

Technical Guideline

Nature-based Solutions for Roadside Slope Stabilization



Government of Bagmati Province

Ministry of Physical Infrastructure Development

Transport Infrastructure Directorate (TID)

Hetauda, Makawanpur

2083

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PREAMBLE



It is my pleasure to present this guideline, Nature-Based Solutions for Roadside Slope Stabilization, to the engineers, technicians, planners, and administrators responsible for the development, management, and maintenance of provincial and local road networks in Bagmati Province. This guideline represents an important milestone in strengthening the technical capacity of provincial and local governments to address roadside slope instability through practical, scientifically informed, and environmentally sustainable approaches.

Bagmati Province lies within the Himalayan region, where complex geology, steep terrain, and intense monsoon rainfall create a landscape that is inherently susceptible to landslides and slope failures. Every year, these hazards disrupt transportation networks, damage public infrastructure and private property, and place communities at considerable risk. In recent years, the frequency and severity of slope failures have increased owing to expanding road construction, changing land use patterns, and the growing impacts of climate change. While existing national publications provide valuable technical guidance, the geological, climatic, and institutional context of Bagmati Province necessitates guidance tailored specifically to provincial and local road management. This guideline responds to that need by integrating sound engineering practice with nature-based solutions in a form that is practical, accessible, and readily applicable in the field.

The guideline is intended to serve as a practical reference for engineers, supervisors, field technicians, and planners involved in roadside slope management. It provides guidance on site investigation, slope assessment, the selection and design of appropriate stabilization measures, construction practices, and post-construction monitoring. Its recommendations are founded on research conducted in Nepal, field investigations across Bagmati Province, and the extensive professional experience of engineers, researchers, and practitioners working throughout the Nepal Himalaya.

I express my sincere appreciation to the engineers, academics, researchers, and practitioners whose knowledge and commitment contributed to the preparation of this guideline. I am confident that it will serve as a dependable technical reference for roadside slope stabilization and contribute to safer roads, more resilient infrastructure, and improved public safety throughout Bagmati Province.

Dr. Dinesh Chandra Devkota

Honourable Minister

Ministry of Physical Infrastructure Development

Government of Bagmati Province, Hetauda

2083 BS



FOREWORD



The Ministry of Physical Infrastructure Development recognizes that sustainable roadside slope stabilization cannot rely solely on conventional engineering structures. Although concrete and masonry structures remain indispensable in many critical locations, they are often expensive, require substantial technical resources, and may not adequately address the underlying causes of slope instability, including vegetation loss, surface erosion, and uncontrolled seepage. Naturebased solutions, which integrate bioengineering techniques with appropriate structural measures, provide an effective, economical, and environmentally sustainable approach, particularly for the extensive network of provincial and local roads where resources are often constrained.

This guideline is the outcome of rigorous academic research, systematic field investigations conducted throughout Bagmati Province, extensive stakeholder consultations, and a comprehensive review of national and international technical literature. It provides practical guidance covering the full spectrum of roadside slope stabilization, including site investigation, hazard assessment, drainage design, bioengineering techniques, structural stabilization measures, construction practices, maintenance, and long-term monitoring.

The guideline has been developed specifically for the environmental and engineering conditions of Nepal. It incorporates Nepal's geological characteristics, local rainfall patterns, native bioengineering plant species, and provincial road standards, ensuring that its recommendations are directly applicable to field conditions in Bagmati Province rather than adaptations of guidance developed elsewhere.

I extend my sincere appreciation to the study team from the Center for Disaster Studies, Institute of Engineering, Tribhuvan University, for their expertise, diligence, and commitment in preparing this guideline. I also acknowledge the valuable contributions of the engineers and officials of the Transport Infrastructure Directorate, together with representatives of federal, provincial, and local government agencies, academic institutions, and professional organizations whose participation in consultations and technical reviews substantially strengthened this document.

I am confident that this guideline will become an authoritative technical reference for roadside slope stabilization within Bagmati Province. I encourage all concerned agencies and officials to adopt its recommendations in the planning, design, construction, supervision, and maintenance of road infrastructure to enhance safety, resilience, and sustainability across the provincial road network.

Ishwor Chandra Marahatta

Secretary

Ministry of Physical Infrastructure Development

Government of Bagmati Province, Hetauda

2083 BS



ACKNOWLEDGEMENT



This guideline is the outcome of a collaborative effort involving engineers, researchers, technicians, administrators, and institutions committed to improving the safety and resilience of roadside infrastructure in Bagmati Province. It reflects the collective knowledge gained through field investigations, technical research, stakeholder consultations, and the professional experience of practitioners working in roadside slope stabilization.

The Transport Infrastructure Directorate extends its sincere appreciation to the study team from the Center for Disaster Studies, Institute of Engineering, Tribhuvan University, led by Dr. Bhim Kumar Dahal, for their professionalism, technical expertise and dedication throughout the preparation of this guideline. The Directorate also gratefully acknowledges the Ministry of Physical Infrastructure Development, Government of Bagmati Province, for its continued institutional support and guidance.

We express our sincere gratitude to all participants of the Stakeholder Consultation and Pre-drafting Workshop held on Falgun 1, 2082, and the Validation Workshop held on Ashad 12, 2083, in Lalitpur. The constructive discussions and technical recommendations provided during these consultations significantly strengthened the scope, structure, and technical content of this guideline. We extend our special appreciation to Hon. Dr. Dinesh Chandra Devkota, Minister, and Mr. Ishowar Chandra Marahatta, Secretary, Ministry of Physical Infrastructure Development, as well as Prof. Dr. Sushil B. Bajracharya, Dean of the Institute of Engineering, for their valuable guidance and continued encouragement. We also gratefully acknowledge the contributions of numerous experts and participants from academia, industry, and federal, provincial, and local government agencies whose knowledge and practical experience greatly enriched the development of this document.

We sincerely thank Dr. Ellen Robson, Senior Lecturer at the University of Canterbury, New Zealand, for her independent technical review of the guideline and for the valuable comments and recommendations that enhanced its scientific and technical quality. We also acknowledge the dedicated technical coordination provided by Er. Raju Shrestha and Er. Chandra Dev Bhatta, together with the continued cooperation of officials from the Infrastructure Development Offices throughout the preparation of this guideline.

Finally, we acknowledge the many researchers, practitioners, and institutions whose published work has contributed to the scientific foundation of this guideline. It is our sincere hope that this document will serve as a practical and dependable reference for engineers, technicians, and planners throughout Bagmati Province, contributing to safer roads, more resilient slopes, and sustainable transport infrastructure for the benefit of the communities they serve.

Navin Kumar Singh

Director

Transport Infrastructure Directorate

Government of Bagmati Province, Hetauda

2083 BS



CONTENTS

Preamble.....	iii
Foreword	iv
Acknowledgement	v
List of figures	xiii
List of Tables.....	xv
Abbreviations	xvii
Symbols and Notations	xix
CHAPTER 1. Introduction.....	1
1.1 Background.....	1
1.2 Status of Road Network Development	1
1.2.1 National road network.....	1
1.2.2 Bagmati province road network	3
1.3 Road and Landslides	3
1.4 Need of Guideline for the Provincial and Local Network	5
1.5 Institutional Framework and Governance for Road Infrastructure	6
1.6 Target Users and Document Hierarchy	6
1.7 Scope and Applicability	7
1.8 Structure of the Guideline	7
CHAPTER 2. Roadside Slope Mitigation Practices.....	9
2.1 Current Road Construction Practices in Nepal.....	9
2.2 Typical Challenges in Mountainous Terrain	11
2.3 Common Roadside Slope Failure Mechanisms	12
2.3.1 Erosion-induced failures: Sheet, rill and gully erosion	13
2.3.2 Landslides.....	15
2.4 Review of Existing Mitigation Approaches	15
2.4.1 Bioengineering (Green / Eco) approaches	16
2.4.2 Hybrid approaches	17
2.5 Compounded and Cascading Risks.....	18
2.6 Roadside Slope Mitigation Framework.....	20
2.7 Preventive versus Remedial Approach: Guiding Philosophy.....	21
CHAPTER 3. Site Characterization	23
3.1 Desk Study and Preliminary Assessment	23



3.2	Geology and Geomorphology	24
3.2.1	<i>Geological setting of Bagmati Province</i>	24
3.2.2	<i>Geomorphological setting of Bagmati Province</i>	26
3.2.3	<i>Rate of weathering for different rock types, exposures and altitudes</i>	27
3.2.4	Key Considerations and Field Assessment.....	28
3.2.5	Rock strength determination	29
3.3	Hydrological and Rainfall Assessment.....	40
3.3.1	Rainfall pattern analysis.....	40
3.4	Summary of Key Findings	52
3.4.1	<i>Rainfall threshold for landslide initiation</i>	53
3.4.2	<i>Surface and sub-surface runoff</i>	53
3.5	Soil Slope Investigation.....	56
3.5.1	<i>Field identification and characterization</i>	56
3.5.2	Estimation of strength parameter	57
3.5.3	<i>Investigation of soil slope</i>	59
3.5.4	Detailed analysis using software	61
3.6	Vegetation and Slope Relationships	62
3.6.1	Vegetation distribution.....	63
3.6.2	Basic site requirements for vegetation.....	64
3.6.3	<i>Stoniness and drought factor</i>	65
3.7	Land-use, Settlements and Upstream-Downstream Considerations	66
CHAPTER 4.	Engineering Mitigation Structures	67
4.1	Generalized Countermeasures	70
4.2	Surface Protection Techniques	71
4.2.1	Stone soling.....	71
4.2.2	Riprap (Random stone protection).....	72
4.2.3	Boulder pitching	73
4.2.4	Shotcrete	74
4.3	Selection of Appropriate Excavation Slope.....	75
4.3.1	Cut Height and Benching.....	77
4.4	Retaining and Supporting Structures	78
4.4.1	<i>Design of retaining walls</i>	78
4.4.2	<i>Selection of appropriate retaining structure</i>	81
4.4.3	Dry stone wall.....	84
4.4.4	Banded masonry wall	84



4.4.5	Cement masonry walls	85
4.4.6	Gabion wall	86
4.4.7	<i>Cantilever retaining walls</i>	88
4.5	Mechanically Stabilized Earth Wall.....	90
4.5.1	Design philosophy	90
4.5.2	External stability	90
4.5.3	Internal stability.....	91
4.5.4	MSE wall construction procedure.....	93
4.6	Soil Nailing	94
4.7	Fills and Spoil Management	96
4.7.1	Site selection criteria	96
4.7.2	Components of a designed spoil disposal site	97
4.8	Construction Sequencing and Temporary Support.....	98
CHAPTER 5.	Water Management	99
5.1	Scope and Regulatory Framework	99
5.2	Principles of Roadside Water Management.....	100
5.3	Hydrological Studies.....	101
5.3.1	<i>Catchment delineation</i>	101
5.3.2	<i>Rainfall analysis</i>	102
5.3.3	<i>Estimation of peak flow</i>	103
5.4	Channel Hydraulics	104
5.5	Surface Drainage Systems	105
5.5.1	Catch drains.....	105
5.5.2	Side Drain (Roadside Longitudinal Drain)	108
5.6	Sub-Surface Drainage Systems	109
5.6.1	Sand blanket (Drainage blanket).....	109
5.6.2	French drain	110
5.6.3	Counterfort drains	111
5.6.4	Drilled horizontal drain.....	112
5.6.5	<i>Herringbone or chevron drains or wire Bolster</i>	114
5.7	Cross-Drainage Structures	118
5.7.1	Culverts	118
5.7.2	<i>Common failures: Hume pipe clogging and drainage-induced landslides</i>	123
5.8	Energy Dissipation Structures	124
5.8.1	Cascade drains	126



5.8.2	Chute / drop inlet.....	127
5.9	Conservation Ponds and Water Harvesting.....	130
5.9.1	Rationale for conservation ponds on road corridors	130
5.9.2	Design and siting of conservation ponds.....	131
CHAPTER 6.	Nature-Based Mitigation Techniques	132
6.1	Concept and Principles of Nature-based Solutions.....	132
6.1.1	<i>Global standard for NbS</i>	132
6.1.2	<i>Scope of NbS</i>	133
6.2	Slope Work.....	134
6.2.1	Mass Balance and Mass Management.....	134
6.3	Bio-Engineering Approaches	134
6.3.1	<i>Definition, functions, justifications and sustainability</i>	134
6.3.2	Grass seeding.....	141
6.3.3	Grass plantation.....	142
6.3.4	<i>Shrubs, trees and mixed planting systems</i>	143
6.3.5	<i>Bamboo plantation</i>	146
6.3.6	<i>Brush layering</i>	147
6.3.7	<i>Palisades</i>	149
6.3.8	<i>Fascines</i>	150
6.3.9	<i>Live check dams</i>	151
6.3.10	<i>Jute netting</i>	153
6.3.11	<i>Vegetated stone pitching</i>	154
6.3.12	<i>Vegetated gabion</i>	156
6.4	Variation in Function of Vegetation under Different Site Conditions	159
6.5	Vegetation Selection and Planting Techniques.....	160
6.5.1	<i>Selection criteria</i>	160
6.5.2	Use of local species and nursery establishment	161
6.5.3	<i>Strength development timeline of bioengineering measures</i>	162
6.6	Maintenance of NbS Interventions.....	162
6.7	Ecosystem-Based Slope Management and Use of Invasive Species.....	164
CHAPTER 7.	Selection of Appropriate Structures and Techniques	166
7.1	Decision-Support Framework	166
7.1.1	Tier 1: Hazard screening and escalation threshold.....	166
7.1.2	Tier 2: <i>Solution domain selection flowchart</i>	167
7.1.3	Tier 3: Technique selection.....	167



7.2	Criteria for Selecting Engineering vs. NbS Solutions	168
7.3	Merits and Demerits: Comparative Assessment	169
7.4	The Companion Field Tool: GeoSlope Nepal	170
7.5	Cost-Benefit Consideration (Economic, Ecological, Social).....	171
7.5.1	Economic dimension	171
7.5.2	Ecological dimension.....	172
7.5.3	Social dimension	173
7.6	Case-Based Mitigation Selection.....	174
7.6.1	Site Type 1- Cut slope in colluvial soil (Height 3-10m)	174
7.6.2	Site Type 2- Fill Slope (>10m high spoil disposal site)	175
7.6.3	Site Type 3- Mitigation/management of large gully	176
7.6.4	Site Type 4- Shallow seated landslide in the downslope	177
7.6.5	Site Type 5- Complex failure in the uphill slope	178
7.6.6	Site Type 6- Down slope filling and gully erosion.....	179
7.6.7	Site Type 7 – Rock cut slope (Jointed Sandstone).....	180
7.7	Integrated/Hybrid Solutions	181
7.7.1	Rationale for integration.....	181
7.7.2	<i>Integration timeline: Sequencing civil and bioengineering works</i>	181
7.7.3	<i>Monsoon planting window: Critical timing constraints</i>	183
7.8	Selection of Appropriate Bioengineering Techniques.....	184
7.9	Conditions Requiring Site-Specific Design: Non-Negotiable	184
CHAPTER 8.	Implementation Guidelines	187
8.1	Planning and Design Process	187
8.1.1	<i>Design-to-construction Pathway</i>	187
8.1.2	<i>Priority sequencing: Drain before you stabilize</i>	188
8.1.3	<i>Nursery lead time and plant stock planning</i>	189
8.2	Necessity of Geotechnical Engineering Input.....	189
8.2.1	<i>Mandatory, recommended and field-level assessment matrix</i>	190
8.2.2	<i>Engaging geotechnical input: Practical guidance</i>	190
8.3	Construction Quality Control and Specifications	191
8.3.1	<i>Quality standards for civil engineering works</i>	191
8.3.2	<i>Quality standards for bioengineering/NbS Works</i>	193
8.3.3	<i>Documentation and non-conformance</i>	194
8.4	Rate Analysis and Bill of Quantities (BoQ)	195
8.4.1	<i>BoQ structure for integrated slope stabilization works</i>	195



8.4.2	<i>Rate analysis: Standard bioengineering items</i>	195
8.4.3	<i>Common BoQ error to avoid</i>	197
8.5	Safety Considerations during Construction	197
8.5.1	<i>Site hazard categories on slope stabilization sites</i>	198
8.5.2	<i>Mandatory safety requirements: Non-negotiable site standards</i>	199
8.5.3	<i>Safety for community labor on bioengineering works</i>	199
8.6	Community Engagement, Societal Engineering and Local Participation	200
8.6.1	<i>The societal engineering framework</i>	200
8.6.2	<i>Minimum community engagement requirements</i>	201
8.7	Consolidated Implementation Form/Checklist	202
8.8	Common Implementation Challenges and Practical Solutions	204
CHAPTER 9.	Monitoring, evaluation and maintenance	208
9.1	Routine Monitoring of Slopes and Structures	208
9.1.1	<i>Three-tier monitoring system</i>	208
9.1.2	<i>Tier 1 community monitoring checklist</i>	209
9.1.3	<i>Tier 2 technical inspection parameters</i>	210
9.2	Performance Indicators and Evaluation Criteria	212
9.2.1	<i>Outcome performance indicators</i>	212
9.2.2	<i>Output performance indicators</i>	213
9.2.3	<i>Evaluation at key milestones</i>	214
9.3	Maintenance Plan for Engineering Structures	215
9.3.1	<i>Routine annual maintenance –Pre-monsoon and Post-monsoon cycles</i>	215
9.3.2	<i>Periodic and emergency maintenance</i>	217
9.4	Maintenance and Replantation of Bioengineering Works	218
9.4.1	<i>Bioengineering maintenance calendar</i>	218
9.4.2	<i>Replantation standards and gap-filling criteria</i>	220
9.5	Early Warning Indicators and Remedial Action Triggers	221
9.5.1	<i>Tiered early warning indicator system</i>	221
9.5.2	<i>Rainfall thresholds as early warning triggers</i>	223
9.5.3	<i>Post-event inspection protocol</i>	223
9.6	Review and Performance Evaluation Workshops (“Learning by Doing”)	224
9.6.1	<i>Two-level workshop structure</i>	225
9.6.2	<i>From workshops to guideline updates: The continuous improvement loop</i>	225
REFERENCES		227
ANNEXES		231



Annex 1: Vegetation Characteristics Database.....	232
A1.1 Grasses and Ground Cover	232
A1.2 Trees	238
A1.3 Shrubs and Climbers	243
Annex 2: Species Selection Guide for Bio-Engineering	247
A2.1 Site Condition to Species Matrix	247
A2.2 Engineering Function to Technique and Species Matrix	248
A2.3 Step-by-Step Species Selection Process.....	249
Annex 3: Reference / Success Cases	250
Annex 4 Templates for Field Data Collection	258
A4.1 Geology and Morphology (Form A)	258
A4.2 Geotechnical Data (Form B)	260
A.4.3 Rainfall, Infiltration, Runoff, Erosion and Scouring (Form C).....	261
A4.4 Vegetation Survey (Form D)	262
Annex 5: Bioengineering Design and Estimate Templates	263
A5.1 Project Identification.....	263
A5.2 Work Norms for NbS	263
Annex 6 BoQ Format for Nbs / Bioengineering Items	280
A6.1 Contract Information	280
A6.2 Bill of Quantities	280
Annex 7 Nursery Establishment and Operation Guide (Local Species).....	282
A7.1 Nursery Site Selection Criteria.....	282
A7.2 Nursery Layout and Infrastructure	282
A7.3 Propagation Methods by Species Type.....	283
A7.4 Seed Collection, Processing, and Storage.....	283
A7.5 Annual Calendar of Nursery Operations.....	284
Annex 8 Quick-Reference Decision Charts for Supervisors and Contractors.....	285
Chart 8.1 Step-by-Step Problem Diagnosis and Intervention Decision Tree	285
Chart 8.2 Slope Type × Problem × Solution Quick Reference	286
Chart 8.3 Early Warning Signs and Required Actions	287
Chart 8.4 Bioengineering Strength Development Timeline	288
Annex 9 Culverts: Calculations and Nomographs.....	289



LIST OF FIGURES

Figure 1.1: Development of road network from federal government (Source: Economic Survey (2024/25)).....	2
Figure 1.2: Provincial and local road development.....	2
Figure 1.3: Distribution of Provincial Highway (PH) and Provincial Road (PR) by district, Bagmati province (Source: PTMP, 2024)	3
Figure 2.1: Progressive erosion stages on unprotected roadside slopes	13
Figure 2.2: Common erosion problem in bare slope.....	13
Figure 2.3: Common roadside slope failure problem (Varnes, 1978).....	14
Figure 2.4: Comparative performance of roadside slope mitigation approaches scores.....	18
Figure 2.5: Slope stability analysis, mitigation design and implementation framework.....	21
Figure 2.6: Preventive philosophy for roadside slope	22
Figure 3.1: Geological map of the Bagmati Province	25
Figure 3.2: Step-by-step process for rock slope characterization	28
Figure 3.3: Field assessment of a limestone rock cut slope showing wedge and plane failure susceptibility	38
Figure 3.4: Identification of different discontinuities in the field.	38
Figure 3.5: Location map of DHM rainfall stations used in the analysis, Bagmati Province.....	40
Figure 3.6: Annual rainfall time series with long-term trends for station 903.....	42
Figure 3.7: SPI-12 time series for Station 903 (Jhuwani) illustrating wet episodes (blue bars, SPI > 0) and dry episodes (red bars, SPI < 0).	43
Figure 3.8: Seasonal rainfall distribution (% contribution of Pre-monsoon, Monsoon, Post-monsoon, and Winter seasons to long-term mean annual total) for station 903.....	44
Figure 3.9: Year-by-year seasonal rainfall time series for station 903, showing inter-annual variability in Pre-monsoon, Monsoon, Post-monsoon, and Winter rainfall.	45
Figure 3.10: Seasonal rainfall trend plots for Station 1017 (Duwachaur). A highly significant decreasing trend is evident in Monsoon (JJAS) rainfall ($p < 0.001$, Mann-Kendall), which is the primary driver of the declining annual total at this station.	46
Figure 3.11: Monthly rainfall time series with trend lines for station 1017	48
Figure 3.12: Monthly rainfall time series with trend lines for station 1103	48
Figure 3.13: Bagmati province digital elevation model (DEM) showing the north-south cross-section line used for elevation-rainfall transect profiling. Chainage 0 km is at the southern end of the transect.....	49
Figure 3.14: Elevation and average annual rainfall profile along the north-south transect, Bagmati Province. Blue bars represent long-term mean annual rainfall in 2 km bands (right axis, mm). Elevation profile shown in orange (left axis, m)	49
Figure 3.15: Elevation and average pre-monsoon (March-May) rainfall profile along the north-south transect, Bagmati Province	50
Figure 3.16: Elevation and average monsoon (June-September) rainfall profile along the north-south transect, Bagmati Province.	51
Figure 3.17: Elevation and average post-monsoon (October-November) rainfall profile along the north-south transect, Bagmati Province.....	51
Figure 3.18: Elevation and average winter (December-February) rainfall profile along the north-south transect, Bagmati Province.	52
Figure 3.19: A sample of IDF (Intensity-Duration-Frequency) curve of precipitation. (Note: we can make a log-log plot as well, though this sample is semi-log plot).....	55



Figure 3.20: Field identification of soil	57
Figure 3.21: Site characterization of soil slope.....	59
Figure 3.22 Different methods of slope stability analysis (NRA/NDRRMA, 2021)	61
Figure 3.23: Vegetation distribution a) Bagmati province b) along the section A-A.....	63
Figure 3.24: Drought factor scoring system for vegetation site assessment on roadside slopes sum scores across five factors; Class I (Score <6) = Cool/Moist to Class VI (Score >30) = Very Severely Hot/Dry (Source: Howell, 1999)	66
Figure 4.1: Generalized matrix for selection of countermeasures	70
Figure 4.2: Generalize sketch of cut slope condition for a) soil b) rock (source: DoR, 2003)	77
<i>Figure 4.3: Typical Retaining wall and load</i>	<i>80</i>
Figure 4.4: Design flow chart of retaining wall.....	81
Figure 4.5: Typical construction details for dry stone masonry wall	84
Figure 4.6: Typical section of Banded masonry wall	85
<i>Figure 4.7: Schematic diagram of cement masonry wall</i>	<i>85</i>
Figure 4.8: Toe protection for retaining walls	86
<i>Figure 4.9: Layouts of gabion walls.....</i>	<i>87</i>
<i>Figure 4.10: a) Typical RC cantilever wall b) Different configuration of RC cantilever walls</i>	<i>88</i>
<i>Figure 4.11: Forces acting in Cantilever wall.....</i>	<i>89</i>
<i>Figure 4.12: Mechanically stabilized earth wall.....</i>	<i>90</i>
Figure 4.13: Typical component of spoil disposal sites	98
Figure 5.1: Catchment delineation workflow using Google Earth.....	102
Figure 5.2: Flow chart for estimation of flow capacities of drains.....	107
Figure 5.3: Network of SSDs consisting of tributary(branch) and main drains.....	117
Figure 5.4: Typical Relief Culvert.....	119
Figure 5.5: Benefits of cut-off walls (Source: Manual for Low volume Roads, Part C; Sierra Leone Road Authority).....	121
Figure 5.6: Position of Culvert Headwall and Wingwalls	122
Figure 5.7: Culvert Apron	123
Figure 5.8: Gabion Cascade Design (Hearn, 2011).....	125
Figure 5.9: Cross drainage configuration and its influence on inlet blockage and outlet scour potential (with or without protection) (Hearn, 2011).....	129
<i>Figure 6.1: Mass balance and mass management (NRA/NDRRMA, 2021)</i>	<i>134</i>
<i>Figure 6.2: Framework for plant species selection</i>	<i>161</i>
Figure 7.1: Simplified decision-support flowchart for solution domain selection.	167
<i>Figure 7.2: Overall architecture of field assessment and design tool</i>	<i>171</i>
<i>Figure 7.3: Colluvial slope: Site photographs, landslide map, section and proposed mitigation measures</i>	<i>174</i>
<i>Figure 7.4: Fill slope: Site photograph, topography and mitigation plan, cross-section</i>	<i>175</i>
<i>Figure 7.5: Active gully: Site photographs, landslide map and proposed mitigation measures (WRRDC, 2023).....</i>	<i>176</i>
<i>Figure 7.6: Shallow seated landslide: Site photographs, landslide map and proposed mitigation measures</i>	<i>177</i>
<i>Figure 7.7: Complex landslide (Slides, flows, block slides, gullies) and proposed mitigation measures</i>	<i>178</i>
<i>Figure 7.8: Downslope fill/spoil problems and its management</i>	<i>179</i>
<i>Figure 7.9: Rock slope instability and its mitigation</i>	<i>180</i>



LIST OF TABLES

Table 1-1: Target users and primary sections.....	6
Table 2-1: Estimated cost breakdown in different categories of work (EEAP 2020)	10
Table 2-2: Key geotechnical and environmental challenges for roadside slope stability	12
Table 3-1: Data types, use and sources.....	23
Table 3-2: Rock weathering grades and engineering significance (Durham/TU, 2024; DoR, 2007) ..	27
<i>Table 3-3: Additional information for the slope assessment</i>	29
<i>Table 3-4: Lithology of rocks in Bagmati Province</i>	30
Table 3-6: Field indicators for assessing rock strength and weathering condition.....	37
Table 3-6: Rock strength classification based on the field investigation.....	37
Table 3-7: Field identification of discontinuities and their slope stability concern	37
Table 3-8: Field guide for rock slope failure mode identification	39
Table 3-9: DHM rainfall stations selected for analysis – Bagmati Province	41
Table 3-10: SPI-12 drought characterization summary for selected stations	43
Table 3-11: Long-term seasonal mean rainfall (mm) and % contribution to annual total.....	44
Table 3-12: Long-term annual rainfall trend statistics – Mann-Kendall test and Sen's Slope estimate	46
Table 3-13: Summary of statistically significant seasonal rainfall trends (Mann-Kendall, $p < 0.05$).47	47
Table 3-14: Statistically significant monthly rainfall trends (May–October), $p < 0.05$	47
Table 3-15: Runoff coefficients for different land use/cover types and slopes.....	54
Table 3-16: Shear strength parameters of different soil (Durham/TU, 2025)	57
Table 3-17 Soil classification and its characteristics as construction materials	58
<i>Table 3-18: Different methods of detailed investigation</i>	59
Table 3-19 Comparison between limit equilibrium and deformation analysis (NRA/NDRRMA, 2021)	62
Table 3-20: Soil moisture parameters relevant to bioengineering site assessment.....	65
Table 3-21: Climatic parameters affecting bioengineering species performance	65
Table 4-1: Types of slope stabilization measures.....	68
Table 4-2: Preliminary cut slope gradients (H:V) for cut height.....	75
Table 4-3: Indicative safe unsupported vertical cut heights.....	76
<i>Table 4-4: Unit weight of different masonry wall</i>	78
<i>Table 4-5: Typical values bearing capacity for different soil types</i>	79
Table 4-6: Detail about different types of retaining structure (Source : IS 14588 part 1 Clause 3.1) 82	82
Table 4-7: Selection of breast walls (Source: IS 14588-part 1 Clause 3.1)	83
<i>Table 4-8: K_h / K_a ratio by reinforcement type and depth (FHWA NHI-10-024)</i>	91
<i>Table 4-9: Reduction factors for geosynthetic long-term design strength (FHWA NHI-10-024)</i>	91
<i>Table 4-10: LRFD resistance factors for internal stability limit states (AASHTO 2020, Table 11.5.6-1)</i>	92
<i>Table 4-11: MSE wall - granular reinforced fill gradation requirements (FHWA NHI-10-024)</i>	93
Table 4-12: Components of spoil disposal site	97
Table 5-1: Values of runoff coefficient, C (DoR-Road drainage guidelines and regional references)	103
Table 5-2: Manning coefficients and limiting velocities for different channel linings.....	105
Table 5-3: Types of slope drainage, their functions and limitations (Hearn, 2011)	117
Table 5-4: Different culverts with selection features	120
Table 5-5: Basic description of upstream and downstream protections	123



Table 5-6: Additional energy dissipating structures.....	129
Table 5-7: Benefits of conservation ponds.....	130
Table 6-1: NbS principles for roadside slope stabilization	132
Table 6-2: Functional roles of bioengineering and engineering measures in slope stabilization ...	135
Table 6-3: Relative functional strength of vegetation.....	136
Table 6-4: Standard bioengineering techniques for roadside slope stabilization: classification by application, slope range, and soil suitability.....	138
Table 6-5: Vegetation zonation for bioengineering in Nepal	158
Table 6-6: Criteria for selecting bioengineering species and techniques	160
Table 6-7: Growth and performance timeline of bioengineering techniques.....	162
Table 6-8: Operational maintenance schedule for bioengineering works in Nepal.....	163
Table 6-9: Invasive and risk-prone species management in bioengineering contexts.....	164
Table 7-1: Three-tier framework for slope stabilization decision-making and technique selection	166
Table 7-2: Criteria for selecting engineering vs. Nbs solutions.....	168
Table 7-3: Comparative assessment of engineering, NbS and hybrid approaches.....	169
Table 7-4: Indicative Comparison of the Relative Costs and Benefits	172
Table 7-5: Ecosystem services and beneficiary impacts of NbS.....	172
Table 7-6: Civil engineering and NbS roles in hybrid slope stabilization	181
Table 7-7: Integration Timeline: civil and bioengineering works sequencing	182
Table 7-8: Seasonal suitability and operational plan for bioengineering activities in Nepal	183
Table 7-9: Slope bioengineering technique selection guide	185
Table 8-1: Standard workflow for slope stabilization design and implementation.....	187
Table 8-2: Plant production lead-time in nursery (DoR, 1999).....	189
Table 8-3: Geotechnical engineering input requirements by site condition	190
Table 8-4: Quality control standards: civil engineering works	191
Table 8-5: Quality control standards: bioengineering works	193
Table 8-6: Bill of quantities structure for slope stabilization works	195
Table 8-7: Rate analysis: bioengineering items	196
Table 8-8: Key hazards and control measures in slope stabilization works.....	198
Table 8-9: Community and social factors in slope stabilization design	200
Table 8-10: Consolidated implementation checklist (see Annex 8 for field form).....	202
Table 8-11: Common implementation challenges and practical solutions.....	205
Table 9-1: Three-tier monitoring system for slope stabilization works	208
Table 9-2: Tier 1 Community monitoring checklist (reference version)	209
Table 9-3: Slope stabilization monitoring parameters and maintenance thresholds.....	211
Table 9-4: Outcome performance indicators and evaluation benchmarks.....	212
Table 9-5: Slope stabilization output indicators and performance targets.....	214
Table 9-6: Annual civil engineering maintenance schedule	215
Table 9-7: Major repair and renewal schedule for slope stabilization structures	217
Table 9-8: annual bioengineering maintenance calendar	219
Table 9-9: Replantation measures	220
Table 9-10: Early warning indicator system: classification and response chain.....	222
Table 9-11: Rainfall thresholds and triggered monitoring actions	223
Table 9-12: Post Event inspection and repair procedure	224
Table 9-13: Annual review and learning workshops for slope stabilization	225



ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ADPC	Asian Disaster Preparedness Center
AWC	Available Water Capacity
BCPR	Bureau for Crisis Prevention and Recovery
BoQ	Bill of Quantities
CRI	Climate Risk Index
CSM	Cutter Soil Mix
DEM	Digital Elevation Model
DHM	Department of Hydrology and Meteorology
DMG	Department of Mines and Geology
DoLID	Department of Local Infrastructure Development
DoR	Department of Road
DoS	Department of Survey
DRSP	District Roads Support Program
DSCWM	Department of Soil Conservation and Watershed Management
DSCWM	Department of Soil Conservation and Watershed Management
DUDBC	Department of Urban Development and Building Construction
EEAP	Earthquake Emergency Assistant Project
EIA	Environmental Impact Assessment
FC	Field Capacity
FHWA	Federal Highway Administration
FoS	Factor of Safety
GFRP	Glass Fiber Reinforced Polymer
GPS	Global Positioning System
HCL	Hydrochloric Acid
HDPE	High-Density Polyethylene
ICIMOD	International Centre for Integrated Mountain Development
IDF	Intensity Duration Frequency
IDW	Inverse Distance Weighting
IEE	Initial Environmental Examination
IS	Indian Standard
IUCN	International Union for Conservation of Nature
LRFD	Load and Resistance Factor Design
LRN	Local Road Network
Masl	meters above sea level
MK	Mann-Kendall
MoHA	Ministry of Home Affairs
MoPIT	Ministry of Physical Infrastructure and Transport



MPa	Mega Pascal
MSE	Mechanically Stabilized Earth
NbS	Nature Based Solutions
NDRRMA	National Disaster Risk Reduction and Management Authority
NHI	National Highway Institute
NIRTP	Nepal-India Regional Trade and Transport Project
NRA	National Reconstruction Authority
NRS	Nepal Road Standards
NTFP	Non-Timber Forest Products
OLS	Ordinary Least Squares
PAW	Profile Available Water
PCC	Plain Cement Concrete
PH	Provincial Highway
PR	Provincial Road
PRN	Provincial Road Network
PTMP	Provincial Transport Master Plan
PVC	Polyvinyl Chloride
PWP	Permanent Wilting Point
QC	Quality Control
RCC	Reinforced Cement Concrete
RRS	Reduced Strength Ratio
RUC	Road User Committee
SDR	Standard Dimension Ratio
SMD	Soil Moisture Deficit
SPI	Standardized Precipitation Index
SRN	Strategic Road Network
SSP	Shared Socioeconomic Pathways
TID	Transport Infrastructure Directorate (TID)
UNDP	United Nations Development Programme
uPVC	Unplasticized Polyvinyl Chloride
USGS	U.S. Geological Survey
WWF	World Wide Fund for Nature



SYMBOLS AND NOTATIONS

A	Catchment area or flow cross-sectional area (depending on context)
ABW	Allowable backwater depth
Ac	Net cross-sectional area of steel reinforcement per unit width
A _h	Horizontal seismic coefficient
AHW	Allowable headwater depth
ARF	Areal Reduction Factor
A _v	Vertical seismic coefficient
b	Gross width of a reinforcement strip
C	Runoff coefficient
c, c'	Cohesion
C _c	Coefficient of curvature
C ^{trial} , ϕ^{trial}	Reduced (trial) shear-strength parameters
C _u	Coefficient of uniformity
D	Culvert diameter or barrel height
d	Flood depth in the natural channel
dc	Critical depth
de	Depth of culvert invert below the streambed
F*	Pullout friction/ bearing factor
FS, FOS	Factor of safety
F _y	Yield strength of steel reinforcement
H	Height difference/ head
HW	Headwater depth
I, i	Rainfall, rainfall intensity
I	Importance factor
K _a	Active earth pressure coefficient
K _e	Entrance loss coefficient
K _h	Horizontal earth pressure coefficient
L	Length of flow path
L, L _a , L _e	Total, adherence and effective (pullout) embedment length of reinforcement
M _o	Overturning Moment
M _r	Resisting Moment
n	Manning's roughness coefficient
N	Standard penetration test blow count
N _c , N _q , N _y	Bearing capacity factors



P	Wetted perimeter
P_a	Active earth pressure resultant
Q	Maximum discharge
q_a	Surcharge load
q_u	Ultimate bearing capacity
R	Hydraulic radius (A/P); Response reduction factor
R_c	Coverage ratio of reinforcement
$RF_{ID}, RF_{CR}, RF_{CD}$	Reduction factors for installation damage, creep, and chemical/biological degradation respectively
S	Channel slope
S_v, S_h	Vertical and horizontal reinforcement spacing
T	Storm duration
T_{ac}	Nominal long-term connection strength
T_{al}	Allowable long-term design strength of reinforcement
t_c	Time of concentration
T_{max}	Maximum tension induced in the reinforcement layer
T_{ult}	Ultimate tensile strength of reinforcement
TW	Tailwater depth
V_o	Outlet flow velocity
W_1, W_2	Weight components of the wall/soil mass
x_1, x_2	Moment arms corresponding to W_1, W_2
Z	Seismic zone factor
z'	Lever arm height
α	Scale effect correction factor (pullout resistance)
γ	Unit weight of soil
δ	Wall friction angle
σ_0'	Net vertical stress at the wall base
σ_v	Vertical stress
ϕ, ϕ	Angle of internal (shearing) friction
$\phi_t, \phi_{po}, \phi_{cr}$	LRFD resistance factors for rupture, pullout and connection limit states



CHAPTER 1. INTRODUCTION

1.1 Background

Nepal is among the countries most exposed to climate and geophysical hazards. The Climate Risk Index 2026 ranked Nepal as the sixth most affected country globally based on impacts recorded in 2024 ([Germanwatch, 2026](#)), while earlier global assessments ranked it 11th for earthquake risk and 30th for flood risk ([UNDP/BCPR, 2004](#)). More than 80 percent of the country's land area comprises hills and mountains, where steep terrain, fragile geology, intense monsoon rainfall, and seismic activity create inherently unstable slopes. As Nepal's road network has expanded to approximately 100,000 km, many roads, particularly at the provincial and local levels, have been constructed with limited geotechnical investigation, inadequate drainage, and insufficient slope protection. Road construction frequently removes vegetation, alters natural drainage, and destabilizes slopes, resulting in recurrent landslides, road closures, and costly maintenance.

Roadside slope stabilization can be achieved using conventional engineering, Nature-based Solutions (NbS), or hybrid approaches that combine both. Conventional measures rely on structural works such as retaining walls and gabions, whereas NbS use vegetation and natural ecological processes to improve slope stability. According to the IUCN Global Standard ([IUCN, 2020](#)), NbS are actions that protect, sustainably manage, and restore ecosystems to address societal challenges while providing benefits for both people and biodiversity. Compared with purely structural measures, NbS can improve resilience, reduce long-term maintenance requirements, enhance ecosystem services, and provide more sustainable slope protection. Among these approaches, bioengineering and hybrid measures are particularly suitable for roadside applications because they combine engineering performance with environmental benefits.

Bioengineering is the most established Nature-based Solution for roadside slope stabilization in Nepal. By integrating living vegetation with simple structural measures, it provides effective erosion control, reinforces soil, and improves slope stability over time. Although bioengineering has been successfully applied since the 1990s ([DoR, 1999](#)), its wider adoption remains constrained by the lack of standardized technical guidance, inconsistent implementation practices, and limited technical capacity. This guideline addresses these challenges by providing practical and scientifically sound guidance for planning, designing, implementing, and maintaining nature-based roadside slope stabilization measures. While the principles are broadly applicable across Nepal, the recommendations have been developed specifically to reflect the physiographic, climatic, geological, and institutional conditions of Bagmati Province.

1.2 Status of Road Network Development

1.2.1 National road network

Nepal's road network tells a story beyond its statistics. As shown in [Figure 1.1](#) and [Figure 1.2](#), the network has expanded to more than 100,000 km, with much of the recent growth occurring in the hills and mountains. While this expansion has improved connectivity and socioeconomic development, it has also increased exposure to slope instability, particularly where roads have been constructed without adequate geotechnical investigation, drainage, and slope protection. The Strategic Road Network (SRN), under the Department of Roads (DoR), spans 36,132 km covering 80 National Highways and the Feeder Roads that connect them. Following institutional reforms under



federalization, the Local Road Network had grown to 67,662 km by 2024 (Figure 1.2), the overwhelming majority of which are unpaved: 68% earthen, 29% gravel, and barely 3% blacktop, predominantly tracks pushed through hillsides with minimal geotechnical consideration (DoLI, 2023). Across the national road network, only 19% of total road length is paved to an all-weather standard. The remaining 81% consists of earthen and gravel roads with unprotected cut slopes and unlined side drains. Every monsoon season, this network functions collectively as a vast system for concentrating surface runoff and directing it onto terrain that is already among the most geologically fragile and erosion-prone region. Similarly, seventy percent of the SRN passes through Nepal's hills and mountains (DoR, 2000), where fragile geology, rugged terrain, weak soils, and intense monsoon rainfall combine to make roadside slope failure not an occasional risk but a seasonal certainty. This reality is further compounded by the manner in which much of the network has been constructed: rapid alignment-driven earthworks on steep terrain, with limited geotechnical investigation, inadequate drainage provision, and little or no slope protection. The consequence is a road network that is structurally predisposed to recurring failure, not because the hazard is unavoidable, but because the conditions that trigger it have been systematically created and left unaddressed.

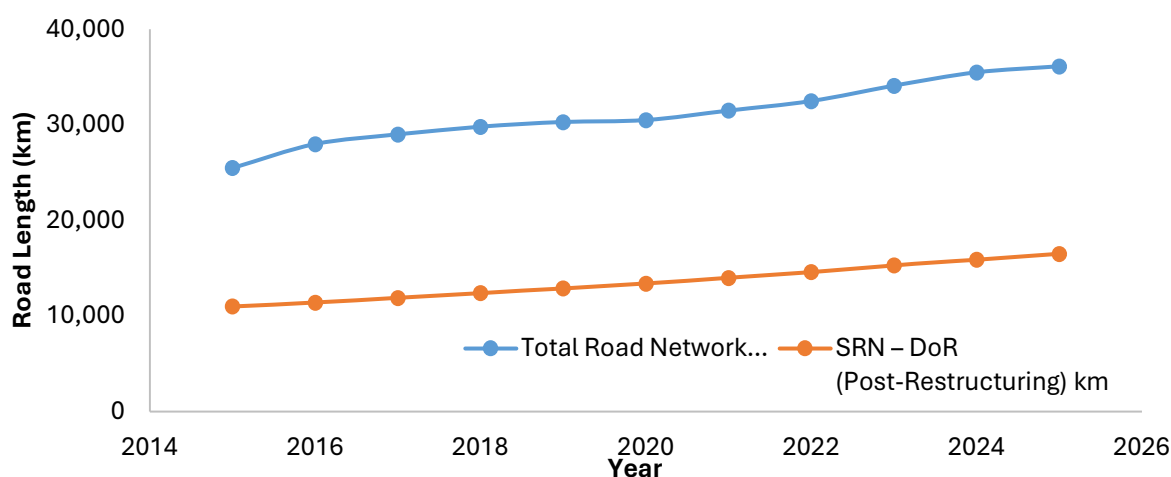


Figure 1.1: Development of road network from federal government (Source: Economic Survey (2024/25))

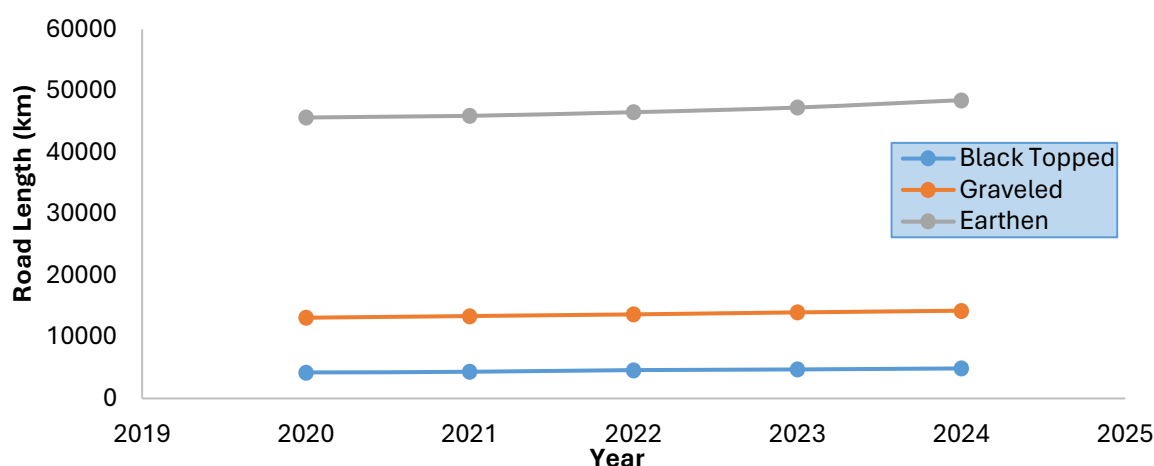


Figure 1.2: Provincial and local road development



1.2.2 Bagmati province road network

Bagmati Province holds the largest share of the provincial and local road network in Nepal, accounting for approximately 24.68% of Nepalese Road. The province spans 13 districts from the Terai plains to the High Himalayan ranges, and its road network reflects both the ambition and the unfinished nature of post-federalization infrastructure development.

Under the Provincial Transport Master Plan (PTMP, 2024), the Provincial Road Network (PRN) comprises 26 Provincial Highway (PH) sections totaling 1,010.1 km and 288 Provincial Road (PR) sections totaling 5,363.8 km, a combined network of approximately 6,374 km under the jurisdiction of the Transport Infrastructure Directorate (TID). Figure 1.3 shows the district-wise distribution; Kavrepalanchok leads in provincial highway length at 159.9 km, while Sindhupalchok accounts for the greatest share of provincial roads at 720.4 km.

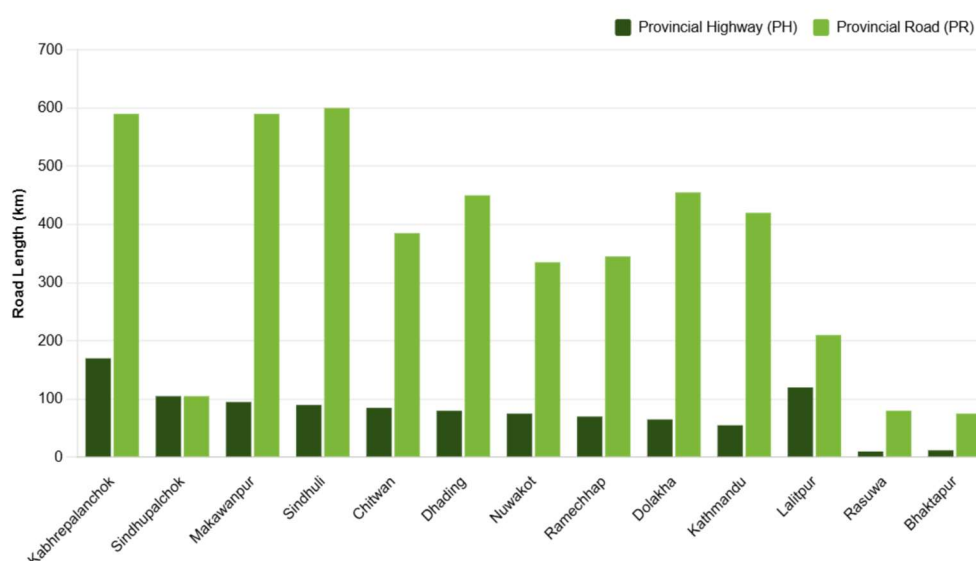


Figure 1.3: Distribution of Provincial Highway (PH) and Provincial Road (PR) by district, Bagmati province (Source: PTMP, 2024)

The pavement condition of the network highlights significant infrastructure challenges. Of the total PRN, 55.4% (3,534 km) remains earthen, 25.2% (1,609 km) is gravel, and only 19.3% (1,231 km) is blacktopped. This reflects the broader national scenario, where only about 7% of provincial and local roads are paved. Most earthen roads were constructed using excavators without adequate geotechnical investigation and design, leaving cut and fill slopes unprotected and highly susceptible to monsoon-induced erosion, landslides, and slope failures. The PTMP five-year investment programme aims to reduce the proportion of earthen roads to 25.5% and increase blacktop coverage to 29.6%, which will require substantial investment. For the sustainable development of the road network, integrating slope protection measures into road upgrading contracts from the outset is estimated to be 3–5 times more cost-effective than implementing remedial measures after slope failure occurs.

1.3 Road and Landslides

Road infrastructure is a fundamental component of socio-economic development, particularly in mountainous countries such as Nepal, where roads serve as lifelines connecting remote communities to markets, services, and administrative centers. However, in steep and geologically fragile terrains like the Himalayas, road construction has emerged as one of the most significant



anthropogenic drivers of landslide activity. The interaction between rugged topography, complex geology, intense monsoon rainfall, seismic activity, and rapid road expansion has resulted in widespread slope instability along road corridors, posing persistent challenges to infrastructure safety and sustainability.

Road construction alters natural slope systems through excavation, removal of lateral and basal support, modification of slope geometry, and disruption of surface and subsurface drainage. These interventions often push slopes beyond their natural stability thresholds, particularly where excavation is carried out without adequate geotechnical investigation or design control (Crosta et al., 2013). Numerous studies have demonstrated that proximity to roads is a strong predictor of landslide occurrence, emphasizing the role of road cuts in triggering slope failures (McAdoo et al., 2018; Robson et al., 2025). These landslides are predominantly rainfall-induced, with shallow slides and debris flows frequently initiated during the monsoon season. Prolonged or high-intensity rainfall increases pore water pressure in soils and weathered rock masses exposed by road excavation, leading to rapid reductions in soil suction and shear strength (Timsina et al., 2026).

Seismicity further aggravates slope instability in the Himalayan region. Earthquake shaking can directly trigger failures or weaken slopes that subsequently fail under rainfall loading. Road cut slopes, already excavated near limit equilibrium conditions, are particularly vulnerable to such combined triggering mechanisms (Petley et al., 2018). Repeated cycles of monsoon rainfall and seismic shaking lead to progressive degradation of slope stability, resulting in recurring failures at the same locations.

Box 1.1: Consequences of Landslides and Slope Failures on Road Infrastructure

Even when landslides occur at only one or a few points along a road alignment, they can destroy or block entire sections and disrupt much larger transportation networks, with consequences that extend well beyond the immediate site.

Social Consequences

- Loss of lives and injury to road users
- Psychological trauma among affected communities
- Displacement and resettlement of affected families
- Loss of income and livelihood for road-dependent communities
- Disruption to education for children in isolated communities
- Damage to cultural heritage and community assets

Economic Consequences

- Damage to public infrastructure including roads, bridges, and drainage works
- Damage to private property and agricultural land

Case 1. Krishnabhir Landslide, Prithivi Highway (2000).

The Krishnabhir Landslide, located approximately 83 km west of Kathmandu in Dhading District, blocked the Prithivi Highway (Nepal's primary road connection between Kathmandu and Pokhara) for 11 days, causing shortages of daily commodities in the capital city. The highway is particularly vulnerable, with approximately 46 percent of its length running through hillside terrain with multiple cut slopes (Maskey, 2016).

Case 2. Multi-district slope failures, Far-Western Nepal (2009).

In October 2009, simultaneous slope failures across Achham, Doti, and Dadeldhura districts closed all district roads for a minimum of 10 days. The Karnali Highway sustained severe damage and remained closed for several weeks, isolating communities from essential services and supply chains (MoHA, 2009).



• Disruption to goods movement and supply chains • Loss of tourism revenue and productive working days • High cost of emergency reinstatement and repeated maintenance Environmental Consequences • Loss of soil fertility through erosion and mass movement • Loss of biodiversity and destruction of riparian ecosystems • Increased sediment load in rivers and downstream deposition • Degradation of landscape and loss of aesthetic and ecological value	Case 3. Jure Landslide, Araniko Highway (2014). On 2 August 2014, a massive landslide at Jure village in Sindhupalchok District killed at least 156 people and buried approximately 1 km of the Araniko Highway, which was Nepal’s primary overland connection to China. The highway remained closed for three months, with significant consequences for Nepal–China trade and regional mobility with an estimated daily trade value of NPR 38 million (approximately USD 370,000). The landslide also dammed the Sunkoshi River, forming a 55 m-high debris dam that threatened downstream settlements and infrastructure (DHM, 2014; ICIMOD, 2014).
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The impacts of road-related landslides extend beyond physical damage to slopes and pavements. Landslides disrupt transport connectivity, isolate communities, delay emergency response and impose significant economic burdens due to repeated maintenance and rehabilitation. In rural and provincial road networks, even small-scale slope failures can have disproportionate social and economic consequences (McAdoo et al., 2018; Paudyal et al., 2023) as presented in the Box1.1.

Although advances have been made in landslide susceptibility mapping, rainfall threshold analysis, and numerical modeling, a persistent gap remains between scientific knowledge and routine engineering practice. Field observations indicate that slope angles, drainage provisions, and stabilization measures are often selected based on experience or budgetary constraints rather than systematic geotechnical evaluation (Robson et al., 2025). This gap underscores the need for structured, context-specific guidance that translates research findings into practical design and construction standards.

1.4 Need of Guideline for the Provincial and Local Network

The development of slope stabilization guidelines is essential to address the growing frequency and impact of road-related landslides in mountainous regions. In Nepal, a substantial proportion of landslides originate from inadequately designed road cut slopes, where steep excavation, poor drainage, and limited stabilization measures prevail (McAdoo et al., 2018; Paudyal et al., 2023). In the absence of standardized guidelines, slope design practices vary widely among projects and agencies, leading to inconsistent safety performance and repeated failures. Guidelines that integrate terrain classification, material properties, rainfall regime, and excavation height can support informed decision-making during planning and construction stages.

The clear slope stabilization guidelines enhance consistency, improve technical capacity at provincial and local levels, and reduce reliance on reactive maintenance. Proactive slope design and stabilization are demonstrably more cost-effective than post-failure repairs and emergency interventions (Robson et al., 2025). In the context of increasing climate variability and expanding road networks, slope stabilization guidelines are therefore critical tools for resilient infrastructure development, disaster risk reduction, and sustainable transport planning.



1.5 Institutional Framework and Governance for Road Infrastructure

Constitution of Nepal (2072) restructured infrastructure governance into federal, provincial and local tiers. Road infrastructure is now managed across four primary categories under distinct agencies, each with slope stabilization responsibilities relevant to this guideline:

Agency	Road Category / Jurisdiction
Department of Roads (DoR) / MoPIT	National Highways and Strategic Road Network (SRN)
Transport Infrastructure Directorate (TID)	Provincial Highways and Provincial Roads (PRN)
Department of Local Infrastructure Development (DoLID) / Municipalities	Provincial and District Roads
DUDBC / Urban/ Rural Municipalities	Urban/Rural Road Networks

While the constitutional restructuring has devolved significant infrastructure responsibility to the provincial and local governments, the accompanying transfer of technical capacity has not kept pace. Provincial governments are now responsible for managing road networks that traverse some of the most geologically complex and landslide-prone terrain in the country, yet the technical guidelines, institutional knowledge, and specialist support systems that underpin effective slope management remain largely concentrated at the federal level.

Within Bagmati Province, the TID is the principal agency responsible for the provincial road network. At the field level, TID is staffed predominantly by mid-level engineers and technicians who carry direct responsibility for slope assessment, construction supervision, and maintenance decisions with limited access to geotechnical specialist support. This guideline is designed to address that gap. It provides technically grounded, field-applicable decision support that enables practitioners at all levels, i.e., from field technicians to design engineers, to assess slope conditions, select appropriate stabilization measures, and supervise their implementation with confidence.

1.6 Target Users and Document Hierarchy

This guideline is designed as a hierarchical reference serving multiple practitioner levels. It is written technically rigorous but accessible to field technicians, with catalogue designs and quick-reference tools for routine cases, and clear escalation pathways to specialist input for complex situations.

[Table 1-1](#) maps target users to relevant sections.

Table 1-1: Target users and primary sections

Target User Group	Primary Chapters	Key Annexes
Policy makers, Provincial Government officials, TID senior management	Chapters 1, 2, 7	Annex 9 (Decision charts)
Design engineers (TID, consultants)	Chapters 3, 4, 5, 6, 7, 8	Annexes 1, 2, 3, 5, 6
Field supervision	Chapters 7, 8, 9	Annexes 5, 8, 9
Contractors and site foremen	Chapters 8, 9	Annexes 6, 8, 9



Within the broader documentation framework for slope stabilization works on provincial road projects, this guideline occupies the uppermost position as the policy and technical basis for all subsequent project-level documentation. The hierarchy is as follows:

1. Policy framework and technical basis for slope stabilization practice
2. Engineered drawings, stability calculations, and site-specific specifications prepared by the design engineer
3. Template for rate analysis, specification and bill of quantities
4. Construction supervision checklist
5. Post-construction performance monitoring and community maintenance arrangements

Each level of documentation draws on and must be consistent with the level above it. Project-specific designs that depart from the guidance contained in this document should be supported by written technical justification from a qualified geotechnical engineer.

1.7 Scope and Applicability

These guidelines are intended to provide **systematic, practical, and context-specific guidance** for the planning, design, construction, and maintenance of roadside slopes along **provincial and local road networks** in mountainous and hilly terrains. The scope of the guidelines includes, but is not limited to, the following components:

1. Site characterization and investigation of roadside slopes, including geological and geomorphological mapping; identification and classification of soil slopes (Colluvial soils, residual soils, and fill materials); identification and classification of rock slopes based on lithology, degree of weathering, and rock mass structure; assessment of discontinuities such as joints, bedding planes, and faults with respect to their orientation, spacing, and persistence; evaluation of groundwater conditions and seepage paths; and documentation of slope history, evidence of past failures, and surface drainage patterns
2. Design criteria for the selection of appropriate cut slope geometry, including determination of slope angle, slope height, and benching requirements, with due consideration of material properties, site-specific stability conditions, and seismic and rainfall-induced loading
3. Design of slope protection measures aimed at controlling erosion and surface degradation, including surface drainage provisions, bioengineering and vegetation-based techniques, shotcrete, stone pitching, and other surface armoring methods.
4. Integration of surface and subsurface drainage systems to enhance slope stability by reducing infiltration and pore water pressure
5. Design of slope stabilization and mitigation measures, including structural solutions such as gravity retaining walls and reinforced soil structures as well as mechanical stabilization techniques such as soil nailing, rock bolting, ground anchors, hybrid systems, and other ground improvement methods
6. Guidance on construction practices, including excavation sequencing, provision of temporary support measures, and quality control procedures during construction
7. Maintenance, monitoring, and inspection of roadside slopes, including routine assessment, identification of early warning indicators of instability, and planning of timely remedial actions.

1.8 Structure of the Guideline

[Chapter 1](#) presents the introduction and background of the relationship between road and landslides. [Chapter 2](#) reviews existing roadside slope mitigation practices and establishes the failure



mechanisms, cascading risk framework, and prevention-first philosophy. [Chapter 3](#) provides site characterization tools covering geology, hydrology, soils, land use, and vegetation. [Chapters 4](#) and [Chapter 5](#) address engineering mitigation structures and integrated water management respectively. [Chapter 6](#) covers NbS and bioengineering techniques in detail, including the IUCN eight principles framework, species selection, and strength development. [Chapter 7](#) provides the decision framework for selecting appropriate solutions by site type. [Chapter 8](#) gives implementation guidance including quality control, BoQ, community engagement, and safety. [Chapter 9](#) covers monitoring, evaluation, and maintenance. Nine technical annexes provide species databases, design templates, field checklists, BoQ formats, nursery guides, and quick-reference decision charts.



CHAPTER 2. ROADSIDE SLOPE MITIGATION PRACTICES

This chapter discusses the context of roadside slope mitigation in Bagmati Province by examining current road construction practices, the causes of slope instability, common failure mechanisms, and available mitigation approaches. It draws upon Nepal's geotechnical experiences from projects such as Dharan-Dhankuta Road, Lamosangu-Jiri Road, and the Charnawati Rehabilitation Project, together with guidelines developed by International Centre for Integrated Mountain Development (ICIMOD), Department of Roads (DoR), and the Landslide Risk Assessment Project, to establish the conceptual basis for an integrated slope stabilization approach.

2.1 Current Road Construction Practices in Nepal

Road construction activities in Nepal are implemented through multiple government institutions, including the Department of Roads (DoR), Department of Local Infrastructure (DoLID), provincial Transport Infrastructure Directorates (TIDs), local governments, and the Department of Urban Development and Building Construction (DUDBC) for urban road development. Among these agencies, the DoR is mainly responsible for the Strategic Road Network, whereas provincial and local road systems are developed and managed by DoLID, provincial authorities, and local governments. In line with these institutional arrangements, several road design standards are currently practiced in Nepal, including the Nepal Road Standards (NRS-2070), Nepal Rural Road Standards (2071), provincial standards such as the Bagmati Province Road Standards-2076, and the Nepal Urban Road Standards-2076. Despite the existence of these various standards, Nepal still lacks a unified and effectively enforced standard specifically applicable to local roads, which form the largest proportion of the national road network. This fragmented institutional and regulatory framework has contributed to considerable inconsistencies in road planning, design, construction, and maintenance practices throughout the country.

To address roadside slope instability and related geotechnical challenges, the DoR has published several technical manuals and guidelines, including *Roadside Geotechnical Problems: A Practical Guide to Their Solution* (DoR, 2007), *Guide to Road Slope Protection Works* (DoR, 2003), and bioengineering guidelines for roadside slope stabilization (DoR, 1999). These publications were developed to support engineers and practitioners in designing stable cut slopes, fill slopes, and appropriate mitigation measures under Nepal's difficult terrain conditions. However, recent studies (Paudyal et al., 2023; Robson et al., 2022) have highlighted significant limitations within these guidelines, particularly their inability to adequately address Nepal's highly variable geological, lithological, geomorphological, and topographic conditions. The guidelines are often too generalized, insufficiently descriptive, and sometimes overly conservative, while their presentation formats are not always user-friendly or easily applicable in field conditions (Robson et al., 2025). Consequently, the practical use of these documents remains limited, especially at the local government level where engineering capacity and technical expertise are often constrained. Research findings indicate that only a small proportion of local-level engineers actively use these guidelines because they do not sufficiently incorporate site-specific geological realities or practical construction challenges. This situation has frequently resulted in incorrect characterization of geomaterials, improper slope cutting, and unsafe slope geometries, thereby increasing the likelihood of roadside slope failures. These observations clearly demonstrate the urgent need to revise existing standards and develop more practical, geology-sensitive, and context-specific guidelines for roadside slope mitigation in Nepal (Robson et al., 2025).



Several studies have further identified poor road engineering and construction practices as one of the primary causes of roadside slope failures across Nepal. Excessively steep cut slopes, inadequate surface and subsurface drainage systems, uncontrolled disposal of excavated materials, and the absence of suitable slope protection measures are widely recognized as major contributing factors. The issue is particularly critical in local roads, commonly referred to as “dozer roads,” which are frequently initiated under political or community pressure and constructed rapidly by bulldozer operators without adequate engineering design, geotechnical investigation, or environmental assessment (ITAD, 2017). During the monsoon season, many of these roads experience repeated failures, washouts, and landslides, requiring expensive post-monsoon rehabilitation and debris clearance works. In many locations, this cycle of repeated damage and repair continues for several years until slopes gradually attain a natural state of equilibrium. As a result, road construction has been identified as one of the most significant human-induced drivers of soil erosion, environmental degradation, sediment generation, and landslide occurrence in Nepal (McAdoo et al., 2018).

Even in projects where roads are developed based on detailed engineering surveys, design reports, and environmental assessments such as Initial Environmental Examination (IEE) or Environmental Impact Assessment (EIA), geotechnical investigations are often limited in scope and detail. Comprehensive slope stability assessments are rarely carried out systematically during all phases of project planning, design, construction, and operation. Instead, many projects continue to rely heavily on empirical or rule-of-thumb approaches for determining cut slope angles and fill slope configurations. In some cases, numerical slope stability analyses are performed using poorly constrained geotechnical parameters, which can result in unreliable interpretations and unsafe engineering decisions. Detailed geotechnical studies and stabilization analyses are therefore commonly undertaken only after slope failures occur, mainly as part of maintenance, rehabilitation, or emergency stabilization interventions.

Table 2-1: Estimated cost breakdown in different categories of work (EEAP 2020)¹

Description	Estimated cost (%)				
	Lesser and Higher Himalaya Zone			Siwalik Zone	
Part 01: General	1.61	2.14	2.98	0.43	0.43
Part 02: Site clearance	1.21	0.18	0.07	0.72	0.81
Part 03: Earthwork	14.02	10.83	11.89	9.80	11.27
Part 04: Structures (stability, cross drainage and side drainage)	59.19	66.70	59.81	25.22	37.03
Part 05: Pavement works	22.98	15.22	23.21	43.46	34.94
Part 06: Road furniture and traffic safety measures	0.31	0.50	0.76	1.54	1.12
Part 07: River training, slope protection and bio-engineering works	0.24	4.02	0.62	18.84	14.40
Part 08: Others	0.43	0.42	0.65	0	0
Total	100	100	100	100	100

Note: Roadside structures and slope protection works are designed without detailed geotechnical study

A review of detailed project reports from roads constructed in different geological regions of Nepal further illustrates this imbalance in resource allocation (Table 2-1). While earthworks generally account for approximately 10–15% of overall project costs, roadside structures in mountainous

¹ Cost Estimate of different roads under Earthquake Emergency Assistant Project (EEAP)



terrain may contribute up to 60% of the total construction estimate. Nevertheless, the explicit budget allocation for slope stabilization and mitigation measures often remains around only 1% of the total project cost, indicating a serious underestimation of slope-related hazards and long-term maintenance risks. In contrast, road projects in the Churia region often allocate more than 15% of project costs to river training and fluvial protection works, reflecting relatively greater recognition of river-related hazards compared to slope instability issues. Therefore, it is essential to develop infrastructure in a manner that minimizes disturbance to the mountain landscape and surrounding environment. Achieving this requires appropriate mitigation planning based on detailed slope assessment and stability analysis.

2.2 Typical Challenges in Mountainous Terrain

The mountainous regions of Nepal are naturally highly susceptible to landslides because of their steep terrain, fragile geological conditions, diverse lithological formations, and intense climatic influences. The Himalayan landscape is composed of complex and highly deformed rock masses affected by weathering, faulting, folding, joints, fractures, and other discontinuities that significantly control slope behavior and instability processes (Paudel et al., 2023). These geological complexities, combined with rugged topography and weak surface materials, make slopes particularly vulnerable to failure, especially when disturbed by human activities such as road construction and excavation.

The monsoon season, which extends from June to September, delivers the majority of Nepal's annual rainfall and plays a major role in triggering landslides across mountainous terrain. Intense and prolonged rainfall allows water to infiltrate into soil and rock masses, increasing pore water pressure and reducing the shear strength of slope materials. This process weakens already unstable slopes and frequently initiates failures in areas disturbed by road cutting, slope excavation, and inadequate drainage management (Gyawali & Dahal, 2025). In many road corridors, uncontrolled runoff and concentration of surface water further aggravate slope instability and erosion problems.

Seismic activity is another major factor influencing slope instability in Nepal's mountainous regions. Nepal lies within an active tectonic zone of the Himalayas, where frequent earthquakes and continuous tectonic movements affect slope conditions. Earthquake shaking can directly trigger landslides and rockfalls or weaken slope materials and discontinuities, making slopes more susceptible to rainfall-induced failures in subsequent years (Robson et al., 2025). Many slopes that appear stable under normal conditions may therefore become highly vulnerable after seismic disturbances.

The topographic characteristics of mountainous terrain also create substantial challenges for road alignment and infrastructure development. Rapid elevation changes, steep and variable slope gradients, narrow valleys, and limited alignment corridors often force roads to pass through unstable colluvial deposits, weathered rock masses, and natural drainage channels. Such conditions complicate engineering design and require careful integration of geological, hydrological, geomorphological, and geotechnical considerations. In many hilly road projects, inadequate drainage systems, improper spoil disposal, and poorly managed cut-and-fill practices further alter natural water flow patterns and intensify slope failures and erosion.

Institutional and governance-related challenges additionally contribute to roadside slope instability problems in Nepal. Weak enforcement of engineering standards, inconsistent technical practices, and limited technical capacity at provincial and local levels often result in inadequate application of slope stabilization measures. In many cases, engineers and contractors rely heavily on empirical methods and rule-of-thumb practices because of insufficient geotechnical investigations, lack of accessible technical guidelines, limited availability of investigation tools, and financial constraints.



These limitations frequently lead to inconsistent design quality, unsafe slope geometries, and recurring slope failures (Robson et al., 2025).

The interaction of steep terrain, intense monsoon rainfall, active seismicity, fragile geology, and evolving road construction practices creates an extremely challenging environment for infrastructure development in Nepal's mountainous regions. Together, these factors significantly increase landslide susceptibility and demonstrate the urgent need for integrated, site-specific, and context-sensitive approaches to slope assessment, planning, design, and stabilization to develop resilient and sustainable road infrastructure systems in Nepal.

Table 2-2: Key geotechnical and environmental challenges for roadside slope stability

Challenge Category	Technical Description
Geological condition	The Himalayan region is tectonically active, resulting in highly fractured and weathered rock masses. Common lithologies include weak sedimentary rocks and foliated metamorphic rocks with closely spaced joints, bedding planes, foliation surfaces, and shear zones that significantly reduce rock mass strength and slope stability.
Thick Colluvial Soils	Extensive deposits of colluvial soils commonly overlie bedrock in mountainous terrain. These unconsolidated to poorly consolidated materials exhibit low shear strength making them highly susceptible to shallow translational and debris slide failures.
Monsoon Concentration	More than 80% of Nepal's annual precipitation occurs during the monsoon period from June to September. High-intensity rainfall events, often exceeding 200 mm within 24 hours, generate rapid infiltration, elevated pore water pressure, and increased surface runoff, frequently surpassing critical landslide triggering thresholds.
Seismic Exposure	Nepal is located within an active tectonic setting along the Indo-Eurasian plate boundary, where recurrent seismic activity continuously alters slope conditions. The 2015 Gorkha Earthquake caused widespread slope destabilization, the effects of which continue to influence slope instability in many regions.
Limited Right-of-Way	Mountain road corridors are often constrained by steep terrain, narrow valleys, and limited available space, restricting the implementation of stable slope geometries, adequate benching, retaining structures, and safe fill slope configurations.
Compressed Construction Seasons	Safe earthwork operations are generally limited to the dry pre-monsoon period of approximately 4 months, as monsoon conditions significantly increase instability risks and restrict construction activities. Short construction windows often create pressure for rapid slope cutting without sufficient stabilization and drainage measures.
Inadequate Geotechnical Input	Many low-cost and local road projects are developed with limited geotechnical investigation and insufficient engineering supervision. Road alignment and slope design are frequently based on empirical practices or precedent-based approaches rather than detailed geotechnical analysis, while field implementation is often supervised by sub-engineers rather than specialized geotechnical engineers.

2.3 Common Roadside Slope Failure Mechanisms

Roadside slope failures in Nepal's mountainous terrain occur across a wide range of scales and mechanisms, varying from gradual surface erosion processes to rapid and catastrophic mass movements. A clear understanding of the failure mechanism is therefore essential for selecting suitable stabilization and mitigation measures. Different types of failures are controlled by varying geological, hydrological, geomorphological, and structural conditions, requiring context-specific

assessment and engineering responses. This section adopts different landslide and slope failure classification frameworks.

2.3.1 Erosion-induced failures: Sheet, rill and gully erosion

Erosion is defined as the removal of surface particles by flowing water, wind, or other agents. On roadside slopes, rainfall-induced erosion operates progressively i.e., from surface film flow to concentrated channel erosion, and ultimately triggers mass failures by removing supporting material, undercutting slopes, and increasing infiltration pathways to failure planes (Mercy Corps, 2014; DoR, 1999).

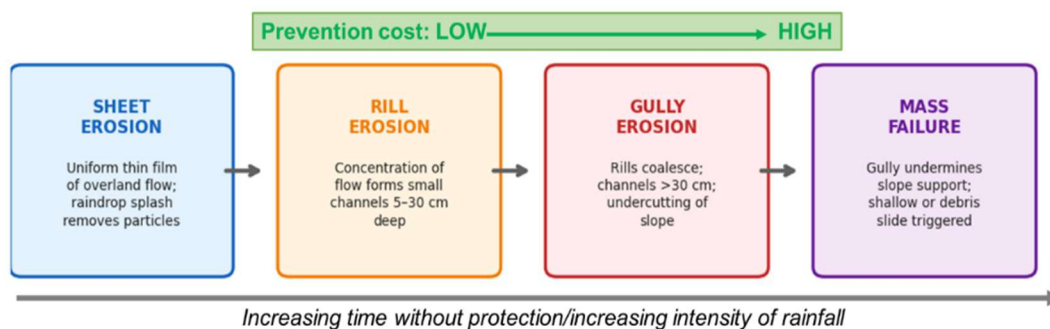


Figure 2.1: Progressive erosion stages on unprotected roadside slopes

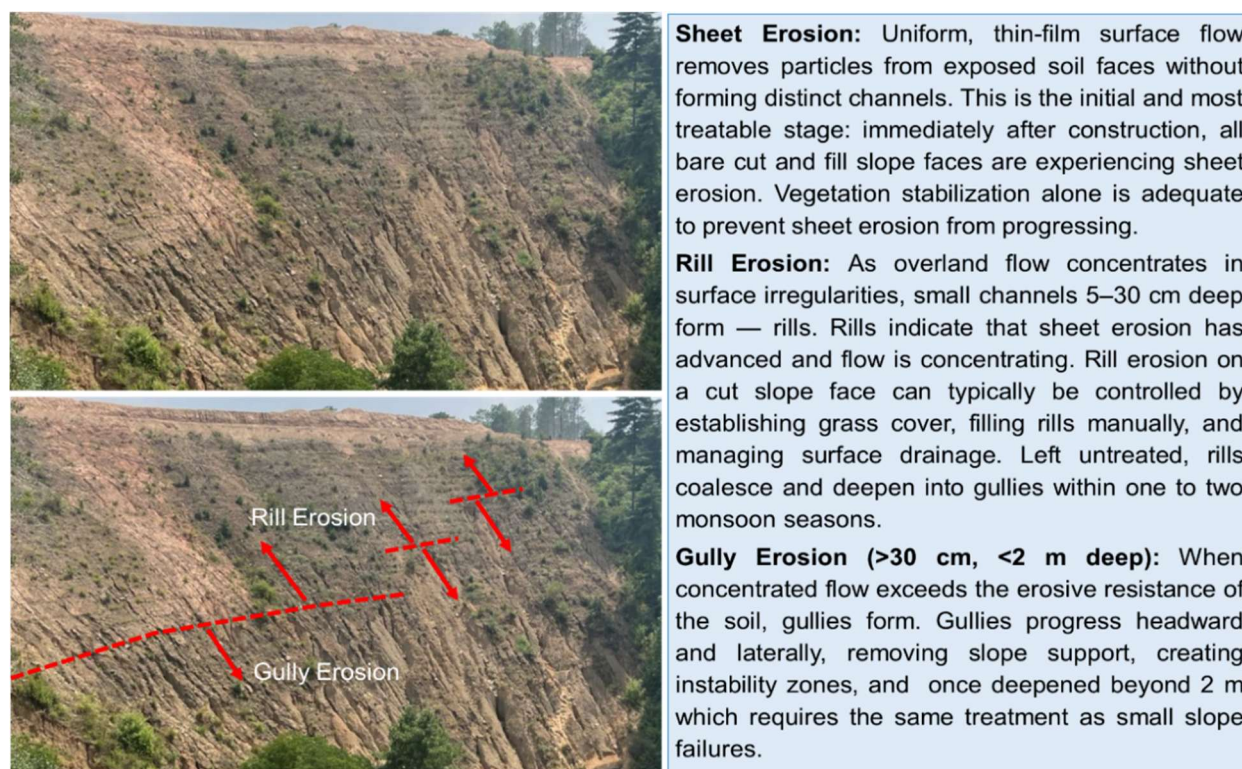


Figure 2.2: Common erosion problem in bare slope

Figure 2.1 and Figure 2.2 illustrate this progression on a single slope i.e., from early sheet erosion to fully developed gully incision, and reflects what is commonly observed in the field after just a couple of monsoon seasons. A slope that looks stable immediately after excavation/fill can deteriorate rapidly once seasonal rainfall takes hold. This trajectory, from surface wash to structural compromise, is precisely what makes early erosion control and slope mitigation necessary rather than optional.



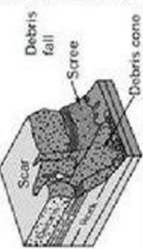
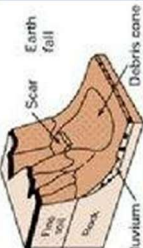
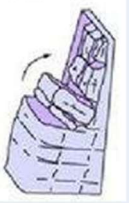
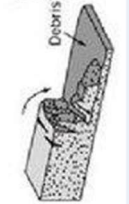
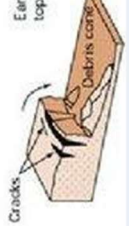
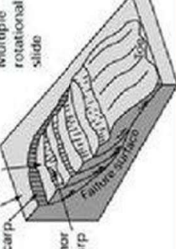
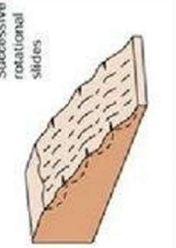
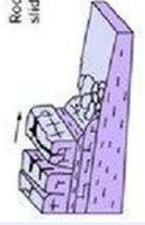
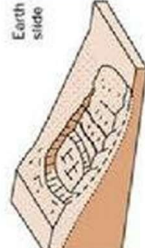
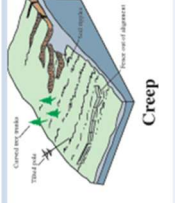
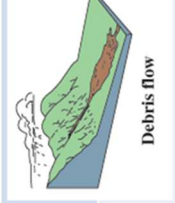
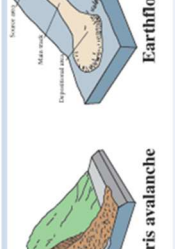
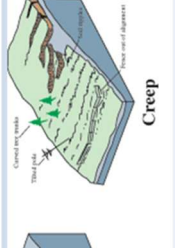
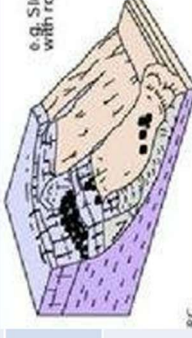
Type of Mass Movement	Definition	Key Features	Diagram
Falls	Abrupt detachment of rock or soil from a steep slope or cliff, moving downslope mainly by free fall, bouncing, or rolling.	- Very rapid movement - Occurs on steep cliffs - Little contact with slope surface - Triggered by weathering, rainfall, earthquakes	  
Topples	Forward rotation or tilting of a rock or soil block about a pivot or hinge, followed by detachment and downslope movement.	- Rotational movement - Controlled by joints/fractures - Common in columnar or layered rocks - May evolve into falls	  
Rotational Slide	A slide in which movement occurs along a curved, concave-upward slip surface.	- Backward tilting of mass - Common in cohesive soils - Spoon-shaped failure surface	  
Translational Slide	A slide in which movement occurs along a planar or nearly planar slip surface.	- Movement parallel to slope - Slip surface is straight - Common along bedding planes or joints	  
Creep	Extremely slow, continuous downslope movement of soil under gravity.	- Very slow (mm/year) - Tilting of trees/poles - Common on gentle slopes	
Rapid Flows (Debris/Mud Flow)	Rapid flow of saturated soil, debris, and water downslope.	- High water content - Very destructive - Triggered by intense rainfall	  
Spreads	Lateral extension of soil or rock over a weaker, liquefied or highly deformable layer.	- Caused by liquefaction - Occurs in saturated loose sands - Often earthquake-induced	
Complex Movements	Combination of two or more types of mass movement occurring sequentially or simultaneously.	- Example: slide → flow - Common in large landslides - Behavior changes with time	

Figure 2.3: Common roadside slope failure problem (Varnes, 1978)



2.3.2 Landslides

Roadside slope instability in mountainous terrain is governed by a complex interaction of geological, hydrological, geomorphological, seismic, topographic, and construction-related factors that affect cut slopes, fill slopes, and spoil disposal areas in different ways. Intense monsoon rainfall and inadequate drainage management are among the most significant controlling factors of slope failure in Nepal. During the monsoon season, rainfall infiltration into exposed cut slopes increases pore water pressure and reduces shear strength, resulting in shallow slides, planar failures, wedge failures, and progressive instability, particularly where drainage systems are blocked or poorly maintained. The detailed classification of landslide based on type of movement and slope forming materials is presented in [Figure 2.3](#). In fill slopes, inadequate drainage and poor compaction lead to saturation, rotational and translational failures, settlement, and progressive erosion, while spoil disposal areas rapidly become unstable due to debris slides, debris flows, gully erosion, and mass movement under saturated conditions. Drainage-induced failures such as seepage and piping further weaken slope materials internally, producing settlement, internal erosion, and eventual collapse in both engineered slopes and spoil deposits.

2.4 Review of Existing Mitigation Approaches

Three major categories of mitigation measures are commonly applied to address roadside slope instability problems: engineering or “grey” approaches, bioengineering or “green” approaches, and hybrid approaches that combine structural and vegetative measures. Each category has distinct technical characteristics, applicability, limitations, maintenance requirements, and cost implications depending on slope conditions, geology, hydrology, and project scale. Nepal has developed substantial practical experience in the application of these mitigation measures through road construction and slope stabilization projects across different physiographic and geological regions, supported by both national practice and international technical guidance.

Engineering or grey approaches primarily rely on structural interventions designed to resist slope movement, reinforce unstable ground, control erosion, and safely convey surface and subsurface water. Nepal’s roadside geotechnical practice includes extensive use of retaining and support structures such as dry-stone masonry walls, gabion retaining walls, reinforced concrete retaining walls, reinforced earth systems using geogrids, crib walls, and toe-bench stabilization structures. The documents that the Charnawati Project introduced large-scale application of gabion structures, composite revetments, and spurs for slope and riverbank stabilization in Nepal ([DoR, 2007](#)). Stone masonry retaining walls remain the most commonly used stabilization structure along provincial and local roads because of the widespread availability of local stone materials and relatively low construction cost. Gabion walls are generally preferred in locations where differential settlement is expected or where suitable flat stone for masonry construction is limited. Similarly, the report published by Department of Soil Conservation and Watershed Management ([DSCWM, 2016](#)) categorizes retaining structures into crib walls constructed from bamboo or timber, loose stone retaining walls, gabion walls, and masonry or concrete retaining structures depending on site conditions and material availability.

Slope drainage systems form another critical component of engineering mitigation approaches. Commonly used drainage measures in Nepal include roadside side drains, catch drains, cascade drains, subsurface French drains or counterfort drains and horizontal drilled drains extending up to 45 m in length, as implemented in the Charnawati stabilization works. Effective drainage management is widely recognized as one of the most economical and technically effective approaches for improving slope stability because it reduces infiltration, controls surface runoff,



lowers groundwater levels, and minimizes pore water pressure within slope materials. Studies and field experience documented indicate that drainage improvement alone can significantly increase the factor of safety of unstable slopes even without major structural reinforcement (DoR, 2007, MercyCorps, 2014).

Ground reinforcement measures are applied in more complex or high-risk slope conditions where conventional retaining structures are insufficient. These measures include rock bolts, soil nails, and grouted ground anchors used to stabilize deep cut slopes, fractured and jointed rock masses, active landslides, bridge abutments, and critical road sections. Such stabilization systems generally require detailed geotechnical investigation, slope stability analysis, and specialist engineering design, and are therefore beyond the scope of regular engineering practice. Nevertheless, they are included in these guidelines as reference measures and escalation options for technically challenging slope conditions requiring higher-level engineering intervention.

Erosion protection structures also include a range of erosion protection and water control structures intended to reduce surface erosion, sediment transport, and concentrated flow energy. Common measures used in Nepal include live check dams, stone masonry check dams, concrete check dams, cascades, lined chutes, energy dissipators, rip-rap aprons, and stone pitching works. These structures are widely practiced in road and watershed management projects and are extensively documented in technical guidelines (DoR, 2007; DSCWM, 2016). Together, these engineering measures provide the primary structural framework for roadside slope stabilization and hazard reduction in Nepal's mountainous terrain.

2.4.1 Bioengineering (Green / Eco) approaches

Bioengineering refers to the application of living vegetation, either independently or in combination with civil engineering structures and non-living plant materials, to control shallow slope instability, surface erosion, and slope degradation (Rai, 2010; DoR, 1999; Mercy Corps, 2014). In Nepal, bioengineering is not a completely new concept, as communities have long used vegetation-based stabilization practices on agricultural terraces, trails, and hill slopes. However, systematic application of bioengineering in road construction and slope stabilization was formally introduced through major hill road projects such as the Dharan-Dhankuta Road and Lamosangu-Jiri Road projects, which demonstrated the effectiveness of integrating vegetation with engineering measures in mountainous terrain.

The engineering basis of bioengineering lies in the ability of vegetation to perform several mechanical and hydrological functions like conventional structural systems. The principal engineering functions include: **(i) catch**, where vegetation intercepts and slows falling debris and loose materials; **(ii) armour**, where vegetation cover protects the soil surface from rainfall/runoff impact and erosion; **(iii) reinforce**, where root systems bind soil particles and increase soil shear strength; **(iv) support**, where vegetation provides resistance against lateral earth pressures on long slopes; **(v) anchor**, where deep root systems anchor unstable upper soil layers to more stable underlying strata; and **(vi) drain**, where roots and organic matter improve soil permeability, increase surface roughness and other hydrological functions. Through these combined functions, vegetation contributes significantly to slope stabilization and erosion reduction.

Bioengineering systems provide important hydrological functions that directly influence slope stability. Vegetation canopies intercept and store rainfall and reduce raindrop impact energy on exposed soil surfaces, thereby minimizing erosion initiation. Root systems absorb both surface and subsurface water, maintaining soil saturation and pore water pressure within slopes. Stems, grasses, and root networks also slow surface runoff velocity, reduce sediment transport, and



improve infiltration control. Furthermore, evapotranspiration processes help remove moisture from the slope mass and maintain drier soil conditions, contributing to improved long-term stability. Common bioengineering techniques used in Nepal include grass seeding, grass plantation, shrub plantation, tree plantation, live stakes, brush layering, wattle fencing, live check dams, vegetated drains, and erosion control mats.

Bioengineering approaches offer several technical, environmental, and socio-economic advantages compared to purely structural stabilization measures. Studies and experiences indicate that bioengineering measures require lower initial investment and lower long-term maintenance costs than conventional engineering structures. Unlike rigid structural systems, vegetative stabilization gradually improve in strength and effectiveness as root systems develop and mature over time. Bioengineering also provides significant environmental benefits, including habitat improvement, ecological restoration, enhanced landscape aesthetics, improved water quality, and reduced environmental impacts.

In addition, these systems are highly compatible with environmentally sensitive areas and contribute to local livelihoods by generating products such as fodder, fuelwood, timber, and other vegetation resources. Bioengineering construction and maintenance activities also create opportunities for local employment and community participation in slope management programs.

Despite the engineering advantages described above, bioengineering systems have important limitations that must be understood before application. Vegetation typically requires one to three growing seasons before root systems develop sufficient tensile strength and root area ratio to contribute meaningfully to slope shear resistance (DoR, 1999), and during this establishment phase, planted slopes remain vulnerable to surface erosion and shallow failure under high-intensity monsoon rainfall. Bioengineering alone is therefore not appropriate for actively failing slopes or sites requiring immediate structural stabilization. It should also be noted that established vegetation imposes additional loads on the slope, including the self-weight of above-ground biomass and dynamic wind loads transmitted through the root-soil interface, both of which must be accounted for in stability assessment. Successful application of bioengineering in roadside slope stabilization requires the concurrent design of appropriate civil engineering structures and drainage management systems, with species selection made in the context of the full integrated design rather than as a standalone or supplementary measure.

2.4.2 Hybrid approaches

Hybrid approaches integrate engineering structures with bioengineering measures in order to utilize the complementary advantages of both systems. In these approaches, structural measures provide immediate mechanical stability and protection against slope failure, while vegetation-based measures contribute long-term reinforcement, erosion control, hydrological regulation, and ecological improvement as root systems mature over time. Because of this combined functionality, hybrid stabilization approaches are widely considered the most suitable and sustainable option for roadside slope management in mountainous terrain. For most roadside slopes in Bagmati Province, hybrid systems are recommended as the preferred or default mitigation approach because they provide superior overall cost-effectiveness, durability, environmental compatibility, and long-term performance throughout the infrastructure lifecycle.

