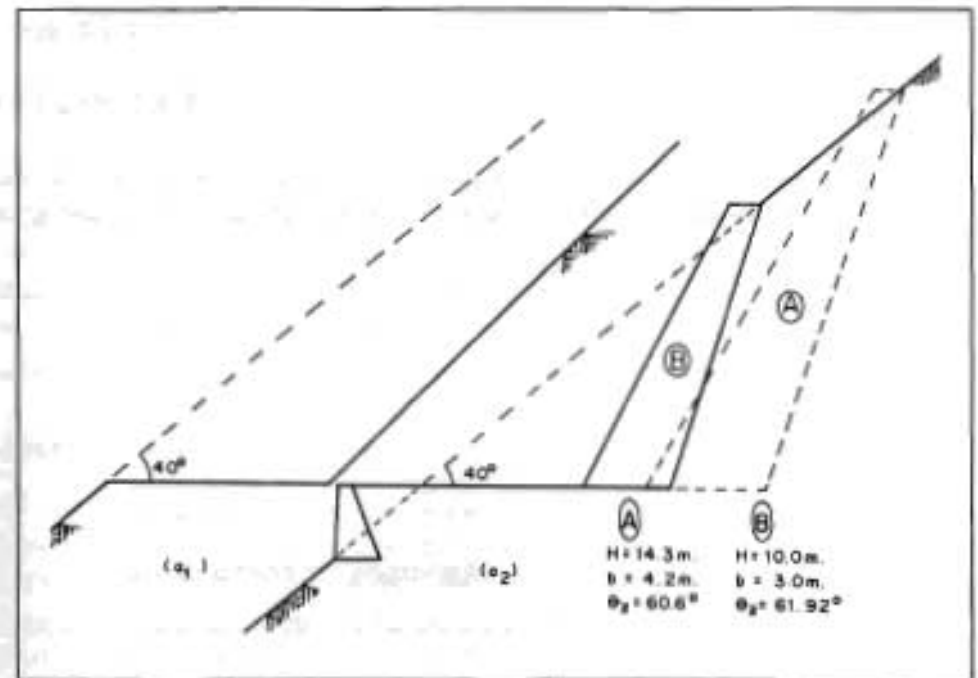
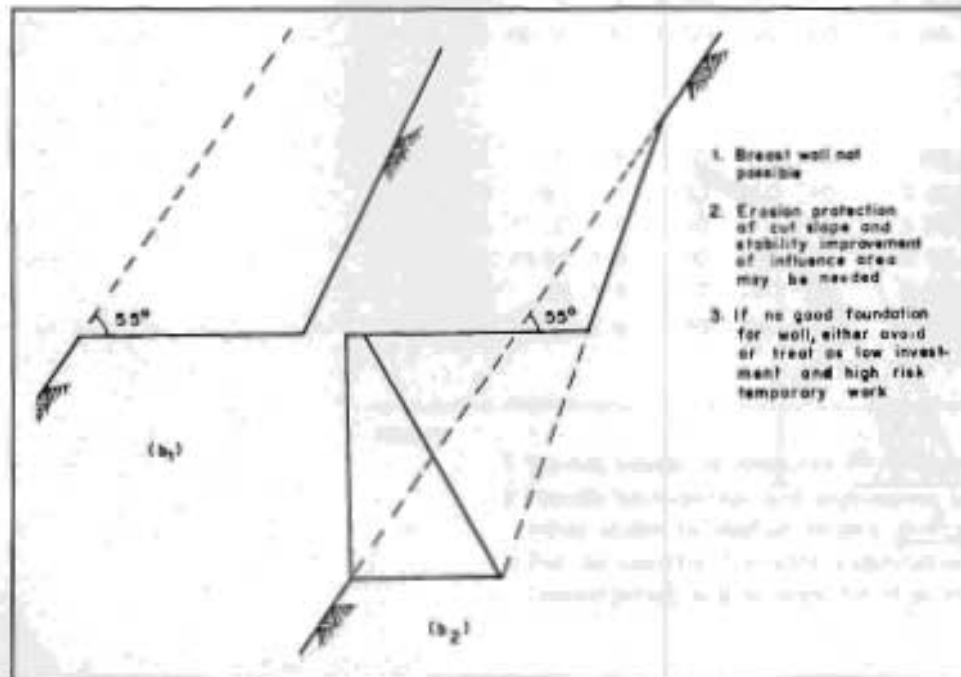
#### 3.4.1 Road Formation Design

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.

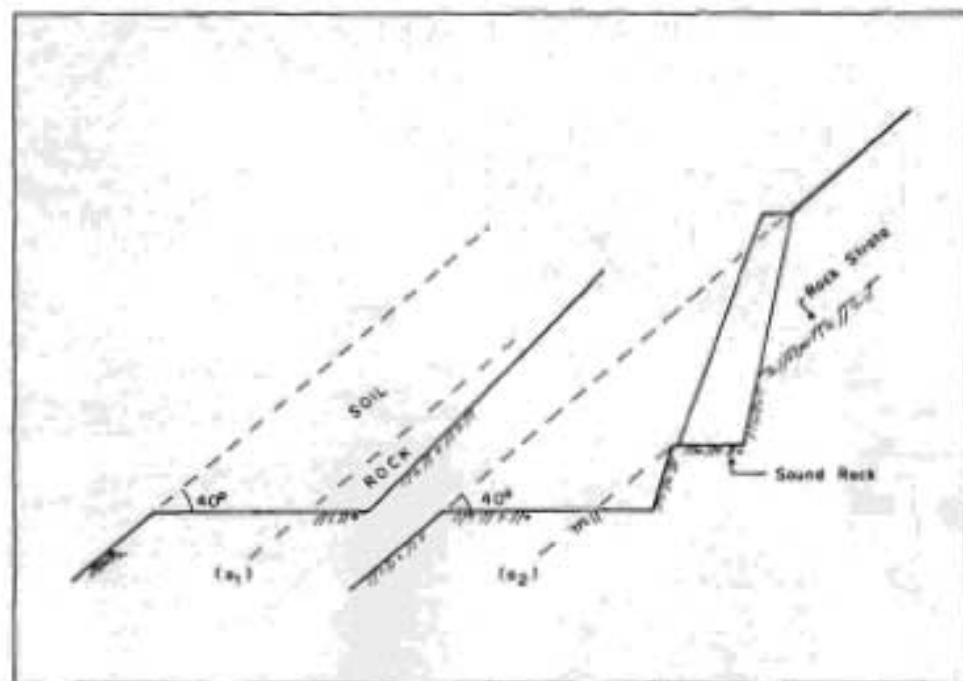
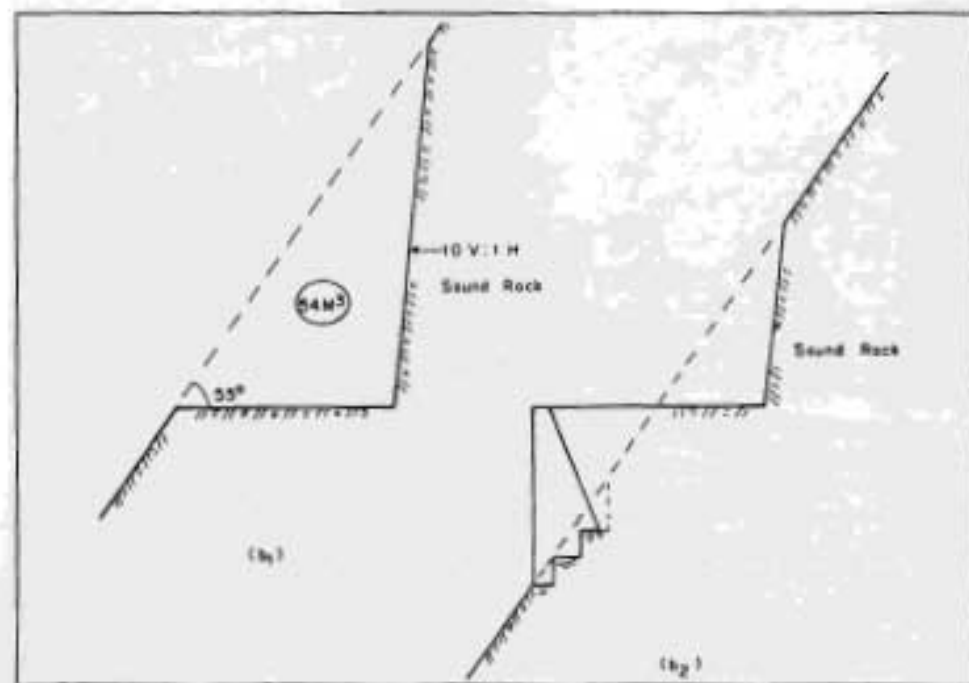


- A valley side retaining wall is supporting the fill section.



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 10m.**

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 breast wall or minor protection work (vertical to horizontal)
1	2	3	4
1.	Soil or soil mixed with boulders		
	(a) Disturbed vegetation	1:1	n:1*
	(b) do-overload 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.

# Coarse Grained Soils with plastic Fines (High Water Conditions)

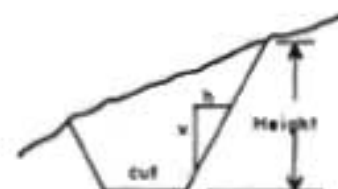
Each curve indicates the maximum cut height or the steepest slope that can be used for the given soil type.