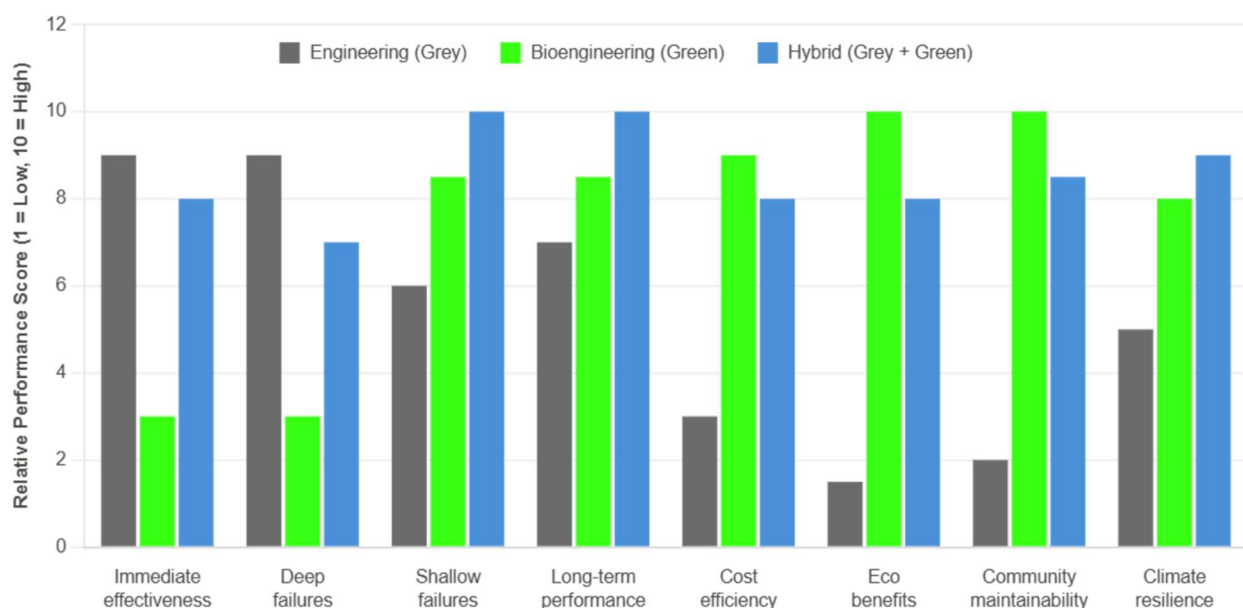
The technical basis of hybrid stabilization lies in the different time-dependent behaviors of structural and vegetative measures. Engineering structures such as retaining walls, gabions, drainage



systems, and erosion control structures can provide immediate support and hazard reduction immediately after construction. In contrast, bioengineering systems require a certain establishment period before vegetation develops sufficient root strength to contribute significantly to slope stabilization.

In practical application, hybrid systems commonly combine retaining structures with vegetation planting, drainage systems with grass and shrub stabilization, gabion walls with live stakes, check dams with brush layering, or reinforced slopes with vegetative cover. These combinations improve slope resistance against erosion, shallow failures, surface runoff, and long-term degradation while also enhancing ecological and visual conditions along road corridors. Hybrid systems are particularly effective in Nepal's mountainous environment where intense monsoon rainfall, steep terrain, weathered geology, and evolving slope conditions require both immediate structural support and adaptive long-term stabilization mechanisms.

Comparative assessment of engineering, bioengineering, and hybrid stabilization approaches across multiple technical and environmental criteria indicates that hybrid systems generally provide the most balanced overall performance (Figure 2.3). While purely engineering approaches offer high short-term effectiveness and immediate structural stability, they often involve higher construction costs, greater environmental disturbance, and long-term maintenance requirements. Conversely, pure bioengineering approaches provide significant ecological and economic benefits but require time to develop effective structural reinforcement. Hybrid systems combine the strengths of both approaches by integrating the immediate reliability of engineering structures with the progressive self-improving characteristics, environmental benefits, and long-term sustainability of vegetation-based stabilization measures.



Note: Values are indicative and not derived from a single study.

Figure 2.4: Comparative performance of roadside slope mitigation approaches scores

Represents expert-judgement synthesis based on published literature (Capobianco et al., 2024; Storesund et al., 2008; Stokes et al., 2008; von der Thannen et al., 2020; DoR, 1999).

2.5 Compounded and Cascading Risks



A defining characteristic of roadside slope instability in Bagmati Province is that slope failures rarely occur as isolated events. Instead, they commonly develop as cascading and compounding hazard sequences in which one triggering event initiates a chain of interconnected failures and secondary impacts that extend well beyond the original failure location. The importance of incorporating cascading and compounding hazards into roadside slope mitigation planning was emphasized. The concept aligns with the theory of “earthquake-induced chains of geologic hazards” developed by [Fan et al. \(2019\)](#), although similar cascading mechanisms are equally applicable to rainfall-triggered roadside slope failures in Nepal’s mountainous terrain. In such systems, an initial disturbance progressively triggers additional failures, amplifying the overall hazard intensity, spatial extent, and socio-economic consequences.

Rainfall-induced cascading hazards represent the most common form of roadside slope failure sequence in Bagmati Province. During intense monsoon rainfall events, colluvial and residual soils rapidly become saturated as pore water pressure rises beyond the available shear strength of the slope material. Research specific to the Nepal Himalaya indicates that shallow landslides can be triggered by 24-hour rainfall totals as low as 130 to 150 mm, particularly on slopes already wetted by antecedent monsoon accumulation ([Froehlich et al., 1990](#); [Dahal and Hasegawa, 2008](#); [Gabet et al., 2004](#)). The triggering threshold is not fixed: as seasonal rainfall accumulates through the monsoon, the daily rainfall required to initiate failure decreases substantially, meaning that slopes which were stable in June may fail under moderate rainfall events in August or September. These conditions frequently initiate shallow translational failures on cut slopes, fill slopes, and spoil disposal areas. The displaced debris commonly blocks roadside drains, culverts, and natural drainage channels, causing water to pond and overtop road embankments. Subsequent uncontrolled runoff and localized infiltration then saturate adjacent fill slopes and lower slope sections, generating secondary failures that progressively enlarge the instability zone. In many cases, mobilized debris enters nearby streams and rivers, increasing sediment loading, altering channel morphology, and intensifying downstream flooding and bank erosion. This sequence illustrates how a localized roadside slope failure can evolve into a broader multi-hazard event affecting transportation infrastructure, river systems, agricultural land, and downstream communities. Critically, each stage within this cascade represents a potential intervention point. Timely slope stabilization, drainage management, and nature-based measures applied at the right stage can interrupt hazard propagation and substantially reduce the overall risk to infrastructure and the communities it serves.

Earthquakes are a defining feature of Nepal’s geohazard landscape and a significant source of compounding risk for roadside slopes across Bagmati Province. The 2015 Gorkha Earthquake (Mw 7.6) provided a clear example of how earthquakes create long-term slope instability conditions rather than only immediate failures. Strong seismic shaking weakened rock mass structures, enlarged tension cracks, destabilized discontinuities, and reduced the overall integrity of many slopes throughout Bagmati Province. While numerous earthquake-triggered landslides occurred immediately after the event, a more significant long-term consequence was the elevated susceptibility of weakened slopes during subsequent monsoon seasons. Many slopes that did not fail directly during the earthquake progressively deteriorated and later failed under comparatively normal rainfall conditions. Studies by [Bai et al. \(2020\)](#) emphasized the importance of pre-conditioning factors in cascading hazard systems, while [Fan et al. \(2019\)](#) estimated that post-earthquake landslide susceptibility may remain elevated for approximately three to five years within directly affected regions. This demonstrates that seismic events can compound future rainfall-induced hazards by fundamentally altering the mechanical condition of slopes over extended periods.



Land-use change associated with road development also contributes significantly to compounding hazard processes. Road construction frequently accelerates deforestation, agricultural expansion, settlement growth, and uncontrolled land modification both above and below road corridors. These changes reduce root reinforcement, increase surface runoff, disturb natural drainage pathways, and enhance seepage infiltration into unstable slopes. Consequently, slopes located on the upslope of roads become increasingly susceptible to failure, thereby increasing loading pressures and overland flow concentration on road cuts and embankments. This creates a form of “upstream compounding” where land-use change progressively amplifies roadside instability risks over time. Research conducted by Institute for Social and Environmental Transition Nepal ([ISETN, 2023](#)) in Changanarayan Municipality found that road density contributed approximately 36.8% to landslide occurrence, making it the single most influential factor, followed by geology (22%) and land use (11.6%). These findings clearly illustrate the interconnected relationship between road expansion, environmental change, and landslide susceptibility in mountainous terrain.

Climate change acts as a systemic hazard amplifier that intensifies nearly all components of cascading and compounding slope failure processes simultaneously. Increasing frequency and intensity of extreme rainfall events raise the probability of cascade initiation through more frequent slope saturation and drainage exceedance. Changes in monsoon timing and seasonality also disrupt traditional construction schedules and slope stabilization practices. In higher elevation districts of Bagmati Province, warming temperatures may additionally alter snowmelt patterns, freeze-thaw cycles, and permafrost-related slope conditions. At the same time, continuing land-use changes within expanding road influence zones compound the effects of increasing rainfall intensity and environmental degradation. According to projections landslide risk in Bagmati Province is expected to increase substantially under SSP 4.5, SSP 7.0, and SSP 8.5 climate scenarios ([ISETN, 2023](#)). This indicates that roadside infrastructure designed under present-day conditions may face significantly greater hazard exposure during its operational lifetime. Consequently, roadside slope mitigation and infrastructure planning in Bagmati Province must adopt forward-looking, climate-resilient, and systems-based approaches capable of addressing not only isolated failures but also the cascading and compounding nature of future geohazard risks.

2.6 Roadside Slope Mitigation Framework

Landslide hazard refers to the likelihood of slope failures occurring at a specific location within a defined period. Nepal, situated within the geologically young and tectonically active Himalayan range, exhibits high susceptibility to landslides, making both human settlements and infrastructure highly vulnerable. Landslides in such mountainous regions have far-reaching socio-economic, environmental, and technical consequences, particularly for road networks, bridges, and buildings. For instance, slope failures can block roads, disrupt transportation, damage structures, and require extensive reconstruction, resulting in substantial financial burdens on the state and impacting national productivity and service delivery. Beyond direct economic loss, repeated slope failures compromise accessibility to essential services, affect local livelihoods, and degrade the surrounding environment due to erosion and sedimentation. Consequently, systematic assessment of landslide hazard and risk, coupled with the design and implementation of context-specific mitigation measures, is essential during the planning, design, and construction phases of infrastructure projects to ensure long-term resilience and sustainability. In this context, valuable lessons have been derived from slope stabilization works carried out under the Nepal–India Regional Trade and Transport Project ([NIRTP, 2025](#)), which emphasize integrated mitigation, risk-based investigation, nature-based solutions, and monitoring-driven risk management. The project experience demonstrates that the combined application of engineering measures, effective



drainage systems, and bioengineering significantly enhances slope resilience. It also highlights the effectiveness of using local and mixed species of grasses, shrubs, and plants, supported by timely maintenance and replantation. For large or complex slope failures, NIRTTP underscores the necessity of detailed site investigations to identify governing failure mechanisms. Furthermore, the findings indicate that long-term slope stability depends not only on roadside interventions but also on regulating upstream and downstream construction activities that may destabilize slopes. The importance of strengthening early warning systems and traffic control measures during extreme weather events is also emphasized to minimize loss of life and property.

Based on this existing knowledge base and project experience, a robust landslide mitigation framework has been developed and is presented in (Figure 2.5). The framework provides a systematic, scalable, and implementable approach to roadside slope mitigation by integrating slope assessment, susceptibility analysis, site investigation, mitigation design, and monitoring. Its application is expected to promote more consistent and safer road development practices and to reduce the recurring cycle of slope failures and post-disaster repair works.

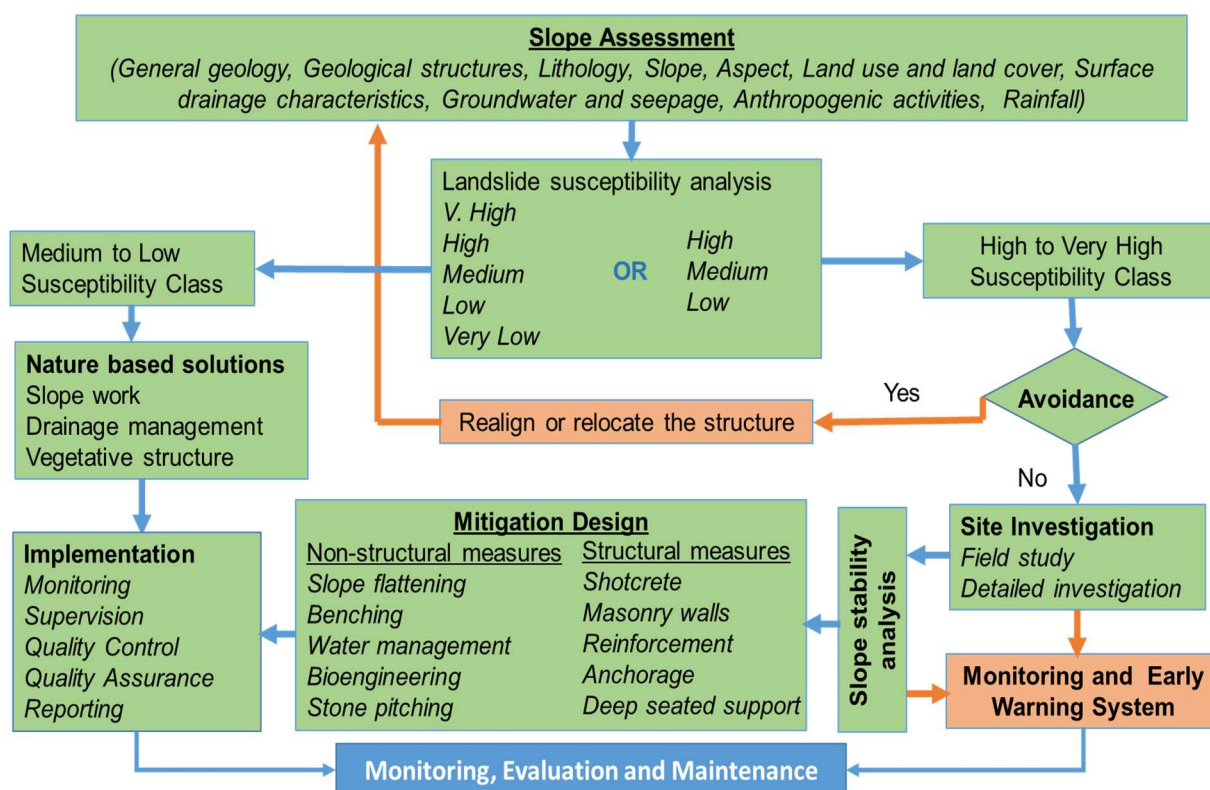


Figure 2.5: Slope stability analysis, mitigation design and implementation framework

2.7 Preventive versus Remedial Approach: Guiding Philosophy

Experience from roadside slope management in Bagmati Province consistently demonstrates that preventive stabilization measures are significantly more cost-effective than post-failure rehabilitation and emergency response works. Studies and field observations indicate that preventive treatment of potentially unstable slopes using bioengineering or hybrid stabilization approaches generally costs only a small fraction of the expenditure required for emergency reinstatement after slope failure, particularly when indirect costs associated with road closure, traffic disruption, maintenance, and socio-economic losses are considered. Over a long-term operational period, preventive slope stabilization provides substantially higher economic returns



compared to repeated repair and reconstruction approaches. Similarly, [DoR \(2007\)](#) emphasizes that the cost of slope protection is consistently lower than the cost of repairing failed slopes and damaged infrastructure after instability occurs. The preventive philosophy for roadside slope management operates across multiple timescales and intervention stages as presented in the [Figure 2.6](#).

LEVEL 1 BEFORE CONSTRUCTION Design-stage prevention Geotechnical assessment, slope angle optimization, drainage planning, spoil management, and bioengineering measures are integrated into the road design before any ground is broken. The goal is to prevent instability problems from being created in the first place, not to correct them after failure. Key actions • Alignment selection • Slope design • Drainage integration • Stabilization planning	LEVEL 2 DURING CONSTRUCTION Immediate prevention Slope protection and drainage measures must be in place before the first monsoon season. Newly excavated slopes are at peak vulnerability, and any delay in stabilization or vegetation establishment can trigger progressive degradation that becomes far costlier to reverse. Key actions • Slope protection • Drainage installation • Early vegetation establishment	LEVEL 3 OPERATIONAL LIFE System-level prevention Continuous long-term management across the full life of the road corridor. Roadside slopes are dynamic systems influenced by rainfall, land-use change, seismic activity, and environmental degradation. Sustained institutional commitment, technical supervision, and community participation are all required. Key actions • Catchment protection • Drainage maintenance • Routine slope inspection • Early warning response
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Figure 2.6: Preventive philosophy for roadside slope

Adopting a preventive approach requires a significant institutional and cultural shift in roadside infrastructure management practices. In many road projects, slope protection measures are still treated as optional or secondary components that are frequently reduced or removed under financial constraints and value-engineering decisions. However, the guiding philosophy of this framework, supported by the PTMP implementation approach, recognizes roadside slope stabilization as an essential and mandatory component of road infrastructure rather than an optional add-on. Effective slope protection, drainage management, erosion control, and stabilization measures are considered fundamental elements of safe and sustainable road construction, equivalent in importance to the road pavement and structural components themselves. Roads constructed without adequate slope protection are inherently vulnerable and remain at high risk of progressive failure, repeated maintenance problems, and long-term infrastructure instability.



CHAPTER 3. SITE CHARACTERIZATION

In Nepal, site characterization and investigation are critical components of roadside slope stabilization because of the country's fragile geology, steep terrain, intense monsoon rainfall, and active seismic conditions. The process involves detailed assessment of geological formations, soil and rock conditions, slope geometry, drainage patterns, groundwater conditions, land use, and existing signs of instability such as cracks, erosion, rockfall, or previous landslides. In many hill road projects, investigations are carried out through field reconnaissance, engineering geological mapping, discontinuity surveys, simple geotechnical testing, and hydrological observations to understand slope behavior and identify suitable stabilization measures

3.1 Desk Study and Preliminary Assessment

A thorough desk study draws on four categories of secondary information before any field investigation begins. Topographic maps from Department of Survey (DoS), satellite imagery, and digital elevation models reveal terrain morphology, drainage patterns, and slope conditions across the corridor (Table 3-1, a). Geological maps from the Department of Mines and Geology (DMG) establish the lithological setting, fault systems, and structural controls on slope behavior (Table 3-1, b). Rainfall records from Department of Hydrology and Meteorology (DHM) gauging stations and GPM satellite data characterize the monsoon regime and catchment hydrology (Table 3-1, c). Historical maintenance records, national disaster reports, and validated landslide inventories identify where slope problems have occurred before (Table 3-1, d). Together, these sources determine where limited field investigation time is best directed.

Table 3-1: Data types, use and sources

a. Topographic data

Data source	Scale / resolution	Information provided	Access
Topographic maps	1:25,000 and 1:50,000	Terrain morphology, drainage networks, ridge and valley systems, contour patterns, settlement locations	DoS
Google Earth satellite imagery	Variable (sub-metre to 5 m)	Slope gradients, aspect, landslide scars, stream networks, erosion features, and land use	Google Earth
SRTM DEM	~30 m	Watershed delineation, slope classification, terrain analysis, drainage assessment	USGS EarthExplorer
ALOS PALSAR DEM	~12.5 m	Finer pixel spacing for detailed corridor assessment	JAXA

b. Geological data

Data source	Scale	Information provided	Agency
Geological maps	1:250,000, 1: 1,000,000	Lithology, geological formations, fault systems - regional corridor assessment	DMG



Data source	Scale	Information provided	Agency
Detailed geological maps	1:50,000, 1:25,000	Detailed rock type, structural conditions, weathering zones	DMG

Geological maps should be read in conjunction with topographic data. A fault zone running oblique to the road alignment may not be apparent on the geology map alone — it often shows up as a linear valley, a stream deflection, or a change in slope morphology visible on the DEM or satellite image.

c. Climate and rainfall

Data source	Coverage	Information provided	Use in assessment
DHM daily rainfall records	Gauge stations (point)	Rainfall intensity, seasonal distribution, extreme events	Rainfall thresholds, drainage design return periods
GPM IMERG satellite rainfall	Basin-wide (~10 km grid)	Spatial monsoon distribution where gauge coverage is limited	Catchment hydrology, saturation potential in ungauged catchments

d. Landslide inventories

Record type	Source agency	Information provided
Road maintenance and closure records	TID, DoR, local governments	Repeated closure locations, landslide activity, erosion problems, drainage failures
National disaster records	Nepal Disaster Report (MoHA)	Historical landslide occurrence, event magnitude, affected roads and settlements
Landslide inventory	Dhakal, S. (2016)	Active and dormant landslide zones
District disaster records	District/local disaster management committees	Local hazard patterns, historical event locations, seasonal failure trends

3.2 Geology and Geomorphology

3.2.1 Geological setting of Bagmati Province

Bagmati Province, in central Nepal, extends from the Terai plains to the High Himalaya, bordering China and India. It includes major cities like Kathmandu and Bharatpur, serving as Nepal's political and economic center. The province displays a complete geological cross-section of the Nepal Himalaya. As illustrated in the uploaded geological map ([Figure 3.1](#)), the province is characterized by a series of east-west trending geological belts formed due to the collision between the Indian and Eurasian plates.

The youngest geological sediments in Bagmati Province occur mainly in the Terai plains and river valleys as recent alluvial and floodplain deposits. These unconsolidated sand, silt, clay, gravel, and boulder sediments are highly porous and permeable, reflecting active river deposition processes. Due to their loose nature, they are highly vulnerable to flooding, riverbank erosion, and earthquake-induced liquefaction, especially during the monsoon season.

Siwalik Groups



The Siwalik Group of Bagmati Province, ranging from the Middle Miocene to Lower Pleistocene, forms the fragile Churia foothills and consists mainly of weakly consolidated sedimentary rocks deposited in fluvial environments. It is divided into Lower, Middle, and Upper Siwalik units. The Lower Siwalik contains fine-grained sandstone, mudstone, and shale, highly prone to weathering and erosion. The Middle Siwalik consists of medium to coarse sandstone with mudstone and siltstone interbeds, making slopes vulnerable to landslides under saturated conditions. The Upper Siwalik is dominated by loosely consolidated conglomerates and coarse deposits from high-energy river systems, highly susceptible to erosion and mass wasting. Overall, the Siwalik Group is highly erosion-prone and landslide susceptible due to weak lithology and loose structure. Despite this, its relatively high permeability supports groundwater recharge, though instability creates major challenges for infrastructure and disaster risk management.

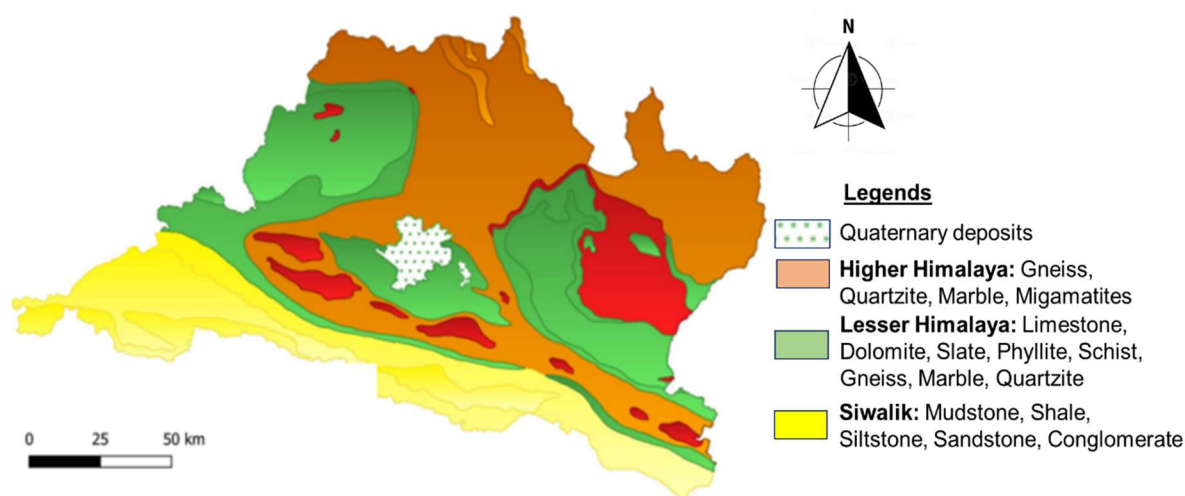


Figure 3.1: Geological map of the Bagmati Province

Lesser Himalaya

The Midland Group (Upper Precambrian–Late Paleozoic) and Kathmandu Group (Precambrian–Devonian) form major geological units of the Lesser Himalaya in Bagmati Province. These units consist of sedimentary and low- to medium-grade metamorphic rocks that have undergone folding, faulting, and metamorphism during Himalayan tectonic evolution. The Midland Group includes formations such as Lakhapata, Syangja, Sangram, Galyang, and Ghan Pokhara, composed of limestone, quartzite, shale, slate, phyllite, and gneiss deposited in shallow marine to low-energy environments. Younger formations like Ulleri contain augen gneiss and schists, indicating intense tectonic deformation. The Kathmandu Group, widely exposed in Kathmandu Valley, is divided into the Phulchoki and Bhimphedi Sub-groups. The Phulchoki Sub-group mainly contains dolomite, limestone, slate, and phyllite with fossil evidence of marine deposition, while the Bhimphedi Sub-group consists of highly metamorphosed marble, schist, quartzite, and calc-silicate rocks. These rocks are important for construction materials, groundwater storage, and landscape formation in central Nepal.

Higher Himalayan Crystalline

The Higher Himalayan Crystalline unit occupies the northern high mountain region of Bagmati Province. This unit is composed predominantly of high-grade metamorphic rocks formed under extreme pressure and temperature conditions deep within the Earth's crust and later uplifted during the Himalayan orogeny. The rock types are dominated by Precambrian high grade metamorphic rocks comprising gneisses, quartzites and marble. Migmatites and granite gneisses are predominant



in the upper part. Overall, this unit is marked by high-grade metamorphism, resulting in rocks that are strong and compact. However, due to intense tectonic forces, these rocks are often highly fractured, influencing slope stability and engineering properties. The presence of such metamorphic and intrusive rocks clearly indicates deep crustal processes, including metamorphism, partial melting, and subsequent uplift, making this unit crucial for understanding the tectonic evolution of the Himalayas.

3.2.2 *Geomorphological setting of Bagmati Province*

Bagmati Province is characterized by a complex and diverse geomorphological structure, shaped by the interactions of the Nepal Himalaya, the Indo-Gangetic plains, and local river systems. The province exhibits a wide range of landscapes, including rugged mountains, deep valleys, intermontane basins, and flat land, contributing to its vulnerability to natural hazards.

Terai Region: The southernmost part of Bagmati Province, the Terai, lies at an altitude of 64 to 200 masl. This area consists of Pleistocene to Holocene sediments transported by the major rivers of the Nepal Himalayas, such as the Bagmati and Rapti rivers. The sediments range from large boulders in the north to fine clays in the south. The Terai is divided into three zones: The Bhabar zone (with poorly sorted sediments), the Middle Terai (with sandy and silty soils), and the Lower Terai (comprising pebbles, fine silt, and clays). This region experiences a subtropical climate, with monsoonal rainfall from June to July. Erosion is generally low, though gully erosion can be observed in certain areas.

Siwaliks (Churia Hills): The Siwalik range, or Churia Hills, forms the foothill region of the Nepal Himalayas, with altitudes ranging from 100 to 1500 m. This area consists mainly of sedimentary rocks and exhibits a fragile landscape, prone to erosion and debris flows during the monsoon season. It is dissected by numerous valleys formed by river erosion over time.

Mahabharat Range: The Mahabharat Range forms the steep frontal ridge of the Lesser Himalaya, immediately north of the Siwaliks, at altitudes of about 1,000 to 2,700 m. It is built of relatively stronger rocks such as limestone, quartzite, dolomite, and schist. Because the range is still actively rising, its rivers incise deep gorges with steep to near-vertical banks, and the zone is highly landslide-active. It is largely forested, with limited permanent settlement, and its crest carries the high points that rim the Kathmandu Valley, such as Phulchoki (2,782 m) and Shivapuri (2,732 m).

Midland: The Midland lies between the Mahabharat Range to the south and the Fore Himalaya to the north, at altitudes of about 600 to 2,000 m. Its topography is strongly dissected by streams and rivers, with old river terraces and thick residual soils developed on deeply weathered Lesser Himalayan phyllite, schist, quartzite, and the granites and gneisses of the Kathmandu complex. This zone contains the major intermontane basins of the province, including the Kathmandu Valley (floor near 1,300 m), Banepa, and Panauti. It is the most densely settled and intensively cultivated part of Bagmati Province and carries the highest density of provincial and local roads; combined with deep weathering and high monsoon rainfall, this makes the Midland the zone where roadside slope failure and erosion are most frequent.

Fore Himalaya: The fore Himalaya, ranging from 2000 to 5000 masl, is marked by steep slopes and fragile landscapes. This region is dissected by major rivers like the Trishuli, which have shaped the topography over time. The area is home to higher Himalayan rocks, often covered by snow in winter. Agriculture is practiced on gentle slopes, where the micro-climate supports crops like wheat, maize, and millet. The climate is warm-temperate, though it varies across the region due to geomorphological differences.

Higher Himalaya: The higher Himalaya, with altitudes above 5000 masl, represents the northern part of Bagmati Province. This area is dominated by steep slopes and narrow valleys, with high peaks covered by snow year-round. The region is primarily made up of metamorphic and some sedimentary



rocks. The High Mountain acts as a barrier to the Indian monsoon, resulting in heavy rainfall on the southern slopes and dry conditions on the northern side. Agriculture is concentrated in the valley bottoms, and the climate is cold temperate, often below freezing for more than six months.

3.2.3 Rate of weathering for different rock types, exposures and altitudes

Weathering processes begin immediately after rock, and soil materials are exposed during road cutting and excavation. In Nepal's mountainous environment, high temperatures, intense monsoon rainfall, and elevated moisture conditions significantly accelerate physical and chemical weathering processes. Rocks containing dark-colored minerals, particularly schist, phyllite, and slate, generally exhibit lower resistance to weathering, whereas quartz-rich rocks such as quartzite are comparatively more durable. Consequently, mica-rich rocks such as phyllite and schist weather and deteriorate much more rapidly than quartzite or granite under exposed slope conditions. While Siwalik mudstone is considered one of the most vulnerable rock types because of its high content of swelling clay minerals, which rapidly weaken and degrade upon exposure to water and atmospheric conditions, making such slopes highly susceptible to erosion and failure (Table 3-2).

Table 3-2: Rock weathering grades and engineering significance (Durham/TU, 2024; DoR, 2007)

Grade	Name	Description	Engineering Significance	Nepal Occurrence
A	Unweathered	Original strength, colour, fracture spacing preserved	Stable cuts; design on intact rock strength and discontinuity orientation	Fresh granite, quartzite, competent gneiss
B	Partially Weathered	Slightly reduced strength; closer fractures; brown oxidation	Slightly lower safe cut angle; drainage improvement beneficial	Schist/gneiss mid-slope; fresh phyllite
C	Distinctly Weathered	Further weakened; much closer fractures; grey colour reduced	Significant reduction in safe cut angle; immediate bioengineering needed	Phyllite, schist on mid-hill road cuts
D	Deconstructed	Greatly weakened; mottled; disordered bedding	High landslide susceptibility; benching and immediate protection essential	Upper Siwalik; deeply weathered schist/phyllite
E	Residual Soil	Rock fabric and structure completely converted to soil	Treat as soil slope; factor of safety analysis for soil failure mechanisms	Colluvium on all mid-hill zones

Weathering intensity and dominant weathering processes vary considerably with altitude, climatic conditions, and slope aspect across Bagmati Province. In lower elevation areas below approximately 1,500 masl, warm and humid climatic conditions promote intense chemical weathering, often producing deep weathered profiles exceeding 4-8 m in thickness. At mid-altitude zones between approximately 1,500 masl and 2,500 masl, alternating monsoon and dry-season cycles create combined physical and chemical weathering effects, resulting in progressive weakening of exposed rock masses and residual soils. These processes are particularly pronounced on south-facing slopes, where greater solar radiation and higher temperature fluctuations



accelerate rock disintegration and moisture variation. In higher elevation areas above approximately 2,500 masl, freeze-thaw processes become an important form of physical weathering, where repeated freezing and expansion of water within rock discontinuities progressively weaken slope materials. Slope aspect also strongly influences weathering behavior, as south-facing slopes generally experience greater solar exposure, larger thermal cycles, faster drying, and increased vegetation stress, all of which contribute to accelerated physical weathering and reduced long-term slope stability.

3.2.4 Key Considerations and Field Assessment

The geological field mapping process for rock identification is a critical step in understanding the composition and stability of rocks, especially for road slope engineering in the Nepal Himalaya. Field engineers and geologists conduct hands-on investigations using systematic methods to assess rock types, their orientation, and structural features that affect slope stability. The following process outlines key steps and practical applications for rock identification, ensuring that data collection is both accurate and efficient for making informed decisions in construction and environmental assessments (Figure 3.2).

Preliminary Site assessment

This preliminary site assessment provides the identification of general slope condition. The inspector shall observe and record the following items.

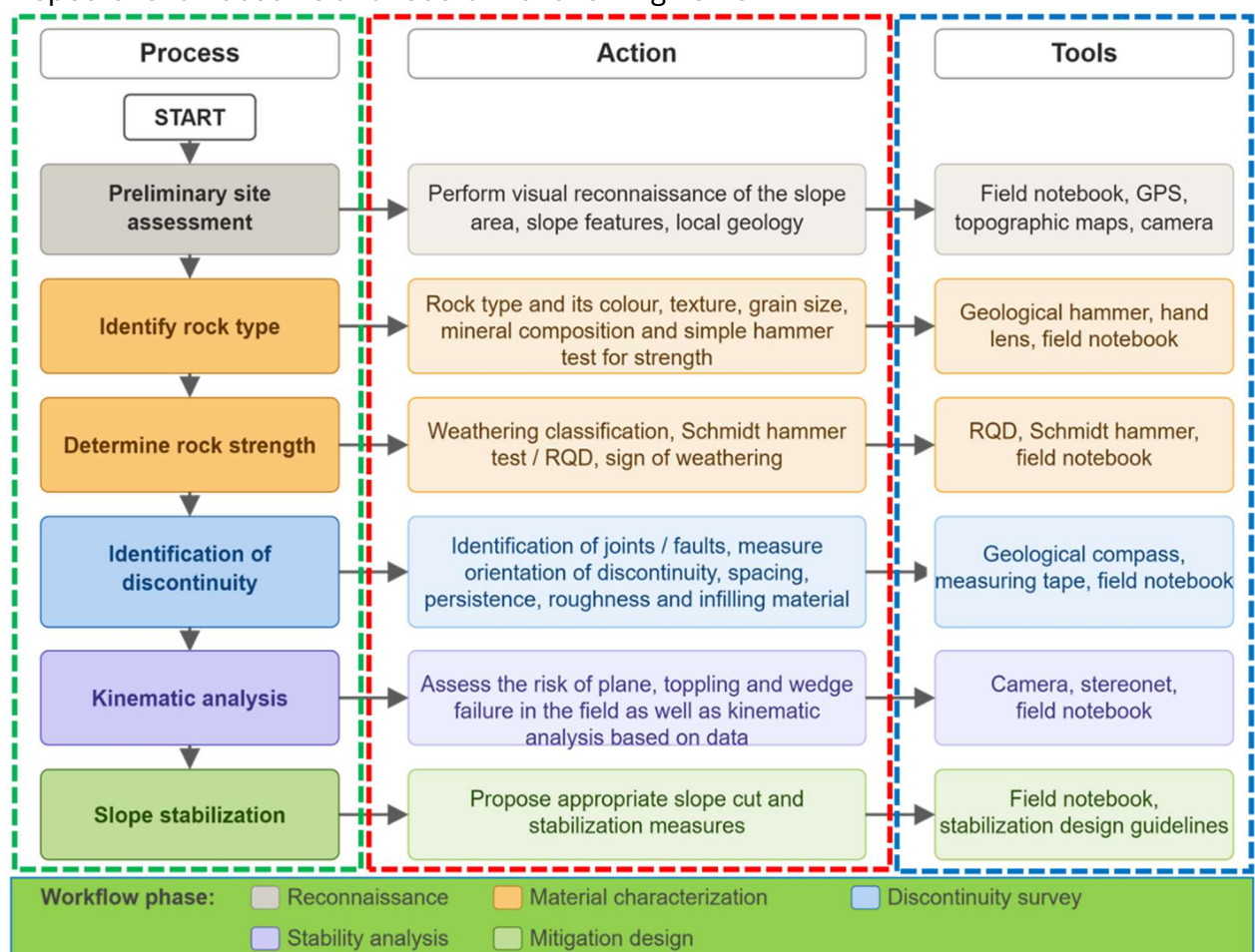


Figure 3.2: Step-by-step process for rock slope characterization



Table 3-3: Additional information for the slope assessment

Item	What to Record
Location	GPS point, chainage, road/river name
Slope type	Natural, road-cut, river-cut, quarry, or construction-cut
Slope size	Approximate height and slope angle
Slope material	Rock, soil, mixed rock-soil, debris, or alluvium
Rock condition	Fresh, weathered, fractured, or loose
Drainage	Surface runoff, seepage, wet patches, blocked drains
Vegetation	Dense, sparse, removed, or absent
Instability signs	Cracks, fallen blocks, scarps, bulging, tilted trees
Toe condition	River cutting, road undercutting, or excavation
Past failure	Old landslide, rock fall deposit, gully, repaired section

Identification of rock type

The inspector shall identify the dominant rock type exposed on the slope. Rock type should be recorded because the slope behavior depends on whether the rock is soft, hard, layered, fractured, foliated or loose. The following table shall guide to identify the rocks in the field (Table 3-4).

The inspector should record the rock name, color, grain size, weathering condition, layering or foliation, hammer response and main slope problem observed. The inspector should take a decision based on the following observation. The tools required for this work is geological hammer, hand lens, measuring tape, field notebook, GPS and camera.

Instruments and tools

- **Geological compass:** To measure strike, dip, and orientation of rock layers and faults.
- **Measuring tape:** For recording distances between geological features.
- **Hammer and chisel:** To collect rock samples and assess rock strength.
- **Field notebook:** To record measurements, observations, and sketches.
- **Camera:** To capture key rock features and geological formations.
- **Hand lens:** For examining rock texture and mineral composition.
- **GPS:** For precise mapping of samples and observations.
- **Field mapping symbols:** To represent rock units and features on geological maps consistently.

3.2.5 Rock strength determination

The inspector shall assess the strength and weathering conditions of the exposed rock. Rock strength shows how easily the rock may break, slide, fall or erode. Weathered rock is weaker than fresh rock and may behave like soil during rainfall. It is suggested to use geological hammer or Schmidt hammer to observe how the rock responds when hit and whether it is fresh, weathered, fractured, soft or soil like.



Table 3-4: Lithology of rocks in Bagmati Province

Siwalik Zone:



Rock Name: Mudstone

Criteria	Description	Engineering behavior
Texture	Very fine-grained, smooth, compact to earthy texture	Very weak, low bearing capacity, highly compressible, prone to swelling and erosion
Color	Commonly grey, greenish grey, brownish grey, reddish brown, purple brown, yellowish brown, or mottled	
Grain Size	Dominated by clay- and silt-sized particles, finer than siltstone and sandstone	
Hardness	Weak to moderately weak; may break easily with a hammer	
Weathering	Fresh mudstone may appear compact, but weathered mudstone becomes soft, sticky, crumbly, and highly erodible	



Rock Name: Siltstone

Criteria	Description	Engineering behavior
Texture	Fine-grained, smooth to slightly gritty texture; less gritty than sandstone	Moderate strength, susceptible to erosion and weathering, moderate slope stability
Color	Commonly grey, greenish grey, brownish grey, yellowish brown and reddish brown	
Grain Size	Dominated by silt-sized particles, finer than sandstone and coarser than mudstone	
Hardness	Weak to moderately hard; may break with a hammer blow and may scratch weakly	
Weathering	Fresh siltstone may be moderately compact, but weathered siltstone becomes soft, flaky, friable, and easily erodible	



Criteria	Description	Engineering behavior
Texture	Gritty, rough, sandy texture; individual sand grains may be felt by hand	Moderate to good strength, relatively stable but weak if poorly cemented
Color	Commonly grey, light grey, greenish grey, brownish grey, yellowish brown	
Grain Size	Mainly sand-sized grains, fine to coarse sand	
Hardness	Moderately hard; generally, scratches a knife or hammer	
Weathering	Fresh sandstone is relatively hard, but weathered sandstone becomes weak	



Rock Name: Sandstone

Criteria	Description	Engineering behavior
Texture	Coarse, pebbly to cobbly texture; rounded to sub-rounded clasts	Variable strength, weak if poorly cemented, prone to erosion and slope failure
Color	Commonly grey, brownish grey, yellowish brown, reddish brown, or mixed colour	
Grain Size	Dominated by gravel-sized clasts, mainly pebbles and cobbles, sometimes with coarse sand matrix	
Hardness	Variable; individual clasts may be hard, but the overall rock mass may be weak if the matrix is poorly cemented	
Weathering	Fresh conglomerate may appear compact, but weathered conglomerate becomes loose as the sandy or muddy matrix is washed out	



Rock Name: Conglomerate



Lesser Himalaya:



Rock Name: Limestone

Criteria	Description	Engineering behavior
Texture	Compact, smooth to crystalline texture; massive/bedded (react with HCL)	Moderate strength, soluble, prone to karst formation and dissolution
Color	grey, bluish grey, dark grey, blackish grey, cream, or white	
Grain Size	Mainly fine-grained to medium crystalline calcite grains	
Hardness	Moderately hard; can be scratched by a knife, but not scratch glass	
Weathering	Fresh limestone is compact and hard, but weathered limestone becomes fractured, rough, pitted, and may develop solution cavities	



Rock Name: Dolomite

Source:

<https://sandatlas.org/dolomite-rock>

Criteria	Description	Engineering behavior
Texture	crystalline to massive texture; bedded/fractured (react with HCL in power form)	Stronger than limestone; less soluble; good construction material
Color	grey, light grey, bluish grey, cream, white, or brownish grey	
Grain Size	fine- to medium-grained crystalline dolomite minerals	
Hardness	Moderately hard to hard; generally harder than limestone and can scratch a knife	
Weathering	Compact and hard, but weathered dolomite becomes fractured, rough and sugary	

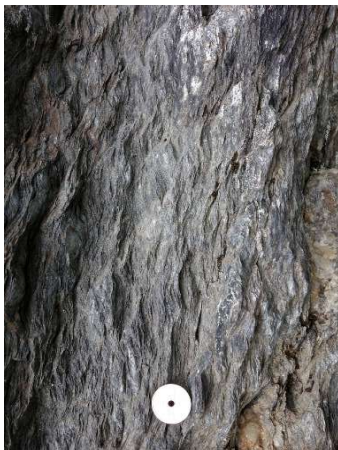


Criteria	Description	Engineering behavior
Texture	Fine-grained, smooth, compact, and foliated; splits into thin flat sheets or plates	Low to moderate strength, failure along cleavage planes, used in roofing
Color	dark grey, blackish grey, greenish grey, bluish grey, or purple grey	
Grain Size	Very fine-grained; individual minerals are generally not visible to the naked eye	
Hardness	Moderately hard; harder than shale, but splits easily along cleavage planes	
Weathering	Fresh slate is compact and hard, but weathered slate becomes flaky, fractured, and may break into thin slabs	



Rock Name: Slate
Source: <https://geologyistheway.com/it/metamorphic/slate>

Criteria	Description	Engineering behavior
Texture	Fine-grained, foliated, silky to shiny surface; splits into thin wavy sheets or flakes	Weak to moderate prone to deformation, unstable slopes due to foliation
Color	grey, greenish grey, silver grey, bluish grey, brownish grey, or dark grey	
Grain Size	Very fine- to fine-grained; minerals are usually small but may show a silky	
Hardness	Weak to moderately hard; generally harder than shale but weaker than schist	
Weathering	Fresh phyllite is compact and shiny, but weathered phyllite becomes flaky, slippery, fractured, and weak along foliation surfaces	



Rock Name: Phyllite
Source: <https://structuralgeo.wordpress.com/wp-content/uploads/2014/08/phyllite-53.jpg>



Criteria	Description	Engineering behavior
Texture	Medium- to coarse-grained, strongly foliated, flaky or platy texture	Moderate strength, anisotropic, failure along foliation planes common
Color	grey, silver grey, greenish grey, brownish grey, dark grey, or blackish grey	
Grain Size	Fine- to medium-grained, visible mica, quartz, and feldspar grains	
Hardness	individual minerals may be hard, but the rock breaks easily along foliation planes	
Weathering	Fresh schist is compact and shiny, but weathered schist becomes flaky, fractured, soft along foliation, and may form loose slabs or debris	
 Rock Name: Schist		

Criteria	Description	Engineering behavior
Texture	Hard, compact, massive to slightly foliated; sugary or glassy texture on fresh	Very strong, high bearing capacity, good for construction and slope stability
Color	white, grey, light grey, pinkish grey, brownish grey, or reddish brown when weathered	
Grain Size	Fine- to medium-grained quartz crystals; grains are tightly interlocked	
Hardness	Very hard; scratches glass and cannot be scratched easily by a knife	
Weathering	Fresh quartzite is very hard and resistant, but weathered quartzite becomes fractured	
 Rock Name: Quartzite		



Higher Himalayan Crystalline

Criteria		Description	Engineering behavior
Texture	 Rock Name: Gneiss Source: https://sandatlas.org/gneiss	Coarse-grained, hard, compact, and banded texture; shows alternating light and dark mineral bands	Very strong but fractured; joint-controlled instability; good foundation rock, if intact
Color		grey, light grey, dark grey, pinkish grey, or black and white banded	
Grain Size		Medium- to coarse-grained; visible quartz, feldspar, mica, and dark minerals	
Hardness		Hard to very hard; generally difficult to break with a hammer	
Weathering		Fresh gneiss is hard and compact, but weathered gneiss becomes jointed, fractured, rough	

Criteria		Description	Engineering behavior
Texture	 Rock Name: Marble Source: https://www.facebook.com/photo?fbid=716616907670335&set=pcb.716623851002974	Crystalline, compact, massive to slightly banded; smooth to sugary texture on fresh surface	Moderate strength, brittle, susceptible to weathering and dissolution
Color		white, grey, bluish grey, cream, pinkish, greenish, or blackish depending on impurities	
Grain Size		Fine- to coarse-grained calcite or dolomite crystals; grains may be visible on fresh surface	
Hardness		Moderately hard; can be scratched by a knife, but generally does not scratch glass	
Weathering		Fresh marble is compact and crystalline, but weathered marble becomes rough, fractured, pitted	



Criteria	Description	Engineering behavior
Texture	Coarse-grained, hard, compact, massive, and crystalline texture	Very strong, high bearing capacity, good for construction and slope stability
Color	Commonly light grey, pinkish grey, whitish grey, reddish grey, or black-white speckled	
Grain Size	Medium- to coarse-grained; visible quartz, feldspar, mica, and other minerals	
Hardness	Hard to very hard; difficult to break with a hammer and generally scratches glass	
Weathering	Fresh granite is very hard and compact, but weathered granite becomes rough, jointed, fractured, and may break into angular blocks or sandy fragments	



Rock Name: Granite

Criteria	Description	Engineering behavior
Texture	Coarse-grained, hard, compact, massive, and crystalline texture	Strong but brittle, may fracture easily due to large crystals
Color	Commonly light grey, pinkish grey, whitish grey, reddish grey, or black-white speckled	
Grain Size	Medium- to coarse-grained; visible quartz, feldspar, mica, and other minerals	
Hardness	Hard to very hard; difficult to break with a hammer and generally scratches glass	
Weathering	Fresh granite is very hard and compact, but weathered granite becomes rough, jointed, fractured, and may break into angular blocks or sandy fragments	



Rock Name: Pegmatite
Source: <https://www.nps.gov/places/pegmatite.htm>



The rock strength can be classified based on the following [Table 3-6](#).

Table 3-6: Field indicators for assessing rock strength and weathering condition

Item	What to Check
Hammer response	Breaks by hand, breaks by light blow, breaks by strong blow, or does not break easily
Surface condition	Fresh, discolored, cracked, softened, or decomposed
Weathering depth	Weathered only on surface or deeply weathered
Fragment condition	Sharp, blocky, flaky, crumbly, or soil-like
Moisture effect	Becomes soft or slippery when wet
Clay content	Presence of clayey, sticky, or softened material
Joint condition	Tight, open, weathered, clay-filled, or wet

Table 3-6: Rock strength classification based on the field investigation

Field Observation	Strength Class
Can be broken by hand	Very weak
Breaks easily with light hammer blow	Weak
Breaks with firm hammer blow	Moderately strong
Breaks only with repeated strong blows	Strong
Very difficult to break, ringing sound	Very strong

The inspector can take the decision based on the following observation. S/he should record rock strength class, weathering grade, hammer response, moisture condition, clay or soil-like materials and whether the slope needs drainage, trimming, toe protection or further investigation.

Rock discontinuity identification

The identification of discontinuity is very important because they are natural weakness planes such as joints, bedding planes, foliation, faults, cracks, and shear zones. Most rock slope failures occur along these planes rather than through intact rock. The inspector should identify the following discontinuity type.

Table 3-7: Field identification of discontinuities and their slope stability concern

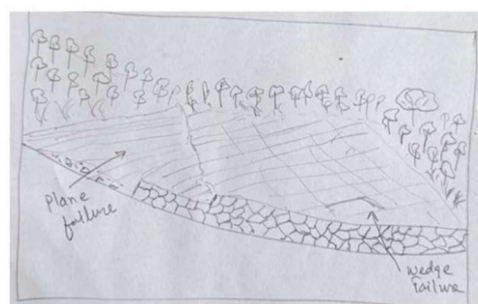
Discontinuity Type	Field Identification	Slope Concern
Joint	Crack or fracture cutting the rock mass	May form loose blocks or rockfall
Bedding plane	Layering in sedimentary rocks such as sandstone, shale, limestone	Sliding may occur if bedding dips toward slope face
Foliation	Planar surface in slate, phyllite, schist, or gneiss	Failure may occur along foliation planes
Fault zone	Crushed, broken, or displaced rock zone	Very weak and unstable zone
Shear zone	Clayey, crushed, polished, or wet surface	High risk of sliding
Open crack	Visible opening in rock mass	Water entry and block separation
Tension crack	Crack near top of slope, usually parallel to slope edge	Warning sign of slope movement

The inspector should record the following information at the road slope. The inspector should have geological compass, measuring tape, field notebook, GPs, camera, and marker pen. S/he should



record the following minimum parameters: Type of discontinuity; dip direction and dip angle; spacing between discontinuities, persistence or visible length; aperture or opening width; surface condition, rough or smooth; infilling materials, if present; water condition; whether the discontinuity dips toward the slope face and photograph number and location.

The inspector can take a field-based decision based on the following observation. If discontinuities are open, wet, clay-filled, closely spaced, or dipping toward the slope face, the slope should be considered potentially unstable. Such slopes require drainage, scaling, wire mesh, toe support, rock bolting, or detailed geotechnical investigation depending on the risk level.



Parameter	Observed Value	Significance for Stability / Design
Aspect	South-West	Higher afternoon insolation and a drier microclimate
Altitude	1500 m	Sub-tropical to warm-temperate transition
Natural slope	25 degrees	Stable natural slope
Cut angle	60 degrees	Cut face steeper than stable slope
Rock type	Limestone	Stability governed by bedding and joints
Weathering	Fresh	Low weathering grade; instability is discontinuity-controlled
Failure mode	Plane (planar)	A discontinuity daylighting in the cut face
Rainfall	Medium	Moderate regime; check discontinuity seepage
Runoff	Nonvisible	No concentrated surface flow observed
Vegetation cover	Sparse	Little existing surface protection or root reinforcement
Average root depth	1 m	Root reinforcement effective for shallow soil

Recommendation: Slope work
(Flattening the slope)

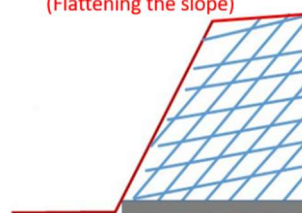


Figure 3.3: Field assessment of a limestone rock cut slope showing wedge and plane failure susceptibility

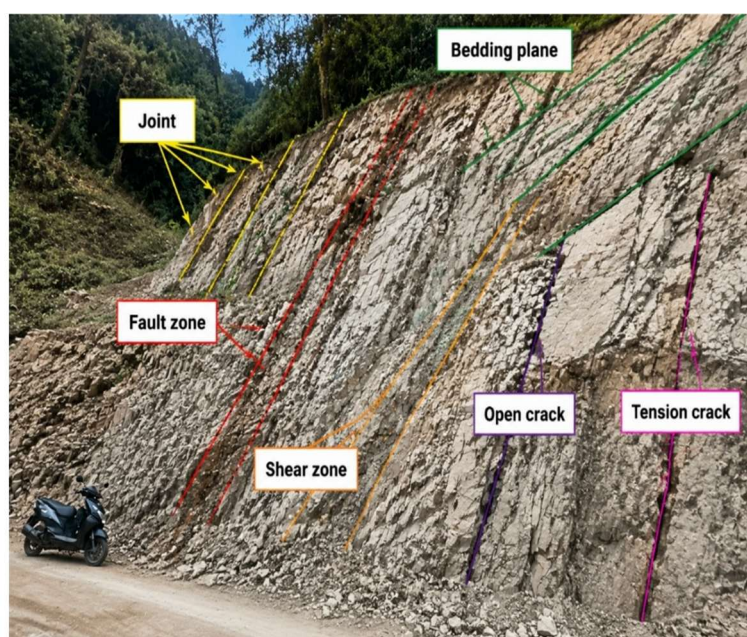


Figure 3.4: Identification of different discontinuities in the field.

Kinematic analysis of rock slope

The inspector shall identify the likely rock slope failure mode by observing rock type, discontinuity orientation, slope face direction, slope angle, joint condition, seepage, weathering and toe cutting. Most rock slope failures occur along joints, bedding planes, foliation planes, faults, or weathered weak zones (Figure 3.4).



The following Table 3-8 guides for the slope failure identification in different road slope:
Table 3-8: Field guide for rock slope failure mode identification

Failure Mode	Failure criteria	Photo	Kinematic analysis
Planar failure	1. The joint plane and the hill slope should dip in the same direction. 2. The dipping of the joint plane should be less than the dip of the Hill slope. 3. The strike difference should be between 20°. 4. The dip of the joint should be more than the internal friction angle		
Wedge failure	1. The joint plane and the hill slope should dip in the same direction. 2. The dipping of the wedge should be less than the dip of the Hill slope. 3. The strike difference should be between 20°. 4. The dip of the joint should be more than the internal friction angle		
Toppling failure	1. The joint plane and the hill slope should dip in opposite directions. 2. The strike difference should be between 20°. 3. The dip of the joint should be more than the internal friction angle		



In rock slope assessment, the inspector should carefully observe the orientation and behaviour of bedding planes, joints, and foliation planes. If a bedding plane, joint, or foliation plane dip toward the slope face, the slope may be prone to planar failure, because the rock mass can slide along a single continuous weak plane. If two joint sets intersect and open toward the slope face, they may form a wedge-shaped block, creating the possibility of wedge failure. Similarly, if vertical or steep rock blocks are leaning outward from the slope, the slope may be at risk of toppling failure, where rock blocks rotate or fall forward due to gravity, weathering, or toe undercutting.

3.3 Hydrological and Rainfall Assessment

3.3.1 Rainfall pattern analysis

Rainfall is the primary driver of the hydrological cycle within Bagmati Province, determining streamflow regimes, groundwater recharge, agricultural productivity, and flood and drought risk. This section presents a comprehensive analysis of the historical rainfall record based on daily precipitation data obtained from the Department of Hydrology and Meteorology (DHM), Government of Nepal. The analysis covers 15 representative stations spanning all major physiographic zones of the province - from the Terai and Siwalik foothills in the south to the High Himalayan ranges in the north - over a period of at least 43 years (1980–2022), except for stations 1079 and 1080, which have 25 and 23 years of record, respectively.

(a) Station selection and spatial coverage

DHM data from 15 rainfall stations were used in this analysis. Stations were selected based on data quality, spatial representativeness, and coverage of the distinct physiographic zones of Bagmati Province: the Terai/Siwalik lowlands, the Middle Hills, the High Mountain zone, and the High Himalayan belt. Stations with extended records and minimal missing data gaps were prioritized to ensure statistical reliability of long-term trend analyses.

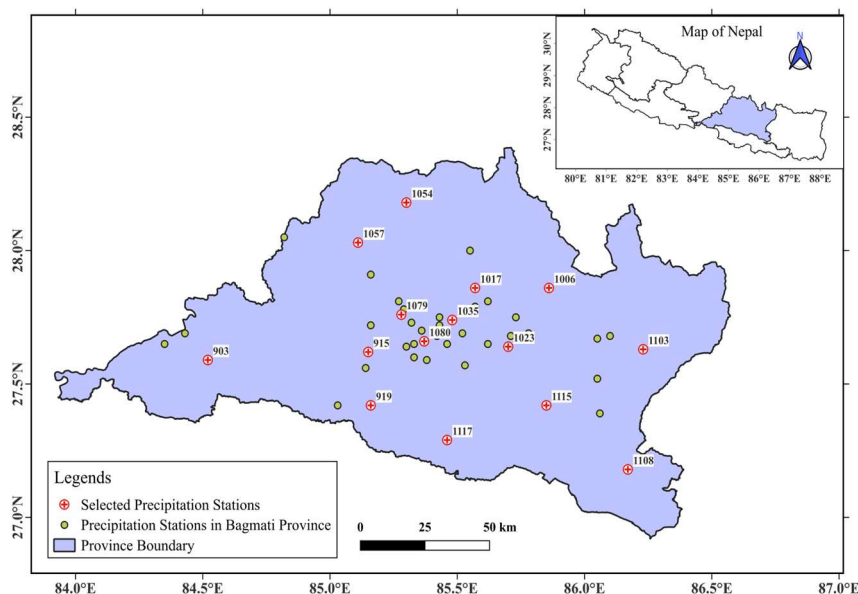




Table 3-9: DHM rainfall stations selected for analysis – Bagmati Province

Station ID	Station Name	Physiographic Zone	Long-term Mean Annual Rainfall (mm)	Record Length (yrs)	Analysis Period
903	Jhuwani	Siwalik	1734.2	43	1980–2022
915	Markhu Gaun	Middle Mountains	1204.3	43	1980–2022
919	Makwanpur Gadhi	Siwalik	1852.1	43	1980–2022
1006	Gumthang	High Mountains	3281.0	43	1980–2022
1017	Duwachaur	Middle Mountains	2097.8	43	1980–2022
1023	Dolal Ghat	Middle Mountains	1054.0	43	1980–2022
1035	Sankhu	Middle Mountains	1694.3	43	1980–2022
1054	Thamachit	High Mountains	763.5	43	1980–2022
1057	Pansayakhola	High Mountains	2735.1	43	1980–2022
1079	Nagarjun	Middle Mountains	1545.1	25	1980–2022
1080	Tikathali	Middle Mountains	1146.9	23	1980–2022
1103	Jiri	Middle Mountains	2176.1	43	1980–2022
1108	Bahun Tilpung	Middle Mountains	1500.7	43	1980–2022
1115	Nepalthok	Middle Mountains	675.6	43	1980–2022
1117	Hariharpur Gadhi Valley	Siwalik	1869.5	43	1980–2022

(b) Long-term average annual rainfall

The long-term mean annual rainfall across the 15 selected stations varies considerably, reflecting the strong influence of topography, elevation, and orographic effects on the spatial distribution of precipitation in Bagmati Province. The province-wide average ranges from a minimum of approximately 676 mm at Station 1115 (Nepalthok, Middle Mountains) to a maximum of approximately 3,281 mm at Station 1006 (Gumthang, High Mountains).

The spatial pattern of rainfall is closely linked to the physiographic zonation of the province:

- **Siwalik Zone** (Stations 903, 919, 1117): Long-term mean annual rainfall ranges from 1,734 mm (Station 903, Jhuwani) to 1,869 mm (Station 1117, Hariharpur Gadhi Valley), with the higher values attributable to orographic uplift along the Siwalik ridges.
- **Middle Mountains Zone** (Stations 915, 1017, 1023, 1035, 1079, 1080, 1103, 1108, 1115): This zone exhibits the widest variability, with annual means ranging from 676 mm (Station 1115, Nepalthok) to 2,176 mm (Station 1103, Jiri). Stations on windward slopes and valleys (e.g., Pansayakhola at 2,735 mm - though classified High Mountains - and Duwachaur at 2,098 mm) receive substantially more rainfall than those in more sheltered or rain-shadow positions (e.g., Nepalthok at 676 mm and Tikathali at 1,147 mm).
- **High Mountains Zone** (Stations 1006, 1054, 1057): High-altitude stations show considerable variation. Gumthang (1006) records the highest rainfall in the entire dataset at 3,281 mm, while Thamachit (1054) receives only 764 mm. This reflects the complex interaction of elevation, valley orientation, and exposure to moist monsoon flows in the higher terrain.

The spatial gradient is strongly influenced by topography, with pockets of very high rainfall occurring where moist Indian Summer Monsoon air masses undergo intense orographic uplift, particularly along windward slopes and within certain river valleys. Conversely, lower rainfall is observed in rain-



shadow areas and at some high-elevation locations where moisture has been largely depleted. This pattern is consistent with regional climatological studies for Central Nepal.

(c) Annual rainfall anomaly – Wet and dry year characterization

The variation of annual rainfall from the long-term normal (rainfall anomaly) was calculated for each station over the full period of record. [Figure 3.6](#) below presents the annual rainfall time series for a sample station. Years in which total annual rainfall exceeds the long-term mean are classified as wet years (positive anomaly), while years with rainfall below the long-term mean are classified as dry years (negative anomaly).

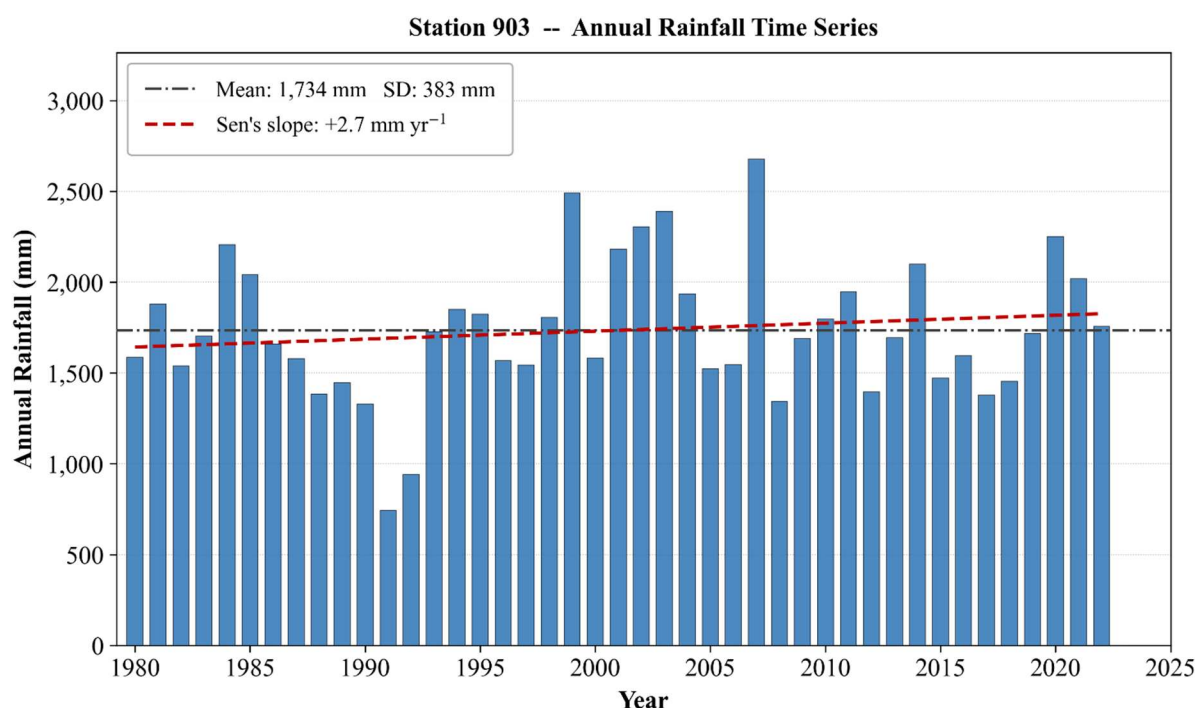


Figure 3.6: Annual rainfall time series with long-term trends for station 903.

Several consistent patterns emerge across the province:

- The early 1990s (particularly 1991–1992) were a widespread dry period across virtually all stations, with negative anomalies exceeding 40–50% of the long-term mean at several locations. Station 903 (Jhuwani) recorded only 742 mm in 1991, compared to its long-term mean of 1,734 mm.
- The late 1990s to early 2000s were generally wet, with 1999 and 2001–2003 showing strong positive anomalies at most stations. At Station 903, 1999 recorded 2,490 mm versus the long-term mean of 1,734 mm (+44%).
- The 2010s exhibited mixed conditions, with alternating wet and dry years across the province, suggesting increased inter-annual variability potentially linked to large-scale circulation patterns such as ENSO.

The Standardized Precipitation Index at 12-month accumulation (SPI-12) (see [Figure 3.7](#), [Table 3-10](#)) provides a standardized measure of wet and dry episode severity.

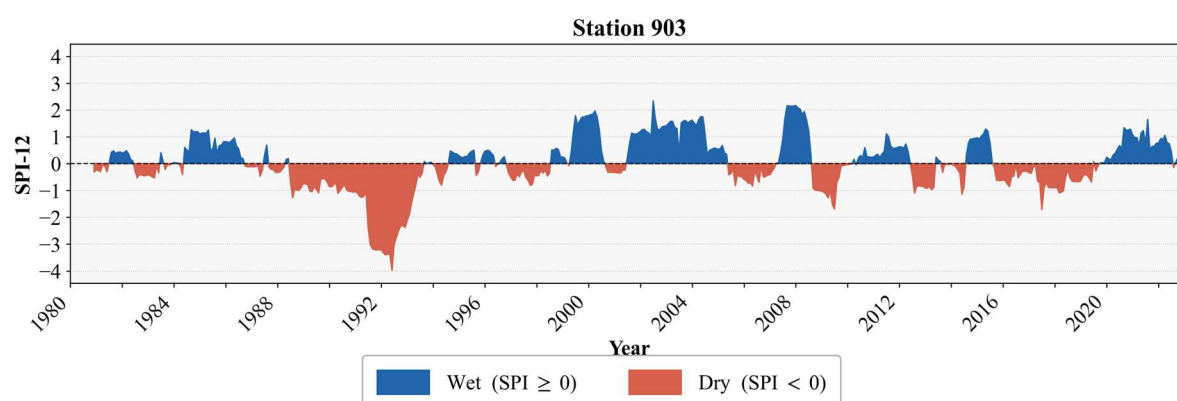


Figure 3.7: SPI-12 time series for Station 903 (Jhuwani) illustrating wet episodes (blue bars, $SPI \geq 0$) and dry episodes (red bars, $SPI < 0$).

Table 3-10: SPI-12 drought characterization summary for selected stations

Station	Name	Months	Extreme Dry (≤ -2.0)	Severe Dry (-2 to -1.5)	Moderate Dry (-1.5 to -1.0)	Min SPI	Max SPI
903	Jhuwani	505	19	5	27	-3.98	2.34
915	Markhu Gaun	505	7	21	56	-2.47	2.62
919	Makwanpur Gadhi	505	24	18	32	-2.68	2.00
1006	Gumthang	505	31	9	41	-3.18	1.96
1017	Duwachaur	505	24	13	29	-4.08	1.46
1023	Dolal Ghat	505	11	23	60	-2.78	2.65
1035	Sankhu	505	23	10	56	-3.11	2.03
1054	Thamachit	505	0	2	114	-1.74	2.21
1057	Pansayakhola	505	22	23	31	-2.81	2.22
1079	Nagarjun	289	8	15	22	-2.44	2.40
1080	Tikathali	265	11	12	9	-2.30	2.62
1103	Jiri	505	16	26	35	-3.01	2.23
1108	Bahun Tilpung	505	7	14	72	-2.57	2.35
1115	Nepalthok	505	11	29	30	-3.08	2.67
1117	Hariharpur Gadhi Valley	505	3	22	60	-2.19	2.58

The SPI-12 analysis reveals that Station 1017 (Duwachaur) experienced the most extreme drought conditions, with a minimum SPI of -4.08 , indicating exceptional dryness exceeding 4 standard deviations below the long-term mean. Station 1006 (Gumthang) recorded the highest number of extreme dry months (31 months with $SPI \leq -2.0$), while Station 1054 (Thamachit) in the High Himalayan zone showed no months of extreme dryness and the highest frequency of moderate dryness (114 months), consistent with its persistently low and variable rainfall regime.

(d) Seasonal distribution of rainfall

Rainfall in Bagmati Province is highly seasonal, driven by the South Asian Monsoon system. Four seasons were defined for analysis: Pre-monsoon (March–May, MAM), Monsoon (June–September, JJAS), Post-monsoon (October–November, ON), and Winter (December–February, DJF). Table 3-11 below presents the long-term seasonal mean rainfall and percentage contribution of each season to the total annual rainfall for all 15 stations.



Table 3-11: Long-term seasonal mean rainfall (mm) and % contribution to annual total

Stn	Station	Pre-mon (mm)	Pre-mon (%)	Monsoon (mm)	Monsoon (%)	Post-mon (mm)	Post-mon (%)	Winter (mm)	Winter (%)
903	Jhuwani	202.3	11.6	1432.1	82.4	52.6	3.0	48.3	2.8
915	Markhu Gaun	177.1	14.7	942.6	78.0	36.4	3.0	49.0	4.1
919	Makwanpur Gadhi	149.0	8.0	1609.2	85.8	60.4	3.2	34.2	1.8
1006	Gumthang	305.8	9.3	2805.4	85.6	135.6	4.1	34.6	1.1
1017	Duwachaur	214.9	10.3	1779.0	85.0	58.8	2.8	46.2	2.2
1023	Dolal Ghat	155.6	14.7	818.4	77.4	46.0	4.3	34.7	3.3
1035	Sankhu	172.2	10.2	1450.3	85.8	40.7	2.4	31.8	1.9
1054	Thamachit	54.8	7.5	665.3	90.6	18.4	2.5	25.1	3.4
1057	Pansayakhola	209.7	7.7	2431.2	88.9	45.1	1.6	50.0	1.8
1079	Nagarjun	184.0	12.0	1277.4	83.1	43.6	2.8	40.9	2.7
1080	Tikathali	192.3	16.8	887.5	77.7	29.5	2.6	39.2	3.4
1103	Jiri	258.6	11.9	1813.9	83.2	62.1	2.9	41.9	1.9
1108	Bahun Tilpung	201.4	13.3	1206.7	79.9	62.7	4.2	30.5	2.0
1115	Nepalthok	93.4	13.8	521.6	76.8	27.4	4.0	33.9	5.0
1117	Hariharpur Gadhi Valley	154.2	8.2	1636.3	87.2	50.7	2.7	29.0	1.6

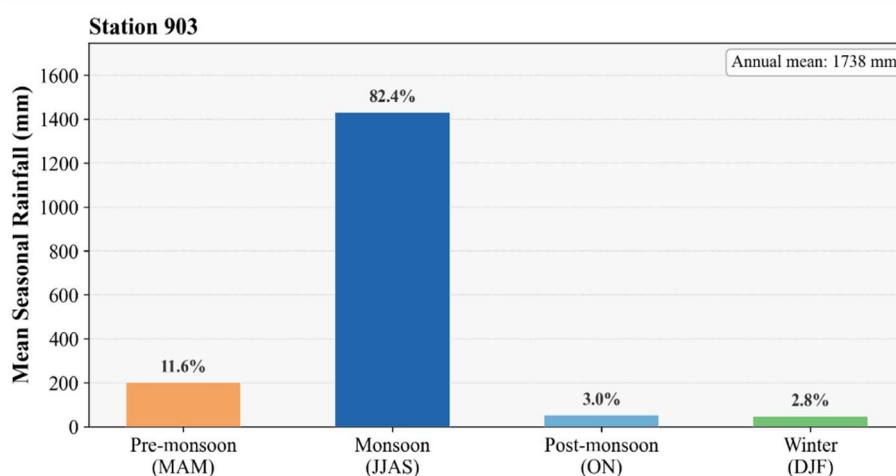


Figure 3.8: Seasonal rainfall distribution (% contribution of Pre-monsoon, Monsoon, Post-monsoon, and Winter seasons to long-term mean annual total) for station 903

The monsoon season (JJAS) overwhelmingly dominates the annual rainfall across all stations in Bagmati Province. The monsoon contribution ranges from 76.8% at Station 1115 (Nepalthok) to 90.6% at Station 1054 (Thamachit), with a provincial average of approximately 83-85%. The pre-monsoon season contributes 7.5-16.8% of annual rainfall, with the highest relative contribution at Station 1080 (Tikathali, 16.8%) and Station 1023 (Dolal Ghat, 14.7%). Post-monsoon (ON) and winter (DJF) seasons together account for only 5-9% of annual rainfall.

An important physiographic pattern emerges in the pre-monsoon contribution: stations in the high-elevation zones (particularly 1054 Thamachit at 7.5%) show lower relative pre-monsoon contributions than Middle Hills stations, reflecting the stronger influence of convective thunderstorms and orographic lifting on pre-monsoon rainfall in the lower-elevation Siwalik and



Middle Hills zones. The high winter contributions at stations 1023 (Dolal Ghat, 3.3%) and 1115 (Nepalthok, 5.0%) reflect their exposure to westerly disturbances that bring winter precipitation to the northern reaches of the province.

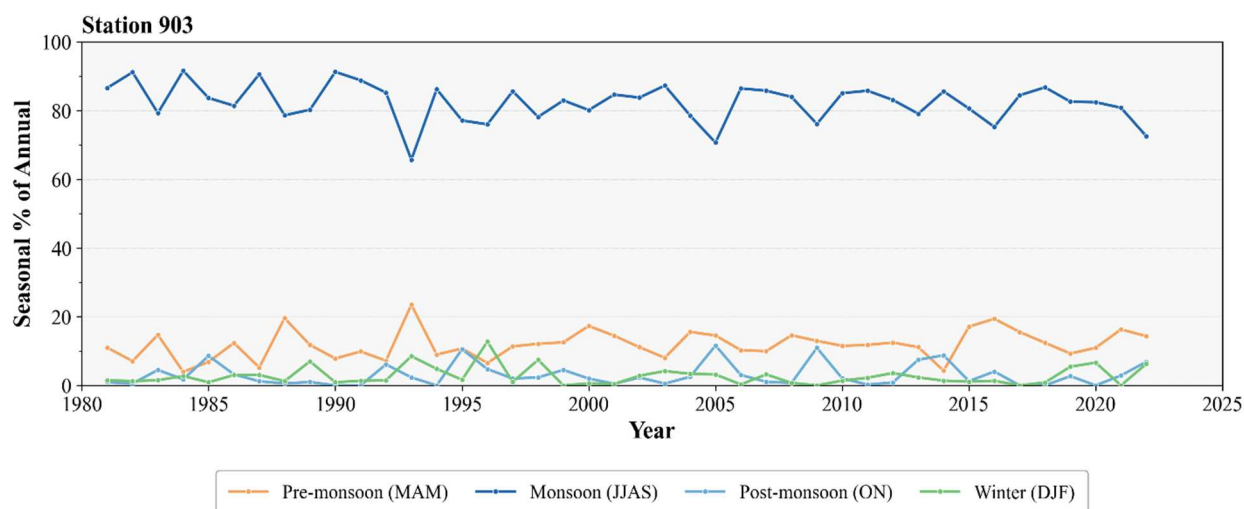


Figure 3.9: Year-by-year seasonal rainfall time series for station 903, showing inter-annual variability in Pre-monsoon, Monsoon, Post-monsoon, and Winter rainfall.

(e) Long-term trends in annual and seasonal rainfall

Long-term trends in annual and seasonal rainfall were assessed using both Ordinary Least Squares (OLS) linear regression and the non-parametric Mann-Kendall (MK) trend test with Sen's slope estimator (Table 3-12). The Mann-Kendall test is preferred for hydrometeorological data as it is robust to non-normality and the presence of outliers. Significance levels are reported as: *** ($p < 0.001$), ** ($p < 0.01$), * ($p < 0.05$), and ns (not significant at the 5% level).

Annual trend analysis reveals a mixed picture across the province. Of the 15 stations analyzed, statistically significant trends were detected at 4 stations:

- Station 1017 (Duwachaur): A highly significant decreasing trend ($p = 0.001$, MK) with a Sen slope of -14.4 mm/year, implying a total reduction of approximately 620 mm over the 43-year record. This is the most robust negative trend in the dataset and has significant implications for the Kathmandu Valley water supply and urban hydrology.
- Station 1103 (Jiri): A statistically significant increasing trend ($p = 0.0003$, MK) with Sen slope of $+10.2$ mm/year, indicating approximately 438 mm increase in annual rainfall over the 43-year period.
- Station 1079 (Nagarjun): A significant increasing trend ($p = 0.047$, MK; Sen slope $+15.1$ mm/year), though based on a shorter record (25 years, 1998–2022).
- Station 1117 (Hariharpur Gadhi Valley): A marginally significant increasing trend ($p = 0.040$, MK; Sen slope $+7.6$ mm/year).

The remaining 11 stations show no statistically significant trend in annual rainfall, though visual inspection of the time series suggests weak declining tendencies at several stations (1006, 1035, 1057, 1108) and weak increasing tendencies at the Terai/Siwalik stations. The absence of significance at these stations likely reflects high inter-annual variability, masking underlying directional shifts.



Table 3-12: Long-term annual rainfall trend statistics – Mann-Kendall test and Sen's Slope estimate

Stn	Station	N (yr)	LT Mean (mm)	OLS Slope (mm/yr)	Sen Slope (mm/yr)	p (MK)	Trend
903	Jhuwani	43	1734.2	4.374	2.654	0.5301	ns
915	Markhu Gaun	43	1204.3	-2.492	-2.283	0.4387	ns
919	Makwanpur Gadhi	43	1852.1	12.083	16.752	0.1214	ns
1006	Gumthang	43	3281.0	-15.545	-13.359	0.1873	ns
1017	Duwachaur	43	2097.8	-18.813	-14.409	0.0014	***
1023	Dolal Ghat	43	1054.0	-2.625	-2.205	0.2858	ns
1035	Sankhu	43	1694.3	-5.158	-6.073	0.2169	ns
1054	Thamachit	43	763.5	7.652	2.480	0.7695	ns
1057	Pansayakhola	43	2735.1	-4.658	-7.109	0.2858	ns
1079	Nagarjun	25	1545.1	13.629	15.052	0.0471	*
1080	Tikathali	23	1146.9	-14.682	-14.109	0.0813	ns
1103	Jiri	43	2176.1	8.993	10.213	<0.001	**
1108	Bahun Tilpung	43	1500.7	-7.043	-6.422	0.1070	ns
1115	Nepalthok	43	675.6	-1.374	0.005	1.0000	ns
1117	Hariharpur Gadhi Valley	43	1869.5	7.798	7.572	0.0402	*

Seasonal trend analysis indicates (Table 3-13) that the significant decreasing annual trend at Duwachaur (Station 1017) is driven primarily by a highly significant decline in Monsoon (JJAS) rainfall (Sen slope -13.7 mm/year, $p = 0.0002$), which has cumulatively reduced monsoon precipitation by an estimated 590 mm over the 43-year period (Figure 3.10). This is critical finding for water resources planning. In contrast, Station 1103 (Jiri) shows a significant monsoon increase ($+10.2$ mm/year), and Station 903 (Jhuwani) shows a significant increasing pre-monsoon trend ($+2.3$ mm/year, $p = 0.035$), suggesting that convective pre-monsoon activity may be intensifying in the lower Siwalik zone.

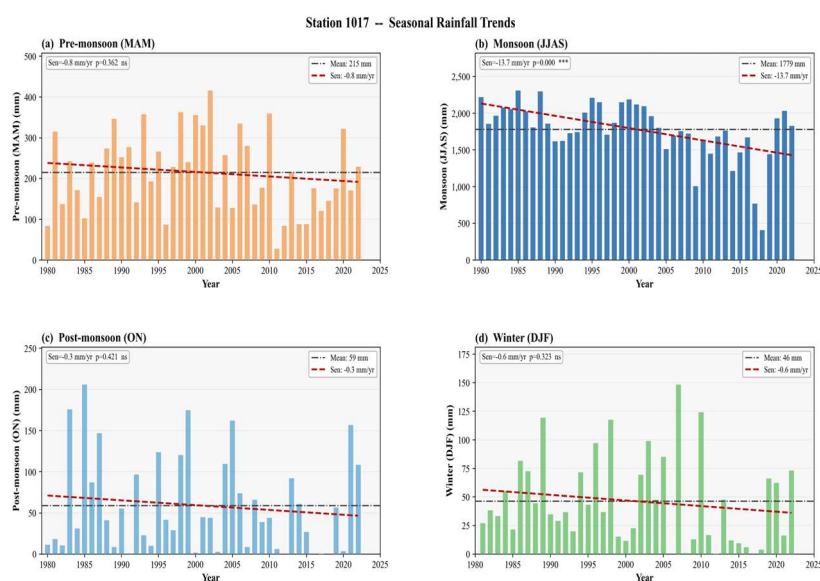


Figure 3.10: Seasonal rainfall trend plots for Station 1017 (Duwachaur). A highly significant decreasing trend is evident in Monsoon (JJAS) rainfall ($p < 0.001$, Mann-Kendall), which is the primary driver of the declining annual total at this station.



Table 3-13: Summary of statistically significant seasonal rainfall trends (Mann-Kendall, $p < 0.05$)

Stn	Station	Season	LT Mean (mm)	Sen Slope (mm/yr)	p (MK)	Sig
903	Jhuwani	Pre-monsoon (MAM)	202.2	2.287	0.0350	*
1017	Duwachaur	Monsoon (JJAS)	1779.0	-13.745	0.0002	***
1054	Thamachit	Winter (DJF)	25.1	0.434	0.0130	**
1103	Jiri	Monsoon (JJAS)	1813.9	10.199	0.0005	**
1117	Hariharpur Gadhi Valley	Monsoon (JJAS)	1636.3	7.731	0.0380	*

(f) Changes in monthly rainfall during the key monsoon months (May–October)

Monthly rainfall trends were analyzed for the six key monsoon and transition months (May, June, July, August, September, October) at all 15 stations over the full period of record. For each station and month, OLS regression and Mann-Kendall tests were applied, and the first-decade versus last-decade decadal means were compared to quantify the magnitude of change.

Table 3-14 below presents the statistically significant monthly trends ($p < 0.05$) identified across all stations. The per-month collage plots illustrate the temporal evolution of monthly rainfall at a sample station simultaneously, enabling cross-station comparison.

The monthly trend analysis reveals several important patterns:

- July and August rainfall at Duwachaur (Station 1017) has declined significantly, with Sen slopes of -6.1 mm/year (July) and -5.4 mm/year (August). This represents a cumulative reduction of approximately 263 mm in July and 233 mm in August rainfall since 1980 - a reduction of approximately 30–32% relative to the long-term monthly mean.
- Station 1006 (Gumthang) shows a significant July decline (-6.9 mm/year, -34.8%), the steepest proportional reduction among the high-rainfall High Mountains stations. In absolute terms, July rainfall at Jalbire has declined by approximately 320 mm since 1980.
- Station 915 (Markhu Gaun) shows a significant decline in September rainfall (-2.3 mm/year, -52% decadal change), suggesting a shortening or early withdrawal of the monsoon season at this location.
- Station 1103 (jiri) is the only station showing significant positive monthly trends - an increasing July ($+3.8$ mm/year) and September ($+2.2$ mm/year) - suggesting spatial redistribution of monsoon rainfall, with increases in the Sunkoshi watershed (eastern Bagmati Province) compensating for decreases in the Kathmandu Valley and upper Kulekhani basin.

Table 3-14: Statistically significant monthly rainfall trends (May–October), $p < 0.05$

Stn	Station	Month	LT Mean (mm)	Sen Slope (mm/yr)	Decadal Δ (%)	Sig
915	Markhu Gaun	Sep	161.9	-2.309	-52.1	*
1006	Gumthang	Jul	835.5	-6.946	-34.8	*
1017	Duwachaur	Jul	592.8	-6.149	-30.0	***
1017	Duwachaur	Aug	567.9	-5.429	-32.0	**
1080	Tikathali	Aug	264.9	-5.752	-24.6	*
1103	Jiri	Jul	601.6	3.839	14.2	*
1103	Jiri	Sep	305.0	2.221	24.9	*

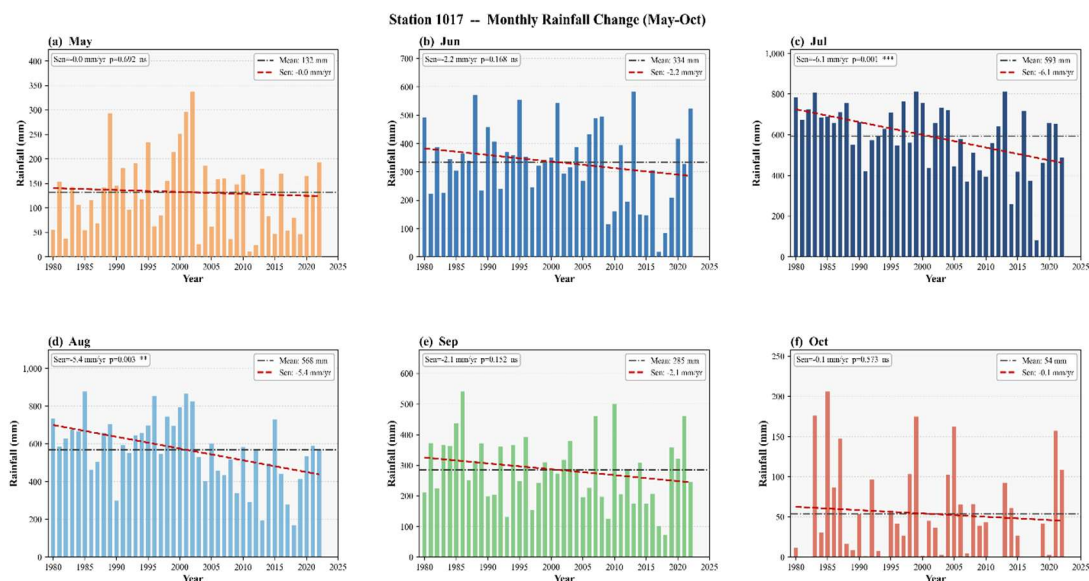


Figure 3.11: Monthly rainfall time series with trend lines for station 1017

(g) Spatial relationship between elevation and rainfall: Transect profile analysis

To examine the orographic influence on the spatial distribution of precipitation across Bagmati Province, elevation-rainfall transect profiles were constructed along a north-south cross-section traversing the full length of the province. Rainfall values used in the profiles represent long-term annual/seasonal averages derived by IDW interpolation (distance coefficient 1.5) from the 15 DHM station records analyzed in the preceding sections. The transect spans approximately 135 km from the southern provincial boundary to the northern limit, passing through all principal physiographic zones. The location of the cross-section line on the Bagmati Province is shown below.

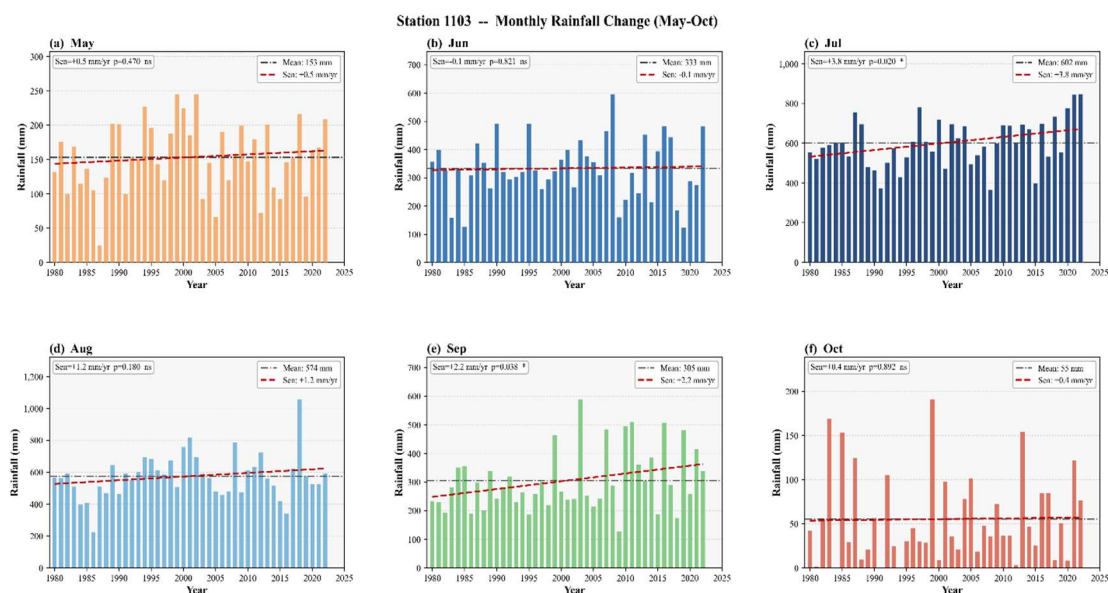


Figure 3.12: Monthly rainfall time series with trend lines for station 1103

Annual Rainfall Profile

The annual rainfall profile clearly demonstrates a non-monotonic relationship between elevation and precipitation along the transect. Annual rainfall is relatively moderate in the Siwalik zone (0 to approximately 20 km), in the range of approximately 1,500 mm, consistent with the station-based



long-term means of 1,734 to 1,869 mm recorded at Jhuwani, Makwanpur Gadhi, and Hariharpur Gadhi Valley. As the transect advances northward through the Middle Mountains (approximately 20 to 80 km), rainfall values show considerable spatial variability, ranging broadly between approximately 1,000 and 1,700 mm, reflecting the complex interaction of valley orientation, ridge geometry, and exposure to monsoon airflow that governs precipitation distribution across the Kathmandu Valley and its surrounding ridges. A localized secondary enhancement is apparent in the Sivapuri Nagarjun ridge zone (approximately 60 to 75 km), where windward slopes intercept moisture-laden airflow.

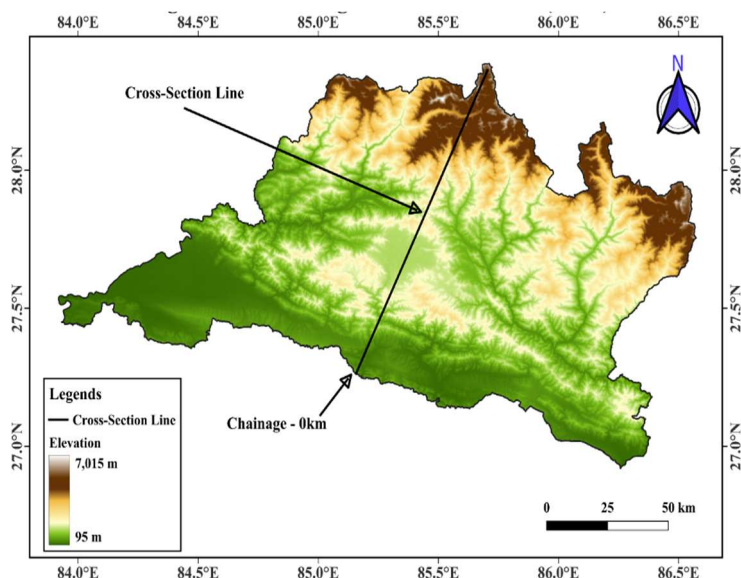


Figure 3.13: Bagmati province digital elevation model (DEM) showing the north-south cross-section line used for elevation-rainfall transect profiling. Chainage 0 km is at the southern end of the transect.

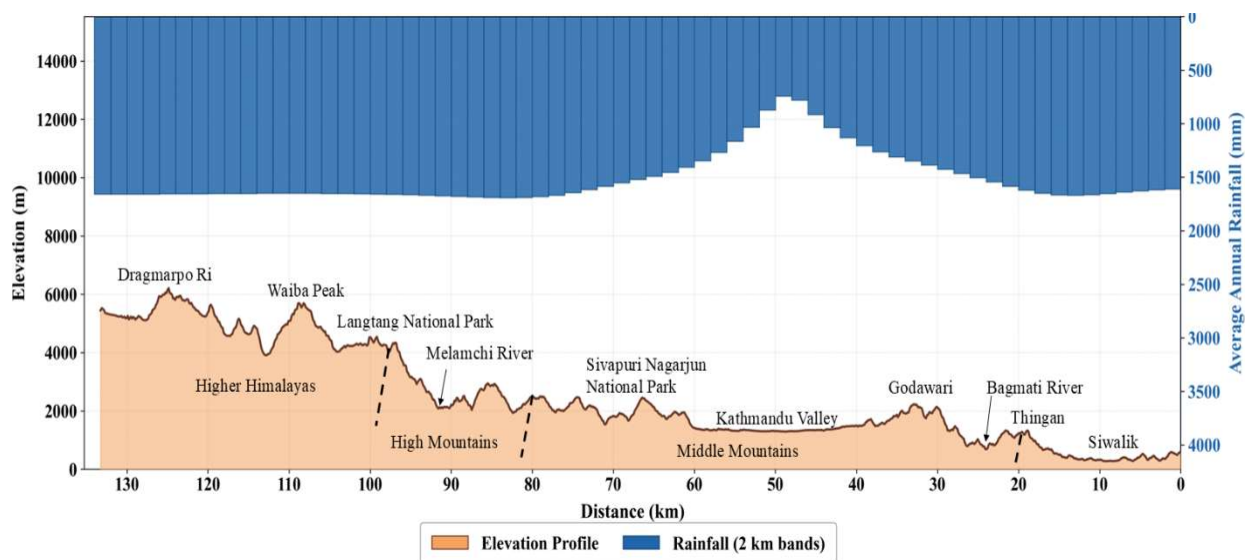


Figure 3.14: Elevation and average annual rainfall profile along the north-south transect, Bagmati Province. Blue bars represent long-term mean annual rainfall in 2 km bands (right axis, mm). Elevation profile shown in orange (left axis, m)

The most prominent feature of the annual profile is the marked rainfall maximum occurring in the High Mountains zone between approximately 80 and 100 km along the transect, where annual totals



reach approximately 2,700 to 3,300 mm. This is consistent with the station records at Gumthang (3,281 mm) and Pansayakhola (2,735 mm), which lie within this zone.

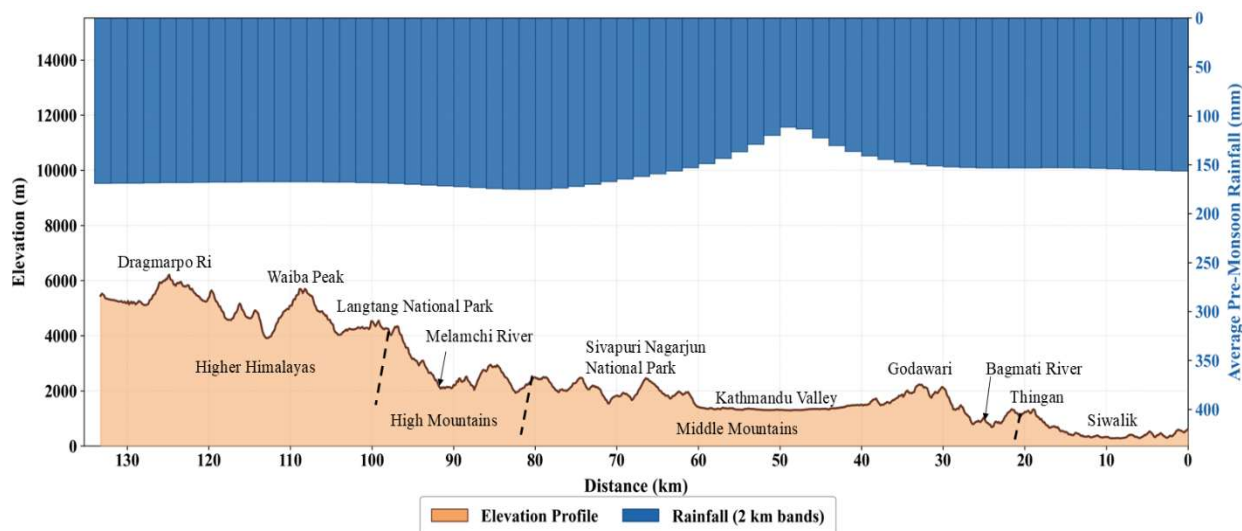


Figure 3.15: Elevation and average pre-monsoon (March-May) rainfall profile along the north-south transect, Bagmati Province

Pre-monsoon rainfall profile

The pre-monsoon profile is the most spatially uniform of all seasons. Rainfall totals are low throughout the entire transect, remaining broadly in the range of 130 to 170 mm with only modest variation from south to north. Unlike the monsoon and annual profiles, the pre-monsoon distribution does not exhibit a pronounced orographic maximum. A slight increase can be seen in the 80 to 100 km segment, but it is much less clear than in the monsoon profile.

This spatial uniformity reflects the different atmospheric dynamics governing pre-monsoon precipitation. During March to May, rainfall is generated primarily by convective thunderstorms and occasional western disturbance remnants rather than by sustained orographic uplift associated with the monsoon circulation. The absence of a strong elevation-dependent gradient confirms that the topographic barrier does not preferentially enhance pre-monsoon rainfall in the same manner as it does monsoon rainfall.

Monsoon rainfall profile

The monsoon seasonal profile (June to September) exhibits a spatial pattern that is closely analogous to the annual profile, confirming that the orographic control over provincial precipitation distribution operates almost entirely through monsoon-season dynamics. The monsoon accounts for 77 to 91% of annual totals at all stations, and this dominance is clearly expressed in the transect.

In the Siwalik zone (0 to approximately 20 km), monsoon totals are in the range of 1,300 to 1,500 mm, rising gradually through the Middle Mountains (approximately 1,000 to 1,600 mm depending on local exposure) and reaching a maximum in the High Mountains zone between 80 and 100 km. The shape of the rainfall peak in the monsoon profile is sharper and more spatially concentrated than in the annual profile, underscoring that it is during the monsoon that orographic enhancement is most effective. The Melamchi River corridor and the approaches to Langtang National Park (80 to 105 km) represent the zone of maximum orographic precipitation interception in the province.

A secondary but distinct rainfall enhancement is also visible in the Sivapuri Nagarjun ridge segment (approximately 60 to 75 km), where the ridge acts as a localized orographic barrier and generates a rainfall shadow on its lee side, contributing to the relatively lower monsoon totals observed at



Kathmandu Valley floor stations compared to surrounding ridge stations. The asymmetry in monsoon rainfall across the Kathmandu Valley, visible in the profile as a mid-transect undulation, has direct implications for the spatial distribution of surface runoff and slope instability within and around the valley.

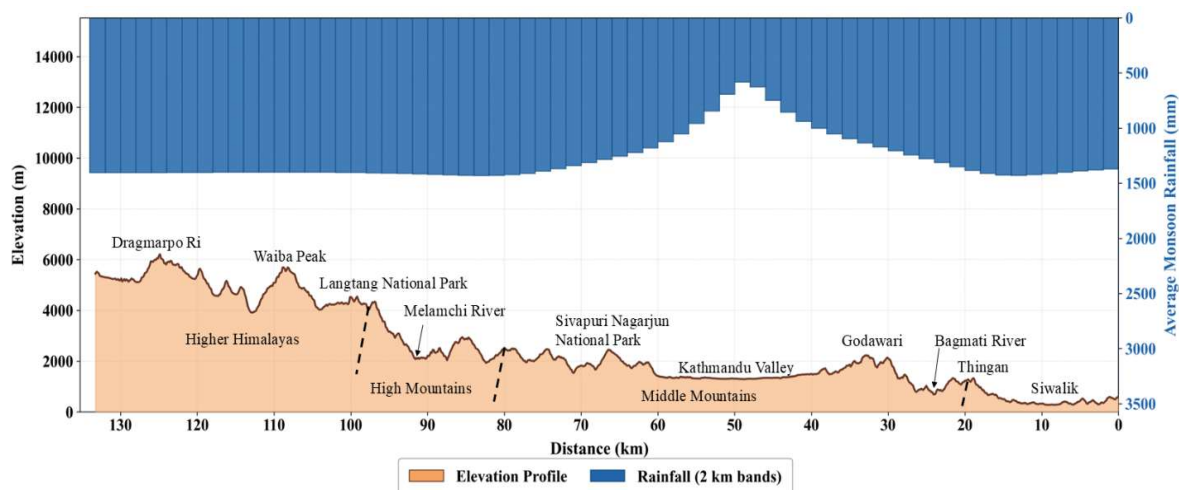


Figure 3.16: Elevation and average monsoon (June-September) rainfall profile along the north-south transect, Bagmati Province.

Post-monsoon rainfall profile

Post-monsoon rainfall (October to November) is low in absolute magnitude throughout the transect, with totals generally in the range of 50 to 100 mm. However, the profile reveals a more structured orographic response than the pre-monsoon season. A noticeable rainfall peak is present in the 10 to 20 km segment of the transect, where post-monsoon totals rise to approximately 50 to 55 mm compared to 25 to 45 mm in the Middle Mountains zones.

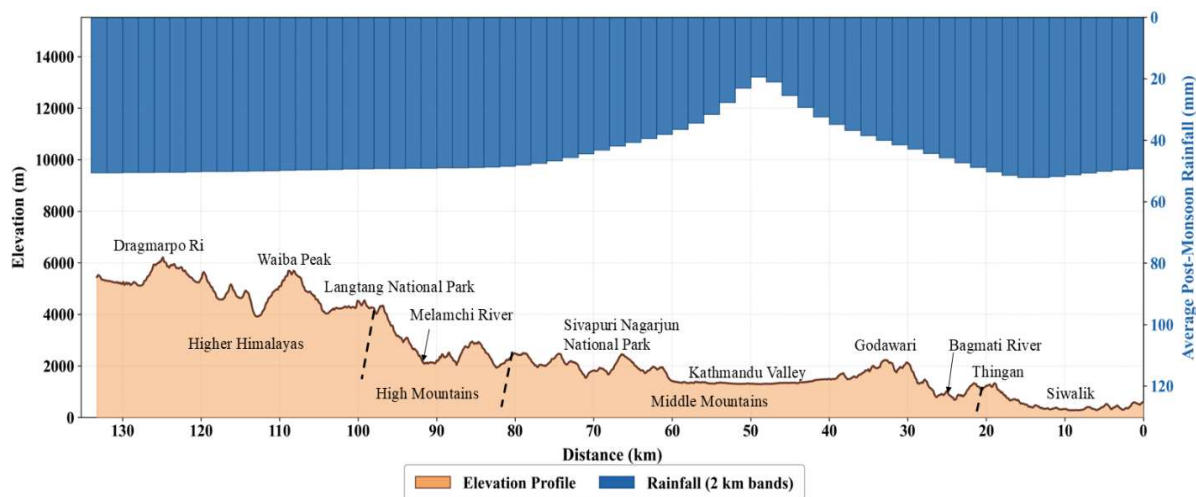


Figure 3.17: Elevation and average post-monsoon (October-November) rainfall profile along the north-south transect, Bagmati Province.

The post-monsoon profile is hydrologically significant beyond what the modest rainfall amounts suggest. Following the intense monsoon season, hillslope soils across the province are saturated or near-saturated, and groundwater tables remain elevated. Under these antecedent conditions, even moderate post-monsoon rainfall events are capable of sustaining elevated pore water pressures in hillslope materials, thereby extending the period of landslide susceptibility well into October and



November. The relatively higher post-monsoon totals in the High Mountains zone amplify this risk at the orographically exposed higher-elevation slopes where regolith cover tends to be shallower and drainage less effective.

Winter rainfall profile

In Winter season, the rainfall totals are minimal throughout the transect, ranging from approximately 30 to 55 mm with no pronounced spatial gradient or orographic peak. The profile is notably flat relative to all other seasons, with a slight relative increase visible in the 80 to 100 km zone that is considerably less distinct than in the monsoon or post-monsoon profiles.

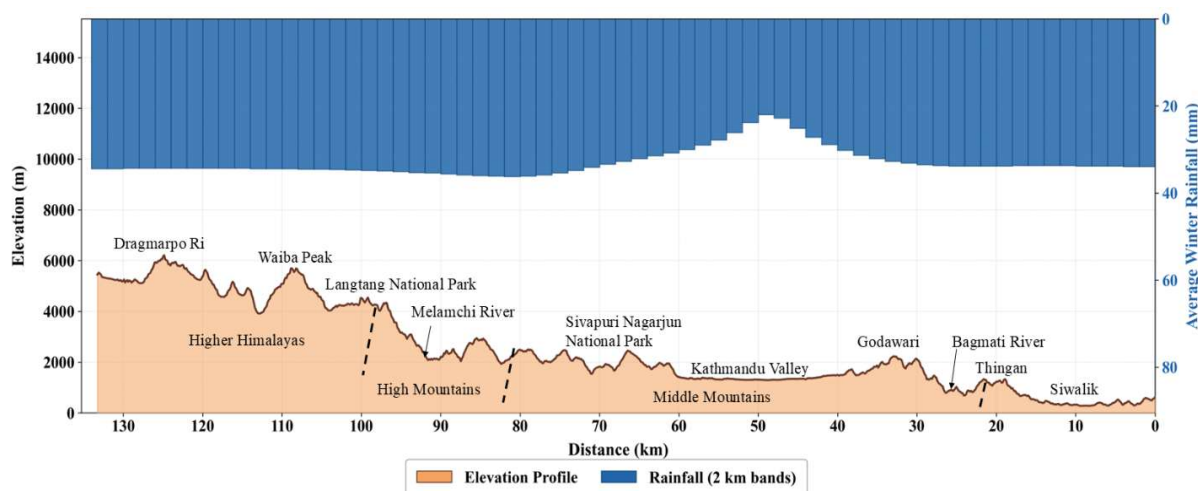


Figure 3.18: Elevation and average winter (December-February) rainfall profile along the north-south transect, Bagmati Province.

3.4 Summary of Key Findings

The rainfall pattern analysis of Bagmati Province based on 43 years of DHM data at 15 stations yields the following key findings:

1. Spatial variability is very high: mean annual rainfall ranges from 675 mm (Nepalthok, Middle Mountains) to 3,277 mm (Gumthang)
2. The monsoon season (JJAS) contributes 77–91% of annual rainfall at all stations, with the highest monsoon dominance at high-altitude stations (Thamachit 91%).
3. A statistically significant decreasing trend in annual rainfall was detected at Duwachaur (-14.4 mm/year, $p = 0.001$), driven by declining monsoon (JJAS) rainfall (-13.7 mm/year, $p = 0.0002$). This is the most critical hydrological trend in the province.
4. Significant increasing annual trends were detected at Station 1103 (Jiri, $+10.2$ mm/year), Station 1079 (Nagarjun, $+15.1$ mm/year), and Station 1117 (Hariharpur Gadhi Valley, $+7.6$ mm/year), suggesting spatial heterogeneity in long-term rainfall change.
5. Peak monsoon months (July, August) show significant decreasing trends at Duwachaur (-30% and -32% decadal change) and Gumthang (-35%), with compensating increases at Jiri.
6. September rainfall has declined significantly at Markhu Gaun (Station 915, -52% decadal change), suggesting a trend toward earlier monsoon withdrawal in parts of the province.



The SPI-12 analysis confirms recurrent drought episodes, most severely at Duwachaur (minimum SPI = -4.08) and Gumthang (31 months of extreme dryness), with the early 1990s and mid-2000s as the most widespread.

3.4.1 Rainfall threshold for landslide initiation

Minimum intensity or duration of rainfall necessary to cause mass movement in a slope is called as rainfall threshold. There is direct correlation of rainfall intensity and duration with incidence of landslides. As mentioned in [NRA and NDRRMA \(2021\)](#),

- A cumulative 1-day precipitation of 50-100 mm will result in a small-scale landslide.
- A cumulative 2-days precipitation of 150 mm and daily precipitation of 100 mm cause several landslides.
- A cumulative precipitation of more than 250 mm in 2 days causes a sharp increase in large landslides.

As per Dahal et al (2012), landslide triggering rainfall intensity (I)-duration (D) threshold for Nepal is

$$I = 73.90 D^{-0.79} \quad (\text{Eq 3-1})$$

Which indicates that,

- For rainfall events of shorter duration (e.g., < 10 hrs), a rainfall intensity of 12.0 mm/hr is necessary to trigger landslides
- If rainfall is continued for > 100 hrs, average rainfall intensity of < 2mm/hr could be sufficient to cause landslide

3.4.2 Surface and sub-surface runoff

A) Field Study

Field study for hydrological/drainage investigation is expected to gather following information;

- Water sources and their flow paths: map water sources (e.g. springs, streams) in the hill slope, measure discharge (m^3/s) of each source, and map their flow paths.
- Existing drainage systems: After observing topographical conditions, map existing and historical drainage systems, potential locations for main and tributary drainages, length of longest flow path (L), drainage area, maximum and minimum elevation differences, etc. L , drainage area, and elevation differences of longest flow path can also be calculated using GIS if we have digital elevation model (DEM).
- Signs of slope erosion and potential links with water: explore water flow through joints, seepage and its flow paths; carry out mapping of sheet/rills/gullies; explore whether slope failures are caused by excessive seepage problems; get ideas on depth and extent of groundwater table and its fluctuation; check for permeable layers of soil mass, springs and aquifers for the necessity of horizontal drilled drains.

B) Runoff Estimation:

Here are the steps for estimation of runoff from the slope surface

- Delineate catchment area (A) for each drain and compute design runoff based on rainfall intensity, catchment area, and surface characteristics.
- Use Rational Method to estimate peak runoff (for, $t \geq t_c$); $Q_p (\text{m}^3/\text{s}) = (1/3.6) * C * i * A$; where C is runoff coefficient, i is intensity of rainfall (mm/hr), A is catchment area (km^2)



- Runoff coefficient (C) has a value generally in a range of 0.7 – 0.8 for mountainous areas. Furthermore, based on data from Eastern Nepal value of C for different land use/cover types and slopes, as shown in [Table 3-15](#).

Table 3-15: Runoff coefficients for different land use/cover types and slopes

Predominant land use/cover type	Slope		
	Shallow (<25 °)	Mild (25 – 35 °)	Steep (> 35 °)
Agricultural terrace (large storage capacity)	0.5-0.6	0.6-0.7	-
Mixed terrace scrub and forest	0.6	0.7-0.8	0.9-0.95
Forest (usually steep rocky slopes, thin soils)	-	0.8-0.9	0.9-1.0

- For rainfall intensity (i), develop intensity-duration-frequency (IDF) curve (please refer [Figure 3.19](#), for a sample) by analysis of historical rainfall (hourly or daily rainfall) time series in that area, as continuous rainfall data are usually analyzed and presented in the form of IDF. 24-hours data that are usually available provides little indication of rainfall intensity or the duration-frequency characteristics of intense rain that are most important for hydraulic design. In the absence of sub-daily or hourly data, disaggregate 24-hr rainfall into sub-daily using Eq. 3-2 or 3-3.

[Shakya \(2002\)](#) model:

$$\frac{P_t}{P_{24}} = \left[\sin \left(\frac{\pi * t}{48} \right) \right]^{0.4727} \quad (\text{Eq. 3-2});$$

where, t is the duration [hrs];

P_t is the accumulated rainfall amount [mm] in t hours (T is taken as T_c);

P_{24} is the accumulated rainfall [mm] in 24 hours.

Monobe equation,

$$I_T \left(\frac{\text{mm}}{\text{hr}} \right) = \frac{P_{24}}{24} \left[\frac{24}{T_c} \right]^{\frac{2}{3}} \quad (\text{Eq. 3-3});$$

where, P_{24} is daily rainfall (mm),

I_T is mean rainfall intensity (mm/hr) in a period of time T_c .

T_c is time of concentration (hrs), which can be estimated using Kirpich Equation;

$$T_c = 0.01947 * L^{0.77} * S^{-0.385} \quad (\text{Eq. 3-4})$$

where, T_c is the time of concentration (in minutes);

L is the maximum length of travel of water or the longest flow path (in meters);

S is slope of the catchment = $\Delta H/L$, in which,

ΔH is the difference in elevation between the most remote point on the catchment and outlet.

In the absence of any continuous rainfall data, rainfall intensities corresponding to duration T_c (time of concentration) and the desired probability of exceedance P (i.e. return period, $T = 1/P$) can be calculated from rainfall-frequency-duration relationship for a given catchment;

$$i_{t_c, p} = \frac{K * T^x}{(t_c + a)^m} \quad (\text{Eq. 3-5});$$

where: K , a , x and m are constants. Values of those constants generally used in Nepal can be assumed same as in Northern India, and they are, $K = 5.92$, $x = 0.162$, $a = 0.5$, $n = 1.013$.

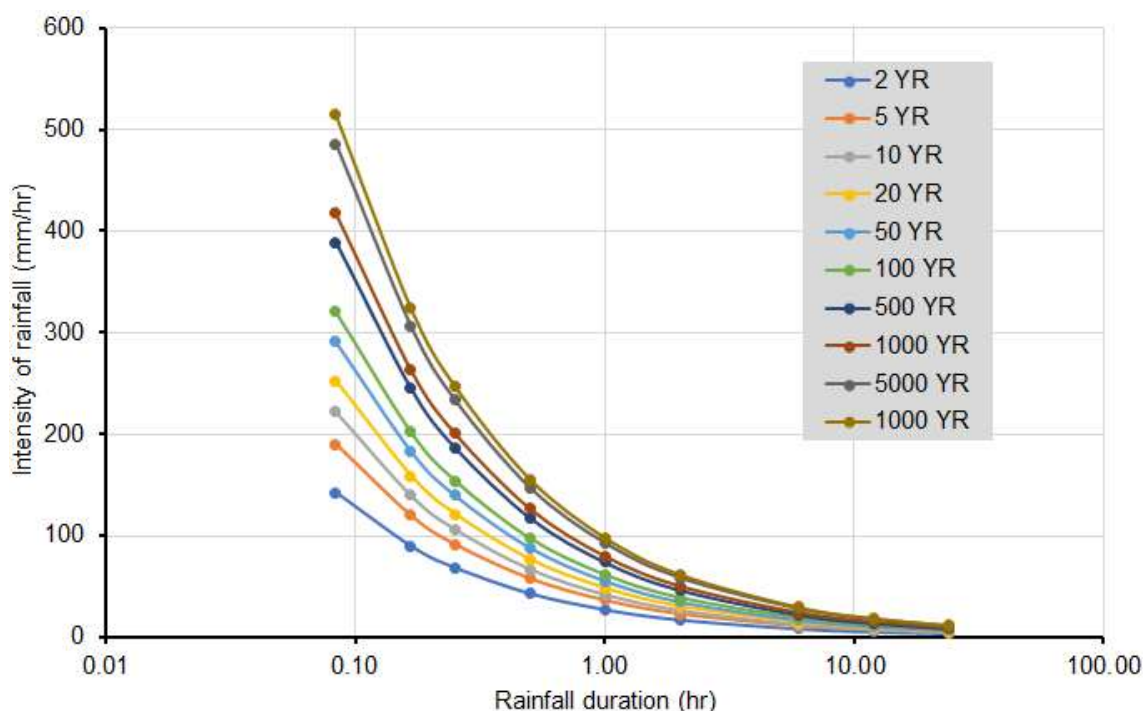


Figure 3.19: A sample of IDF (Intensity-Duration-Frequency) curve of precipitation. (Note: we can make a log-log plot as well, though this sample is semi-log plot)

- Steps for developing IDF curve, if maximum daily rainfall (P_{dmax}) time series (or 24-hr rainfall) is available;
 - Identify the most suitable rainfall station for the study area (e.g., nearby, similar elevation, considering rain shadow zone, if applicable)
 - Disaggregate 24-hr rainfall into different durations (e.g., 5 mins, 10 mins, 15 mins, 30 mins, 1 hr, 2 hr, 6 hr, 12 hr & 24 hr) using appropriate model (e.g. [Shakya, 2002](#)), as elaborated earlier.
 - Calculate frequency factor for different return period (K_T) using

$$K_T = -\frac{\sqrt{6}}{\pi} [0.5772 + \ln(\ln(\frac{T}{T-1}))] \quad (\text{Eq. 3-6})$$

- Calculate rainfall of return period T , P_T (mm) = $K_T + P_{mean} + K_T * SD$, where SD is standard deviation. Repeat this for rainfall of other durations (5 min – 24 hr)
- Calculate rainfall intensity (mm/hr) for each return period and each period (5 min – 24 hr) by dividing rainfall of T return period with duration (hrs).
- Based on data obtained above, plot IDF curve as shown in [Figure 3.19](#).



C) Hydrological Design:

Both hydrologic and hydraulic considerations are to be considered while designing structural measures for slope protection. Following are the aspects to be considered while performing hydrologic design of drainage structures;

- **Design life:** The concept of design life for a hydraulic structure in road-side is difficult to apply. However, 10-25 years can be considered as design life for side drains, culverts, and short-sections of road in flood-prone areas.
- **Risk:** Percentage risk of encountering an event within a particular design life (L) for different return periods (T) can be calculated using; $R = 100 (1 - (1 - 1/T))^L$.
- **Rainfall intensity:** it varies significantly throughout the duration of a storm, and between one catchment and the next. However, it can be estimated using approach described in the [Section 3.4.2](#).
- **Peak discharge (Q_p):** Q_p (m^3/s) is estimated as described in [Section 3.4.2](#)
- **Hydraulic design:** Culverts are typically designed 75-90% full under inlet control to cater for storms of between 10 and 20 years in recurrence interval.
- **Size of drains:** The sizing of drains is done as described in [Section 5.4](#). This cross-section area is increased by 20% (or multiplied by 1.2) to cater for reduction in cross-sectional areas due to soil sedimentation. Then defining certain breath or depth (depending upon site condition), we can define cross-section.

3.5 Soil Slope Investigation

- ✓ Distinguish between residual soil, colluvium, and alluvium
- ✓ Map colluvial deposits carefully: Colluvium is typically at residual strength and highly susceptible to failure on steep slopes or where groundwater is in the shallow depth
- ✓ Record soil depth and transition to bedrock

3.5.1 Field identification and characterization

Identification of soil types in the field which is typically limited to defining the **color** and estimating the basic characteristics of **texture** and **plasticity**, is normally done without the benefit of major equipment, supplies, or time. This method is very useful for the investigation of less important structure or an emergency mitigation work or the description of the soil during detailed investigation.

- I. **Texture:** Soil texture is identified by visual examination for coarse grained soil while sedimentation/dispersion test is required to identify the proportion of silt and clay ([Figure 3.20, a, b](#)).
- II. **Plasticity:** The ability to be molded within a certain range of moisture contents is termed plasticity. It depends on the percentage and type of clay component presence in the soil. Two tests related to plasticity are ribbon/tread test and dilatancy test ([Figure 3.20, c, d](#))
- III. **Dry Strength/Breaking:** The dry strength/breaking test is normally made on a dry pat of soil about 12.5mm and about 32mm in diameter that has been allowed to air dry completely. Attempts are made to break the pat between the thumb and fingers ([Figure 3.20, e](#)).
- IV. **Color:** The changes in colors can help determine the changes in mineral content of the soils, or indicate fluctuations in groundwater. Most soils fall into the gray to brown range with combinations quite common. Use combinations and hues to make the soil descriptions more exact, such as light gray, yellowish brown, or dark reddish-brown, and to help differentiate between strata.



3.5.2 Estimation of strength parameter

Shear strength of the soil is governing parameter for the stability of slope or load carrying capacity of a foundation. After soil identification, the generalized soil properties presented in Table 3-16 shall be used as the basis for design calculations covering bearing capacity, slope stability, and earth pressure.

Table 3-16: Shear strength parameters of different soil (*Durham/TU, 2025*)

S.N.	Soil Type	USCS	Defining Characteristics	c' kPa	ϕ°
1	Coarse-grained soil (CG)	GW, SW, GP, SP	More than 50% of particles larger than 0.074 mm (sand and gravel), with little or no fines	0-2	35-45
2	Coarse-grained soil with non-plastic fines (CGNPF)	SC, SM-SC, SM, GM	More than 50% of particles larger than 0.074 mm (sand and gravel) with non-plastic fines	2-6	29-40
3	Coarse-grained soil with plastic fines (CGPF)	GC, SC	More than 50% of particles larger than 0.074 mm (sand and gravel) with plastic fines	3-8	25-40
4	Silt	ML, MH	Fine-grained soil; feels smooth or silky to touch	3-17	20-32
5	Low Plasticity Clay (CL)	CL	Fine-grained soil; forms short ribbons in ribbon test	5-20	15-25
6	High Plasticity Clay (CH)	CH	Fine-grained soil; forms long, strong ribbons in ribbon test	10-40	5-20

Indian Standard Soil Classification System

Very coarse soils	Boulder size	> 300 mm
	Cobble size	80 - 300 mm
Coarse soils	Gravel size (G)	Coarse 20 - 80 mm
		Fine 4.75 - 20 mm
	Sand size (S)	Coarse 2 - 4.75 mm
		Medium 0.425 - 2 mm
Fine soils	Silt size (M)	0.002 - 0.075 mm
	Clay size (C)	< 0.002 mm



a. Visual Examination: The examination is done by spreading a sample on a flat surface, and then simply segregating it into its various components and estimating the relative percentage of each. The naked eye can distinguish the particle down to 0.075mm

b. Sedimentation Test: Soil sample and water is well mixed in a transparent jar and allow to settle. The gravel and coarse sand will settle almost immediately, the fine sand within about a minute, the silt requiring as much as about an hour, and the clay remaining in suspension indefinitely.

c. Ribbon/Thread Test: In the ribbon/thread test, a roll of soil moist enough to have workability, approximately 12.5 to 20 mm in diameter and about 50mm long, is pressed between the thumb and index finger into a ribbon and about 3mm thick. The longer the ribbon can be formed before the soil breaks under its own weight, the higher the soil's plasticity.

Plasticity	Length of Ribbon
Non Plastic	0 mm
Slightly Plastic → Plastic	0-25 mm
Plastic → Highly Plastic	25-50 mm
Highly Plastic	>50 mm

d. Shaking/Dilatency: A small part of moist soil, soft but not sticky, of about 5ml volume is prepared by adding water. The pat is placed on the palm and shaken horizontally striking against the other hand. If the water appears in the surface and changes to lively consistency and appears glossy. If the reaction on shaking is quick the soil is silt while the very slow to none the soil is clay

Key features of sedimentation test
The gravel and coarse sand will settle almost immediately
The fine sand will take 30 seconds to less than 5 minutes
The silt may require as much as about an hour
Clay shall remain suspended for several hours

e. Dry strength test

Plasticity	Resistance to breakage
Non Plastic	Little to no effort
Plastic	Medium effort
Highly Plastic	Great effort

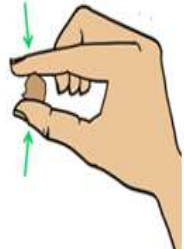


Figure 3.20: Field identification of soil



Table 3-17 Soil classification and its characteristics as construction materials

UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART			LABORATORY CLASSIFICATION CRITERIA	
COARSE-GRAINED SOILS (more than 50% of materials are larger than No. 200 Sieve size.)				
GRAVELS more than 50% of coarse fraction larger than No. 4 Sieve size.	Clean Gravels(Less than 5% fines)		GW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4, $C_c = \frac{D_{30}}{D_{10} \cdot D_{60}}$ between 1 and 3
		GW	Well graded gravels, gravel sand mixtures, little or no fines	
		GP	Poorly graded gravels, gravels sand mixtures, little or no fines	
	Gravels with fines(more than 12%)			
		GM	Silty gravels, gravels-sand-silt mixtures	
		GC	Clayed gravels, gravels-sand-silt mixtures	
SANDS 50% or more of coarse fraction smaller than No. 4 Sieve size.	Clean sands (less than 5% fines)		SW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4, $C_c = \frac{D_{30}}{D_{10} \cdot D_{60}}$ between 1 and 3
		SW	Well-graded sands, gravely sand, little or no fines	
		SP	Poorly graded sands, gravely sands, little or no fines	
	Sands with fines(more than 12%)			
		SM	Silty sands, sand-silt mixtures	
		SC	Clayed sands, sand-clay mixtures	
FINE-GRAINED SOILS (50% or more of materials is smaller than 200 sieve Size)				
SILTS AND CLAYS liquid limit less than 50 %		ML	Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity.	
		CL	Inorganic clay of low to medium plasticity, gravely clays, sandy clays, silty clays, lean clays.	
		OL	Organic silts and organic silty clays of low plasticity.	
SILTS AND CLAYS liquid limit 50 % or greater		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	
		CH	Inorganic clay of high plasticity, fat clays	
		OH	Organic clays of medium to high plasticity, organic silts	
HIGHLY ORGANIC SOILS		PT	Peats and other highly organic soils	

Determine percentage of sand and gravel from grain size curve. Depending on percentage of lines (fraction smaller than No. 200 Sieve size)-

Coarse grained soils are classified as follows:-

PLASTICITY

Once field identification and interpretation of soil characteristics, topography, vegetation, and hydrology are complete, any site can be assessed and appropriate mitigation measures recommended including the appropriate cut slope angle, as illustrated in [Figure 3.21](#).

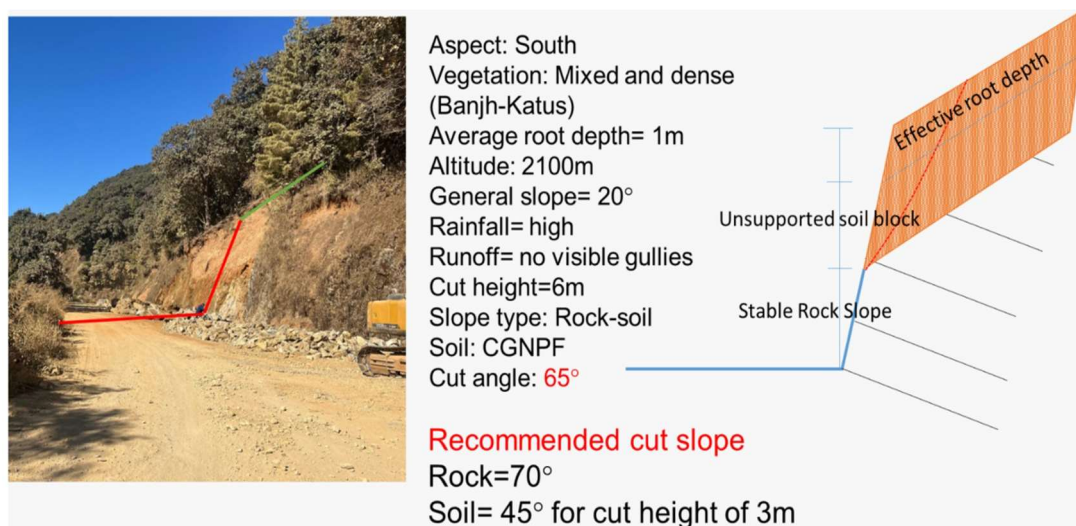


Figure 3.21: Site characterization of soil slope

3.5.3 Investigation of soil slope

Site exploration

Objective of Detailed Investigation

- ✓ Depth of bedrock depth
- ✓ Geotechnical characteristics of overlying materials: cohesion (c), friction angle (ϕ), density (ρ)
- ✓ Presence of weak or sensitive soil layers that may control the failure surface location
- ✓ Groundwater table depth and seasonal fluctuation
- ✓ Depth and configuration of existing or potential slip/shear surfaces
- ✓ Hydraulic conductivity and permeability of soil layers

Based on the type, extent and nature of project method of detailed exploration is selected for the evaluation of soil properties. For example, the structure like highway, airfield etc. direct exploration is best suited. Details of use, merits, demerits, equipment, manpower/expert required for different method is presented in

Table 3-18.

Table 3-18: Different methods of detailed investigation

Description	Direct	Semi-direct	Indirect
Principle	Physically excavate to expose and sample the ground in place	Advance a borehole to depth; recover samples and test in-situ	Measure physical property from the surface and infer stratigraphy
Typical methods	Trial pits, trenches, drifts, inspection shafts	Boring (auger, wash, percussion, rotary core); sampling (disturbed, undisturbed); in-situ tests (SPT, CPT, DCPT, vane)	Electrical resistivity tomography (ERT), seismic refraction tomography (SRT); also, Ground penetrating radar (GPR); penetration/sounding (Mackintosh probe, DCPT)



Description	Direct	Semi-direct	Indirect
Merits	Directly inspect the stratification and collect the samples.	Merits over accessible investigation is suitable for any depth	• Non-destructive • Fast and economical • Suitable for shallow depth (up to 30m) over large area. • Instrumentation is simple.
Demerits	• Depth of exploration is limited to 6m • Hard to excavate a trench in sandy soil. • Difficult to work when water table is presence in shallow depth	Unable to inspect the stratification and collect the samples.	• Tentative engineering and index properties are interpreted from data obtained from the test.
Use	This is very useful for shallow seated failure or medium size slope excavation.	This method is suitable for any problems requires large depth of exploration i.e. Deep seated and complex instabilities, large excavation (>10m in soil and >25m in rock)	• Estimating depth to bedrock and water table • Mapping and detecting geological features • Delineation of soil stratification
Manpower used	Exploration: Technician, helper Lab testing: Lab technicians, helper Data interpretation and analysis: Geotechnical Engineer	Exploration: Technician, Driller, helper Lab testing: Lab technicians, helper Data interpretation and analysis: Geotechnical Engineer	• Exploration: Technician, helper • Lab testing: Not required • Data interpretation and analysis: Geophysicist, Geotechnical Engineer
Equipment	• Digging equipment, block samplers, plastic bag • Laboratory testing equipment	• Drill rig, core box, undisturbed/disturbed samplers, • plastic bag • In-situ testing equipment • Laboratory testing equipment	• In-situ testing equipment
References and standard	IS 4453; BS 5930:2015; ASTM D420	IS 1892; IS 2131 (SPT); IS 4968 (DCPT); ASTM D1586, D2113, D1587, D5778; BS 5930:2015; EN 1997-2	ASTM D5777 (seismic refraction); ASTM D6431 (DC resistivity); ASTM D6432 (GPR); BS 5930:2015

Slope stability assessment

There are various approaches to slope stability analysis based on the mechanism of failure. If failure is translational, the slope is analyzed as an infinite slope. While most of the slope failures along the roadside are wedge failures. If the slope is homogeneous the failure surface will be circular and analyzed as a rotational failure. Analysis of different possible slope failures is presented hereunder (Figure 3.22).

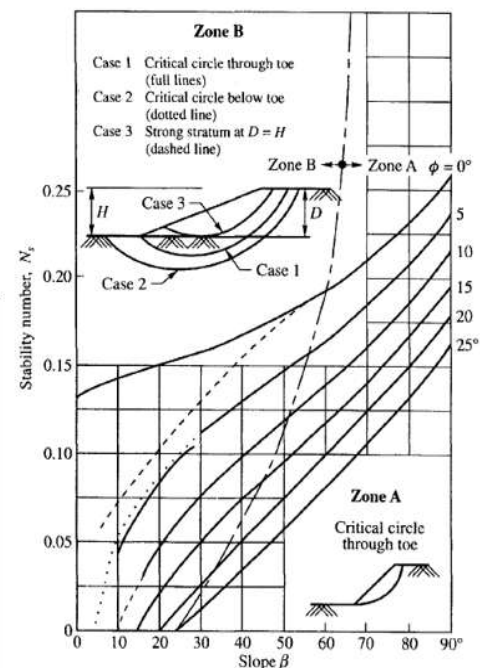
Infinite slope q= Surcharge per unit length	General equation for factor of safety $FS = \frac{\tan \phi'}{\tan \beta} \left(\frac{\frac{c'}{\cos^2 \beta \tan \phi'} + (q + \gamma H) + H_w(\gamma_{sat} + \gamma_w - \gamma)}{(q + \gamma H) + H_w(\gamma_{sat} - \gamma)} \right)$ Factor of safety for slope without surcharge Cohesionless soil $FS = \frac{\tan \phi'}{\tan \beta} \left(\frac{(q + \gamma H) + H_w(\gamma_{sat} + \gamma_w - \gamma)}{(q + \gamma H) + H_w(\gamma_{sat} - \gamma)} \right)$ Cohesionless, dry and without surcharge $FS = \frac{\tan \phi'}{\tan \beta}$
--	--

	Wedge failure $FS = \frac{cL + W(\cos \beta) \tan \phi'}{W \sin \beta}$ $W = \frac{d^2 \gamma (\tan \theta - \tan \beta)}{2 \tan \theta \tan \beta}$
--	--

Circular Failure

The factor of safety of any slope can be determined using Taylor stability chart. The factor of safety for cohesion is assumed and stability number is calculated using equation $S_N = \frac{c'}{F_c \gamma H}$.

Now, the same factor of safety is used to calculate the mobilized friction angle. The value of S_N and ϕ_m give the stable slope



Taylor's stability chart

Method of slices: Simplified Bishop Method

$$F_s = \frac{\sum \left[\frac{1}{m_a} (c'b + (W - ub) \tan \phi') \right]}{\sum W \sin \theta}$$

$$m_a = \left(1 + \frac{\tan \phi' \tan \theta}{F_s} \right) \cos \theta$$

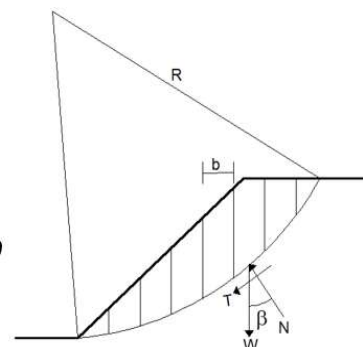


Figure 3.22 Different methods of slope stability analysis (NRA/NDRRMA, 2021)

3.5.4 Detailed analysis using software

There are two basic approaches to soil slope stability analysis with respect to mode of failure, they are:



- I. **Limit Equilibrium Analysis:** The limit equilibrium method of analysis is based on an assumed failure plane and the assumption that Coulomb's Failure Criterion is satisfied along the failure surface. Stress-strain relationships and in-situ stress are not considered, and the deformation cannot be predicted by this method. The shear strength parameters such as cohesion (c) and angle of friction (ϕ) used in most soil slope analysis is based on either total stress or effective stress.

For permanent roadside cuts and fills in Nepal, the governing case is the long-term, drained, effective-stress condition with the monsoon water table in place. Undrained (total-stress, $\phi = 0$) analysis applies only to short-term, end-of-construction conditions in low-permeability clays and must not be used as the design case for a monsoon slope.

- II. **Deformation analysis (using Finite Element or Finite Difference Method):** determination of safety factors for slopes is defined as proportion of soil shear strength to the minimum shear stress required for creating preliminary failure. In shear strength reduction method, soil shear strength is gradually decreased by applying finite element and finite difference programs as long as the first indications of failure appear. Safety factors are defined as the ratio of real shear strength of soil to reduced shear strength. To examine slopes stability through shear strength reduction method, modeling is carried out using a set of safety factors such as trial and error. In this method (SSR), slopes stability is defined using soil strength characteristics as follows:

$$C^{trial} = \frac{1}{FS^{trial}} C$$

$$\phi^{trial} = \arctan\left(\frac{1}{FS^{trial}} \tan \phi\right)$$

Where C^{trial} and ϕ^{trial} are soil reduced strength characteristics in proportion to the real value.

Key features of these methods are also presented in [Table 3-19](#).

Table 3-19 Comparison between limit equilibrium and deformation analysis ([NRA/NDRRMA, 2021](#))

Limit Equilibrium Analysis	Deformation Analysis
• Simplicity and accuracy • Must search for critical surface by using geometry • The method of slices is based purely on the principles of static equilibrium • It requires only a simple Mohr-Coulomb soil model • It cannot compute displacement • It cannot model progressive failure Software: Slide, Slope/W, Geo5 etc.	• Computer application is required • The critical surface is automatically found out by software • Better visualizes the deformation of soil in place • It must have complete stress-strain model for soil • It can compute displacement • It can model progressive failure Software: Phase2, Plaxis, abaqus, FLAC
 GeoStudio  GE05  Slide2	 RS2  PLAXIS CONNECT Edition  SIMULIA  FLAC

3.6 Vegetation and Slope Relationships



3.6.1 Vegetation distribution

Five primarysoilors govern the distribution of vegetation in Nepal and are directly relevant to bioengineering species selection: (i) altitude; (ii) aspect; (iii) rainfall and its seasonal distribution; (iv) geology and soil; and (v) land-use history and disturbance. Of these, altitude is the principal macro-scale control and forms the basis for Nepal's ecological zonation.

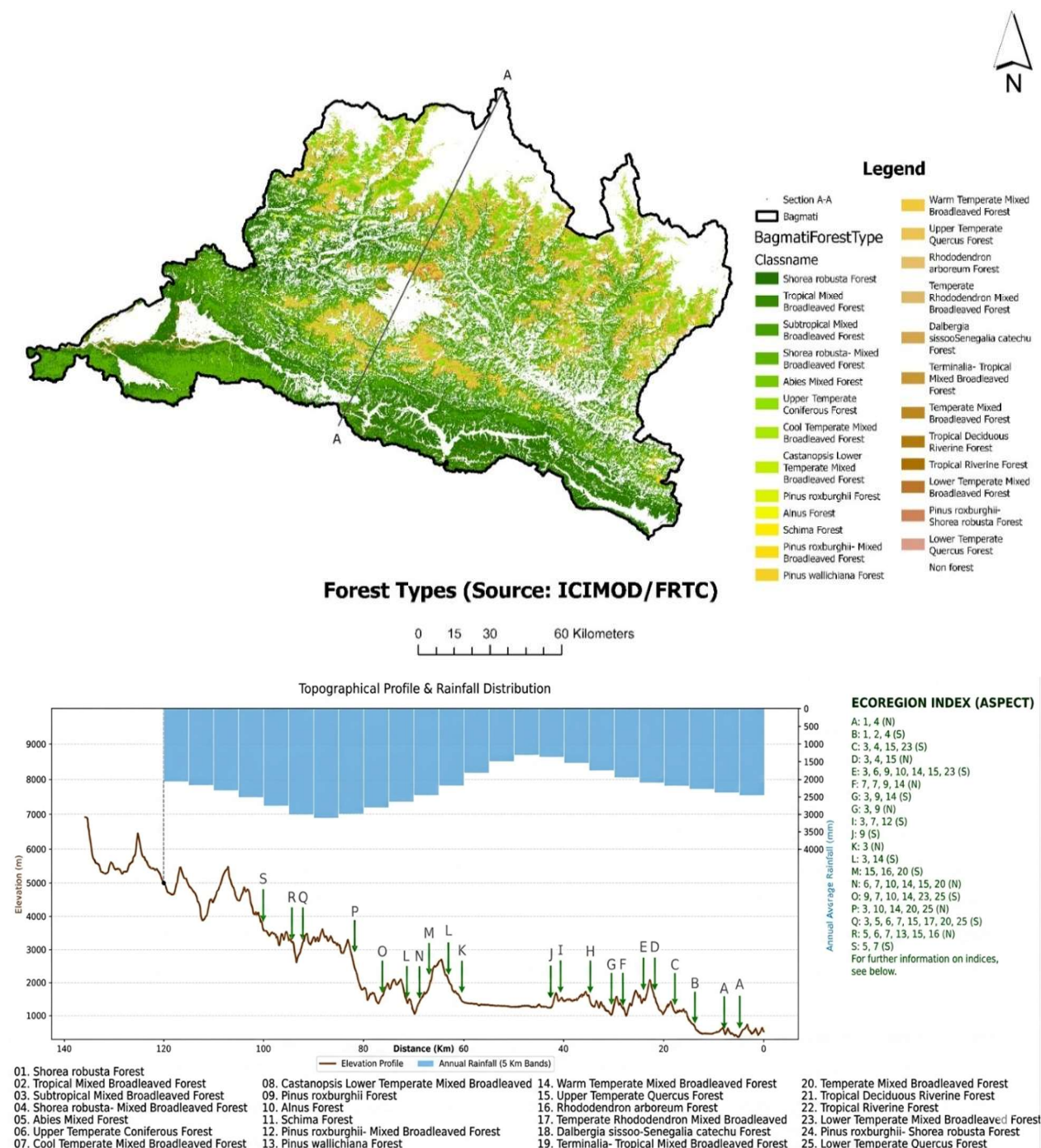


Figure 3.23: Vegetation distribution a) Bagmati province b) along the section A-A

Nepal's vegetation is organized into five altitudinal zones, each characterized by distinct forest communities. The **Tropical zone** (below 1,000 m) supports *sal* (*Shorea robusta*), *khayer-sisau* (*Acacia catechu-Dalbergia sissoo*) and *riverine forest* associations. The **Sub-tropical zone** (1,000–



2,000 m) is dominated by *khote salla* (*Pinus roxburghii*), *chilaune-katus* (*Schima wallichii*–*Castanopsis indica*) and *utis* (*Alnus nepalensis*). The **Lower Temperate zone** (2,000–2,700 m) transitions to *hasru* (*Quercus semecarpifolia*), *gobre salla* (*Pinus wallichiana*) and *banjh* (*Quercus spp.*), while the **Upper Temperate zone** (2,700–3,000 m) is characterized by *banjh-gurans* (*Rhododendron spp.*) and *coniferous forest*. Above 3,000 m, the **Sub-alpine zone** supports *gurans*, *gobre salla* and *dhupi* (*Juniperus spp.*). Although this classification is based primarily on altitude, the zone boundaries are not rigid (Figure 3.23 a). The distribution of species along a representative south–north transect, illustrating the combined influence of altitude, aspect and mean annual rainfall, is shown in Figure 3.21 (b) and provides a practical reference for bioengineering species selection at a given location.

Most roads in Bagmati Province passes through the tropical to lower temperate zones (approximately 200–2,500 m), where bioengineering species diversity is highest and field experience of successful establishment under monsoon conditions is most extensive. The detailed vegetation in each slope segment is presented in the **Annex**.

3.6.2 Basic site requirements for vegetation

Successful bioengineering depends on plants surviving, establishing root systems, and fulfilling their engineering function within the first one to two monsoon seasons. Four categories of physiological requirements must be assessed at every site (nutrients, light, air, and water) and evaluated against two site-specific conditions (soil physical properties and climatic parameters).

Key Point: A plant that cannot meet its basic physiological requirements will fail regardless of how well it is planted or maintained. Site assessment must precede species selection, not follow it.

Nutrients

Three main nutrients dominate plant physiology.

Nitrogen drives leaf growth and above-ground biomass.

Phosphorus is the most critically limiting nutrient on disturbed roadside slopes which promotes root elongation and early establishment.

Potassium regulates drought resistance, sugar storage, and stomatal function.

Secondary nutrients (S, Mg, Ca) and **micronutrients** (Fe, Mn, B, Cu, Zn, Mo) become limiting on cut faces where the organic topsoil horizon is absent.

Light

All plants require sunlight for photosynthesis to produce the carbohydrates needed for growth, root development, and establishment. On **steep south-facing slopes**, excessive solar radiation causes photo-inhibition stress; use sun-demanding pioneer grasses. In **deep north-facing cuts**, insufficient light suppresses pioneer grasses; use shade-tolerant colonizers such as *Alnus Nepalensis* to initiate canopy.

Air and Gas Exchange

Oxygen is required for root respiration; **carbon dioxide** is the raw material for photosynthesis. On compacted fill slopes and consolidated landslide debris, **soil aeration is the critical limiting factor**. Bulk density above ~1.6 g/cm³ restricts oxygen diffusion, impairs root growth, and reduces root reinforcement depth.

Water

Water is simultaneously the most critical establishment resource and in excess the primary slope-failure trigger. **Deficit kills newly planted material** during the pre-monsoon (March–May) before roots develop. **Waterlogging** saturates soil pores, excludes oxygen, and promotes root rot. Five soil moisture parameters (Table 3-20) must be understood correctly.



Table 3-20: Soil moisture parameters relevant to bioengineering site assessment

Parameter	Definition	Relevance to bioengineering
Field Capacity (FC)	Moisture remaining after free drainage under gravity ceases.	Upper limit of plant-available water; optimal planting moisture.
Permanent Wilting Point (PWP)	Moisture content at which plants cannot extract water and will not recover.	Lower threshold below which newly planted species die. Critical dry-season limit.
Available Water Capacity (AWC)	Difference between field capacity and permanent wilting point.	Determines drought tolerance window. Low AWC (stony/sandy soils) requires drought-tolerant species.
Profile Available Water (PAW)	AWC integrated over the full rooting depth of the soil profile.	Total water reserve between rainfall events; directly linked to soil depth.
Soil Moisture Deficit (SMD)	Cumulative reduction in soil moisture below field capacity when potential evapotranspiration exceeds rainfall.	Quantifies pre-monsoon drought stress. High SMD requires high Drought Factor class species. Key input to Section 3.6.3 .

Soil Physical Properties

Three properties determine root penetration, moisture retention, and reinforcement capacity.

Soil texture (particle size distribution) controls drainage, aeration, and surface erodibility.

Rooting potential governed by bulk density and mechanical strength which determines maximum root depth and reinforcement effectiveness; high compaction confines roots to the shallow zone where reinforcement is least effective against deep failure.

Soil structure (aggregate arrangement) is almost entirely absent on fresh cut and fill surfaces where organic matter has been stripped; pioneer nitrogen-fixing species and grasses must be used first to rebuild structure before long-term species can establish.

Climatic Parameters

Seven climatic parameters interact to govern growing season length, moisture stress, and plant vigour across the altitudinal and aspect range ([Table 3-21](#)).

Table 3-21: Climatic parameters affecting bioengineering species performance

Climate parameter	Effect on plant performance
Temperature	Controls metabolic rate, growing season length, and frost risk above 2,000 m.
Rainfall	Primary moisture source; controls soil moisture availability and SMD intensity.
Rainfall Season	80–90% falls June–September. Long dry pre-monsoon is principal establishment stress.
Altitude	Determines temperature regime, frost risk, and ecological zone.
Aspect	Controls solar radiation receipt, evapotranspiration demand, and drought intensity.
Evapotranspiration	Atmospheric drying demand. High PET on south-facing slopes drives high SMD.
Growing Season	Number of frost-free, moisture-sufficient months available for establishment.

3.6.3 Stoniness and drought factor

The Drought Factor scoring system ([DoR, 1999](#)) is the most practical field-applicable tool for vegetation site assessment in Nepal. It combines five site factors into a single composite score predicting site dryness and guiding species selection. [Figure 3.24](#) presents the scoring system.



Slope Angle degrees (°)		Stoniness % fines		Altitude (masl)		Annual Rainfall mm/year		Aspect slope orientation		Drought factor class		
> 49°	6	< 5	6	< 500	6	< 500 mm	6	S	12	Score	Class	Definition
45 – 49°	5	5 – 9	5	300 – 850	5	500 – 1000 mm	5	SE / SW	10	<6	I	Cool, moist sites
40 – 44°	4	10 – 14	4	1000 – 1500	4	1000 – 1500 mm	4	W	8	6-11	II	Damp sites
35 – 39°	3	15 – 19	3	1500 – 2000	3	1500 – 2000 mm	3	E	6	12-17	III	Moderately dry sites
30 – 34°	2	20 – 25	2	2000 – 2500	2	2000 – 2500 mm	2	NW	4	18-23	IV	Warm dry sites
< 30°	1	> 25	1	> 2500	1	≥ 2500 mm	1	NE	2	24-30	V	Very hot and dry
								N	0	>30	VI	Very severely hot and dry sites

Score interpretation—colour key:

Very low	Low	Moderate	Medium	High	Very high
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Light green = most favourable for bioengineering; Dark red = least favourable

Figure 3.24: Drought factor scoring system for vegetation site assessment on roadside slopes sum scores across five factors; Class I (Score <6) = Cool/Moist to Class VI (Score >30) = Very Severely Hot/Dry (Source: Howell, 1999)

Stoniness (% rock fragments in soil) deserves particular attention. Soils with <5% fines (essentially gravels or screes) have very limited available water and rooting space, scoring 6 for stoniness and receiving high drought factor scores even when other factors are favorable. Site preparation (importing fine soil amendment) or extremely deep-rooting pioneer species may be the only viable approaches for such sites.

3.7 Land-use, Settlements and Upstream-Downstream Considerations

Land use, settlements, and upstream–downstream conditions are important factors that directly influence the stability, safety, and long-term sustainability of roadside slopes in the Bagmati province. Changes in land use patterns, such as deforestation, agricultural activities, uncontrolled excavation, and urban expansion, can significantly alter natural drainage systems and weaken slope materials. Similarly, settlements and infrastructure located near unstable slopes increase the potential risk to human life, property, and essential services during slope failures. In addition, upstream water flow and downstream drainage conditions strongly affect erosion, groundwater infiltration, sediment transport, and slope instability. Therefore, these factors must be carefully evaluated during the preparation of road slope stabilization guidelines to ensure effective, environmentally sustainable, and socially responsible slope management practices.

What to do

- Document current and historical land use: forest, cultivated terraces, settlements, roads
- Identify uphill and downhill settlements and infrastructure at risk
- Assess irrigation practices: Leaking canals and flooded paddies are a major hidden trigger
- Consult local communities: They often have multi-generational knowledge of slope movements, spring locations, and past events
- Note presence of stressed or displaced structures (cracked buildings, walls, retaining structures): Reliable indicators of ground movement
- Identify barren slopes requiring revegetation
- Assess colluvial slope conditions (average slope angle, stone size, soil depth for bioengineering suitability)



CHAPTER 4. ENGINEERING MITIGATION STRUCTURES

Engineering mitigation structures are purpose-built interventions designed to arrest, prevent, or manage slope instability and erosion in roadside environments. In the Nepal Himalayan context, where road corridors traverse steep, geologically complex terrain subjected to intense monsoon rainfall and episodic seismic loading, engineering structures frequently form the primary and non-negotiable component of an integrated slope management system at high-risk locations where drainage and bioengineering measures alone are insufficient. This chapter covers surface protection, cut slope design, retaining /supporting structures, soil reinforcement, spoil management and temporary works for construction safety.

Main Category	Category / Group	Subcategory	Countermeasure Works
CONTROL MEASURES	Earthwork	Earthwork	Removal of Top
			Rock Cutting
			Soil Cutting
			Filling at Toe
	Bio-engineering	Vegetation	Re-Vegetation
			Vegetative Structure
	Water Management	Surface Drainage	Drain Ditch
			Cascade
			Culverts
		Subsurface Drainage	Horizontal Drill Hole Drain
RESTRAINT MEASURES	Slope Work	Shotcrete Work	Sub-surface Drains
			Shotcrete (mortar)
			Shotcrete (concrete)
	Slope Work	Frame Work	Frame work (Precast or in-situ)
		Pitching	Stone Pitching
	Anchoring	Anchoring	Soil Nail
			Rock Bolt
			Ground Anchor
	Wall and Resisting Structures	Retaining Wall	Stone Masonry Wall
			Composite Wall
			Frame Wall
			Gabion Wall
			Crib Wall
			Gabion Wall
	Protection Work	Catch Wall	Concrete Wall
			Rock Netting
			Check Dam (Sabo Dam)
	Pile Work	Protection Work	Check Dam
			Steel Pipe Pile
			Steel Pile (H section)
ALT. WORK	Realignment of Road		Diversion, Bridge and/or Tunnel
			Route Relocation

presents different types of slope stabilization and landslide mitigation measures used in road engineering. These countermeasures are classified into three main categories: Control Measures, Restraint Measures, and Alternative Works (Table 4-1).



Table 4-1: Types of slope stabilization measures

Main Category	Category / Group	Subcategory	Countermeasure Works
CONTROL MEASURES	Earthwork	Earthwork	Removal of Top
			Rock Cutting
			Soil Cutting
			Filling at Toe
	Bio-engineering	Vegetation	Re-Vegetation
			Vegetative Structure
	Water Management	Surface Drainage	Drain Ditch
			Cascade
			Culverts
		Subsurface Drainage	Horizontal Drill Hole Drain
Sub-surface Drains			
RESTRAINT MEASURES	Slope Work	Shotcrete Work	Shotcrete (mortar)
			Shotcrete (concrete)
		Frame Work	Frame work (Precast or in-situ)
		Pitching	Stone Pitching
	Anchoring	Anchoring	Soil Nail
			Rock Bolt
			Ground Anchor
	Wall and Resisting Structures	Retaining Wall	Stone Masonry Wall
			Composite Wall
			Frame Wall
			Gabion Wall
			Crib Wall
			Gabion Wall
			Concrete Wall
	Protection Work	Protection Work	Rock Netting
		Check Dam	Check Dam (Sabo Dam)
	Pile Work	Pile Work	Steel Pipe Pile
Steel Pile (H section)			
ALT. WORK	Realignment of Road		Diversion, Bridge and/or Tunnel
			Route Relocation



Main Category	Category / Group	Subcategory	Countermeasure Works
CONTROL MEASURES	Earthwork	Earthwork	Removal of Top
			Rock Cutting
			Soil Cutting
			Filling at Toe
	Bio-engineering	Vegetation	Re-Vegetation
			Vegetative Structure
	Water Management	Surface Drainage	Drain Ditch
			Cascade
			Culverts
		Subsurface Drainage	Horizontal Drill Hole Drain
Sub-surface Drains			
RESTRAINT MEASURES	Slope Work	Shotcrete Work	Shotcrete (mortar)
			Shotcrete (concrete)
		Frame Work	Frame work (Precast or in-situ)
		Pitching	Stone Pitching
	Anchoring	Anchoring	Soil Nail
			Rock Bolt
			Ground Anchor
	Wall and Resisting Structures	Retaining Wall	Stone Masonry Wall
			Composite Wall
			Frame Wall
			Gabion Wall
			Crib Wall
			Gabion Wall
			Concrete Wall
		Protection Work	Protection Work
	Check Dam		Check Dam (Sabo Dam)
	Pile Work	Pile Work	Steel Pipe Pile
			Steel Pile (H section)
ALT. WORK	Realignment of Road		Diversion, Bridge and/or Tunnel
			Route Relocation

Control measures are preventive methods used to reduce the causes of slope instability before failure occurs. These include earthwork activities such as rock cutting, soil cutting, and toe filling to improve slope geometry and stability. Bio-engineering methods like re-vegetation and vegetative structures help control erosion naturally. Water management systems such as drain ditches, cascades, culverts, and subsurface drains are used to safely remove surface and groundwater, which is one of the major causes of landslides.

Restraint measures are structural techniques used to resist or control slope movement in unstable areas. These include slope protection works such as shotcrete, frame works, and stone pitching. Anchoring systems like soil nails, rock bolts, and ground anchors strengthen the slope internally. Retaining and resisting structures such as stone masonry walls, gabion walls, crib walls, composite walls, and concrete walls provide support against earth pressure. Additional protection works like rock netting and check dams protect roads from falling rocks and debris flow. Pile systems such as steel pipe piles and H-section piles are used for deep-seated slope failures.

Alternative works are adopted when slope stabilization is difficult or uneconomical. In such cases, the road alignment may be changed through road realignment, route relocation, diversion,



4.1 Generalized Countermeasures

Figure 4.1 presents a generalized matrix for the selection of slope stabilization and landslide mitigation countermeasures based on different types of slope failure mechanisms. This matrix was revised and updated by our team based on the newly developed methodology adopted in this study. The updated framework improves the classification and applicability of countermeasures according to field conditions, slope behaviour, and failure mechanisms observed in roadside environments. The revision was carried out to make the countermeasure selection process more practical, systematic, and suitable for local geological and topographical conditions. The countermeasures are grouped into seven generalized approaches:

A. Problem Avoidance: These methods avoid unstable areas instead of directly stabilizing them. Measures such as removal of unstable material and road realignment are included in this category. They are mainly suitable for highly hazardous and difficult-to-stabilize slopes.

B. Reduction of Driving Force: These measures reduce the forces responsible for slope failure. Earthwork operations and drainage systems help reduce slope weight, infiltration, seepage pressure, and surface runoff, which are major triggering factors for landslides.

A. Problem Avoidance	B. Reduction of Driving Force	C. Increase of Internal Strength	D. External Restraint	E. Slope Protection	F. Debris Control	G. Bank Protection	General Options / Solution	Earth Fall	Rock Fall / Topples	Rock Slide	Debris Slide	Soil Slide (Rotational)	Soil Slide (Translational)	Debris Flow	Earth Flow (Soil Creep)	River Erosion	Slope Erosion
•							Removal	◆	◆	◇	◇	◇	◇	◇	◇		
•						•	Realignment	◆	◆	◇		◇	◇			◆	
	•	•					Earthwork	◆	◆	◇	◇	◆	◇				
	•	•		•			Drainage			◇	◆	◆	◆	◆	◇		◆
		•		•		•	Retaining Wall			◇	◇	◆	◇	◇	◆	◆	
			•	•		•	Revetment Wall				◇	◆	◇	◇		◆	◆
		•		•		•	Bio-engineering				◇	◇	◆	◇	◆	◆	◆
					•		Check Dams				◆			◆		◇	◇
		•				•	Tie-back Wall			◆	◆	◆	◇	◇	◇	◆	
		•				•	Pile Wall			◇	◆	◆	◇	◇	◇	◆	
			•				Buttress	◆				◆	◇				
						•	River Training			◇	◇	◇	◇	◇		◆	
		•					Anchors / Bolts	◆	◆	◇			◇		◇		
•					•		Catch Work	◇	◇	◇	◇						
					•		Surface Protection	◇	◇	◇							◆
Symbol		Category/ Group						Description									
•		Column applicability (left columns)						Method is applicable to this general approach									
◆		Problem matrix						Principal Option									
◇		Problem matrix						Secondary Option									

Figure 4.1: Generalized matrix for selection of countermeasures



C. Increase of Internal Strength: These methods improve the internal shear strength and stability of soil or rock masses. Retaining walls, anchors, bolts, bio-engineering systems, and pile walls are commonly used to strengthen unstable slopes.

D. External Restraint: These measures provide external resistance against slope movement. Revetment walls, retaining structures, buttresses, and pile systems physically support the slope and restrain movement.

E. Slope Protection: Slope protection works are used to prevent weathering, erosion, and shallow surface failures. Surface protection systems, stone pitching, vegetation cover, and shotcrete applications fall under this category.

F. Debris Control: These measures control falling debris, sediment movement, and debris flow hazards. Catch works and check dams are commonly used to intercept and manage debris before it reaches the roadway.

G. Bank Protection: These measures protect riverbanks and slope toes from erosion and undercutting. River training and revetment structures are applied in areas affected by river action.

The matrix also correlates these countermeasures with different types of slope failures such as earth fall, rock fall, rock slide, debris slide, soil slide, debris flow, earth flow, river erosion, and slope erosion. The symbols used in the table indicate the degree of suitability of each countermeasure. This revised generalized matrix provides a more localized and methodology-based framework for selecting appropriate engineering mitigation measures for roadside slope stabilization and landslide risk reduction.

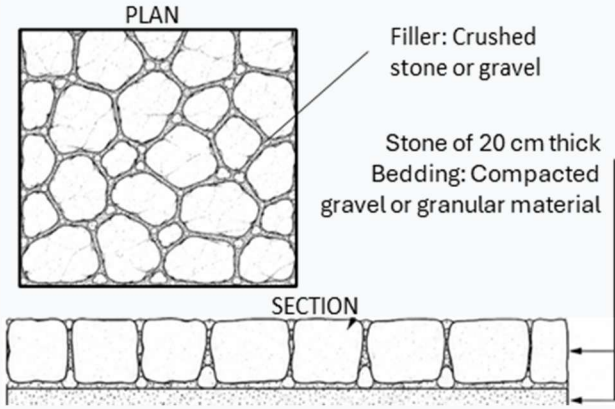
4.2 Surface Protection Techniques

Surface protection techniques are applied to exposed cut or fill slopes, embankments, and channel beds to prevent erosion from rainfall impact, surface runoff, wind, and freeze-thaw action. They are critical first-line measures to prevent progressive deterioration of slopes.

4.2.1 Stone soling

Stone Soling <i>Hand-laid flat stones placed on slopes and channel beds to protect against surface erosion</i>	
Functions and Applicability Protect embankment faces, cut slopes and drain side slopes against rainfall splash and surface runoff erosion. Suitable for slopes up to 1V:1H (45°). Cost-effective where local stone is readily available.	
Design Considerations & Specifications Stone size: minimum 150 mm smallest dimension; preferably 200–300 mm. Stone shape: flat on at least one face; angular preferred over rounded. Slope: up to 1V:1H with good stone. Bedding: 75–100 mm compacted gravel or granular material beneath stones. Joints: stones laid with minimum gaps; voids backfilled with smaller stones.	Materials Hard, durable stone (quartzite, granite, schist preferred). Bedding: well-graded gravel or crushed stone. Geotextile filter fabric (non-woven, 150–200 g/m ²) for very soft soil. Limitations Susceptible to undercutting if drainage is inadequate Not suitable for slopes >45°.



	Requires skilled labour; poor workmanship leads to stone dislodgement.
	Site Preparation & Construction Procedure Trim slope to even grade; remove loose material. Install geotextile filter fabric, overlapping by 300 mm at joints. Spread and compact 75 mm granular bedding. Begin at slope toe; work upward. Set header stones (long dimension into slope) every 1–1.5 m vertically. Place flat face outward; embed each stone firmly. Pack voids with chinking stones. Install toe protection (masonry or concrete kerb) before stone soling.

Source: Clause 3111 (DoR, 2025); DoR, (2003)

4.2.2 Riprap (Random stone protection)

Riprap (Random Stone Protection)

Randomly placed durable stones to protect slopes and channel banks against scour

Functions and Applicability

Protects channel banks, bridge abutments, culvert outlets, and toe-of-fill slopes from high-velocity flow and scour. Used where flow velocities exceed the capacity of hand-placed stone pitching (typically above about 2 m/s) with the stone sized to the design velocity as given below.

Design Considerations and Specifications

Stone size by design flow velocity (Shields' criterion / Manning's equation):

— $V < 2$ m/s: $D_{50} \approx 150\text{--}200$ mm

— $V = 2\text{--}3$ m/s: $D_{50} \approx 250\text{--}350$ mm

— $V = 3\text{--}4$ m/s: $D_{50} \approx 400\text{--}500$ mm

Layer thickness: $1.5 \times D_{50}$ (minimum 300 mm).

Grading: well-graded; minimum D_{85}/D_{15} ratio ≥ 2 .

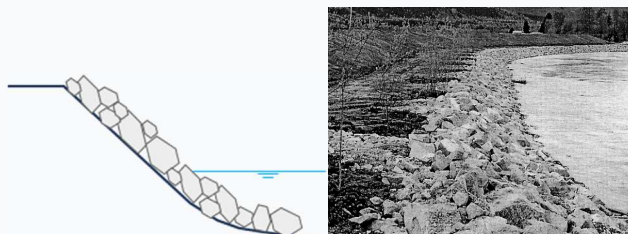
Filter: granular filter or geotextile ($200\text{--}300$ g/m²) beneath riprap.

Toe embedment: minimum 500 mm below anticipated scour depth.

Materials

Hard, durable angular stone; LA abrasion loss $< 30\%$; water absorption $< 1\%$.

Non-woven geotextile filter or well-graded granular bedding.



Source: (Province of British Columbia, Ministry of Environment, Lands and Parks, 2000)

Limitations

Site Preparation and Construction Procedure



Less aesthetically acceptable than stone soling. Not suitable for slopes >1V:1.5H without additional anchoring. Stone displacement can occur under very high velocity or flood flows.	Excavate toe protection trench to required depth. Grade slope surface; install filter layer (geotextile or gravel blanket). Place stones from toe upward; avoid rolling stones into position. Key largest stones at toe; ensure even distribution of stone sizes. No voids > 0.3 × D50 should remain unfilled with smaller stone.
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Source: [DoR, 2007](#); [FHWA HEC-11 \(riprap revetment\)](#) and [HEC-23 \(bridge scour countermeasures\)](#); [USACE EM 1110-2-1601](#); [Province of British Columbia, Ministry of Environment, Lands and Parks \(2000\)](#).

4.2.3 Boulder pitching

Boulder Pitching

Large boulders set vertically into slopes or channel beds for high-energy flow protection

Functions and Applicability

Used where flow velocities are high and individual stone mass is required to resist displacement. Effective for channel training, drop structures, and landslide debris impact zones.

Design Considerations and Specifications

Boulder diameter: minimum 400 mm (typically 400–700 mm); mass ≥ 50 kg per stone.

Place boulders with their largest dimension well keyed into the slope or perpendicular to flow direction to maximize stability.

Interlocking: boulders keyed against each other; no through-voids.

Bedding: 100–150 mm granular bedding or large gravel.

Toe embedment: minimum 500 mm into stable ground.

Materials

Fresh, hard, rounded or sub-angular boulders (granite, quartzite preferred).

Free from cracks, joints, or weathered rind.

Granular or gravel bedding layer.



Source: AZNC Construction-company, UP, India

Limitations

Labour-intensive placement and heavy transport requirements.

Not suitable for slope >45° without anchoring.

Difficult to achieve watertight joints without mortar.

Site Preparation and Construction Procedure

Clear channel and slope of loose material. Grade and compact base.

Place largest boulders first at toe and critical points.

Key each boulder firmly against neighbours; pack voids with small stones.

Inspect for stability before flow event.

Source: [DoR, 2007](#)



4.2.4 Shotcrete

Shotcrete

Pneumatically applied mortar or concrete to protect cut rock and soil faces from weathering and erosion

Functions and Applicability

Prevents external weathering and erosion of the rock surface and reduces the risk of rock falls and shallow slope failures in highly weathered or heavily fractured rock. Applied to soil faces only in combination with mesh and soil nails. Because it forms an impermeable, non-vegetated face, shotcrete is reserved for steep, highly fractured or slaking rock where bioengineering is not feasible, and any springs or seepage must be drained before spraying.

Design Considerations & Specifications

Mix: cement mortar 1:3 or 1:4 (w/c 45–50%) [short-term]; sprayed concrete 1:3:1 or 1:5:2 (w/c 40–45%) [permanent]. Materials and grades per Clause 2710 (DoR 2025).

Thickness: mortar 80–100 mm; concrete 100–200 mm; built in passes of about 50 mm with initial set between layers.

Reinforcement: welded wire mesh or steel-fibre concrete; permanent shotcrete requires mesh plus rock bolts / soil nails.

Anchors: rock bolts / soil nails about 1–2 per m² for permanent work, fully encased in the shotcrete and carried to sound rock beyond the loosened zone.

Aggregate: maximum ≤ 10 mm (8 mm typical); larger sizes sharply increase rebound.

Accelerator: alkali-free (weakly acidic); dosage per manufacturer.

Durability: air-entrained (wet-mix) where freeze-thaw exposure occurs at altitude.

Drainage: 50 mm weep holes with pipes at least 1 per 2–4 m²; drain springs and seepage before spraying.

Materials

Cement: OPC; sand: well-graded river sand free of silt.

Coarse aggregate: max 10 mm (wet process); 12 mm (dry process).

Admixture: alkali-free accelerator (weakly acidic, avoiding the caustic spray of alkaline types).

Reinforcement: welded wire mesh or steel fibre; rock bolts / soil nails.



Source: (Bluestar Development Co., n.d.)

Limitations

Requires specialist equipment and trained operators.

Counter-productive where springs or seepage exist; the impermeable face traps water if weep holes or drainage are inadequate.

Site Preparation & Construction Procedure

Scale loose rock; remove all vegetation and weak material from face.

Install rock bolts or soil nails as required. Fix wire mesh to anchors.

Dampen rock face (not saturated) before spraying.



Vegetative treatment cannot be applied over shotcrete (conflicts with nature-based objectives; use as a last resort). Does not reduce earth pressure; surface protection only, not a structural solution. Rebound is high (dry-mix 15–40%, wet-mix 5–15%) and must not be reused; relatively high cost.	Apply in layers: layer thickness is project-specific and depends on wet/dry-mix process, surface conditions, and material properties Spray perpendicular to face from distance 0.6–1.2 m, , from top to bottom, in ~50 mm layers; do not reincorporate rebound. Cure minimum 7 days. Install weep holes at specified locations.
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Source: [C13.1 \(Shotcrete Work; DoR, 2007\)](#); [Clause 2710 \(DoR, 2025\)](#); [ACI 506R](#), [ACI 506.2](#), [EN 14487-1](#)

4.3 Selection of Appropriate Excavation Slope

The design of cut slopes is one of the most critical decisions in hill road construction. The selected slope angle must balance long-term stability against economic and environmental constraints. An overly steep slope creates long-term maintenance liabilities; an excessively flat slope wastes land and increases earthwork volume.

This [Table 4-2](#) presents combined preliminary cut slope gradients for cut heights below 15 m for soil and rock (Average slope angles for bed rock excavation for plane of weakness dipping < 30°). The lowest recommended cut angle ranges were adopted to improve stability and provide safer preliminary design values.

Table 4-2: Preliminary cut slope gradients (H:V) for cut height

1. Soil classification 1		Cut Height		
		< 5 m	5-10 m	10-15 m
Sand	Loose, poorly graded	1.5:1		
Sandy soil	Dense or well graded	1:1	1:1 – 1.5:1	-
	Loose	1.5:1	1.5:1 – 2:1	-
Sandy soil, mixed with gravel or rock	Dense, well graded	0.85:1 – 3:1		1:1 – 3:1
	Loose, poorly graded	1.3:1 – 1.5:1		
Cohesive soil		0.8:1 – 1.2:1		-
Cohesive soil, Mixed with rock or cobbles		1:1 – 1.2:1	1.2:1 – 1.5:1	-
2. Soil classification 2		Cut Height		
		0-3 m	4-6 m	7-10 m
Clayey silt (transported)		1:1-1:1.5	1:0.8-1:1	1:0.5-1:0.8
Silts		1:1	≤1:0.8	≤1:0.8
Coarse-grained colluvium		1:1	1:0.8-1:1	≤1:0.8
Silty clay (residual)		1:1-1:1.5	1:1-1:1.5	1:1



3. Rock Classification (dipping <30°)	Description	Maximum slope gradient (V:H)
Igneous	Granite, trap, basalt, tuff	1:0.25 – 1:0.5
Sedimentary	Massive sandstone and limestone	1:0.25 – 1:0.5
	Interbedded sandstone, shale and limestone	1:0.5 – 1:0.75
	Massive claystone and siltstone	1:0.75 – 1:1
Metamorphic	Gneiss, schist and marble	1:0.25 – 1:0.5
	Slate	1:0.25 – 1:0.75
	Serpentine	Special investigation

Note: For Soil Classification 1, the recommended cut slope ranges from 1:0.8 to 1:1.5 (V:H) across the full cut height range of 0 to 15 m, so a single broad band covers the entire range. Soil Classification 2 has more classes (divided into three height categories for heights up to 10 m) with slopes ranging from 1:0.67 to 1:1. Because Classification 1 applies one recommendation over such a wide range of heights, the final selection of cut slope geometry is left to the judgment of the site engineer.

Within the given range, the engineer should select the most appropriate cut slope from field observations such as soil types, moisture condition, stratification, and the short-term stability seen during excavation, and should consult [Table 4-3](#) before fixing the slope. Any decision must still follow basic geotechnical principles and ensure stable, safe excavation conditions on site.

Table 4-3: Indicative safe unsupported vertical cut heights

Soil type	c' (kPa)	φ' (°)	γ (kN/m³)	Safe unsupported vertical height	Key precautions / field remarks
Coarse-grained soil (CG)	0-2	35-45	19-20	0.5-1.0 m***	c' = 0; apparent cohesion from capillary suction (~2-3 kPa) provides brief stability only. Excavation >1.0 m requires immediate shoring. No open cut left overnight.
Coarse-grained soil with non-plastic fines (CGNPF)	2-6	29-40	19-21	1.0-1.5 m** ~1.0m*	Provide immediate surface protection after excavation. Shoring required above 1.5 m. Do not stack cuts without structural toe support.
Coarse-grained soil with plastic fines (CGPF)	3-8	25-40	19-21	1.2-2.0 m** ~1.0m*	Structural support/appropriate cut slope recommended above 2.0 m. Watch for softening during rainfall. Colluvial deposits of this type are common in Middle Hills and show highly variable strength (field assessment essential).
Silt (ML / MH)	3-17	20-32	15-19	1.0-1.5 m** ~1.0m*	Extremely sensitive to moisture. Immediate protection with surface pitching/revetment

Soil type	c' (kPa)	ϕ' (°)	γ (kN/m ³)	Safe unsupported vertical height	Key precautions / field remarks
					or geotextile mandatory for heights above 1.5m.
Low plasticity clay (CL)	5–20	15– 25	18–20	2.0–4.0 m** ~2.0m*	Stability analysis required for height of excavation above 3m. Retaining structure recommended above 4 m. Desiccation cracks form in dry season — reduce effective c' on wetting.
High plasticity clay (CH)	10– 40	5– 20	17–19	2.0–4.0 m ~3.0m*	Benching and staged cutting in dry season mandatory above 5 m.

*For high water table and seepage condition, ** For dry condition, *** Temporary works

A cut excavation slope is not uniform and varies according to the lithology and stratification of soil and rock layers. As shown in the Figure 4.2, different materials such as sediment, soft rock, hard rock, and weathered rock require different slope angles depending on their strength and stability. Flatter slopes are needed in weak soils, while steeper slopes may be possible in stronger rock formations. Benching is commonly used at transitions between layers to improve stability and control potential failures (Box 4.1). In weathered or unstable zones, additional measures such as removal of overhangs are required. Overall, the final slope profile becomes a composite system adjusted to site-specific ground conditions to ensure safe and stable excavation.

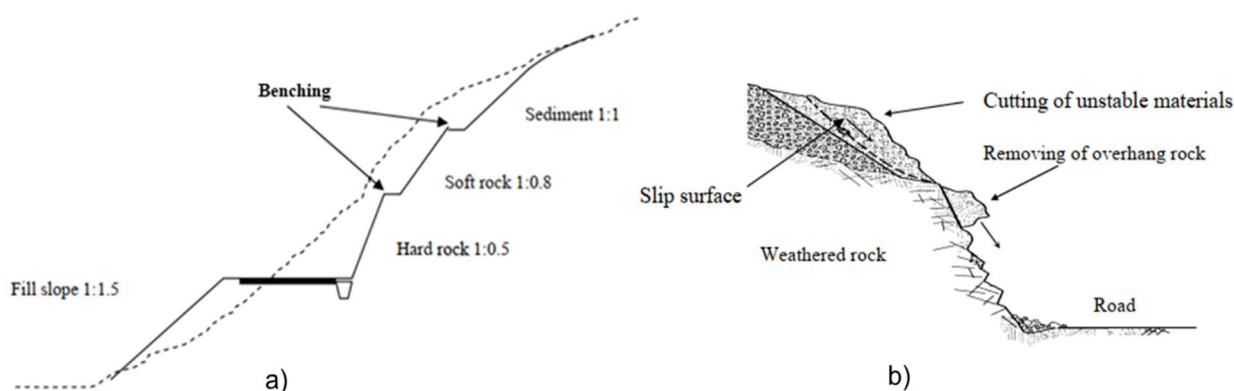


Figure 4.2: Generalized sketch of cut slope condition for a) soil b) rock (source: DoR, 2003)

4.3.1 Cut Height and Benching

Recommended slope angles and benching are indicative and must be adjusted by the engineer based on actual material encountered during excavation.



Box 4.1: Minimum Bench Specifications (Modified after; DoR, 2003)

Bench width: minimum 1.5 m clear width to allow safe access for inspection, maintenance, and a bench drain; 2.0 m where access for compact construction plant is required. Where access for light vehicles is intended, a minimum width of 3.0 m should be provided.

Bench slope: 2–5% inward toward hillside, draining to collection drain at rear of bench.

Vertical interval: typically, 5 to 6 m for firm, well-drained cohesive soils, reduced to 3 to 5 m for soft, weathered, or saturation-prone material; 8 to 10 m for soft rock; and 10 to 15 m for hard rock, subject to discontinuity control.

Bench drain: V-shaped or trapezoidal; minimum 300 mm wide × 200 mm deep; lined if erodible material.

Top of cut: rounded ($R \geq 0.5$ m) to reduce stress concentration and prevent tension cracking.

Toe of cut: rounded ($R \geq 0.3$ m) to reduce drainage concentration and ease grass establishment.

Drain outfall: bench drains discharge to side drains via energy-dissipating drop structures or chutes.

4.4 Retaining and Supporting Structures

Retaining structures resist lateral earth pressure generated by cut or fill slopes, thereby preventing slope movement, controlling erosion at the toe, and protecting the road formation and carriageway. In Nepal Himalayan Road the common types are dry stone masonry walls, banded masonry walls, cement stone masonry walls, gabion walls, and reinforced concrete walls (cantilever or counterfort); mechanically stabilized earth (MSE) walls using geogrid or reinforcing strips are also used where embankments require additional tensile reinforcement.

4.4.1 Design of retaining walls

The stability of all gravity retaining walls must be verified against three fundamental failure modes: overturning, sliding, and bearing capacity failure. Before analysis the weight of the wall is calculated using the unit weight for different material as mentioned in the [Table 4-4](#). Similarly, surcharge from traffic ($q = 12$ kPa for NH/SH; $q = 10$ kPa for other roads per [IRC:6-2017](#)) is considered as live load. The following equations and criteria form the basis of design. Minimum factors of safety (FoS) are specified for both static and seismic ([IS 1893](#)) loading conditions.

Table 4-4: Unit weight of different masonry wall

Type of Wall	Unit Weight of Wall Material (kN/m ³)			Wall Unit Weight used in design (kN/m ³)
	Brick	Granite	Limestone	Recommended
Dry Stone Masonry	13.8	18.8	17.4	17–19
Banded Stone Masonry	13.8	18.8	17.4	18–20
Cement Stone Masonry (1:4)	17.9	24.4	22.0	22–24
Gabion Wall	—	18.8	17.4	16–18



PCC	—	—	—	22–24
RCC	—	—	—	23–25

Use Rankine theory for vertical smooth walls with horizontal fill ($\beta < 15^\circ$). Use Coulomb theory for inclined back face, wall friction present, or $\beta \geq 15^\circ$. Seismic: use Mononobe–Okabe method (IS 1893 Part 1:2016, Annex F).