Height limitations:

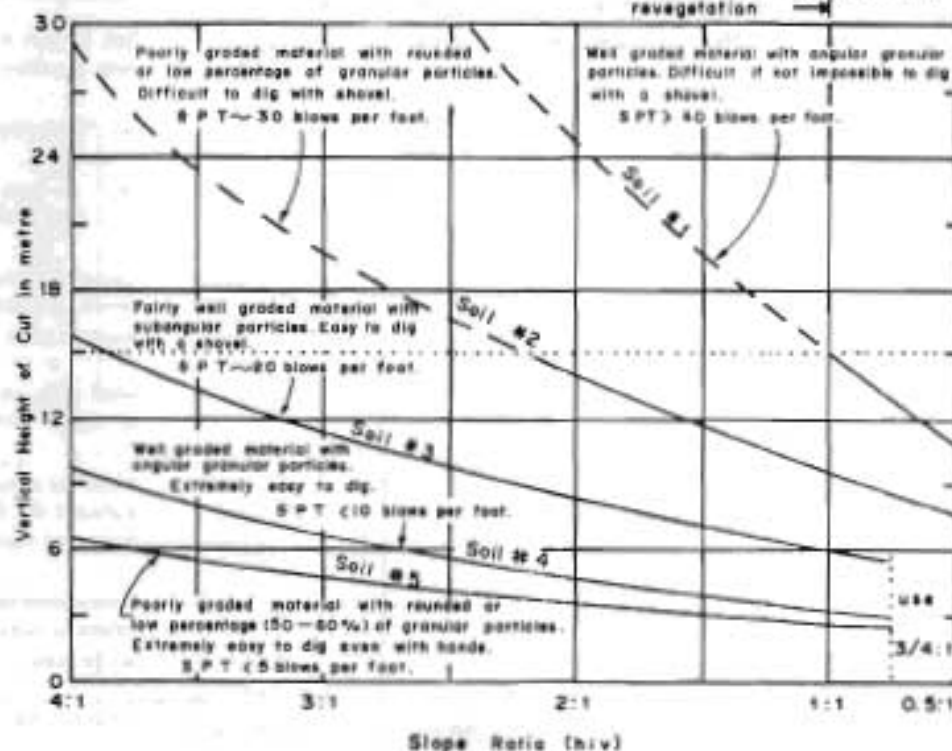
15 metre : minimal investigation.

15-30 m. : intensive investigation.

Over 30 m. : investigation by a specialist.



Normal limit for successful revegetation →



### 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

$$W = 0.55 H$$

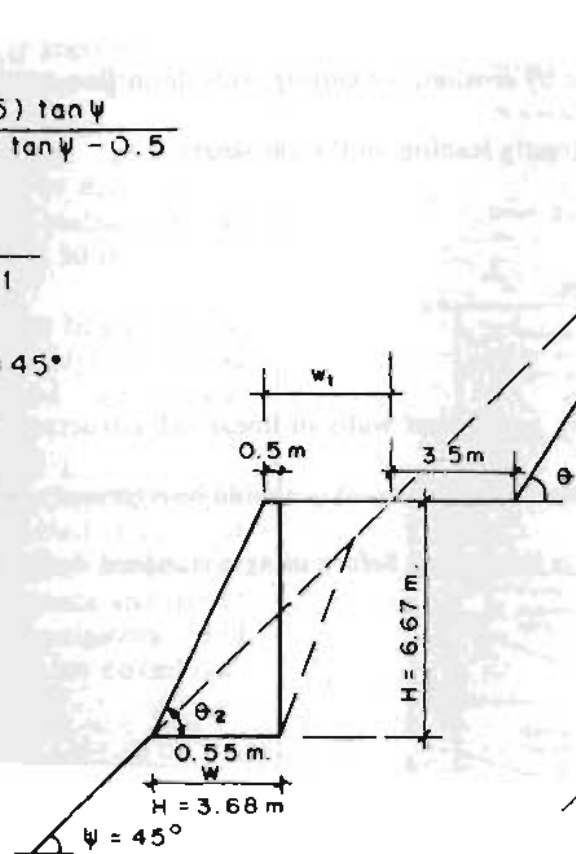
$$\tan \theta_2 = \frac{(W_1 - 0.5) \tan \psi}{0.55 W_1 \tan \psi - 0.5}$$

$$H = \frac{0.5 \tan \theta_2}{0.55 \tan \theta_2 - 1}$$

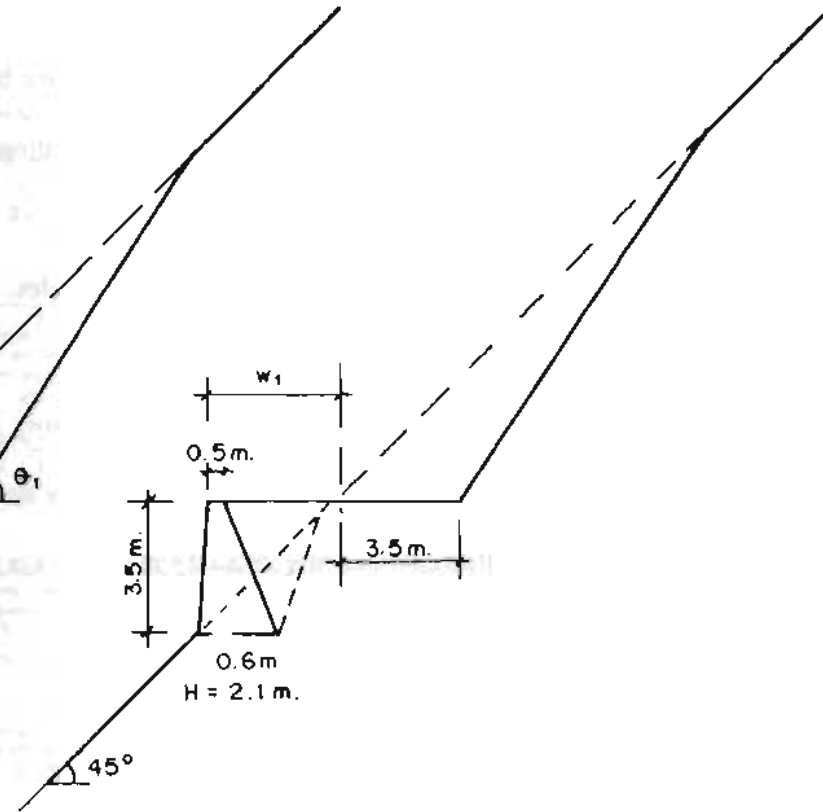
For.  $W_1 = 3.5, \psi = 45^\circ$

$$\theta_2 = 64.5^\circ$$

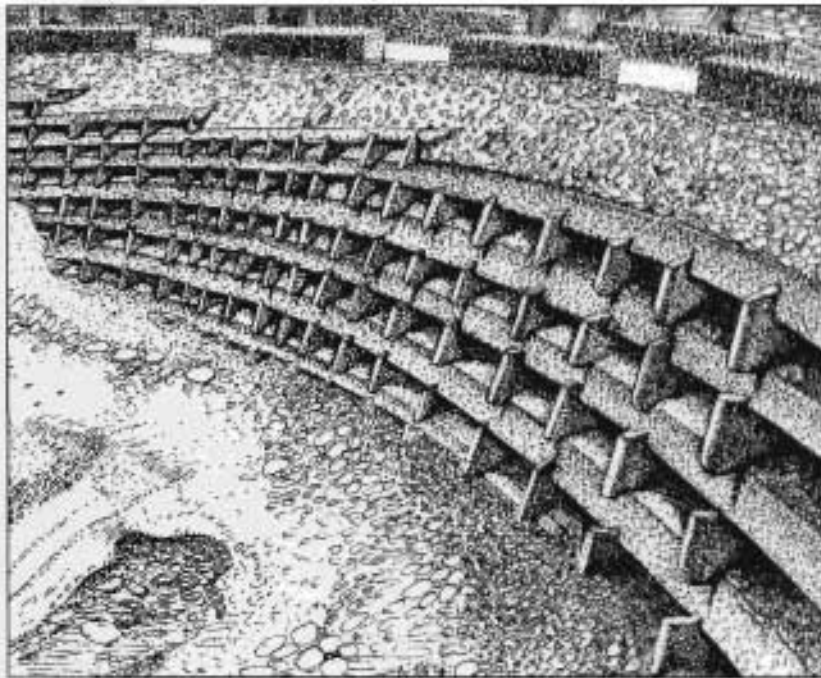
$$H = 6.67 \text{ m}$$



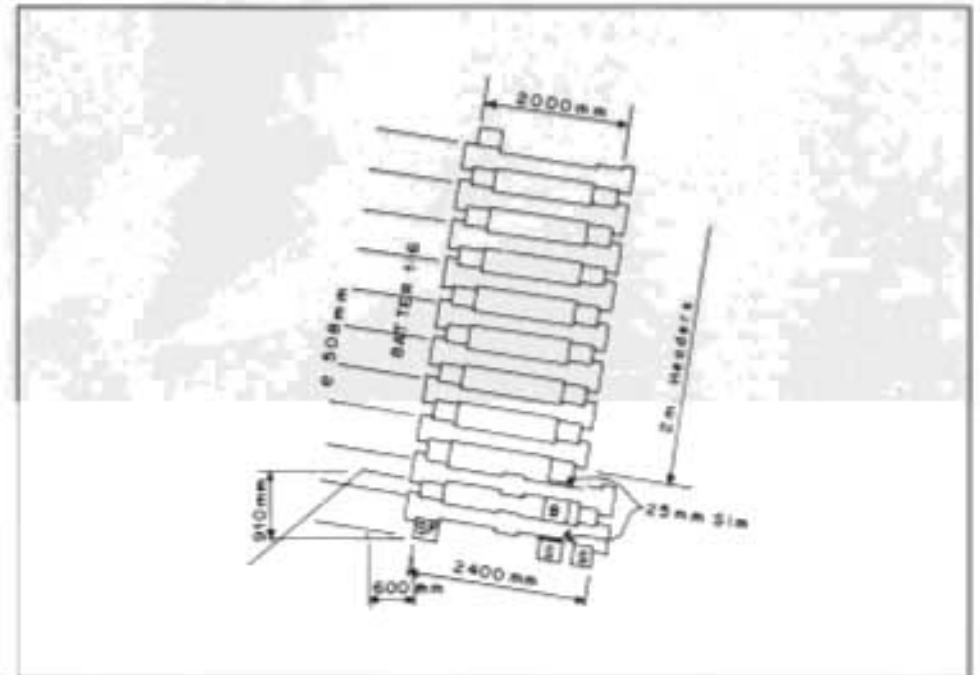
$$\begin{aligned} \text{Quantity of wall } m &= \frac{1}{2} \times (3.68 + 0.5) \times 6.67 \\ &= 13.94 \text{ m}^3 \end{aligned}$$



$$\begin{aligned} \text{Quantity of wall } m &= \frac{2.1 + 0.5}{2} \times 3.5 \\ &= 4.55 \text{ m}^3 \end{aligned}$$



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.