Active Earth Pressure Coefficient - Rankine Theory		
Horizontal backfill ($\beta = 0$)	$K_a = \frac{(1 - \sin \phi)}{(1 + \sin \phi)} = \tan^2(45^\circ - \phi/2)$	Most common case for road retaining walls. Assumes smooth vertical wall and horizontal backfill.
Inclined backfill ($\beta \neq 0$)	$K_a = \cos \beta \times \frac{[\cos \beta - \sqrt{\cos^2 \beta - \cos^2 \phi}]}{[\cos \beta + \sqrt{\cos^2 \beta - \cos^2 \phi}]}$	β = slope angle of backfill surface Condition: $\beta \leq \phi$ required for real solution
Active Earth Pressure Coefficient - Coulomb Theory		
$K_a = \frac{\sin^2(\alpha + \phi)}{\sin^2 \alpha \sin(\alpha - \delta) \left[1 + \sqrt{\frac{\sin(\phi + \delta) \sin(\phi - \beta)}{\sin(\alpha - \delta) \sin(\alpha + \beta)}} \right]^2}$		α = inclination of wall back face; δ = wall friction angle; β = backfill slope
$P_a = \frac{1}{2} K_a \gamma H^2$ Resolve P_a into P_{aH} and P_{aV} considering inclination of back of wall and δ		

Identify: backfill geometry (β), wall face inclination (α), water table depth, presence of surcharge. Assign wall friction angle (δ) as per wall type.

Gravity wall: Top width 0.35–0.70 m;
Base width $B = 0.5$ – $0.7H$.
Semi-gravity/cantilever: Web thickness 0.35 m;
Base = 0.5 – $0.7H$ (Table 4-6).

Bearing capacity of the foundation shall be calculated from different bearing capacity theories

$$[q_s = \frac{cN_c S_c d_c i_c + q(N_q - 1)S_q d_q i_q R_{wq} + \frac{1}{2} \gamma B N_\gamma S_\gamma d_\gamma i_\gamma R_{w\gamma}}{FoS} + \gamma D_f]$$

or shall be adopted from presumptive bearing capacity Table 4-5.

Table 4-5: Typical values bearing capacity for different soil types



Type of Bearing Material	Symbol	Consistency of Place	Safe Bearing Capacity (kN/m ²)
Well graded mixture of fine and coarse-grained soil, glacial till, hard pan, boulder clay	GW-GC, GC, SC	Very compact	1000
Gravel, gravel-sand mixtures, boulder-gravel mixtures	GW, GP, SW, SP	Very compact	800
		Medium to compact	600
		Loose	400
Coarse to medium sand, sand with little gravel	SW, SP	Very compact	400
		Medium to compact	300
		Loose	300
Fine to medium sand, silty or clayey medium to coarse sand	SW, SM, SC	Very compact	300
		Medium to compact	250
		Loose	150
Fine sand, silty or clayey medium to fine sand	SP, SM, SC	Very compact	300
		Medium to compact	200
		Loose	150
Homogeneous inorganic clay, sandy or silty clay	CL, CH	Very stiff to hard	400
		Medium to stiff	200
		Soft	50
Inorganic silt, sandy or clayey silt, varied silt-clay-fine sand	ML, MH	Very stiff to hard	300
		Medium to stiff	150
		Soft	50

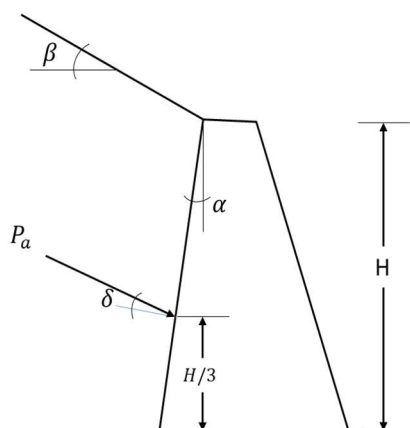


Figure 4.3: Typical Retaining wall and load

$$\text{Horizontal Seismic Coefficient: } A_h = \frac{Z \times I}{2 \times R}$$

Z = Seismic Zone factor (Zone IV = 0.24; Zone V = 0.36 per IS 1893:2016, Table 3)

I = Importance factor (retaining walls: I = 1.0 for normal; I = 1.5 for critical infrastructure)

R = Response reduction factor = 1.5 for unreinforced masonry/gravity walls

Vertical Seismic Coefficient: $A_v = \pm A_h/2$ (both - and + cases shall be checked; adopt larger resultant)

$$\text{Seismic Inertia Angle: } \lambda = \tan^{-1} [A_h / (1 \pm A_v)]$$

Compute λ for both $(1 + A_v)$ and $(1 - A_v)$.

Adopt the larger $C_{a(dyn)}$ from the two calculations.

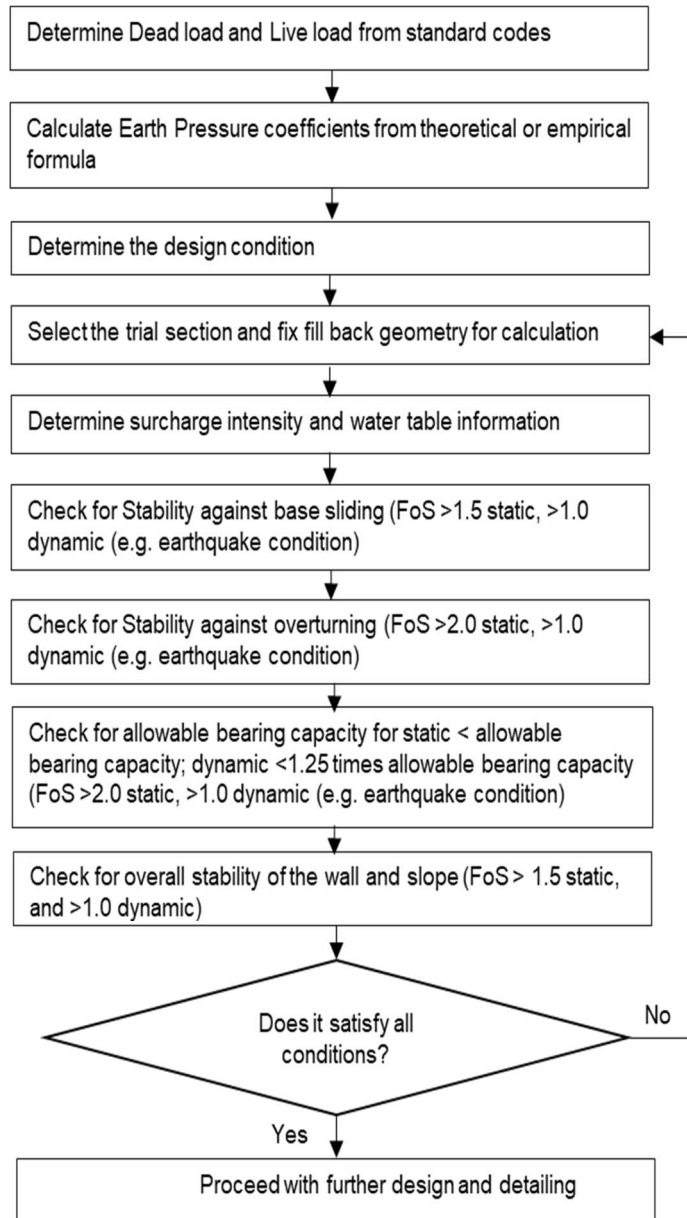
$$C_{a,dyn} = \sin^2(\alpha + \varphi - \lambda) / \{ \cos \lambda \times \sin^2 \alpha \times \sin(\alpha - \delta - \lambda) \times [1 + \sqrt{(\sin(\varphi + \delta) \cdot \sin(\varphi - i - \lambda) / (\sin(\alpha - \delta - \lambda) \cdot \sin(\alpha + i)))^2} \}$$

The point of application of the dynamic increment ($\Delta P = P_{a,dyn} - P_a$) shall be assumed to be applied at $0.5 H$ above the base and shall be considered separately



4.4.2 Selection of appropriate retaining structure

The following tables (Table 4-6 and Table 4-7) provide guidance for the selection of retaining and breast wall types based on site conditions and wall height, in accordance with IS 14588 Part 1 (Clause 3.1) and adapted to the DoR practices. Detailed design considerations and construction procedures are presented in the subsequent sections.



Stability check

Factor of Safety against sliding,

$$FoS_s = \frac{Rv' \mu}{Rh'} \geq 1.0 - 1.5$$

Rv' = Net Vertical Force

Rh' = Net Horizontal force

μ = coefficient of friction
between base of wall and soil

Factor of safety against Overturning,

$$FoS_o = \frac{\sum M_r}{\sum M_o} \geq 1.0 - 2.0$$

$\sum M_r$ = Sum of all resisting
moment about toe

$\sum M_o$ = Sum of all overturning
moment about toe

Eccentricity (e) calculation

$$e = \frac{B}{2} - \bar{X} \quad B = \text{Base width of wall}$$

$\bar{X}$ = C.G of the load

Check for allowable bearing capacity

$$p_{\max} = \frac{Rv'}{b} \left(1 + \frac{6e}{b}\right) \quad p_{\max} < (1 - 1.25) \times q_{na}$$

$$p_{\min} = \frac{Rv'}{b} \left(1 - \frac{6e}{b}\right) \Rightarrow e \leq \frac{b}{6}$$

$$F_{sb} = \frac{q_{na}}{p_{\max}} \text{ where}$$

q_{na} = allowable
bearing pressure

Figure 4.4: Design flow chart of retaining wall



Table 4-6: Detail about different types of retaining structure (Source : IS 14588 part 1 Clause 3.1)

	Type	Retaining Walls						
		Timber Crib	Dry Stone	Banded Dry Stone/ Masonry	Cement Masonry	Gabion		Reinforced Earth
	Diagrammatic Cross-section							
C O N S T R U C T I O N	Top width	2 m	0.6–1.0 m	0.6–1.0 m	0.5–1.0 m	1 m	1–2 m	4 m or 0.7–0.8 m
	Base width	—	0.5–0.7 H	0.6–0.65 H	0.5–0.65 H	0.6–0.75 H	0.55–0.65 H	4 m or 0.7–0.8 H
	Front batter	4:1	vertical	varies	10:1	6:1	6:1	3:1
	Back batter	4:1	varies	vertical	varies	varies	varies	3:1
	Inward dip of foundation	1:4	1:3	1:3	horizontal or 1:6	1:6	1:6	horizontal
	Foundation depth below drain	0.5–1 m	0.5 m	0.5–1 m	0.5–1 m	0.5 m	1 m	0.5 m
	Range of height	3–9 m	1–6 m	6–8 m	1–10 m	1–6 m	6–10 m	4 m or 0.7–0.8 H
N O T E S	Hill slope angle	<30°	<35°	20°	35–60°	35–60°	35–60°	<35°
	Toe protection in case of soft rock/soil	Boulder pitching Bioengineering		Boulder Pitching Bioengineering		No Bioengineering		
A P P L I C A T I O N	General	Timbers 15 cm well stone rubble well packed behind timbers. 10% of all headers to extend into fill. Ecologically unacceptable.	Set stones along foundation toe. Use long bond stones. Hand packed stones in back fill.	Cement masonry in courses of 50 cm thickness at 3 m centers for dry stone wall.	Weep holes 15 × 15 cm size at 1–2 m c/c. Provide rubble backing for drainage.	Stones to be hand packed. Stone shape important, blocky preferable to tabular. Specify maximum/minimum stone size. No weathered stone to be used. Compact granular back fill in layers (< 15 cm). Use H type gabion wall.	Granular back fill preferred. Use geogrid for H < 4 m and tensile grid for H > 4 m. Provide drainage layer in case of seepage problems. Specify spacing of reinforcement grids.	
		1. Foundations to be stepped up if rock encountered. 2. All walls require durable rock filling of small to medium size. 3. Drainage of wall bases not shown. Provide 15 cm thick gravel layer in case of clayey foundation.						
	Application	Least durable	Most durable	Can take differential settlement and slope movement		Huge potential used more as stable reinforced fill platform for road rather than preventive method of slope support.		
		Non ductile structure most susceptible to earthquake damage						
		1. Design as conventional retaining walls.. Assume surcharge on road of 20 kPa. 2. Used both as cut slope and fill slopes support. Breast wall is more economical for cut slope. 3. Choice of wall depends on local resources, local skill, hill slope angle, foundation conditions and also shape of back fill wedges as illustrated in diagrams and compatibility of materials.						



Table 4-7: Selection of breast walls (Source: IS 14588-part 1 Clause 3.1)

Type	Breast Walls/Revetment Walls						Remarks
	Dry Stone (2)	Banded Dry Stone Masonry (3)	Cement Masonry (4)	Gabion (5)	Horizontal Drum Walls (6)	(7)	
Diagrammatic cross-section							
Top width	0.5	0.5	0.5	2	1		1. Wall construction requires special skills and practical labour. Curing of masonry walls generally not feasible in hills due to paucity of water.
Base width	0.29H 0.3H 0.33H		0.23H	2	1		2. The typical dimensions shown rely both on well-drained backfill and good foundation conditions.
Front batter							
Back batter	3:1 4:1	3:1 5:1	3:1	3 to 5:1	3:1		3. Detailed design is necessary in case of soil slopes and walls higher than 6 m and poor foundation conditions.
Inward dip of foundation	1:3 1:4	1:3 1:5	1:3	1:5	1:3		
Foundation depth below drain	0.5 m	0.5 m	0.5 m	0.5-1 m	0.25 m		4. Gabion walls should be used in case of poor foundation/seepage conditions. They can take considerable differential settlement and some slope movement.
Range of height	6 m	4 m	1-10 m	1-8 m	2.2 m		
Hill slope angle	35-60	35-60	35-70	35-60	35		5. Other measures should also be taken, for example, 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.
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. Revetment walls have uniform section of 0.5 m to 0.75 m thickness for batter of 2:1 or more. Section shaped to suit variation and overbreak in rock cut slope.	Cement masonry (1:6) bands of 0.5 m thick- ness at 3 m c/c.	Weep holes 15 x 15 cm at 1.5-2 m c/c and grade 1:10. Cement sand (1:6)	Step in front face 20-50 cm wide. Other- wise as for retaining walls.	Use vertical single drum for 0.7 m height. Anchor drum walls on sides. Fill debris material.		
Application	Least durable/ economical	Little used	Most durable/costly	Quite durable/costlier or	Promising/most economical or		
	Non ductile structures most susceptible to earthquake damage. Revetments are used to prevent only major erosion, rock fall, slope degradation particularly where vulnerable structures are of risk.			Very flexible	Flexible		



4.4.3 Dry stone wall

Dry stone walls are gravity retaining structures built from locally available, roughly dressed or undressed stone laid without mortar with careful interlocking for integrity. The typical section of the dry masonry wall is shown in [Figure 4.5](#).

Design considerations	Key Construction Requirements
- Cheapest and weakest form of wall structure - Suitable for heights up to 4 m - Location should be at least 1 m away from road edge to avoid direct - application of earth pressure, seepage pressure and vibration due to vehicle movement - Base width ranges from 0.6 to 1xH - For foundation in muddy condition provide stone soling at foundation	- Provide inward base slope (preferably 1V:6H to 1V:3H) for better keying and sliding resistance - Use large, rough, flat stones properly interlocked - Bond stones at least 45 cm in length and reasonable shaped are required at 0.6 m intervals of wall surface - Place longest stone dimension across wall thickness for better bonding and stability - Fill all voids with coarse angular spalls/stone chips; avoid fine soil and smooth shingle - Ensure proper drainage and free-draining hand-packed backfill during construction 300 mm thick impervious soil layer must be laid above the top backfill layer.

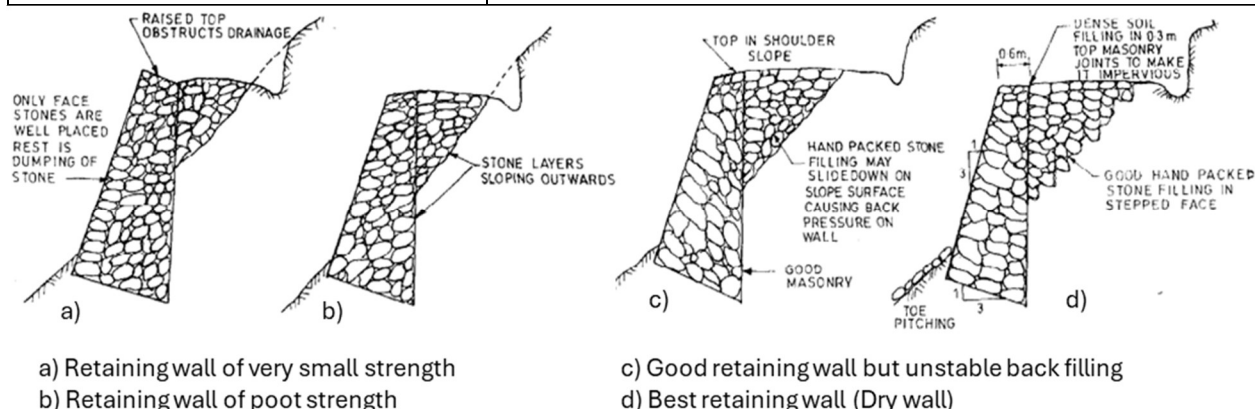


Figure 4.5: Typical construction details for dry stone masonry wall

The figure shows good and bad construction practices for dry stone masonry retaining walls. [Figure 4.5 \(a\) and \(b\)](#) show weak wall construction due to poor stone arrangement, dumping of stones, improper drainage, and outward sloping stone layers. [Figure 4.5 \(c\)](#) shows a well-constructed wall but unstable backfill condition causing additional pressure on the wall. [Figure 4.5 \(d\)](#) shows the recommended practice with proper hand-packed stone filling or back filling, stepped face, drainage arrangement, impervious top layer, and toe protection, resulting in a stable and durable retaining wall.

4.4.4 Banded masonry wall

Design consideration	Construction Procedure
- Designed as gravity structure - Dry masonry panels of about 0.6 to 1 m square form a grid pattern on wall face with 0.5 m strip of cement masonry	Provide inward base slope (1V:6H to 1V:3H) to improve sliding resistance and seismic stability



- Stronger than dry masonry but weaker than cement masonry wall
- Dry panels serve the function of weep holes; Base width ranges from 0.5 to 0.75 of wall height
- Use rule of thumb up to 3 m height, standard designs up to 6 m height.

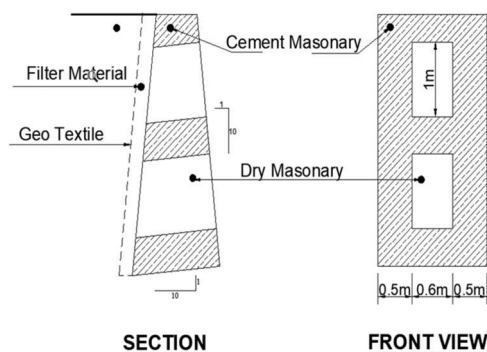


Figure 4.6: Typical section of Banded masonry wall

- Use fresh rectangular interlocking stones properly hand packed between masonry bands
- Cement mortar of specified grade
- Provide graded inverted filter backfill with boulder, gravel, and sand layers for proper drainage
- Ensure toe protection or toe drain to prevent erosion and instability at wall base
- Provide impervious compacted top soil layer with outward slope to reduce water infiltration into backfill

4.4.5 Cement masonry walls

Cement stone masonry walls are the most widely used retaining structures in road construction. They are built from locally available stone with cement-sand mortar, which binds the stones into a monolithic mass and gives the wall greater strength and structural integrity than dry or banded masonry. The typical section of the cement masonry wall is shown in Figure 4.7

A: Purpose and Function:

- Retaining backfill
- Supporting cut slope

B. Design Considerations

- Designed as gravity structure
- Base width ranges from 0.5 to 0.75 of wall height
- Use rule of thumb up to 3 m height, standard designs up to 6 m height and standard program for height > 6 m
- Foundation should be in firm ground
- For foundation on soil, a nominal layer (5 cm) of blinding concrete is required
- For foundation in muddy conditions, stone soling is required prior to blinding concrete
- For weak subsoils, reinforced concrete footing is required to distribute soil pressure to wider strip
- For drainage, weep holes (75-100 mm in size) at 2-3 m² of surface are provided either in rectangular or diagonal pattern
- For high seepage and water table condition, vertical filter material layer with geotextile is provided at back of wall with proper outlet from heel at 10-20 m intervals
- Vertical construction joints are required for walls > 10 m long

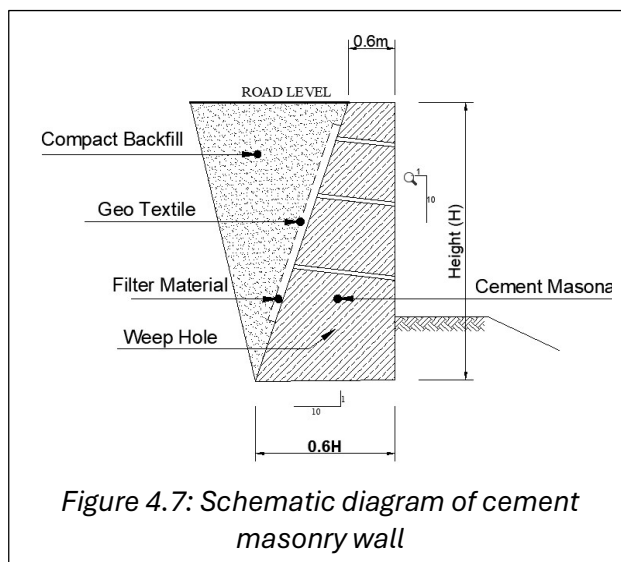


Figure 4.7: Schematic diagram of cement masonry wall



- xi. At unstable area, spacing of joints should be reduced to 6m.
- xii. For drainage, weep holes (75-100 mm in size) at 2-3 m² of surface are provided either in rectangular or diagonal pattern
- xiii. For high seepage and water table condition, vertical filter material layer with geotextile is provided at back of wall with proper outlet from heel at 10-20 m intervals
- xiv. Vertical construction joints are required for walls > 10 m long
- xv. At unstable area, spacing of joints should be reduced to 6m.

The figure shows different toe protection methods for retaining walls. Figure 4.8 (a) shows a wall without toe protection where surface runoff may erode soil and weaken the wall foundation. Figure 4.8 (b) shows a toe wall constructed as part of the retaining wall to dissipate energy and reduce erosion. Figure 4.8 (c) shows a separately constructed toe support which protects toe of the retaining wall and improves overall stability.

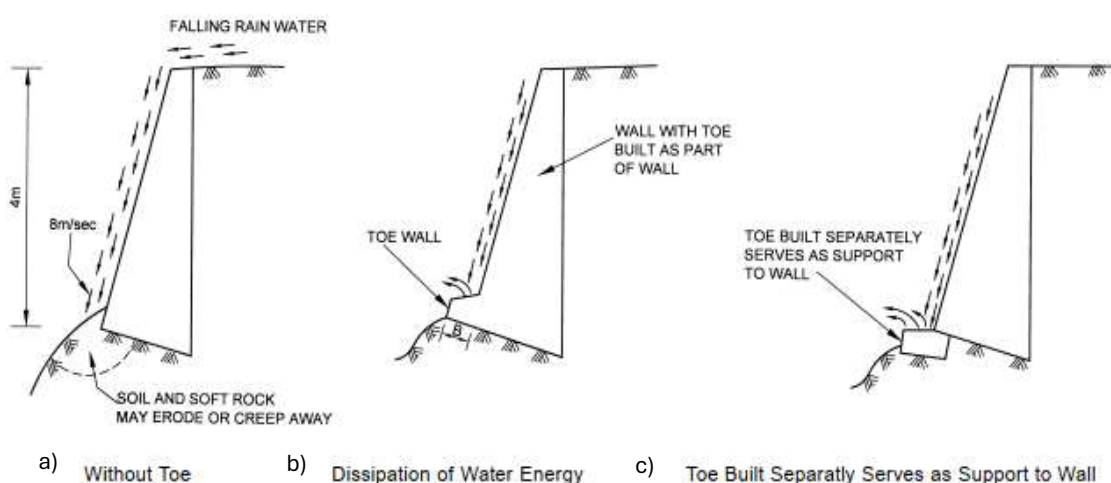


Figure 4.8: Toe protection for retaining walls

4.4.6 Gabion wall

The gabion crates are assembled in their designated positions and then tightly packed with stones, similar to the construction of a dry stone wall within a wire mesh enclosure. The individual crates are securely laced, braced, and tied together in accordance with the standard requirements (Clause 2401/2402, DoR (2025)). Gabion walls are usually battered (angled back towards the slope), or stepped back with the slope, rather than stacked vertically as shown in Figure 4.9 (a) and 3D view as shown in Figure 4.9, b. The geometry and assumptions for different types of gabion wall is shown Figure 4.9.

A: Purpose and Function

- i. Retaining backfill
- ii. Supporting cut slope

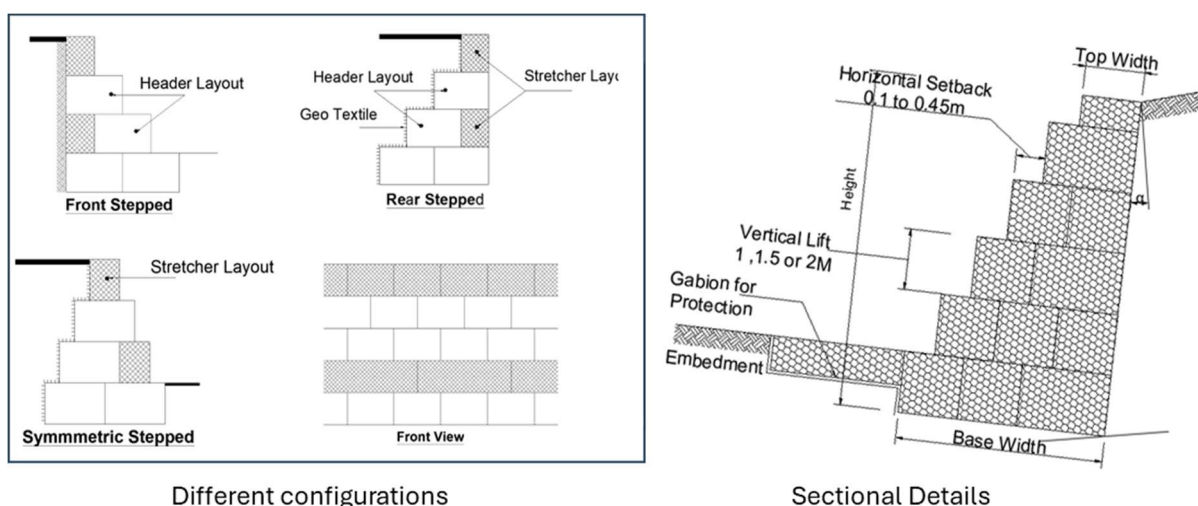


Figure 4.9: Layouts of gabion walls

B. Design consideration

- i. Designed as gravity structure, light density (about 70% of cement masonry) and larger section in comparison to cement masonry wall.
- ii. The loading parameters are shown in *Figure 4.3*
- iii. Accommodates settlements and deformations without rupture
- iv. Flexible nature makes it suitable in weak foundations and unstable /creeping slopes and allows free drainage through the wall. In wet areas, either graded filter or geotextile is recommended at back face
- v. Outlet drain should be provided from the lowest point of gabion wall
- vi. Ensure that heel drainage discharge can be visually inspected at outlet to catch pits
- vii. Can be constructed in short sections (2 or 3 m) and therefore suitable for construction in unstable areas
- viii. When used in river or cascades, the flow surface up to design high flood level should be lined either with concrete 10-15 cm thick or shotcrete
- ix. Limit height to 8 m
- x. Joints across cross section should be staggered, joints along length should be staggered where possible
- xi. No need of blinding concrete at foundation
- xii. At muddy and weak foundation, either stone soling or graded gravel layer with 93% modified proctor should be ensured

C. Specifications

- i. GI wire with heavy coating
- ii. Good quality stone > 10 cm size
- iii. Bracing wires about 4 per m²
- iv. Selvedge wire 7 or 8 SWG, netting wire 10 SWG and binding wire 12 SWG
- v. Tight packing of stones

D. Limitations

- i. Breaking of wires by abrasion of bed load
- ii. Corrosion of wires



- iii. Relatively short life
- iv. Height limit 8 m
- v. Proper stone filling inside gabion crates is a problem

4.4.7 Cantilever retaining walls

Cantilever retaining walls are constructed using reinforced cement concrete of specified grade and are commonly provided in L-shaped or inverted T-shaped configurations, with or without shear keys depending on stability requirements (Figure 4.10 (a)). However, these walls behave as rigid structures and are therefore not feasible for unstable or deformable foundations. In addition, their application may be limited in wet colluvial soils unless adequate drainage and ground improvement measures are incorporated.

A. Features of cantilever retaining wall

- i. Cantilever retaining wall composed of stem and base slab
- ii. It is constructed from reinforced concrete, precast concrete, or pre-stress concrete.
- iii. Cantilever retaining wall is the most common type used as retaining walls.
- iv. Cantilever retaining wall is either constructed on site or prefabricated offsite i.e. precast.
- v. The portion of the base slab beneath backfill material is termed as heel, and the other part is called toe.
- vi. Cantilever retaining wall is economical up to height of 10m.
- vii. It requires smaller quantity of concrete compared with gravity wall but its design and construction shall be executed carefully.

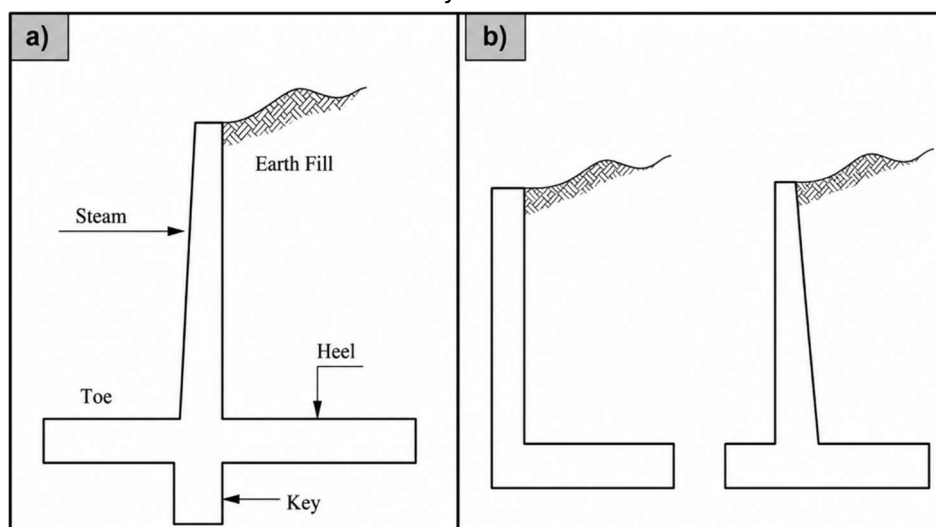


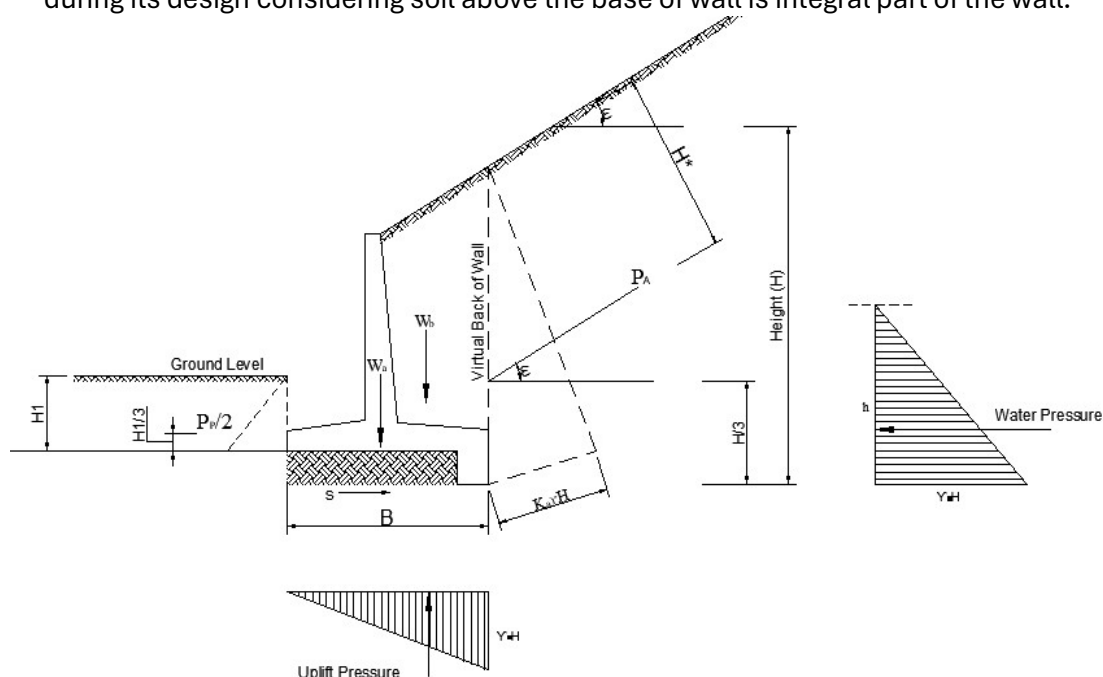
Figure 4.10: a) Typical RC cantilever wall b) Different configuration of RC cantilever walls

B. Purpose and function

- i. Retaining backfill
- ii. Supporting cut slope



Similar to gravity wall, sliding, overturning, and bearing pressure shall be taken into consideration during its design considering soil above the base of wall is integral part of the wall.



The forces acting on a cantilever wall are shown in Figure 4.11. Some of the design considerations are given below:

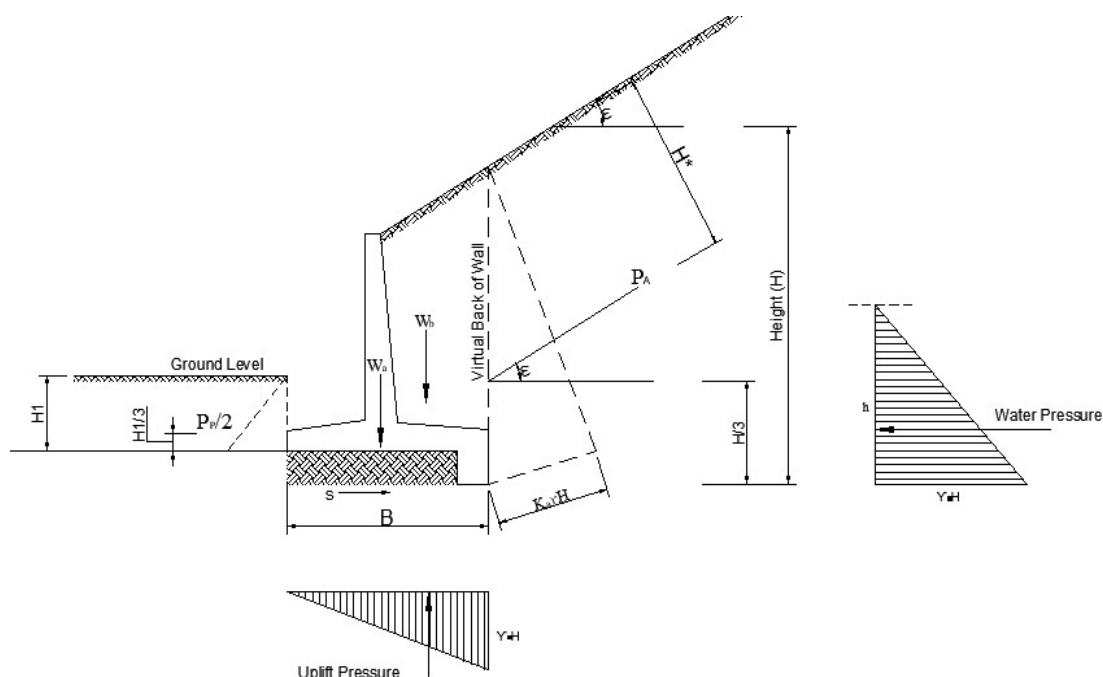


Figure 4.11: Forces acting in Cantilever wall

C. Design consideration

- Designed as semi gravity structure
- Base width ranges from 0.5 to 0.75 of wall height
- Foundation should be in firm ground or stable rock
- For foundation on soil, a nominal layer (50 cm) of blinding concrete is required



- v. For foundation at muddy layer, stone soling must be provided prior to blinding concrete
- vi. For weak foundation either provide graded gravel layer 30 cm with 93% modified proctor or
- vii. RCC mat to distribute soil pressure in wider strip
- viii. For drainage, weep holes (75-100 mm in size) at 2-3 m² of surface are provided either in rectangular or diagonal pattern
- ix. For high seepage and water table condition, vertical filter material layer with geotextile is provided at back of wall with proper outlet from heel at 10-20 m intervals
- x. Vertical construction joints are required for walls > 10 m long
- xi. Consider earth pressure at virtual back of wall i.e., vertical from end of heel
- xii. Consider surcharge and weight of soil between web and virtual back of wall
- xiii. Where shear key is used, consider contribution of weight of soil below footing in sliding stability
- xiv. Only 50% of passive resistance should be considered.

A cantilever retaining wall is recommended only when its design is undertaken with appropriate input from both geotechnical and structural engineers.

4.5 Mechanically Stabilized Earth Wall

Mechanically Stabilized Earth (MSE) walls are engineered retaining structures that combine compacted soil with tensile reinforcement materials such as steel strips or plastic geogrids. Rather than relying on a massive, rigid concrete wall to retain earth, MSE systems interlock soil and reinforcement elements to create a strong, self-supporting composite block. This synergy makes MSE walls cost-effective, flexible, and suitable for a wide range of site conditions.

4.5.1 Design philosophy

The general design procedure for any mechanically stabilized retaining wall is divided into two key components:



Figure 4.12: Mechanically stabilized earth wall

4.5.2 External stability

The following minimum factors of safety shall be satisfied for external stability of the MSE wall:

Overturning Moment	$M_o = P_a \times z'$	P_a = active earth pressure resultant; z' = lever arm height
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Resisting Moment	$M_R = W_1x_1 + W_2x_2 + \dots + q_a'(b' + a'^2/2)$	$W_1, W_2 = \text{weight components}; x_1, x_2 = \text{moment arms}$
FOS — Overturning	$FOS_{OT} = \frac{M_R}{M_o} \geq 2.0$	Must be checked at each reinforcement level
FOS — Sliding	$FOS_{sliding} = \frac{[(W_1 + W_2 + \dots + q_a) \cdot \tan(\delta)]}{P_a} \geq 2.0$	Sum of the weights and surcharge ($\delta = 2/3 \phi'$)
Ultimate Bearing Capacity	$q_u = c'N_c + \frac{1}{2}\gamma_2L_2N_\gamma$	$N_c, N_\gamma = \text{bearing capacity factors for } \phi_2'; L_2 = \text{effective base width}$
Vertical Stress at Base	$\sigma_o' = \gamma_1H + \gamma_2h$	Sum of overburden from wall fill (γ_1H) and underlying strata (γ_2h)
FOS — Bearing Capacity	$FOS_{BC} = q_u / \sigma_o' \geq 2.0$	$\sigma_o' = \text{net vertical stress at wall base}$

4.5.3 Internal stability

Tear Resistance

The Simplified Method applies to both inextensible (steel) and extensible (geosynthetic) reinforcement. It treats each reinforcement layer as a tieback resisting lateral stress within its tributary area. The active failure plane is the Rankine plane at $(45^\circ + \phi/2)$ from the horizontal, and K_a is computed assuming a horizontal backslope and no wall friction:

$$T_{max} = K_h \times \sigma_v \times S_v \times S_h$$

Where $\sigma_v = \gamma \cdot z + q$ (vertical stress including surcharge), and K_h varies with depth and reinforcement type as follows:

Table 4-8: K_h / K_a ratio by reinforcement type and depth (FHWA NHI-10-024)

Reinforcement Type	K_h at Surface ($z = 0$)	K_h at Depth ≥ 6 m
Steel strip / bar mat (inextensible)	$1.7 K_a$	K_a
Welded wire grid (inextensible)	$2.5 K_a$ (varies)	K_a
Geogrid / Geotextile (extensible)	K_a	K_a

$$\text{Long term tear resistance } 1.35 \times T_{max} \leq \phi_t \times T_{al}$$

Long-term design strength (Steel reinforcement):

$$T_{al} = F_y \times A_c / b$$

Where, F_y = yield strength; A_c = net cross-sectional area per unit width after computed corrosion losses over the design life (typically 75 – 100 years); b = gross width of strip.

Long-term design strength (Geosynthetic reinforcement):

$$T_{al} = T_{ult} / (RF_{ID} \times RF_{CR} \times RF_{CD})$$

Table 4-9: Reduction factors for geosynthetic long-term design strength (FHWA NHI-10-024)



Factor	Description	Typical Range
T_{ult}	Ultimate tensile strength (MARV from testing)	kN/m
RF_{ID}	Reduction factor for installation damage	1.05 – 3.0
RF_{CR}	Reduction factor for creep (100-year design life)	1.6 – 5.0
RF_{CD}	Reduction factor for chemical/biological degradation	1.0 – 1.5

Table 4-10: LRFD resistance factors for internal stability limit states (AASHTO 2020, Table 11.5.6-1)

Reinforcement Type	ϕ_t (Rupture)	ϕ_{po} (Pullout)	ϕ_{cr} (Connection)
Steel strip	0.75	0.90	1.00
Steel grid / welded wire	0.65	0.90	1.00
Geosynthetic (all types)	0.90	0.90	0.90

The embedment length L_e is measured from the back of the theoretical failure surface to the free end of the reinforcement. The total reinforcement length is: $L = L_a + L_e$. The minimum total length is typically **0.7H** and not less than 2.4 m (8 ft).

Connection Strength

The connection between the reinforcement and the wall facing must be checked at both the facing panel and the reinforcement:

$$1.35 \times T_{max} \leq \phi_{cr} \times T_{ac}$$

Where T_{ac} = nominal long-term connection strength determined from laboratory testing per ASTM D6638 (geosynthetic) or from manufacturer certification data (steel connectors). The connection strength is often the controlling limit state for segmental block (MBW) faced walls, particularly in the upper portion of the wall where connection capacity is lowest relative to T_{ac} .

Pullout Resistance

The reinforcement must not pull out of the resistant zone. The pullout resistance P_r is computed from the soil-reinforcement interaction along the embedment length L_e beyond the Rankine failure plane:

$$1.35 \times T_{max} \leq \phi_{po} \times P_r$$

The nominal pullout resistance per unit width of reinforcement is:

$$P_r = F^* \times \alpha \times \sigma_v \times C \times L_e \times R_c$$

Where,

F^* = Pullout friction / bearing factor [Geotextile/geogrid: $\frac{2}{3} \tan \phi_r$; Steel strip at $z \geq 6$ m: 1.2 refer to [FHWA NHI-10-024 Table 3-6](#)]

α = Scale effect correction factor [0.6 (geosynthetic); 1.0 (steel)]

C = Reinforcement perimeter factor [2 (strips/geogrids); 2 (sheets)]

R_c = Coverage ratio (Area of reinforcement / Total plan area) [1.0 (full-width sheets)]

Backfill Material



The reinforced fill must conform to the gradation envelope specified in [FHWA NHI-10-024 Table 3-1](#). Gradation has a direct impact on the design, construction, and performance of the wall system. Fine particle content and plasticity are strictly limited to maintain high shear strength and low compressibility.

Table 4-11: MSE wall - granular reinforced fill gradation requirements ([FHWA NHI-10-024](#))

US Sieve Size	Sieve Opening (mm)	% Passing (Min)	% Passing (Max)
4 in (102 mm)	102	100	100
¾ in (19 mm)	19	75	100
No. 4 (4.75 mm)	4.75	20	100
No. 40 (0.425 mm)	0.425	0	60
No. 200 (0.075 mm)	0.075	0	15

Additional requirements:

- Maximum particle size for geosynthetic reinforcement walls: 19 mm (¾ in).
- Maximum particle size for inextensible (steel) reinforcement walls: up to 102 mm (4 in), subject to reinforcement bar spacing.
- Plasticity Index (PI) ≤ 6 ([FHWA NHI-10-024](#)); some agencies permit PI ≤ 10 as an upper bound.
- Fill shall be substantially free of shale, caliche, gypsum, or other soft/soluble particles.
- Coefficient of uniformity $C_u \geq 4$ and C_c between 1 and 3 are preferred for well-graded material.

4.5.4 MSE wall construction procedure

MSE wall construction is a bottom-up, sequential layered process. Each phase must be completed and inspected before proceeding to the next. The flowchart and procedure below outline the standard construction sequence.

01	Foundation Preparation Remove all unsuitable materials (organic soil, vegetation, debris) and compact the foundation to the required bearing capacity. Apply ground improvement measures (stone columns or replacement fill) if the soil is weak.
02	Construction of Leveling Pad Construct a thin unreinforced concrete leveling pad to establish alignment and provide a stable bearing surface for the first row of facing units. The leveling pad is not a structural element.
03	Erection of First Row of Facing Panels Place and carefully align the first row of precast facing elements or modular blocks on the leveling pad. Install temporary bracing or alignment frames where required to maintain verticality.
04	Placement & Compaction of Reinforced Fill



	Place approved select fill material in controlled lifts (typically 200–300 mm compacted) and compact to $\geq 95\%$ of Modified Proctor density up to the elevation of the first reinforcement layer.
05	Installation of Reinforcement Layer Connect geogrid/steel strip reinforcement elements to the facing units and extend them perpendicularly into the fill mass as specified in the design. Ensure proper overlap and embedment length.
06	Repeat Layered Construction Continue the cycle: place and compact reinforced fill, then install the next reinforcement layer. Maintain proper connection at the facing panel, check alignment, and ensure drainage materials are placed as required.
07	Construction of Finishing Elements Complete the wall by installing coping units, traffic barriers, drainage outfalls, erosion protection, and any other appurtenances specified in the project design.

4.6 Soil Nailing

Soil nailing reinforces existing ground by installing closely spaced steel bars grouted into pre-drilled holes. This technique increases the shear resistance and tensile capacity of the soil mass. The soil nailing is a top-down construction method particularly well-suited for steep cuts in residual soils, weathered rock, stiff clays, silty soils, and dense granular soils that can temporarily stand unsupported during nail installation.

Soil nailing may not be suitable for very soft clays, loose sands, or highly organic soils with insufficient self-supporting capacity and are with the shallow water table.

Design Principles and Parameters

The principal design parameters for soil nail walls are as follows:

- i. **Nail Inclination:** 10° – 20° below horizontal (optimum $\approx 15^{\circ}$). Steeper angles reduce nail tension but improve drainage.
- ii. **Nail Length:** Typically, $0.6\text{--}0.8 \times H$ (wall height). Minimum 3.0 m; critical locations may require $L = H$ or longer.
- iii. **Nail Spacing:** 1.0–1.5 m horizontally; 1.0–1.5 m vertically. Typical grid: 1.2 m $\times$ 1.2 m or 1.5 m $\times$ 1.5 m.
- iv. **Nail Diameter:** $\varnothing 25\text{--}40$ mm ribbed Fe415 or Fe500 steel bar. GFRP bars for corrosive environments.
- v. **Grout:** Cement grout w/c = 0.40–0.45; minimum compressive strength 28 MPa at 28 days.
- vi. **Hole Diameter:** 75–150 mm for grouted nails. Grout cover ≥ 20 mm around bar.
- vii. **Facing (Shotcrete):** 100–150 mm reinforced M20 shotcrete (permanent); 75 mm mesh + shotcrete (temporary).
- viii. **Bearing Plate / Nut:** 150 $\times$ 150 $\times$ 10 mm bearing plate; nut torqued to 100–150 Nm.
- ix. **Factor of safety:** Factor of safety against pullout is taken as 2 while for global stability ≥ 1.5 for permanent works

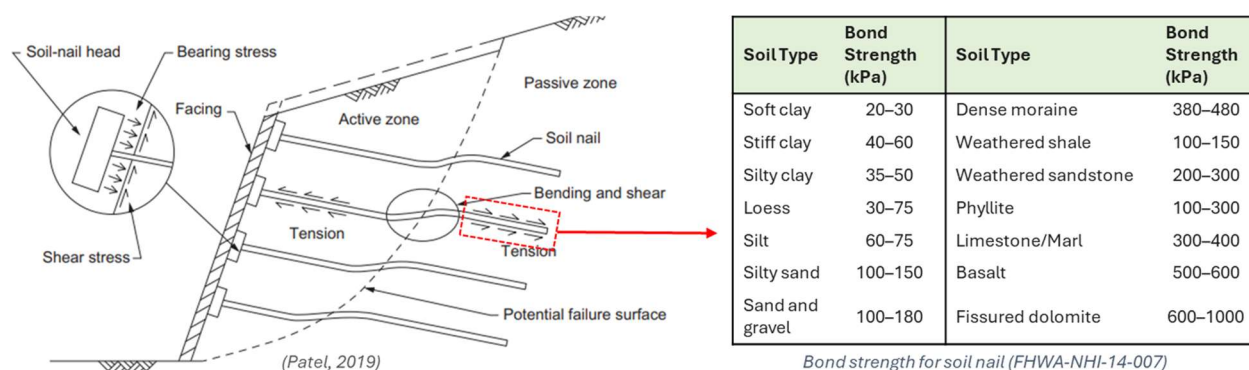


Figure 2.1 — Soil Nailing System: grouted nail bars, shotcrete facing, bearing plates, weep holes, active and stable zones

Key Design Equations

The following fundamental equations govern the design of soil nail walls:

Pullout Resistance	$T_{pullout} = \pi \cdot d_h \cdot L_e \cdot q_s$	d_h = hole dia. (m); L_e = embedment in stable zone (m); q_s = bond stress (kPa)
FOS (Pullout)	$FOS_{pullout} = \frac{T_{pullout}}{T_{design}} \geq 2.0$	Must be verified for every nail at each design stage
FOS (Global)	$FOS = \frac{(c \cdot L_{slip} + N \cdot \tan \phi + \sum T_n \cdot \cos \alpha)}{\sum T_{driving}} \geq 1.5$	$\sum T_n$ = sum of nail forces crossing failure surface; α = nail inclination
Tensile Capacity	$T_{nail} = f_y \cdot A_\beta$	f_y = yield strength (MPa); A_β = cross-sectional area (mm ²)
Facing Flexure	$M_{face} = C_{FP} \cdot T_{nailmax} \cdot S_h \cdot S_v$	$C_{FP} \approx 0.25$ (FHWA coefficient); S_h , S_v = nail spacing (h & v)
Punching Shear	$V_{punchout} = f_{cp} \cdot \pi \cdot d_{eff} \cdot t_f$	f_{cp} = punching shear strength; d_{eff} = effective dia.; t_f = facing thickness
FOS (Sliding)	$FOS = \frac{[(W + q \cdot B) \cdot \tan \phi + c \cdot B]}{P_a} \geq 1.5$	P_a = active earth pressure; W = wall weight; q = surcharge; B = base width
Embedment Length	$L_e = (T_{design} \cdot FOS_{pullout}) / (\pi \cdot d_h \cdot q_s)$	Solve for L_e ; use actual q_s from site pull-out tests where possible

Soil Nailing Construction Procedure (Clause 302, DoR (2025))

01	Initial Excavation Cut (1.0–1.5 m depth) Excavate the first cut to the design depth (typically 1.0–2.0 m). Trim the cut face to a smooth, stable surface. No over-excavation permitted since stability depends on soil stand-up time.
02	Drilling of Nail Holes



	Drill nail holes at the designed inclination (10°–20° below horizontal) using rotary percussion or air-track drills. Hole diameter typically 75–200 mm. Verify alignment and depth with survey instruments.
03	Nail Installation and Grouting Insert centralized steel bar into the drilled hole. Inject cement grout (w/c = 0.4–0.5) under low pressure from the bottom upward until full. Grout must achieve 20MPa minimum at 28 days.
04	Installation of Bearing Plate & Nut Once grout has gained sufficient strength, install the bearing plate (200×200×19 mm) and hex nut. Torque nut to 100–150 Nm to confirm nail integrity (load test on selected nails per specification).
05	Application of Shotcrete Facing Apply 75–100 mm (temporary) or 100–150 mm (permanent) reinforced shotcrete to the cut face. Install welded wire mesh, drainage strips/geo-composite, and weep holes before applying the final shotcrete layer.
06	Repeat for Next Stage Proceed to the next excavation lift. Repeat Stages 1–5 for each subsequent cut level, maintaining a maximum unsupported height in accordance with soil stand-up time. Overlap reinforcement as designed.
07	Final Facing and Surface Drainage Apply the final permanent shotcrete layer, architectural finish (if required), coping elements, and surface drainage ditches. Install subsurface drainage as designed. Conduct final inspection and load testing.

4.7 Fills and Spoil Management

Road construction in hilly terrain generates significant volumes of excavated material (spoil) from cutting. Improper spoil management is one of the primary triggers of road-induced landslides in Nepal spoil tipped unsupported without drainage or compaction becomes a major instability hazard during the monsoon.

4.7.1 Site selection criteria

Box 4.2: Spoil Disposal Site Selection Criteria

Mandatory Exclusion Zones:

- Side-cast or tipped uncontrolled down the hillslope, or tipped over retaining walls unless the wall is founded on non-erodible rock.
- Placed in or adjacent to active stream channels or rivers.
- Placed in areas of known or suspected deep-seated instability, "sinking" ground, or active landslide scarps.
- Placed at sites with natural springs, high groundwater, or upslope of any intake.
- Placed within 50 m of any structure (house, school, health post, public building).

Preferred Site Characteristics:

- Level ground or stable terraces; dry valleys; tops of spurs.
- Stable, gently sloping ground (natural slope < 25°) on a competent foundation.
- Sites where material can be contained by natural topography (hollow, depression, stable toe).



- Locations where a toe structure (masonry wall, gabion, or compacted berm) can be built.
- Several smaller sites in preference to one large one, to avoid slope overload.

Minimum Requirements:

- Spoil placed and compacted in layers; on completion the surface reshaped, drained, and bioengineered (grass/shrub cover) against erosion.
- Site drainage designed and completed before placement begins; natural watercourses left undisrupted.
- Environmental clearance where the site exceeds the threshold (IEE/EIA).
- Landowner consent documented in writing before disposal commences.
- Spoil disposal identified at design stage, included in the Environmental Management Plan, and prepared separate BoQ item.

4.7.2 Components of a designed spoil disposal site

Table 4-12: Components of spoil disposal site

Component	Requirements and Specifications
1. Toe Wall / Structure	Toe wall (H = 1.5–3.0 m) or compacted rock toe berm at the downslope edge. Must be constructed before any spoil is placed.
2. Drainage Network	Surface runoff drains along upslope edge. Sub-surface perforated drain at base of spoil above natural ground level. Similarly, a grannual layer of 300mm thick shall be used to enhance the subsurface drainage (Figure 4.13).. Side slope drains at 30–50 m intervals. All drains discharge to stable outlet.
3. Compaction	All fill placed in horizontal layers ≤ 300 mm loose thickness. Compact to achieve $\geq 90\%$ Modified Proctor density (AASHTO T-180). Each layer of compaction should approved by Engineer.
4. Battered / Reinforced Face	Final outer face not to exceed 1V:1.5H slope. Where steeper face is unavoidable, wrap with geotextile reinforcement at 0.5 m vertical intervals, or construct terrace walls at 3–4 m vertical intervals (Figure 4.13).
5. Bioengineering	All exposed faces vegetated within one monsoon season. See Chapter 6 for techniques and species selection. Jute netting required on slopes $> 30^\circ$.

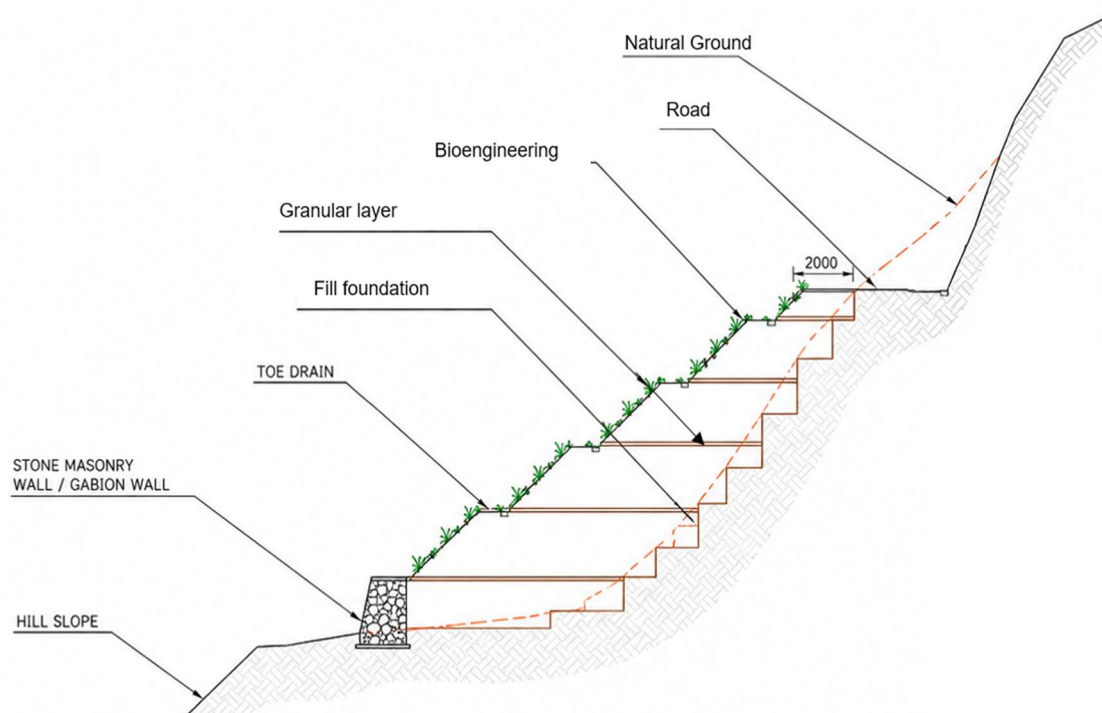


Figure 4.13: Typical component of spoil disposal sites

4.8 Construction Sequencing and Temporary Support

On steep terrain or in deep excavations, stability of exposed slopes and surrounding structures must be maintained throughout construction. This requires careful sequencing, the order in which excavation proceeds and the use of temporary support systems where the ground cannot safely stand unsupported.

Safety Requirements for All Excavations (Nepal Labour and Occupational Safety Regulations)

- No person shall enter an excavation unless it is properly sloped, benched, or supported with shoring where required by soil conditions. Protective systems are mandatory for unstable excavations typically deeper than 1.2–1.5 m
- Warning signs, barriers and lighting must be in place at all times around open excavations.
- If unexpected seepage, movement or cracking is observed: immediately remove personnel; do not re-enter until stability is confirmed.
- Spoil shall be placed at least 1.0 m from the edge, or beyond the calculated failure zone, whichever is greater.



CHAPTER 5. WATER MANAGEMENT

Water is the most critical factor contributing to roadside slope instability in Nepal. Almost every major landslide and slope failure along the road network of Bagmati Province is primarily triggered by water-related processes. These include soil saturation from monsoon rainfall, erosive surface runoff on cut faces, increased pore-water pressure from subsurface seepage, and the failure of drainage infrastructure such as blocked culverts or channels, that redirects flow onto unprotected slopes.

Effective water management is not only important for erosion control; it is essential prerequisite for all slope stabilization efforts. Without integrated drainage, other engineering interventions are likely to fail:

- **Bioengineering systems** are easily undermined if slopes remain saturated.
- **Retaining structures** without adequate weep holes succumb to hydrostatic pressure.
- **Cut slopes** lacking upslope catch drains are subject to continuously destabilized by runoff.

The core technical principle is to intercept water before it reaches the slope, collect it in well-engineered channels, convey it at non-erosive velocities, and discharge it safely at stable locations.

5.1 Scope and Regulatory Framework

This section details the essential components of roadside water management, ranging from surface and subsurface systems to energy dissipation and river setbacks.

Component	Function
Surface Drainage	Intercepts and removes runoff from the road surface and cut slopes via side drains and catch drains.
Subsurface Drainage	Lowers the water table and reduces pore-water pressure within the soil mass using sub-drains or horizontal drains.
Cross-Drainage	Facilitates the safe passage of water across the road alignment through culverts and bridges.
Energy Dissipation	Reduces the velocity of water at discharge points using cascading steps, rip-rap, or stilling basins to prevent downstream scouring.

The design procedures presented are based on the following national standards:

- **DoR Standard Specifications for Road and Bridge Works** (2073/2078 BS)
- **DoR Guide to Road Slope Protection Works** (2003)
- **DoR Roadside Geotechnical Problems**
- **DoR Road Safety Notes on Drainage Design**
- **DHM Rainfall Data** (specific to the Bagmati Province catchments)



5.2 Principles of Roadside Water Management

The following four principles form the basis of all water management decisions for roads in Bagmati Province. These principles are hierarchical; each must be systematically addressed to ensure the effectiveness of subsequent measures.

Principle	Application
Intercept	Prevent upslope surface water from reaching the road formation and vulnerable slope faces. Typical measures include catch drains above cut slopes and scour checks in natural channels above the road.
Collect	Collect water from the road surface, slope face, and subsurface seepage into properly designed drainage systems. Common measures include side drains, bench drains, and subsurface drains.
Convey	Transport collected water at a controlled velocity—engineered to be high enough to prevent siltation, yet low enough to avoid channel erosion. Typical structures include lined channels, cascade drains, and chutes.
Discharge	Release water at designated stable locations safely away from slopes and road structures. Preferred discharge points include natural watercourses, gabion-protected outfalls, or dedicated energy dissipating structures.

Additional principles specific to mountain road drainage are outlined below:

- **Frequency over size:** A larger number of smaller and more frequent drainage outlets is generally more reliable than a few large structures. In mountainous terrain, blockage of a single large culvert can lead to severe slope failure or road washout, whereas multiple smaller culverts provide redundancy and reduce overall risk.
- **Gravity-based drainage:** Drainage systems should be designed to function entirely by gravity, without dependence on pumping systems in permanent infrastructure. Road alignments and drainage layouts should ensure that runoff can discharge naturally downhill into stable watercourses.
- **Drain before stabilization:** Slope stabilization and bioengineering works should only be implemented after the drainage system is fully functional. Proper drainage must be established first to prevent saturation and failure of stabilization measures during rainfall events.
- **Design for blockage:** All drainage structures, particularly culverts and cross-drains, should be designed with the assumption that partial blockage from debris will occur periodically. For mountain roads, an additional 25–50% hydraulic capacity should be provided to accommodate debris flow and sediment accumulation.
- **Maintenance as a design requirement:** Drainage structures that are not regularly maintained will eventually fail, regardless of their design capacity. Therefore, drainage systems must be planned and constructed with maintainability in mind, including safe and practical access for routine inspection, cleaning, and repair at least once every year.



5.3 Hydrological Studies

Comprehensive drainage systems are engineered to collect and remove surface runoff while mitigating unfavorable groundwater conditions that could compromise road stability. To ensure these systems are both effective and resilient, detailed hydrological studies are a must prior to the selection or design of any drainage infrastructure. These studies are undertaken to:

- Determine catchment area for drainage systems;
- Determine rainfall intensities for project areas;
- Determine the runoff coefficient of the different land use and cover of the catchment;
- Estimate peak/maximum flows.

5.3.1 Catchment delineation

The catchment area is the area of the watershed that contributes runoff to a specified point in the drainage system. The catchment area for a given location can be estimated using topographical maps, aerial photographs or by using terrain model map in Google Earth Pro.

1. Catchment Delineation using Topographical Maps

Topographical maps use contour lines to represent the 3D shape of the terrain. Delineation on these maps follows the principle that water flows perpendicular to contour lines. It is generally done using topographic maps with a scale of 1:25,000 or larger.

Steps for Delineation:

- I. **Map the proposed Road alignment:** Plot the proposed road alignment on the topographic map.
- II. **Identify the potential drainage location:** Locate the specific points along the road alignment for drainage structures. These locations should be established through field locations.
- III. **Locate High Points and Ridges:** Identify the high points and ridgelines surrounding each drainage location. The catchment boundary follows the ridges connecting these high points. Water on one side of the ridge flows toward the catchment, while water on the other side flows away. The catchment boundary should cross contour lines at right angles. Existing paths or trails often follow ridgelines and can be used as a guide.
- IV. **Trace the Boundary:** Starting from the outlet, draw a line upward, crossing contour lines at right angles (perpendicularly).
- V. **Follow the Ridge Line:** Continue the line upward until you reach the highest point (peak). Then, follow the ridge lines around the slope until the boundary closes back at the outlet.
- VI. **Verify Flow Direction:** Ensure that all area inside your boundary slopes toward the roadside outlet.

2. Catchment Delineation using Google Earth Pro

Google Earth provides a more visual approach using satellite imagery and built-in Digital Elevation Models (DEM). A step-by-step interactive workflow for catchment delineation is presented in [Figure 5.1](#).

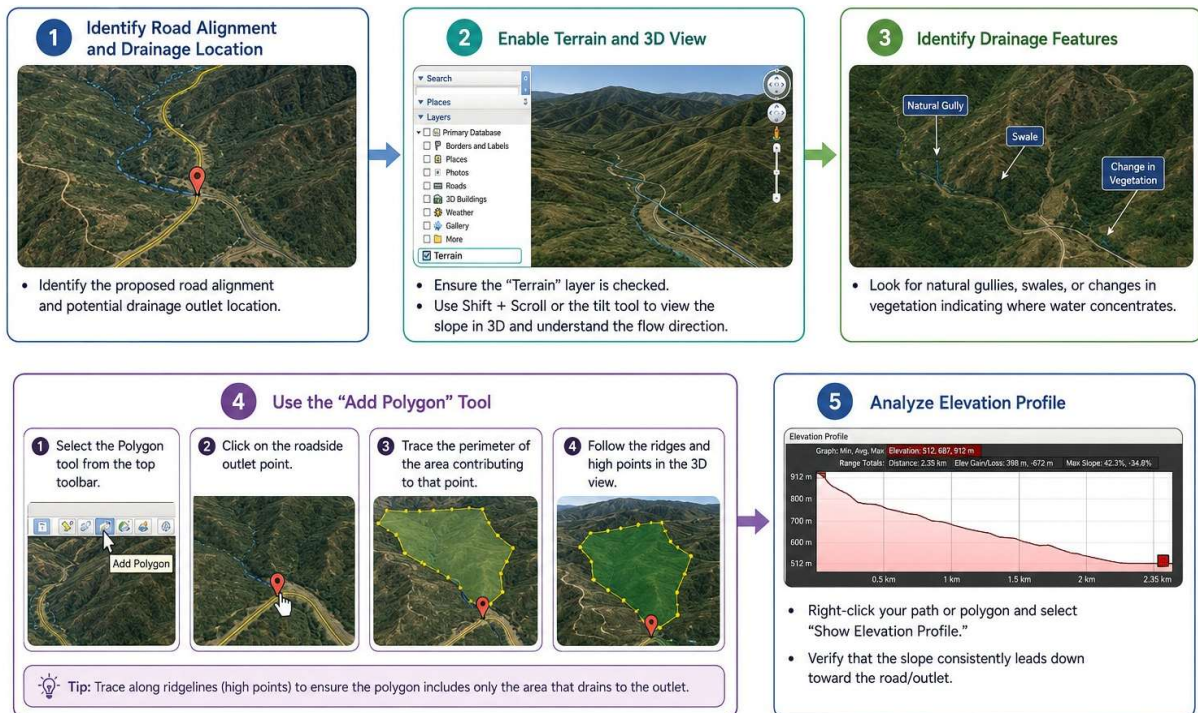


Figure 5.1: Catchment delineation workflow using Google Earth.

5.3.2 Rainfall analysis

Rainfall characteristics, together with catchment conditions, determine the flows on which storm drainage design is based. Although actual rainfall intensity varies throughout a precipitation event, standard engineering procedures often utilize an assumed constant intensity to calculate peak discharge during the design storm period.

Rainfall Intensity and IDF Curve

Rainfall Intensity (I) represents the rate of precipitation over a specific timeframe, typically measured in millimeters per hour (mm/h). Because rainfall patterns vary geographically, Intensity-Duration-Frequency (IDF) curves, developed from long term rainfall data provided by Department of Hydrolog and Meteorology (DHM) are used to determine the design intensity for a specific project. These curves relate rainfall intensity to storm duration and probability of occurrence for specific locations within the country.

Key Principles of IDF Application

- Inverse Relationship:** As the duration of a storm increases, the average intensity typically decreases. Short-duration storms (e.g., 15 minutes) usually exhibit much higher intensities than long-duration storms (e.g., 24 hours).
- Return Period Selection:** The Frequency or Return period is chosen based on the importance of the road and the risk of failure.
- Design Accuracy:** Utilizing site-specific IDF data ensures that drainage structures are neither under-designed (leading to washouts) nor over-designed (leading to unnecessary construction costs).



5.3.3 Estimation of peak flow

Estimation of peak flow or maximum discharge is critical for proper design and sizing of drainage structures. The peak flows can be determined using different methodologies depending upon the available information/data and size of catchment area. Some of the methods that used include:

1. Field Observation
 - a. Direct observation of the size of flow channel or watercourse
 - b. Historical and local knowledge
2. Rational Method
3. Modified Rational Method

Rational Method

The Rational Method is the most widely used method for estimating peak flow. It is based on direct relationship between rainfall and runoff. The maximum discharge is given by the expression

$$Q = 0.278 * C * I * A \quad \dots \dots \dots (\text{Eq. 5-1});$$

Where: Q = Maximum Discharge or Peak Flow, (m^3/s); C = Runoff Coefficient; I = Rainfall Intensity, (mm/h); A = Catchment Area, (Sq. Km)

The Rational formula gives satisfactory discharge results for small catchment areas.

Runoff Coefficient, C

The runoff coefficient depends on the type of ground cover, vegetation, and road surface within the catchment area. Typical runoff coefficient values for different surface conditions, used in the Rational Formula, are presented in the [Table 5-1](#) below. For catchments containing different types of vegetation cover and land surfaces with varying areas (A), the effective runoff coefficient is determined using the following expression:

$$C = \frac{\sum C_i \cdot A_i}{\sum A_i} \quad \dots \dots \dots (\text{Eq. 5-2});$$

Table 5-1: Values of runoff coefficient, C (DoR-Road drainage guidelines and regional references)

Surface / Land Use Description	Runoff Coefficient C
Steep bare rock; concrete / bitumen pavement surface	0.85 – 0.95
Steep rock with some vegetative cover	0.75 – 0.85
Bare stiff clay (impervious soil); cut slope	0.60 – 0.70
Stiff clay with vegetative cover; compacted gravel road	0.45 – 0.60
Loam soil, lightly cultivated or covered; disturbed slope	0.35 – 0.45
Loam largely cultivated, turfed, or grassed	0.25 – 0.35
Sandy soil, light growth, parks, meadows	0.15 – 0.25
Sandy soil with heavy brush or forested areas	0.05 – 0.15

Time of Concentration, t_c

It is also referred to as “Inlet time”. The Federal Highway Administration defines the time of concentration as the time required for runoff to travel from the hydraulically most distant point in a



drainage area to the point under consideration. This can be determined from the parameter gathered from the topographical maps. From Kirpich formula,

$$t_c = 0.0195 * \left(\frac{L}{H}\right)^{0.385} \quad \dots \dots \dots (\text{Eq. 5-3});$$

Where: L = Length of Flow Path (m); H = Height Difference (m)

For small catchments on steep mountain roads, t_c is typically 5–20 minutes.

Modified Rational Method

The Modified Rational Method takes into account the spatial variation of rainfall intensity across a larger catchment. The effective area of the catchment is reduced by multiplying by the **Areal Reduction Factor (ARF)** given by the following equation:

$$Q = 0.278 * C * I * A * ARF \quad \dots \dots \dots (\text{Eq. 5-4});$$

Where,

Q = Maximum Discharge or Peak Flow, (m^3/s)

C = Runoff Coefficient

I = Rainfall Intensity, (mm/h)

A = Catchment Area, (Sq. Km)

ARF = Areal Reduction Factor ($ARF = 1 - 0.04 * T^{-1/3} * A^{0.5}$)

T = Storm Duration in Hours

5.4 Channel Hydraulics

Hydraulic analysis is carried out to estimate the size of drainage structure that will be able to pass the calculated maximum flow for particular catchment within the limited/allowable flow conditions.

Channel Design Using Manning's Equation

Once the peak discharge Q is known, the drain cross-section and longitudinal slope are selected using Manning's equation for open channel flow:

$$Q = \frac{1}{n} * A * R^{2/3} * S^{1/2} \quad \dots \dots \dots (\text{Eq. 5-5});$$

Where,

Q = Maximum Discharge or Peak Flow, (m^3/s)

n = Manning's roughness coefficient

S = Drain Bed Slope, (m/m)

R = Hydraulic Radius = A/P

A = Flow Area, (Sq. m)

P = Wetted Perimeter of channel flow section, (m)

Manning's roughness coefficient (n) and maximum permissible velocities for roadside drains:



Table 5-2: Manning coefficients and limiting velocities for different channel linings.

Drain Lining / Surface Type		Manning's n	Max. Permissible Velocity (m/s)
Smooth trowel-finished concrete		0.012 – 0.014	6.0
Float-finished concrete		0.013 – 0.015	6.0
Cement stone masonry (1:4)		0.017 – 0.020	4.5 – 5.0
Dressed stone in mortar		0.015 – 0.017	5.0 – 6.0
Rough stone / riprap lining		0.025 – 0.030	4.0 – 4.5
Gabion lining		0.028 – 0.035	3.5 – 4.5
Dense turf (grass-lined)		0.030 – 0.050	0.9 – 1.2
Bare earth, no protection		0.020 – 0.026	0.3 – 0.6
Bituminous / asphalt surface		0.013 – 0.016	5.0 – 6.0
Natural rock channel	smooth and uniform	0.035 – 0.040	5.5 – 6.0
	Jagged	0.040-0.045	-
	Soft	-	2.5
	Hard	-	5.5

5.5 Surface Drainage Systems

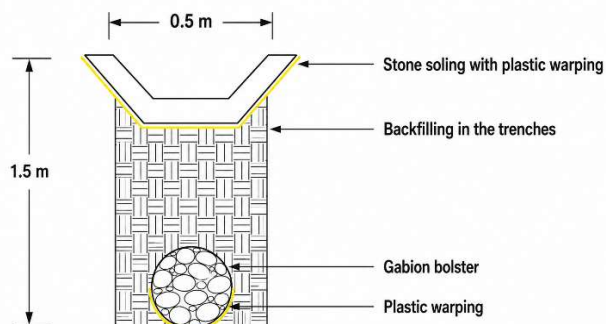
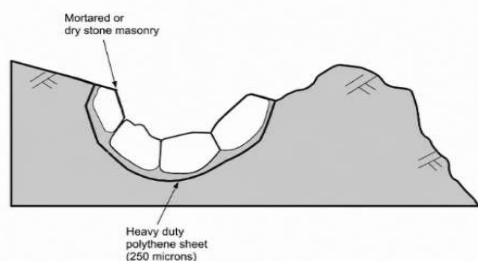
Surface drainage systems are designed to collect and safely discharge rainfall runoff from road surfaces and adjacent slopes before it can cause erosion or slope saturation. The main components include side drains, catch drains, bench drains, cascade drains, and cross-drainage structures.

5.5.1 Catch drains

Catch Drains

Intercepts surface runoff from hillside above cut slope before it reaches the road — the most effective erosion prevention measure

Cut-off drain



(Source: [Hearn, 2011](#))



Overview and Applicability

- Constructed 2–5 m above the top of the cut slope, aligned along the slope contour.
- Intercepts hillside runoff before it cascades over the cut face and erodes it.
- Reduces quantity of water reaching the road and cut slope by 60–90%.
- Most cost-effective single drainage intervention on hill roads (DoR Guide, 2003).
- Also used above fill slopes to prevent overtopping of embankment edge.
- It can be provided with subsurface drains with gabion bolster.
- Types:
 - Unlined or Lined cut-off drain
 - Sub-soil cut-off drain
 - Lined cut-off drains with subsoil drain
 - Bench drains on cut slopes
 - Berm drains on fill slopes

Design Considerations

- Design discharge: Calculated from runoff from natural hillside catchment above the road using Rational Method.
- Catchment delineation: Catchment delineated from topographic maps, typically 50–200 m upslope from road alignment.
- Longitudinal Slope: Provide a minimum gradient of 2% longitudinal gradient, directing flow to stable discharge points on both sides.
- Lining: Stone masonry is preferred; concrete should be used where discharge is high.
- Side slopes: Construct side slopes between 0.5:1 to 1:1; bench width $\geq$ 600 mm.
- Location: Position the catch drain at least 1.5m behind the crest of the cut slope; placing it closer may destabilise the cut face.

Construction

- Survey contour line at selected depth above cut crest.
- Excavate trapezoidal or V-shaped section.
- Line with stone masonry (1:4 mortar) or concrete.
- Discharge at stable natural watercourses, not onto fill slopes or unprotected ground.
- Inspect annually after monsoon; clear blockages

Typical Dimensions

- Typical size: 400–600 mm wide $\times$ 300–400 mm deep.
- Position: 2–5 m above cut crest.
- Longitudinal slope: 2–8% (flatter than road gradient to avoid overtopping).

Common Failures & Remedies

- Blockage by fallen trees / debris :requires clear access; avoid locating in dense forest.
- Poorly sited outfall eroding fill slope : must discharge to stable stream using Cascade structures, not onto slope.
- Under-designed (silted) drains redirect water over cut face : clean after every storm.

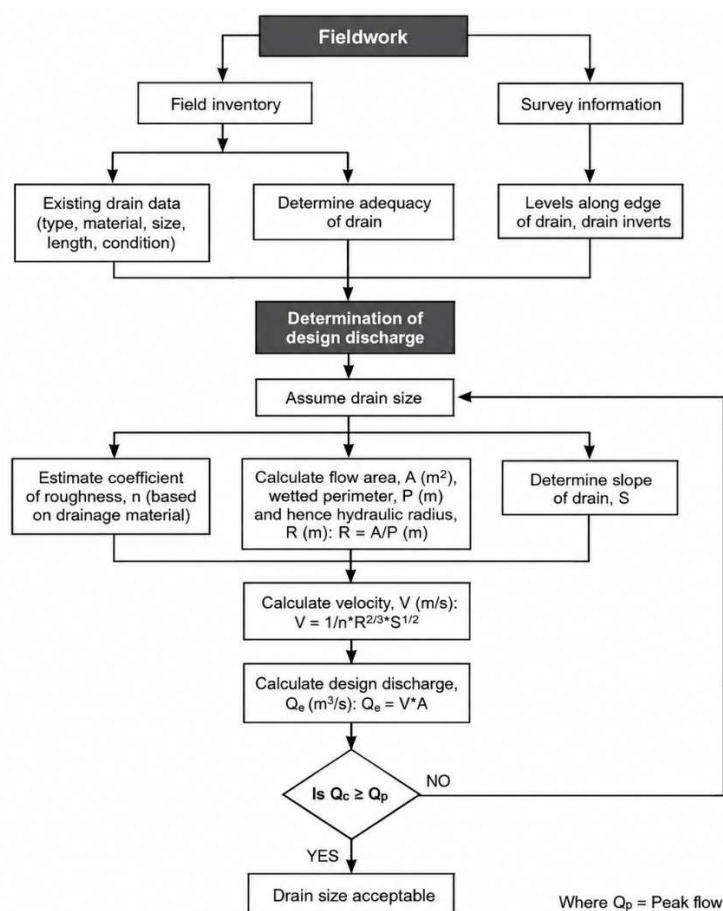


Figure 5.2: Flow chart for estimation of flow capacities of drains

Box 5.1: Experience with cut-off drains in Nepal

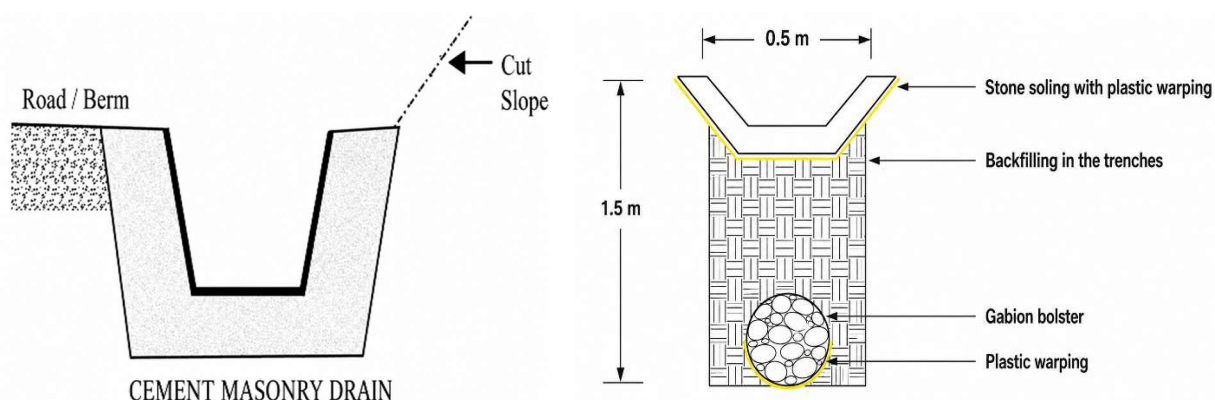
Cut slopes formed along mountain roads constructed in the 1970s and 1980s in Nepal were often provided with cut-off drains located above the slope crest as standard practice. These were predominantly lined with mortared masonry (Type 1) and were intended to intercept surface runoff before it was able to flow over the cut slope and cause erosion or shallow slope failure. Where some of these drains had been excavated into residual soils, they were quickly undermined by seepage erosion caused by shallow subsurface flow in the saturated soils above rock head level. This was most common in the silty, sandy soils derived from in situ weathered high-grade metamorphic rocks. In the more clayey residual soils, the drains tended to be less susceptible to this mode of failure. Where cut-off drains intercepted surface runoff in the manner intended, they often became blocked by sediment and vegetation debris and thus ceased to function due to irregular maintenance. Unlined cut-off drains were sometimes used instead. However, these often became subject to invert scour and ultimately gully on the steeper gradients. They also led to leakage into the surrounding soil as a result of seepage on shallower gradients and at low points in the topography (Hearn, 2011).



5.5.2 Side Drain (Roadside Longitudinal Drain)

Side Drain (Roadside Longitudinal Drain)

Collects road surface runoff and seepage from cut slope; directs it to cross-drainage outlets



(Source: DoR, 2007)

Overview and Applicability

- Primary surface drainage element along the upslope (mountain side) edge of the road.
- Collects: road surface runoff from camber, seepage from cut face, bench drain discharge.
- Discharges to cross-drainage (culverts) at regular intervals: DoR recommends one outlet every 60–100 m on steep hill roads.
- Shape: V, U, trapezoidal, or composite depending on expected discharge and slope.

Design Considerations

- Design discharge: Rational Method for catchment from road surface + adjacent cut slope.
- Design return period: 10-year storm in low hazard zone and 25-year storm in critical areas.
- Minimum slope: 0.5% (0.005 m/m) to prevent silting.
- Maximum slope: Limited by allowable velocity for lining (see Manning table).
- Minimum depth: 300 mm (after accounting for 75 mm freeboard).
- Lining: concrete (M15) preferred; stone masonry acceptable. Unlined only on temporary roads.
- Freeboard: minimum 75 mm above design water depth.
- Debris allowance: size drain for 125% of calculated Q (25% extra for debris blockage).

Construction

- Trim and level drain bed; compact subgrade.
- Cast in-situ concrete (M15 plum) or lay stone in mortar 1:4.
- Construct in 5–10 m panels; include joints at 5 m intervals (filled with bitumen).
- Invert level must fall consistently; verify with level throughout construction.
- Install chute or cascade at base of slope before commencing side drain.
- Ensure outlet discharges away from fill slope face.

Typical Dimensions

Common Failures & Remedies



- | | |
|--|--|
| <ul style="list-style-type: none">• V-drain: depth 300–500 mm, half-angle 45°.• U-drain: width 300–500 mm, depth 250–400 mm.• Trapezoidal: base 400 mm, side slope 1:1 to 1:1.5.• Min slope: 0.5% Max slope (for concrete): up to 5% without cascade. | <ul style="list-style-type: none">• Silting: caused by slope >15% too flat or debris accumulation — clean minimum annually.• Cracking: from differential settlement — construct on firm subgrade; use joints.• Overflow: undersized drain or blockage — resize or install additional outlets. |
|--|--|

5.6 Sub-Surface Drainage Systems

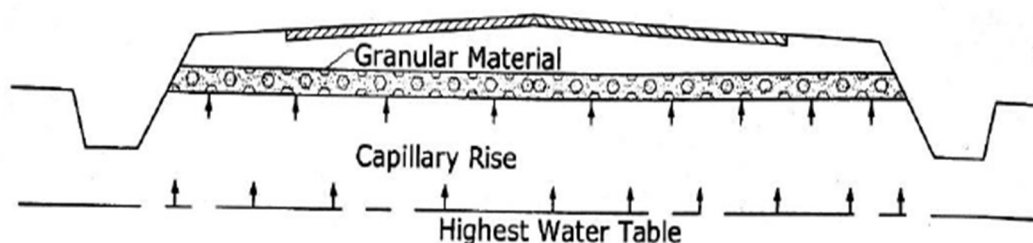
Subsurface drainage deals with water that moves beneath the ground surface through soil layers or geological formations below the road. In the deeply weathered hillsides and fractured rock conditions, subsurface water is often a major factor affecting slope stability. A slope may appear dry at the surface while remaining saturated below ground, resulting in high pore-water pressure that can trigger slope failure even after rainfall has ended.

The main subsurface drainage systems used for road slopes are described below. Proper geotechnical investigation is required to determine the source, depth, and movement of subsurface water before designing these systems.

5.6.1 Sand blanket (Drainage blanket)

Sand Blanket / Drainage Blanket

Permeable granular layer placed beneath road formation or behind retaining wall to intercept and drain subsurface water



Overview and Applicability

- Placed between the natural ground and the road subgrade, or between backfill and retaining wall.
- Intercepts seepage from cut slopes before it reaches the road formation.
- Prevents capillary rise of groundwater into pavement subgrade.
- Must be wrapped in geotextile to prevent contamination by fines.

Design Considerations

- Grading: Type A aggregate: D50 = 9.5–37.5 mm; fines < 5%.
- Thickness: minimum 150 mm (as GSB drainage layer) up to 300 mm for high seepage.
- Geotextile wrap: non-woven geotextile 150 g/m² on all sides except top.
- Discharge: connect to perforated pipe drain or 'daylight' at slope edge.



Permeability: $k \geq 15$ m/day for drainage blanket function

Construction

- Compact subgrade; lay geotextile with 300 mm overlap at joints.
- Place granular material in 150 mm layers; no fines or clay contamination.
- Wrap geotextile over top before placing fill or subgrade layers.
- Connect to outlet drain — do not allow water to pond within blanket.

Typical Dimensions

- Layer thickness: 150–300 mm.
- Aggregate D50: 5–40 mm (well-graded, clean).
- Permeability: $k \geq 15$ m/day

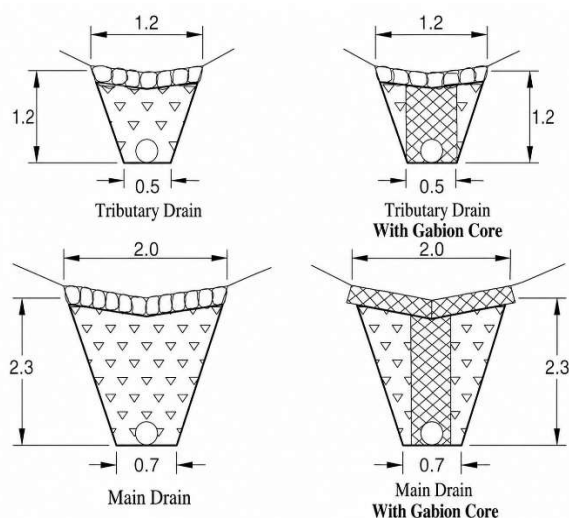
Common Failures & Remedies

- Contamination by fines: geotextile wrapping is critical; re-grading after settlement can damage wrapping.
- Blocked outlet: blanket becomes ponding reservoir — verify outlet is functional and clear.

5.6.2 French drain

French Drain

Gravel-filled trench with perforated pipe that intercepts and collects subsurface water from seeping hillsides



(Source: [DoR, 2007](#))

Overview and Applicability

- Excavated trench filled with clean gravel surrounding a perforated PVC or HDPE pipe.
- Intercepts seepage from cut hill slopes and at the base of fill slopes.
- Can be placed in longitudinal, transverse, or herringbone (fishbone) patterns depending on seepage location.
- Particularly effective for interception of perched water tables or seepage at geological contacts.
- Widely used on Charnawati Rehabilitation (Lamosangu-Jiri) and Arniko Highway stabilization works (DoR, 2007).



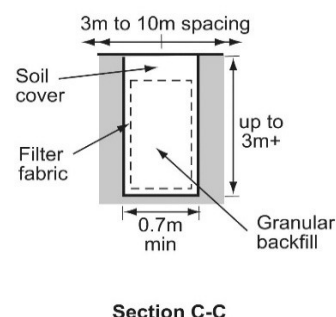
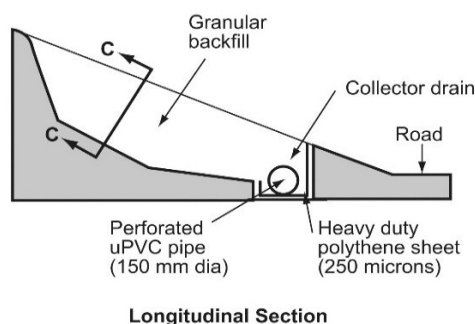
Design Considerations		Construction
- Trench width: minimum 300 mm (DoR drainage guideline); wider for high seepage flows. - Depth: to base of seepage zone or to permeable stratum; typically, 1.0–3.0 m. - Fill: clean washed gravel (D50 = 20–50 mm; < 5% fines) in geotextile sleeve. - Pipe: 100–150 mm perforated HDPE or uPVC pipe; minimum 0.5% slope. - Geotextile: wrap entire gravel-filled trench with non-woven geotextile 200 g/m². - Outlet: pipe discharges to lined channel or stable watercourse; includes rodding eye for maintenance.		- Excavate trench to design depth; keep bottom level; pump if water seeps during construction. - Line trench with geotextile; place 100 mm gravel; lay perforated pipe; surround with gravel. - Fold geotextile over top of gravel before backfilling. - Connect outlet to surface drain with non-perforated solid pipe; install rodding eye at junction. - Record as-built position and depth for future maintenance reference.
Typical Dimensions	Common Failures & Remedies	
- Trench width: 300–600 mm. - Depth: 1.0–3.0 m. - Pipe diameter: 100–150 mm perforated. - Aggregate: D50 = 20–50 mm.	- Geotextile torn during installation — use robust geotextile ($\geq 200 \text{ g/m}^2$); handle carefully. - Pipe crushed or displaced by compaction — use SDR 35 or stronger rated pipe in trench. - Outlet blocked: inspect and flush minimum annually; install rodding eye at change of direction.	

5.6.3 Counterfort drains

Counterfort drains

Gravel-filled trench with perforated pipe that intercepts, collects and provides deeper drainage and groundwater drawdown

Counterfort drain



(source: [Hearn, 2011](#))

Overview and Applicability

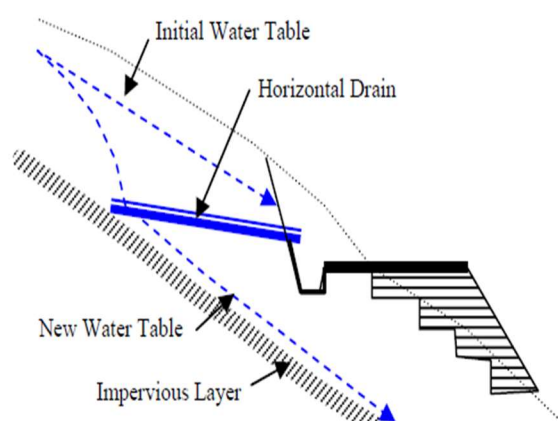


- Excavated trench filled with clean gravel, rocks and granular fills surrounding a perforated PVC or HDPE pipe. - Intercepts seepage from cut hill slopes and at the base of fill slopes. - These drains are usually constructed along the line of maximum slope and are often dug to a depth of 3 m or more at intervals of 3–10m depending on the permeability of the subsoil. - Particularly effective for interception of perched water tables or seepage at geological contacts. - When constructed to sufficient depth, it breaks up the continuity of the failure surface and provide some frictional buttressing against further movement.	
Design Considerations	Construction
- Trench width: minimum 700 mm (Hearn, 2011); wider for high seepage flows. - Depth: to base of seepage zone or to permeable stratum; typically, over 3.0 m. - Fill: clean washed gravel (D50 = 20–50 mm; < 5% fines) in geotextile sleeve. - Pipe: 100–150 mm perforated HDPE or uPVC pipe; minimum 0.5% slope. - Geotextile: wrap entire gravel-filled trench with non-woven geotextile 200 g/m². - Outlet: pipe discharges to lined channel or stable watercourse; includes rodding eye for maintenance. - They are spaced 3-10m between adjacent drains.	- Excavate trench to design depth; keep bottom level; pump if water seeps during construction. - Line trench with geotextile; place 100 mm gravel; lay perforated pipe; surround with gravel. - Fold geotextile over top of gravel before backfilling. - Connect outlet to surface drain with non-perforated solid pipe; install rodding eye at junction. - Record as-built position and depth for future maintenance reference.
Typical Dimensions	Common Failures & Remedies
- Trench width: 600-800 mm. - Depth: over 2.5-3.0 m. - Pipe diameter: 100–150 mm perforated. - Aggregate: D50 = 20–50 mm.	- Geotextile torn during installation — use robust geotextile (≥ 200 g/m²); handle carefully. - Pipe crushed or displaced by compaction — use SDR 35 or stronger rated pipe in trench. - Outlet blocked: inspect and flush minimum annually; install rodding eye at change of direction.

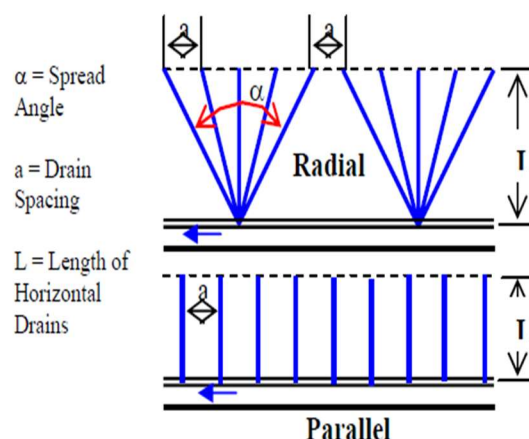
5.6.4 Drilled horizontal drain

Drilled Horizontal Drain

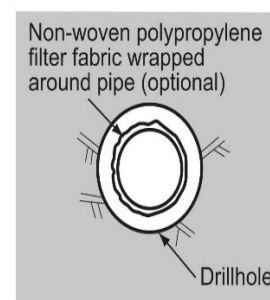
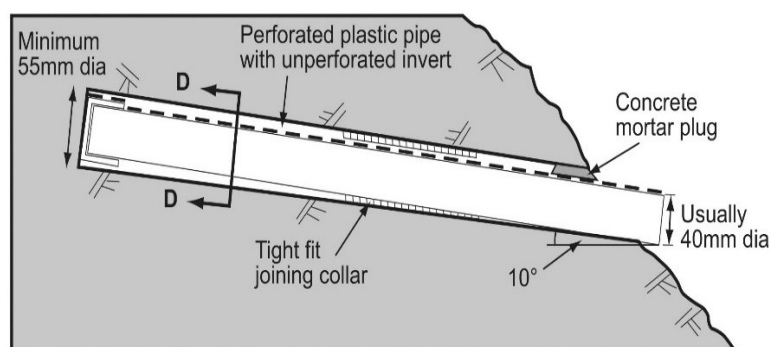
Also called 'pin drains' or 'horizontal borehole drains', small diameter perforated PVC Pipes drilled into slope faces, draining the groundwater from saturated zones by gravity.



(Source: DoR, 2007)



Sub-horizontal drain



Section D-D

(Source: Hearn, 2011)

Overview and Applicability

- Drilled with rotary or air-flush percussion drill and perforated pipe installed afterwards.
- Drains groundwater table at site with fluctuations, during monsoon season.
- Can be placed in parallel orientation or in radial form as shown in diagram.
- Particularly effective for interception of perched water tables or seepage at geological contacts.
- Widely used on Charnawati Rehabilitation works used drains up to 45 m (DoR, 2007).

Design Considerations

- Slope stability is highly sensitive to rise of water table
- Suitable at slopes where water table rises during wet period
- Shallow ground water drained out using French drains

Construction

- Drilled with rotary or air-flush percussion drill
- Drilling is done at an inclination above horizontal as flat drilling may not drain by gravity and steep inclination reduces effective length in saturated zone.



• Deep ground water (> 5m) can be drained out using horizontal drains • Options: horizontal drilled drains, drainage wells, drainage tunnels or their combination • Most effective method for stabilizing landslide activated fluctuation of ground water table • Geological and geophysical investigation should be carried out to determine whether the instability is caused by high seepage problem • Explore depth of water table, its fluctuation and effect on landslide activity • Identify permeable and impermeable layers in the subsoil • Provide outlet support (in cement masonry, gabion or concrete) and outlet channels (lined with concrete or cement masonry) as required • Spacing of horizontal drain pipes at far end is fixed considering permeability of the subsoil material. • Pipe is provided with Non-Woven Polypropylene geotextile.	• Holes can be drilled in parallel orientation or radial form depending upon the ease of construction and site condition. • Pipe should be perforated with solid end cap and be of sufficient strength so as not to be damaged after installation. • Length must penetrate through the slip surface and into the saturated zone. • Collect in longitudinal collection drain below drain hole exits; channel to stable outlet. • Measure discharge from each drain after installation; periodic re-measurement tracks pore-water pressure reduction.
Typical Dimensions	Common Failures & Remedies
• Hole diameter: 75-150 mm • Inclination: 3°–10° • Length: 10-30m • Spacing: 2-5m (horizontal parallel orientation) and 2-4m (vertical rows) • Pipe diameter: 50-100 mm • Pipe: Perforated uPVC screen pipe (2 mm slots or 3-5 mm holes at 10-15 mm distance in zigzag pattern), with perforated length extending from wall to 90% of hole length; warped in highly permeable geotextile. • Layout: parallel or radial (fan) pattern with up to 7 drains at a point	• Geotextile torn during installation — use robust geotextile ($\geq 200 \text{ g/m}^2$); handle carefully. • Pipe crushed or displaced— use SDR 35 or stronger rated pipe in trench. • Outlet blocked: inspect and flush minimum annually; install rodding eye at change of direction. • Clogging of pipe perforation-checkup after heavy downpour.

5.6.5 Herringbone or chevron drains or wire Bolster

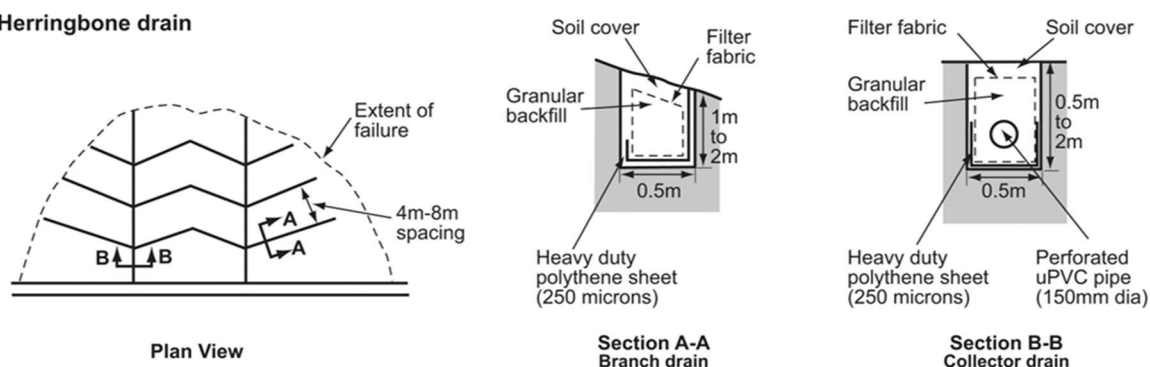
Herringbone or chevron drains/wire bolster

Collects near-surface groundwater on slope faces and direct it to collector drains or Counterfort or trench drain.



(Source: [Hearn, 2011](#))

Herringbone drain



(Source: [Hearn, 2011](#))

Overview and Applicability

- Surface and sub-surface drainage element on the slope (mountain side) faces.
- comprise a central collector trench drain and offset diagonal feeder or branch drains.
- Mostly used to collect and drain out groundwater of shallow depth or near-surface groundwater on slope faces up to depth of 3 m (max).
- Shape: trapezoidal, or composite depending on expected discharge and slope (branch drains) and trapezoidal or rectangular (collector drains).
- Can be used to stabilize shallow failures and reduce the risk of landslides due to pore water pressure.

Design Considerations

- For design, it is important to find out if the instability is or can be caused by high seepage problems.
- Design discharge: Rational Method for catchment from road surface.
- Design return period: 10-year storm in low hazard zone and 25-year storm in critical areas.
- Depth: 0.5–1.5 m (although deeper drains are not uncommon where a greater degree of groundwater lowering is required)



- Lining: upslope face of the diagonal drains should be lined with a filter fabric and the lower face and invert lined with heavy-duty polythene.
- The drain is filled with free-draining granular fill or stones in case of bolster.
- In the event of large, anticipated flows, diagonal drains can be constructed as surface water interceptor drains with a perforated high-density polyethylene pipe in the base of the collector drain (Herringbone Bolster).
- Greatest drainage efficiency will usually be achieved by maximizing the number of collectors drains, thus reducing the required length of the diagonal drains.
- The spacing between herringbone branch drain is usually around 4-8 m, depending upon the size of each branch drain and site requirements.

Construction

- Trim the area to an even slope with no protrusions and depressions.
- Starting from the bottom of the slope, mark out the lines for the drains; there should be one vertical line and sloping lines joining vertical line making an angle of 45° with each line about 5 meters long.
- Dig a trench along the line, Lay a sheet of black polythene along the bottom and lower side; but not the upper side of the trench.
- In case of chevron drains, fill the drain with granular fill and cover it with filter textile and cover the drain.
- In case of herringbone bolster, lay the gabion bolster panels lengthways in the trenches. Ensure the edge of the gabion on the lower side is in line with lower edge of the trench.
- Fill the bolster with stones larger than the mesh size.
- Fold the upper edge of the panel over the stones and join it to the lower panel edge; the slanting lines at the end are closed.
- Repeat until all slanting lines meet the vertical line.
- Once the slanting lines are complete, dig a vertical trench straight down the slope and install a vertical bolster to collect water from the bottom.
- Tie the vertical bolster with slanting bolsters. Backfill the materials around the bolsters, compact it and clean away debris.
- Drive 1-meter-long steel bars, angles, or sprouting poles into the ground at right-angle to the slope every 2 meters along the bolsters. Position them immediately below and touching the bolsters, and drive them in far enough so that they cannot be pulled out by hand.

Typical Dimensions

- Typical size: 400–600 mm wide × 400–700 mm deep. (herringbone drains)
- Typical size: 1–2 m wide × 300–500 mm thick. (gabion wire bolster)

Common Failures & Remedies

- Blockage by fallen trees / debris: requires clear access; avoid locating in dense forest.
- Poorly sited outfall eroding fill slope: must discharge to stable stream using Cascade structures, not onto slope.
- Under-designed (silted) drains redirect water over cut face — clean after every storm.

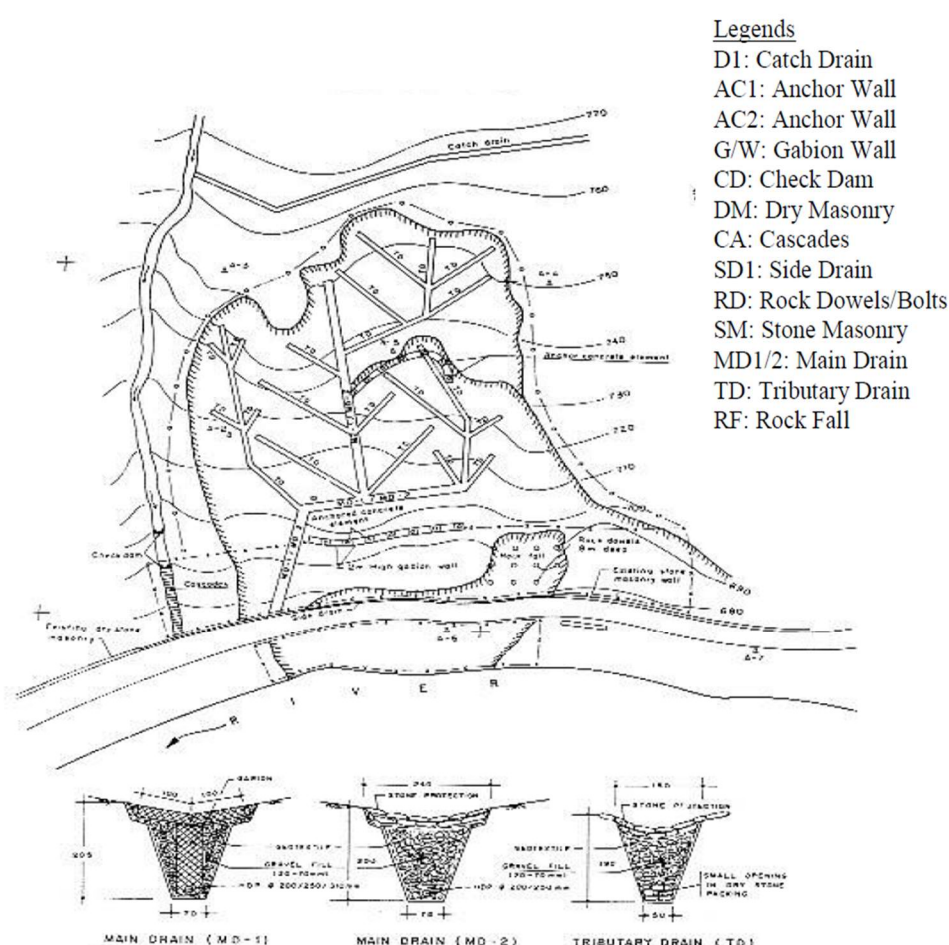


Figure 5.3: Network of SSDs consisting of tributary(branch) and main drains
With various drainage and retaining structures that are used to stabilize large scale landslide in Arniko Highway (Source: [DOR, 2003](#)).

[Hearns \(2011\)](#) also classified the sub-surface and surface drains on slope based on their functions, as shown in [Table 5-3](#).

Table 5-3: Types of slope drainage, their functions and limitations ([Hearn, 2011](#))

Function	Type	Advantage	Limitation
Interception of surface runoff	Unlined cut-off drains (open ditch)	Cheap, can in some instances prevent ingress of surface runoff into landslide masses	Prone to leakage and erosion; may act as incipient tension crack beyond slope crest; requires frequent inspection for damage/blockage; access may be difficult for maintenance
	Lined cut-off drain	As above, though less prone to erosion and leakage	Requires frequent inspection for damage/blockage; access may be difficult for maintenance; concentrates flow and erosion if ruptured by ground movement
	Sub-soil drain	Usually not prone to erosion and leakage and can tolerate some ground	May become clogged with silt; can be surcharged during large surface flows; may encourage water to enter the slope where excessive ground movements



		movements while continuing to function	create 'sags' in vertical alignment or tears in the polythene; access may be difficult for maintenance
	Lined cut-off drains with subsoil drain	Combines surface and subsurface drainage. Can accommodate large surface flows	Requires frequent inspection for damage/blockage; may encourage water to enter the slope where excessive ground movements create 'sags' in vertical alignment or tears in the polythene; access may be difficult for maintenance
	Bench drain on cut slopes	Collects and discharges surface runoff from one bench or berm to the next. Reduces the tendency for large quantities of water to pond and seep into the slope material	Will crack and dislocate following any ground movements, may become blocked by falling debris or silt if not properly maintained
	Berm drain on fill slopes		
Reduction of shallow sub-surface water and drainage of seepages	Herringbone drain	Depending on depth, usually able to intercept water up to 1.5m below slope face; can be used to drain seepage areas; can accommodate some slope movement; can be used to help stabilize shallow slope failures up to 2-3m deep.	May have very limited effect on overall stability of deep-seated failures; may create shallow instability during construction, hence preference to minimize branch length
	Counterfort or trench drain	Generally, able to intercept water up to 3m depth below slope face; can act as a 'buttress' if base is below slip-surface	Usually needs to be machine dug; difficult to construct in boulder material
Interception of deep-water table	Drilled sub-horizontal drain	Only feasible method of intercepting groundwater at depth	Relatively high cost; drilling equipment required; may not always be successful

5.7 Cross-Drainage Structures

Cross-drainage structures are essential hydraulic components that enable water flowing through drainage channels to pass safely beneath or across road embankments and cut sections, thereby maintaining roadway stability and preserving the natural drainage pattern. In hilly terrain, every natural valley, gully, and seasonal stream intersected by the road alignment requires an appropriately designed and adequately sized cross-drainage structure. Inadequate or improperly designed cross-drainage systems have been identified as a major cause of road washouts and road-induced landslides, particularly during periods of intense rainfall and monsoon.

5.7.1 Culverts

Culverts are hydraulic conduits constructed beneath the roadways to convey runoff water from one side of the road to the other, thereby ensuring the uninterrupted passage of surface and channelized flows. Depending upon their functional purpose, culverts may be provided to discharge runoff collected in side drains (relief culverts, [Figure 5.4](#)), accommodate the flow of natural watercourses



intercepted by the road alignment (watercourse culverts), or carry side-drain runoff across junctions and property access points (access culverts).

Although culverts and bridges involve similar hydraulic and structural design considerations, a structure is generally classified as a culvert when its span is less than 6 m, whereas structures exceeding a span of 6 m are considered bridges. Similarly, structures with depths of less than 4 m are commonly categorized as culverts, while those with greater depths are classified as bridges.

The culvert barrel may be constructed in a variety of shapes and configurations, including circular, elliptical, square, rectangular, semi-circular, and U-shaped sections. Among these, reinforced concrete pipe culverts and box culverts are the most widely used forms. U-shaped culverts are commonly adopted as relief culverts because they require comparatively less installation depth than circular pipe culverts.

The construction of U-culverts requires greater precision and workmanship in formwork construction and generally involves greater construction time than the installation of equivalent pre-fabricated pipe culverts. However, when properly designed and constructed, U-culverts are capable of providing better hydraulic performance than pipe culverts of similar dimensions.

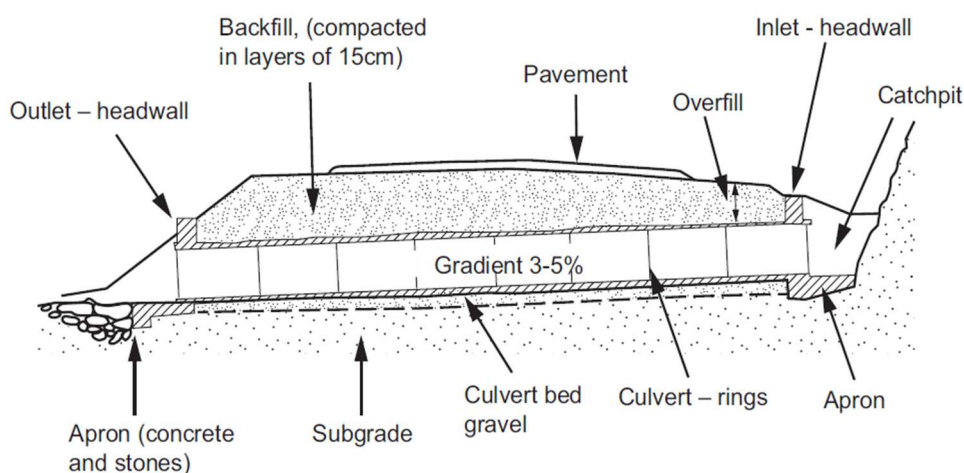


Figure 5.4: Typical Relief Culvert

Design Discharge for Culverts

Peak discharge for culvert design is typically calculated using the Rational Method (for small catchments < 5 km²) or regional flood frequency analysis for larger catchments. The design return period is 25 years for culverts and 50 years for causeways and bridges, per DoR standard practice.

For ungauged catchments in Nepal's mid-hills, the Dickens formula provides an empirical check:

$$Q = C * A^{3/4} \dots \dots \dots (\text{Eq. 5-5});$$

Where,

Q = Maximum Discharge or Peak Flow, (m³/s)

C = Dickens constant ≈ 11-14 (For Bagmati Province mid-hills)



$$= \begin{cases} 6; \text{Annual Rainfall} < 600 \text{ mm} \\ 11 - 14; \text{Annual Rainfall} < 600 - 1200 \text{ mm} \\ 14 - 19; \text{Annual Rainfall} > 1200 \text{ mm} \end{cases}$$

A = Catchment Area, (Km²)

Culvert Size Selection

Once design discharge Q is known, the culvert size is determined from the Manning's pipe flow equation, ensuring full-pipe capacity exceeds the design discharge by a minimum 20% safety margin:

Table 5-4: Different culverts with selection features

Hume Pipe Dia. (mm)	Full-pipe Q (m ³ /s) n=0.013	Max. Catchment (ha)	Max. Road Length (m)	Remarks
600	0.11 – 0.18	< 2	< 50	Minimum for maintenance access. Rarely adequate on mountain roads.
900	0.28 – 0.45	2 – 8	50 – 120	Standard for small gullies and seasonal streams.
1200	0.55 – 0.90	8 – 20	120 – 250	Use as default for hill roads for ease of cleaning and maintenance.
1500	0.95 – 1.50	20 – 50	250 – 500	For moderate perennial streams.
1800	1.55 – 2.50	50 – 120	500 – 1000	Large gully or perennial stream.
Box / Slab Culvert	Variable by size	> 100	> 800	Where debris load, boulder movement, or maintenance access requires larger opening.

Note: Q values shown are indicative for S = 1–3% and n = 0.013 (smooth concrete). Actual capacity depends on headwater, tailwater, entrance conditions and slope. Always verify by hydraulic calculation. The culvert size selection and design can be done using simple calculation and nomographs provided by [FHWA, 2012](#).

The most important aspect in the design of relief culverts is the frequency along the road alignment and the slope of the culvert (which should be a minimum of 2-3% to ensure self-cleaning).

Upstream and Downstream Protection

A culvert failure rarely begins at the pipe itself; it begins at the headwall or outlet where flow transitions from the culvert to open channel. These transition zones require energy dissipation and scour protection.

Scour is the erosion and removal of material from the bed and sides of a channel due to flowing water. Damage caused by scour is one of the most common causes of structural failure in drainage structures. Therefore, reducing or preventing the effects of scour should be a major consideration in the design of any drainage structure. Although scour can occur under all flow conditions, the risk is generally higher during floods. For this reason, the proposed structure site and the upstream and



downstream sections of the watercourse should be inspected for signs of existing scour, erosion, sediment deposition, or channel instability.

Accurately predicting the extent of scour for a particular design is difficult. Many empirical formulae are available for estimating scour depth around structures; however, these methods usually require detailed information on river flow, channel characteristics, and bed materials. In addition, different formulae may produce different estimates of scour depth. Therefore, sound engineering judgement is necessary when selecting an appropriate design value. This manual provides several practical design guidelines to improve resistance against scour. However, these guidelines should not be considered universally applicable, and local site conditions and experience should always be considered during the design process.

The extent and depth of scour are influenced by the following factors:

- Constriction of the flow width;
- Maximum flow discharge; and
- The type and characteristics of the material forming the bed and sides of the watercourse.

Cut-off Walls

Cut-off walls, also known as curtain walls, should be provided at the edges of drainage structures to prevent erosion of adjacent soil or foundation material. Such erosion can gradually undermine the structure and eventually lead to structural failure.

The absence of a cut-off wall at the inlet may allow water to seep beneath the apron and the structure, resulting in settlement and possible collapse. Similarly, at the downstream end, flowing water may erode the material adjacent to the apron, eventually undermining the apron foundation and causing structural failure.

The depth of cut-off walls depends on the prevailing ground conditions. Where a rock layer exists close to the ground surface, the cut-off walls should extend down to the rock level. In the absence of a firm stratum near the surface, the cut-off walls should be constructed to at least the minimum required depth based on site conditions, but not less than 0.6m.

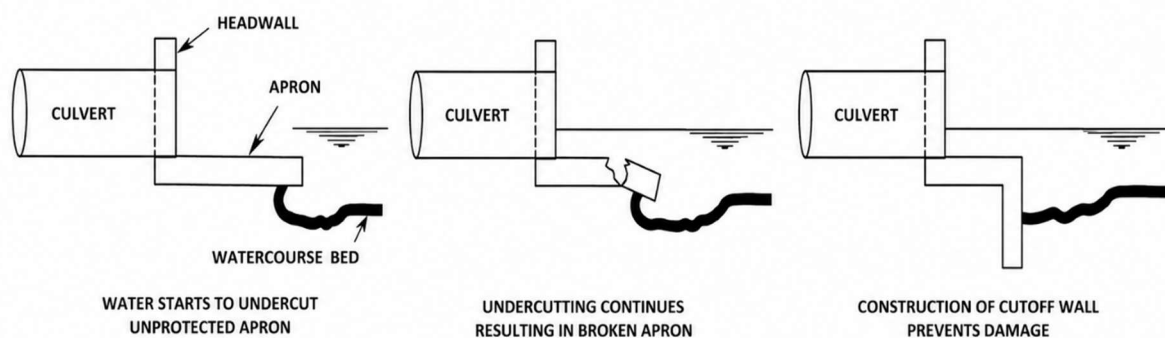


Figure 5.5: Benefits of cut-off walls (Source: Manual for Low volume Roads, Part C; Sierra Leone Road Authority)

Headwalls and wingwalls

Headwalls and wingwalls should be provided at both end of a culvert to perform several important functions:

- Directing the flow of water into and out of the culvert;
- Retaining the surrounding soil around the culvert openings; and



- Preventing erosion and seepage around the culvert, which may otherwise lead to settlement and structural instability.

The headwall can be positioned at different locations in the road verge or embankment. Headwalls should project 300 mm above the road surface and be painted white to improve visibility for drivers. They should always be positioned at right angles to the culvert alignment at both inlet and outlet to minimize disruption to water flow, including skew culverts. Headwalls and adjacent works must be designed so that the culverts can be manually de-silted during maintenance activities. Cleaning can be difficult with a drop inlet arrangement.

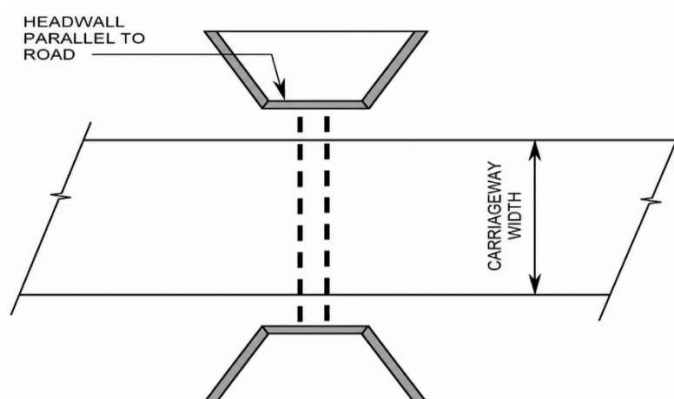


Figure 5.6: Position of Culvert Headwall and Wingwalls

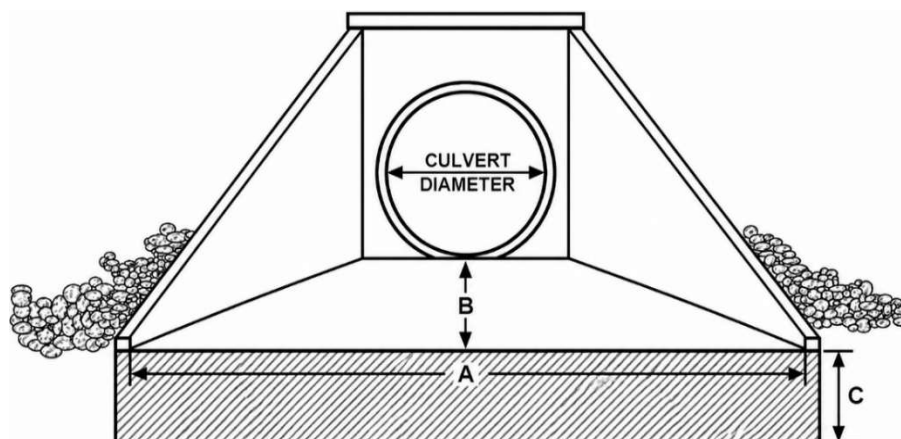
Wingwalls are provided to retain the soil behind culverts and bridge abutments, guide flood flows safely through the structure, and prevent erosion of the backfill material. In practice, wingwalls are generally constructed at an angle between these two standard arrangements: parallel to road or parallel to watercourse. Wingwalls should always extend down to the toe of the slope rather than terminating partway down the embankment. Wingwalls that do not reach the bottom of the slope are more susceptible to erosion around their ends, which may lead to instability and structural damage.

Aprons

An apron should be provided at the inlet and outlet of culverts to protect against erosion. As water flows out of or over a drainage structure, it tends to erode the downstream channel bed and banks, which may result in undercutting and eventual damage to the structure. Aprons should therefore be constructed using materials that are more resistant to erosion than the natural material forming the natural bed.

Aprons should be provided at both the inlet and outlet ends of culverts to protect the structure and surrounding channel from erosion. The apron should extend across the full width between the headwalls and any wingwalls. Where wingwalls are not provided, the apron width should be at least twice the diameter of the culvert pipe. In addition, the apron should extend a minimum distance of 1.5 times the culvert diameter beyond the pipe outlet or inlet.

Cut-off walls should also be constructed along the edges of all apron slabs to prevent undermining and erosion beneath the apron. The type of apron construction generally depends on the materials used for the culvert structure. Common apron construction materials include gabion baskets, cement masonry, and concrete.



- A - Distance between wingwalls or 2 x culvert dia. for culvert without wingwalls
B - 1.5 x culvert dia.
C - Min 500mm

Figure 5.7: Culvert Apron

Additionally, these transition zones are provided with further protections like traps, the Table 5-5 below provides a basic understanding these works.

Table 5-5: Basic description of upstream and downstream protections

Location	Required Protection	Specification
Upstream headwall	Wingwalls to guide flow into the barrel; inlet cutoff wall to prevent undermining; short apron against inlet scour; debris control where debris load is high.	CSM or plain concrete wingwalls; trash rack: 25 mm dia. bars at 150 mm spacing; concrete apron min. 0.5 m long.
Upstream silt trap	Stone-lined settling basin to trap gravel and coarse sediment before the pipe; accessible cleaning bay.	Depth 300–500 mm below invert; gabion or CSM walls; inspect and clean before and through each monsoon.
Downstream outlet	Riprap apron / energy-dissipation pool over a filter, with an end cutoff wall. Concrete or impact energy dissipator – loose riprap and gabion mattress are inadequate.	Riprap apron: $L \geq 3 \times \text{pipe diameter}$; $D_{50} \geq 300 \text{ mm}$; gabion mattress 300 mm thick alternative.
Downstream channel	Stone soling or riprap for minimum 5 m below apron; vegetated further downstream.	Stone soling $D_{50} \geq 150 \text{ mm}$ for minimum 5 m; grass-lined beyond.
Causeway / Irish crossing	Concrete slab with vented openings; guide walls; upstream apron; downstream protected channel.	Slab M20 minimum 200 mm thick; vents $\geq 0.6 \text{ m dia.}$; check scour at wing extremities annually.

5.7.2 Common failures: Hume pipe clogging and drainage-induced landslides

Box 5.2: Hume Pipe Clogging: Causes, Prevention and Remediation

CAUSES OF CLOGGING (most common on hill roads):

- Undersized pipe: pipe sized for design discharge without allowing debris load; the first debris flow can block the pipe



- No trash rack at inlet: boulders, branches, and root mats enter and jam pipe.
- No silt trap: fine sediment and gravel accumulate in pipe over time.
- Improper invert: pipe laid at wrong level can create low points where sediment deposits.
- Pipe damage: joint failure, settlement, or crushing allows soil to enter the pipe.

PREVENTION:

- Provide a minimum pipe diameter of 1200 mm on all mountain roads for easy maintenance and to avoid clogging.
- Install trash racks at all culvert inlets; inspect and clear before monsoon each year.
- Construct upstream silt trap / settling basin; clean minimum twice per year.
- Verify invert level at construction; ensure minimum 0.5% slope throughout.
- Where high boulder/debris load expected: use box culvert instead of Hume pipe.

REMEDIATION (if clogged):

- Do not wait: a clogged culvert during monsoon can cause road damage within hours.
- Flush from outlet end using water pressure (tanker truck or pump).
- If flushing fails: mechanically excavate at inlet; manually clear blockage.
- After clearing: install permanent trash rack and silt trap if not already present.

Box 5.3: How Poor Drainage Directly Causes Landslides: Mechanism and Prevention

MECHANISM 1 — Overtopping from blocked drain: water backs up behind blocked culvert or filled drain → overflows onto fill slope or cut face → concentrated flow erosion → deep gully forms within 1–2 monsoon seasons → slope failure.

MECHANISM 2 — Subsurface seepage from drain: cracked or unlined drain leaks water into slope → soil saturation increases → pore-water pressure rises → effective shear strength falls → slope fails (often 1–2 days after peak rainfall).

MECHANISM 3 — Concentrated outlet flow: culvert or side drain outlet discharges onto unprotected fill slope → erosion at toe → toe failure → progressive slope failure.

MECHANISM 4 — Upslope water not intercepted: no catch drains above cut slope → monsoon runoff flows over cut face → surface erosion → rill development → gullying → slope destabilization.

PREVENTIVE DESIGN RESPONSES:

- Always install catch drain above cut before exposing the cut face.
- All drain outlets must discharge to riprap-protected or energy-dissipated stable channels.
- Inspect drains before monsoon (Jestha/Ashad) and clear all blockages.
- Never allow side drain to overflow onto fill slope — install additional cross-drains if needed.
- Design drains for 125% of calculated Q to accommodate debris blockage.

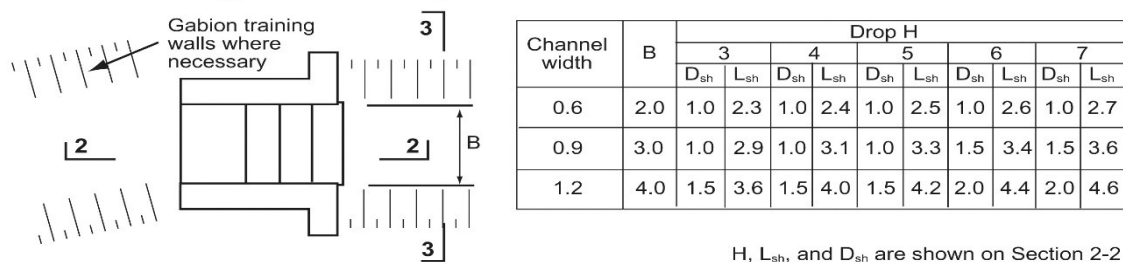
5.8 Energy Dissipation Structures

In steep mountain terrain, water draining from roads and slopes accumulates significant kinetic energy as it descends. Without controlled energy dissipation, this energy is released destructively — eroding channels, undermining structures, and triggering gully formation. Energy dissipation structures reduce flow velocity and convert kinetic energy to turbulence and heat, releasing flow

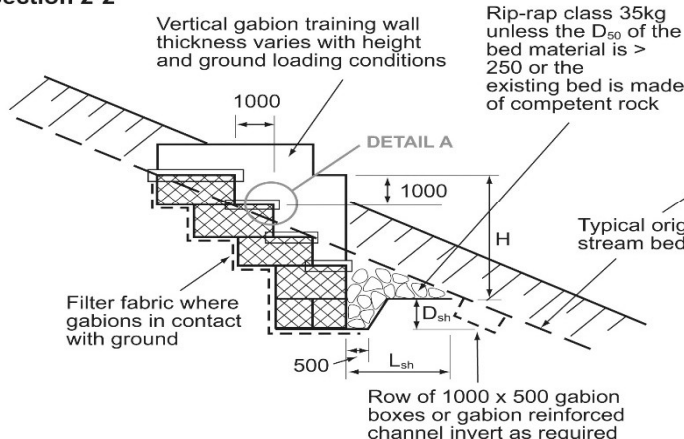


safely at non-erosive speeds. The choice of energy dissipation structure depends on the volume of flow, the drop height available, the space available, and the construction materials available.

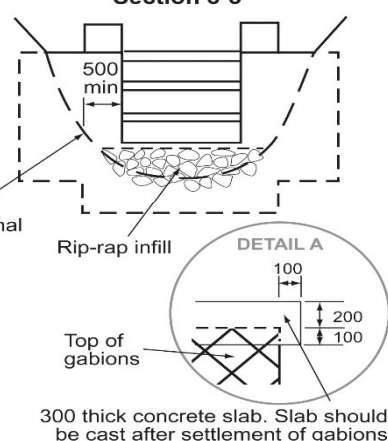
Gabion Cascade Type A - short outfall protection



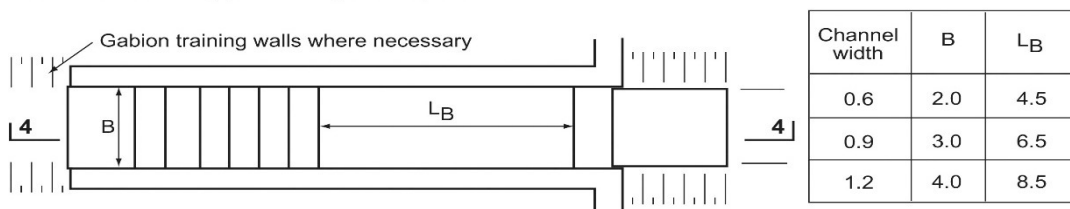
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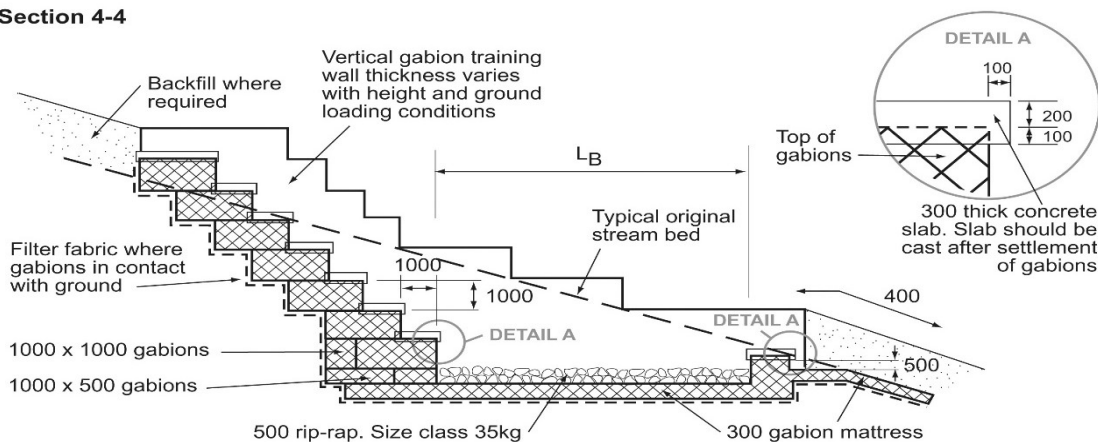
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Gabion Cascade - Type B - long outfall protection



Section 4-4



All dimensions in mm, with exception of tables which are in metres
Detail A optional depending upon sediment load and flow velocity

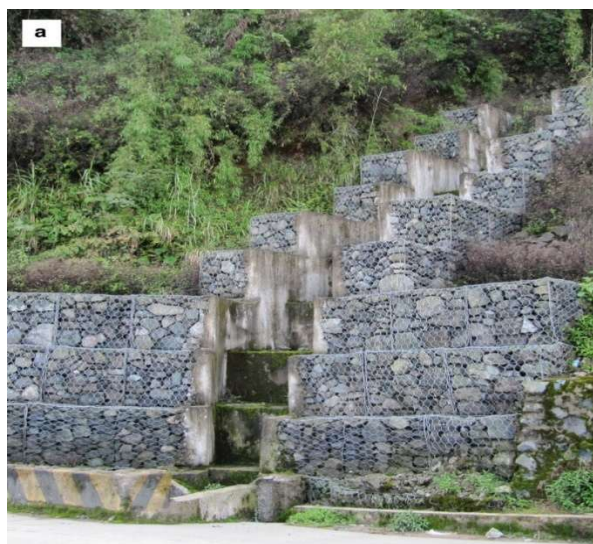
Figure 5.8: Gabion Cascade Design (Hearn, 2011)



5.8.1 Cascade drains

Cascade Drains

Also called “Stepped drain”, “Drop drain” or “chute with energy dissipators”, stepped drainage that conveys water down cut slopes or other steep section with significant surface runoff flow.



Gabion cascade with concrete lining



Masonry cascade

(Source: [Hearn, 2011](#))

Overview and Applicability

- Used where the slope of the ground is too steep for a plain channel to carry flow at non-erosive velocity.
- Instead of a single steep channel, the flow is broken into multiple drops, with each drop dissipating energy in a stilling pool before the next step.
- Dissipate surplus kinetic energy of flowing water through sudden vertical drop.
- Reduce velocity of flow.
- Prevent erosion in bed and bank.
- Improve stability of stream bed slopes.
- Usually applied at inlets and outlets of cross drainage structures.

Design Considerations

- Layout dictated by site condition
- Drop rise and width to suit the gradient of gully and discharge
- Tread shall be larger than rise to allow for dissipation of energy at each tread
- The base of gabion cascade is lined with geotextile.
- Stilling basin with water cushion should be created at each tread either with raised crest or with inward inclination of tread (10-15%), to allow turbulence to dissipate before next step.
- Ensure proper embedding at top and good foundation at bottom of the cascade
- Toe protection: energy dissipation pool at the base of the full cascade before discharge to natural drainage and Apron of boulder rip rap should be provided at outfall of cascade to dissipate surplus energy and to protect cascade structure from scour.
- Provide weep hole, filter material and filter fabric to drain out water trapped within cascade structure



- Cascade side walls are essential to protect from erosion due to water splash with concrete lining.
- For relatively good foundation condition, cement masonry cascade is recommended and for relatively weak foundation condition and where flexibility is required, gabion cascades are suitable.
- Gabion cascades should be lined with outward sloping treads.

Construction

- Cascade structure can be constructed in dry masonry, gabion, mortared masonry, or concrete, or composited in gabion cascade with concrete lining.
- Where coarse bed load is expected gabion cascades should be protected with wire protection.
- Follow bottom to top construction sequence.
- Trim the area to an even slope with no protrusions and depressions.
- Starting from the bottom of the slope, mark out the lines for the drains.
- Process of construction is similar to process for gabion bolster/ walls.

Typical Dimensions

- Step height: 0.3–0.6 m per step. (Larger drops concentrate energy and require more robust pool protection.)
- Pool (stilling basin) length: minimum $1.5\text{--}2.0 \times$ step height; concrete M15 or gabion 300 mm.
- Pool floor protection: concrete slab minimum 150 mm thick, or gabion mattress (300 mm thick).
- Wall protection: side walls must extend 200–300 mm above design water level.

Common Failures & Remedies

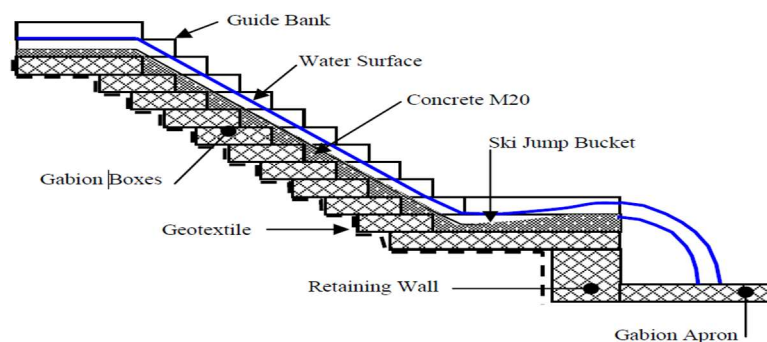
- Both gabion and masonry cascades are also prone to abrasion when stream flows contain large-sized debris.
- Concrete or cement masonry cascades are not suitable where flexibility is desirable.
- Erosion of the side walls is the most common cascade failure mode.

Hearn (2011) also provides a basic (rule of thumb) design method for cascade (gabion cascade) as shown in the Figure 5.8 below, for both long and short outfall protection. This cannot be solely relied upon, with peak flow / runoff for a particular region.

5.8.2 Chute / drop inlet

Chute / Drop Inlet

Single steep inclined channel (chute) leading to energy dissipator at base, acting as conveyor for surface runoff or for cross drainage to stable stream.



(Source: DoR, 2007)

Overview and Applicability



- Used where the slope of the ground is too steep for a plain channel to carry flow at non-erosive velocity.
- A single steep channel with energy dissipator at base.
- Dissipate surplus kinetic energy of flowing water by stilling pool, ski jump bucket, roller bucket, chute blocks or impact baffle.
- Prevent erosion in bed and bank.
- Improve stability of stream bed slope.
- Usually applied at outlets of cross drainage structures.

Design Considerations

- Layout dictated by site condition
- Free board should be high to accommodate turbulent flow.
- The base of gabion chute is lined with geotextile.
- When coarse bed load is expected chute should be protected with RCC bedding lined with flagstones
- Provide largest possible horizontal and vertical radii to ensure smooth flow
- Follow Ogee shaped profile to avoid bed cavitation by negative pressure and subsequent separation
- Ensure proper embedding at top and good foundation at bottom of the cascade.
- Toe protection: energy dissipation pool at the base of the chute before discharge to natural drainage and Apron with boulder rip rap should be provided at outfall of chute to dissipate surplus energy and to protect cascade structure from scour.
- Provide weep hole, filter material and filter fabric to drain out water trapped within cascade structure
- Chute side walls are essential to protect from erosion due to water splash with concrete/RCC lining.
- For relatively good foundation condition, cement masonry cascade is recommended and for relatively weak foundation condition and where flexibility is required, gabion cascades are suitable.
- **Proper structural / geotechnical design is required**

Construction

- Follow bottom to top construction sequence.
- Trim the area to an even slope with no protrusions and depressions.
- Process of construction is similar to process for cascade drains.

Common Failures & Remedies

- Both gabion and masonry Chute are also prone to abrasion when stream flows contain large-sized debris.
- Erosion of the side walls is the most common cascade failure mode.

The different cross drainage configurations and its inlet blockage and outlet scour potential was illustrated by [Hearn \(2011\)](#) in the [Figure 5.9](#) below.

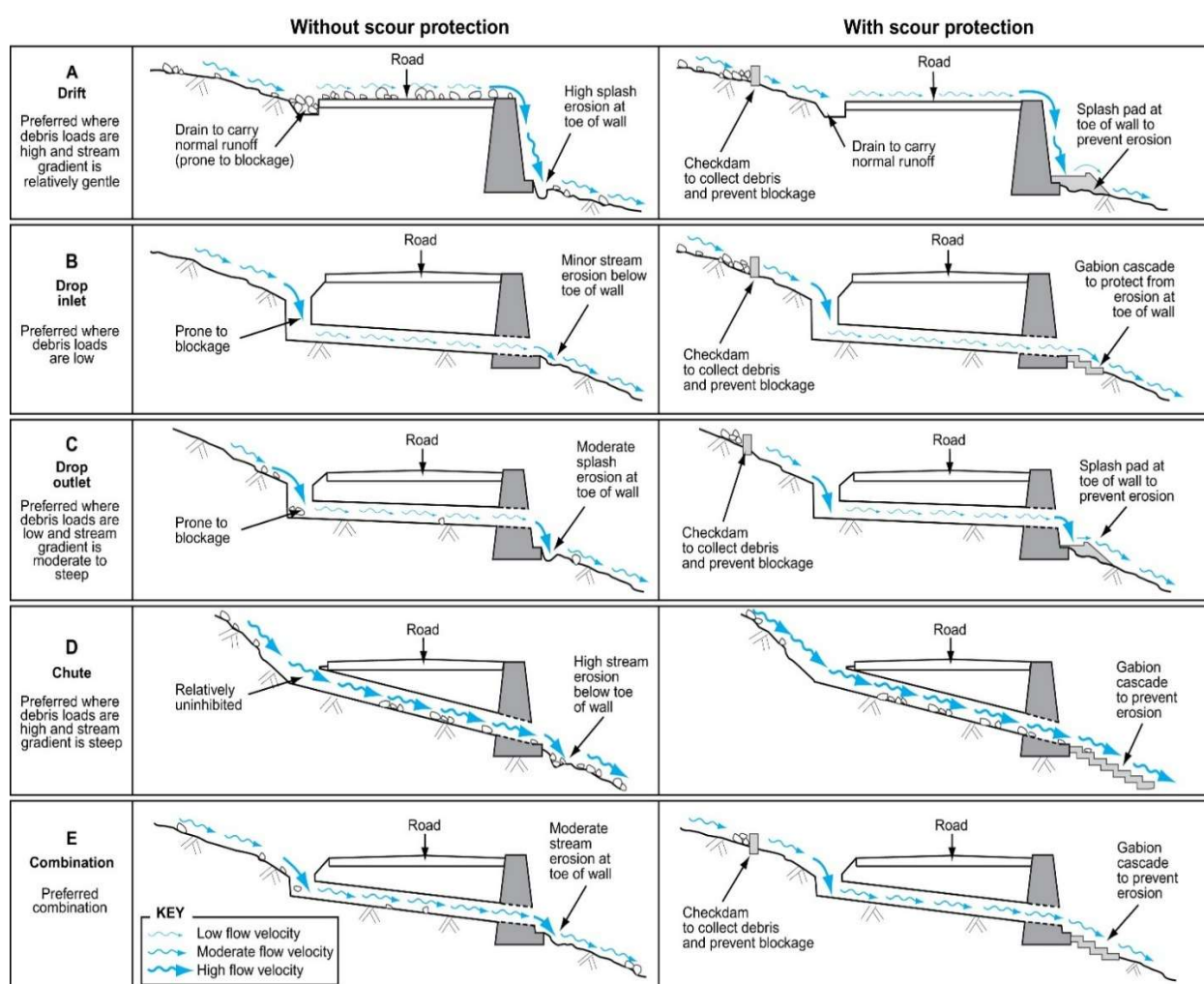


Figure 5.9: Cross drainage configuration and its influence on inlet blockage and outlet scour potential (with or without protection) (Hearn, 2011)

Additionally, some of the other types of energy dissipating structure can further illustrated in the Table 5-6 below.

Table 5-6: Additional energy dissipating structures

Type	Principle	Best Application	Design Key Points
Stilling Basin (Apron)	Flat or slightly sloped concrete apron below a drop or chute outlet. Turbulent hydraulic jump dissipates energy before discharge.	At base of cascade drains, chutes, culvert outlets, waterfall drops.	Length: 3–5 × chute width; depth: 0.3–0.5 m below outlet; floor: M20 concrete; side walls to contain hydraulic jump.
Check Dam (Vegetated / Masonry)	Small cross-wall in gully floor reduces slope and velocity of flow; allows sediment deposition upstream.	Gully erosion control; slope stabilization at valley heads; sediment trapping.	Height ≤ 2 m (CSM) or ≤ 1.5 m (live); spillway width ≥ 1.2 × normal channel width; apron downstream.



Rock / Gabion Sill	Single large rock or gabion mattress sill across channel or drain outlet; causes shallow hydraulic jump.	Small gullies; drain outlets; simple cross-channel protection at culvert tails.	Sill height 150–300 mm; width ≥ 1.0 m; D50 ≥ 300 mm for rocks; standard gabion mattress 0.3 m thick.
Riprap Apron	Random stone protection at channel outlet or below drop; energy absorbed by turbulence in stone voids.	Culvert outlets; side drain outlets; base of embankment toe drains.	D50 as designed for velocity; $L \geq 3 \times$ pipe diameter; laid in $1.5 \times$ D50 thick layer on geotextile filter.

5.9 Conservation Ponds and Water Harvesting

Conservation ponds, locally known as *Pokhari* in Nepal, are small water storage impoundments designed to collect and retain surface runoff for multiple water management purposes, including roadside slope stabilization. Their importance is particularly evident on south-facing (*Pakho*) slopes, where intense solar radiation and high evapotranspiration rates result in rapid moisture loss and prolonged dry conditions. Under such conditions, the establishment of vegetation through conventional bioengineering measures becomes difficult, making conservation ponds an important supplementary measure for maintaining soil moisture and supporting vegetation growth.

5.9.1 Rationale for conservation ponds on road corridors

The south-facing slope problem is distinct and important: south-facing slopes receive direct sun throughout the day, dry out rapidly between rainfall events, and support sparse natural vegetation. Bioengineering species that establish readily on north-facing slopes fail to survive the dry season on south-facing slopes without supplemental moisture. Cut slopes on south-facing aspects are therefore particularly difficult to revegetate and stabilize.

A conservation pond constructed on or near the road corridor on a south-facing slope achieves multiple objectives simultaneously, as explained by [Table 5-7](#).

Table 5-7: Benefits of conservation ponds

Benefit	Mechanism and Outcome
Enhanced vegetation establishment	Stored water used for drip irrigation of newly planted bioengineering species during dry season (Chaitra–Jestha). Increases survival rate from $< 30\%$ (without water) to $> 70\%$ (with supplemental irrigation) on south-facing slopes.
Runoff attenuation	Pond intercepts and stores peak monsoon runoff before it reaches the slope. Releases water slowly, reducing peak flow and erosion intensity on the slope below. UNDP Khotang-Okhaldhunga projects showed ponds reduced peak runoff by 20–40% in the immediate catchment.
Reduced drainage load	By temporarily storing runoff, ponds reduce the instantaneous peak discharge that side drains and culverts must handle. This either reduces the required drain size or provides a safety margin against overflow during extreme rainfall.



Groundwater recharge	Ponded water slowly percolates into the slope, recharging springs and improving soil moisture downslope. ICIMOD research (Jhikhu Khola watershed, Kavre) showed conservation ponds improved spring yields in adjacent hillsides.
Community benefit	Water from ponds used for livestock watering, dry-season vegetable irrigation, fire suppression, and biodiversity habitat. Increases community ownership of the road corridor environment.
Sedimentation trap	Pond acts as a sediment trap for eroded material from upslope, reducing sedimentation in downstream drains and watercourses.

5.9.2 Design and siting of conservation ponds

Box 5.4: Conservation Pond Siting and Design Criteria

SITING REQUIREMENTS:

- South or south-west facing slopes where vegetation is difficult to establish due to dryness.
- Natural depression or saddle where excavation volume is minimized.
- Location where collected water can gravity-feed to planted slopes below via pipes or channels.
- Minimum 10 m from road edge (to avoid seepage weakening road formation).
- Minimum 15 m from any retaining wall or slope structure.
- Avoid locating above known unstable areas or active landslide scars.

DESIGN PARAMETERS:

- Pond capacity: size for 5–7 days dry-season irrigation demand of slope below, or 50% of peak monsoon storm runoff from contributing catchment, whichever is larger.
- Typical size for roadside use: 50–500 m³ (10 m × 10 m × 1–2 m depth).
- Spillway: concrete or CSM spillway to pass 25-year return period overflow safely.
- Inlet: stone-lined channel from upslope catch drain; silt trap at inlet to reduce sediment load.
- Outlet: 75–100 mm uPVC pipe at 300 mm above pond floor (to retain sediment layer); tap or control valve.
- Lining: compacted clay (300 mm) or HDPE liner (0.5 mm minimum) where soils are permeable.
- Embankment: compacted earth bund; upstream face clay-lined; downstream face grassed.
- Safety fence: where pond is near road or public access; warning signs.

MAINTENANCE:

- Remove silt from inlet and pond floor annually (before dry season).
- Inspect embankment and spillway before monsoon.
- Manage aquatic vegetation to prevent excessive evapotranspiration loss.
- Coordinate water uses with community.



CHAPTER 6. NATURE-BASED MITIGATION TECHNIQUES

6.1 Concept and Principles of Nature-based Solutions

The International Union for Conservation of Nature (IUCN) defines Nature-based Solutions (NbS) as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." In the context of roadside slope stabilization, NbS involves the strategic use of vegetation, natural materials, and ecological processes to reinforce soil, reduce erosion, regulate surface and subsurface water, and restore ecosystem functions disturbed by road construction. The spectrum of NbS ranges from green measures, such as grass seeding, brush layering, live check dams, and tree planting, to grey measures, including stone pitching, drainage ditches, and dry stone masonry walls, as well as hybrid solutions that integrate vegetation with conventional engineering structures such as gabion walls, retaining walls, and subsurface drainage systems.

The Sendai Framework for Disaster Risk Reduction 2015–2030 recognizes Nature-based Solutions as an effective approach for reducing disaster risk and enhancing resilience. For Nepal's mountainous road network, where steep terrain, intense monsoon rainfall, and limited maintenance resources present persistent challenges, NbS offer advantages that conventional engineering measures alone cannot provide. Unlike rigid structures, performance generally declines with age, the stabilizing capacity of vegetation increases as root systems develop. When implemented using locally adapted species such as Utis, Amliso, and bamboo, NbS progressively improve slope stability while enhancing environment, reducing maintenance requirements, supporting carbon sequestration, and generating local employment through locally available materials and labour. Consequently, NbS represents a technically sound, economically viable, and environmentally sustainable approach to roadside slope stabilization.

6.1.1 Global standard for NbS

The IUCN Global Standard for NbS (2020) provides an authoritative framework for verifying whether an intervention genuinely qualifies as a NbS (IUCN, 2020). The Standard comprises eight criteria, each with associated indicators. For roadside bioengineering and slope stabilization, these criteria serve as the framing standard for both design and verification.

Table 6-1: NbS principles for roadside slope stabilization

No.	Criterion	Application in Roadside Slope Context
1	NbS effectively address societal challenges	The primary societal challenge is slope-instability, erosion, and road disruption. Techniques must demonstrably reduce slope failure risk, improve road access, and contribute to community resilience.
2	NbS design is informed by scale	Interventions should be planned at the slope or watershed scale, not only at the spot scale. Water pathways, upslope contributions, and downstream effects must be considered.
3	NbS result in a net gain to biodiversity and ecosystem integrity	Native species must be prioritized. Monospecific planting with exotic species should be avoided. Interventions should support ecological connectivity along road corridors.



4	NbS are economically viable	Bioengineering must be cost-effective relative to civil alternatives over the full lifecycle (including maintenance). Local material sourcing and community labour reduce cost.
5	NbS are based on inclusive, transparent, and empowering governance	Local communities, women's groups, and landowners should participate in species selection, planting, and maintenance. Socio-economic co-benefits (fodder, timber, NTFPs) must be equitably distributed.
6	NbS equitably balance trade-offs	Horizontal contour grass lines increase infiltration but may increase slumping risk in poorly drained materials. Trade-offs must be explicitly assessed.
7	NbS are managed adaptively, based on evidence	Post-monsoon survival assessment, periodic thinning, and replanting are essential. Monitoring data should inform future species selection and technique adjustments.
8	NbS are sustainable and mainstreamed within the appropriate jurisdictional context	NbS specifications must be embedded in contracts, BoQ formats, and maintenance schedules.

6.1.2 Scope of NbS

It includes a wide range of ecological interventions operating at multiple spatial and temporal scales:

- **Surface protection:** grass seeding, hydroseeding, grass plantation (contour/vertical/diagonal/random), and jute netting. These provide immediate armour against rain splash and rill erosion.
- **Shallow slope reinforcement:** brush layering, palisades, and fascines. *These strengthen the slope* through rooted woody cuttings within the top 0.3–1.5 m of the slope.
- **Deep anchoring:** tree plantation (utis, sisoo, phaledo), whose root systems can penetrate to 2–5 m, crossing potential slip surfaces and anchoring the soil mantle.
- **Debris management:** bamboo plantation, live check dams, and vegetated stone pitching. They catch and slow debris movement in gullies and at slope toes.
- **Gully rehabilitation:** live check dams, vegetated fascines in herringbone pattern, and riparian plantation. They control concentrated flow erosion.
- **Structural integration:** vegetated gabions, vegetated dry-stone walls, and bio-retaining structures that combine civil and biological elements in hybrid systems.
- **Watershed-level interventions:** upslope afforestation, conservation ponds, and contour trenching addresses root causes of slope instability at the catchment scale/hydrological boundary.

Critically, these interventions work best when they are applied as an integrated system. They should be arranged in layers across the slope profile, combining fast establishing species that provide immediate surface protection with slower growing, deep-rooted species that ensure long term stability. The choice of technique and plant species must always be guided by a site-specific assessment of drainage conditions, slope angle, soil or rock type, altitude, and the required engineering function.



6.2 Slope Work

Nature-based approaches do not eliminate the need for sound earthwork, rather, they require earthwork to be carried out thoughtfully, minimizing soil disturbance, managing spoil responsibly, and shaping the slope to facilitate planting. Moreover, road construction in hilly terrain inevitably involves excavation into the hillside and filling into downslope. Both cut and fill slopes are susceptible to failure if not properly designed. The interaction between earthwork design and bioengineering application is fundamental for long term slope stability.

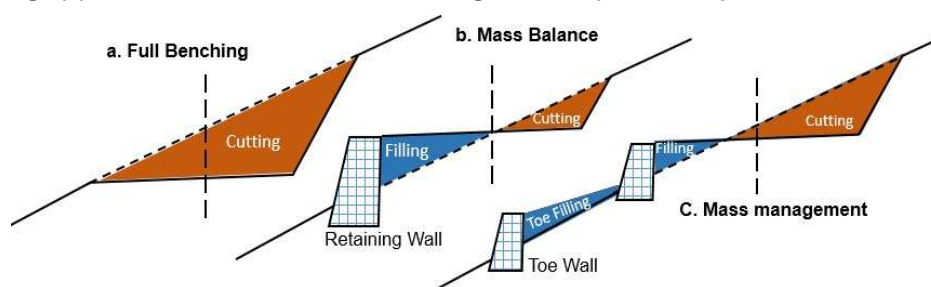


Figure 6.1: Mass balance and mass management (NRA/NDRRMA, 2021)

6.2.1 Mass Balance and Mass Management

Mass balance refers to the management of excavated material (spoil) from road cutting. In hill roads, inadequate spoil management is a leading cause of roadside slope failure, gully formation, and downstream sedimentation. The following principles should guide mass management in NbS-oriented road construction:

- **Minimize excavation:** Apply the minimum cut angle necessary for stability; avoid excessive over-cutting 'for safety' which simply increases spoil volume and slope height (Figure 6.1, a).
- **Cut-fill balance:** Where feasible, design road geometry to balance cut and fill volumes along a road section, eliminating the need for off-road spoil disposal (Figure 6.1, b). If there is excess spoil it can be further manage to the down slope with appropriate mitigation structures as presented in Figure 6.1, (c).
- **Controlled spoil disposal:** Where spoil must be disposed of off-road, select stable disposal sites away from drainage lines. Spoil should be compacted in layers and immediately vegetated.
- **Spoil as fill:** Clean rock spoil can be used as wall fill or check dam material, reducing the need for quarried stone. Soil spoil can be used as earth fill behind walls (Figure 6.1, b).
- **Topsoil conservation:** Where topsoil is present, it should be stripped separately, stored, and reapplied to cut and fill slope surfaces before bioengineering. Topsoil contains organic matter, and beneficial microorganisms that significantly improve vegetation establishment.

6.3 Bio-Engineering Approaches

6.3.1 Definition, functions, justifications and sustainability

Bioengineering, in the context of roadside slope stabilization, is defined as the use of living vegetation, either alone or in conjunction with civil engineering structures and non-living plant materials, to reduce shallow-seated instability and erosion on slopes.

The principal engineering functions that bioengineering measures must provide are:



Table 6-2: Functional roles of bioengineering and engineering measures in slope stabilization

Function	Engineering Description	Bioengineering Method
Catch	Intercept and hold debris and eroded material moving down the slope	Palisades, fascines, brush layering, bamboo clumps, live check dams
Armour	Protect the slope surface from direct rainfall impact and runoff erosion	Grass seeding, grass plantation, hydroseeding, jute netting
Reinforce	Bind and strengthen the soil through root tensile strength and root-soil friction	All rooted vegetation; most effective with shrubs (0–1 m depth) and trees (>1 m depth)
Anchor	Connect the surface soil layer to deeper stable strata through deep root penetration across potential slip surfaces	Deep-rooted trees (utis, sisoo, phaledo); large bamboo in specific conditions
Support	Resist lateral earth pressure and prevent lateral movement of slope material	Bamboo clumps at slope toe; vegetated gabion walls; brush layering terraces
Drain	Remove surface and shallow subsurface water from the slope, reducing pore-water pressure	Vertical grass lines; herringbone fascine patterns; deep-rooted trees via evapotranspiration

In addition to these mechanical functions, vegetation performs critical hydrological functions: interception of rainfall by the canopy, absorption of soil water by roots, improvement of soil porosity for infiltration, evapotranspiration to reduce soil moisture, and surface roughness to slow runoff velocity. The combined mechanical and hydrological effects make bioengineering a uniquely multifunctional approach to slope management.

The key advantages of bioengineering that justify its application include:

- **Low cost:** A documented case study reported that an integrated bioengineering approach reduced construction costs by approximately 50% compared with an equivalent conventional civil engineering solution. When the cost of riverbank protection was excluded (Plum concrete wall), the remaining bioengineering works represented only about 15% of the cost of the corresponding civil engineering structures (Rai, 2010).
- **Self-improving over time:** Unlike concrete structures that degrade, well-maintained vegetation grows stronger each season, with root systems deepening and plant communities diversifying.
- **Community employment:** Labour-intensive installation using local species provides employment opportunities for roadside communities, particularly women.
- **Ecological compatibility:** Bioengineering restores ecological function in areas disturbed by road construction, supporting biodiversity, water quality, and landscape aesthetics.
- **Adaptability:** Bioengineering measures can be adapted to a wide range of sites, slopes, and ecological zones; species can be selected from locally available material.



Box 5.5: Limitations of NbS in Slope Stabilization

NbS is NOT a universal solution. The following conditions require engineering intervention before, alongside, or instead of bioengineering:

- Deep-seated landslides (failure planes >2–3 m depth): Vegetation roots typically do not reach the slip surface. Drainage, retaining structures, soil nailing, etc. must precede bioengineering.
- Very steep slopes (>60°) without structural support: Bioengineering alone cannot provide adequate support on near-vertical cut faces. Structural measures are required as a base.
- Active gullies with high discharge: Live check dams and fascines are only suitable for small to medium gullies. Large active gullies require masonry or gabion check dams first.
- Rocky slopes with minimal soil: Vegetation establishment is severely limited on bare rock.
- Dry season planting without irrigation: Bioengineering requires adequate moisture for establishment. Dry-season planting without supplemental water leads to high failure rates.
- Very high altitudes (>3000 m): Extreme temperatures, frost, and short growing seasons limit available species and establishment rates. Specialist advice should be sought.
- Catastrophic or rapidly moving landslides: Bioengineering cannot prevent or stop active mass movement. Life safety measures and structural stabilization must take priority.

Relative functional strength of vegetation

Table 6-3: Relative functional strength of vegetation

Function	Woody Plants			Non-Woody Plants		
	Trees	Shrubs	Bamboos	Clumping Grasses	Matting Grasses	Other Herbs†
Catch	★	★★★★	★★★★	★★	★	—
Armour	★	★	★	★★★★	★★★★	★
Reinforce	★★	★★★★	★★	★★	★★	★
Anchor	★★★★	★★	★	★	—	—
Support	★★★★	★★	★★	—	—	—
Drain	★	★	★	★★★★	★	—
Root Cohesion (cr)	★★★★	★★	★★	★★	★	★
Intercept / Evapotranspiration	★★★★	★★	★★	★	★	★
Erosion Control	★	★★	★★	★★★★	★★★★	★★

(Source: Modified after [DoR \(1999\)](#))

Rating	Meaning
★★★★	Excellent — primary/best engineering function for this plant category
★★	Good — significant contribution; recommended for this function
★	Moderately useful — some contribution; may be used in combination
—	Not useful at all — plant category does not serve this function meaningfully

Notes:

- † Herbs are small plants without wood in the stems or roots (e.g. legumes, forbs, ferns). Does not include grasses.
- Certain functions (particularly Catch and Support) require plants to be grown in closely spaced lines or dense configurations. At the micro scale, small plants can provide limited anchoring and supporting functions.
- Ratings represent the general case. Site-specific performance depends on species selection, establishment density, age, and soil type.



Box 5.6: General Principles for Successful Bioengineering

Long-term vegetation cover should be encouraged to develop the following characteristics. The aim is a resilient, self-sustaining community that protects the slope with minimal external intervention.

1. Mixed Structure: Develop an irregular (uneven) vertical structure with trees at the canopy layer, shrubs at the intermediate layer, and grasses providing continuous ground cover on a single site. Each layer serves a distinct engineering and ecological function: trees provide deep anchorage and high evapotranspiration; shrubs provide lateral root reinforcement and mid-slope catch; grasses armour and reinforce the surface.

2. Mixed Age: Maintain an uneven-aged (all-aged) stand structure so that plants at different life stages coexist. This means not all plants need replacement simultaneously — there will always be strong, well-established plants providing structural protection while younger plants establish. This reduces the risk of complete vegetation loss following drought, disease, or harvesting.

3. Mixed Species: Maintain a diversity of species on each site. Single-species or species-poor communities are unlikely to develop irregular structure or uneven ages, and are more vulnerable to pest, disease, and climate variability. Species diversity also maximizes the range of root depths and architectures, providing reinforcement across multiple soil horizons.

4. Low Maintenance: Aim to establish vegetation communities that achieve long-term self-sustaining stability with minimal intervention. This means: a mixture of species that can coexist indefinitely; species that regenerate naturally (without replanting); species that do not grow too fast or tall (requiring frequent cutting); and species with longer individual lifespans.

- Avoid monocultures of fast-growing species (e.g. pure Eucalyptus) that cannot self-perpetuate and require periodic replanting.
- Choose pioneer species that naturally facilitate establishment of later-successional species (facilitation succession).

5. Native / Locally Adapted Species: Wherever possible, use indigenous species that are naturally adapted to the local soils, altitude, aspect, and monsoon climate. Locally sourced planting material (seed, cuttings, wildlings) ensures genetic adaptation, reduces establishment failure rates, and supports native biodiversity and ecological connectivity.



Commonly Used Bio-Engineering Techniques in the Nepal Road Sector and their Engineering Functions

Table 6-4: Standard bioengineering techniques for roadside slope stabilization: classification by application, slope range, and soil suitability

No.	System / Technique	Description	Slope	Soil Suitability
A1	Planted grass lines: <i>contour / horizontal</i>	Grass slips (rooted cuttings), rooted stem-cuttings or clumps grown from seed are planted in lines running along the contour across the slope. They provide a surface cover which reduces the speed of runoff and catches debris, thereby armouring the slope against surface erosion. Horizontal lines also intercept overland flow and promote infiltration.	<65°	All types CG, CGNPF, CGPF, M
A2	Planted grass lines: <i>downslope / vertical</i>	Grass slips (rooted cuttings) or seedlings are planted in lines running down the slope, parallel to the direction of flow. They armour the slope and help to drain surface water by channeling runoff between lines in a controlled way, developing a semi-natural drainage system and preventing gulying. Not recommended on slopes >40° without combined horizontal lines.	<65°	CGPF, M, CL and CH
A3	Planted grass lines: <i>diagonal</i>	Grass slips (rooted cuttings) or seedlings are planted in lines running diagonally across the slope, combining the functions of both contour and downslope planting. Lines armour the slope and drain surface water while also catching debris. This technique offers the best compromise of the grass line planting systems in many situations.	<65°	All types
A4	Planted grasses: <i>random planting</i>	Grass slips (rooted cuttings) or seedlings are planted at random on the slope, to an approximately specified density, to armour and reinforce the slope. Plants provide a surface cover and have a limited function of catching debris. Commonly used in conjunction with standard mesh/jute netting. Where complete surface protection is needed on very steep or harsh slopes, structured grass line planting (contour, downslope, or diagonal) offers better protection.	Any	All types
A5	Grass seeding	Grass seed is sown direct on to the site, often in conjunction with mulching and jute / coir netting to aid establishment and prevent seed wash-off. It allows easy vegetation coverage of large areas at low cost. Hydroseeding (a slurry of seed, fertilizer, mulch, and tackifier sprayed under pressure) is an increasingly used modern alternative particularly suited to inaccessible or extensive road cuts in Nepal.	10–45° (Hydroseeding up to 60°)	All types (Avoid bare CH without stabilizer)
A6	Turfing	Turf, consisting of a shallow layer of growing grass and the topsoil in which it is growing, is cut from a donor site and placed directly on the slope to be protected. It provides immediate, established armour cover, with no establishment lag period. A technique commonly used on gentler embankment slopes and in areas where immediate protection is required. Its only engineering function is armouring.	10–30° (Practical limit for turf laying)	All types (Fertile topsoil preferred)



No.	System / Technique	Description	Slope	Soil Suitability
B1	Shrub and tree planting	Shrubs or trees are planted at regular intervals on the slope. As they grow, they create a dense network of roots in the soil that reinforce and anchor the slope. The main engineering functions are to reinforce and, later as the plants mature, to anchor. In the long term, large trees can also be used for support and slope stabilization. Typical planting density: 1 x 1 m to 2 x 2 m depending on species and slope hazard level.	<45° (Shrubs) <30° (Tree)	CGPF, CL, CH Most types (avoid waterlogged)
B2	Shrub and tree seeding	Shrub or tree seeds are applied directly to the site by hand or by hydro seeder. This allows very steep, rocky, and unstable slopes to be revegetated where cuttings and seedlings cannot be planted. There are two methods: direct sowing (seeds placed individually) and broadcasting (seed thrown broadcast over the site). Germination rates are lower than planting, requiring higher seed rates (2–5 x planting density). The main engineering functions are to reinforce and, later, to anchor.	Upto 60° suitable for <45° (Shrubs) <30° (Tree)	CG, CGNPF (rocky / steep inaccessible)
C1	Large bamboo	Large bamboos can reduce movement of material and stabilize slopes. They are usually raised by the traditional method or by rooted culm cuttings from a nursery. Large clumps of larger stature bamboos are one of the most substantial vegetation structures available to reinforce and support a slope. Their pachymorph (clumping) rhizome systems do not extend deeply, but the dense rhizome mat provides excellent soil grip and lateral reinforcement; however, they cannot serve as a primary anchoring structure. They can also surcharge upper slope areas.	<30°	CGPF, CL, M (moist soils preferred)
D1	Live stakes	Hardwood or softwood cuttings of suitable species are cut to lengths of 0.3–1.0 m and driven vertically into the slope face, through the unstable material and into more stable substrate below. As they root and shoot, they form a matrix of live roots that progressively reinforces the slope. They are simple, cheap, and very fast to install. Used extensively on road cut slopes and embankments in Nepal. The main engineering function is to reinforce and, in the longer term, to anchor.	<65°	CGPF, CL, CG (must allow cutting penetration)
D2	Brush layering	Woody (or hardwood) cuttings are laid in lines across the slope, usually following the contour. They form a strong barrier which prevents the development of rills, and traps material moving down the slope. In the long term, a small terrace will develop. The main engineering functions are to catch debris, and to armour and reinforce the slope. In certain locations, brush layers can be angled to provide drainage.	<45°	CGPF, CL, M (most soils)
D3	Palisades	Woody (or hardwood) cuttings are planted in lines across the slope, usually following the contour. They form a strong barrier and trap material moving down the slope. In the longer term, a small terrace will develop. The main engineering functions are to catch debris, and to armour and reinforce the slope. In certain locations, palisades can be angled to provide drainage. Palisades are structurally stronger than brush layers as cuttings are driven vertically into the soil.	<65°	CGPF, CL, CGNPF



No.	System / Technique	Description	Slope	Soil Suitability
D4	Live check dams	Large woody (or hardwood) cuttings are planted across a gully, usually following the contour. They form a strong barrier and trap material moving downwards. In the longer term, a small step will develop in the floor of the gully. The main engineering functions are to catch debris and to armour and reinforce the gully floor. Check dam spacing: $L = (H_e + F) / (S_{gully} - S_{comp})$, where H_e = effective dam height; F= Free board; S_{comp} = compensation gradient ($\leq 3\%$). Must be supplemented with structural check dams for active debris flow gullies.	Gully bed $<45^\circ$ (channel grade)	CGNPF, M, CL (gully floor soils)
D5	Fascines	A fascine is a bundle of cut branches or live cuttings. Bundles of live branches are laid in shallow trenches; after burial in the trench, they put out roots and shoots, forming a strong line of vegetation. Sometimes called live contour wattling. The main engineering functions are to catch debris and to armour and reinforce the slope. In certain locations, fascines can be angled to provide drainage. Fascines are generally slower to establish than brush layers as the bundles require trenching.	$<45^\circ$	CGPF, CL, M
E1	Vegetated stone pitching	Slopes are strengthened by a combination of dry stone walling or cobbling and vegetation planted in the gaps between the stones. There are two distinct sub-types: reinforced toe walls and protected gully beds. This technique provides a very strong form of armouring, and specifically uses vegetation to strengthen a simple civil engineering technique. It represents a stronger form of normal stone pitching. Vegetation in the gaps progressively develops root systems that bind the stone structure.	$<55^\circ$	All types (stone pitching base required)
E2	Biomat / erosion control blanket	Biodegradable matting (made from jute, coir, or straw) is pinned to the slope surface and seeded or planted through. The mat protects the surface from raindrop impact and overland flow erosion while vegetation establishes (typically 1–3 monsoon seasons). Jute mat degrades in 1–2 years; coir mat in 3–5 years, by which time root systems take over. Primary function is armouring during the critical establishment period.	$>60^\circ$	Effective on CGNPF, CGPF

Some of them are further elaborated in the subsequent sections.



6.3.2 Grass seeding

Grass Seeding

Direct sowing of grass seeds onto prepared slope surfaces

Functions and Suitability

- Quick vegetation covers large areas; suitable for slopes up to 45°.
- Acts as surface armour against splash erosion and rill formation.
- Reinforces slope over time through root development.
- Best used with mulching or jute netting to improve seed establishment.
- Suitable for well-drained soils; not recommended where slumping risk is high.

Specific Provisions

- Seeds: fully mature, cleaned, sun-dried, stored in cool dry conditions.
- Seeds collected from local areas and multiple healthy plants.
- Avoid unapproved commercial seeds without engineer's consent.
- Poor germination due to mishandling is contractor's liability.
- Maintain application rate ~25 g/m².

Materials

- High-quality, viable grass seeds of selected species.
- Tools for surface scarification.
- Mulching materials (banmara).
- Hessian (jute) sheeting or wide-mesh netting.

Site Preparation and Construction

- Remove loose debris and unstable materials.
- Lightly scarify the slope surface before sowing.
- Start sowing from top and move downward; cover immediately with mulch.
- Use jute netting on slopes steeper than 30° to hold mulch in place.

Limitations

- No immediate structural strength (unlike grass slips).
- Vulnerable to heavy rainfall immediately after sowing.
- Slower establishment than vegetative propagation.

Recommended Grass Species for Seeding

SN	Local Name	Botanical Name	Altitude	Site Suitability
1	Babiyo	<i>Eulaliopsis binata</i>	Terai–1500 m	Hot and dry
2	Dhonde	<i>Neyraudia reynaudiana</i>	Terai–1500 m	Hot and dry
3	Kans	<i>Saccharum spontaneum</i>	Terai–2000 m	Hot and dry; moist
4	Katara Khar	<i>Themeda spp.</i>	Terai–2000 m	Varied
5	Khar	<i>Cymbopogon microtheca</i>	500–2000 m	Hot and dry; varied
6	Phurke	<i>Arundinella nepalensis</i>	700–2000 m	Varied; stony
7	Sito	<i>Neyraudia arundinacea</i>	Terai–1500 m	Varied



6.3.3 Grass plantation

Grass Plantation

Planting of grass slips, rizome, stolon or seedlings in defined patterns for erosion control and slope stabilization

Functions and Suitability

Grass planting involves slips, rooted cuttings, or seedlings in horizontal (contour), vertical (downslope), diagonal, or random patterns.

- Provides immediate surface cover and root reinforcement.
- Suitable for slopes up to 65° depending on pattern.
- Patterns selected according to soil type, drainage conditions and functional requirement.

Specific Provisions

- Species selection as per instruction or approved list.
- Use healthy, vigorous plants only; avoid weak or stunted material.
- Collect from local areas; obtain landowner permissions.
- Wrap cuttings in wet hessian; keep cool and moist. Plant same day.

Materials

- Grass slips, rooted cuttings, or nursery-grown plants.
- Planting tools (bars, knives, secateurs).
- Line string, tape, spirit level for line planting.
- Hessian and water to keep roots moist.
- Manure or compost to improve establishment.
- Jute netting (especially for random pattern on steep slopes).

Pattern-wise Suitability, Limitations & Execution

Pattern	Function & Suitability	Limitation	Execution	Sketches
Horizontal (Contour)	Armours, reinforces; catches debris, reduces runoff Suited to dry, well-drained soils.	May increase infiltration and risk of instability in poorly drained soils.	Mark contour lines accurately using level and string. Line-line spacing 1m for slope <30° 0.5m for slope 30-45° 0.3m for slope 45-65°	
Vertical (Downslope)	Armours reinforces; drains surface water Suited to wet, poorly drained soils.	May cause rill erosion or drying due to excess drainage.	Align planting along slope direction (line of fall). Line-line spacing: 0.5m	



Diagonal / Herringbone	Partial drainage, debris catching Suited to mixed or uncertain conditions.	Not ideal where specific drainage or catching function is required.	Lay lines diagonally; chevron/herringbone pattern if required. Line-line spacing: 0.5m	
Random	Armours, reinforces; uniform surface coverage Suited to very steep slopes.	Less effective than line systems; lacks directional control.	Plant uniformly across surface without fixed alignment; combine with jute netting. Slip to slip spacing: 0.1m	

Recommended Grass Species for Planted Grass Lines

SN	Local Name	Botanical Name	Altitude	Site Suitability
1	Amliso	<i>Thysanolaena maxima</i>	Terai–2000 m	Varied
2	Babiyo	<i>Eulaliopsis binata</i>	Terai–1500 m	Hot and dry
3	Dhonde	<i>Neyraudia reynaudiana</i>	Terai–1500 m	Hot and dry
4	Kans	<i>Saccharum spontaneum</i>	Terai–2000 m	Hot and dry; moist
5	Khar	<i>Cymbopogon microtheca</i>	Terai–2000 m	Hot and dry; varied
6	Khus	<i>Vetiveria zizanioides</i>	Terai–1500 m	Varied
7	Narkat	<i>Arundo donax</i>	Terai–1500 m	Hot and dry; varied
8	Phurke	<i>Arundinella nepalensis</i>	700–2000 m	Varied; stony
9	Sito	<i>Neyraudia arundinacea</i>	Terai–1500 m	Varied
10	Padang Bans	<i>Himalayacalamus hookerianus</i>	1500–2500 m	Moist
11	Tite Nigalo Bans	<i>Drepanostachyum intermedium</i>	1000–2500 m	Varied

6.3.4 Shrubs, trees and mixed planting systems

Beyond grass, a range of woody bioengineering techniques use shrub and tree cuttings, seedlings, and living structures to provide deeper mechanical reinforcement and longer-term slope stability. These techniques form the core of structural bioengineering for mountain road slopes.



Shrub and Tree Planting

Bio-engineering technique in which shrubs and trees are planted on slopes to stabilize the soil

Functions and Suitability

- Shrubs and trees reinforce and anchor slopes through root development
- Large trees can provide long-term slope support
- Suitable for almost any slope up to 30°
- Can be used carefully on slopes between 30°–45°
- Applicable on any material and site condition

Specific Provisions

- Ensure minimum disturbance to slope during pit excavation
- Larger pits improve plant growth but excessive excavation should be avoided
- Seedlings require protection and care during first three years

Materials

- Nursery-raised plants or polypot seedlings
- Digging tools
- Transport facilities for plants
- Compost or mulch

Limitations

- Seedlings take about 5 years to significantly strengthen the slope
- Regular care and protection are required during the first 3 years

Site Preparation & Construction

- Remove debris and surface irregularities
- Compact backfill properly, preferably when wet
- Cut weeds before planting
- Prepare planting pits in advance if possible
- Pit size: about 300 mm deep and 300 mm wide
- Plant when soil moisture is sufficient
- Carefully remove polypot without damaging roots
- Place seedling in pit and fill soil firmly without cavities
- Mix compost with backfill soil if available
- Add mulch around seedling without touching stem
- Plant in offset rows
- Recommended spacing: 1 m × 1 m (10,000 plants/hectare)

Recommended Species

SN	Local Name	Botanical Name	Altitude	Site Suitability
Shrubs				
1	Areri	<i>Acacia pennata</i>	500–1500 m	Hot and dry; harsh
2	Dhanyero	<i>Woodfordia fruticosa</i>	Terai-1500 m	Hot and dry; harsh
3	Dhusun	<i>Colebrookea oppositifolia</i>	Terai-1000 m	Hot and dry; harsh
4	Kanda phul	<i>Lantana camara</i>	Terai – 1750m	Hot and dry
5	Keraukose	<i>Indigofera atropurpurea</i>	Terai-2000 m	Hot and dry; harsh



6	Tilka	<i>Wendlandia puberula</i>	Terai -1500 m	Hot and dry; harsh
<i>Lantana camara</i> is an invasive alien species in Nepal. Its use should be restricted or avoided where there is a risk of spreading into natural ecosystems.				
Trees				
7	Bakaino	<i>Melia azedarach</i>	Terai-1800m	Hot and dry; harsh
8	Chilaune	<i>Schima wallichii</i>	900-2000 m	Varied; dry-moist
9	Gobre salla	<i>Pinus wallichiana</i>	1800–3000 m	Dry; varied
10	Kalo siris	<i>Albizia lebbeck</i>	Terai-1200 m	Hot and dry; varied
11	Khanyu (Khosro)	<i>Ficus semicordata</i>	Terai-2000 m	Hot and dry; varied
12	Khayer	<i>Acacia catechu</i>	Terai-1000 m	Hot and dry; harsh
13	Lankuri	<i>Fraxinus floribunda</i>	1200-2700 m	Varied;moist best
14	Painyu	<i>Prunus cerasoides</i>	500-2400 m	Varied/dry;stony
15	Rani (khote) salla	<i>Pinus roxburghii</i>	500-1950 m	Hot and dry; varied
16	Rato siris	<i>Albizia julibrissin</i>	800-3000 m	Varied and moist
17	Seto siris	<i>Albizia procera</i>	Terai-1350 m	Moist
18	Sisau	<i>Dalbergia sissoo</i>	Terai-1400m	Varied
19	Utis*	<i>Alnus nepalensis</i>	900-2700 m	Varied and moist

***Utis (*Alnus nepalensis*):** This is one of the most important species for roadside bioengineering because of its rapid growth, extensive root system, and nitrogen-fixing ability.