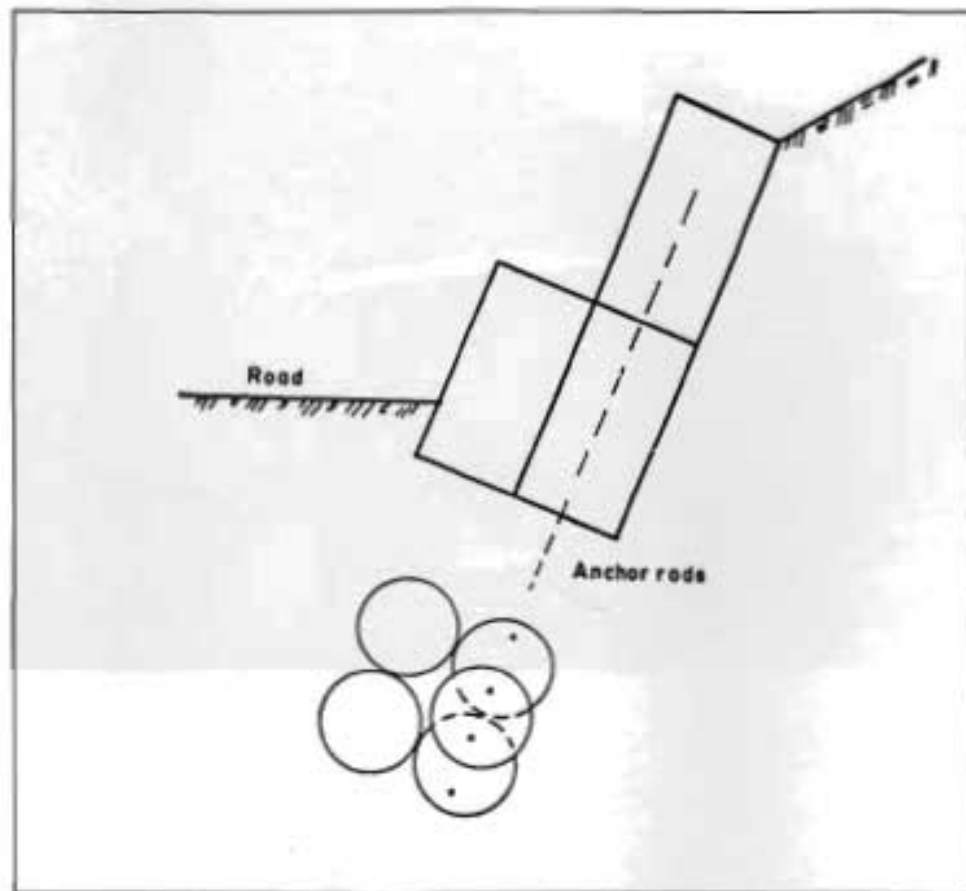


Anchored H-piles can be used for low-bearing capacity foundations and high walls.



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.



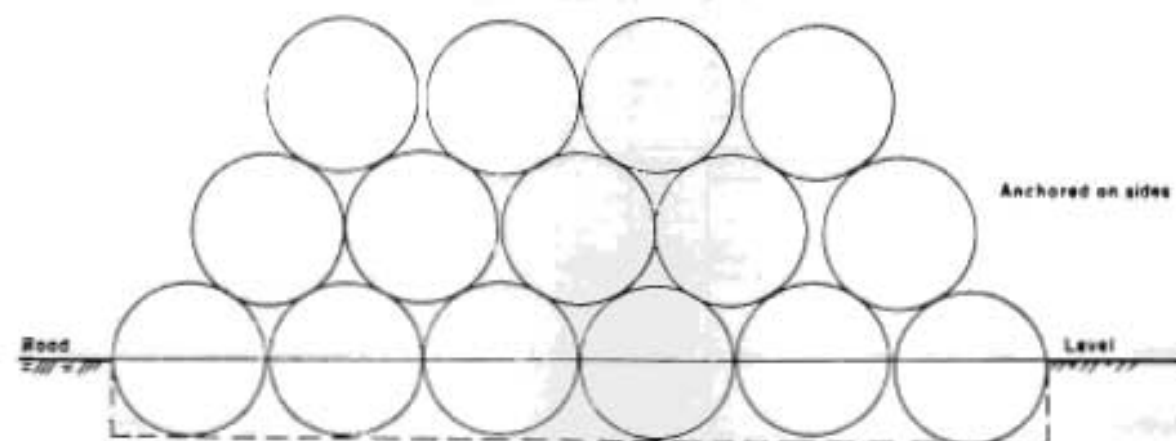


Heavy cylindrical walls are useful for retaining higher earth pressure.

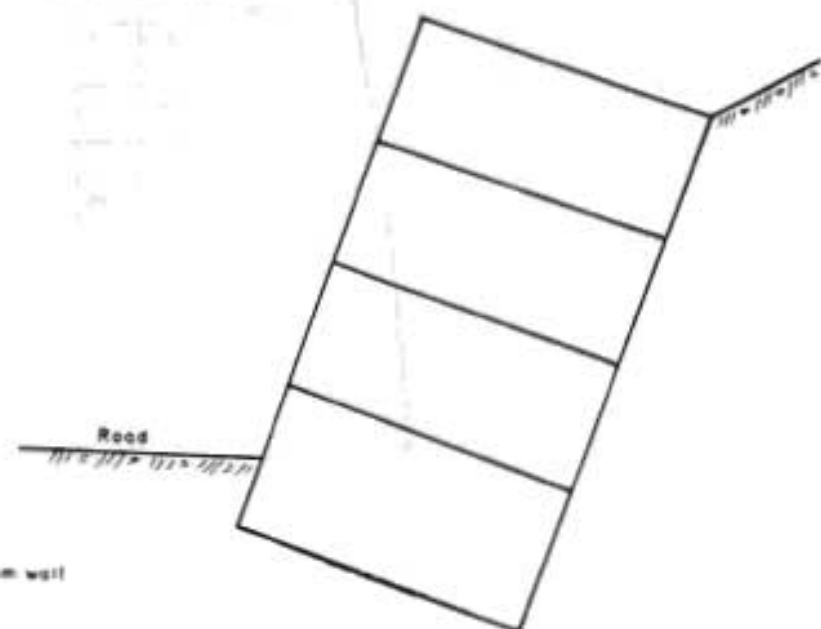


Gabion walls are easy to construct, flexible for yielding foundations, self draining, and do not require cement, sand, and water.