Shrub and Tree Seeding

Bio-engineering technique in which shrubs and trees are sown directly on slopes to establish vegetation and stabilize the soil

Functions and Suitability

- Reinforces and anchors slopes through root development
- Suitable for steep, rocky, and unstable slopes
- Useful on fractured rock slopes where planting seedlings is difficult
- Direct seeding suitable up to about 60° slopes
- Broadcasting suitable up to 45° slopes, but less effective above 30°

Specific Provisions

Site Preparation & Construction



- Choose larger seeds for direct seeding and smaller seeds for broadcasting - Avoid concentration of seeds in one location - Ensure proper surface roughness for better seed establishment Spacing - Plant spacing: about 250 mm centre to centre - Use three seeds for each plant required to improve survival rate	- Remove loose debris from the site - Roughen smooth surfaces to help seed retention and root growth Direct Seeding - Start from top of slope and move downward - Make small holes using planting bar - Place seed into hole and cover with soil - Ensure seeds are protected from direct sunlight and not damaged Broadcasting - Throw seeds evenly over slope surface - Prevent seeds from blowing away or collecting in crevices and rills - Small seeds are commonly used, though larger seeds can also be used			
Limitations	Materials			
- Seedlings require about 5 years to significantly strengthen slopes - Protection is necessary during the first few years	- Shrub or tree seeds - Small planting bars (for direct seeding)			
Recommended Species				
SN	Local Name	Botanical Name	Altitude	Site Suitability
Direct Seeding and Broadcasting (Shrubs)				
1	Areri	<i>Acacia pennata</i>	500–1500 m	Hot and dry; harsh
2	Bhujetro	<i>Butea minor</i>	500-1500 m	Hot and dry; harsh
5	Keraukose	<i>Indigofera atropurpurea</i>	Terai-2000 m	Hot and dry; harsh
Broadcasting				
6	Bakaino	<i>Melia azedarach</i>	Terai-1800m	Hot and dry; harsh
7	Chilaune	<i>Schima wallichii</i>	800-1800m	Varied and moist
8	Gobre salla	<i>Pinus wallichiana</i>	1800–3000 m	Dry; varied
9	Khayer	<i>Acacia catechu</i>	Terai-1000 m	Hot and dry; harsh
10	Rani (khote) salla	<i>Pinus roxburghii</i>	500-1950 m	Hot and dry; varied
11	Sisau	<i>Dalbergia sissoo</i>	Terai-1400m	Varied
12	Utis	<i>Alnus nepalensis</i>	900-2700 m	Varied and moist

6.3.5 Bamboo plantation

Bamboo Plantation

Planting of bamboo rhizomes or culm cuttings for slope support and rehabilitation

Functions and Suitability



- Provides slope support at the base of slopes; helps catch and slow debris movement.
- Does not provide deep anchoring (shallow roots); may cause surcharge on upper slopes.
- Effective on fill slopes, gullies, and disturbed areas on slopes <30°.
- Significant contribution from year 3–5; not immediate protection.

Specific Provisions

- Source bamboo from healthy, mature clumps or nurseries.
- Wrap in wet hessian during transport; plant same day.
- Minimum 2 m spacing across slope, ~5 m along slope.
- Apply mulch and create water basin around plant.
- Obtain permissions from landowners.

Materials

- One-year-old rhizomes with culms (traditional) or rooted culm cuttings (nursery).
- Hessian and water for moisture. Digging tools for large pits.
- Mulching material. Jute rope for support structure.

Site Preparation & Construction

- Clear debris; identify suitable bamboo clumps.
- Ensure soil is workable and accessible.
- Dig large pit (5× size of rhizome); plant upright or perpendicular to slope.
- Backfill, firm soil, apply mulch, water thoroughly.
- Optional: support using culm tripod tied with jute rope.

Limitations

- Slow effectiveness (~5 years to full function).
- Not suitable for hot, dry, stony, or upper steep slopes.
- May cause instability if planted on steep upper slopes after several years.

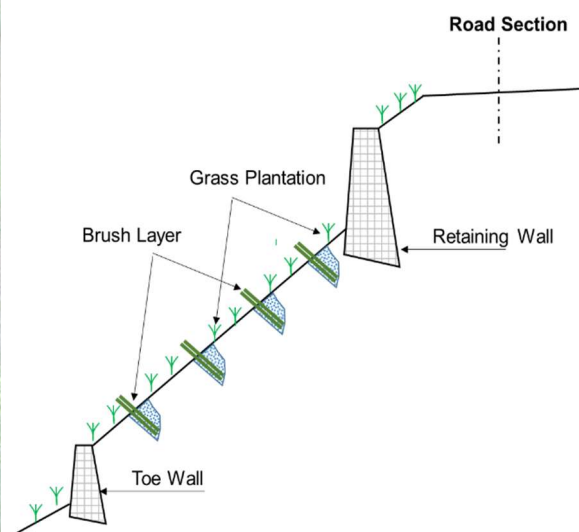
Recommended Species

SN	Local Name	Botanical Name	Altitude	Site Suitability
Traditional planting method only				
1	Mal Bans	<i>Bambusa nutans</i>	Terai–1500 m	Dry / varied
2	Nibha / Ghopi Bans	<i>Ampelocalamus patellaris</i>	1200–2200 m	Moist
Traditional or rooted culm cutting				
3	Choya / Tama Bans	<i>Dendrocalamus hamiltonii</i>	300–2000 m	Moist
4	Dhanu Bans	<i>Bambusa balcooa</i>	Terai–1200 m	Varied
5	Kalo Bans	<i>Dendrocalamus hookeri</i>	1200–2500 m	Moist

6.3.6 Brush layering

Brush Layering

Layers of woody cuttings placed along contour terraces to stabilize debris slopes and fill embankments



Functions and Suitability

- Catches debris; armours surface and prevents rill formation; reinforces through root development.
- Can provide drainage when layers are slightly angled.
- Leads to formation of small natural terraces over time.
- Particularly effective on debris slopes, fill slopes, and high embankments up to $\sim 45^\circ$.
- Not suitable for poorly drained soils prone to slumping.

Specific Provisions

- Use hardwood cuttings (6–18 months old stems), 20–40 mm diameter, 450–600 mm length.
- Top cut straight, bottom at 45° ; never remove $>60\%$ of parent plant.
- Wrap in wet hessian immediately; keep cool and moist throughout. Plant same day.

Materials

- Hardwood cuttings. Hessian and water.
- Shovels, pickaxes for trenching.
- Line string, tape measure. Forest topsoil (for gravel embankments).

Site Preparation & Construction

- Remove debris; mark contour lines using string from ~ 500 mm above slope base.
- Start from bottom, work upwards; cut terraces ~ 400 mm wide with $\sim 20\%$ inward slope.
- Place cuttings at 50 mm spacing, buds facing outward; add 20 mm soil between layers.
- Row spacing: 2m for slope $< 30^\circ$ and 1m for slope 30° – 45°
- Stagger second layer; backfill and compact gently. Repeat at required vertical intervals.

Limitations

- Causes significant slope disturbance during construction.
- Requires careful supervision and skilled execution.
- Not suitable for unstable, poorly drained materials.

Recommended Species

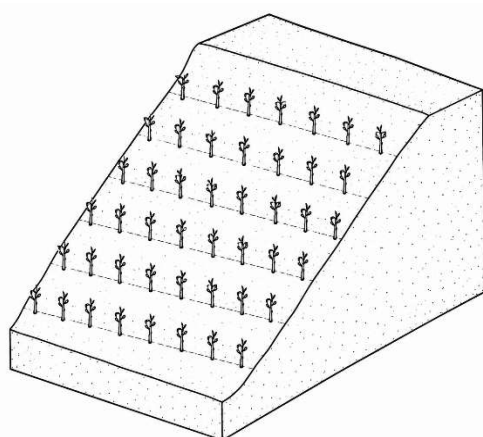


SN	Local Name	Botanical Name	Altitude	Site Suitability
1	Assuro	<i>Adhatoda vasica</i>	Terai–1000 m	Varied
2	Bainsh	<i>Salix tetrasperma</i>	Terai–2700 m	Moist
3	Kanda Phul	<i>Lantana camara</i>	Terai–1750 m	Hot and dry
4	Namdi Phul	<i>Colquhounia coccinea</i>	1000–2000 m	Varied
5	Phaledo	<i>Erythrina species</i>	900–3000 m	Varied
6	Saruwa / Bihaya	<i>Ipomoea fistulosa</i>	Terai–1500 m	Varied; hot or wet
7	Simali	<i>Vitex negundo</i>	Terai–1750 m	Hot and dry; varied

6.3.7 Palisades

Palisades

Woody cuttings planted vertically in contour lines to form vegetative barriers on steep slopes



Functions and Suitability

- Catches debris; armours the slope; reinforces soil through root development.
- Gradually forms small terraces over time.
- Effective on slopes up to ~60°, especially on steep landslide debris slopes.
- Not suitable for poorly drained soils prone to slumping.

Specific Provisions

- Use healthy woody plants, 6–18 months old stems, 20–40 mm diameter, 300–500 mm length.
- Prepare clean cuts; keep moist using wet hessian at all times. Plant same day.

Materials

- Hardwood cuttings.
- Hessian and water.
- Pointed planting bars or crowbars for making holes.



Site Preparation & Construction	Limitations
- Clean slope; remove loose debris. Mark contour lines using string. - Start from top, work downward; make holes deep ($\geq 2/3$ of cutting). - Insert carefully; firm soil around cutting. - Leave only ~100 mm or one node exposed. - Ensure alignment along contour lines to avoid runoff concentration. - Spacing (row spacing: 2m for slope $< 30^\circ$; 1m for slope $30-60^\circ$; Cutting to cutting spacing: 20-50 cm)	- Not suitable for unstable, waterlogged soils. - Cuttings may fail if not kept moist or properly planted. - Requires proper supervision.

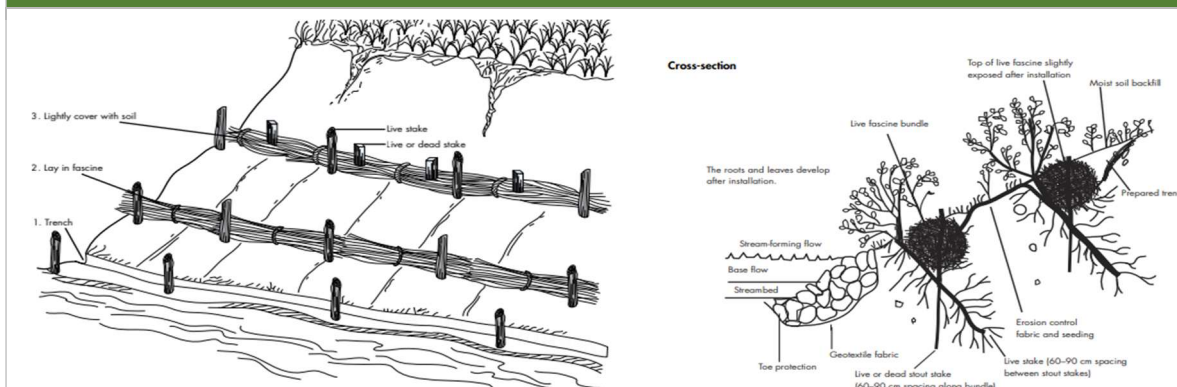
Recommended Species

SN	Local Name	Botanical Name	Altitude	Site Suitability
1	Assuro	<i>Adhatoda vasica</i>	Terai–1000 m	Varied
2	Bainsh	<i>Salix tetrasperma</i>	Terai–2700 m	Moist
3	Kanda Phul	<i>Lantana camara</i>	Terai–1750 m	Hot and dry
4	Namdi Phul	<i>Colquhounia coccinea</i>	1000–2000 m	Varied
5	Phaledo	<i>Erythrina species</i>	900–3000 m	Varied
6	Saruwa / Bihaya	<i>Ipomoea fistulosa</i>	Terai–1500 m	Varied; hot or wet
7	Simali	<i>Vitex negundo</i>	Terai–1750 m	Hot and dry; varied
8	Assuro	<i>Adhatoda vasica</i>	Terai–1000 m	Varied

6.3.8 Fascines

Fascines

Bundles of live woody cuttings placed in trenches along slope contours to form vegetative barriers



Source: Adapted from ODNR

Functions and Suitability

- Catches debris; armours slope against erosion; reinforces soil through root development.



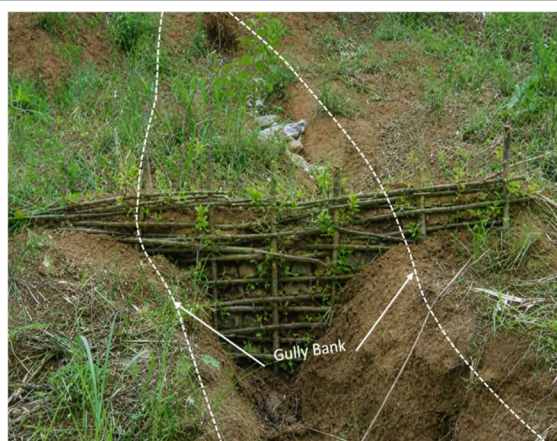
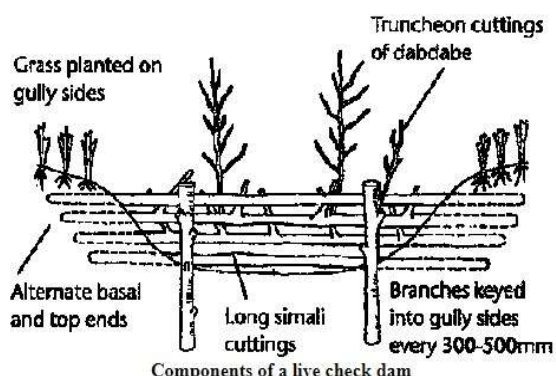
- Can provide drainage when laid at an angle (herringbone on wet slopes).
- Forms a strong, low-cost vegetative barrier.
- Slopes up to ~45°; on well-drained soils use contour; on poorly drained use herringbone pattern.
- Not suitable for very hard soils (slow growth).

Materials		Specific Provisions		
- Woody cuttings (≥1 m long, 20–40 mm diameter). - Hessian and water. Tools for digging trenches. - Jute/coir string or wire for binding bundles.		- Use healthy, vigorous woody cuttings: at least 1 m long, 20–40 mm diameter. - Keep moist using wet hessian; prepare and plant same day. - Spacing: 4 m interval(<30° slope); 2 m interval(30–45° slope).		
Limitations		Site Preparation & Construction		
- Slower establishment compared to brush layering. - Not suitable for hard or compact soils. - Requires proper moisture conditions for successful growth.		- Clear loose material; fill depressions; mark contour or pattern lines. - Start from bottom; dig trenches ~100 mm deep, 200 mm wide in short sections. - Place cuttings in bundles (4–8 cuttings) with overlapping ends across the slope. - Bind if necessary; backfill and compact firmly. - Peg fascines on slopes >25° (one peg per 500 mm).		
Recommended Species				
SN	Local Name	Botanical Name	Altitude	Site Suitability
1	Assuro	<i>Adhatoda vasica</i>	Terai–1000 m	Varied
2	Bainsh	<i>Salix tetrasperma</i>	Terai–2700 m	Moist
3	Dabdabe	<i>Garuga pinnata</i>	Terai–1300 m	Varied and dry
4	Kanda Phul	<i>Lantana camara</i>	Terai–1750 m	Hot and dry
5	Namdi Phul	<i>Colquhounia coccinea</i>	1000–2000 m	Varied
6	Phaledo	<i>Erythrina species</i>	900–3000 m	Varied
7	Saruwa / Bihaya	<i>Ipomoea fistulosa</i>	Terai–1500 m	Varied; hot or wet
8	Simali	<i>Vitex negundo</i>	Terai–1750 m	Hot and dry; varied

6.3.9 Live check dams

Live Check Dams

Bioengineering structures of large woody cuttings placed across gullies to control erosion and stabilize the gully floor



Functions and Suitability

- Catch and trap debris moving down the gully; reduce flow velocity and control erosion.
- Armour and reinforce the gully floor over time; lead to formation of small steps/terraces.
- Low-cost, flexible alternative to rigid masonry check dams.
- Suitable for gullies on slopes up to $\sim 45^\circ$, small to medium gullies.
- Not suitable for highly unstable or actively slumping materials.

Specific Provisions

- Use healthy, vigorous woody material from 6–30-month-old stems.
- Keep cuttings moist using wet hessian at all times; plant same day.
- Spacing: 3–5 m between check dams, 30–50 mm between cuttings; double offset rows for stronger structure.

Materials

- Large hardwood cuttings: 2 m length, 20–50 mm diameter.
- Truncheon cuttings: 2 m length, 30–80 mm diameter (simali, dabdabe, phaledo).
- Hessian and water. Pointed planting bars or crowbars.

Limitations

- Not effective for large or highly active gullies.
- Limited structural strength vs masonry structures.
- Effectiveness depends on plant survival; monitoring is essential.

Site Preparation & Construction

- Select location for maximum gully stabilization effect.
- Clear debris; ensure proper alignment across the gully.
- Dig deep holes for vertical cuttings (truncheons); place firmly with ~ 300 mm above ground.
- Place horizontal members (fascines or long cuttings) on upstream side.
- Key horizontal members into gully sides; backfill and compact around structure.

Recommended Species

SN	Local Name	Botanical Name	Altitude	Site Suitability
Horizontal cuttings				
1	Assuro	<i>Adhatoda vasica</i>	Terai–1000 m	Varied

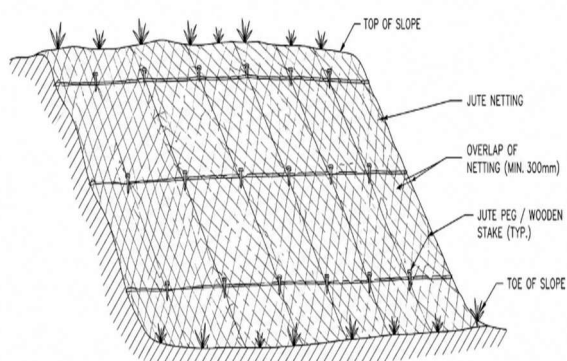


2	Bainsh	<i>Salix tetrasperma</i>	Terai–2700 m	Moist
3	Kanda Phul	<i>Lantana camara</i>	Terai–1750 m	Hot and dry
4	Namdi Phul	<i>Colquhounia coccinea</i>	1000–2000 m	Varied
5	Saruwa / Bihaya	<i>Ipomoea fistulosa</i>	Terai–1500 m	Varied; hot or wet
6	Simali	<i>Vitex negundo</i>	Terai–1750 m	Hot and dry; varied
Vertical support (truncheon) cuttings				
7	Dabdabe	<i>Garuga pinnata</i>	Terai–1300 m	Varied and dry
8	Phaledo	<i>Erythrina species</i>	900–3000 m	Varied

6.3.10 Jute netting

Jute Netting

Biodegradable geotextile placed on slopes to protect the surface and support vegetation establishment



Source: DWIDP/JICA, 2004

Functions and Suitability

- Woven jute mesh ($\approx 40 \times 40$ mm) laid over slopes as temporary protective layer.
- Armour surface against erosion; traps small debris; supports seed germination.
- Improves microclimate; retains moisture, increases infiltration.
- Acts as mulch after decay, aiding vegetation growth.
- Suitable for steep slopes $45\text{--}60^\circ$, hard well-drained soils exposed to sun and drought.
- Not suitable for soft/poorly drained soils or slopes prone to shallow slumping.

Specific Provisions

- Cover entire slope fully; ensure proper anchoring and overlap of strips.
- Integrate with bioengineering: random grass planting (~ 100 mm spacing).

Materials

- Woven jute netting: $\sim 10\text{--}11.5$ m $\times$ 1–1.2 m rolls; mesh ~ 40 mm; weight $\sim 1\text{--}1.2$ kg/m².
- Hardwood pegs or cuttings (20–50 mm diameter, 300–400 mm length) or bamboo pegs.

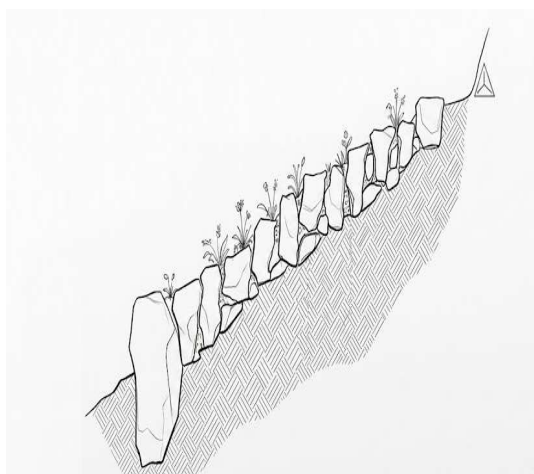


- Vegetation must establish within 1–2 seasons. - Heavier jute preferred for better moisture retention and durability.	Cutting tools, iron bar, wooden mallet.			
Limitations	Site Preparation & Construction			
- Temporary: effective for only 1–2 monsoon seasons. - Can increase soil moisture; risk of liquefaction in poorly drained soils. - Vegetation must establish quickly for long-term stability.	- Trim slope to even surface; remove protrusions, depressions, and loose material. - Start from top; unroll netting downward. Fix with pegs at 500–1000 mm spacing. - Ensure strips meet without gaps; adjust to lie closely against slope (not tight). - After installation, plant grass slips through netting.			
Recommended Species				
SN	Local Name	Botanical Name	Altitude	Site Suitability
Grass slips planted through netting (random pattern, ~100 mm spacing)				
1	Amliso	<i>Thysanolaena maxima</i>	Terai–2000 m	Varied
2	Babiyo	<i>Eulaliopsis binata</i>	Terai–1500 m	Hot and dry
3	Khus	<i>Vetiveria lawsoni</i>	Terai–1500 m	Varied
4	Kans	<i>Saccharum spontaneum</i>	Terai–2000 m	Hot and dry; moist
5	Khar	<i>Cymbopogon microtheca</i>	Terai–2000 m	Hot and dry; varied
6	Phurke	<i>Arundinella nepalensis</i>	700–2000 m	Varied; stony

6.3.11 Vegetated stone pitching

Vegetated Stone Pitching

Combination of stone pitching with vegetation for slope toe protection and gully floor stabilization





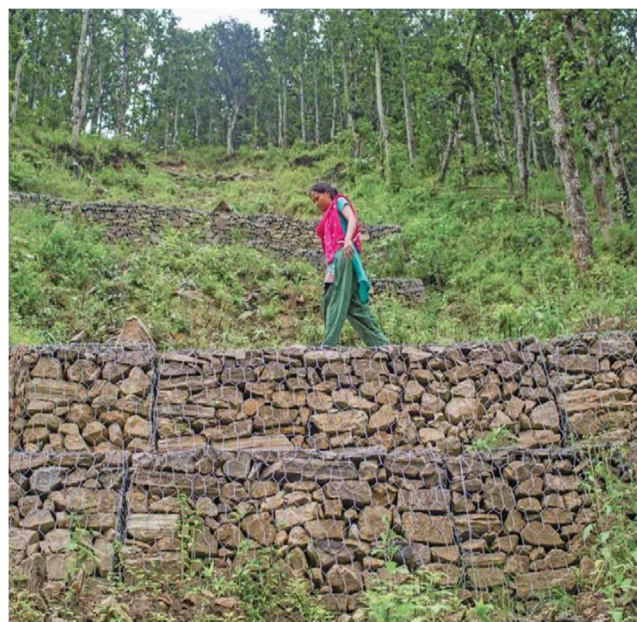
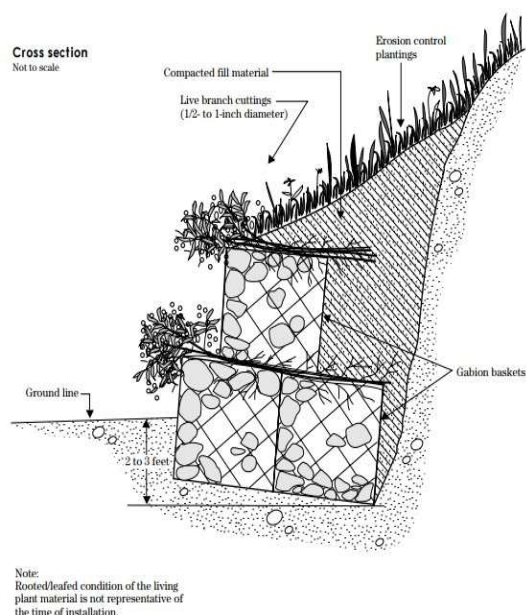
Functions and Suitability				
- Armours slopes and gully beds; reinforces through plant roots. - Prevents undermining at slope toes; stabilizes gully floors and prevents downcutting. - Vegetation binds stones and resists water flow. - Suitable for: toe walls up to ~2 m height (~60° slope); gully floors up to 45°.				
Specific Provisions			Materials	
- Use suitable plant species: shrubs for walls, grasses for gullies. - Dense planting (~250 mm spacing, random pattern). - Avoid large tree species (may destabilize structure). - Ensure proper soil packing between stones for plant growth.			- Stones for pitching or wall construction. - Hardwood cuttings or shrub seeds (for walls). - Grass slips (for gully floors).	
Limitations			Site Preparation & Construction	
- Can be costly over large areas. - Not suitable where heavy structural support (gabions/masonry) is required. - Requires proper construction and plant establishment.			- Clear debris; expose firm base; shape to U-section. - Lay stones tightly; minimize gaps; fill voids with soil. - Plant grass slips between stones after onset of rains.	
Recommended Species				
SN	Local Name	Botanical Name	Altitude	Site Suitability
Shrubs / hardwood cuttings — for toe walls				
1	Assuro	Adhatoda vasica	Terai–1000 m	Varied
2	Kanda Phul	Lantana camara	Terai–1750 m	Hot and dry
3	Namdi Phul	Colquhounia coccinea	1000–2000 m	Varied
4	Simali	Vitex negundo	Terai–1750 m	Hot and dry; varied
Grass slips — for gully floors and channels				
5	Khus	Vetiveria lawsoni	Terai–1500 m	Varied
6	Kans	Saccharum spontaneum	Terai–2000 m	Hot and dry; moist
7	Khar	Cymbopogon microtheca	Terai–2000 m	Hot and dry; varied
8	Amliso	Thysanolaena maxima	Terai–2000 m	Varied



6.3.12 Vegetated gabion

Vegetated Gabions

Gabion structures integrated with vegetation to enhance long-term slope stability and reinforcement



Source: [Rossow, 1992](#)

Source: [WWF Nepal/Nabin Baral](#)

Functions and Suitability

- Two types: stone-filled gabions (seeds/cuttings in voids) and earth-filled gabions (seedlings planted on top).
- Provide slope support and retention; vegetation adds reinforcement over time.
- Roots improve long-term stability after wire corrosion.
- Applicable on any slope where gabion walls are required.

Specific Provisions

- Maintain planting spacing: ~500 mm centres (random pattern).
- Cuttings must reach original ground for effective rooting.
- Stone gabions: sow seeds into gaps (~25 seeds/m³) or insert cuttings through gabion.
- Earth-filled gabions: plant seedlings (~4 per m³) on top.

Materials

- Stones, wire mesh, tools for gabion construction.
- Earth fill (earth-filled type). Seeds (utis, dar) for stone gabions.
- Hardwood cuttings (dabdabe, phaledo). Polypot seedlings (earth-filled type).

Limitations

- Vegetation in stone gabions contributes slowly to structural strength.

Site Preparation & Construction

- Prepare foundation and alignment for gabion wall.
- Ensure adequate moisture conditions for plant growth.



- Stability after wire corrosion is uncertain without established root system. - Limited research, especially on earth-filled type.	- Construct gabion structure. Fill according to type. - Insert seeds or cuttings after construction (stone type). - Plant seedlings on top after filling (earth-filled type).			
Recommended Species				
SN	Local Name	Botanical Name	Altitude	Site Suitability
Stone-filled gabions — seeds in voids; cuttings through structure				
1	Dabdabe	Garuga pinnata	Terai–1300 m	Varied and dry
2	Phaledo	Erythrina species	900–3000 m	Varied
3	Utis	Alnus nepalensis	1000–3000 m	Moist
4	Dar	Boehmeria rugulosa	500–2000 m	Moist; varied
Earth-filled gabions — polypot seedlings on top				
5	Bainsh	Salix tetrasperma	Terai–2700 m	Moist
6	Phaledo	Erythrina species	900–3000 m	Varied
7	Simali	Vitex negundo	Terai–1750 m	Hot and dry; varied



Table 6-5: Vegetation zonation for bioengineering in Nepal

Parameter	Teraí & Foothills	Riverine / Lower Hills	Mid-Hill Slopes	Riparian & Hill Slopes	Upper Hills & Sub-Alpine
Altitude & site conditions	200–1,000 m asl Any aspect Rainfall 1,400–2,500 mm/yr	200–1,200 m asl Riparian / valley Rainfall 1,200–2,000 mm/yr	600–1,800 m asl All aspects Rainfall 1,500–3,500 mm/yr	300–2,200 m asl Moist / riparian Rainfall 1,800–3,500 mm/yr	1,800–3,200 m asl North-facing Rainfall 1,000–2,500 mm/yr
Pioneer grasses Stage 1 (Yr 0–5)	Babiyo (<i>Eulaliopsis binata</i>) Khar (<i>Imperata cylindrica</i>) Kans (<i>Saccharum spontaneum</i>)	Kans (<i>Saccharum spontaneum</i>) Narkat (<i>Arundo donax</i>) Vetiver/Khus (<i>Chrysopogon zizanioides</i>)	Vetiver/Khus (<i>Chrysopogon zizanioides</i>) Babiyo (<i>Eulaliopsis binata</i>) Amriso (<i>Thysanolaena latifolia</i>)	Napier (<i>Pennisetum purpureum</i>) Ashare (<i>Miscanthus nepalensis</i>) Lemon grass (<i>Cymbopogon flexuosus</i>)	Nigalo bamboo (<i>Drepanostachyum</i> spp.) Ashare (<i>Miscanthus nepalensis</i>) Khar (<i>Imperata cylindrica</i>)
Pioneer woody Stage 1 (Yr 0–8)	Tilka (<i>Wendlandia puberula</i>) Dhanyero (<i>Woodfordia fruticosa</i>) Bhujetro (<i>Crotalaria pallida</i>)	Khair (<i>Acacia catechu</i>) Sisau (<i>Dalbergia sissoo</i>) Uttis (<i>Alnus nepalensis</i>)	Khote salla (<i>Pinus roxburghii</i>) Ipil-ipil (<i>Leucaena leucocephala</i>) Flemingia (<i>Flemingia macrophylla</i>)	Uttis (<i>Alnus nepalensis</i>) Asuro (<i>Justicia adhatoda</i>) Titepati (<i>Artemisia indica</i>)	Gobre salla (<i>Pinus wallichiana</i>) Chutro (<i>Berberis aristata</i>) Lali gurans (<i>Rhododendron arboreum</i>)
Open forest Stage 2 (Yr 10–50)	Sal (<i>Shorea robusta</i>) Karma (<i>Haldina cordifolia</i>) Bel (<i>Aegle marmelos</i>)	Sal (<i>Shorea robusta</i>) Sisau (<i>Dalbergia sissoo</i>) Karma (<i>Haldina cordifolia</i>)	Chilaune (<i>Schima wallichii</i>) Tooni (<i>Toona ciliata</i>) Katus (<i>Castanopsis indica</i>)	Chilaune (<i>Schima wallichii</i>) Katus (<i>Castanopsis indica</i>) Banjh (<i>Quercus</i> spp.)	Khasru (<i>Quercus semecarpifolia</i>) Banjh (<i>Quercus leucotrichophora</i>) Gurans (<i>Rhododendron arboreum</i>)
Climax target Stage 3 (Yr 50–100+)	Mixed hardwood forest + Sal dominant + diverse understorey Open structure (<50% shade)	Riverine gallery forest Mixed hardwood Multi-layered riparian structure	Open Schima–Castanopsis forest Mixed subtropical broadleaved Open structure (<50% shade)	Open Chilaune–Katus forest Mixed subtropical montane Alnus nurse layer retained	Open Khasru–Banjh–Gurans forest Mixed temperate broadleaved <i>Abies</i> / <i>Betula</i> at upper fringe
Approximate timeline	Pioneer 0–5 yr Open forest 10–40 yr Climax 50–100+ yr	Pioneer 0–5 yr Open Sal 10–30 yr Climax 50–80 yr	Pioneer 0–5 yr Broadleaved 15–35 yr Climax 50–80 yr	Pioneer 0–8 yr Open forest 15–30 yr Climax 50–80 yr	Pioneer 0–8 yr Oak/Rhodo 20–50 yr Climax 70–100+ yr



6.4 Variation in Function of Vegetation under Different Site Conditions

A critical but often overlooked aspect of bioengineering is that the same species perform very differently depending on altitude, aspect, drainage, and soil conditions. Understanding this variability is essential for correct species selection and realistic performance expectations.

The Case of Amliso (*Thysanolaena maxima*) -Broom Grass

Amliso is one of the most widely used bioengineering species in Nepal, valued for its rapid establishment, dense tussock form, erosion control effectiveness, and significant economic value as a broom-making material. However, its performance varies considerably across the altitudinal gradient:

Characteristic	Lower Altitude (Terai to ~800 m)	Mid-Hills (800–1500 m)	Higher Altitude (1500–2000 m)
Growth rate	Rapid; reaches full tussock size in 1–2 seasons	Moderate; well-established by Year 2	Slow; may take 2–3 seasons for full establishment
Stem height	Up to 3–4 m in favourable conditions	2–3 m; denser tussocks	1.5–2 m; more compact
Rooting depth	Shallow-moderate (0.3–0.5 m)	Moderate (0.4–0.6 m)	More limited by cold and rocky substrate
Biomass production	Very high; rapid canopy closure	High	Moderate; limits broom-making productivity
Primary engineering function	Strong armour + surface reinforcement	Armour + reinforce + limited catch	Armour + surface protection
Economic value	High (broom market well-developed)	High to moderate	Lower (limited market access)
Risk	Can outcompete desired shrubs if not thinned	Manageable with regular maintenance	Frost damage in severe winters possible

Species performance in bioengineering varies with altitude and site conditions. For example, Kans (*Saccharum spontaneum*) performs well in warm, moist lowlands but declines above 2000 m. Assuro (*Adhatoda vasica*) is effective in the mid-hills but becomes less competitive at higher elevations, while Utis (*Alnus nepalensis*) is well suited to moist mid-hill sites but performs poorly in dry aspects and the Terai.

The species lists in this guideline indicate the altitudinal range for establishment; however, practitioners should select species based on their engineering performance under site-specific conditions. Observations of naturally established vegetation on nearby stable slopes provide the most reliable basis for species selection.



6.5 Vegetation Selection and Planting Techniques

6.5.1 Selection criteria

Species selection is one of the most critical determinants of bioengineering success or failure (Figure 6.2). Selection must be based on a structured assessment of multiple criteria, not simply on what is familiar or easily available. The following framework guides selection:

Table 6-6: Criteria for selecting bioengineering species and techniques

Criterion	Parameters to Assess	Implication for Species/Technique Selection
Site Condition	Slope angle, aspect, altitude, soil type, drainage, rainfall, stoniness	Determines applicable techniques and suitable species. Steep, dry slopes favour grass seeding + jute netting; moist slopes favour brush layering + willow species.
Engineering Function	Catch, armour, reinforce, anchor, support, drain	Grasses: primarily armour + reinforce (surface). Shrubs/trees: deeper reinforcement + anchoring. Bamboo: support at toe. Fascines/palisades: catch + reinforce.
Availability	Local occurrence, nursery supply, propagation method, seasonality	Prioritise species found within 1 km. Establish nursery for species not locally abundant. Collect during monsoon for immediate planting.
Socio-economic	Livelihood value (fodder, timber, NTFP), community ownership, gender equity	Species with fodder or NTFP value (amliso, khus, bambo) increase community buy-in. Align with local land-use practices.
Environmental	Invasive potential, biodiversity compatibility, soil compatibility	Avoid species with invasive potential at high altitudes. Prefer native keystone species. Avoid monospecific planting.
Drought factor	Integrates slope angle, stoniness, altitude, rainfall intensity, and aspect	Drought factor classes I, II and III are favourable to bioengineering sites while precaution should be taken for classes V and VI
Growth Characteristics	Growth rate, persistence, drought tolerance, root architecture	Use pioneer species first (utis, assuro). Plant perennials for long-term stability. Deep-rooted species for anchoring function.

A core principle is to prioritize diversity over monospecific planting. Bioengineering systems that rely on a single species are vulnerable to pest and disease incursion, are unable to adapt to environmental change, and may arrest natural succession. An ideal bioengineering plant community combines fast-establishing pioneer grasses for immediate protection, medium-term shrubs for structural reinforcement, and longer-lived trees for deep anchoring and ecological complexity.

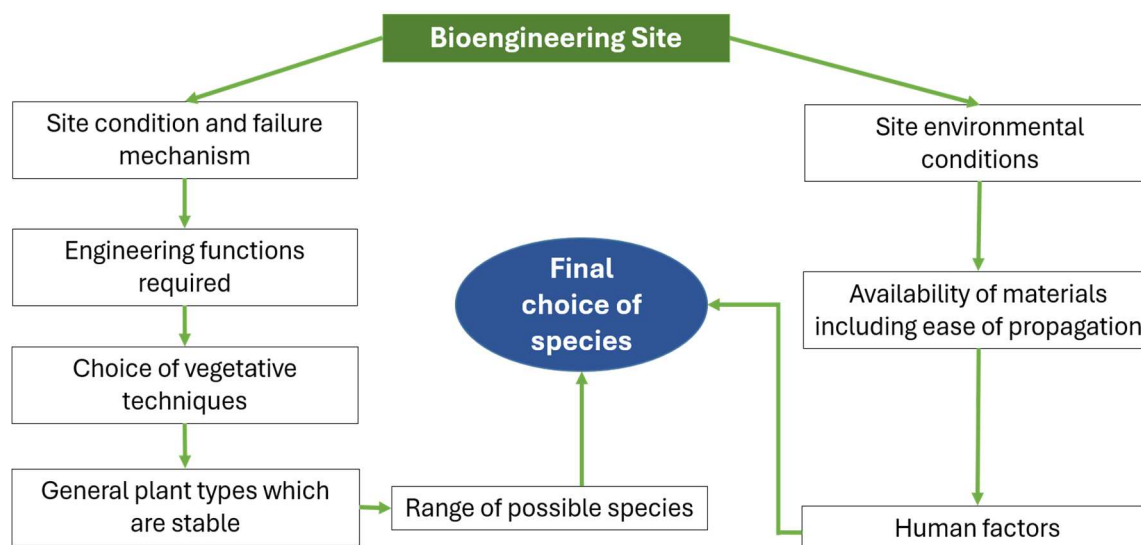


Figure 6.2: Framework for plant species selection

6.5.2 Use of local species and nursery establishment

Local species which naturally occur within the immediate project area should be the first choice for bioengineering. Local species are already adapted to the site's climate, soil, and ecological conditions; they establish more rapidly and survive the dry season more reliably than exotics; and they are compatible with the existing plant community, supporting rather than disrupting succession dynamics (Figure 6.2).

The key steps for identifying and using local species are:

1. Conduct a site vegetation survey: Walk the natural slopes adjacent to the road corridor and record all naturally occurring grasses, shrubs, and trees. These are potential bioengineering candidates.
2. Identify bioengineering suitability: From the survey list, identify species that meet the required engineering functions (armour, reinforce, catch, etc.) and that are present in sufficient quantities for collection.
3. Establish a site nursery: Where local species are not available in sufficient quantities for immediate collection, establish a simple nursery near the road corridor. Nurseries require minimal infrastructure, shade netting, watering facilities, polypot growing medium (forest soil + compost), and dedicated care.
4. Collect planting material ethically: Collect seeds, slips, or cuttings from healthy parent plants; never collect more than 30–40% of material from any single plant or clump. Obtain permissions from landowners and coordinate with local community and authority.
5. Propagate by appropriate method: Grasses are propagated by slips (separated clumps with roots). Shrubs may be propagated by hardwood cuttings (directly planted) or seeds in polypots. Trees are typically raised in polypots for 3–6 months before transplanting.

Where local species cannot provide all required engineering functions the approved species list may be selected upon for supplementary introduction. However, non-local species should not



comprise more than one-third of the planting mix, and species with invasive potential must be strictly avoided.

6.5.3 Strength development timeline of bioengineering measures

A common source of misunderstanding between clients, engineers, and contractors is the timeline for bioengineering measures to be developed fully functional. Unlike civil engineering structures that provide immediate protection, bioengineering requires time for vegetation to establish, root systems to grow, and mechanical reinforcement to develop. The following table provides indicative timelines of growth for different techniques and species types:

Table 6-7: Growth and performance timeline of bioengineering techniques

Technique / Species Type	Month 1–3	Month 4–6	Year 1	Year 2	Year 3	Year 5+
Grass Seeding (surface)	Seeds germinate	Cover 30–60%	Full surface cover	Root mat forms	Stable armour	Mature stand
Grass Plantation (slips)	Establishment	Cover 50–70%	Full cover + root mat	Root network deepens	Strong armour + reinforce	Mature stand
Palisades / Brush Layering	Cuttings root	Shoot growth	Partial shrub canopy	Root reinforces (active)	Full structural function	Terrace formation
Fascines	Bundled barrier active	Rooting starts	Vegetation on bundle	Root reinforces	Full function	Stable terraces
Tree Seedlings (e.g. Utis)	Establishment	Early growth	1–2 m height	Roots 0.5–1 m	Roots 1–2 m depth	Deep anchoring
Bamboo Plantation	Planting only	Shoot emergence	Small clump	Clump expands	Clump structural	Full debris catch
Civil Structure (Baseline)	Full (immediate)	Full	Full	Degrades w/o maint	Maintenance required	Significant maintenance

The practical implication of this timeline for project planning is significant: bioengineering interventions installed at the beginning of the monsoon should be considered 'in establishment phase' for at least 12–18 months. During this period, complementary civil measures (erosion control drains, temporary sediment traps, mulching) must remain in place, and monitoring and gap-filling maintenance is critical.

6.6 Maintenance of NbS Interventions

Maintenance is the single most critical factor in the long-term success of bioengineering interventions. Field experience in Nepal consistently shows that well-installed bioengineering sites



that receive adequate Year 1 and Year 2 maintenance outperform both poorly maintained sites and civil structures in terms of long-term slope stability and cost-effectiveness.

The key maintenance activities and their timing within the Nepali calendar are as follows:

Table 6-8: Operational maintenance schedule for bioengineering works in Nepal

Activity	Nepali Month	Gregorian Approx.	Purpose	Applicable To
Protection / Gap-filling inspection	Kartik 1	October	Assess survival post-monsoon; replant failures	All techniques
Weeding (1st round)	Shrawan 1	July	Remove competing weeds during early growth	All
Weeding (2nd round)	Bhadra 1	August	Mid-monsoon weed control	All
Weeding (3rd round)	Ashwin 1	September	Late monsoon weed control	All
Grass Cutting	Poush 1	December	Maintain grass height; prevent shading of seedlings	Grass systems
Thinning (from Year 3)	Kartik 1	October	Prevent overcrowding; allow canopy development	Shrubs, trees, bamboo
Watering (Year 1 only, dry season)	Chaitra–Jestha	March–June	Ensure survival through first dry season	Bamboo, tree seedlings
Mulching (Year 1–2)	Mangsir 1	November	Soil moisture retention; winter protection	Bamboo, trees
Structural inspection	Post-monsoon	October	Check live check dams, fascines, jute netting integrity	Structural bio-measures

Maintenance responsibilities should be clearly defined in the works contract and should continue for at least two monsoon seasons after construction. Community based maintenance, where local communities are trained and encouraged to carry out routine weeding, thinning, and gap filling, has proven highly effective. Linking maintenance activities with the collection of useful products, such as broom grass, fodder, and timber, can further strengthen community participation and improve the long-term sustainability of bioengineering interventions.

The following checklist should be completed at each maintenance visit (DoR, 1999):

- Record survival percentage for each technique and species : target >70% survival at 6 months post-planting.
- Identify and fill gaps : where survival is <50% in any section, investigate the cause (drought, grazing, soil condition) before replanting.



- Assess weed competition : aggressive colonizers (banmara, lantana, mikania) should be removed before they shade out planted species.
- Check structural elements : inspect live check dams, jute netting, and fascines for damage; repair as needed.
- Document and photograph : maintain a photographic record of each site at each maintenance visit to track progress and identify problems early.

6.7 Ecosystem-Based Slope Management and Use of Invasive Species

Ecosystem based slope management extends the concept of bioengineering beyond the application of individual techniques to a broader understanding of slope ecology. Instead of treating a slope as a blank surface for planting, this approach recognises that every slope is already part of a larger ecological system, with existing vegetation, soil microorganisms, natural seed banks, hydrological connections, and ongoing ecological succession. By working with these natural processes rather than replacing or disrupting them, more resilient, sustainable, and cost-effective slope stabilization outcomes can be achieved.

Key principles of ecosystem-based slope management include:

- Natural regeneration first: Before planting, assess the site's natural regeneration potential. On less disturbed sites, simply removing invasive species and protecting the area from grazing may allow natural re-colonization to provide adequate slope protection within 2–3 seasons.
- Succession management: Bioengineering should be designed to initiate and accelerate ecological succession, from bare slope through pioneer herbs and grasses, to shrub communities, to mixed tree-shrub woodland. Species selection should support, not arrest, this progression.
- Soil microbiome conservation: Topsoil stripping and reapplication (where feasible) brings forward the existing seed bank and beneficial soil organisms, significantly accelerating plant establishment.
- Connectivity: Where possible, bioengineering planting should be designed to connect with adjacent natural vegetation patches, supporting species dispersal and genetic diversity.

Invasive Species: Risks and Potential Roles

Several species that are commonly encountered on disturbed roadsides are invasive or potentially invasive, and their management requires careful consideration:

Table 6-9: Invasive and risk-prone species management in bioengineering contexts

Species	Local Name	Status and Risk	Management Recommendation
Chromolaena odorata / Eupatorium adenophorum	Banmara	Highly invasive; rapid colonizer of disturbed slopes; outcompetes native species; allelopathic; not suitable for bioengineering use.	Remove and dispose; do not compost. Use as cut mulch only if seed-free. Replace with native pioneers (assuro, kans).
Lantana camara	Kanda Phul	Invasive in lower altitude; however, it establishes rapidly on disturbed slopes and	May be used in the approved bioengineering species list (up to 1750 m) as a pioneer (as a last



		provides reasonable short-term armour and shallow reinforcement.	resort), but must be managed and replaced by native species within 3–5 years.
<i>Ipomoea carnea</i>	Bhangeri	Semi-aquatic invasive; forms dense thickets. Not suitable for bioengineering.	Remove from slope sites. Do not use as planting material. Confused with <i>Ipomoea fistulosa</i> (Saruwa/Bihaya) distinguish carefully.
<i>Mikania micrantha</i>	Banmara jhari / Mile-a-minute	Highly invasive vine; smothers planted species in early establishment. One of the most damaging weeds on bioengineering sites.	Priority weed management target. Remove during all maintenance visits. Remove physically to avoid herbicide near waterways.
<i>Leucaena leucocephala</i>	Ipil-Ipil	Fast-growing nitrogen-fixing shrub; useful for initial establishment and fodder but can become invasive below 1500 m and may inhibit native succession.	Use sparingly, only below 1000 m; thin aggressively at Year 2–3 to allow native canopy development.

The use of invasive species as 'quick fix' bioengineering is tempting but they establish rapidly on disturbed sites and are freely available. However, this approach trades short-term cover for long-term ecological damage. In diverse and ecologically sensitive mountain environment, the long-term ecological and economic costs of invasive species establishment far outweigh the short-term benefits of their use in bioengineering. It is advised to emphasise in local species collection and nursery establishment rather than relying on invasive colonizers.



CHAPTER 7. SELECTION OF APPROPRIATE STRUCTURES AND TECHNIQUES

7.1 Decision-Support Framework

Every slope stabilization decision begins with site information obtained through the characterization process described in [Chapter 3](#). The framework presented here translates that field information into a structured pathway leading to one of three solution domains: engineering-led, NbS-led, or integrated (hybrid). It operates across three tiers. [Table 7-1](#) sets out this three-tier framework for slope stabilization decision-making and technique selection, identifying the key input data and the decisions required at each stage.

Table 7-1: Three-tier framework for slope stabilization decision-making and technique selection

Tier	Input Data Required	Output and Decision
Tier 1: Hazard Screening	Topography, geology, failure type, failure depth, and anticipated consequence	Determine whether the site is within the scope of field assessment and routine mitigation, or whether specialist involvement is required
Tier 2: Solution Domain Selection	Drainage conditions, altitude, slope length, urgency of intervention, and available budget	Determine whether the primary approach should be engineering-led, nature-based, or a hybrid of both
Tier 3: Technique Selection	Site-specific characteristics, site type (cut slope, fill slope, gully, or toe), implementation timeline, and maintenance capacity	Identify specific techniques or combinations of techniques from Chapters 4, 5, and 6; refer to selection matrices in Section 7.5

7.1.1 Tier 1: Hazard screening and escalation threshold

Before proceeding with technique selection, the site must be checked against the escalation thresholds. Certain site conditions are beyond the scope of normal field practice and need escalation to a geotechnical engineer or specialist. The escalation criteria below are not optional.

Box 7.1: Mandatory Escalation: When to Call a Geotechnical Specialist

Escalate the site immediately to a qualified geotechnical engineer or design specialist if ANY of the following conditions are present:

- Deep-seated failure: estimated failure plane depth greater than 3 m.
- Active mass movement: debris is currently moving; slope is continuously creeping.
- Failure height exceeding 15 m of affected slope face.
- Road blockage with risk to life: active failure onto carriageway.
- Tension cracks observed on the road surface or at the cut crest.
- Springs or artesian seepage emerging at the slope face under pressure.



- Complex geology: interbedded hard rock and weak shale; faults; heavily jointed rock.
- Infrastructure at risk: settlement, school, hospital, water intake within the failure zone.
- Previous treatment failure: a previously treated slope has failed again.

The presence of **any one** of these conditions is sufficient to trigger escalation. **DO NOT PROCEED** with field-level treatment until the site has been assessed by a specialist.

7.1.2 Tier 2: Solution domain selection flowchart

For solution domain selection, the flowchart below (Figure 7.1) summarizes the Tier 2 decision logic leading to the three solution domains. The key distinguishing variables are: (i) failure depth, (ii) slope angle, (iii) material type and drainage condition, (iv) urgency, and (v) available budget and maintenance capacity.

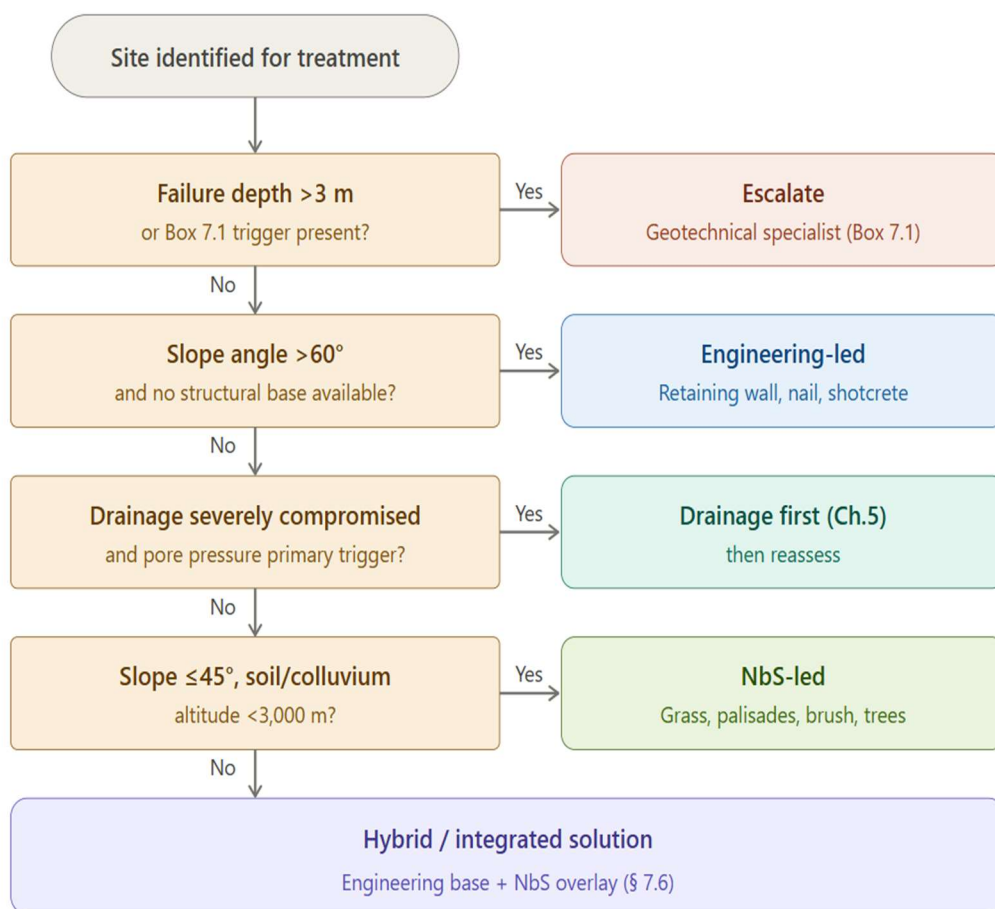


Figure 7.1: Simplified decision-support flowchart for solution domain selection.

7.1.3 Tier 3: Technique selection

The appropriate stabilization technique(s) shall be selected considering the site characteristics, site type (cut slope, fill slope, gully or toe), implementation timeline and maintenance capacity. Selection shall be made using the matrices provided in section 7.5. and may include engineering measures (Chapter 4), water management and drainage measures (Chapter 5), bioengineering measures (Chapter 6) or an appropriate combination of these measures.

Note: The depth ranges in this guideline help in selecting suitable stabilization measures. As a general guide, failures less than 1m deep can be typically treated using vegetation, those between 1



and 3 m generally require hybrid measures, and failures deeper than 3 m should be referred for specialist assessment (Box 7.1). These are guideline values and should always be used with sound engineering judgment.

7.2 Criteria for Selecting Engineering vs. NbS Solutions

The selection between engineering-led, NbS-led, and hybrid approaches is not a binary decision, but a graduated assessment based on multiple criteria. Table 7-2 presents a criteria framework that applies six discriminating variables, each of which may favour engineering, NbS, or hybrid solutions depending on site-specific conditions in Bagmati Province. In practice, it is uncommon for all criteria to indicate the same solution domain; consequently, most slopes require a hybrid approach.

Table 7-2: Criteria for selecting engineering vs. Nbs solutions

Criterion	Favour Engineering-Led	Favour NbS-Led	Hybrid Indicated
Slope Angle	>60° (near-vertical); no bench possible	≤45° with accessible face; ≤30° for grass-only	45°–60°: structural toe + vegetation above
Failure Depth	>2 m (structural measure or drainage required)	<1 m (root reinforcement zone)	1–2 m (brush layering + structural drainage)
Failure Type	Rotational (deep); rockfall; rock slide	Translational (shallow); surface erosion; soil creep	Debris slide; shallow rotational; gully
Drainage Conditions	High artesian pressure; waterlogged; active springs	Moderately drained; seasonal seepage only	Subsurface drains required before planting
Urgency Timeline /	Immediate threat; road closure; life risk	Preventive treatment; low-risk susceptible slope	Structural base immediate; NbS in following season
Budget & Maintenance Capacity	Where high capital investment is justified by road importance and consequence of failure	Low capital availability; strong community capacity for maintenance	Moderate budget; phased investment over 2–3 years

Source: Adapted from *DoR (2007)*, *DSCWM (2016)*, and *ADPC (2020)*

Box 7.2: The "Drainage-First" Principle

Regardless of whether the selected solution is engineering-led or NbS-led, drainage must always be addressed first. A bioengineering system planted on a slope with inadequate drainage is likely to be undermined in the first monsoon. Similarly, a retaining wall without weep holes and a functional subsoil drainage system will fail from build-up of hydrostatic pressure. A cut slope without a catch drain above it is likely to remain continuously saturated and may fail repeatedly.

The sequence is always: (1) Intercept → (2) Collect → (3) Convey → (4) Discharge, and only then: (5) Stabilize (engineering or NbS).



7.3 Merits and Demerits: Comparative Assessment

Several performance dimensions can be used to assess the merits and demerits of different stabilization approaches through comparative assessment. The following comparative table (Table 7-3) is designed for use in design review, technical appraisal, and communication with decision-makers. It assesses engineering-led and NbS-led, and hybrid approaches against eight performance dimensions.

Table 7-3: Comparative assessment of engineering, NbS and hybrid approaches

Performance Dimension	Engineering-Led (Civil Only)	NbS-Led (Green Only)	Hybrid (Integrated)
Immediate stability	High	Low (Effective only after 1–3 years)	Best (provides immediate structural stability with long-term biological reinforcement)
Long-term stability	Degrades without maintenance; mortar joints may crack; gabion wires may corrode	Strengthens over time as root systems deepen; self-repairing	Structural integrity maintained; biological component provides long-term reinforcement
Suitability: steep slopes (>60°)	Yes (Walls, soil nails, shotcrete applicable)	No (Vegetation cannot anchor without structural base)	Yes (Structural base enables NbS on benches and upper slopes)
Ecological benefit	None (Impervious surfaces reduce habitat availability; concrete production is carbon-intensive)	High (Restores native vegetation, biodiversity, water quality, soil carbon)	Moderate to High (NbS component provides ecological restoration)
Carbon footprint	High: (Cement production, steel, heavy machinery result in significant carbon emissions)	Positive (Carbon sequestration by woody vegetation with minimal equipment requirements)	Low to neutral overall (Civil works emissions are partially offset by carbon sequestration from NbS over the project lifecycle)
Socio-economic co-benefits	Limited (Skilled labour and materials are often imported, providing limited local employment opportunities)	High (uses local species, community labour, and provides fodder, NTFPs, and employment opportunities, particularly for women)	High (retains the socio-economic benefits of NbS while providing structural reliability)
Climate change adaptability	Fixed structures may be exceeded by increasing rainfall intensity and have limited adaptability	High (Vegetation becomes more resilient over time as root	Highest (combines structural redundancy with an adaptive biological system)



Performance Dimension	Engineering-Led (Civil Only)	NbS-Led (Green Only)	Hybrid (Integrated)
		systems develop and access deeper moisture)	
Community acceptance	Moderate (Communities value road access but generally prefer solutions with less visual intrusion)	High (Vegetation is perceived as natural and familiar, and communities can participate in implementation and maintenance)	High (Combines the reliability of engineering measures with the ecological and social benefits of NbS)

Ratings are an expert-judgement synthesis drawn from [Capobianco et al. \(2024\)](#), [Storesund et al. \(2008\)](#), [Stoke et al. \(2009\)](#) and [DoR \(1999,2007\)](#).

7.4 The Companion Field Tool: GeoSlope Nepal

The GeoSlope Nepal – Roadside Slope Checker (available at geoslophenepal.github.io/Slope-checker) is a companion web tool developed to support the application of this guideline in the field. It runs in any modern web browser on a mobile phone, tablet, or computer, requires no installation or login, and once loaded can be used without a continuous internet connection. All calculations are performed within the browser, so no site data is uploaded or stored externally. The tool follows the same sequential workflow presented in this guideline, carrying the site data entered at the first step through to every subsequent recommendation, and is intended to simplify and speed up field decision-making.

The tool is organized as five linked modules that mirror the structure of this guideline ([Figure 7.2](#)):

- Site characterization records the site identification details and captures soil parameters, rock-mass condition, and the structural (discontinuity) assessment needed to distinguish soil-controlled from rock-controlled slopes.
- Slope stability assessment applies Taylor’s stability method to soil cut and fill slopes and a kinematic planar-failure check to rock slopes, returning an indicative factor of safety and flagging slopes that require a retaining structure or additional drainage.
- Retaining wall design provides preliminary sizing of gravity and gabion walls, checking the proposed wall dimensions against the estimated safe bearing capacity of the founding material.
- Bioengineering technique selection recommends suitable techniques and plant species filtered by slope type, altitude, and moisture regime, drawing on the species database compiled for this guideline.
- Drainage design sizes surface drains and channels from a rainfall intensity–duration relationship and reports the design discharge and channel dimensions.

The tool provides preliminary recommendations and should always be used in conjunction with this guideline. Engineering judgment remains essential, and any site meeting the escalation criteria specified in [Box 7.1](#) shall be referred for specialist assessment, regardless of the tool output. The default rainfall intensities used in the tool are based on an empirical rainfall intensity–duration relationship developed for North India ([Rambabu et al., 1979](#)). Where available, intensity–duration–



frequency (IDF) rainfall data should be entered instead, as they more accurately represent local rainfall conditions and improve the accuracy of drainage design.

Figure 7.2: Overall architecture of field assessment and design tool

Because the tool reproduces the workflow of guideline rather than replacing it, each screen corresponds to a stage of this document. Users should consult the relevant chapter for the design assumptions, limitations, and worked examples that lie behind every value the tool reports. The tool is maintained as a living resource and will be updated as the guideline is revised.

7.5 Cost-Benefit Consideration (Economic, Ecological, Social)

During selection of the NbS for roadside slope stabilization, cost-Benefit consideration on economic, ecological and social aspects must be understood while designing and implementing the program.

7.5.1 Economic dimension

The economic case for NbS and hybrid solutions are supported by documented evidence from experiences of landslides mitigations works implemented across multiple districts. Table 7-4 presents an indicative qualitative comparison of the relative costs and benefits of engineering-led, NbS-led, and hybrid approaches, highlighting differences in treatment costs, maintenance requirements, lifecycle costs, and benefit-cost performance. The comparison is intended to support decision-making during preliminary planning and should not replace project-specific cost estimation.



Table 7-4: Indicative Comparison of the Relative Costs and Benefits

Cost Category	Engineering-Led	NbS-Led	Hybrid
Preventive treatment	 (high)	 (low)	 (medium)
Emergency reinstatement	 (high)	 (low)	 (medium)
Annual maintenance	 (high)	 (low)	 (medium)
10-year lifecycle cost	 (high)	 (low)	 (medium)
Benefit–cost ratio	 (low)	 (high)	 (medium)

Note: The ratings presented in this table are qualitative and are intended to illustrate the relative performance of the three solution domains. They are based on engineering judgment, published literature, and documented DRSP landslide mitigation experience discussed in this guideline. Actual costs and benefits will vary depending on site conditions, project scale, material availability, labour costs, maintenance practices, and the level of engineering intervention required.

The Balephi landslide case study (Sindhupalchok, 2002 failure, 120 m × 110 m slide) provides one of the most clearly documented comparisons between conventional engineering and an integrated stabilization approach. The conventional engineering design prepared by a geotechnical consultant estimated the treatment cost of NRs 12,201,833. While integrated bio-engineering approach, which retained necessary civil structures (plum concrete wall, gabion wall, dry masonry) but supplemented them with slope trimming, subsurface drainage, coir netting, grass plantation, brush layering, and bamboo, achieved the same stabilization outcome at NRs 5,875,704: a saving of 48%.

7.5.2 Ecological dimension

Ecological benefits of NbS and hybrid approaches create measurable value over the road life-cycle that conventional cost–benefit analysis typically omits. The following ecosystem service values should be considered during project appraisal. Table 7-5 outlines the key ecosystem services provided by nature-based slope stabilization measures and identifies the primary beneficiaries associated with each service.

Table 7-5: Ecosystem services and beneficiary impacts of NbS

Ecosystem Service	Quantified / Qualitative Value	Who Benefits
Carbon sequestration	Mixed shrub-tree planting: 2–5 tones CO ₂ /ha/year; contributes to Nepal's national carbon-sink accounting and NDC targets	National carbon accounting
Biodiversity / habitat restoration	Roadside native vegetation corridors support pollinator and bird species; measured in species richness improvement	Ecosystem; downstream communities
Water quality improvement	Reduced road sediment load to rivers: measurable decrease in suspended solids; protects hydropower intakes and irrigation headworks	Downstream communities; hydropower operators



Ecosystem Service	Quantified / Qualitative Value	Who Benefits
Hydrological regulation	Canopy interception: 15–30% rainfall reduction to soil (short duration rainfall); ET-driven soil moisture reduction; infiltration improvement	Adjacent agricultural land; flood risk reduction
Soil formation / prevention	NbS prevents 5–20 tonnes/ha/year of topsoil loss, which is unrecoverable over engineering timescales	Agricultural land owners; road corridor
Aesthetic value	Green road corridors improve aesthetic value	Tourism; local communities

7.5.3 Social dimension

The social co-benefits of nature-based and hybrid approaches are quantifiable and, in communities dependent on road access and natural resources, frequently exceed the direct engineering value.

Employment: Bioengineering installation is labour-intensive. A 1 km road section with grass planting, palisades, brush layering, and tree planting generates 800 to 2000 person-days of local employment at community wage rates, which is a direct income transfer to roadside households, DRSP records show one Okhaldhunga rehabilitation site generated 1,517 person-days of local employment.

Women's economic empowerment: Bioengineering is one of the few road sector activities where women have traditionally taken part on equal terms with men. TID should include community labor requirements and gender equality targets in NbS contract conditions to ensure fair participation and employment opportunities for local communities, especially women.

Fodder and non-timber forest products: The vegetation established through bioengineering measures provides fodder, broom, paper, medicinal plants, and other plant-based products that generate long-term socio-economic returns for adjacent communities.

Community ownership: The long-term success of bioengineering improves significantly when local communities are involved in installation and can benefit from the planted vegetation. Community participation builds a stronger sense of ownership, leading to better maintenance and higher effectiveness than purely civil engineering structures.

Reduced road closure impacts: Good slope stabilization prevents road closures and the economic losses that go with them, which can range from NRs 50,000 to 500,000 per day to affected communities. Beyond the direct financial cost, long closures also cut off access to healthcare, markets, schools and other essential services, causing serious social harm that is hard to put a number on.

Box 7.3: Multi-Criteria Appraisal: Recommended Tool for Project Justification

TID is encouraged to use a multi-criteria appraisal framework for slope stabilization investment decisions on higher-value sites, rather than capital cost comparison alone. The framework should consider: (a) 10-year lifecycle cost; (b) ecological service value; (c) social co-benefits (employment, fodder, community participation); and (d) climate resilience. When these dimensions are included, NbS and hybrid approaches systematically score higher than engineering-only solutions on all but the most technically extreme sites.

7.6 Case-Based Mitigation Selection

To understand the subject matter, a number of cases are incorporated based on-site types. The following six selection matrices address the most common slope problem types encountered along the roadside slopes. For each site type, the matrix identifies the problem characteristics, primary failure risks, recommended solution domain, and specific techniques drawn from Chapters 4, 5, and 6.

7.6.1 Site Type 1 - Cut slope in colluvial soil (Height 3-10m)

Figure 7.3 presents the procedure for landslide assessment and the selection of appropriate mitigation measures, including trimming of overhanging material at the crown and landslide debris to form a stable slope. Similarly, the development of an effective drainage network is essential to control surface water. The selection of bioengineering measures, particularly grass planting and its pattern, is equally important. A diagonal planting pattern is generally recommended, depending on soil type and site moisture conditions. Based on the height and severity of instability, toe protection measures, such as toe or retaining wall, play a key role in ensuring long-term slope stability.

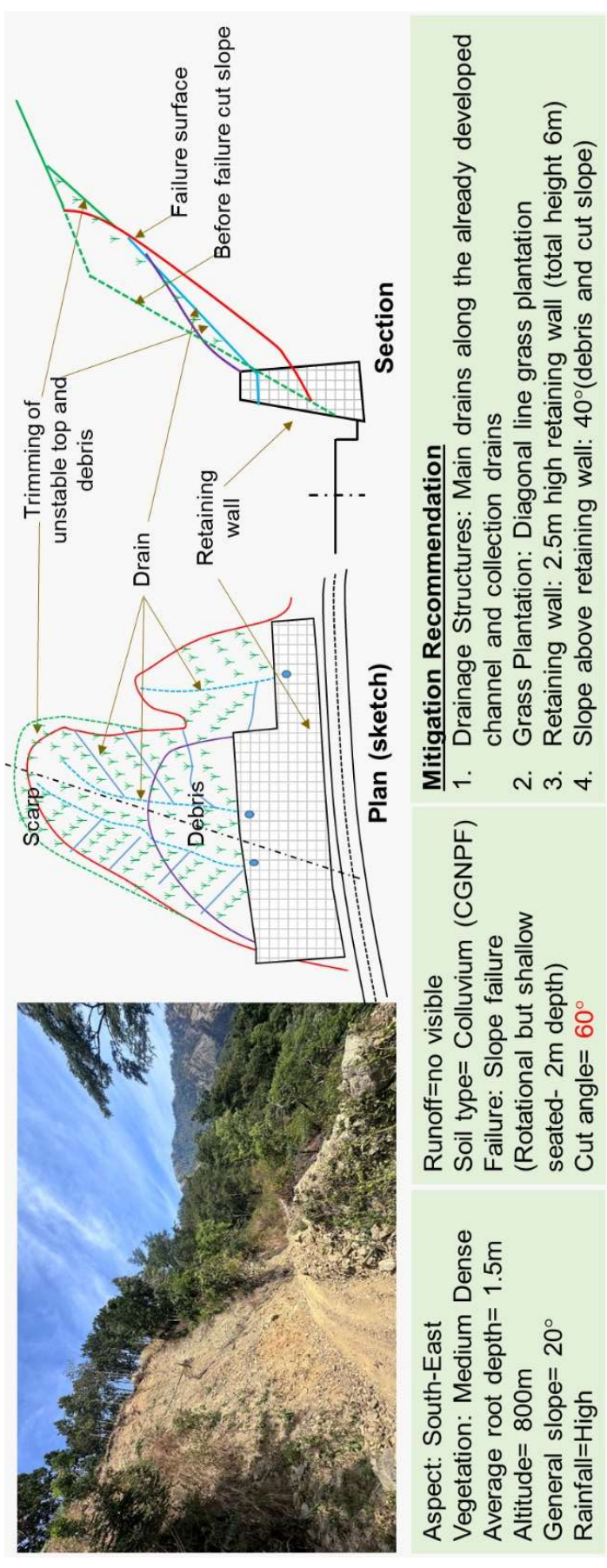


Figure 7.3: Colluvial slope: Site photographs, landslide map, section and proposed mitigation measures

7.6.2 Site Type 2- Fill Slope (>10m high spoil disposal site)

Figure 7.4 represents a typical example of uncontrolled downslope filling and spoil disposal. Two natural gullies near the ridge line originally provided suitable space for engineered spoil management. However, excavated material was dumped without proper design, compaction and drainage, resulting in an unstable embankment. The fill slope, ranging from 30° to 40°, is steeper than the stable angle for the CGNPF material. Although the soil possesses some cohesion, the steep slope and uncontrolled runoff make the fill slope highly susceptible to surface erosion and rotational failure during monsoon rainfall.

Aspect: South-west	Vegetation: Barren	Surface erosion: Construct intercepting and conveyance drains, benching, and grass plantation and brush layering
Altitude: 1700 masl	Rainfall: Medium	Rotational failure: Reduce the slope angle by benching, provide toe support with gabion retaining walls and passive backfill, establish bamboo at the toe for long term reinforcement, and install brush layers within the fill to improve internal stability
Runoff: Concentrated with rills and gullies		
Failure: Erosion and rotational failure (middle and lower slope)		
Fill slope: 30° to 40°	Soil: CGNPF	

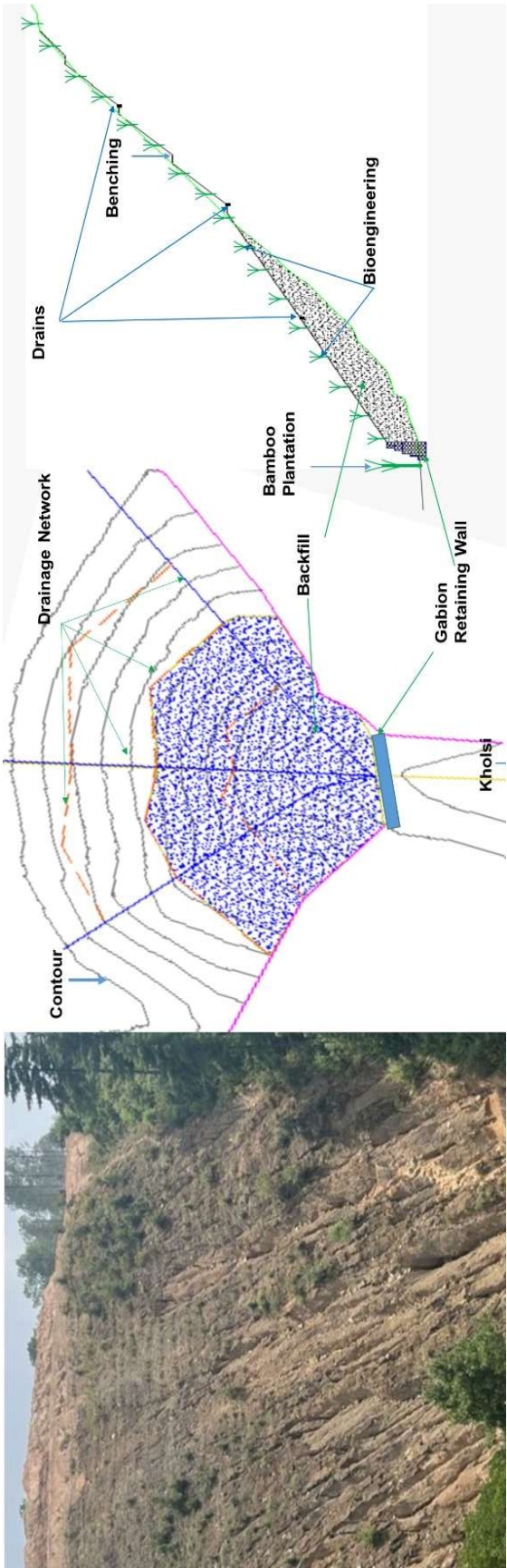


Figure 7.4: Site photograph, topography and mitigation plan, cross-section

7.6.3 Site Type 3- Mitigation/management of large gully

Figure 7.5 illustrates a representative example of comprehensive gully stabilization undertaken prior to conveying concentrated runoff through a cross-drainage structure. Uncontrolled discharge caused severe gully erosion within a single monsoon season, deepening the channel by more than 6 m and triggering multiple side failures and landslides. The upper section requires priority attention because of the presence of a road and nearby buildings, whereas the lower right bank is naturally protected by competent rock outcrop. Based on the site conditions, the recommended mitigation measures are: (1) Upper section: gully bed stabilization using cascaded PCC check structures, bank protection with retaining walls on both sides, followed by soil nailing and grass plantation; (2) Lower section: protection of the vulnerable left bank using gabion retaining walls integrated with brush layering and grass plantation, while utilizing the existing rock outcrop on the right bank as a stable natural boundary. **Considering the scale of the landslide (Upper section), expert input is recommended.**

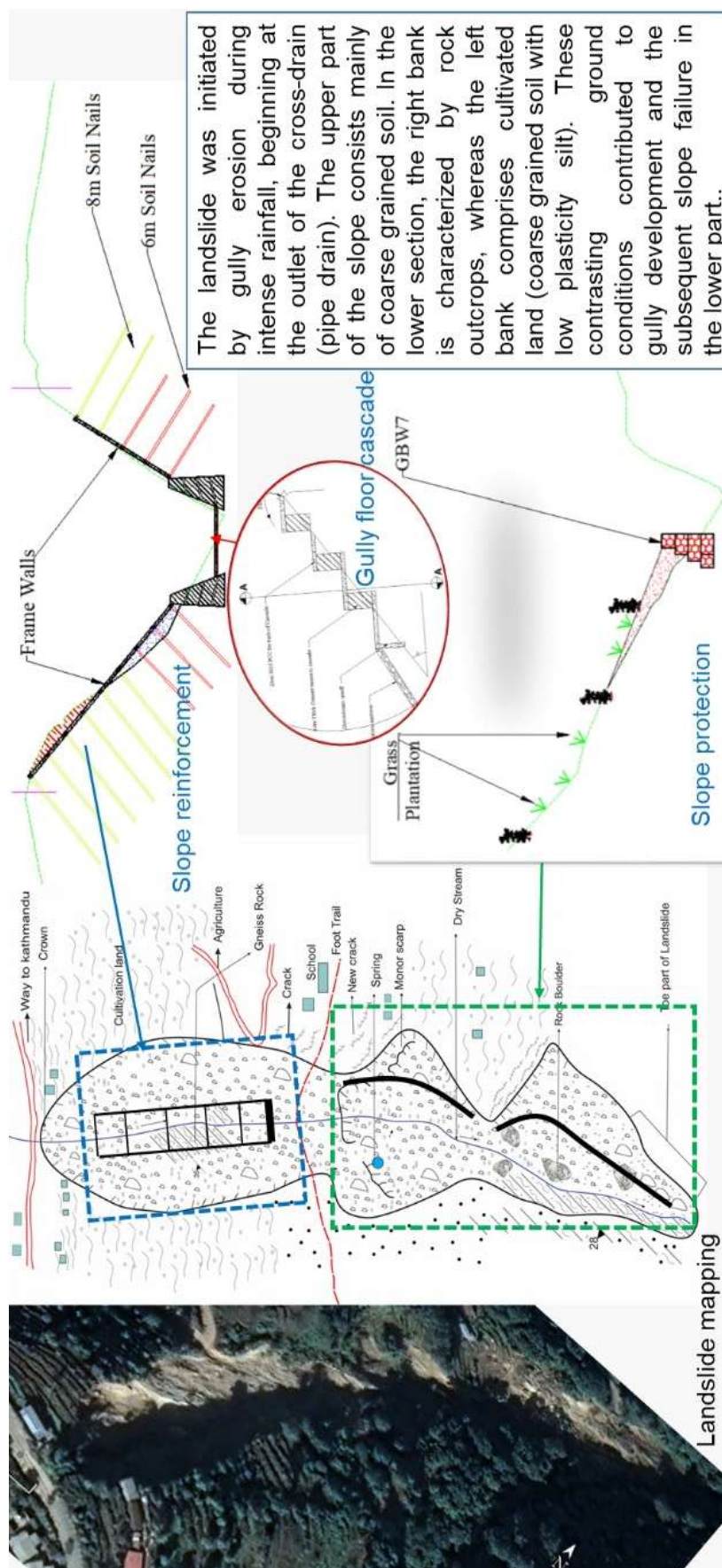


Figure 7.5: Active gully: Site photographs, landslide map and proposed mitigation measures (WRRDC, 2023)



7.6.4 Site Type 4- Shallow seated landslide in the downslope

This site is a typical example of a shallow translational landslide triggered by haphazard disposal of runoff near a hairpin bend (Figure 7.6). Uncontrolled discharge initiated progressive slope failures. The downslope soil cover is generally less than 1.5 m, with rock outcrops exposed in the lower slope, while the soil thickness increases to approximately 4.0 m near the road edge and is underlain by fractured rock, providing suitable foundation conditions for retaining structures.

Aspect: South-east	Vegetation: sparse	Surface erosion: Construct two lined drains to intercept and safely convey runoff and stabilize exposed soil using grass plantation and brush layering.
Altitude: 1070 masl	Rainfall: Medium	Translational failure: Cement stone masonry retaining wall to support the road and backfill, grass plantation and brush layers in a herringbone pattern, and gabion check walls control to support downslope.
Runoff: Concentrated with rills and gullies		
Failure: Translation	Slope: 30°	
Soil: Residual soil (CGPF)		



Figure 7.6: Shallow seated landslide: Site photographs, landslide map and proposed mitigation measures



7.6.5 Site Type 5- Complex failure in the uphill slope

This site is characterized by a medium to large landslide, exceeding 120 m in length, that repeatedly generates slides, block slides and debris flows during the monsoon season, frequently disrupting road traffic. Concentrated runoff from the catchment has developed two active gullies, accelerating erosion. The central portion of the landslide comprises highly fractured rock that is susceptible to block sliding, while the steep crown consists of residual soil. During intense rainfall, failure and liquefaction of the slope material create favourable conditions for debris flow. The proposed mitigation measures are illustrated in Figure 7.7, including the aerial photograph, mitigation master plan, and representative cross section. Although only one cross section is presented, the measures indicated by dashed lines are intended to be applied to the remaining sections. **Considering the scale of the landslide, expert input is recommended.**

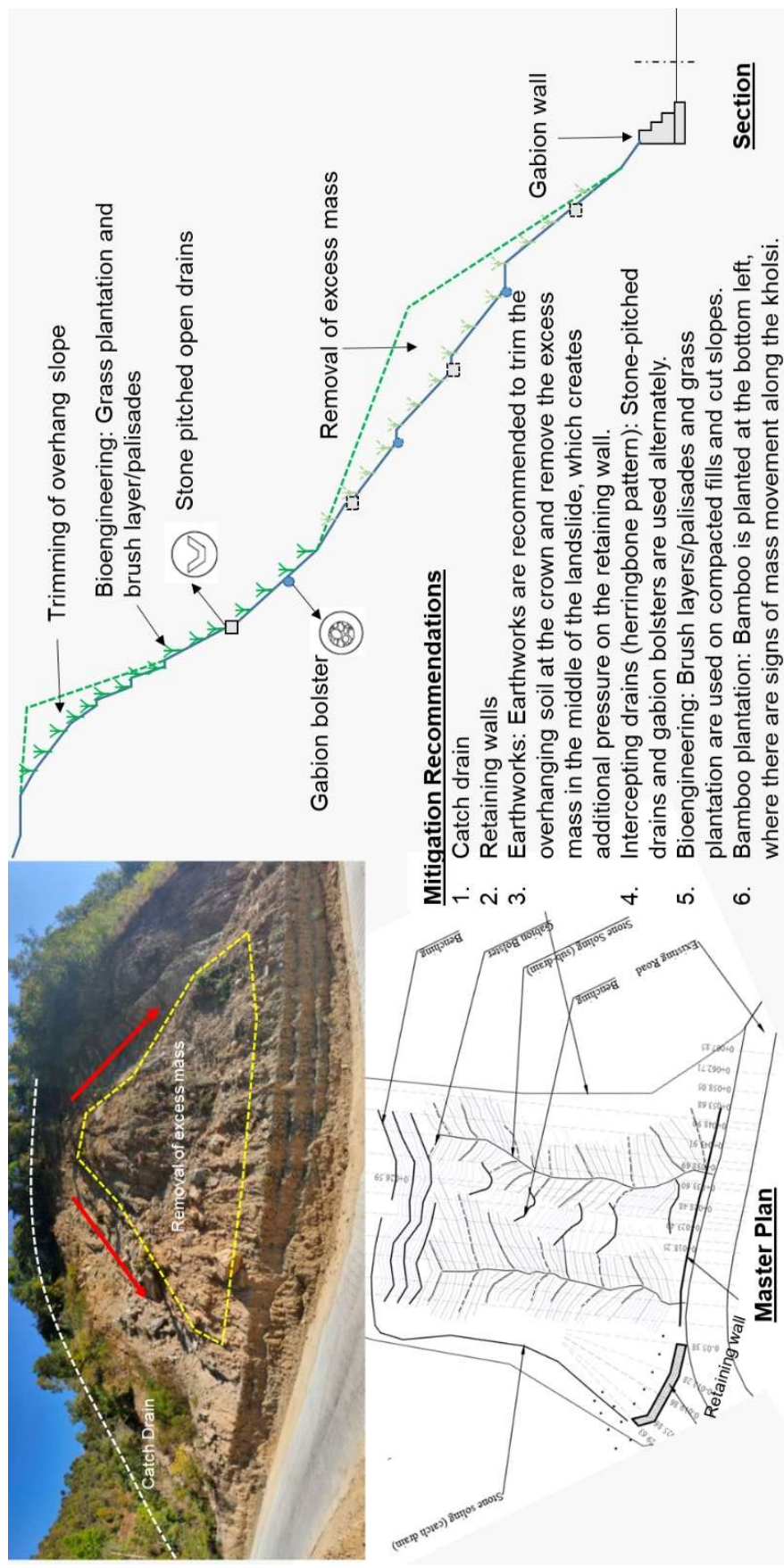


Figure 7.7: Complex landslide (Slides, flows, block slides, gullies) and proposed mitigation measures

7.6.6 Site Type 6- Down slope filling and gully erosion

Figure 7.8 illustrates a typical example of improper spoil disposal during road construction and its adverse effects on natural drainage channels (kholis) and adjacent slopes. Based on the site characteristics and observed failure mechanisms, this site is classified as a medium-scale instability problem that can be effectively stabilized through site-specific engineering assessment. The recommended mitigation measures include improved drainage management, slope armouring and reinforcement using bioengineering techniques, and stabilization of the gully bed and side slopes, as illustrated in Figure 7.8.

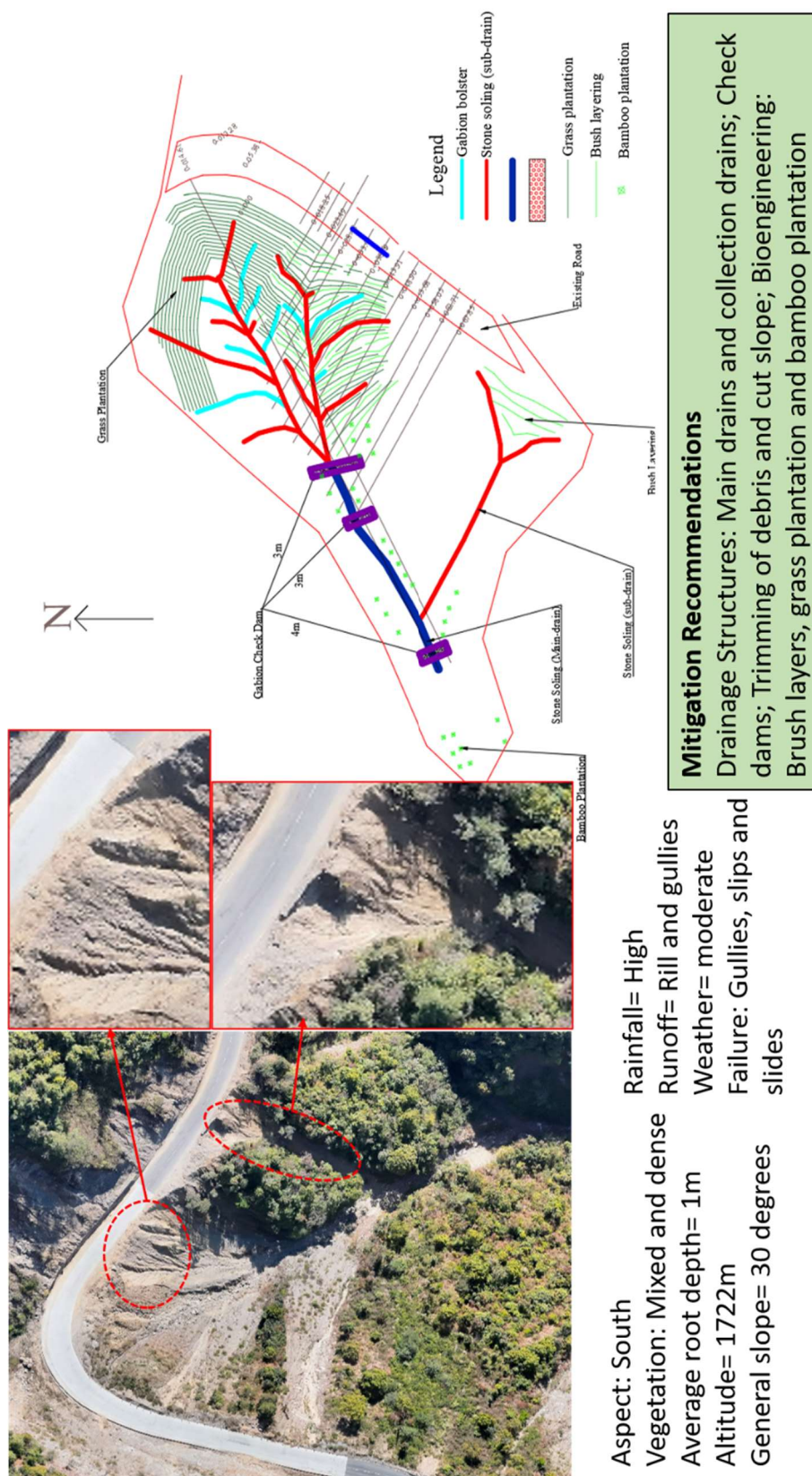


Figure 7.8: Downslope fill/spoil problems and its management

7.6.7 Site Type 7 – Rock cut slope (Jointed Sandstone)

Figure 7.9 represents an example of structurally controlled rock slope failure. The face has been excavated at 80° , which, together with the orientation of the joints and bedding, is the root of the instability. The slope carries mixed, dense vegetation with a shallow rooting depth of around 1 m, which holds the thin surface cover but plays no structural role on the rock face itself. The failure is classified as structurally controlled toppling and wedge failure on intersecting discontinuities. Given the site conditions, reshaping the slope is appropriate, though structural measures are recommended where space is the main constraint.