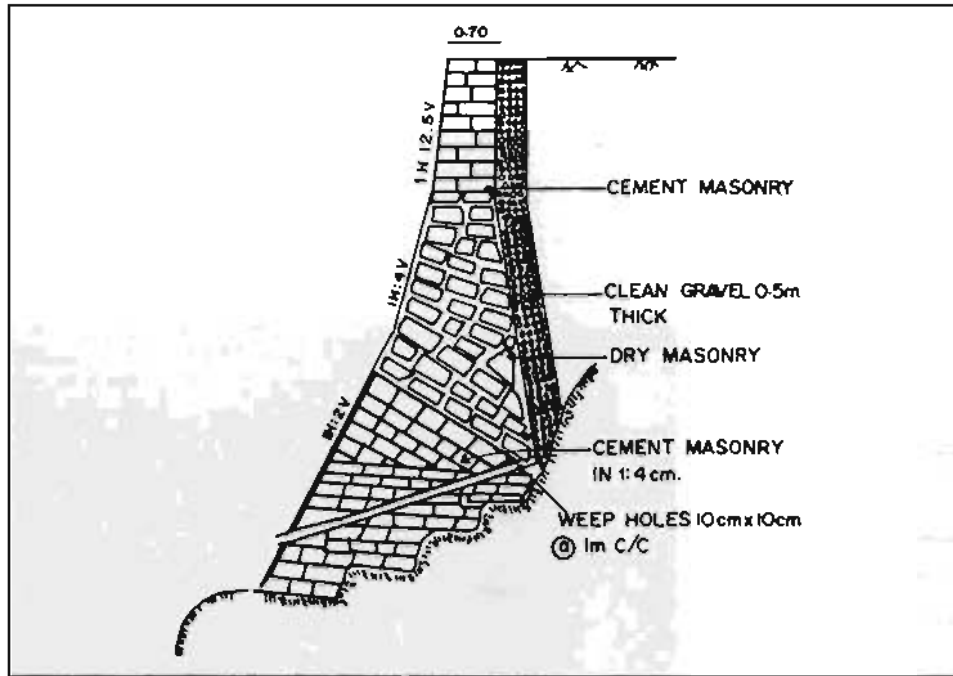
## Horizontal Drum Walls



(a) Front view of horizontal drum wall

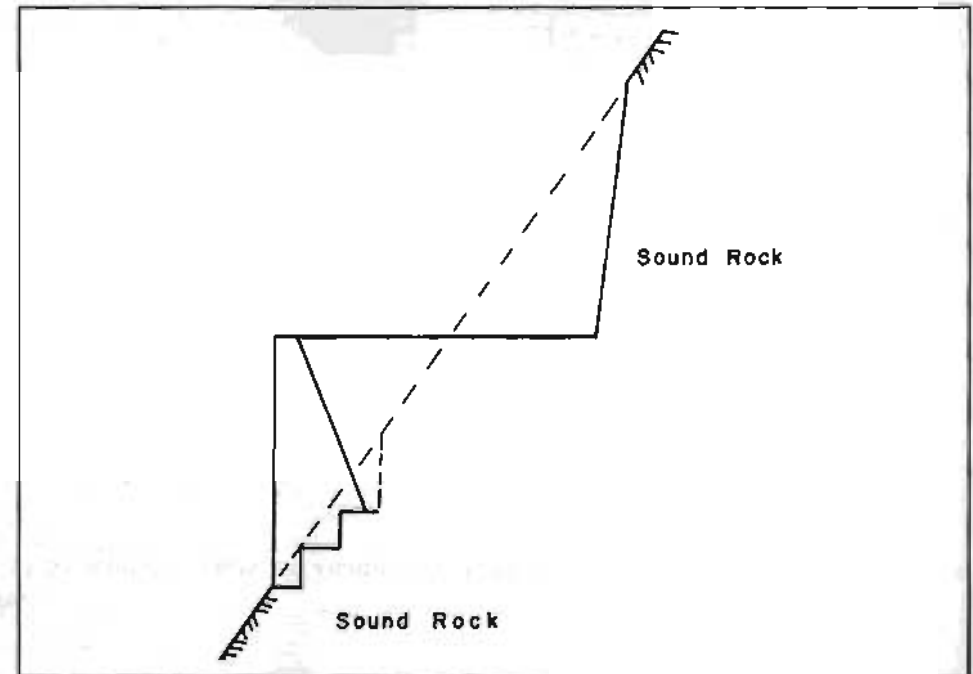


(b) 1.2m high drum wall



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 Walls

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		HEIGHT OF WALL (FT)	HILL SLOPE DESCRIPTION	HAZARD LEVEL	FILL SLOPE	CONSTRUCTION TIME	LIFE OF WALL (YEARS)	FOUNDATION MATERIAL	CONSTRUCTION MATERIAL		EQUIPMENT REQUIRED	AESTHETIC REQUIRED	INITIAL COST
BY MECHANICS	BY STRUCTURAL MATERIAL								BACKFILL MATERIAL	STRUCTURE			
GRAVITY	DRYSTONE MASONRY	1-8	<35	L	<35	SHORT	<20	GOOD	GOOD	HARD, RECT-ANGULAR STONE BLOCKS	PORTABLE COMPACTOR	GOOD	LOW COST
GRAVITY	DRYSTONE MASONRY	1-5	<35	H	<35	SHORT	<5	FAIR	GOOD TO FAIR	HARD, RECT-ANGULAR STONE BLOCKS	PORTABLE COMPACTOR	GOOD	LOW COST
GRAVITY	GABION	1-10	<40	L, H	<35	SHORT	<20	FAIR	GOOD TO FAIR	HARD STONE BLOCKS OR BOULDERS, G.S. WIRE	PORTABLE COMPACTOR	GOOD	MEDIUM COST
GRAVITY	ROCK CRIB	1-10	<35	L, H	<35	SHORT	<20	FAIR	GOOD TO FAIR	PRECAST RCC CRIBS	PORTABLE COMPACTOR	GOOD	LOW COST
GRAVITY	DRUM WALL	<2.5	<35	L, H	<35	SHORT	<5	FAIR	FAIR	EMPTY RETURN 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 SANDS OF CEMENT MASONRY	4-8	<15	L	<20	AS REQUIRED	<20	GOOD TO FAIR	GOOD TO FAIR	PARTIAL CEMENT, SAND, AND WATER	PORTABLE COMPACTOR	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, PREPARED FABRICATED PRODUCTS	COMPACTOR	FAIR	MEDIUM COST

Source:

1. Other wall types such as anchored walls may be considered depending on unusual problems, site conditions, 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, length 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		Type	Hazard level	Project Cycle
	Height, m	Area, m <sup>2</sup>			
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




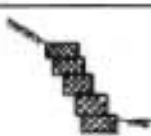

#### HAZARD LEVEL OF THE AREA

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					Notes
	DRY STONE	HANDL DRY STONE MASONRY	CEMENT MASONRY	GABION	HORIZONTAL DRUM WALLS	
Diagrammatic cross-section						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.
Construction notes	Top width	0.5			2	3. Detailed design is necessary in case of soil slopes and walls higher than 6m and poor foundation conditions.
	Base width	0.25H	0.3H	0.33H	0.23H	4. Gabion walls should be used in case of poor foundation/seepage conditions. They can take considerable differential settlement and some slope movement.
	Front batter				2	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.
	Back batter	3:1	4:1	5:1	3:1	
	Inward dip of foundation	1:3	1:4	1:5	1:3	
	Foundation depth below drain	0.5m	0.5m	0.5m	0.5m	
	Range of height	6m	4m	3m	3-6m	
	Hill slope angle	35-60			35-70	
General	Tee protection in case of soft rock/soil	No pitching			No	
		Pack stone along foundation bed. Use band stones. Specify minimum stone size.	Cement masonry (1:1.5) bands 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 (1:1.6)	Step in front face 20-50cm wide. Otherwise as for retaining walls.	Use vertical single drum for 0.7m 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	Promising/most economical of	
	Not ductile structures most susceptible to earthquake damage			Very flexible	Flexible	
	Revetments are used to prevent only major erosion, rockfall, slope degradation particularly where vulnerable structures are at risk.					



### 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.

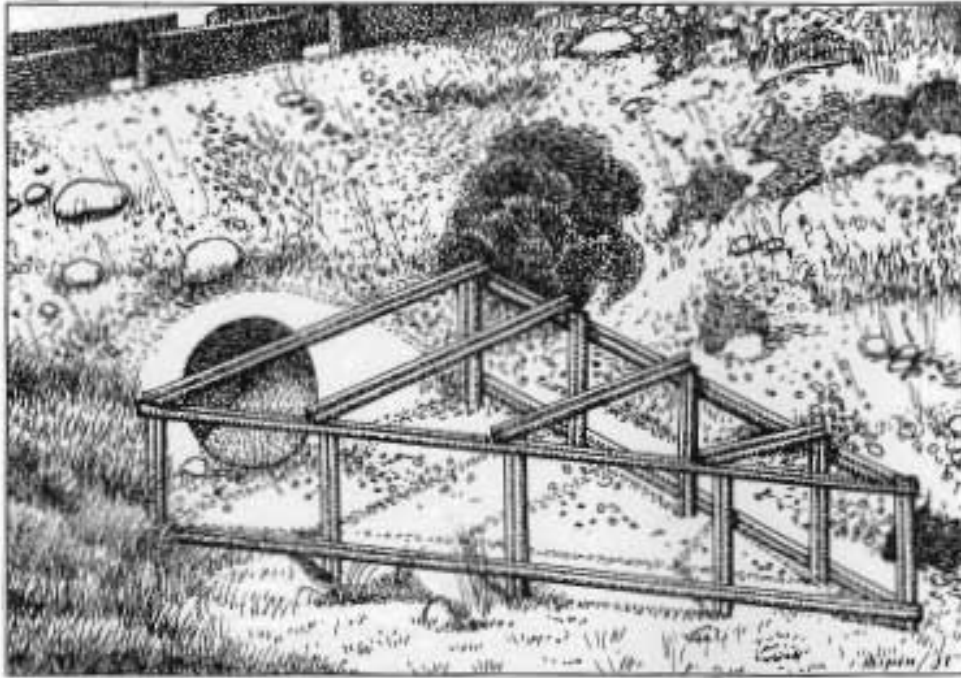


Debris relief riser to relieve water passage in the event of the culvert entrance clogging.

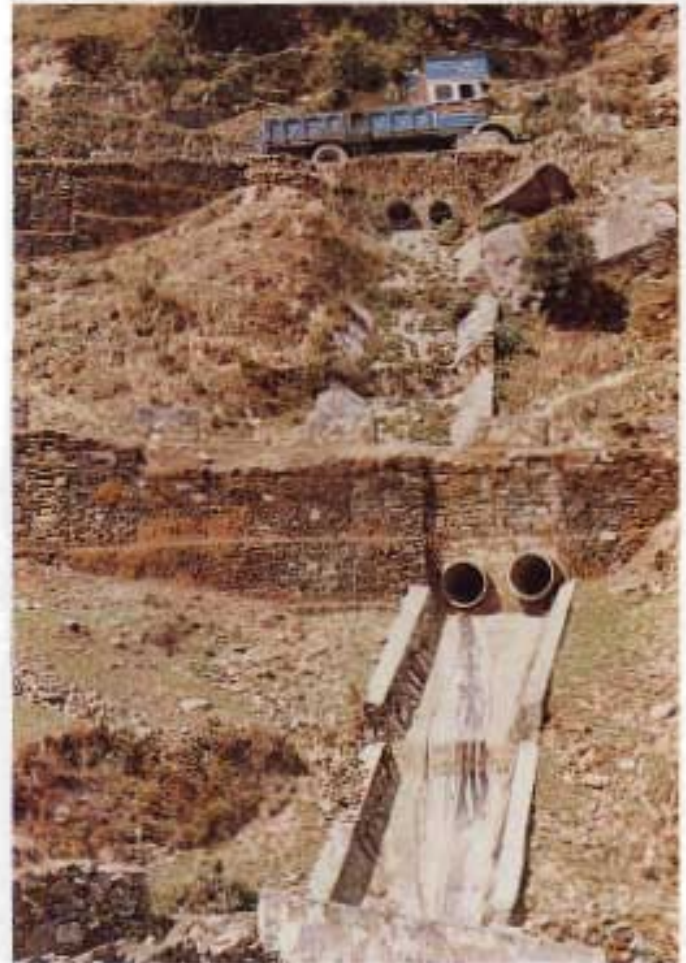


A debris relief riser





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)

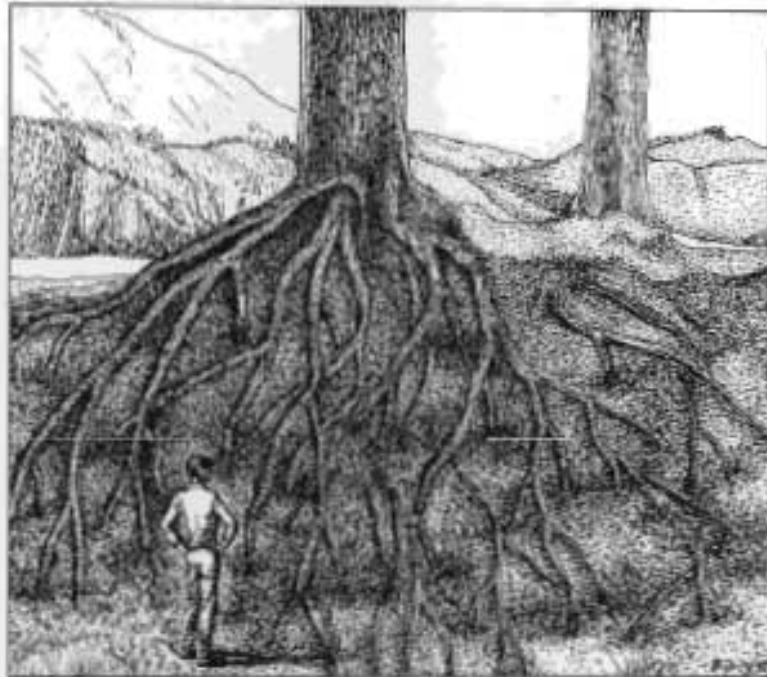


### 3.4.5 Biotechnical Stabilization

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

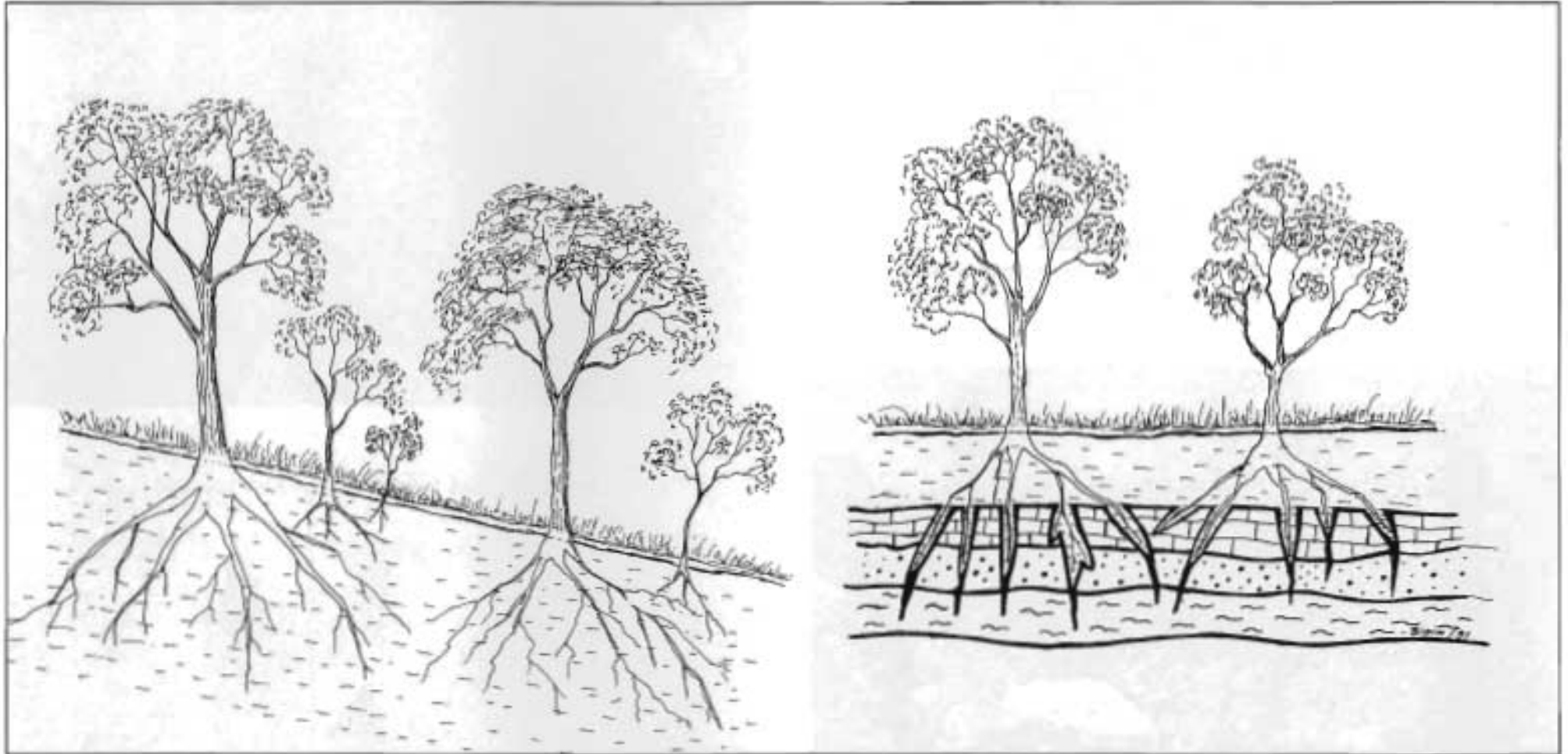
- providing cover against surface erosion,
- increasing soil shear strength, and
- reducing the groundwater table or moisture content.

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.

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



In spite of thick forest, landslips have occurred





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.

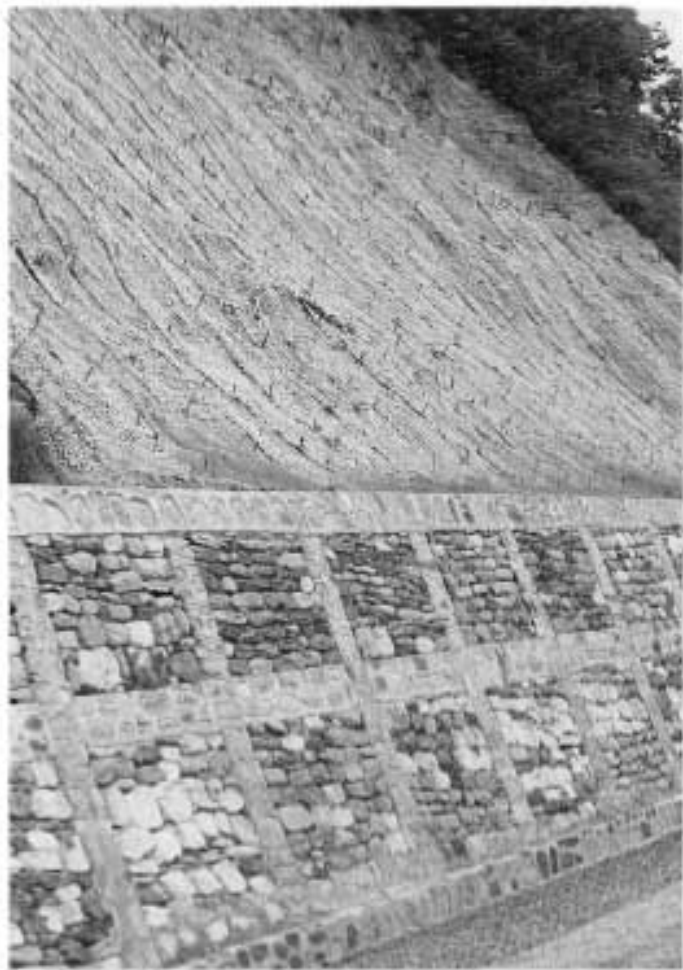


Diagonal grass lines planted on a steep slope



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.



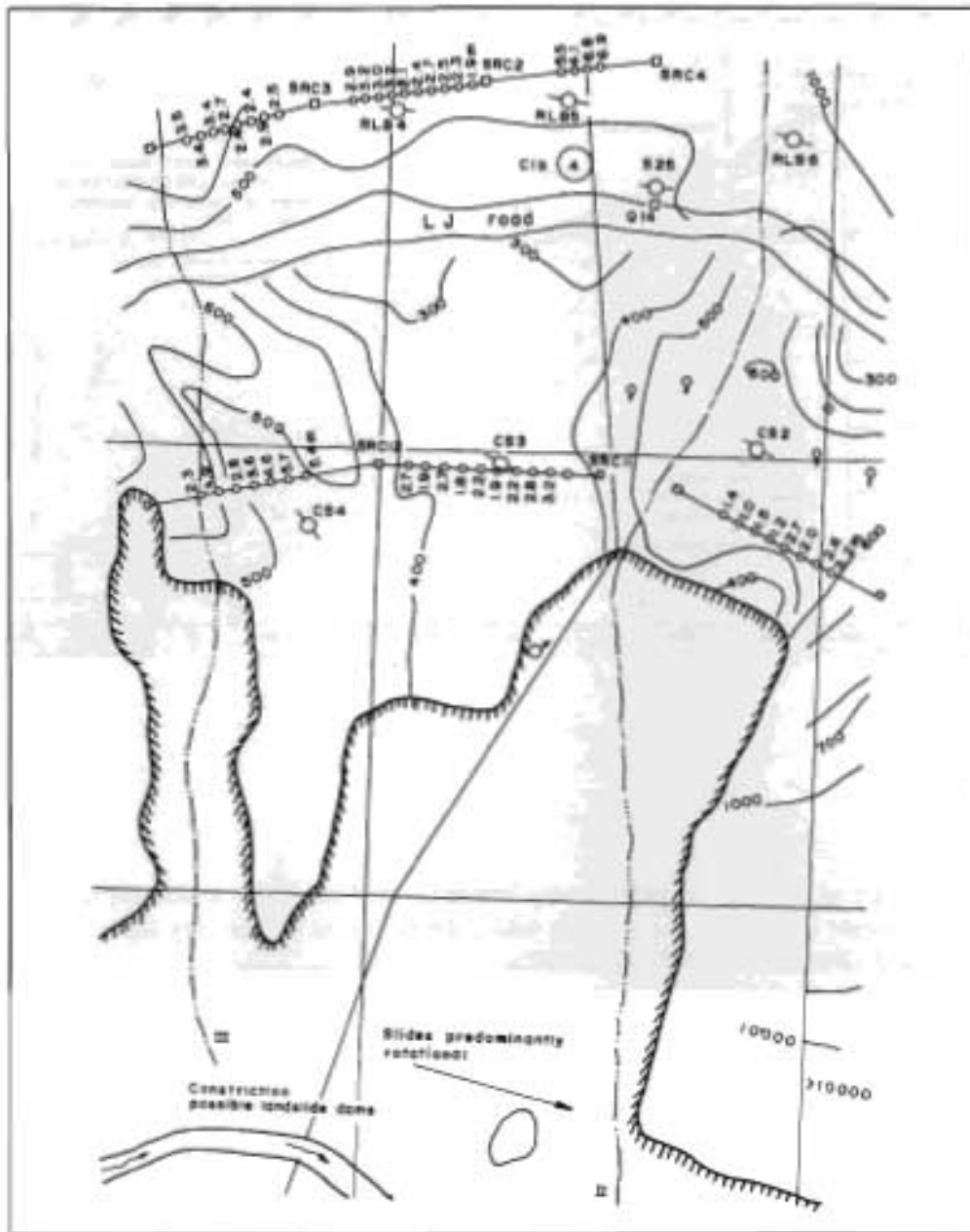
Seabuckthorn fruits from the Langtang area, Nepal