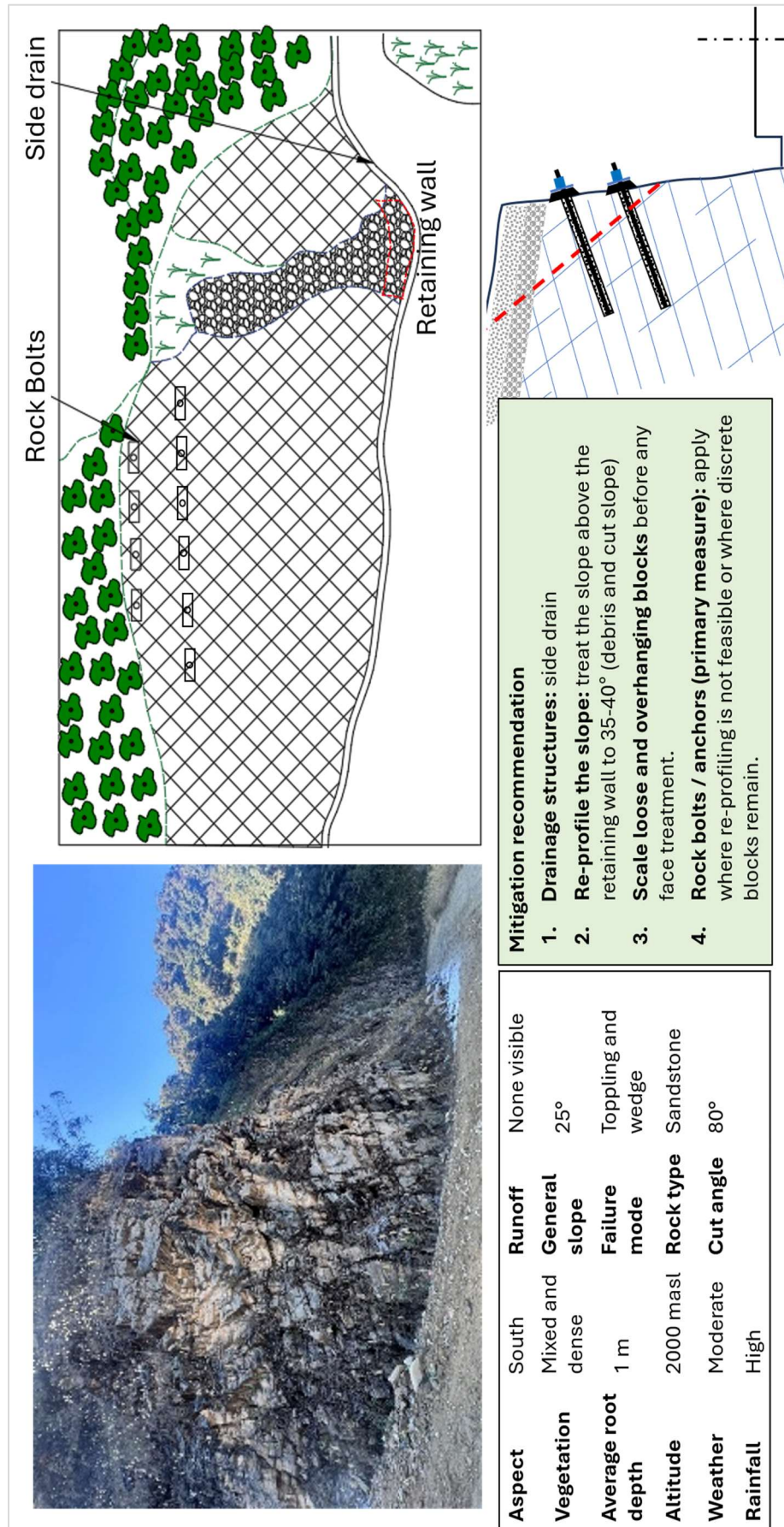


Figure 7.9: Rock slope instability and its mitigation



7.7 Integrated/Hybrid Solutions

Most roadside slope conditions in Bagmati Province are best treated by integrated hybrid solutions that combine civil engineering with Nature-Based Solutions in a complementary, mutually reinforcing system. This section sets out the design principles for that integration.

7.7.1 Rationale for integration

Civil engineering and NbS address different aspects of the slope stability problem at different depths, timescales, and spatial scales. [Table 7-6](#) highlights the respective functional roles of civil engineering and NbS components within hybrid slope stabilization systems.

Table 7-6: Civil engineering and NbS roles in hybrid slope stabilization

Functional Role	Civil Engineering Component	NbS / Bioengineering Component
Immediate stability	Structural (toe wall, retaining wall, shotcrete)	Jute netting, coir mat, immediate grass seeding
Drainage	Stone masonry drains, culverts, weep holes, subsurface drains	Brush layer/ fascine (herringbone), grass plantation
Surface armour	Stone soling, riprap, concrete channel linings	Grass seeding, grass plantation, dense grass mat
Shallow reinforcement	Soil nails (0.5–3 m depth)	Palisades, brush layering, shrub root systems (0–1.5 m)
Deep anchoring	Soil nails and rock bolts (3–15 m depth)	Deep-rooted trees (2–5 m depth)
Long-term self-maintenance	Regular inspection, repair, re-pointing	Self-reinforcing biological growth; gap-filling; community maintenance

7.7.2 Integration timeline: Sequencing civil and bioengineering works

The sequencing of civil and bioengineering works is one of the most critical aspects of hybrid slope stabilization and one that is frequently misunderstood in practice. Bioengineering measures are often implemented too late in the construction process, applied to slopes that have been left exposed through an entire monsoon season. This section establishes the correct sequencing framework as a standard for contract documentation and construction supervision.

Progressive revegetation means that vegetation is established on each completed slope section before construction moves to the next section or before the monsoon. It is not acceptable to leave large areas of bare cut or fill slope exposed through a monsoon season. This principle must be embedded in contract conditions and enforced at site supervision level.

The following [Table 7-7](#) presents the standard integration timeline for a new road construction or rehabilitation project, covering 24 months from the start of earthworks.



Table 7-7: Integration Timeline: civil and bioengineering works sequencing

Phase / Timing	Civil / Engineering Works	NbS / Bioengineering Works	Key Decision Points
Phase 0 — Design (pre-construction)	Site characterization (Chapter 3); slope stability analysis; drainage design; retaining wall design; BoQ preparation	Species selection (Annex 2); nursery establishment (Annex 7); community engagement; bioengineering BoQ	Solution domain confirmed; hybrid configuration selected; nursery lead time initiated (seedlings require 3–6 months)
Phase 1 — Earthworks (Months 1–3, Dry Season)	Controlled excavation; bench formation; fill placement in compacted lifts; catch drain installation; temporary diversion drains	Topsoil stripping and storage for later use; jute netting or coir mat applied to each completed fill section within 30 days	Drainage functional before earthworks advance to next section; no wet season earthworks in cohesive soils without drainage in place
Phase 2 — Structural Works (Months 2–5)	Retaining walls, breast walls, gabion walls, check dams, culverts, stone soling, shotcrete on rock faces	Arrangement or seeding of necessary plants in nursery	Weep holes and subsurface drains must be installed and confirmed flowing; structural completion inspection before NbS Phase 1 commencement
Phase 3 — NbS Phase 1 (Months 6–9, Monsoon Onset)	Maintenance and completion of drainage structures; inspection of structural works	Primary bioengineering installation: grass plantation (contour rows); palisades on mid-slope; brush layering on benches; tree seedling planting. This phase must coincide with monsoon onset (Baishakh–Shrawan).	Weather window: plant at monsoon onset for highest survival. Confirm soil moisture adequate. Species availability from nursery confirmed.
Phase 4 — NbS Phase 2 (Months 9–12, post-monsoon)	Post-monsoon inspection of all civil structures; repair of any damaged elements; weep hole clearance; drain cleaning	Survival assessment of Year 1 bioengineering; gap-filling with replacement species; thinning of over-dense pioneer growth; first application of organic mulch on tree seedlings; bamboo planting if not done in Phase 3	Minimum 70% survival rate for grass and pioneer shrubs is required. Sites below this threshold require gap-filling before second monsoon.



Phase / Timing	Civil / Engineering Works	NbS / Bioengineering Works	Key Decision Points
Phase 5 — Establishment (Years 2–3)	Annual inspection; minor repairs; drain maintenance; scour monitoring at toe	Deep-rooted shrub and tree species establish root systems; annual weeding and gap-filling; monitoring of root cohesion development per Annex 9; thinning of pioneer species as canopy develops	By Year 3: bioengineering system should be self-sustaining with annual community maintenance; civil structures should be performing as designed. Full performance assessment at Year 3.
Phase 6 — Long-Term Operation (Year 3+)	Biennial structural inspection; repair of isolated structural failures; drainage clearance each monsoon season	Annual post-monsoon survival check; periodic replanting of gaps (especially trees); community-led maintenance under local road committee; harvest of NTFP species as agreed	Adaptive management: if slope conditions change (new failure, adjacent works), reassess solution domain per Section 7.2 criteria.

7.7.3 Monsoon planting window: Critical timing constraints

Nepal's monsoon creates a narrow but critical window for bioengineering establishment that must be embedded in project scheduling. [Table 7-8](#) presents the seasonal suitability and operational plan for bioengineering activities in Nepal, outlining the most appropriate periods for planting, maintenance, and civil works.

Table 7-8: Seasonal suitability and operational plan for bioengineering activities in Nepal

Month (Nepali BS / AD)	Rainfall Condition	Bioengineering Suitability	Priority Actions
Baisakh–Jestha (Apr–May)	Pre-monsoon; low-moderate	Nursery readiness check; species preparation; DO NOT plant — survival will be low	Nursery verification; site preparation; drainage installation
Ashadh–Shrawan (Jun–Jul)	Monsoon onset; rainfall rapidly increasing	OPTIMAL PLANTING WINDOW: highest survival rates for grass and shrubs; install palisades, brush layering, grass plantation simultaneously	All primary bioengineering installation
Bhadra (Aug–Sep)	Peak monsoon; heavy continuous rainfall	Acceptable for establishment plants already in the ground; difficult to plant new material in saturated soils	Monitoring; emergency gap-filling only; drainage maintenance



Month (Nepali BS / AD)	Rainfall Condition	Bioengineering Suitability	Priority Actions
Aswin–Kartik (Oct–Nov)	Post-monsoon; reducing rainfall	Good for tree seedling planting; soil still moist; survival rates high for woody species	Tree planting; post-monsoon survival assessment; gap-filling
Mangsir–Falgun (Dec–Feb)	Dry season; cold at altitude	Avoid: low survival for grass and shrubs; acceptable for dormant-season tree establishment at lower altitudes (<1,500 m)	Civil works only; earthworks and structural installation
Chaitra (Mar)	Pre-monsoon warming	Nursery production peak; civil works completion; do not plant — dry conditions before monsoon	Complete all civil works before monsoon; nursery stock preparation

7.8 Selection of Appropriate Bioengineering Techniques

Selection of appropriate bioengineering techniques depends on several site-specific factors, including slope geometry, drainage condition, moisture level, material type, and the nature of slope instability. [Table 7-9](#) provides a comprehensive guide for selecting suitable bioengineering measures based on different slope conditions and required stabilization functions.

7.9 Conditions Requiring Site-Specific Design: Non-Negotiable

The following conditions require site-specific design, regardless of the apparent simplicity of the slope at first inspection which are non-negotiable.

- Any retaining wall exceeding 8 m height, or 6 m height in poor foundation conditions.
- Any failure with observed tension cracks, springs, or evidence of deep-seated movement.
- Any site within 50 m of a dwelling, school, health post, or other critical facility.
- Any slope with a history of previous treatment failure (treated and failed more than once).
- Any slope where soil nail or ground anchor installation is proposed.
- Any site requires river training or modification of a natural water course.
- Any site above 2,500 m elevation requiring species selection outside standard catalogues



Table 7-9: Slope bioengineering technique selection guide

(a) Slope Angle	(b) Slope Length	(c) Material Drainage	(d) Site Moisture	(e) Previous / Potential Problems	(f) Functions Required	(g) Recommended Techniques
> 45°	> 15 m	Good	Damp	Erosion, slumping	Armour, reinforce, drain	Diagonal grass lines
			Dry	Erosion	Armour, reinforce	Contour grass lines
		Poor	Damp	Slumping, erosion	Drain, armour, reinforce	1. Downslope grass lines and vegetated stone pitched rills 2. Chevron grass lines and vegetated stone pitched rills
			Dry	Erosion, slumping	Armour, reinforce, drain	Diagonal grass lines
	< 15 m	Good	Any	Erosion	Armour, reinforce	1. Diagonal grass lines 2. Jute netting and randomly planted grass
						1. Downslope grass lines 2. Diagonal grass lines
		Poor	Dry	Erosion, slumping	Armour, reinforce, drain	1. Jute netting and randomly planted grass 2. Contour grass lines 3. Diagonal grass lines
						1. Horizontal bolster cylinders and shrub/tree planting 2. Downslope grass lines and vegetated stone pitched rills 3. Site grass seeding, mulch and wide mesh jute netting
30° – 45°	> 15 m	Good	Any	Erosion	Armour, reinforce, catch	1. Herringbone bolster cylinders and shrub/tree planting 2. Another drainage system and shrub/tree planting
		Poor	Any	Slumping, erosion	Drain, armour, reinforce	1. Brush layers of woody cuttings 2. Contour grass lines 3. Contour fascines 4. Palisades of woody cuttings 5. Site grass seeding, mulch and wide mesh jute netting
	< 15 m	Good	Any	Erosion	Armour, reinforce, catch	



(a) Slope Angle	(b) Slope Length	(c) Material Drainage	(d) Site Moisture	(e) Previous / Potential Problems	(f) Functions Required	(g) Recommended Techniques
						1. Diagonal grass lines
						2. Diagonal brush layers
		Poor	Any	Slumping, erosion	Drain, armour, reinforce	3. Herringbone fascines and shrub/tree planting
						4. Herringbone bolster cylinders and shrub/tree planting
						5. Another drainage system and shrub/tree planting
< 30°	Any	Good	Any	Erosion	Armour, catch	1. Site seeding of grass and shrub/tree planting
						2. Shrub/tree planting
	Any	Poor	Any	Slumping, erosion	Drain, armour, catch	1. Diagonal lines of grass and shrubs/trees
Base of any slope	< 15 m	Any	Any	Erosion	Armour, catch	2. Shrub/tree planting
	—		—	Planar sliding or shear failure	Support, anchor, catch	Turfing and shrub/tree planting
						1. Large bamboo planting
						2. Large tree planting
SPECIAL CONDITIONS						
Any *	Any *	Any *	Any *	Planar sliding, shear failure	Reinforce, anchor	Site seeding of shrubs/small trees
> 30°	Any	Any rocky material	—	Debris fall	Reinforce, anchor	Site seeding of shrubs/small trees
Any loose sand	—	Good	Any	Erosion	Armour	Jute netting and randomly planted grass
Any ratio mato	—	Poor	Any	Erosion, slumping	Armour, drain	Diagonal lines of grass and shrubs/trees
Gullies ≤ 45°	Any gully	—	—	Erosion (major)	Armour, catch	1. Large bamboo planting
						2. Live check dams
						3. Vegetated stone pitching

(Source: DoR, 1999)



CHAPTER 8. IMPLEMENTATION GUIDELINES

An important aspect of the developing slope stabilization guidelines is the provision of clear implementation guidelines to address the growing frequency and impact of road-related landslides in mountainous regions.

8.1 Planning and Design Process

Effective slope stabilization does not start in the field; It begins much earlier during planning and design. Decisions made at these stages largely determine whether the most appropriate stabilization measures are selected, designed, and implemented at the right time, or whether even well designed techniques fail because of inadequate planning, inaccurate quantity estimation, or contract arrangements that encourage shortcuts.

The process described here follows the Roadside Slope Mitigation Framework introduced in [Chapter 2](#) and links directly to the decision hierarchy outlined in [Chapter 7](#).

8.1.1 Design-to-construction Pathway

All slope stabilization works should follow a five-step pathway, as mentioned in Table 8-1, from site identification to construction commencement. The level of detail and documentation required at each step depends on the design level.

Table 8-1: Standard workflow for slope stabilization design and implementation

Step	Activity	Output Document	Who is Responsible
Step 1 Site Identification and Screening	Field visit and Tier 1 screening (Chapter 7). Complete Annex 4 field data sheet. Confirm whether escalation triggers are present. Classify hazard as Low / Moderate / High / Very High.	Completed Annex 4 Field Data Sheet; Tier 1 screening decision recorded	Sub-engineer (field); Engineer (Office review)
Step 2 Solution Domain Selection	Apply Tier 2 and Tier 3 decision criteria (Chapter 7). Select solution domain (engineering / NbS / hybrid). Identify technique(s) from Chapter 7 selection matrices. Confirm design level required.	Site treatment recommendation sheet with solution domain, technique(s), and design level recorded	Sub-engineer for erosion, slips and small-scale landslide (L1-L2); engineer for gullies, scouring, piping translational failure and shallow seated landslide (L2-L3); specialist for complex geology, failure mechanism and deep-seated landslide (L4)
Step 3 Design Preparation	For Level 1: complete Annex 5 template. For L2: adapt standard design with site-specific dimensions. For L3+: prepare design report, calculations, and	Level 1–2: Annex 5 completed template with BoQ. L3: Design report + drawings + BoQ. L4: Full	Sub-engineer (L1–2); engineer (L2–3); specialist geotechnical engineer (L4)



Step	Activity	Output Document	Who is Responsible
	drawings. In all cases, check drainage adequacy first.	geotechnical investigation + drawings.	
Step 4 Procurement and Contracting	Prepare contract package with BoQ (Annex 6 format), specifications, safety plan, community engagement plan, and NbS planting schedule. Include progressive revegetation clause (Chapter 7). Confirm nursery stock availability before contract award.	Contract documents; BoQ; specifications; planting calendar; nursery confirmation	Procurement and technical sections
Step 5 Pre-Construction Verification	Pre-construction site visit: verify site conditions match design assumptions. Check drainage system functional. Confirm nursery species availability. Brief contractor on quality standards (Section 8.3) and safety requirements (Section 8.5). Issue site supervision checklist (Section 8.7).	Pre-construction verification record; contractor briefing record; site supervision checklist issued	Site engineer or sub-engineer

8.1.2 Priority sequencing: Drain before you stabilize

The most common cause of slope stabilization failure at the planning stage is not technical; it is sequencing. Works are designed and let as a single package in which the drainage structures and the slope stabilization measures are awarded and implemented simultaneously, or in the wrong order. The drainage-first principle from [Chapter 5 \(Section 5.1\)](#) and [Chapter 7 \(Box 7.2\)](#) is restated here as an implementation requirement:

Box 8.1: Mandatory Implementation Sequence

For all slope stabilization works, the following sequence is mandatory and must be reflected in the work programme, construction schedule, and payment milestones in the contract:

1. Install the catch drain above the cut crest to intercept and divert upslope runoff before earthworks begin.
2. Complete all drainage works, including side drains, culverts, bench drains, and subsurface drains and confirm they are functioning before starting any structural or bioengineering works.
3. Complete structural works such as slope trimming, bench formation, and toe wall construction while the drainage system is operational.
4. Carry out bioengineering works during the appropriate planting season (see [Chapter 7, Table 7-8](#)). Planting shall only begin after the drainage system is confirmed to be functional.
5. Complete project handover, establish baseline monitoring, and implement the maintenance plan with agreed responsibilities.



Contract payment milestones should follow the same sequence, with completion of drainage works preceding payments for structural works, and completion of structural works preceding payments for bioengineering works.

8.1.3 Nursery lead time and plant stock planning

A critical and often overlooked planning constraint is that bioengineering relies on living plant material that has to be raised in nurseries well before the planting season. Tree seedlings typically need three to six months to be ready, shrubs require about two to four months, and grass slips can usually be collected within two to four weeks from established grass beds.

This makes one thing clear: nursery production has to start before the contract is awarded, not after.

Table 8-2: Plant production lead-time in nursery (DoR, 1999)

Plant Type	Nursery Production Lead Time	Planting Season (Nepal)	Source
Grass slips (Babiyo, Kans, Napier, Vetiver)	2–4 weeks from established grass beds	Jestha–Shrawan (June–July)	Community nursery or existing slope
Shrub cuttings (Phaledo, Simali, Pyracantha)	6–8 weeks for rooted cuttings	Ashadh–Bhadra (June–August)	Polypot nursery
Tree seedlings — bare root (Utis, Sisoo)	3–4 months from seed	Ashadh–Asoj (June–October)	Central or district nursery
Tree seedlings — polypot (Utis, Phaledo, Khayar)	4–6 months from seed	Ashadh–Kartik (June–October)	Central or district nursery
Bamboo rhizomes (Dendrocalamus, Bambusa)	1–2 months for rhizome splitting; available from mature clumps	Ashadh–Shrawan (June–July)	Local bamboo clumps or nursery
Live stakes / brush layer cuttings (Sisoo, Phaledo)	1–2 weeks (cut fresh before use)	Ashadh–Shrawan (June–July)	Roadside or community sources

Any slope stabilization contract exceeding NRs 500,000 in bioengineering works must include a nursery letter confirming that the required species and quantities will be available at the required planting window.

8.2 Necessity of Geotechnical Engineering Input

Most slope stabilization decisions are currently made without any geotechnical support. In many routine cases, this approach has proven reasonably effective, especially for measures like vegetative techniques, drain construction, and small retaining walls.



However, without geotechnical input, problems can arise on more complex sites. In these situations, standard catalogue solutions may be applied where a more detailed technical analysis is required, which can lead to repeated or systematic failures.

8.2.1 Mandatory, recommended and field-level assessment matrix

The required geotechnical input, the qualifications of the experts or personnel involved, and the associated level of risk shall be determined based on the site conditions, as mentioned in Table 8-3 below.

Table 8-3: Geotechnical engineering input requirements by site condition

Site Condition	Geotechnical Input Required	Minimum Qualification
Any Box 7.1 escalation trigger present (Chapter 7)	MANDATORY. No treatment without specialist assessment	Qualified engineer with geotechnical experience; minimum 5 years in Nepal slope work
Retaining wall height >8 m or any wall in poor foundation	MANDATORY. stability calculation and foundation design required	Qualified engineer with wall design competency; Standard Specifications compliance required
Soil nail or ground anchor installation	MANDATORY. Nail design, grout specification, and pull-out testing required	Specialist geotechnical engineer; reference to specialist design standards
Deep-seated failure; active movement observed	MANDATORY. Stability analysis before treatment	Qualified geotechnical engineer; slope stability software (SLOPE/W or equivalent)
Shotcrete on rock cut; complex jointed rock	MANDATORY for rock bolt design; RECOMMENDED for shotcrete thickness	Engineer with rock slope experience; discontinuity analysis for bolt pattern
Cut slope height >6 m in cohesive soil or colluvium	STRONGLY RECOMMENDED. Field-level design may underestimate rotational failure risk	Engineer review minimum; geotechnical engineer preferred
Infrastructure at risk (dwelling, school, health post within fall zone)	STRONGLY RECOMMENDED. Risk to third party makes professional assessment necessary	Engineer with risk assessment training

8.2.2 Engaging geotechnical input: Practical guidance

TID currently does not have geotechnical engineers, the following practical pathways are available for accessing geotechnical input when required.

- Provincial Technical Office: The provincial technical office has, or should have, access to qualified engineers with geotechnical backgrounds. For Level 3 sites, sub-engineers should submit the completed [Annex 4](#) field data sheet and site photographs to the provincial office for remote preliminary assessment and scheduling of a site visit.
- Consulting engineers: For contracted road projects, the consultant responsible for the road design should include a geotechnical specialist in the design team for any section with slope stabilization requirements above Level 2. This must be specified as a contract requirement in the consultant's terms of reference.



- University and research institutions: Tribhuvan University (Institute of Engineering, Pulchowk) and other Universities can provide technical support for site assessments through research collaborations, particularly for technically interesting or data-generating sites.

8.3 Construction Quality Control and Specifications

Quality control in slope stabilization construction is the process of checking at every stage of work that the completed construction confirms to the approved design and specifications. In the context of Bagmati Province, where contracts are often small, supervision is not continuous, and failures can worsen over time, quality control needs to be systematic, well documented, and integrated into the payment certification process.

8.3.1 Quality standards for civil engineering works

The quality control standards presented in Table 8-4 apply to all civil engineering slope stabilization works on roads in Bagmati Province. Unless otherwise specified, the Standard Specifications for Road and Bridge Works (DoR, 2025), Standards, Norms and Specifications for Road and Bridge Construction for Provincial Roads (DoLI, 2023), DoR Norms for Rate Analysis (DoR, 2018), and other relevant national standards and guidelines shall govern the execution and quality control of the works.

Table 8-4: Quality control standards: civil engineering works

Work Item	Key Quality Parameters	Method of Verification	Minimum Frequency	Rejection / Remediation Criteria
Slope trimming and bench formation	Slope angle within $\pm 3^\circ$ of design; bench width ≥ 1.5 m clear; bench inward slope 2–5%; no loose hanging material on face	Batter board and slope gauge (set to design angle); tape measure on bench width; visual scan for loose material	100% of each completed bench or slope section before next section begins	Re-trim if angle exceeds design by $>3^\circ$; remove all loose material; no payment for section until bench width confirmed
Retaining wall-dry stone / banded masonry	Foundation depth ≥ 500 mm below ground; batter 1:5 minimum; stone size ≥ 150 mm smallest dimension; no through-joints vertically; hearting (infill) stone placed not tipped; weep holes at design spacing	Depth tape at foundation trench; batter board; visual joint check; weep hole count and position check	Foundation: 100%; wall face: every 1.0 m lift; weep holes: 100%	Foundation too shallow: require re-excavation. Through-joints: immediate remediation. Missing weep holes: drill openings — never omit. Tipped hearting: dismantle and rebuild section.
Gabion wall / revetment	Wire mesh: minimum 2.7 mm galvanized or PVC-coated; basket	Wire gauge check with calipers; visual fill density;	Wire check: 5% sample per delivery;	Under-gauge wire: reject entire delivery. Fill density $<85\%$: open



Work Item	Key Quality Parameters	Method of Verification	Minimum Frequency	Rejection / Remediation Criteria
	fill: stone density $\geq$ 85% of basket volume; no voids $>0.3 \times D50$; lacing: complete at all panel joints; batter per design; top fill (NbS zones): organic mix as specified	lacing inspection; batter board; top layer mix sample	fill density: every basket; lacing: 100%; batter: every basket layer	basket and supplement. Missing lacing: require completion before proceeding. Wrong batter: dismantle to course at fault.
Cement stone masonry (CSM) wall and drains	Mortar mix - 1:4 (cement:sand by volume); no dry-stacking without mortar; full mortar beds; weep holes at design spacing; cure minimum 7 days before loading; drain gradient $\geq 0.5\%$	Mix check by batch: measure cement and sand volumes by gauge box; joint fullness visual; weep hole check; gradient by spirit level or level staff	Mix: every 5 batches minimum; joint: continuous visual; gradient: every 10 m run; weep holes: 100%	Wrong mix: reject batch, wash out and restart. Dry joints: cut out and repoint. Drain gradient $<0.5\%$: regrading required. Missing weep holes: core-drill required.
Subsurface drain (herringbone / French drain)	Trench dimensions per design; geotextile filter fully wrapping gravel aggregate; no gaps in geotextile; aggregate gradation: well-graded clean gravel; pipe perforations facing down; drainage outlet confirmed at design discharge point	Trench dimension tape; geotextile lap and pinning visual; aggregate sample; pipe orientation visual; outlet flow test before backfilling	100% inspection before backfilling — once covered, defects cannot be corrected	Geotextile gap: open trench and repair before backfilling — no exceptions. Wrong aggregate: remove and replace. No flow at outlet before backfilling: investigate and clear.
Shotcrete (sprayed concrete)	Mix M20 (28-day strength ≥ 20 N/mm ²); layer thickness: 75–100 mm plain; 100–150 mm reinforced; no rebound material incorporated in face; cure minimum 7 days; weep holes clear; crack width <0.3 mm after curing	Cube sampling: 3 cubes per 5 m ³ or per day, whichever more frequent; thickness gauge pins; weep hole count; crack survey at Day 7	Cube test: every day of spraying; thickness: every 5 m ² ; weep holes: 100%; crack survey: Day 7 after completion	Cube strength <20 N/mm ² : remove and reapply that section. Insufficient thickness: additional application required. Cracked face: seal cracks; assess for structural adequacy.



8.3.2 Quality standards for bioengineering/NbS Works

Quality control in bioengineering is fundamentally different from that in civil engineering because it involves living material that responds to weather, soil conditions, and management decisions over time. QC for bioengineering has three phases: installation quality, immediate post-planting survival, and establishment-period performance as shown in Table 8-5.

Table 8-5: Quality control standards: bioengineering works

Technique	Installation Quality Standards	Acceptance Criterion at 4 Weeks	Performance Criterion at 1 Year
Grass seeding (broadcast)	Seed broadcast evenly; seed mixture per design specification; topsoil scarified to 50 mm depth before seeding; no seeding during heavy rain or waterlogged conditions; light rake to cover seed; mulch applied where available	Germination visible across $\geq 70\%$ of seeded area; no bare patches $> 1 \text{ m}^2$	$\geq 80\%$ ground cover; no active rill formation under established grass; grass height 150–300 mm (not overgrown)
Grass plantation (contour slip lines)	Rows exactly at contour (spirit level or A-frame level used); row spacing per design (typically 300–600 mm on slope); grass slips: minimum 3 tillers per slip; slips planted at 150–200 mm spacing within row; planted to 150 mm depth; not planted in waterlogged conditions	$\geq 70\%$ survival across each row; row alignment maintained; no large gaps ($> 500 \text{ mm}$) within rows	$\geq 80\%$ survival; continuous rows with self-filling; no rill formation between rows
Palisades (live stakes)	Cuttings: minimum 1.5 m long, 20–50 mm diameter, cut at 45° at base; planted by dibble bar to 500 mm depth; spacing per design (typically 200–300 mm apart in rows); rows horizontal at contour; no dead or diseased material used	$\geq 60\%$ sprouting (visible shoots); stakes firmly set — cannot be pulled out by hand; row alignment maintained	$\geq 70\%$ established (rooted with shoots $> 300 \text{ mm}$); barrier effect visible; root mats beginning to develop
Brush layering	Layer excavated to 200–300 mm depth across slope; brush bundles: 50–100 mm diameter, woody cuttings mixed with grass slips; placed with base ends into slope and tips slightly downhill; covered and compacted with excavated soil to 150 mm depth; rows per design spacing (typically 0.5–1.0 m vertically)	$\geq 60\%$ sprouting along each layer line; layer material still in position; soil cover intact	$\geq 70\%$ established; vegetated terrace effect visible; sediment catchment function operating
Tree and shrub planting	Pit size: minimum 300 mm $\times$ 300 mm $\times$ 300 mm; topsoil and compost mix in pit (30:70 by volume); rootball of polypot plant fully covered; no air pockets around rootball; staking required for exposed windy sites; planted at crown	$\geq 70\%$ alive and not wilted; root ball still moist (no desiccation); stake secure, where used	$\geq 70\%$ alive with measurable new shoot growth; plants $\geq 300 \text{ mm}$ above planting height



Technique	Installation Quality Standards	Acceptance Criterion at 4 Weeks	Performance Criterion at 1 Year
	root level — not buried deeper; watering after planting		
Jute netting / coir mat	Mat laid flat against slope surface — no bridging over irregularities; pegs at 500 mm centres on contour lines; 300 mm overlap at mat joints; mat anchored at top and toe; grass seeding through mat per design; mat edge tucked into narrow trench at top and toe	Mat lying flat; all pegs intact; overlaps maintained; germination through mat $\geq 60\%$	Mat partially degraded (acceptable for biodegradable types); grass growing through mat and holding slope
Live check dams (bamboo/brushwood)	Check dam perpendicular to gully direction; height per design (typically 0.3–0.8 m); bamboo/brushwood tightly woven; anchored stakes minimum 600 mm deep at 400 mm centres; backfill zone behind dam level with dam crest; wingwalls keyed into gully banks	Structure intact and level; no bypass flow around wingwalls; sediment beginning to accumulate	Sediment trapped behind dam to design level; living material (bamboo, brush) sprouting; no undermining at base

8.3.3 Documentation and non-conformance

All QC inspections must be documented. The site supervisor must maintain a site quality record using the consolidated implementation form ([Section 8.7](#)) or equivalent. Non-conforming work must be recorded, the contractor notified in writing, and remediation must be confirmed before the next construction payment.

Box 8.2: Non-Conformance Response Protocol

When a QC inspection identifies work that does not meet specifications:

1. Stop that specific work activity immediately. Do not allow the contractor to proceed until the non-conformance is resolved.
2. Record the non-conformance on the QC log with: date, location, nature of defect, specification reference, and recommended remediation.
3. Issue the contractor with a written non-conformance notice specifying remediation required and the deadline for completion.
4. Withhold payment for the non-conforming section until remediation has been independently verified.
5. If a non-conformance recurs on the same item after remediation, escalate to TID district engineer for review of contractor capability.

The most critical non-conformances, those that must never be passed despite contractor pressure, are drainage structures covered before being confirmed flowing; bioengineering planted on a slope with unresolved hydrostatic pressure; wall sections with missing weep holes; and gabion baskets with undersized wire mesh. These defects are invisible once covered and invariably cause failure.



8.4 Rate Analysis and Bill of Quantities (BoQ)

Accurate rate analysis and bill of quantities preparation are essential for fair payment, cost control, and post-project value-for-money evaluation. This section provides the framework for preparing BoQs for slope stabilization works in Bagmati Province, with indicative rate analysis for the most common bioengineering items. Civil engineering rate analysis follows DoR Norms for Rate Analysis (2075 BS) as presented in [Chapter 4](#); this section supplements those norms with bioengineering-specific items not covered in the standard DoR norms.

8.4.1 BoQ structure for integrated slope stabilization works

The BoQ for an integrated slope stabilization work should follow the chapter structure of this guideline, organized into five parts. This structure ensures that drainage, civil, and bioengineering items are separately identified, measurable, and payable. It prevents the common failure of all three being bundled into a single lump sum that hides the cost of each component and makes QC payment enforcement impossible Table 8-6.

Table 8-6: Bill of quantities structure for slope stabilization works

BoQ Part	Content	Measurement Basis	Reference
Part A: Preparation and Drainage Works	Site clearance; catch drain; side drain; bench drain; subsurface drain; culvert installation; cascade/chute; energy dissipator	Rm (running metre) for drains; m ³ for culverts; LS for site clearance	Chapter 5; DoR Spec. 2073/2078
Part B: Earthworks and Slope Preparation	Topsoil stripping and storage; slope trimming; bench formation; spoil disposal; mass balance earthworks	m ³ for excavation and disposal; m ² for trimming	Chapter 4; DoR Spec. 2073/2078
Part C: Civil / Structural Works	Retaining walls (type); breast walls; stone soling; riprap; gabion; shotcrete; soil nailing	m ³ for walls; m ² for surface protection; m for nails	Chapter 4; DoR Norms 2075
Part D: Bioengineering / NbS Works	Grass seeding; grass plantation; palisades; brush layering; tree planting; shrub planting; jute/coir netting; live check dams; bamboo planting	m ² for area-based items; Rm for row-based items; No. for individual plants	Chapter 6; Annex 6 BoQ templates
Part E: Establishment Period Maintenance	Year 1 gap-filling; Year 1 weeding and thinning; Year 2 replanting; Year 3 assessment visit	LS or % of Part D value (typically 15–25% per year)	Chapter 7 (Section 7.7); Annex 5

8.4.2 Rate analysis: Standard bioengineering items

The rate analyses presented in Table 8-7 cover the most common bioengineering works used for slope stabilization in Bagmati Province. The analyses follow the DoR Norms for Rate Analysis (DoR, 2018) methodology, incorporating labour, materials, equipment, and overhead costs, and also have been adapted for bioengineering activities not currently included in the standard DoR norms. For



contract documentation, the prevailing district rates shall be applied, while the indicative rates provided below are intended solely for planning and preliminary cost estimation.

Table 8-7: Rate analysis: bioengineering items

Ref.	Item Description / Unit	Labour (per unit)	Materials (per unit)	Notes
BE-1	Grass seeding: broadcast on prepared slope, incl. seed, light raking and mulch / m ²	0.02 skilled + 0.08 unskilled	Grass seed: 3–5 g/m ² ; mulch (where available)	Higher end for steep inaccessible slopes; seed cost varies by species
BE-2	Grass slip plantation: contour rows, 3 tillers/slip at 200 mm spacing, incl. levelling with A-frame / Rm of row	0.05 skilled + 0.15 unskilled	Grass slips: ~5 slips/Rm; no other materials	Rate per running metre of planted row; row levelling with A-frame adds 10–15%
BE-3	Palisade installation: live stakes 1.5 m long at 250 mm spacing, incl. dibbling to 500 mm depth / Rm of row	0.10 skilled + 0.20 unskilled	Live stakes (cut on site or from nursery): ~4 per Rm	Higher end for hard ground or remote sites; stake material cost varies
BE-4	Brush layering: full installation incl. excavation, cutting placement and compaction / Rm of layer	0.15 skilled + 0.35 unskilled	Brush bundle (cuttings): 5–8 kg/Rm;	Labour-intensive; higher end for deep layers (>300 mm) or high altitude
BE-5	Tree seedling planting: polypot, 300 mm pit, topsoil + compost mix / No.	0.05 skilled + 0.10 unskilled per tree	Polypot seedling: NRs 25–80 depending on species and size; compost: 0.5 kg/pit	High range for remote sites or premium species; staking adds NRs 30–50/tree
BE-6	Shrub planting: polypot or bare root, 250 mm pit / No.	0.03 skilled + 0.06 unskilled per shrub	Shrub seedling: NRs 15–50; compost	Lower range for easily propagated species (Phaledo cuttings)
BE-7	Jute netting / coir mat — supply and lay, incl. pegging at 500 mm centres / m ²	0.05 unskilled	Jute netting: NRs 25–60/m ² ; bamboo pegs: 4/m ²	Coir mat is higher range; jute netting lower range; peg cost negligible if bamboo available locally
BE-8	Bamboo planting — rhizome division, 400 mm pit, topsoil backfill / No.	0.08 skilled + 0.20 unskilled	Bamboo rhizome: NRs 50–200 depending on species	Dendrocalamus higher cost; Bambusa nutans lower; rhizome



Ref.	Item Description / Unit	Labour (per unit)	Materials (per unit)	Notes
				from local clumps reduces cost
BE-9	Live bamboo/brushwood check dam in gully (full installation incl. stakes and backfill / No)	0.50 skilled + 1.00 unskilled	Bamboo/brushwood bundle; stakes: 4–6 per dam; binding wire	Higher end for larger dams (H > 0.5 m) or gullies with active flow
BE-10	Year 1 gap-filling and maintenance: incl. replacement plants, weeding, thinning, at rate per 100 m ² / 100 m ²	0.50 skilled + 2.00 unskilled per 100 m ²	Replacement plants (10% rate): NRs 300–800/100 m ²	Per 100 m ² of NbS treatment area; Year 2 rate typically 60–70% of Year 1

Full BoQ templates with measurement rules are provided in Annex 6.

8.4.3 Common BoQ error to avoid

- Bioengineering and civil works should not be combined into a single lump sum item, as this limits the ability to make meaningful milestone-based payments and makes value for money assessment difficult.
- Grass plantation should not be specified only in square metres without clearly defining the species mix, row spacing, number of tillers per slip, and planting density. Without these specifications, planting often ends up too sparse to be effective.
- The establishment period maintenance (Part E) should not be left out of the BoQ. Bioengineering works without first year maintenance are highly likely to fail. Although maintenance typically costs around 15 to 25 percent of the installation cost per year, it is a relatively small investment compared to the benefit it provides.
- Civil works measurement practices should not be directly applied to bioengineering items. For example, grass plantation should be measured in running metres of rows or in square metres of coverage, not in cubic metres.
- Payment for bioengineering works should not be based on materials supplied to site. Payment shall only be made for work that has been properly installed and verified against the quality control standards defined in [Section 7.3.2](#).

8.5 Safety Considerations during Construction

Roadside slope stabilization construction takes place in one of the most hazardous environments in civil engineering. Work is carried out on actively unstable slopes, often with limited access, heavy machinery operating in close proximity, hand tools in use, and weather conditions that can rapidly introduce additional risks.

In this context, safety is not merely a procedural requirement; it is a technical discipline in its own right, shaped directly by the conditions of the slope and the nature of the work being carried out.



8.5.1 Site hazard categories on slope stabilization sites

To make more clear for the implementation of the guidelines by the users, hazard category, specific hazard and primary controls measures are given in [Table 8-8](#) below.

Table 8-8: Key hazards and control measures in slope stabilization works

Hazard Category	Specific Hazards	Primary Controls
Slope instability during construction	Active slope movement during earthworks; tension crack formation above work zone; sudden collapse of loose hanging material	Pre-construction instability check; prohibit work within fall zone of unstable material; establish exclusion zone below all cut faces; daily morning inspection by site foreman
Excavation and trench hazards	Trench collapse during subsurface drain installation; undermined slopes during bench excavation; unsupported excavation faces in cohesive soils	Trench support for any excavation >1.5 m depth; shoring in soft or wet soils; minimize time between excavation and backfilling
Machinery and plant hazards	Dozer or excavator rollover on steep terrain; falling rock from machine vibration; machinery instability near the edge of a cut slope	Minimum 2 m setback from cut slope crest for all machinery; dozer only on pre-assessed stable benches; spotter mandatory for machinery near slope edges
Tool and manual labour hazards	Sharp tool injuries (dibble bar, mattock, machete); back injuries from lifting heavy stones; falls on steep slopes	Tool safety briefing before work begins; stone limit manual lifting to a maximum of 25 kg per person; appropriate safety footwear (no sandals or flip-flops); use of hand holds and safety ropes on slopes >40°
Weather hazards	Working during heavy rainfall on saturated slope; lightning during monsoon; poor visibility	Suspend slope face work during rainfall >20 mm/hour; suspend all work during lightning; prohibit night work on slopes without adequate lighting
Traffic hazard	Exposure of road users and workers to traffic; collisions between vehicles and roadside workers.	Warning signs at least 100 m in advance of the work zone in both directions; provide trained traffic controllers where the road is partially closed; require all workers to wear high-visibility reflective vests.
Chemical/material hazards	Inhalation of cement dust during cement stone masonry (CSM) or shotcrete works; skin contact with accelerator admixtures; exposure to herbicides during site clearance.	Dust masks for cement mixing and shotcrete; gloves for admixture handling; herbicide only with PPE and downwind of workers



8.5.2 Mandatory safety requirements: Non-negotiable site standards

Box 8.3: Minimum Site Safety Standards for All Slope Stabilization Contracts

The following standards apply to ALL slope stabilization works regardless of contract value or site size. They must be included as contractual conditions in all contract documents, and compliance must be verified at every site visit.

- No worker shall enter the slope face work zone until a trained site foreman has inspected the slope above and confirmed that there is no unstable material, no tension cracks, and no recent movement since the last rainfall event.
- Hard hats are mandatory for all persons within 30 m of any cut face or cliff. No exceptions shall be permitted, regardless of the perceived level of risk.
- Exclusion zone: A minimum horizontal exclusion zone equal to one times the slope height (1H) shall be established below any cut face higher than 2 m. The exclusion zone shall be clearly marked with tape or rope and enforced at all times. Workers shall not enter the exclusion zone while excavation is in progress above.
- All workers working on slopes steeper than 40° must use safety ropes anchored to stable points above their working position.
- No excavation deeper than 1.5 m shall be carried out without appropriate trench support. Trench support may consist of timber shoring, a steel trench box, or battered trench sides at a safe angle, as specified by the responsible sub-engineer.
- No work on any slope face during rainfall exceeding 20 mm per hour. The site foreman shall have the authority to suspend work immediately for safety reasons without prior approval. The contractor shall appoint at least one trained safety marshal for every 10 workers on site. The safety marshal shall have the authority to suspend work if an unsafe condition is observed.

Any injury requiring medical attention must be reported to office within 24 hours. Failure to report an injury is a breach of contract.

8.5.3 Safety for community labor on bioengineering works

Bioengineering works are often implemented with community labours/workers. Community workers, including women, older members, and individuals without construction experience, require safety guidance that is appropriate to their roles and working conditions.

- Community workers must receive a safety briefing in Nepali (or local language) before commencing work each day. The briefing should cover safe working areas, the correct use of hand tools, and the actions to take if any signs of slope movement are observed.
- Community work groups should not exceed 15–20 people on a single slope section. Larger groups create congestion on steep slopes and increase the risk of workers dislodging material onto others.
- The "no working above/below" rule: Community workers shall not work directly above or below one another on a slope. Workers should be positioned with adequate horizontal separation wherever practicable.
- Community workers shall not be assigned to work on slopes that are considered unsafe for the contractor's trained personnel. Community participation and social pressure should not



compromise safe working practices, and all work shall be supervised by a responsible site supervisor.

- A basic first aid kit should be available on every community workday. The contractor or the sub-engineer responsible for the site shall ensure that the first aid kit is readily accessible throughout the work period.

8.6 Community Engagement, Societal Engineering and Local Participation

Bioengineering systems that are implemented by and for the community, using plant species that the community values and is committed to maintaining, have been shown to achieve higher survival rates, lower long-term costs, and greater resilience to climate variability than systems imposed without meaningful community involvement.

8.6.1 The societal engineering framework

Societal engineering in TID slope stabilization work means looking at people and communities with the same level of systematic thinking that we apply to soil, water, and slope conditions. A community is not a homogeneous group; it comprises individuals with different needs, interests, and levels of influence, and practical constraints, including seasonal labour availability, gender roles, land ownership patterns, and local economic priorities.

These factors directly influence how slope protection measures are implemented and whether they are properly maintained effectively over time. Therefore, understanding the social context before design is just as important as understanding the geotechnical conditions. Table 8-9 shows the key community and social factors that should be considered during the design process.

Table 8-9: Community and social factors in slope stabilization design

Societal Engineering Element	Questions to Ask at Site Assessment	Design Implication
Land tenure and access	Who owns the slope above and below the road? Are there any landownership disputes? Are there community forests or private land within the treatment zone?	Species selection must be acceptable to the landowner. Slopes with shared ownership may require formal agreements before planting. Avoid species that could create boundary disputes.
Community economic priorities	What do households in this corridor need most :fodder, timber, fuel, NTFPs, income? What are the seasonal livelihood patterns?	Select species that provide the co-benefits the community values most. Sisoo provides timber and fodder; Kans grass provides broom grass; Utis provides nitrogen for adjacent fields.
Women's participation and benefit	Do women collect fodder and fuel from the roadside? Are they underrepresented in paid road construction work? Is there an active women's group in the ward?	Include gender equity targets in labour contracts (e.g. minimum 30% women in bioengineering works). Prioritize fodder and NTFP species that women use. Engage women's groups in nursery production.



Societal Engineering Element	Questions to Ask at Site Assessment	Design Implication
Seasonal availability of community labour	When is the community fully engaged in agricultural work? When is labour available? Does this coincide with the bioengineering planting window?	Schedule bioengineering works in Ashadh–Shrawan (onset of monsoon) — this is both the optimal planting window and a period when pre-harvest agricultural work is lighter.
Previous experience with road projects	Has this community been promised benefits from road projects before and not received them? Is there distrust of TID or contractors?	Begin community engagement early and involve local people in identifying needs as well as implementing the works. Ensure timely payment for labour and deliver visible community benefits, such as employment opportunities and useful vegetation, to build trust.
Maintenance commitment	Is there a functioning Ward-level Road maintenance group or user committee? Has it maintained previous works? What incentive exists for ongoing maintenance?	Where no maintenance group exists, its establishment should be incorporated into the project design rather than treated as an afterthought. Species that provide annual harvestable benefits, such as Kans for broom making, Vetiver for thatching, and Utis for fodder, encourage continued community maintenance.

8.6.2 Minimum community engagement requirements

The following community engagement should be prioritized for all slope stabilization contracts that include bioengineering works, regardless of contract size. They should be specified in the contract and verified by IDO supervision.

- 1. Pre-design consultation:** At least one structured consultation meeting shall be held with the ward-level community, preferably facilitated through the Ward Office or the road user committee. The meeting shall explain the proposed works, identify community preferences for plant species, confirm land access arrangements, and document the discussion.
- 2. Plant species selection agreement:** The final plant species mix shall be agreed upon with the community and recorded in writing. Species that are not accepted or valued by the community are unlikely to be maintained, regardless of their technical suitability.
- 3. Labours/workers mobilization:** Community labour for bioengineering works should be mobilized through the Ward Office or the road user committee rather than through the main contractor's labour force. This helps ensure that employment opportunities and wages benefit the local community.
- 4. Wage payment:** Community workers shall be paid at the government-approved District Rate (Jilla Dar Rate), and payment shall be made within seven days of completing the work. Delayed or incomplete payment can seriously undermine community trust in the program.
- 5. Maintenance agreement:** Before construction begins, a signed maintenance agreement shall be established with the Ward Office or a designated community group. The agreement shall specify the responsibilities for maintenance, the required maintenance activities and



their frequency, the materials or support to be provided by IDO, and the procedures for addressing non-compliance.

6. **Post-completion handover:** Upon completion of the work, a formal handover meeting shall be held with the community. This shall include a site walk-through of the completed works, an explanation of indicators of potential failure, a review of the maintenance schedule, and the provision of contact details for reporting problems to IDO/TID.

Box 8.4: The NTFP Incentive Principle: Making Maintenance Self-Funding

The most sustainable maintenance arrangements for bioengineering are those in which the community has a direct economic incentive to maintain the vegetation because the plants provide them with a direct annual income. The following combinations are specifically recommended because they provide both strong engineering functions and annual harvestable returns, thereby encouraging long-term community ownership and maintenance:

- Broom grass: Strong slope reinforcement; broom grass harvest provides annual income to the community.
- Vetiver: Deep root reinforcement; leaves used for thatching, mulch, and handicraft; roots for essential oil at larger scale.
- Utis: Deep anchoring; nitrogen fixation improves adjacent agricultural land; leaves are premium fodder for cattle and goats.
- Sisoo: River bank stabilization; high-value timber after 10+ years; dense leafy fodder.
- Bamboo: Slope toe reinforcement; bamboo shoots (edible), culm (construction), leaves (fodder) provide multiple annual revenue streams.

Wherever technical requirements permit, TID should give preference to species with NTFP value. Such species deliver the required engineering function while creating ongoing economic benefits that encourage communities to maintain the bioengineering system over its service life.

8.7 Consolidated Implementation Form/Checklist

The consolidated implementation checklist below is designed for use by sub-engineers at every slope stabilization site. It is structured around the five-step implementation pathway ([Section 8.1](#)) and the construction quality standards ([Section 8.3](#)). The checklist should be completed at four mandatory inspection points: (1) pre-construction, (2) drainage works completion, (3) civil/structural works completion, and (4) bioengineering installation completion.

A clean copy of this checklist (with signature spaces, site photo log, and GPS coordinate field) is provided in [Annex 8](#) as a standalone form for field use. The version here serves as a reference guide to the purpose of each item (see Table 8-10).

Table 8-10: Consolidated implementation checklist (see [Annex 8](#) for field form)

Stage	Item to Verify	Pass Criteria / Standard	Reference
PRE-CONSTRUCTION	☐ Site characterization complete	Annex 4 field data sheet completed; GPS coordinates recorded; slope failure type identified	Chapter 3 ; Annex 4
	☐ Escalation check completed	Box 7.1 checked (no triggers present, or specialist has been consulted and approved treatment)	Chapter 7 , Box 7.1



Stage	Item to Verify	Pass Criteria / Standard	Reference
	☐ Solution domain confirmed	Chapter 7 decision framework applied; engineering / NbS / hybrid selection documented	Chapter 7, Sec. 7.2
	☐ Design document available on site	Design sketch, BoQ, specifications, and planting plan present on site	Section 8.1
	☐ Nursery stock confirmed	Nursery confirmation letter or direct confirmation that required species and quantities are available at planting window	Section 8.1.3
	☐ Community engagement completed	Pre-design community meeting held; species selection agreed; maintenance group identified; labour arrangement confirmed	Section 8.6.2
	☐ Safety plan briefed to contractor	Box 8.3 safety standards confirmed; contractor safety marshal designated	Section 8.5
DRAINAGE WORKS COMPLETION (Before any civil or NbS works on slope face)	☐ Catch drain above cut crest	Drain positioned 2–5 m above cut crest; gradient $\geq 2\%$; lined; outlet to stable discharge point — not onto fill face	Chapter 5, Sec. 5.2.1(b)
	☐ Side drain and culverts	Gradient $\geq 0.5\%$; lined; outlets discharge away from fill face; culvert inlet and outlet protected	Chapter 5, Sec. 5.2.1(a)
	☐ Bench drains (if benched slope)	2–5% inward gradient; discharge to cascade or stable outlet; no overflow onto slope face	Chapter 5
	☐ Subsurface drain (if seepage present)	Geotextile fully wrapped before backfilling; confirmed flowing at outlet; no gaps in filter wrap	Chapter 5, Sec. 5.3
	☐ Flow test at all drain outlets	Water poured into each drain confirms unobstructed flow to outlet	Section 8.3.1
CIVIL / STRUCTURAL WORKS COMPLETION (Before bioengineering planting)	☐ Slope trimming to design angle	Design angle within $\pm 3^\circ$; no loose hanging material; benches to design width (≥ 1.5 m)	Chapter 4; Section 8.3.1
	☐ Wall foundation depth verified	Foundation trench confirmed at design depth (≥ 500 mm) before masonry commences	Chapter 4, Sec. 4.3
	☐ Weep holes in all walls and shotcrete	75 mm diameter at design spacing (≥ 1.5 m c/c); confirmed clear; connected to drain system	Chapter 4; Section 8.3.1
	☐ Gabion wire gauge checked	Minimum 2.7 mm galvanized or 3 mm PVC-coated; checked on site with calipers	Chapter 4; Section 8.3.1
	☐ Shotcrete cube samples taken	Minimum 3 cubes per day of spraying; marked, stored, and sent to laboratory for testing	Section 8.3.1



Stage	Item to Verify	Pass Criteria / Standard	Reference
	☐ Top fill on gabions (if NbS integration)	Upper 200 mm of gabion filled with organic topsoil mix (30% compost); plant species placed in mix	Chapter 7, Section 7.6.3
	☐ All structural works cured before loading	CSM and concrete: minimum 7 days cure; no load until curing complete	Section 8.3.1
BIOENGINEERING / NbS INSTALLATION (During monsoon planting window)	☐ Planting window confirmed	Works timed to Ashadh–Shrawan (June–July) onset; adequate soil moisture confirmed	Chapter 7, Table 7-8 Table 7-7
	☐ Plant material quality check	All plants from approved nursery; healthy (no wilting, discolouration, insect damage); minimum tiller/stem numbers per specification	Section 8.3.2
	☐ Grass row alignment verified	A-frame or spirit level used for contour rows; no rows running downslope	Chapter 6; Section 8.3.2
	☐ Palisade depth verified	Minimum 500 mm embedment; confirmed by probing or pull-out resistance check	Chapter 6; Section 8.3.2
	☐ Community labour engaged and paid	Local community workers used for bioengineering works; wage rates per Jilapratishtha; payment within 7 days	Section 8.6.2
	☐ Post-planting survival check at 4 weeks	Minimum survival rates per Table 8-5 met for each technique; gap-filling plan prepared for deficient zones	Section 8.3.2
	☐ Maintenance agreement signed	Written maintenance agreement with Ward office or road user committee; first maintenance scheduled	Section 8.6.2
	☐ Formal handover completed	Handover meeting held; community briefed on maintenance, monitoring, and escalation pathway; TID records updated	Section 8.6.2

8.8 Common Implementation Challenges and Practical Solutions

Experience from rehabilitation works in districts such as Sindhupalchok, Dolakha, Ramechhap, Sindhuli, Kabhrepalanchok, and Okhaldhunga, along with TID provincial road projects across Bagmati Province, has consistently highlighted a number of recurring implementation challenges.

This section presents the most common problems and their practical solutions, following the “Learning by Doing” approach that forms the basis of [Section 9.6](#) of these guidelines (see [Table 8-11](#)).



Table 8-11: Common implementation challenges and practical solutions

Challenge	Root Cause(s)	Consequences if Unaddressed	Practical Solution
Bioengineering planted before drainage is complete or functional	Contractor sequencing to complete "bioengineering" items quickly; supervisor not enforcing Box 8.1 sequence; BoQ payments not linked to drainage milestone	Planted slopes fail in first monsoon as saturated soil moves; community trust lost; NRs wasted on plants that never establish; slope condition may be worse than before treatment	Enforce payment milestone sequencing. The drainage checkpoint payment must be signed off before any bioengineering items can be claimed. Supervisor who approves bioengineering payment without drainage sign-off must bear responsibility for the result.
Grass rows planted down the slope instead of along the contour	Contractor or community worker unfamiliar with contour alignment; A-frame or spirit level not used; supervisor not present during planting	Grass rows act as drainage channels, concentrating flow down the slope and accelerating erosion rather than controlling it. Slopes with downslope grass lines frequently fail more severely than unplanted slopes.	Mandatory use of A-frame or spirit level for all grass and palisade row alignment. Sub-engineers must be present at the start of each planting day to verify alignment before community workers begin. Pay per Rm of correctly aligned row — not per person-day.
Weep holes omitted or blocked in retaining walls	Contractor not understanding function of weep holes; masons blocking weep holes to "look neater"; BoQ paying per m ³ wall only (no weep hole item)	Hydrostatic pressure builds behind wall; mortar joints crack; wall tilts or fails entirely. This is among the most common causes of new wall failure on Nepal roads.	Include weep holes as a separate BoQ item (per No.). Verify 100% of weep holes at completion inspection. Reject the entire wall section if weep holes are missing — not repairable without drilling. Enforce as non-negotiable in Box 8.4 non-conformance protocol.
Nursery stock not available at the planting window	Contract awarded without confirming nursery availability; contractor assumes plants can be sourced at last minute; wrong species available at planting time	Contractor substitutes wrong species (often exotic, fast-growing, non-native) to fill contract; correct species planted out of season with low survival rate; engineering function not achieved	Nursery confirmation requirement must be enforced before contract award. IDO should also build a standing supply arrangement with district and ward-level nurseries, with advance production planning linked to the annual road maintenance programme schedule.



Challenge	Root Cause(s)	Consequences if Unaddressed	Practical Solution
Community wage payment delayed or reduced	Contractor delays community payment pending TID payment; community payment "accidentally" reduced; female workers paid less than male workers	Community withdraws from maintenance. In subsequent seasons, no one weeds, replants, or monitors. Bioengineering system degrades.	Community wage payment is a contract condition, not a goodwill gesture. Include a contractual clause requiring community payment within 7 days of work completion, with penalty for non-compliance. IDO supervision must verify payments have been made before certifying the next interim payment certificate.
Spoil disposed on fill slope or into drainage channel	Contractor takes shortest route for spoil disposal over the side; no designed spoil disposal site; contract has no penalty for incorrect spoil disposal	Spoil blocks natural drains, triggering road-induced landslides downstream; overloads fill slopes; creates new erosion and sediment sources; can block streams causing flood damage	Specify a designed spoil disposal site in the contract, with location approved by IDO before earthworks begin. Quantity-measure spoil removal as a BoQ item only for approved disposal site. Include photo documentation of disposal as a payment condition.
Bioengineering maintenance not carried out in Year 1	Maintenance not included in original contract BoQ (no funding); community maintenance group not formed; post-handover responsibility unclear	20–40% of plants die in Year 1 without maintenance; gaps not filled; weed competition kills establishing species; investment lost	Establishment period maintenance (Part E of BoQ, Section 8.4.1) must be included in every bioengineering contract. Budget minimum 15–20% of installation cost per year for Years 1–2. Where TID budget is insufficient, community maintenance with TID-supplied replacement plants is an acceptable alternative — but must be agreed and documented before handover.
Contractor uses wrong mortar mix for masonry works	Contractor over-dilutes cement to reduce cost; gauge box not used; supervisor not checking mix batches	Weak mortar fails in first frost/wet season; wall joints crack and allow water ingress; progressive deterioration of CSM walls	Specify gauge box use as a mandatory construction method in all CSM contracts. Supervisor must verify at least 5 batches per day during masonry works. Any batch found to be wrong mix requires all work produced



Challenge	Root Cause(s)	Consequences if Unaddressed	Practical Solution
			from that batch to be removed and rebuilt.
Works designed correctly but installed in wrong location or orientation	No setting-out survey; contractor interprets design sketch loosely; slope conditions changed between design and construction; design based on desk study only	Subsurface drains installed in wrong location and miss the seepage zone; palisades installed below rather than above the slip surface; retaining wall too far from slope toe	Pre-construction verification visit (Step 5 of Section 8.1.1) is mandatory. Supervisor must physically confirm the design layout on the ground before work starts. Any design that requires revision based on site conditions must be approved by the responsible engineer before the revised works proceed.

Box 8.5: The Top Five Implementation Failures by Frequency

Based on review of records, and field experience, the five most frequently occurring implementation failures are:

- Bioengineering works are carried out before the drainage system is completed, resulting in a high proportion of first-year establishment failures.
- Grass rows are planted downslope rather than along the contour, accelerating erosion on slopes that are otherwise correctly designed.
- Weep holes are omitted or become blocked in newly constructed masonry walls, contributing to wall failures within 2–5 years of construction.
- Establishment-period maintenance is not included in the budget or implemented, leading to the loss of much of the bioengineering investment within the first three years.
- Nursery stock is substituted with unsuitable or non-native species because of inadequate planning, resulting in poor engineering performance and reduced community ownership of the planted vegetation.



CHAPTER 9. MONITORING, EVALUATION AND MAINTENANCE

9.1 Routine Monitoring of Slopes and Structures

Routine monitoring is the foundation of the whole monitoring, evaluation and maintenance system. Its propose is to detect changes in slope or structural condition before they develop into failures, allowing timely intervention while remedial measures are still simple, safe and cost-effective. In Nepal, monsoon rain can turn a minor defect into a major slope failure within a single storm event. Consequently, the most critical monitoring window falls in the pre-monsoon and early monsoon period, when slope conditions change rapidly.

9.1.1 Three-tier monitoring system

Monitoring should operate at three tiers, as given in Table 9-1, matching the depth of technical assessment to the availability of expertise at each level. The three tiers are complementary: routine community monitoring provides high-frequency, low-cost coverage of all treated sites; semi-annual technical inspection by sub-engineers provides structured periodic assessment; and annual engineering review provides the technical depth needed to identify developing problems and assess structural integrity.

Table 9-1: Three-tier monitoring system for slope stabilization works

Tier	Who Monitors	Frequency	Method	Output	Trigger for Escalation
Tier 1 Community Routine Monitoring	Ward Road User Committee (RUC) member or designated community monitor (minimum 1 per treated slope section)	Monthly during dry season; every two weeks during monsoon (Ashadh–Ashwin); after any rainfall event exceeding 50 mm in 24 hours	Visual walkover using Tier 1 checklist (Section 9.1.2); photograph key reference points; note changes since last visit; maintain a community monitoring log	Completed Tier 1 checklist submitted to Ward office monthly; photographs submitted if any change observed; verbal report to TID sub-engineer if any Tier 1 concern identified	Any Early Warning Indicator from Section 9.5 observed shall be immediately reported to IDO sub-engineer on the same day
Tier 2 Sub-Engineer Technical Inspection	IDO sub-engineer trained in the application of this guideline	Bi-annual: pre-monsoon (Chaitra–Baisakh; March–April) and post-monsoon (Kartik–Mangsir; October–November); additionally, after any event	Structured inspection using Tier 2 inspection form (Section 9.1.3); measurement of any crack widths, settlement, displacement; assessment of vegetation survival and	Completed Tier 2 inspection form submitted to IDO; site-specific maintenance instructions issued to community RUC; any Level 3 concerns escalated immediately	Any structural defect requiring repair (cracking, bulging, settlement, missing weep holes); any bioengineering survival below thresholds; any drainage



Tier	Who Monitors	Frequency	Method	Output	Trigger for Escalation
		triggering a Tier 1 escalation	ground cover; drain flow test; photograph log		blockage that cannot be cleared by the community
Tier 3 Annual Engineering Review	TID engineer (or consultant engineer for higher-consequence sites); specialist geotechnical engineer for any site that originally required Level 3 or higher design	Annually, post-monsoon (Mangsir–Poush, November–January), to evaluate the performance of the completed monsoon season	Engineering assessment of all Tier 2 inspection reports for the year; site visit to any site with recorded concerns; structural integrity assessment for walls >5 m; vegetation canopy cover estimation; catchment-scale drainage assessment; preparation of annual performance report	Annual performance report for each road section; maintenance budget request for following year; updated site condition record in TID slope performance database; recommendations for maintenance, remediation or escalation	Structural failure or imminent risk of failure requiring immediate intervention, or site conditions that have deteriorated significantly compared with the Year 1 baseline, requiring specialist geotechnical assessment

9.1.2 Tier 1 community monitoring checklist

The Tier 1 checklist is designed for use by community monitors who may not have engineering training (see Table 9-2). It asks simple YES/NO questions about observable conditions. Any YES answer in the warning column triggers an immediate notification to sub-engineer. The checklist should be completed (provided in [Annex 8](#)).

Table 9-2: Tier 1 Community monitoring checklist (reference version)

Item	What to Look For	Normal (No Action)	Concern (Report to Sub-engineer)	Warning — Call IDO Same Day
Slope face	Overall appearance of slope; any new bare areas; fresh scarps	Vegetation growing; no new bare areas; no fresh disturbed soil	Small bare patches (<1 m ²) appearing; slight movement of vegetation rows	Fresh scarp or bare area >2 m ² ; visible soil movement; slope bulging outward



Item	What to Look For	Normal (No Action)	Concern (Report to Sub-engineer)	Warning — Call IDO Same Day
Tension cracks	Cracks on road surface or ground behind/above treated slope	No cracks; previously noted cracks not widening	Hairline cracks on road edge; shallow ground cracks above slope (<5 mm wide)	Any crack >10 mm wide; crack running parallel to road edge; crack growing since last visit
Drainage channels	Side drains, bench drains, catch drains; flow condition	Drains clear and flowing; no ponding or overflow marks	Partial blockage by debris (>25% blocked); water staining above channel banks	Drain completely blocked; water overflowing onto slope or road; drain structure cracked
Retaining walls and check dams	Wall face, joints, base, crest condition	Wall face clean; no new cracks; joints intact; no water seeping through face	Hairline cracks in mortar joints; slight white efflorescence; minor stone displacement	Visible bulging of wall face; crack >5 mm wide; stone falling from wall; water running through wall face without weep holes
Vegetation	Grass cover, palisade condition, shrub/tree health	Grass rows continuous ($\geq 70\%$ cover); palisades standing and sprouting; trees showing new growth	Gap patches in grass rows (between 10–30% of row length); some palisades leaning or dead; yellowing of shrub leaves	Large continuous gap in grass (>3 m run); majority of palisades dead or pulled out; complete failure of a planted zone
Springs and seepage	Any new water emergence on slope face	No water emerging on slope face in dry weather; subsurface drain outlet flowing normally	Slight seepage on slope face after rain; wet patches on slope that dry within 2 days	Water emerging from slope face under pressure; persistent wet patch not drying between rain events; subsurface drain outlet running dry (possible blockage)
Gabion condition	Wire mesh, stone fill, basket lacing	Wire intact; stones contained; baskets maintaining shape	Minor wire corrosion on surface; one or two stones protruding through mesh	Wire mesh broken or cut; stones spilling out; basket bulging or deforming significantly

9.1.3 Tier 2 technical inspection parameters

The Tier 2 inspection by sub-engineers measures specific parameters that provide an objective, comparable record of site condition over time (see [Table 9-3](#)). The key principle is repeatability:



measuring the same parameters from the same reference points at every visit, so trends can be tracked rather than relying on a single snapshot.

Table 9-3: Slope stabilization monitoring parameters and maintenance thresholds

Parameter	Measurement Method	Recording Unit	Threshold Requiring Maintenance Action
Crack width in masonry / concrete	Steel feeler gauge or calibrated crack gauge; measure at widest point of each crack	mm	Any crack >2 mm in structural masonry; >0.3 mm in shotcrete; any growing crack (width increased since last inspection)
Wall displacement (horizontal)	Reference pin in wall face; measure distance to fixed reference point with tape	mm cumulative from installation	>5 mm displacement in 6 months; >10 mm cumulative from installation
Wall settlement (vertical)	Level staff from fixed benchmark to wall crest; compare to as-built survey	mm cumulative	>20 mm differential settlement between wall sections; any sudden change between inspections
Drain gradient	Spirit level on 1 m straight edge laid in drain; measure fall	% gradient	<0.3% at any point (silting risk); >15% without cascade steps (erosion of drain base risk)
Subsurface drain outlet flow	Visual and hand estimation at outlet pipe; compare to previous inspection; note seasonality	Dry / Seeping / Flowing / Gushing	Outlet dry in wet season (drain blocked); outlet gushing with turbid water (drain filter failed)
Vegetation ground cover	Photo plot method: photograph from fixed reference points; estimate % cover in 1 m × 1 m quadrats at 5 representative points on slope	% cover	<60% at Year 1 inspection; <70% at Year 3 inspection; any zone with <30% cover
Palisade survival rate	Count standing, rooted palisades vs. total installed in a representative 10 m section	% survival	<60% at Year 1; <70% at Year 3
Tree height increment	Measure height of 5 representative trees from fixed mark on stem to leader	cm/year	<20 cm/year increment for pioneer species in Years 1–3 (indicates establishment failure)



Parameter	Measurement Method	Recording Unit	Threshold Requiring Maintenance Action
Scour depth at structure toe	Metal probe to rock or firm substrate at 3 measurement points along wall toe	mm below design toe level	>100 mm scour below design toe level; any undermining of wall foundation visible
Slope face angle	Clinometer on slope face at 3 representative points; compare to design angle	degrees	>5° steeper than design angle (indicates face erosion or creep)

9.2 Performance Indicators and Evaluation Criteria

Performance indicators translate the monitoring data collected in [Section 9.1](#) into structured evaluations of whether the slope stabilization intervention meets its objectives. They are essential for three purposes: (i) triggering maintenance or remediation at the right time; (ii) enabling TID to demonstrate the value of its slope stabilization investments; and (iii) building the institutional knowledge base that allows future designs to be better than current ones.

9.2.1 Outcome performance indicators

Outcome indicators measure whether the fundamental goals of the project have been achieved: has the slope been stabilized, has erosion been controlled, is the road accessible, and is the community benefiting? These are the indicators (see [Table 9-4](#)) that matter to TID senior management and provincial government.

Table 9-4: Outcome performance indicators and evaluation benchmarks

Indicator	Measurement Method	Target / Benchmark	Data Source	Evaluation Period
Slope stability: no failure event	Record of any slope movement, partial failure, or road blockage at treated site since treatment	Zero failure events in the first 3 monsoon seasons following treatment completion	Tier 1 and Tier 2 monitoring records; IDO incident log	Annual (post-monsoon)
Erosion control: no new active gullies	Count of active gully channels with visible scour on treated slope face	Zero new gullies initiated since treatment; existing gullies stabilized (sediment accumulation behind check dams visible)	Tier 2 inspection with photo comparison against Year 1 baseline	Bi-annual
Road accessibility: days closed per year	Count of days road impassable due to slope-origin events (not flood or bridge)	Reduction of ≥75% in road closure days from pre-treatment baseline (where data	IDO road closure log; community road user committee report	Annual



Indicator	Measurement Method	Target / Benchmark	Data Source	Evaluation Period
		exists); zero closures due to the treated slope specifically		
Vegetation establishment: ground cover	Photo-plot percentage cover estimation at fixed reference points (Section 9.1.3)	≥70% cover by Year 2; ≥85% by Year 5; canopy structure developing (grass + shrub + tree layers all present by Year 5)	Tier 2 photo plots; NDVI estimation from drone photography if available at Year 3 and Year 5	Bi-annual (first 3 years); annual thereafter
Structural integrity : no critical defects	Count of Tier 2 inspections recording any critical defect (crack >2 mm, bulging, undermining, missing weep holes)	Zero critical defects at any inspection; all medium defects repaired within 30 days of identification	Tier 2 inspection records	Bi-annual
Community maintenance engagement	Record of community maintenance activities completed per agreed maintenance plan (Section 8.6.2)	≥80% of agreed maintenance tasks completed annually; maintenance group active and meeting at least twice per year	Ward office maintenance log; IDO sub-engineer spot check	Annual
Cost-effectiveness ratio	Actual treatment cost vs. avoided road closure cost and avoided reinstatement cost (estimated from comparable untreated slope event data)	Benefit-cost ratio ≥ 3:1 over 5 years (based on conservative avoidance estimate); 5:1 or above justifies expanded investment	TID financial records; IDO road closure cost estimates	Year 3 and Year 5 formal evaluation

9.2.2 Output performance indicators

Output indicators measure what has been physically delivered, the completeness and quality of the installed works (see [Table 9-5](#)). They are relevant primarily in the first-year post-construction and during the defect's liability period. They link directly to the QC standards in [Chapter 8 \(Section 8.3\)](#).



Table 9-5: Slope stabilization output indicators and performance targets

Output Indicator	Metric	Target	When Measured
Drainage completeness	Proportion of designed drain structures confirmed functional at handover flow test	100% functional at handover	At construction completion
Civil works completeness	Proportion of designed structural elements with zero critical defects at 30-day post-construction inspection	≥95% zero critical defects; all medium defects remediated within DLP	30 days post-completion
Grass planting coverage	Area of slope face with grass planted vs. design area	≥95% of design area planted in monsoon window; ≥70% survival at 6-week check	Planting completion + 6 weeks
Tree and shrub planting	Number of trees and shrubs planted vs. BoQ quantity; survival rate at Year 1	≥95% planted; ≥70% alive at Year 1 assessment	Year 1 post-monsoon inspection
Community maintenance agreement	Written agreement signed before handover	100% of sites with bioengineering works have signed maintenance agreement	At handover
BoQ delivery	Value of works completed and accepted vs. contracted value	≥95% delivery within DLP	At final account

9.2.3 Evaluation at key milestones

Formal evaluation, separate from routine monitoring, should be carried out at three key stages ([Box 9.1](#)) for every major slope stabilization intervention (NbS) with a contracted value above NRs 500,000 or for any Level 3 or Level 4 design site.

Box 9.1: Three Mandatory Evaluation Milestones

Milestone 1 — Year 1 Post-Monsoon Assessment (Kartik–Mangsir): Evaluation of first monsoon season performance. Key questions:

Did the slope survive the first monsoon without failure?

Did all drainage structures perform as designed?

What is the vegetation survival rate?

What maintenance was required and was it carried out?

Produces: Year 1 site performance report with maintenance recommendations for Year 2.

Milestone 2 — Year 3 Performance Review: Assessment of bioengineering establishment and structural condition at mid-lifecycle. Key questions:

Is the vegetation canopy developing the intended multi-layer structure?



Are root systems contributing measurable additional cohesion?

Are civil structures still at or above design performance?

Does the maintenance agreement need revision?

Produces: Year 3 performance report; updated site condition record; recommendation on whether additional treatment is needed.

Milestone 3 — Year 5 Lifecycle Evaluation: Full lifecycle value assessment for institutional learning and investment justification. Key questions:

What is the actual benefit-cost ratio?

What worked, what did not, and why?

What would be done differently?

Is this technique/hybrid configuration worth replicating?

Produces: Year 5 evaluation report; case study material of this guideline and knowledge base; input to [Annex 3](#) reference case study updates.

9.3 Maintenance Plan for Engineering Structures

Engineering structures such as retaining walls, gabions, check dams, drainage channels, revetments, and subsurface drains gradually deteriorate over time due to hydraulic pressure and scour, temperature changes and freeze thaw effects at higher elevations, seismic activity, root growth within masonry joints, and chemical weathering of construction materials. Without regular maintenance, small problems can quickly develop into major structural failures. The maintenance schedule below is intended to stop this from happening and to keep maintenance costs well below the cost of full replacement.

9.3.1 Routine annual maintenance –Pre-monsoon and Post-monsoon cycles

Civil engineering maintenance should be organized around two mandatory annual cycles synchronized with the monsoon calendar (see Table 9-6).

Table 9-6: Annual civil engineering maintenance schedule

Maintenance Task	Pre-Monsoon (Chaitra–Baisakh)	Post-Monsoon (Kartik–Mangsir)	Responsible Party	Required Materials / Tools
Drainage channel clearance	MANDATORY: clear all side drains, bench drains, catch drains, culvert inlets and outlets of accumulated debris, sediment, and vegetation growth before monsoon begins	Clear post-monsoon debris; check for damage to channel lining; repair cracked or displaced sections; confirm gradient is maintained	Community RUC (clearance); IDO sub-engineer (verification)	Spades, picks, brush cutters; repair mortar mix 1:4; stone for relining where damaged



Maintenance Task	Pre-Monsoon (Chaitra–Baisakh)	Post-Monsoon (Kartik–Mangsir)	Responsible Party	Required Materials / Tools
Culvert inspection and clearance	Probe each culvert with rod to confirm clear; clear inlet screens; remove sediment at inlet; confirm outlet protection intact	Inspect for scour at outlet; confirm energy dissipator intact; clear any blockage from monsoon debris transport	IDO sub-engineer (inspection); community labour (clearance)	Probe rod or torch; spades; replacement aggregate for scour repair
Weep hole clearance	Clear all weep holes in all masonry and concrete walls by probing with metal rod; confirm water seeps through when probe inserted; mark any blocked weep holes for drilling	Re-check after monsoon; any weep holes that were wet during monsoon should be confirmed freely draining again	Community RUC	Metal rod 75 mm diameter; hand pump to flush blocked weep holes if needed
Masonry joint repointing	Identify all open, cracked, or eroded mortar joints in CSM walls, check dams, and drain linings; repoint with 1:4 cement mortar before monsoon loads joints with water	Assess joints after monsoon loading; repoint any joints that have opened or cracked under monsoon stress	Skilled mason contracted by IDO or community (if trained)	Cement OPC 42.5; sand; water; pointing tools; curing sacking
Gabion wire and lacing inspection	Inspect all gabion wire for corrosion, breakage, or vandalism; check all basket lacing is intact; confirm no stone spillage; check top organic fill zone for plant establishment	After monsoon: re-check for any wire damage from debris impact; re-lace any opened baskets; top up stone fill where scour has removed material	IDO sub-engineer (inspection); community labour (minor repair)	Galvanized binding wire; replacement lacing wire; stone infill; organic mix for top layer
Structural crack and monitoring sealing	Measure all previously identified cracks; record width; seal any crack >0.5 mm in CSM with cement	Post-monsoon: re-measure all cracks; identify any new cracks; classify as structural (requires engineer review) or	IDO sub-engineer (assessment); skilled mason (sealing)	Crack gauge; cement grout; grout injection equipment



Maintenance Task	Pre-Monsoon (Chaitra–Baisakh)	Post-Monsoon (Kartik–Mangsir)	Responsible Party	Required Materials / Tools
	grout injected under pressure or packed with 1:2 cement mortar	superficial (seal and monitor)		for larger cracks
Toe assessment and protection	Measure depth to firm substrate at wall toes; compare to previous measurement; if >100 mm below design level, install additional toe protection before monsoon flows	Assess toe scour after peak monsoon flows; emergency toe protection if foundation exposed during monsoon	IDO sub-engineer (assessment); engineer for any toe protection design	Tape/probe; gabion mesh and stone; riprap for emergency toe protection
Subsurface drain outlet maintenance	Confirm all subsurface drain outlets are clear and accessible; confirm flow when tested with water at inlet	Check outlet flow condition; if outlet was dry during wet season, excavate and investigate blockage at outlet	Community RUC	Water for flow test; spade for outlet excavation if blocked

9.3.2 Periodic and emergency maintenance

Beyond the annual cycle, two further categories of maintenance (see [Table 9-7](#)) need planning and budget allocation.

Table 9-7: Major repair and renewal schedule for slope stabilization structures

Maintenance Category	Trigger	Typical Interval	Actions	Budget Planning
Periodic major repair	Tier 2 inspection identifying structural degradation beyond routine repair; wall displacement or settlement exceeding thresholds in Table 9-3 ; wire mesh corrosion	Every 5–10 years depending on structure type and environment	Gabion cage replacement; full wall reconstruction in sections; major drain relining; foundation underpinning	Budget 10–20% of original construction cost per 5-year cycle; include in TID 5-year maintenance programme



Maintenance Category	Trigger	Typical Interval	Actions	Budget Planning
	exceeding 30% of section			
Emergency repair	Any Tier 1 or Tier 2 Early Warning Indicator (Section 9.5) triggering immediate action; event-triggered damage (flood, earthquake, landslide); road closure	Event-driven; no fixed interval	Emergency stabilization (temporary works within 48 hours); follow-on permanent repair within 30 days; re-assessment and upgraded design if original design failed	Emergency contingency fund
surface protection renewal	Visual inspection showing >15% crack coverage; spalling; detachment of panels; depth below design minimum; or 15+ years from installation	Every 10–20 years	Mechanical scaling and removal of degraded panels; re-application in sections; new weep holes drilled before application	Budget 50–70% of original shotcrete cost per renewal cycle

9.4 Maintenance and Replantation of Bioengineering Works

Bioengineering maintenance is fundamentally different from civil engineering maintenance: instead of resisting decay, it means actively guiding a living system toward a target ecological state. The goal is not to keep the system exactly as it was installed. It is to guide it through stages of growth toward a mature, self-sustaining, ecologically diverse plant community that delivers the full range of engineering and ecological benefits described in [Chapter 6](#).

The natural growth process needs active management for the first 3 to 5 years. After that, if the species selection was right, the plants have established well, and the community is engaged in protecting the slope, the system becomes mostly self-maintaining, needing only light yearly attention. The effort put into years 1 to 3 maintenance pays off across the full 20-to-30-year road design life.

9.4.1 Bioengineering maintenance calendar

A bioengineering maintenance calendar is essentially a structured preventive maintenance schedule to ensuring road slope stabilization, safety, and reduced costs in the future with clear tasks for concerned authorities (see [Table 9-8](#)).



Table 9-8: annual bioengineering maintenance calendar

Month (BS/AD)	Maintenance Tasks	Priority Level	Who Carries Out	Notes
Chaitra-Baisakh (Mar-Apr) Pre-monsoon preparation	Nursery readiness check: confirm plant stock for Year N gap-filling and new planting Slope inspection: identify gaps in grass cover, dead palisades, failed brush layers Prepare maintenance plan with quantities for Ashadh planting Light weeding around tree and shrub seedlings to reduce weed competition before monsoon	High	IDO sub-engineer (assessment); community nursery (stock check)	Do not plant grass in Chaitra, dry conditions cause high mortality. Prepare, do not plant.
Ashadh-Shrawan (Jun-Jul) Primary planting window	Gap-filling: replace all dead grass, palisades, brush layers with fresh material Additional planting in any newly exposed or eroded zones Bamboo rhizome splitting and planting if not done in Year 1 Application of organic mulch around tree seedlings	Critical	Community labour (planting); IDO sub-engineer (supervision)	This is the most productive maintenance investment. Maximum survival rates for all species.
Bhadra-Ashwin (Aug-Sep) Peak monsoon care	Monitoring only: no major planting in saturated soils Emergency gap-filling after landslide debris removal Daily Tier 1 monitoring checks after events >50 mm/24 hr Drain clearance immediately after any blockage observed	Medium (monitoring) / Critical (response)	Community RUC monitor (Tier 1 daily); IDO sub-engineer (event response)	Do not attempt bioengineering work on waterlogged slopes.
Kartik-Mangsir (Oct-Nov) Post-monsoon assessment	Survival assessment: count and photograph all species at fixed reference points Thinning: remove over-dense pioneer growth competing with slower-establishing deep-rooted species Tree and shrub planting: excellent window for woody species establishment (soil still moist, temperature dropping) Weed cutting: cut tall weeds overtopping grass seedlings; do not remove ;use as mulch	High	Community labour + IDO sub-engineer	Year 1 performance assessment milestone (Section 9.2.3). Survival data triggers gap-filling plan.



Month (BS/AD)	Maintenance Tasks	Priority Level	Who Carries Out	Notes
	Record NTFP harvest (broom grass, bamboo shoots) evidence of community benefit for maintenance incentive assessment			
Mangsir–Magh (Nov–Jan) Dry season management	Protection from grazing: confirm grazing exclusion fencing intact; repair if broken Tree pruning: formative pruning of young trees to develop single straight leader Bamboo management: harvest mature culms (Year 3+); leave young shoots to develop Prepare gap-filling plant list for next monsoon planting season	Low-Medium	Community RUC and land user committee	Grass planting not effective in dry season. Focus on protection and woody species management.
Falgun–Chaitra (Feb–Mar) Pre-monsoon closing	Confirm nursery production on schedule for Ashadh planting Light civil maintenance: weep hole clearance, drain sediment removal before monsoon Confirm maintenance agreement remains active with community RUC Report to IDO on annual maintenance completion status	Medium	Community RUC; IDO sub-engineer (reporting)	Annual cycle closes with confirmation that community is ready for next monsoon season.

9.4.2 Replantation standards and gap-filling criteria

Replantation is needed whenever a monitoring assessment identifies vegetation survival below the minimum thresholds specified in [Chapter 8 \(Table 8.3\)](#). The replantation must use the same species, unless the original species performed poorly, in which case an approved substitute can be used. It should follow the same spacing, in the correct planting window.

Table 9-9: Replantation measures

Situation	Gap-Filling Action Required	Timing	Species Notes
Grass row: >20% gap within a row (continuous gap >500 mm)	Replant gap with fresh slips at original spacing; peg new slips if slope is steep	Ashadh–Shrawan (primary); Kartik also acceptable for some species	Use same species as original unless survival was consistently <50%; then consider Vetiver or Kans as more robust alternatives



Situation	Gap-Filling Required	Action	Timing	Species Notes
Palisade row: >30% failure (dead or missing stakes)	Replace all dead stakes in row; check remaining stakes are firmly rooted — pull-test any suspect		Ashadh–Shrawan only	Fresh cuttings from actively growing stock; avoid cut material that has dried; cut on the day of planting
Brush layer: >30% failure along a layer line	Excavate and re-lay the failed section; use fresh material		Ashadh–Shrawan only	If original species failed completely, consult species guide (Annex 2) for site-appropriate alternative
Tree seedling: individual tree dead	Replace with polypot seedling of same species; prepare a larger pit (400 × 400 × 400 mm) if roots had no space		Kartik–Mangsir (preferred) or Ashadh	If same species repeatedly failing on this site, consult species guide and IDO sub-engineer before replanting
Complete zone failure: >50% of all species in a defined zone	Full reassessment of site conditions required before replanting; check drainage functioning; check slope stability; consult TID engineer if cause is unclear		Do not replant until cause understood	Replanting without resolving the underlying cause will simply waste resources again

9.5 Early Warning Indicators and Remedial Action Triggers

Early warning converts monitoring information into timely life-safety action before a developing slope failure becomes a catastrophic event. Guidance documents prepared for Nepal ([DoR, 2007](#); [DSCWM, 2016](#)) together with lessons documented in case studies, identify a range of observable precursor indicators that commonly precede significant slope failures by several hours to several days. Although no single indicator reliably predicts failure, the recognition of multiple warning signs and prompt response are among the most important competencies that community monitors and field engineer/sub-engineers can develop.

9.5.1 Tiered early warning indicator system

Early warning indicators are classified into three alert levels: Watch, Warning, and Emergency. Each alert level triggers a defined response appropriate to the observed level of risk. The classification is adapted for use in road slope stabilization from Nepal’s community-based disaster risk management practices and guidance on structural distress indicators ([MoHA, 2015](#); [DoR, 2007](#)) (see [Table 9-10](#)).



Table 9-10: Early warning indicator system: classification and response chain

Alert Level	Observable Indicators	Immediate Action	Response Timeline	Who Decides
WATCH (Monitor Closely)	Hairline cracks appearing on road surface parallel to slope edge (<5 mm, not growing) New seepage on slope faces that dries between rain events Drain overflow during peak monsoon events (not blockage) Individual stones displaced from gabion without basket deformation Vegetation dies in a defined zone (not individual plants)	Increase monitoring frequency to weekly; photograph and measure crack widths; note in community log; report at next regular sub-engineer visit	1 week notification to IDO sub-engineer	Community monitor notifies Ward RUC chair; Ward chair notifies IDO sub-engineer at next scheduled contact
WARNING (Act Promptly)	Crack on road surface >10 mm wide or growing since last observation Persistent seepage on slope face not drying between rain events Visible bulging of retaining wall face or gabion basket Disrupted or displaced terrace alignments on slope above road Leaning or curved tree trunks (pistol-butt growth) not previously present Unusual gurgling, cracking, or sound of moving material in slope Drain blocked and overflowing onto slope face despite clearance attempt	Immediate notification to IDO sub-engineer by telephone. Restrict road access to essential traffic only. Community monitors increase frequency to twice daily. Do NOT attempt to cross or enter the slope hazard zone.	Same-day notification; IDO sub-engineer site visit within 48 hours	Community monitor / Ward chair notifies IDO sub-engineer by phone immediately
EMERGENCY (Evacuate and Close)	Visible fresh scarp or displacement of slope material Road surface cracking and subsiding simultaneously Retaining wall visibly rotating or leaning rapidly Water emerging from slope under pressure with turbid (muddy) discharge Debris or rockfall onto road from slope above Any structural collapse or partial collapse of civil works Sounds of active earth movement or cracking from slope	CLOSE ROAD IMMEDIATELY. Evacuate all people from hazard zone (minimum distance = slope height × 1.5). Call IDO and local government disaster response. Do not attempt to assess from within the hazard zone.	Immediate road closure (no delay); IDO notification within 1 hour; emergency response within 24 hours	Anyone who observes these signs has authority and responsibility to close the road immediately. No approval required.



9.5.2 Rainfall thresholds as early warning triggers

Alongside the physical warning signs, rainfall provides an objective and measurable early warning trigger that does not depend on continuous observation of the slope. The thresholds in Table 9-11 are operational triggers for monitoring action. They are deliberately set below the rainfall levels at which slopes start to fail, so inspection is already underway before a slope reaches a critical state. They are adapted from Nepal-specific research ([Dahal and Hasegawa, 2008](#); [Timsina et al., 2026](#)) for Bagmati conditions.