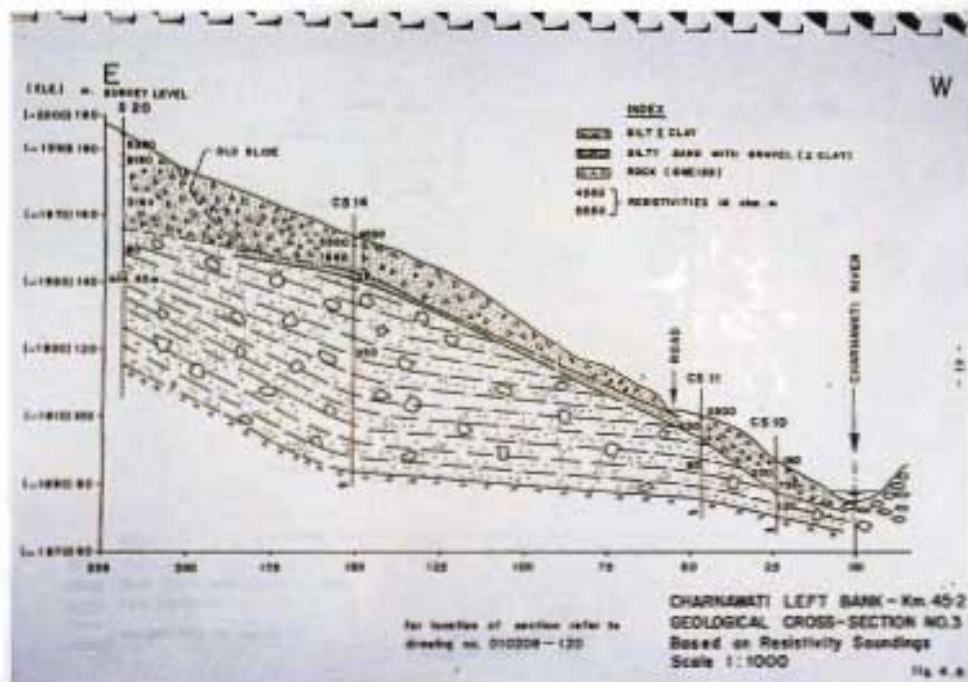
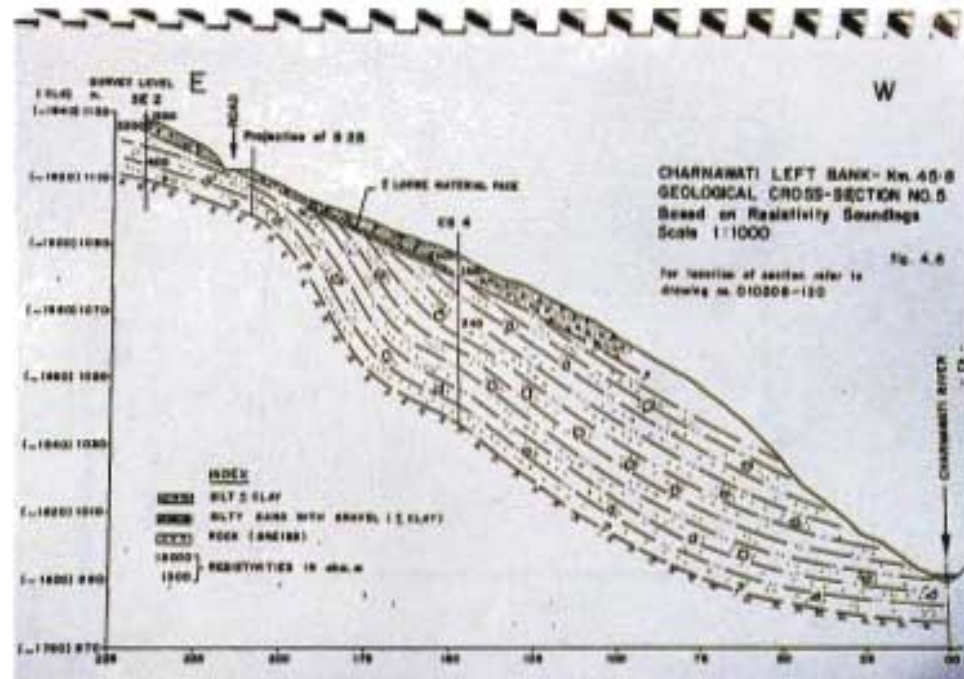
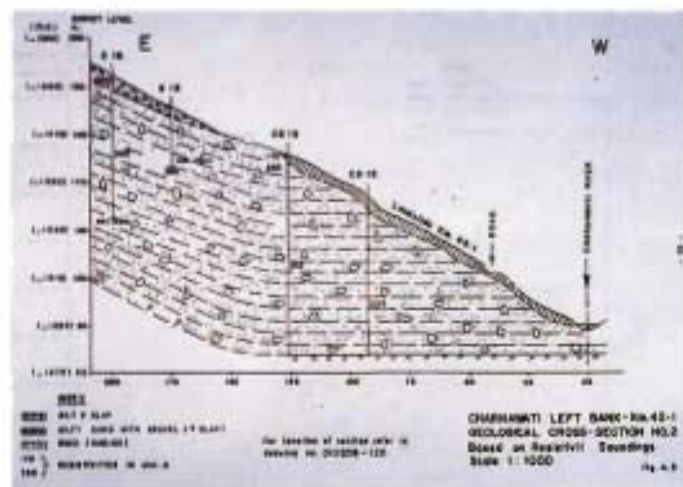
### 3.4.6 Geophysical Methods for Detailed Studies

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 resistivity 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.





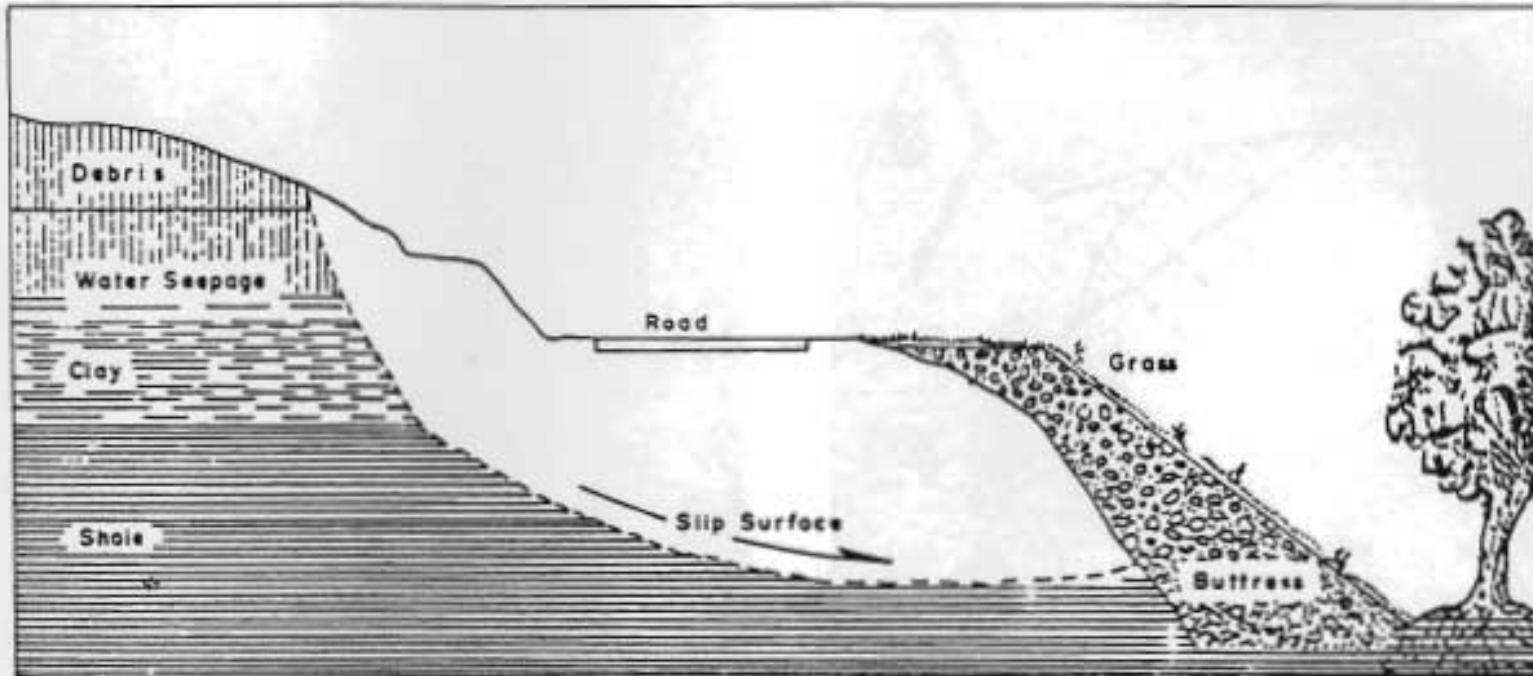
Electrical sounding is another very important method. This method permits one to locate the depth of the water table, the thickness of the clay layer, or the depth of sound bedrock.

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



### 3.4.7 Landslides and Slope Stabilization

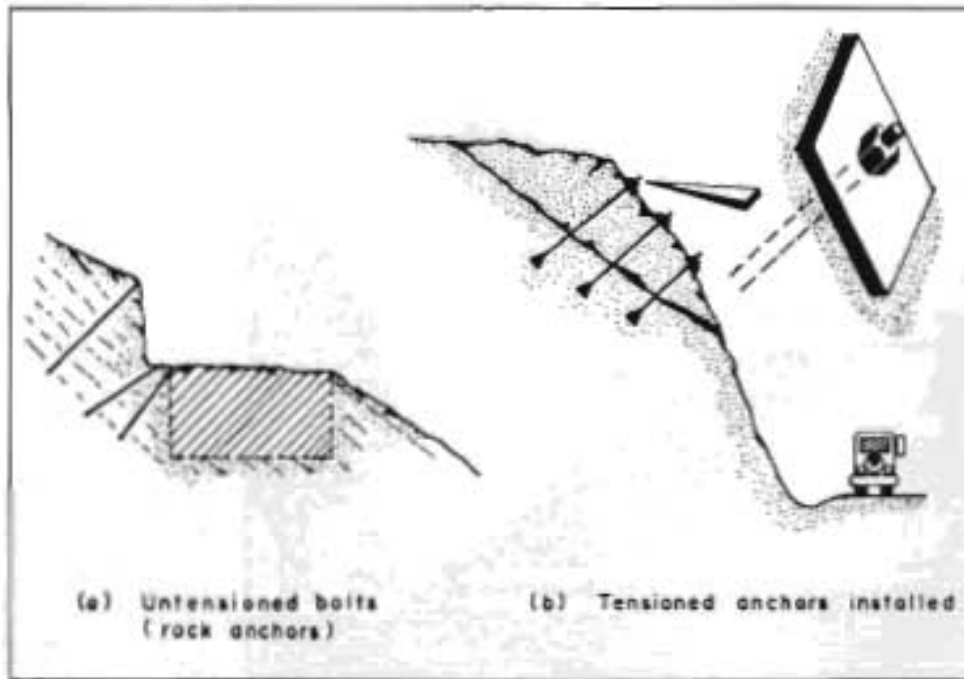
Stabilizing berms in the form of rocks, gravel, or sandfills are placed at the toe of the slope, where upward movement of the sliding mass is possible. This buttress



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.



## *Rock Bolting and Anchoring*



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.

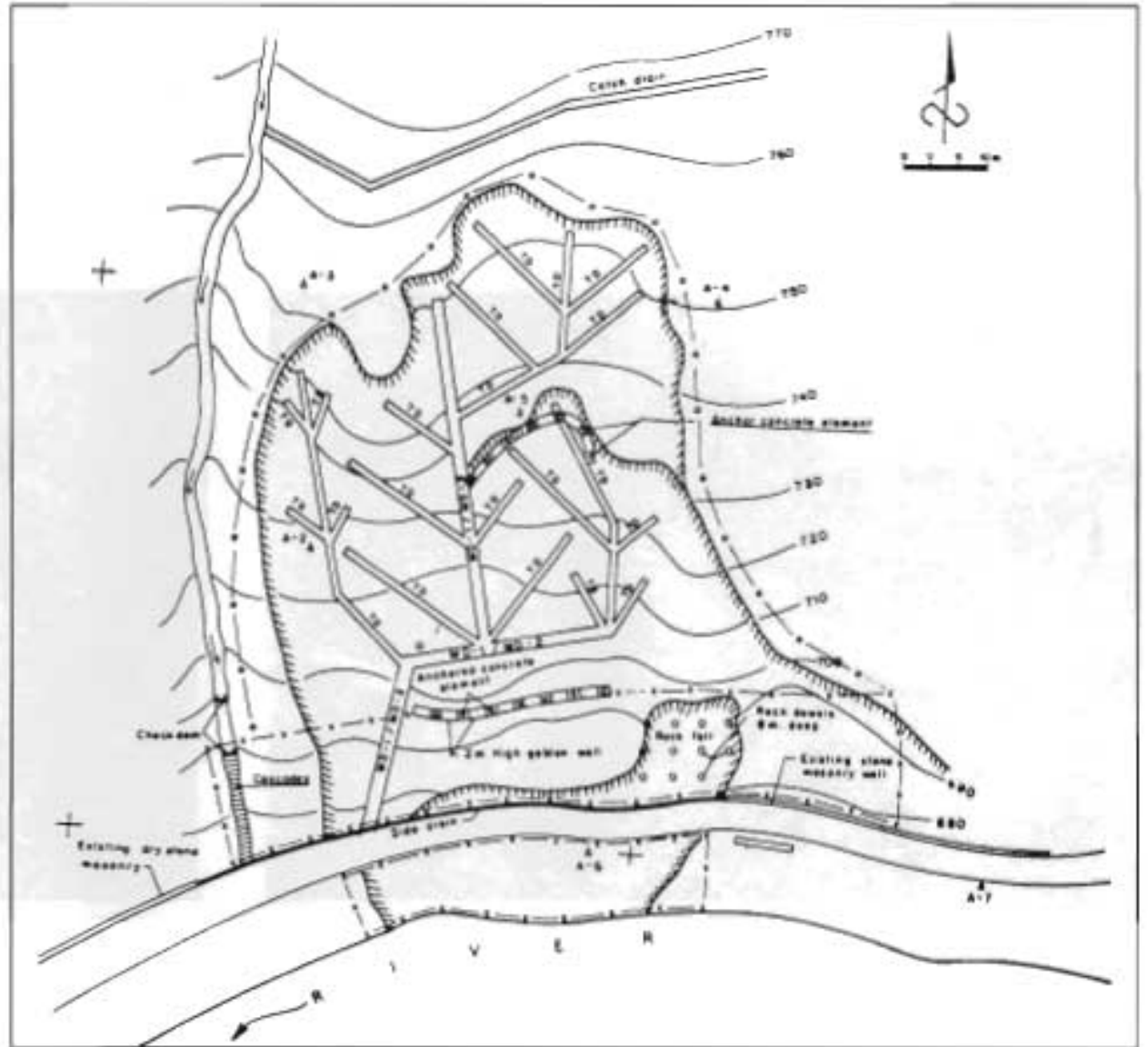
## *Soil Anchoring*



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.



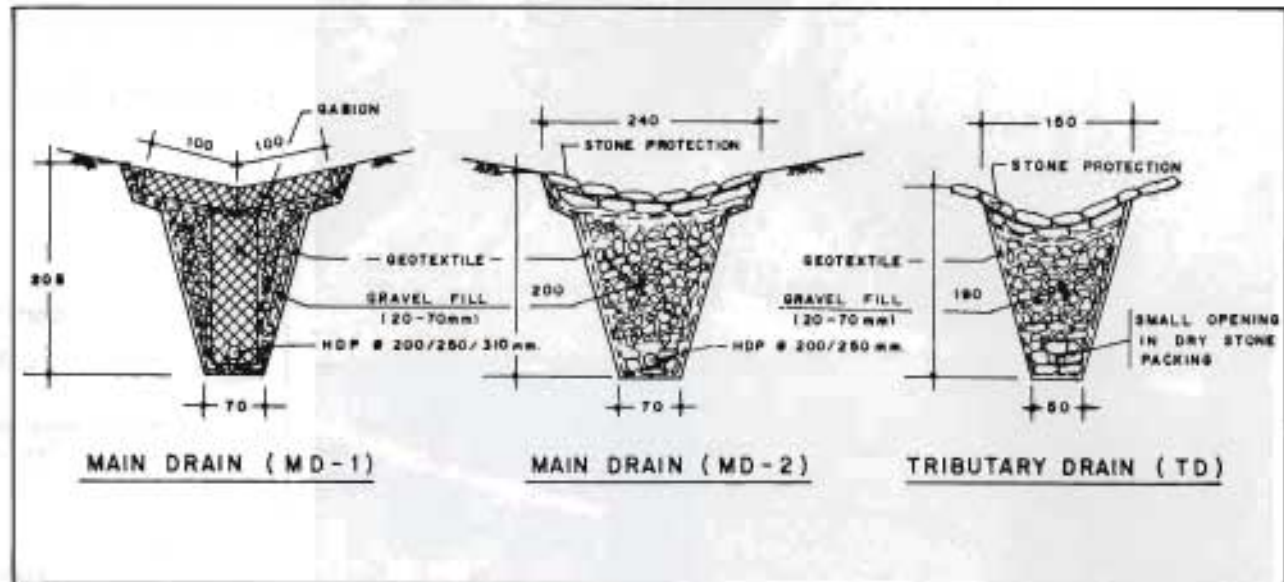
Landslide stabilized by a sub-surface drainage network



Counterfort drains collect water from tributary drains.



## Counterfort Drains (Main Drains) and Tributary Drains



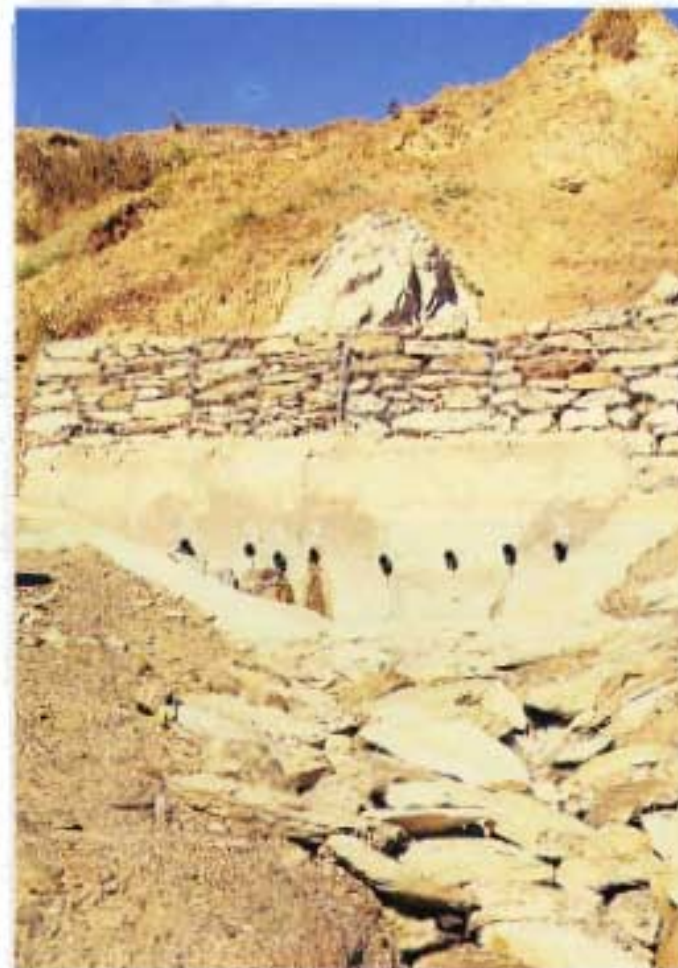
## *Horizontal Drains*

- ◀ Horizontal drains along a forest road, California, USA

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



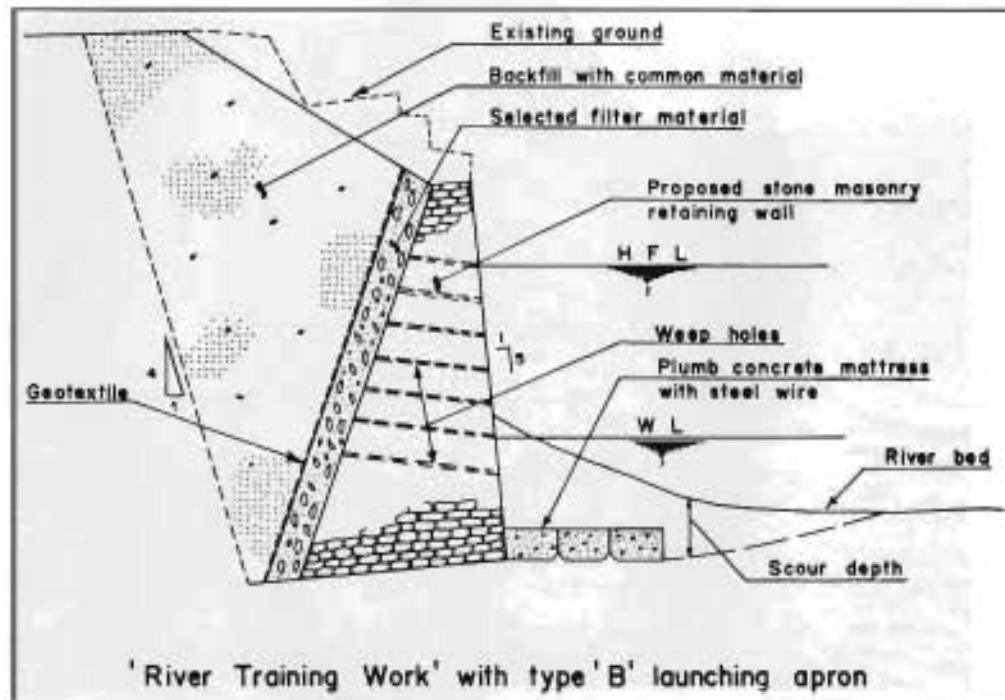
Horizontal drilling





### 3.4.8 River Training

Cement masonry revetment wall with gabions above high flood level



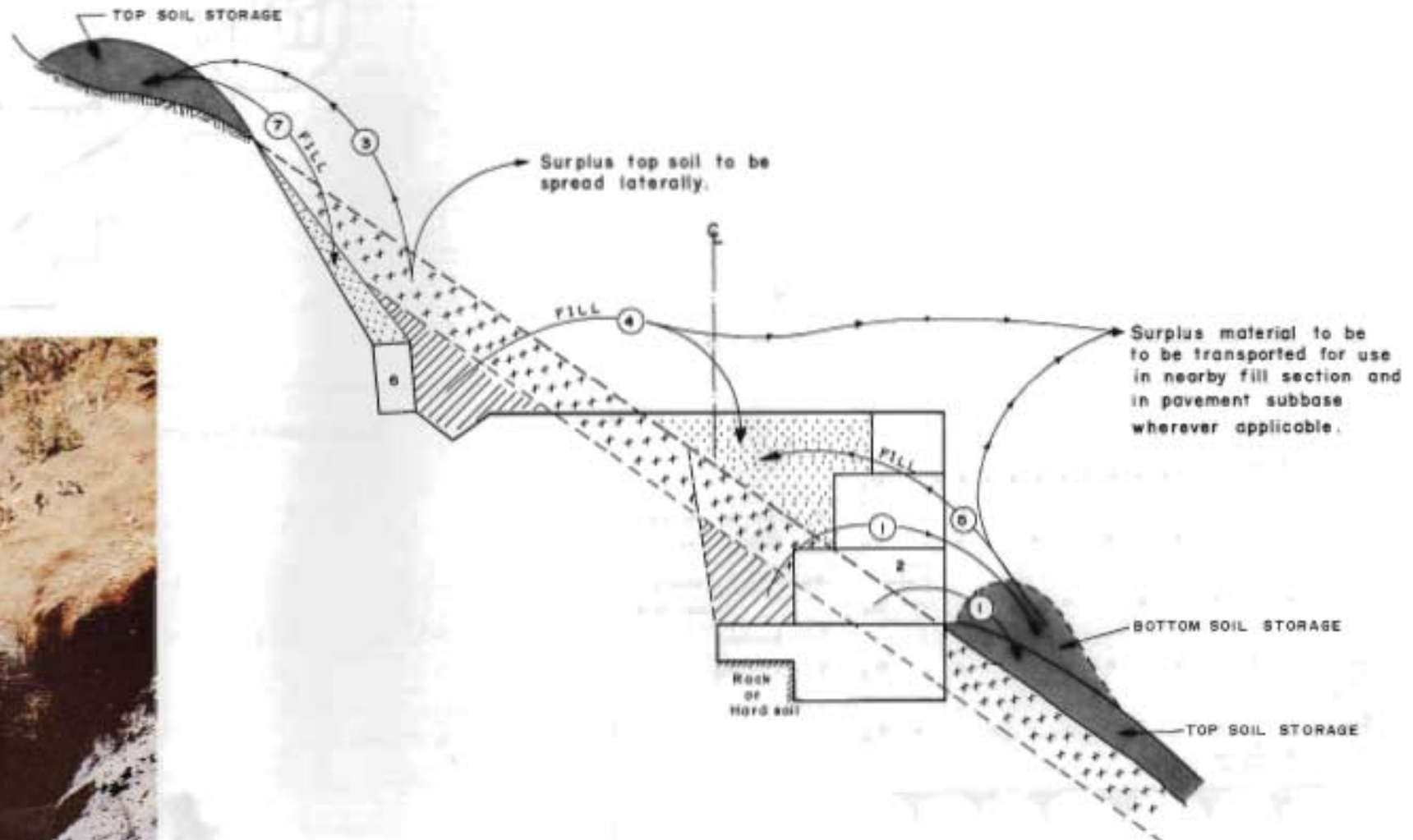




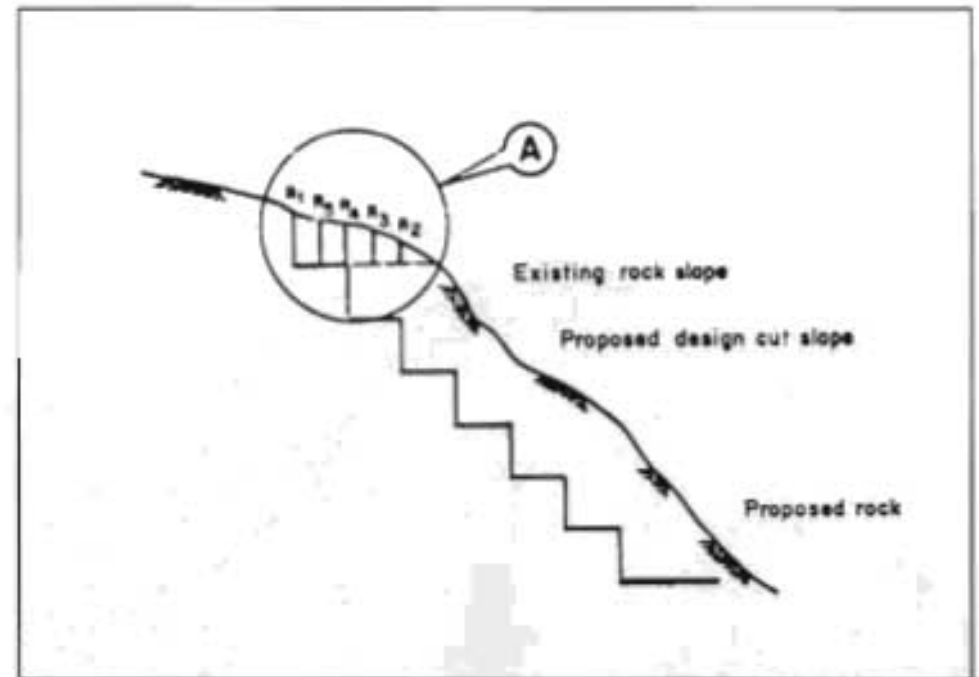
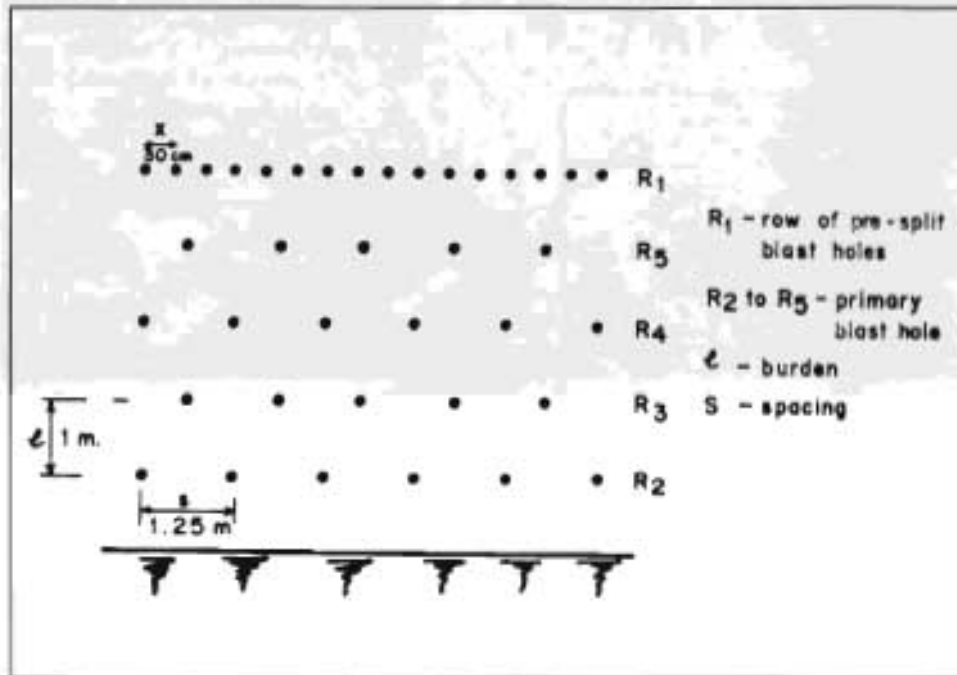
Prevention of bed scour and bank sliding of a steep mountain stream, with thick (more than 30 m) soil cover, by use of concrete armour blocks (tetrapods), along the Charnawati River, Nepal.

### 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

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## 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

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