Table 9-11: Rainfall thresholds and triggered monitoring actions

Rainfall Threshold	Return Period	Bagmati Province Context	Monitoring Action Triggered
≥50 mm in 24 hours	Common (occurs multiple times per monsoon)	Lower threshold for shallow translational failure initiation on unprotected slopes; road erosion possible	Community monitor conducts Tier 1 inspection within 6 hours of rainfall stopping
≥80 mm in 24 hours	Moderate frequency (several times per monsoon in Bagmati Province)	Threshold for debris slide initiation in colluvium; check dam overtopping risk	Community monitor conducts immediate inspection; IDO sub-engineer notified same day
≥100 mm in 24 hours	Less common; 5–10-year return period in most districts	Primary threshold for road-blocking landslide in Nepal mid-hills (Dahal et al., 2006)	IDO sub-engineer site visit within 24 hours; emergency maintenance team on standby
≥200 mm in 24 hours	Rare; 10–25-year return period	Major event threshold; June 2014-scale events triggered above this level; cascade failure risk	Road closure precautionary until inspection completed; district disaster committee notification
≥300 mm cumulative in 3 days	Very rare but documented	Soil saturation approaching limiting condition; progressive failure risk in deep colluvium	All treated slopes in affected watershed to be inspected within 48 hours of rain stopping

9.5.3 Post-event inspection protocol

After any rainfall event exceeding the 80 mm/24 hr. threshold, or any event that triggers a Warning-level indicator, IDO should conduct a structured post-event inspection using the following protocol. This protocol serves both safety and institutional learning purposes. It creates the evidence base needed to improve future designs (see Table 9-12).



Table 9-12: Post Event inspection and repair procedure

Step	Action	Who	Output
1. Initial safety check	Approach from upslope side; confirm no active movement before entering inspection area; no entry within 1H exclusion zone of any active scarp	IDO sub-engineer	Go/No-Go decision on entry
2. Damage classification	Classify each structure or bioengineering zone as: Undamaged / Minor damage / Moderate damage / Severe damage / Failure; record with photographs and GPS coordinates	IDO sub-engineer with community monitor	Completed Tier 2 inspection form with damage classification
3. Root cause assessment	For each damaged element, document the probable cause: drainage overload / design underperformance / construction defect / maintenance failure / extreme event exceeding design / previously unidentified failure mechanism	IDO sub-engineer; engineer if Level 3 site	Cause of damage recorded in the inspection form
4. Emergency stabilization	If any element poses immediate risk to road users; install temporary barriers; divert traffic; cover exposed soil with tarpaulins or jute to prevent further erosion until permanent repairs; clear blocked drains	Contractor or community labour, IDO supervision	Site made safe within 24 hours of event
5. Repair design and programming	Prepare repair specification and BoQ using catalogue items where appropriate; schedule repair within 30 days; confirm nursery stock availability for any bioengineering replacement required	IDO sub-engineer (catalogue works) or engineer (complex works)	Repair programme with cost estimate
6. Learning capture	Complete the post-event learning form (Section 9.6): what worked, what failed, what was the design assumption that was exceeded? This feeds directly into Section 9.6 workshops and guideline update cycles	IDO sub-engineer	Post-event learning record filed with TID knowledge base

9.6 Review and Performance Evaluation Workshops (“Learning by Doing”)

Annual review and performance evaluation workshops shall be conducted at district and provincial levels to systematically assess the performance of implemented slope stabilization measures. The workshops shall compile lessons from field monitoring, post-monsoon inspections, maintenance records, and community feedback to identify successful practices, document implementation challenges, and improve future designs and construction practices. This institutional learning process promotes continuous improvement through experience sharing and evidence-based refinement of slope stabilization techniques.



9.6.1 Two-level workshop structure

Two level of workshops recommended to review and evaluate the existing task related to road slope stabilization (See Table 9-13).

Table 9-13: Annual review and learning workshops for slope stabilization

Workshop Level	Frequency	Participants	Inputs	Outputs
District-Level Site Review Workshop	Annual (Mangsir–Poush, after post-monsoon inspections are complete)	IDO engineers and sub-engineers; Ward-level Road user committee chairs; engineers/sub-engineers from local government; 2–3 community representatives from treated sites	Compiled Tier 2 inspection reports for the year; Tier 1 monitoring logs from community monitors; post-event inspection records; community maintenance completion reports	District-level performance summary: top 5 successes, top 5 failures, top 5 maintenance issues; updated priority list of sites needing attention in next year; specific technique adaptations recommended based on field evidence
Provincial Synthesis Workshop (TID)	Annual (Poush–Magh, after district workshops complete)	TID engineers; district-level workshop rapporteurs; academic or research institution; Representative from DoLI; 1–2 community representatives from outstanding performance sites	District workshop summaries; Year 3 and Year 5 site evaluation reports; any new research findings on Nepal bioengineering or slope stability; climate trend data from DHM	Provincial performance report; specific updates to this guideline's catalogue designs, rate analyses, or species selection guidance; skill gap identification and training recommendation; inputs to annual TID maintenance budget request

9.6.2 From workshops to guideline updates: The continuous improvement loop

The learning gathered in the annual workshop cycle is only useful if it actually changes practice, TID should therefore set up the following update cycle, based on the principle set out in [Chapter 2 \(Section 2.6\)](#), which distinguishes a learning institution from a reactive one.

- **Annual:** Workshop outputs shall be used to update [Annex 8](#) (Quick-Reference Decision Charts) and [Annex 5](#) (Bioengineering Design Templates) with any proven technique adjustments. This does not require a full guideline revision; targeted annex updates can be issued by TID provincial office as numbered amendments.
- **Every 3 years:** [Chapter 7](#) selection matrices and [Chapter 6](#) species recommendations shall be reviewed based on accumulated field performance data. Any species that consistently underperform should be flagged; any new technique proving effective should be elevated to catalogue status.
- **Every 5 years:** Full guideline shall be reviewed in light of accumulated performance data, climate trend information from DHM, and new research from Nepali and international



institutions. The year-5 evaluation reports ([Section 9.2.3](#)) provide the primary evidence base for this review.

- **On significant events:** any slope failure event on a treated site, regardless of whether the treatment is judged to have failed, shall generate a post-event report for submission to the TID provincial office and archived for future reference. The DRSP practice of publishing case studies of both success and failure from Sindhupalchok, Dolakha, Ramechhap, Sindhuli, Kabhrepalanchok, and Okhaldhunga should be used as the standard to emulate.



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ANNEXES



Annex 1: Vegetation Characteristics Database

A1.1 Grasses and Ground Cover

This database covers priority species recommended for roadside bioengineering in Bagmati Province (500–2400 m elevation). Species are ordered by functional category: grasses → trees → shrubs → climbers. Drought Class (I–VI) follows the Howell scoring system (slope angle, stoniness, altitude, aspect, annual rainfall).

Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	Photos
Amliso / Broom grass	<i>Thysanolaena maxima</i>	Dense tufted perennial grass, 1–2 m	Fibrous, dense mat, 30–60 cm	Slip/rhizome	Shallow–medium	Erosion armour, broom making, fodder	Terai – 1500 m	Soil slopes, cut slopes	
Babiyo / Babio	<i>Eulaliopsis binata</i>	Clumping grass, 60–120 cm	Dense fibrous mass, 20–40 cm	Slip/rhizome	Shallow	Rope fibre, soil armouring	Terai – 1500	Dry soil slopes	
Napier / Elephant grass	<i>Pennisetum purpureum</i>	Tall clumping grass, 2–4 m	Deep fibrous, 40–80 cm	Stem cutting, slip	Medium	Fodder, biomass, slope armour	200–1200	Moist soil slopes	

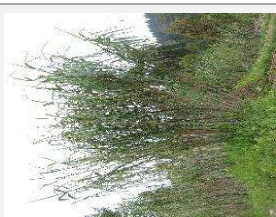


Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	Photos
Kans grass	<i>Saccharum spontaneum</i>	Rhizomatous perennial, 1–3 m	Spreading rhizome, 30–60 cm	Rhizome/slip	Medium	Erosion control, thatching	Terai - 2000 m	Riverbanks, soil slopes	
Khus / Vetiver	<i>Vetiveria zizanioides</i>	Deep-rooted clumping grass, 1.5 m	Vertical deep roots, 1.5–3 m+	Slip	Deep	Soil reinforcement, fragrance, micro-drainage	Terai - 1500 m	Critical soil slopes, embankments	
Dubo / Bermuda grass	<i>Cynodon dactylon</i>	Creeping ground cover, 10–30 cm	Rhizomatous mat, 10–20 cm	Stolon/seed	Very shallow	Surface erosion control	Terai - 2000 m	Gentle slopes, road shoulders	
Dhonde	<i>Neyraudia reynaudiana</i>	Tall reed-like clumping perennial grass, 2–4 m	Fibrous + short rhizomes,	Slip/rhizome	Deep	Erosion control, slope stabilization, fodder, thatching	Terai - 1500 m	Dry slopes, cut slopes, rocky areas	



Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	Photos
Katara Khar	<i>Themeda spp.</i>	Large clumping perennial grass, 1-2 m tall	Fibrous + rhizomatous	Slip cuttings/ seeds	Deep	Erosion control, slope stabilization, thatching, fodder	Tera - 2000 m	Hot and dry slopes, varied, cut slopes	
Khar/Lemon grass	<i>Cymbopogon microtheca</i>	Medium-large clumping perennial grass, 1-2m tall	Fibrous+rhizomatous	Slip cuttings/ seeds	Deep	Erosion control, slope stabilization, thatching, fodder	Tera - 2000 m	Hot and dry slopes, cut slopes	
Narkat	<i>Arundo donax</i>	Tall robust reed-like perennial, 3-6m tall	Rhizomatous + fibrous	Rhizome/ stem cuttings	Deep	Erosion control, slope stabilization, thatching, fodder, bio-engineering	Tera - 1500 m	Dry slopes, cut slopes	



Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	Photos
Padang bans	<i>Himalayacalamus hookerianus</i>	Clumpin g bamboo, 5-9m tall	Pachymorph rhizomes + fibrous, deep and dense	Rhizome division/off sets	Deep	Construction, weaving, fodder, erosion control	1500 - 2500 m	Moist slopes, mid-hills	
Phurke	<i>Arundouella nepalensis</i>	Tufted perennial grass, 0.9-2m tall	Short rhizomes+ fibrous roots, medium- deep	Slip/seeds	Mediu m- deep	Erosion control, slope stabilization, thatching, fodder	700- 2000 m	Dry slopes, cut slopes	
Sito	<i>Neyraudia arundinacea</i>	Tall reed like clumping grass, 2- 4m	Fibrous + short rhizomes, deep (1-2m)	Rhizome/s lip	Deep	Erosion control, slope stabilization, thatching	Terai - 1500 m	Dry and rocky slopes, cut slopes	



Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	Photos
Tite Nigalo Bans/Ringal	<i>Drepanostachyum intermedium</i>	Small clumping bamboo (nigalo), 2-4m	Pachymorph rhizomes + fibrous, dense	Rhizome division	Medium-deep	Weaving, fodder, conservation, high altitude slopes	1000 - 2500	Moist to medium slopes	
Bamboo (Mal bans)	<i>Bambusa nutans</i>	Clumping bamboo, 10-15 m	Dense clump rhizome, 50-80 cm	Culm cutting	Medium-deep	Slope structural, construction support,	Terai - 1500	Moist soil slopes	
Bamboo (Dhanu bans)	<i>Bambusa balcooa</i>	Large clumping bamboo, 15-20 m	Very dense clump rhizome	Culm cutting	Medium-deep	Large-scale slope support, construction	Terai - 1200	Warm moist slopes	



Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	Photos
Nibha/Ghopi /Lyas Bans	<i>Ampelocalamus patellaris</i>	Clumping bamboo, 4-8m tall	Pachymorph rhizomes + fibrous	Rhizome division	Medium-deep	Weaving, construction, fodder, soil conservation	1200 - 2200 m	Moist slopes	
Choya/Tamba bans	<i>Dendrocalamus hamiltonii</i>	Large clumping bamboo, 10-20m tall	Pachymorph rhizomes + fibrous	Rhizome division	Deep	Construction, edible shoots, fodder, erosion control	300-2000 m	Medium slopes	
Kato bans	<i>Dendrocalamus hookeri</i>	Large clumping bamboo, 10-18m tall	Pachymorph rhizomes + fibrous	Rhizome division	Deep	Construction, weaving, fodder, erosion control	1200 - 2500 m	Medium to moist slopes	



A1.2 Trees

Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	
Utis / Alder	<i>Alnus nepalensis</i>	Deciduous tree, 10–25 m	Deep lateral, nitrogen-fixing	Seed/sapling	Deep 60–120 cm	Slope anchor, nitrogen fixation, fodder, timber	900–2700	Moist cut slopes, gully sides	
Sisso / Shisham	<i>Dalbergia sissoo</i>	Deciduous tree, 10–20 m	Aggressive lateral + tap, 1–2 m	Seed/root cutting	Deep	Reinforcement, timber, fodder	Terai–1400	Lower zone soil slopes	
Ipil-ipil / Leucaena	<i>Leucaena leucocephala</i>	Small tree, 3–8 m	Deep tap, lateral roots	Seed	Deep	Fodder, fuelwood, slope anchor, nitrogen	Terai–1500	Warm dry slopes	
Koiralo / Mountain ebony	<i>Bauhinia variegata</i>	Small deciduous tree, 4–10 m	Tap + medium lateral	Seed/sapling	Medium–deep	Slope stabilisation, ornamental, fodder	Terai–1800	Degraded soil slopes	



Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	
Bakaino	<i>Melia azedarach</i>	Medium deciduous tree, 8-15 m tall	Taproot+lateral fibrous	Seeds, cuttings	Deep	Timber, fodder, medicinal, shade, soil conservation	Terai-1800	Dry slopes, cut slopes	
Gobre salla	<i>Pinus wallichiana</i>	Tall evergreen pine, 20-40m tall	Taproot + strong lateral	Seeds	Deep	Timber, resin, watershed	1800-3000	Medium to dry slopes	
Kato siris	<i>Albizia lebbeck</i>	Large deciduous tree, 15-25m tall	Extensive shallow fibrous	Seeds	Medium-shallow	Timber, fodder, N-fixation	Terai-1200	Dry slopes, cut slopes	
Khanyu (Khosro)	<i>Ficus semicordata</i>	Small-medium deciduous fig tree, 5-12 m	Fibrous spreading	Cuttings, seeds	Medium	Fodder, fruit, soil binding	Terai-2000	Moist slopes	



Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	
Khayer	<i>Acacia catechu</i>	Small-medium deciduous tree, 8-15m	Deep taproot + lateral	Seeds	Deep	Tannin, timber, fodder, erosion control	Terai-1000m	Dry and rocky slopes, cut slopes	
Lankuri	<i>Fraxinus floribunda</i>	Medium-large deciduous tree, 10-20m	Fibrous + spreading	Seeds	Medium-deep	Timber, fodder	1200-2700	Moist to medium slopes	
Painyu	<i>Prunus cerasoides</i>	Medium deciduous tree, 10-20m	Taproot + fibrous	Seeds, grafting	Medium-deep	Timber, fodder, ornamental	500-2400	Medium slopes	
Rani (khote) salla	<i>Pinus roxburghii</i>	Tall evergreen pine, 15-30m	Taproot + strong lateral	Seeds	Deep	Timber, resin, fuel, watershed	500-1950	Dry slopes, cut slopes	



Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	
Rato siris	<i>Albizia julibrissin</i>	Medium deciduous tree, 8-15m	Fibrous + spreading	Seeds	Medium	Ornamental, fodder, N-fixation	800-3000	Medium to dry slopes	
Seto siris	<i>Albizia procera</i>	Large deciduous tree, 15-30 m	Extensive fibrous	Seeds	Medium-deep	Timber, fodder, erosion control	Teral-1350	Dry slopes, cut slopes	
Gliricidia	<i>Gliricidia sepium</i>	Small tree, 3-10 m	Tap + nitrogen-fixing lateral	Cutting/seed	Deep	Live stakes, nitrogen, fodder	Teral-1200	Lower zone, tropical slopes	
Chilaune	<i>Schima wallichii</i>	Large evergreen tree, 15-25 m	Deep tap + extensive lateral	Seed/sapling	Deep	Long-term anchor, timber, biodiversity	800-1800	Forest restoration, cut slopes	



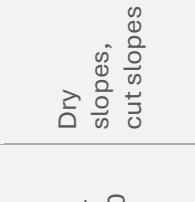
Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	
Pipal / Sacred fig	<i>Ficus religiosa</i>	Large deciduous tree, 15–30 m	Aggressive lateral + aerial roots	Seed/sapling	Very deep	Slope anchor, heritage, agroforestry	Terai–1800	Deep soil slopes near water	
Dabdabe	<i>Garuga pinnata</i>	Medium deciduous tree, 8–20m tall	Taproot + lateral	Seeds	Deep	Timber fodder, soil conservation	Terai–1200	Medium to dry slopes	
Phaledo	<i>Erythrina</i> species	Deciduous tree, 8-15 m tall	Fibrous + spreading	Cuttings/ seeds	Medium-deep	Nitrogen fixation, live fodder, support, erosion control	Terai–1800	Medium slopes	



A1.3 Shrubs and Climbers

Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	
Jatropha / Sajiwan	Jatropha curcas	Shrub, 2–5 m	Dense lateral + tap	Cutting/seed	Medium	Live hedgerow, slope protection, biofuel	500–1200	Dry degraded slopes	
Vitex / Simali	Vitex negundo	Shrub/small tree, 2–5 m	Lateral spreading	Cutting	Medium	Live stake, slope cover, medicine	Terrai–1750	Degraded dry slopes	
Bihaya / Saruwa	Ipomoea fistulosa	Woody shrub, 2–4 m	Fibrous spreading	Cutting	Shallow	Fast surface cover, live stake	Terrai–1500	Tropical moist slopes	
Euphorbia / Studi	Euphorbia royleana	Succulent shrub, 2–4 m	Tap root, moderate	Cutting	Medium	Live hedge / barrier on dry slopes	1000–1500	Very dry rocky slopes	



Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	
Areri	<i>Acacia pennata</i>	Scrambling thorny shrub/climber, 3-10m	Taproot+ lateral fibrous	Seeds, cuttings	Deep	Erosion control, live fencing, fodder, medicinal	500-1500	Dry slopes, cut slopes	
Dhanyero	<i>Woodfordia fruticosa</i>	Small deciduous shrub, 2-4m tall	Fibrous+spreading	Seeds, cuttings	Medium	Erosion control, slope stabilization, medicinal, dye	Terrai-1500	Dry slopes, cut slopes	
Dhusun	<i>Colebrookia oppositifolia</i>	Evergreen shrub, 1-3m tall	Fibrous roots	Cuttings/seeds	Medium	Erosion control, medicinal (roots), fodder	Terrai-1000	Medium to dry slopes	
Kanda Phul	<i>Lantana camara</i>	Evergreen shrub, 1-3m tall, invasive	Fibrous + shallow spreading	Cuttings, seeds	Shallow to medium	Live hedge, erosion control (limited), ornamental	Terrai-1750	High (dry slopes)	
Keraukose	<i>Indigofera atropurpurea</i>	Small shrub, 1-2m tall	Fibrous+N-fixing	Seeds	Medium	Erosion control, soil improvement, fodder	Terrai-2000	Medium to dry slopes	



Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	
Tilka/Tilka na	<i>Wendlandia puberula</i>	Small evergreen shrub/tree, 2-6 m	Fibrous roots	Seeds/cuttings	Medium	Erosion control, soil binding, medicinal	Terrai-1500	Medium slopes	
Bhujetro	<i>Butea minor</i>	Deciduous shrub, 1-3 m tall	Deep taproot + fibrous	Seeds, cuttings	Deep	Erosion control, slope stabilization, fodder	500-1500	Hot and dry slopes, cut slopes	
Assuro	<i>Adhatoda vasica</i>	Evergreen shrub, 1-3 m tall	Fibrous+spreading	Cuttings/seedlings	Medium	Medicinal, live fencing, erosion control	Terrai-1000	Medium to dry slopes	
Bainsh	<i>Salix tetrasperma</i>	Medium deciduous tree/shrub, 5-15m	Fibrous+Spreading	Cuttings	Medium-deep	Soil binding, stream bank stabilization, fodder	Terrai-2700	Moist slopes, river sides	



Local Name	Botanical Name	Form & Structure	Root Architecture	Propagation	Root Depth	Uses	Altitude (m)	Drought Class	
Namdi phul	<i>Colquhounia coccinea</i>	Evergreen shrub, 2-4 m tall	Fibrous roots	Cuttings/seed	Medium	Erosion control, medicinal, ornamental	1000-2000	Medium slopes	
Bhatwasi	<i>Flemingia macrophylla</i>	Shrub, 1-2 m	Tap + lateral, nitrogen fixing	Seed/cutting	Medium	Mulch, fodder, slope cover	300-1500	Exposed soil slopes	

Source: Adapted from DoR(1999); DSCWM (2016); and field surveys in Bagmati Province.



Annex 2: Species Selection Guide for Bio-Engineering

This guide assists field engineers, sub-engineers, and supervisors in matching species and techniques to site conditions. Use Table A2.1 for site-condition matching and Table A2.2 for engineering function matching.

A2.1 Site Condition to Species Matrix

Site Condition	Slope Angle	Altitude (m)	Drought Class	Primary Species	Support Species	Technique	Avoid
Moist N-cut facing slope	<35°	500–2200	I–II	Utis (Alnus nepalensis), Napier grass	Babiyo, Koiralo	Brush layer + tree planting	Single-species grass only
Moist S-cut facing slope	<35°	500–1800	II–III	Amliso, Napier, Ipil-ipil	Chilaune, Sisso	Grass line + shrub planting	Shade-intolerant grasses
Dry hot S/SW-facing cut	35–50°	200–1500	IV–VI	Babiyo, Dubo, Jatropha	Euphorbia, Assuro	Dense grass line + live hedge	Deep-rooted moisture-hungry trees
Embankment / fill slope	<1:1.5	200–1800	II–IV	Khus / Vetiver, Napier	Kans, Dubo	Contour grass lines / coir netting	Bamboo clumps (undermining risk)
High-altitude (>1800 m) slope	Any	1800–3000	I–II	Nigalo (Ringal), Chilaune, Utis	Gurans (Rhododendron)	Brush layer + bamboo cutting	Tropical species
Riverbank / scour-risk slope	<35°	200–1400	II–III	Kans, Ipomoea, Bamboo	Sisso, Utis	Fascine + live stakes + brush layer	Shallow-rooted grasses alone
Gully head / active erosion	<40°	200–1800	II–IV	Bamboo (Mal bans), Amliso	Bhatwasi, Utis	Check dam + brush layer + seeding	No cover — active zone
Rock slope with soil pockets	Any	200–2000	III–V	Assuro, Vitex, Euphorbia	Jatropha, coir netting	Palisade in soil pockets + net	Large trees (root damage)
Combined / hybrid site	Varies	Varies	II–IV	Khus + Utis + Bamboo mix	Koiralo, Ipil-ipil	Civil structure + bioengineering	Single-species stand



A2.2 Engineering Function to Technique and Species Matrix

Engineering Function Needed	Technique / Structure	Compatible Plant Type	Min. Slope Angle	Max. Slope Angle	Time to Full Strength	Notes
Surface erosion control	Grass seeding / coir netting	Grasses (Dubo, Amliso, Napier)	0°	50°	3–6 months	Effective from first monsoon
Surface armour	Brush layering (live/dead)	Shrubs + grasses	20°	55°	6–18 months	Combine with grass seeding
Shallow reinforcement (0–1 m)	Grass plantation in lines	Khus, Kans, Amliso	5°	50°	12–24 months	Khus most effective, 1.5–3 m depth
Shallow–medium reinforcement (1–2 m)	Palisade (live stakes)	Gliricidia, Ipomoea, Vitex	15°	45°	1–3 years	Must be hard-wood cuttings, 1.5 m depth
Deep reinforcement (>2 m)	Tree + shrub plantation	Utis, Sisso, Chilaune, Bamboo	10°	40°	3–7 years	Requires civil structure support in early phase
Slope drainage enhancement	Angled grass lines + French drains	Khus, Napier, Amliso	5°	40°	3–12 months	Root channels direct water to drains
Debris catch / slope support	Fascines + bamboo planting	Bamboo (Mal bans, Dhanu)	20°	45°	2–5 years	Acts like retaining structure once mature
Anchor to deep strata	Large tree plantation	Utis, Pipal, Chilaune	5°	35°	5–10 years	Long-term investment; protect by civil works initially



A2.3 Step-by-Step Species Selection Process

Follow these steps when selecting species for a site:

Step 1: Determine altitude band (Terai <200 m; tropical 200–1000 m; sub-tropical 1000–2000 m; temperate >2000 m).

Step 2: Calculate Drought Factor Score (slope angle score + stoniness score + altitude score + aspect score + annual rainfall score).

Step 3: Identify engineering function required i.e., catch / armour / reinforce / anchor / support / drain (or combination).

Step 4: Cross-reference Tables A2.1 and A2.2 to identify primary and support species.

Step 5: Confirm local availability (nursery, natural stand, cutting source) within 5 km.

Step 6: Select a plant community mix (min. 3 species: pioneer grass + shrub + tree).

Step 7: Document selection on Annex 4D (Vegetation Field Form) and enter into Annex 8 Implementation Checklist.



Annex 3: Reference / Success Cases

Dharan-Dhankuta Road, km 5+700

Site Information

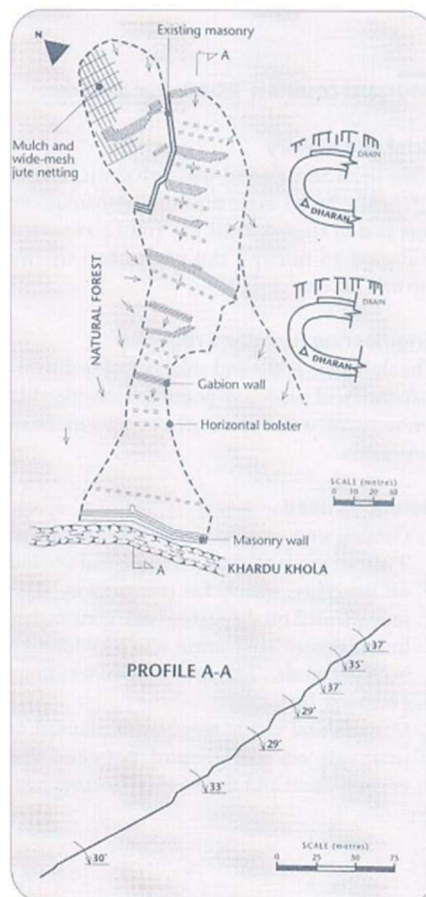
Road	Dharan-Dhankuta Road
Chainage	Km 5+700
Year of Rehabilitation	1988
Category	Slope Support, Reinforcement and Erosion Control

Site History

A complex failure occurred in a gully to the west of a hairpin stack on the steep Mahabharat ascent above Dharan. A long masonry cascade draining the hairpins failed catastrophically in 1988, triggering a large landslide-gully complex.

Engineering Functions Required

The embankment shoulders were unconsolidated and required armouring. Significant surface runoff from the pavement during heavy rainfall further threatened shoulder stability.



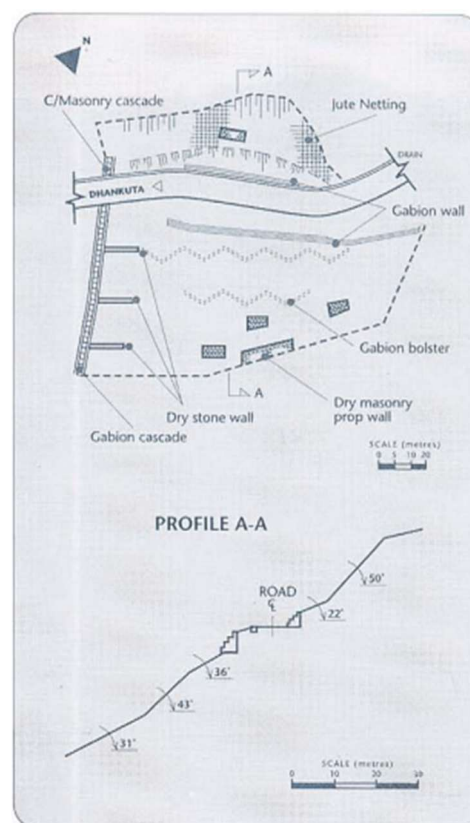
Solutions Used

- Lead-off drains were blocked and side drains re-arranged to discharge through a replacement cascade.
- A concrete masonry retaining wall was constructed at the slope toe for support and river protection against undercutting.
- Seven major gabion check dams were constructed to break the slope into shorter segments; each dam also served as a retaining wall for the slope segment above.
- All walls were backfilled with compacted spoil; excess spoil was removed to a safe tipping location.
- Gabion wire bolsters were installed at 2-metre centres on all fill and loose debris areas to provide armouring and shallow reinforcement.
- Bamboos (Tharu bans / Bambusa nutans) were planted above the toe wall for additional structural support.
- Tree seedlings (Khanyu / Ficus semicordata; Siri / Albizia spp.; Tanki / Bauhinia purpurea) planted at 1-metre centres between gabion bolsters for reinforcement and anchoring.
- Sito grass (Neyraudia arundinacea) slips planted on critical mid-slope sections for armouring and reinforcement.
- The upper failure head scar was seeded with Phurke (Arundinella nepalensis) and Sito, covered in mulch and secured with wide-mesh jute netting for complete armouring.
- Bhujetro (Butea minor) was seeded in the upper section to anchor loose debris.



Dhankuta-Hile Road, km 4+700

Site Information	
Road	Dhankuta Hile Road
Chainage	Km 4+700
Year of Rehabilitation	1990
Geology	Weak, deeply weathered gneiss
Category	Valley-side & Mountain-side slope stabilization
Site History	
An inherently unstable slope in weak, deeply weathered gneiss was disturbed by road construction. Gradual subsidence was observed post-construction. During upgrading in 1990, the deteriorating mountain-side failure required complete rehabilitation, along with stabilization of the steep valley-side slope to prevent distortion of the new metallised surface and avert potential catastrophic failure.	
Engineering Functions Required	
Valley Side: - Major Toe support was ideally required; however, poor foundations and prohibitive costs precluded this. - Planned measures: road support, extensive drainage, slope reinforcement and anchorage, and armoring of the weak, erodible gneiss-derived soil. Mountain Side: - Toe support was required to hold the residual debris mass. - Primary need: armouring, with supplementary reinforcement of debris above the support wall.	



Slope Stabilization with Bio-engineering

Solutions Used

Valley Side:

- A gabion retaining wall was constructed at the top of the valley-side slope to support the road; all subsequent measures were therefore critical to stabilize an already-subsiding, surcharged slope.
- The slope was re-graded after gabion wall construction; concavities were filled with dry masonry for local support.
- On the steeper southern flank, 3-metre high dry masonry support walls divided the slope into shorter segments.
- Drainage measures: herringbone gabion wire bolsters, improvement on the existing cascade and fascines of Simali (*Vitex negundo*) laid in subsoil drains.
- Armouring and shallow reinforcement: Phurke (*Arundinella nepalensis*) sown throughout the slope.
- Deeper reinforcement and anchorage: Utis (*Alnus nepalensis*), Nebharo (*Ficus auriculata*), and other tree seedlings planted.

Mountain Side:

- Toe support: a gabion breast wall was constructed; a concavity in the head slope was filled with dry masonry.
- Large bamboos (*Bans/Bambusa* spp.) were planted south of the breast wall for additional support.
- The head slope was trimmed and armoured with standard jute netting and Kans (*Saccharum spontaneum*) slips. Shrubs Areri (*Acacia pennata*) and Keraukose (*Indigofera atropurpurea*) were planted to reinforce debris above the gabion wall.
- Trees were planted around the head of the scar to provide products for local farmers.



Kilo-Lisangkhu Road, km 2+600

Site Information	
Road	21 Kilo-Lisangkhu Road
Chainage	Km 2+600
Year of Failure	2005
Year of Rehabilitation	2006
Cause of Failure	Surface Water
Failure Mechanism	Gully erosion
Soil Type	Colluvium
Rock Types	Slate, Schist, Gneiss
Category	Slope Stabilization

Site History

A gully head had progressively extended upslope until it reached the road formation, washing away approximately 15 metres of the road's half-width. The remaining road section and private houses located above the scar were at immediate risk.

Engineering Functions Required

Gully head arrest and stabilization to prevent further upslope progression. Erosion control along gully flanks and exposed slope areas. Structural protection of the road bench and adjacent private property.

Solutions Used

Gabion check dams were constructed to arrest gully head progression. Dry stone walls provided supplementary lateral support. Stone pitching was applied to protect exposed surfaces. Slope trimming re-established safe gradients. Coir netting was fixed across bare surfaces for immediate erosion control. Live check dams were constructed using local plant material. Grass plantation and bamboo plantation established on the treated slope.



Gabion check dams, jute netting and grass plantation (Before and after)



Live check dams, jute netting and grass and tree plantation (Before and after)



Balephi-Jalbire Road, km 0+500

Site Information	
Road	Balephi-Jalbire Road
Chainage	Km 0+500
Year of Failure	2002
Year of Rehabilitation	2003/2004/2005
Cause of Failure	River undercutting; surface and sub-surface water
Failure Mechanism	Translational failure and rill erosion
Soil Type	Colluvium
Rock Types	Slate, Phyllite, Gneiss
Category	Slope Stabilization, Water and Flood Management

Site History

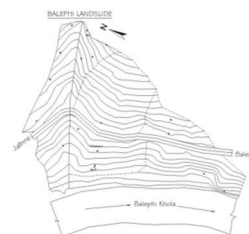
The Balephi Landslide struck Chainage 0+500 of the Balephi-Jalbire Road during the 2002 monsoon. This road is a critical artery for communities travelling to markets in Dhulikhel, Kavre, and Kathmandu. The landslide completely destroyed a 120-metre section of road, disconnecting traffic for days. A temporary repair — basic gabion walling and backfilling — was carried out by the District Development Committee, the local community, and bus operators; however, the slide remained active and posed continued risk in future monsoons. An independent geotechnical and structural assessment was commissioned. The engineer proposed stone masonry revetment and retaining toe walls along the river, four retaining walls at different levels to secure the road bench, and a cutoff drain above the slide. A bioengineering specialist was engaged to integrate bio-engineering techniques for long-term sustainable performance.

Engineering Functions Required

- Structural stabilization of the road embankment and riverbank against undercutting.
- Surface and sub-surface drainage management to control water movement on the slope.
- Erosion control against rill erosion and slope wash.
- Long-term reinforcement and anchoring of slope materials using vegetation.
- Debris management: clearing, removal, and controlled disposal of landslide material.

Solutions Used

- The landslide was divided into nine segments based on material type, water movement behaviour, and failure mechanism; each segment was treated according to its specific requirements.
- Debris removal, slope trimming, and drainage works were carried out as preparatory measures.
- Stone and concrete revetments formed the structural base of stabilization.
- Gabion walls were constructed for embankment retention and riverbank protection.
- Dry stone walls were used for intermediate slope support.
- Rill and ridge formation was carried out to redirect surface runoff.



Site before stabilization



Slope during mitigation construction



Fig: Slope after stabilization



- Sub-soil drains were installed for internal drainage.
- Coir netting was applied to control erosion on bare slope surfaces.
- Backfilling with compacted material restored slope geometry.
- Native grasses, shrubs, and wood cuttings were introduced for natural slope stabilization and water management.
- Brush layering improved slope stability and enhanced habitat for plants and wildlife.
- Grass seeds were broadcast and shrub seeds sown across treated areas.
- Bamboo and fruit trees were planted for additional reinforcement and community benefit.

Melamchi-Tipeni Road

Site Information	
Road	Melamchi-Tipeni Road
Year of Failure	2006
Year of Rehabilitation	2009
Cause of Failure	Road cutting and ground water
Failure Mechanism	Translational failure
Soil Type	Colluvium
Rock Types	Phyllite, Quartzite
Category	Slope Stabilization
Site History	
This road is a critical access corridor serving Jyamire, Langarche, Bhotenamlang, Gunsu, Thamlakot, Bhotang, Thampaldhap, Banskarka, and Dubachaur VDCs, providing market access to Dhulikhel, Kathmandu, and the district headquarters at Chautara. A landslide blocked this road section for two years. DRSP assumed responsibility for rehabilitation in 2009 and applied bio-engineering techniques to successfully stabilize the slide and reopen the road.	



Slope before implementation of bioengineering



Slope Stabilization after Bioengineering

Engineering Functions Required
• Structural stabilization of an active translational failure triggered by road cutting and groundwater. • Sub-surface drainage to manage groundwater contributing to slope instability. • Slope reinforcement and vegetation-based slope armouring.
Solutions Used
• Existing gabion structures were dismantled to allow proper site preparation. • New gabion walls were constructed for slope support. • A skin (crib) wall was constructed for additional structural retention. • Slope trimming established safe slope geometry. • Sub-soil drains were installed to manage groundwater. • Brush layering was applied for shallow reinforcement and surface protection. • Grass plantation and grass seed broadcasting established vegetative cover. • Shrub seeds were sown to build long-term root reinforcement.



Dolakha-Sigati Road, km 4+000

Site Information	
Road	Dolakha-Sigati Road
Chainage	Km 4+000
Year of Failure	2004
Year of Rehabilitation	2005
Cause of Failure	Road cutting and ground water
Failure Mechanism	Deep-seated rotational failure
Soil Type	Colluvium
Rock Types	Gneiss
Category	Slope Stabilization
Site History	
This road is the primary access route for fourteen VDCs in the northern belt of Dolakha to the district headquarters. The site contains five road bench series within a 100-metre slope section. The landslide threatened the road both above and below the failure zone, and posed a high risk of complete monsoon-season blockage.	



Slope Stabilization (Before and after bioengineering)

Engineering Functions Required
Toe stabilization of a deep-seated rotational failure to prevent further slope regression. Sub-surface drainage to mitigate groundwater-induced instability. Slope reinforcement and armouring on treated areas.
Solutions Used
Slide clearance was undertaken as a preparatory measure. A gabion wall was constructed at the toe for structural support. Sub-soil drains were installed to manage internal groundwater. Grass plantation established vegetative armouring on cleared slopes. Bamboo plantation provided deep root reinforcement and anchoring.

Virkot-Chaude Road, km 0+020

Site Information	
Road	Virkot-Chaude Road
Chainage	Km 0+020
Year of Failure	2006
Year of Rehabilitation	2007
Cause of Failure	Road cutting and surface water
Failure Mechanism	Translational failure and rill erosion
Soil Type	Colluvium
Rock Types	Gneiss
Category	Slope Stabilization



Before and after implementation of bioengineering



Site History

Located at the starting point of the road, the hillslope failed and a 30-metre section of road was completely blocked by the landslide. The failure occurred near the road's beginning, disrupting community travel immediately.

Engineering Functions Required

Removal of landslide debris from the road bench. Structural protection of the hillslope against further translational movement. Surface erosion control against rill formation.

Solutions Used

A gabion wall was constructed for slope structural support. Slope trimming established a safe working gradient. Rill and ridge formation directed surface water away from vulnerable areas. Grass plantation provided vegetative armouring. Shrub seeds were sown for supplementary reinforcement.

Manthali-Khurkot Road, km 1+750

Site Information	
Road	Manthali-Khurkot Road
Chainage	Km 1+750
Year of Failure	2002
Year of Rehabilitation	2003
Cause of Failure	Spoil disposal from road cutting
Failure Mechanism	Debris flow and rill erosion
Soil Type	Colluvium
Rock Types	Phyllite
Category	Slope Stabilization
Site History	
Spoil from road cutting was disposed of on the valley side of the road, destabilizing the slope and triggering erosion. The failing slope undermined the road structure and threatened both the existing trail and cultivated land below.	



During and after bioengineering

Engineering Functions Required

Slope stabilization on the valley side to prevent further debris flow. Erosion control against rill formation on spoil-affected areas. Reinstatement of the trail on the slope. Protection of cultivated land and road structure below.

Solutions Used

Brush layering was applied across the slope for shallow reinforcement and surface erosion control. Grass seeds were broadcast to establish rapid vegetative cover.



Sindhuli-Bhimasthan Road, km 4+800

Site Information	
Road	Sindhuli-Bhimasthan Road
Chainage	Km 4+800
Year of Failure	2005
Year of Rehabilitation	2006
Cause of Failure	Road cutting and ground water
Failure Mechanism	Rotational Failure
Soil Type	Colluvium
Rock Types	Sandstone
Category	Slope Stabilization
Site History	
Spoil from road cutting was disposed of on the valley side of the road, triggering erosion and undermining the road bench above. The rotational failure posed an ongoing threat to road stability.	



Slope stabilization after bioengineering

Engineering Functions Required
Structural retention and toe support on the valley-side slope. Sub-surface drainage to address groundwater contributing to rotational failure. Slope erosion control and vegetative armouring. Supplementary reinforcement through shrub and tree planting.
Solutions Used
A gabion wall was constructed for slope structural support. Sub-soil drains were installed to manage groundwater. Slope trimming re-established a safe gradient. Grass plantation established vegetative cover and armouring. Brush layering provided shallow reinforcement.



Annex 4 Templates for Field Data Collection

Four standardized field forms are provided. All forms use checkbox and fill-in-box format for rapid field use. Complete in ink; attach separate sketch sheet where indicated.

A4.1 Geology and Morphology (Form A)

Road Name / Link		Chainage (km+m)	
District		Date of Survey	
GPS (Lat / Long)		Altitude (m)	
Inspector Name		Checked by	

Geomorphic Setting	☐ Valley floor ☐ Lower slope ☐ Mid-slope ☐ Upper slope ☐ Ridgeline		
Slope Type	☐ Natural ☐ Road cut ☐ Fill/embankment ☐ Mixed		
Side of Road	☐ Uphill (cut) ☐ Downhill (fill/valley side)		
Slope Aspect	☐ N ☐ NE ☐ E ☐ SE ☐ S ☐ SW ☐ W ☐ NW		
Natural Slope Angle (°)	Measured by: ☐ Clinometer ☐ Estimate (Value:)		
Cut Slope	Angle (°):	Length of cut face (m):	
Embankment	Angle (°):	Embankment length (m):	
General Bedrock Type	☐ Siltstone ☐ Sandstone ☐ Slate ☐ Phyllite ☐ Schist ☐ Gneiss ☐ Quartzite ☐ Limestone ☐ Granite ☐ Other: ____		
Rock Weathering Grade	☐ Fresh (I) ☐ Slightly (II) ☐ Mod. weathered (III) ☐ Highly (IV) ☐ Completely (V) ☐ Residual soil (VI)		
Rock Mass Strength	☐ Strong ☐ Medium ☐ Weak ☐ Very weak		
Discontinuity Types Present	☐ Bedding ☐ Joints ☐ Faults ☐ Foliation ☐ Shear zones		
Dominant Discontinuity Orientation	Discontinuity Dip (°): Dip Direction (°): Spacing (m):		Type:
Failure/Instability Observed	☐ None ☐ Active ☐ Dormant ☐ Old (stabilized)		
Failure Type	☐ Planar slide ☐ Wedge ☐ Rotational ☐ Translational ☐ Toppling ☐ Debris flow ☐ Rill/sheet ☐ Rockfall		
Existing Engineering Works	☐ None ☐ Retaining wall ☐ Gabion ☐ Rock bolt ☐ Drain ☐ Bioengineering ☐ Other:		



Sketch (plan/profile)

Additional Notes



A4.2 Geotechnical Data (Form B)

Road Name		Chainage	
Inspector		Date	

Soil Profile (describe from surface)	Layer 1 (– cm), Desc:
	Layer 2 (– cm), Desc:
	Layer 3 (– cm), Desc:
Desc details: Colour, Texture (☐ Gravel ☐ Sandy gravel ☐ Gravelly sand ☐ Sand ☐ Silty sand ☐ Silt ☐ Clay ☐ Organic) and Plasticity: (Non-plastic ☐ Low plastic ☐ Medium plastic ☐ High plastic)	
Moisture Condition	☐ Dry ☐ Damp ☐ Moist ☐ Wet ☐ Very wet / saturated
Estimated Bulk Density	☐ <14 kN/m ³ ☐ 14–17 kN/m ³ ☐ 17–20 kN/m ³ ☐ >20 kN/m ³
Failure Plane Observed	☐ Yes ☐ No Depth (m): Material at plane:
Seepage / Spring	☐ Dry ☐ Damp seepage ☐ Active spring ☐ Persistent seepage Elevation of seepage:
Trial Pit Data (if done)	Pit No.: Depth (m): Observations:
Laboratory Samples Taken	☐ Disturbed ☐ Undisturbed Sample ID: Lab analysis required:
Factor of Safety (if analyzed)	FoS = Method used: Software:
Geotechnical Risk Rating	☐ Low (FoS>1.5) ☐ Moderate (FoS 1.3–1.5) ☐ High (FoS 1.1–1.3) ☐ Critical (<1.1)
Additional Notes	



A.4.3 Rainfall, Infiltration, Runoff, Erosion and Scouring (Form C)

Road Name		Chainage	
Date		Inspector	

Nearest DHM Rain Gauge Station	Station name: Distance (km):
Mean Annual Rainfall (mm)	Based on: ☐ DHM record ☐ PTMP 2024 ☐ Estimate Value:
Estimated Peak 24-hr Rainfall (mm)	☐ <100 ☐ 100–150 ☐ 150–200 ☐ >200 Source / recurrence period:
Rainfall Intensity During Last Failure	Date of event: Est. intensity (mm/day):
Drainage Catchment Area above Site	Area (ha): Topography: ☐ Convergent ☐ Divergent ☐ Parallel
Catchment Characteristics	
Surface Runoff Evidence	☐ Rill erosion ☐ Gully erosion ☐ Sheet erosion ☐ None observed
Erosion Stage	☐ Splash ☐ Sheet ☐ Rill ☐ Gully ☐ Landslide triggered
Existing Drainage Structures	☐ Catch drain ☐ Lined drain ☐ Cross drain ☐ Pipe culvert ☐ Energy dissipator ☐ None
Drain Condition	☐ Good ☐ Partially blocked ☐ Blocked ☐ Collapsed ☐ Undersized
Hume Pipe / Culvert (if present)	Dia (mm): Condition: ☐ Clear ☐ Partially blocked ☐ Blocked ☐ Missing
Infiltration Test (if done)	Method: ☐ Double ring ☐ Field est. Rate (mm/hr):
Soil Erodibility (K-factor estimate)	☐ Low (cohesive clay) ☐ Medium (silty loam) ☐ High (sandy silt) ☐ Very high (bare sand)
Evidence of River/Stream Scouring	☐ None ☐ Toe erosion ☐ Bank undercutting ☐ Channel migration Distance from road (m):
Recommended Drainage Action	☐ New catch drain ☐ Enlarge culvert ☐ Lined drain ☐ Sub-surface drain ☐ Check dam ☐ None

Sketch of Catchment Area



A4.4 Vegetation Survey (Form D)

Road Name		Chainage	
Date		Inspector	

Land Use above Slope	☐ Bare/degraded ☐ Cultivated ☐ Community forest ☐ Shrubland ☐ Forest ☐ Settlement
Existing Vegetation Cover (%)	☐ 0–10% ☐ 10–30% ☐ 30–60% ☐ 60–80% ☐ >80%
Dominant Species Present	1. Trees: 2. Shrubs: 3. Grass: _____
Bioengineering Works Present	☐ None ☐ Grass lines ☐ Brushlayer ☐ Palisade ☐ Live check dam ☐ Fascines ☐ Tree planting ☐ Coir netting
Condition of Existing Bioengineering	☐ Good (>70% survival) ☐ Fair (40–70%) ☐ Poor (<40%) ☐ Failed ☐ Not applicable
Drought Factor Score	Slope: + Stoniness: + Altitude: + Aspect: + Rainfall: = Total: Class: ☐ I ☐ II ☐ III ☐ IV ☐ V ☐ VI
Altitude Zone	☐ Tropical (<1000 m) ☐ Sub-tropical (1000–2000 m) ☐ Temperate (>2000 m)
Proposed Primary Species	Name: _____
Proposed Support Species 1	Name: _____
Proposed Support Species 2	Name: _____
Propagation Material Available	☐ Seed (specify): ☐ Sapling from nursery ☐ Cutting/slip ☐ Rhizome ☐ Polypot seedling
Nearest Nursery Source	Name / location: _____ Distance (km): _____
Planting Season	☐ Pre-monsoon (Chaitra–Jestha) ☐ Early monsoon (Ashadh–Shrawan) ☐ Post-monsoon (Ashwin)
Estimated Planting Area (m²)	Cut face: Embankment: Upper slope: Total:
Bioengineering Techniques (Proposed)	
Sketch	



Annex 5: Bioengineering Design and Estimate Templates

This ready-reckoner template is designed for use by sub-engineers and supervisors. Fill in quantities from field measurement and apply local current unit rates.

A5.1 Project Identification

Road Name / Link	
Project/Contract No.	
District / Palika	
Chainage (From – To)	
Date of Estimate	
Prepared by (Name, Designation)	
Checked by	

A5.2 Work Norms for NbS

S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
1	Collection and Preparation of Seeds				
1A	Collection of grass seeds from sources within 1km of the road, including separating and preparing seed for storage, and drying seed in the sun. Unit = kg (for 1 kg)				
	Labour				
	Unskilled	day	1.5		
	Material				
	Sealed Bag	nos	1		
	Equipment				
	Add 3% of Labour cost for Khukuri and other T & P				
1B	Collection of large shrub seeds (eg. Bhujetro) from sources within 1km of the road including seed preparation for storage after drying. Unit = kg (For 1 kg)				
	Labour				
	Unskilled	day	0.45		
1C	Collection of medium-sized shrub seeds (e.g. Keraukose) from sources within 1km of the road, including seed preparation for storage after drying. Unit = kg (For 1 kg)				
	Labour				



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Unskilled	day	0.75		
	Material				
	Sealed Bag	nos	1		
1D	Collection of medium-sized shrub and tree seeds (e.g. areli, khayer, ghobre and rani salla, sisau) from sources within 1km of the road, including seed preparation for storage after drying Unit = kg (for 1 kg)				
	Labour				
	Unskilled	day	0.95		
	Material				
	Sealed Bag	nos	1		
	Equipment				
	Add 3% of Labour cost for Nanglo and other T&P				
1E	Collection of small shrub and tree seeds (eg Dhanyero, dhusun, tilka, utis) from the sources within 1km of the road, including seed preparation for storage after drying. Unit = kg (for 1 kg)				
	Labour				
	Unskilled	day	2.5		
	Material				
	Sealed Bag	nos	1		
	Equipment				
	Add 3% of Labour cost for Nanglo and other T&P				
2	Collection of Grass and Hardwood Cuttings for Vegetative Propagation				
2A	Collection of grass clumps (eg. Amliso, kans, khar) from sources within 1km of the road to make slips for multiplication in the nursery. Unit = slips (For 100 slips)				
	Labour				
	Unskilled	day	1.5		
	Material				
	Adequate supply of appropriate clumps				
	Hessian jute	sqm	5		
	Equipment				
	Add 3% of Labour cost for Kodalo and other T&P				
2B	Collection of cuttings of small bamboos (e.g. padang bans, tite nigalo bans), suitable for traditional planting, from the sources within 1km of the road. Material minimum 10cm of the rooted rhizome and 90cm of culm. Unit = slips (For 100 slips)				
	Labour				
	Unskilled	day	3		



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Material				
	Adequate supply of appropriate clumps				
	Hessian jute	sqm	10		
	Equipment				
	Add 3% of Labour cost for Kodalo, Khukuri and other T&P				
2C	Collection of hardwood cuttings (eg. Assuro, bains, kanda phul, namdi phul, saruwa, simali) from the sources within 1km of the road. Material minimum 30cm in length and 2cm in dia. Unit = slips (For 100 slips)				
	Labour				
	Unskilled	day	0.85		
	Material				
	Hessian jute	sqm	5		
	Equipment				
	Add 3% of Labour cost for Khukuri and other T&P				
3	Nursery Operation and Management (Bed Preparation)				
3A	Materials for beds and shades. Bed is 1 m wide x 17 cm high and made up of 5 cm of washed gravel, 5 cm of unsieved forest soil, 5 cm of 1:3 mix of sieved forest soil, and washed sand, 2 cm of washed, sieved and sterilized sand. [Add 5% to the number of bricks to allow for normal wastage]. Unit = sqm (For 5 sqm)				
	Labour				
	Skilled	day	1.5		
	Unskilled	day	0.85		
	Material				
	Bamboo poles	nos	9		
	Polythene Sheet	sqm	9		
	Bricks	nos	96		
	Gravel	cum	0.25		
	Unsieved Soil	cum	0.1		
	Line String	meter	13		
	Binding Wire	kg	3		
	Equipment				
	Add 3% of Labour Cost for Khanti, Shovel, Pick axe, Screen, mesh and other T&P				
3B	Construction of stand out beds for tree seedling in polypots, including Material for beds and shades. Bed is 100 cm wide x 15 cm high, with a layer of gravel placed above the compacted ground. [Add 5% to the number of bricks to allow for normal wastages.]. Unit = sqm (For 5 sqm)				



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Labour				
	Unskilled	day	6		
	Material				
	Bamboo poles	nos	15		
	Bricks	nos	96		
	Gravel	cum	0.25		
	Line String	meter	13		
	Binding Wire	kg	3		
	Equipment				
	Add 3% of Labour Cost for Khanti, Shovel, Pick axe and other T&P				
3C	Construction of beds for grass seeds, grass slips (i.e. vegetative propagation) and tree cuttings, including Materials and hessian cover. Bed is 100 cm wide x 25 cm high and made up of of washed gravel placed above the ground, of 1:1 mix of sieved soil and compost, and topped with 15 cm of 3:1 mix of sieved forest topsoil and washed sand. Unit = sqm (For 5 sqm)				
	Labour				
	Skilled	day	1		
	Unskilled	day	1.5		
	Material				
	Gravel	cum	0.38		
	Forest soil	cum	1.46		
	Compost	cum	0.38		
	Washed Sand	cum	6		
	Hessian jute	sqm	10		
	Equipment				
	Add 3% of Labour cost for Shovel, Pick axe and other T&P				
3D	Construction of beds for propagation of bamboo culm cuttings, including Materials and hessian cover. Bed is 100 cm wide x 30 cm high. The ground below the bed is dug to a depth of 30 cm. Bed is made with 10 cm unsieved soil and 20 cm high is formed around the edge. Unit = sqm (For 5 sqm)				
	Labour				
	Skilled	day	2		
	Material				
	Gravel	cum	0.38		
	Forest soil	cum	1.46		



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Compost	cum	0.38		
	Washed Sand	cum	6		
	Hessian jute	sqm	10		
	Equipment				
	Add 3% of Labour cost for Shovel, Pick axe and other T&P				
4	Nursery Operation and Management (Seed Sowing, Transplanting & Planting Hardwood Cuttings)				
4A	Tree seed sowing @ 10g per sqm (medium sized seeds) or 2g per sqm (very fine seeds) into seed beds including pre-sowing treatment. Unit = sqm (For 5 sqm)				
	Labour				
	Unskilled	day	0.04		
	Material				
	Seed	cum	0.38		
	Equipment				
	Add 3% of Labour cost for Bowl, Trowel and other T&P				
4B	Preparing potting mix and filling polypots, including all materials for container seedlings. [Note: 1 kg of 200 gauge polypots (4"×7" laid flat) = 464 bags; 200 gauge black polythene preferred]. Unit = nos (For 1000 nos.)				
	Labour				
	Unskilled	day	10		
	Material				
	Polypots	nos	1050		
	Sand	cum	0.46		
	Soil	cum	0.7		
	Compost	cum	0.23		
	Equipment				
	Add 3% of Labour cost for Wooden peg and other T&P				
4C	Direct sowing of tree seeds into polypots including seed treatment; one seed in half the pots and two seeds in the other half. Unit = nos (For 1000 nos.)				
	Labour				
	Unskilled	day	0.62		
	Material				
	Seed	nos	1500		
	Wooden peg	nos	1		



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Equipment				
	Add 3% of Labour cost for Sieve, Shovel and other T&P				
4D	Pricking out young seedlings and transplanting into polypots. Unit = nos (For 1000 nos.)				
	Labour				
	Unskilled	day	0.18		
	Material				
	Wooden peg	nos	1		
	Equipment				
	Add 3% of Labour cost for Tray and other T&P				
4E	Pricking out young seedlings and transplanting into beds. Unit = nos (For 1000 nos.)				
	Labour				
	Unskilled	day	0.12		
	Material				
	Wooden peg	nos	1		
	Equipment				
	Add 3% of Labour cost for Tray and other T&P				
4F	Transplanting grass slips into beds from clumps; slips planted at 10cm centres in rows 25cm apart. Unit = sqm m				
	Labour				
	Unskilled	day	0.12		
	Material				
	Hessian jute	sqm	0.3		
	Equipment				
	Add 3% of Labour cost for Khukuri, Shovel and other T&P				
4G	Planting of hardwood cuttings of minimum length to 20cm depth into prepared beds; cuttings spaced at centres within rows, with 20cm between rows. Unit = nos (For 1000 nos.)				
	Labour				
	Unskilled	day	0.6		
	Material				
	Hard wood cuttings	nos	1000		
	Equipment				
	Add 3% of Labour Cost for Khanti and other T&P				



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
5	Preparation of Raised Materials for Extraction from the Nursery				
5A	Grass culm cutting production from nursery stock: single or double node (eg napier). Unit = nos. (For 1000 nos.)				
	Labour				
	Unskilled	day	0.7		
	Material				
	Hessian jute	sqm	2.7		
	Equipment				
	Add 3% of Labour cost for Khukuri and other T&P				
5B	Uprooting and preparing grass slips ready for site planting from nursery seedling. Unit = nos (For 1000 nos.)				
	Labour				
	Unskilled	day	0.63		
	Material				
	Hessian jute	sqm	1.35		
	Equipment				
	Add 3% of Labour cost for Fork, Pick axe, Khukuri and other T&P				
5C	Uprooting and preparing grass slips ready for site planting from nursery grass clumps raised from slips by vegetative propagation. Unit = nos (For 1000 nos.)				
	Labour				
	Unskilled	day	0.33		
	Material				
	Hessian jute	sqm	4.2		
	Equipment				
	Add 3% of Labour cost for Shovel and other T&P				
6	Compost and Mulch Production				
6A	Mulch production by collection and cutting of weeds and other vegetation (eg. tite pati, banmara etc.) within 1km of the road, and stacking along roadside. Unit = cum (For 1 cum)				
	Labour				
	Unskilled	day	0.12		
	Equipment				
	Add 3% of Labour cost for Hansia, Doko and other T&P				
6B	Compost production by collection and cutting of weeds and other vegetation (eg. tite pati, banmara etc.) within 1km of the road, including fine cutting and filling compost pit. Unit = cum (For 1 cum)				
	Labour				



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Unskilled	day	0.12		
	Equipment				
	Add 3% of Labour cost for Hansia, Doko and other T&P				
6C	Turning compost once per month Unit = cum (For 1 cum)				
	Labour				
	Unskilled	day	0.1		
	Equipment				
	Add 3% of Labour cost for Shovel and other T&P				
7	Direct Seeding on Site				
7A	Broadcasting grass seeds on slopes <40°; seeding rate 25g per sqm. Unit = sqm (For 100 sqm)				
	Labour				
	Unskilled	day	0.17		
	Material				
	Seed	kg	2.5		
7B	Broadcasting grass seeds on slopes <40°; including cover with long mulch; seeding rate 25g per sqm. Unit = sqm (For 100 sqm)				
	Labour				
	Unskilled	day	5		
	Material				
	Seed	kg	2.5		
	Mulch	cum	5		
7C	Broadcasting grass seeds on slopes 40°–45°; including cover with long mulch and jute netting (mesh 300mm × 500mm), seeding @ 25g per sqm; including live pegs or hardwood cuttings (eg Simali) at 1m spacing , jute net of 6.75m size. Unit = sqm (For 100 sqm)				
	Labour				
	Unskilled	day	6.25		
	Material				
	Seed	kg	2.5		
	Mulch	cum	5		
	Jute net	cum	105		
	Live pegs	cum	128		
	Equipment				



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Add 3% of Labour cost for Khukuri, Mallet and other T&P				
7D	Sowing shrub or tree seeds on all slopes at 25cm intervals; digging planting holes to 5cm depth and covering with soil. Two seeds per planting hole. Unit = sqm (For 100 sqm)				
	Labour				
	Unskilled	day	1		
	Material				
	Seed	nos	3200		
	Equipment				
	Add 3% of Labour cost for MS rod (50cm length) and other T&P				
8	Planting Grass on Site				
8A	Planting single node culm cutting of grass (eg napier) on fill slopes <45° and embankment slopes in plain areas. Approx. length 15–20cm; including digging planting hole 10–20cm depth using a metal rod or hardwood peg. Unit = nos (For 100 nos.)				
	Labour				
	Unskilled	day	0.2		
	Material				
	Grass cuttings	nos	100		
	Hessian jute	sqm	0.27		
	Equipment				
	Add 3% of Labour cost for MS rod or hardwood peg and other T&P				
8B	Planting single node culm cutting of grass (eg Napier) on fill slopes <45°; approx. length 15–20cm; including digging planting hole 10–15cm depth using a metal rod or hardwood peg. Unit = nos (For 100 nos.)				
	Labour				
	Unskilled	day	0.35		
	Material				
	Grass cuttings	nos	100		
	Hessian jute	sqm	0.27		
	Equipment				
	Add 3% of Labour cost for MS-rod or hardwood peg and other T&P				
8C	Planting single node culm cutting of grass (eg napier) on fill slopes >45°; approx. length 15–20cm; including digging planting hole 10–15cm depth using a metal rod or hardwood peg. Unit = nos (For 100 nos.)				
	Labour				
	Unskilled	day	0.5		



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Material				
	Grass Cuttings	nos	100		
	Hessian jute	sqm	0.27		
	Equipment				
	Add 3% of Labour cost for MS-rod or hardwood peg and other T&P				
8D	Planting rooted grass slips on embankment slopes in plain areas at spacing withing the row; first row 0.75m from pavement edge; subsequent rows spaced at intervals down the embankment. Unit = meter (For 1 meter)				
	Labour				
	Unskilled	day	0.02		
	Material				
	Grass slips / no. of drills cuttings	nos	11		
	Hessian jute	sqm	0.27		
	Line String	m	1		
	Equipment				
	Add 3% of Labour cost for MS rod or hardwood peg and other T&P				
8E	Planting rooted grass slips on slopes <45° including preparation of slips on site, a max of 5 cm depth with metal rod or Operation includes digging planting hole to hard-wood peg, depending on the nature of the soil. The planting drills should be space. Unit = sqm (For 1 sqm)				
	Labour				
	Unskilled	day	0.2		
	Material				
	Grass slips / no. of drills cuttings	nos	100		
	Hessian jute	sqm	0.27		
	Equipment				
	Add 3% of Labour cost for MS-rod or hardwood peg and other T&P				
8F	Planting rooted grass slips on the slopes 45° - 60° including preparation of slips on site. a max of 5 cm depth with metal rod or Operation includes digging planting hole to hard-wood peg, depending on the nature of the soil. The planting drills should be space. Unit = sqm (For 1 sqm)				
	Labour				
	Unskilled	day	0.3		
	Material				
	Grass slips / no. of drills cuttings	nos	100		
	Hessian jute	sqm	0.27		



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Equipment				
	Add 3% of Labour cost for MS rod or hardwood peg and other T&P				
8G	Planting rooted grass slips on the slopes > 60° including preparation of slips on site. a max of 5 cm depth with metal rod or Operation includes digging planting hole to hard-wood peg, depending on the nature of the soil. The planting drills should be space. Unit= sqm (For 1 sqm)				
	Labour				
	Unskilled	day	0.4		
	Material				
	Grass slips / no. of drills cuttings	nos	100		
	Hessian jute	sqm	0.27		
	Equipment				
	Add 3% of Labour cost for MS rod or hardwood peg and other T&P				
9	Planting Shrub and Tree Seedlings and Cuttings on Site				
9A	Planting containerized tree and shrub seedlings; including pitting, transplanting, composting and placing tree guards on toe of embankment slopes in plain areas, not less than 8m from road centre line. Pit size 30cm dia × depth; compost 1/4 of pit volume mixed with original soil. Unit = nos (For 10 nos.)				
	Labour				
	Unskilled	day	0.25		
	Material				
	Seedling	nos	10		
	Compost	cum	0.05		
	Tree guard	nos	10		
	Green mulch	cum	0.4		
	Equipment				
	Add 3% of Labour Cost for Khanti, Mallet and other T&P				
9B	Planting containerized tree and shrub seedlings; including pitting, transplanting, composting and mulching on slopes <30°. Pit size 30cm dia × depth; mix compost with soil and backfill into pit to 1/4 of pit volume. Unit = nos (For 10 nos.)				
	Labour				
	Unskilled	day	0.33		
	Material				
	Seedling	nos	10		
	Compost	cum	0.05		
	Green mulch	cum	0.04		



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Equipment				
	Add 3% of Labour cost for Khanti, Doko and other T&P				
9C	Planting containerized tree and shrub seedlings; including pitting, transplanting, composting and mulching on slopes 30°–40°. Pit size 30cm dia × depth; compost with soil and backfill into pit to 1/4 of pit volume Unit = nos (For 10 nos.)				
	Labour				
	Unskilled	day	0.4		
	Material				
	Seedling	nos	10		
	Compost	cum	0.05		
	Green mulch	cum	0.04		
	Equipment				
	Add 3% of Labour cost for Khanti, Doko and other T&P				
9D	Planting rooted tree stump cuttings and bare root seedlings; including pitting, transplanting, composting and mulching on slopes <30°. Pit size 10cm dia × depth; compost volume ¼ of volume of the pit mix with original soil. Unit = nos (For 10 nos.)				
	Labour				
	Unskilled	day	0.17		
	Material				
	Seedling	nos	10		
	Compost	cum	0.03		
	Green mulch	cum	0.04		
	Equipment				
	Add 3% of Labour cost for Khanti, Doko and other T&P				
9E	Planting rooted tree stump cuttings and bare root seedlings; including pitting, transplanting, composting and mulching on slopes <30°–45°. Pit size 10cm dia × depth; compost volume ¼ of volume of the pit mix with original soil. Unit = nos (For 10 nos.)				
	Labour				
	Unskilled	day	0.25		
	Material				
	Seedling	nos	10		
	Compost	cum	0.03		
	Green mulch	cum	0.04		
	Equipment				



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Add 3% of Labour Cost for Khanti, Doko and other T&P				
9F	Planting rooted tree stump cuttings and bare root seedlings; including pitting, transplanting, composting and mulching on slopes >45°. Pit size 10cm dia × depth; compost volume 1/4 of pit mix with original soil. Unit = nos (For 10 nos.)				
	Labour				
	Unskilled	day	0.33		
	Material				
	Seedling	nos	10		
	Compost	cum	0.03		
	Green mulch	cum	0.04		
	Equipment				
	Add 3% of Labour cost for Khanti, Doko and other T&P				
10	Vegetative Palisade Construction, Brush Layering and Fascines				
10A	Collection of hardwood cuttings for planting material (eg assured, namdi phul, simali) from sources within 1km of the road. Material approx. 1m in length and minimum 5cm in diameter. Unit = nos (For 1000 nos.)				
	Labour				
	Unskilled	day	0.85		
	Material				
	Adequate supply of bushes				
	Equipment				
	Add 3% of Labour cost for Khukuri and other T&P				
10B	Preparation and planting of live pegs of selected species (eg: Assuro, Namdi phul, Simali) to 0.5m depth into hard ground; pegs spaced at centres within rows and interwoven with vegetation Unit = meter (For 1 meter)				
	Labour				
	Unskilled	day	0.17		
	Material				
	Live peg	nos	20		
	Equipment				
	Add 3% of Labour cost for Crowbar and other T&P				
10C	Preparation and planting of live pegs of selected species (eg: Assuro, Namdi phul, Simali) to 0.5m depth into hard ground; pegs spaced at centres within rows and interwoven with vegetation Unit = meter (For 1 meter)				
	Labour				
	Unskilled	day	0.12		



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Material				
	Live peg	nos	20		
	Equipment				
	Add 3% of Labour cost for Crowbar and other T&P				
10D	Site preparation for fascine laying; earthworks in excavation of trench to 20cm depth. Unit = meter (For 1 meter)				
	Labour				
	Unskilled	day	0.06		
	Equipment				
	Add 3% of Labour cost for Pick Axe, Shovel, Crowbar and other T&P				
10E	Laying of live fascines, using live hardwood cuttings of selected species (eg assuro, namdi phul,simali) of minimum length places in bundles to give 4 running meters of cutting per meter of fascine, including backfilling of trench and careful compaction. Unit = meter (For 1 meter)				
	Labour				
	Unskilled	day	0.17		
	Material				
	Hardwood cutting of at least 1m length	m	8		
	Equipment				
	Add 3% of Labour cost for Crowbar and other T&P				
11	Jute Netting Works				
11A	Standard jute netting for bare slopes and underplanting with slips. Spinning raw jute from 100% jute fiber into yarn and weaving into netting; hand spun yarn 5–8mm dia, width 1.20m, warp strands 27 no per mesh, mesh size 30–40mm sq., weight 1.25 kg/m at 1.20m width. [Note: A toro is the weaving shuttle, normally made from a split large bamboo culm.]. Unit = sqm (For 1 sqm)				
	Labour				
	Unskilled	day	0.36		
	Material				
	Raw Jute	kg	0.25		
	Equipment				
	Add 3% of Labour cost for bamboo sticks (10 nos), Khukuri and other T&P				
11B	Wide mesh jute netting for holding mulch on slopes. Spinning raw jute from 100% jute fiber into yarn and weaving the yarn into netting. Hand spun yarn 3–5mm dia, 1.20m × 11.2m; mesh size 150mm × 500mm rectangular; weight 0.25 kg/m at 1.20m width . [Note: A toro is the weaving shuttle, normally made from a split large bamboo culm.]. Unit = sqm (For 1 sqm)				
	Labour				
	Unskilled	day	0.15		



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Material				
	Raw Jute	kg	0.25		
	Equipment				
	Add 3% of Labour cost for bamboo sticks (10 nos), Khukuri and other T&P				
11C	Placing 30–40mm square mesh jute netting on bare slopes (for later underplanting with grass slips); including pegging with live hardwood cuttings or split bamboo pegs and loosening tension so that the net hugs the slope throughout. Unit = sqm (For 1 sqm)				
	Labour				
	Unskilled	day	0.15		
	Material				
	Woven Jute	sqm	0.25		
	Hardwood cuttings or Split Bamboo pegs	nos	5		
	Equipment				
	Add 3% of Labour Cost for MS rod, Mallet and other T&P				
11D	Placing 150 × 500mm mesh jute netting to hold mulch on slopes; including application of mulch and pegging with live hardwood cuttings or split bamboo pegs and loosening tension so that the net hugs the slope throughout. Unit = sqm (For 1 sqm)				
	Labour				
	Unskilled	day	0.1		
	Material				
	Woven Jute	sqm	1		
	Cut Mulch	cum	0.05		
	Equipment				
	Add 3% of Labour cost for MS rod, Mallet and other T&P				
12	Gabion Bolster Cylinders				
12A	Providing and laying 60cm dia gabion bolsters panels: 70 × 100mm hexagonal mesh wire (10 swg frame and 12 swg mesh); including earthwork excavation, filling with boulder, backfilling — all complete as per Drawing and Technical Specifications. Unit = meter (For 1 meter)				
	Labour				
	Unskilled	day	0.82		
	Material				
	GI wire	kg	4		
	Black Polythene	sqm	0.8		
	Equipment				



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Add 3% of Labour cost for Pick Axe, Shovel and other T&P				
12B	Providing and laying 30cm dia gabion bolsters panels: 70 × 100mm hexagonal mesh wire (10 swg frame and 12 swg mesh); including earthwork excavation, filling with boulder, backfilling — all complete as per Drawing and Technical Specifications. Unit = meter (For 1 meter)				
	Labour				
	Skilled	day	0.55		
	Material				
	GI wire	kg	2		
	Boulder/Stone	cum	0.09		
	Black Polythene	sqm	0.4		
	Equipment				
	Add 3% of Labour Cost for Gabion Frame and other T&P				
12C	Anchoring bolster: 12mm dia MS rebar cut into 2m lengths for anchorage and placed at intervals. Unit = meter (For 1 meter)				
	Labour				
	Unskilled	day	0.36		
	Material				
	MS rod	m	2		
	Equipment				
	Add 3% of Labour cost for Sledge hammer and other T&P				
12D	Providing and laying of terram paper (geotextile). Unit = meter (For 1m)				
	Labour				
	Unskilled	day	0.36		
	Material				
	Terram Paper	sqm	1.15		
	Equipment				
	Add 3% of Labour cost for Sledge hammer and other T&P				
13	Turfing				
13A	Grass sodding works including sod cuttings, transporting, placing in position and water sprinkling (Lead up to 10m). Unit = sqm (For 1 sqm)				
	Labour				
	Unskilled	day	0.05		
	Equipment				



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	Add 3% of Labour cost for Sledge hammer and other T&P				
13B	Providing and spreading manure on the grass turf. Unit = sqm (For 100 sqm)				
	Labour				
	Unskilled	day	0.04		
	Material				
	Chemical manures	kg	7		
	Equipment				
	Add 3% of Labour cost for Sledge hammer and other T&P				
14	Seeding and Mulching				
14A	Providing required material; preparation of seed bed on previously laid top soil; furnishing and placing seeds, fertilizer, mulching material; applying bituminous emulsion at 0.23 litres per sqm; laying and fixing jute netting; including watering for 3 months — all as per specifications Unit = sqm (For 240 sqm)				
	Labour				
	Skilled	day	1		
	Unskilled	day	10		
	Equipment				
	Tractor-trolley	hour	2.4		
	Material				
	Seeds	kg	3.6		
	Sludge / Farm yard manure	cum	0.43		
	Bitumen Emulsion	liter	55.2		
	Jute netting, open weave, 2.5cm square opening	sqm	264		
	Cost of water for 3 months	KL	84		

Rates are inclusive of labour, materials, tools, and 5% contractor overhead. Exclude VAT unless specified.



Annex 6 BoQ Format for Nbs / Bioengineering Items

This standard BoQ format is for use in provincial road contracts. It is intended to be annexed to the contract document.

A6.1 Contract Information

Contract / Project Name	
Road Link and Chainage	
Contracting Office	
Contract No.	
Date of Preparation	
Prepared by	
Approved by	

A6.2 Bill of Quantities

S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
1	Collection of grass seeds from sources within 1km of the road, including separating and preparing seed for storage, and drying seed in the sun.	kg			
2	Collection of small shrub and tree seeds (eg Dhanyero, dhusun, tilka, utis) from the sources within 1km of the road, including seed preparation for storage after drying.	kg			
3	Collection of grass clumps (eg. Amliso, kans, khar) from sources within 1km of the road to make slips for multiplication in the nursery	slips			
4	Collection of hardwood cuttings (eg. Assuro, bains, kanda phul, namdi phul, saruwa, simali) from the sources within 1km of the road. Material minimum 30cm in length and 2cm in dia.	cuttings			
5	Broadcasting grass seeds on slopes <40°; seeding rate 25g per sqm.	sqm			
6	Planting single node culm cutting of grass (eg napier) on fill slopes <45° and embankment slopes in plain areas. Approx. length 15–20cm; including digging planting hole 10–20cm depth using a metal rod or hardwood peg.	Nos			
7	Planting rooted grass slips on embankment slopes in plain areas; first row 0.75m from pavement edge; subsequent rows spaced at intervals down the embankment	m			
8	Planting rooted tree stump cuttings and bare root seedlings; including pitting, transplanting, composting and mulching on	Nos			



S.No.	Description of Works / Resources	Unit	Quantity	Rate (NRs.)	Remarks
	slopes <30°. Pit size 10cm dia × depth; compost volume ¼ of volume of the pit mix with original soil.				
9	Preparation and planting of live pegs of selected species (eg: Aassuro, Namdi phul, Simali) to 0.5m depth into hard ground; pegs spaced at centres within rows and interwoven with vegetation.	m			
10	Laying of live fascines, using live hardwood cuttings of selected species (eg assured, namdi phul, simali) of minimum length places in bundles to give 4 running meters of cutting per meter of fascine, including backfilling of trench and careful compaction.	m			
11	Standard jute netting for bare slopes and underplanting with slips. Spinning raw jute from 100% jute fiber into yarn and weaving into netting; hand spun yarn 5–8mm dia, width 1.20m, warp strands 27 no per mesh, mesh size 30–40mm sq., weight 1.25 kg/m at 1.20m width.	sqm			
12	Providing and laying 30cm dia gabion bolsters panels: 70 × 100mm hexagonal mesh wire (10 swg frame and 12 swg mesh); including earthwork excavation, filling with boulder, backfilling — all complete as per Drawing and Technical Specifications.	m			
13	Anchoring bolster: 12mm dia MS rebar cut into 2m lengths for anchorage and placed at intervals.	m			
	A. Sub-Total				
	B. Provisional sum				
	C. Total (A+B)				
	D. VAT/Tax				
	E. Grand Total (C+D)				



ANNEX 7 NURSERY ESTABLISHMENT AND OPERATION GUIDE (LOCAL SPECIES)

This guide is intended for sub-engineers, and community nursery operators. It covers site selection, facility layout, species-specific propagation, and annual calendar of operations.

A7.1 Nursery Site Selection Criteria

- Located within 5 km of the planting site to minimize transport damage and cost.
- Accessible by motor vehicle or porter track year-round (including monsoon).
- Reliable water source: spring, stream, or rainwater collection tank (min. 5,000 L storage for 1,000 seedlings).
- Gentle slope (2–5°) for drainage — avoid waterlogging; avoid exposed ridgelines.
- Partial shade (40–60%) or provision for shade structure using bamboo + hessian.
- Secure compound: fenced with local materials against grazing animals and theft.
- Proximity to a diversity of local seed source plants for collection.

A7.2 Nursery Layout and Infrastructure

A typical 500 m² nursery for 5,000 seedlings requires:

Zone	Area (m ²)	Quantity / detail	Notes
Seed beds (tree / shrub)	20	4 beds, 5×1 m	Shaded; sieved forest soil + compost
Grass propagation beds (slip / rhizome)	30	3 beds, 10×1 m	Open; regular watering
Polypot stand-out area	100	Shelved rows, 50% shade	Root-pruning platform; ~5,000 pots
Bamboo culm bed	15	1 bed, 15×1 m	Dug ≥ 50 cm; permanently moist and shaded; bunded sides
Stool / stock-plant area	40	Perennial cutting supply	Grass, shrub and hardwood mother stock
Compost bays	20	2 bays, 3×3 m	Leaf litter + manure + soil
Soil & sand store + potting area	25	Covered mixing bay	Sieved topsoil, sand and compost stock
Water tank & irrigation	15	Min. 5,000 L tank	At highest point; gravity-fed if possible
Store, seed store, tools & watchman hut	30	1 shed	Locked seed store; tools; shelter
Vehicle access, turning & unloading	45	Hard / gravel surface	Reversing and turning space at the entrance
Walkways & inter-terrace paths	40	—	Gravel or hard surface; drained
Terracing allowance (risers, batters, retaining)	90	—	Level benches on sloping ground; ~15–20% of gross area
Perimeter buffer (inside fence)	30	—	Bamboo / wire fence line; edge drainage
Total fenced area	500	—	Perimeter: bamboo / wire fence



A7.3 Propagation Methods by Species Type

Grasses (Amliso, Napier, Khus, Kans)

- **Slip / rhizome division** (Amliso, Kans, Khus): separate clumps with 3–5 tillers and as much root as possible. Fibrous-rooted grasses such as Kans and Khar need two slips per planting hole; rhizomatous grasses such as Amliso need only one.
- **Stem cuttings** (Napier): Napier (*Pennisetum purpureum*) is raised from 2–3 node stem cuttings, not from slips or rhizome division — do not group it with the clumping grasses.
- Plant in rows 30 cm apart in the nursery grass bed; water daily for 2 weeks, then on alternate days.
- Ready for site dispatch at 20–30 cm tall; do not hold longer than 8 weeks.
- Lift, split and replant the beds every 6–8 weeks to maximise slip production.

Note: Khus (vetiver) and Napier are introduced species, flag against the native-species preference (IUCN Global Standard, Criterion 3).

Polypot Seedlings (Trees and Shrubs)

- Sow seed in seed beds at a depth of 2× the seed diameter; shade immediately with hessian.
- Prick out into 4"×7" polypots when 2–4 true leaves appear (3–4 weeks after germination).
- Space polypots 10 cm apart; root-prune by lifting and resetting whenever roots emerge from the base.
- Harden off for 2 weeks before dispatch: remove shade, reduce watering, increase sun exposure.
- Target height at dispatch 15–30 cm with a well-formed root ball; reject thin or leggy stock.

Hardwood / Large Cuttings (Salix, Vitex, Jatropha, Gliricidia)

- Take **Salix (willow / bains)** as the primary cutting species on moist sites, with *Vitex negundo* (simali), *Jatropha curcas* (sajiwan) and *Gliricidia sepium* as alternatives.
- Collect large cuttings 0.75–1.0 m long and 2–4 cm in diameter during the dry season (avoid the misleading “pencil-thick” description — these are stakes, not pencil cuttings).
- Cut cleanly at a node; plant immediately, 30–50 cm into prepared soil, or store upright in deep shade for no more than 2 weeks.

Bamboo Culm Cuttings

- Select 1–2 year old culms; cut 2-node sections about 60 cm long.
- Prepare the bed dug to at least 50 cm depth, kept permanently moist and well shaded.
- Lay the sections horizontally about 5 cm below the surface; maintain constant moisture.
- Never let the bed dry out or lose its shade.

A7.4 Seed Collection, Processing, and Storage

- Collect seed from local natural stands (should match the planting site altitude, aspect, and rainfall.)
- Label every collection: species, date, location, altitude, number of mother plants.
- Dry seeds in shade on clean concrete; never in direct sun (heat destroys viability).
- Store in sealed containers (paper bag inside airtight tin) in cool, dark, dry conditions.
- Pre-treatment before sowing: hard-coated seeds (Sisso, Koiralo): soak 24 hr in warm water; others scarify with sandpaper.



A7.5 Annual Calendar of Nursery Operations

● primary window ○ limited / secondary window (winter stem-cutting planting; post-monsoon gap-filling).

Work activity	Shrawan	Bhadra	Aswin	Kartik	Marga	Poush	Magh	Falgun	Chaitra	Baishak	Jestha	Ashadh
Seed collection (grasses: Amliso, Kans)				●	●			●	●			
Seed collection (trees: Utis, Sisau, Koiralo)				●	●	●	●	●	●	●	●	
Seed drying, cleaning, storage				●	●	●	●	●	●	●		
Seed pre-treatment (soaking, scarification)							●	●	●	●		
Seed bed sowing (trees and shrubs)							●	●	●	●		
Grass bed establishment (slip / rhizome)	●	●						●	●	●	●	●
Pricking out to polypots								●	●	●	●	
Polypot management (spacing, watering, root pruning)	●	●						●	●	●	●	●
Hardening off seedlings										●	●	●
Stock: grass slips ready for dispatch	●	●									●	●
Stock: tree / shrub seedlings ready	●	●									●	●
Cutting collection & prep (Napier, bamboo, hardwood)	●					○	○				●	●
Site planting works	●	●	○			○	○				○	●
Nursery maintenance (weeding, fertilising)	●	●	●	●	●	●	●	●	●	●	●	●
Post-monsoon survey + gap filling			●	●								
Compost and mulch making		●	●	●	●	●	●	●				
Fence / boundary repair							●	●	●			

Notes :Seed-collection months: Amliso Mar–Apr (Chaitra–Baishak); Kans Nov–Dec (Kartik–Marga); Utis Nov–Mar (Kartik–Chaitra); Sisau Feb–May (Falgun–Jestha); Koiralo Mar–May (Chaitra–Jestha). Napier carries no seed-collection window — it is raised from stem cuttings, so it sits in the cutting row, not seed collection. Planting: the main window is monsoon onset, Ashadh–Shrawan–Bhadra. Hardwood and other stem cuttings may also be planted in winter (Poush–Magh), per the Guideline on Landslide Treatment and Mitigation. Post-monsoon (Aswin) planting is gap-filling only and gives low survival. Months follow the Nepali fiscal year, which begins in Shrawan. Ashadh is mid-June to mid-July (monsoon onset); Chaitra is mid-March to mid-April (dry season).



ANNEX 8 QUICK-REFERENCE DECISION CHARTS FOR SUPERVISORS AND CONTRACTORS

These charts provide rapid field decision support. No calculation or computer is required. Charts are designed for use by site supervisors, sub-engineers, and contractors during field visits.

Chart 8.1 Step-by-Step Problem Diagnosis and Intervention Decision Tree

Work through each step in order. Follow the YES path immediately; return to the next step only if NO.

Step	Question	If YES →	If NO →	Notes
1	Is the slope actively failing (moving soil / debris on the road)?	EMERGENCY. Stop or control traffic and post warning signs; keep people and plant clear of the ground below the slide; catch or clear debris and monitor movement. Notify TID and call a geotechnical engineer. No planting until stabilised.	Go to Step 2.	Active failure → structural measures first; vegetation only after the slope is stabilised.
2	Is there visible seepage or a spring on the slope?	Design and complete sub-surface drainage (French / counterfort or herringbone drains) before any bioengineering. Deep or artesian seepage → refer to specialist.	Go to Step 3.	Unresolved seepage negates all bioengineering investment — water first.
3	Is the slope angle greater than 50°?	Engineering intervention required (gabion / retaining wall / rock bolt). Bioengineering supplementary only.	Go to Step 4.	Above ~50° exceeds the practical limit for vegetative primary reinforcement; the Site Handbook slope scoring itself tops out at >49°.
4	Is rock the dominant material (>60% rock outcrop)?	Rock engineering (bolts, mesh, shotcrete) + vegetation only in joints and soil pockets.	Go to Step 5.	On rock, vegetation performs erosion control only, not reinforcement (see Case Type 7).
5	Is the slope in a high-scour zone (river toe, active gully)?	Structural toe protection first (gabion / stone pitching), founded below computed scour depth; then brush layer + Kans / bamboo planting.	Go to Step 6.	Scour undermines even the best bioengineering; toe protection founded above scour depth will fail (see Case Type 6).
6	Is the site above 2000 m (lower temperate)?	Select lower-temperate species only — Utis, Nigalo, Painyu, Lankuri, Okhar; grasses Kans / Amliso. Avoid tropical / subtropical species (including Chilaune, which tops out near 2000 m).	Go to Step 7.	Species–altitude match governs survival. Altitude zones per Site Handbook: >2000 m = lower temperate.
7	Is the Drought Factor Score ≥ 18	Prioritise drought-tolerant pioneers — Babiyo, Khus, Asuro, Jatropha.	Go to Step 8.	Drought Factor classes (Site Handbook): 18–23 warm-dry (IV), 24–30



Step	Question	If YES →	If NO →	Notes
	(Class IV or above)?	Avoid water-demanding trees; plant trees only after ~2 years.		very hot-dry (V), >30 severe (VI).
8	Is the failure deeper than the root-reinforcement range (> ~1 m)?	Hybrid / engineering solution — civil structure + brush layer + planting; consult engineer and route to the matching case matrix (Figure 7.2). A large area (>500 m ²) additionally needs extra resourcing and specialist input.	Go to Step 9.	Root reinforcement reaches only ~0.5–1 m, so depth governs the domain regardless of area. Consistent with the depth band: vegetation <1 m, hybrid 1–3 m, specialist >3 m.
9	Is planting material (slips / seedlings) available within ~5 km?	Proceed to bioengineering works; confirm the planting season (Step 10).	Establish a temporary nursery (Annex A7) or procure from the district nursery.	Never delay monsoon planting for distant material — use local stock.
10	Is it monsoon season (Ashadh–Bhadra)?	PLANT NOW — monsoon onset is the optimal window; begin works immediately.	Late pre-monsoon (Jestha, just before the rains): grass slips + hardwood cuttings. Early dry season (Chaitra): site preparation, drainage and nursery work only. Post-monsoon: gap-fill only.	Survival depends overwhelmingly on monsoon-season establishment (DoR planting calendar).

Chart 8.2 Slope Type × Problem × Solution Quick Reference

Match the site type and observed problem to the solution category. Refer to Chapters 4–7 for detailed design.

Slope Type / Location	Observed Problem	Recommended Solution Category
Road cut — soil slope	Surface rill erosion	Grass seeding + coir netting; apply first monsoon
Road cut — soil slope	Shallow translational slide (<1.5 m)	Brushlayer + grass lines + drainage
Road cut — soil slope	Deep rotational failure (>1.5 m)	Structural toe wall + brushlayer + tree planting
Road cut — soil slope	Seepage / wet slope	French drain FIRST + Khus lines + Utis planting
Rock cut — hard rock	Planar / wedge failure	Rock bolt + mesh; vegetation in rock pockets



Slope Type / Location	Observed Problem	Recommended Solution Category
Rock cut — weathered rock	Debris and rockfall	Rock netting / toe wall + shrub planting in pockets
Fill / embankment	Surface erosion	Khus / Bermuda grass coir netting + contour lines
Fill / embankment	Embankment slide (side slope)	Brushlayer + tree planting on lower benches
Riverbank / stream toe	Scour and undermining	Gabion/stone pitching (toe) + Bamboo/Kans plantation
Gully head	Active gully erosion	Live bamboo check dams + brushlayer + Utis seedlings
Natural hillslope above road	Creep / slow deformation	Drainage + deep-rooted trees (Sisso, Chilaune, Utis)
Combined / multiple failures	Complex hillslope failure	Geotechnical engineer; hybrid design; layered approach

Chart 8.3 Early Warning Signs and Required Actions

Inspect all slope sites immediately after any rainfall event exceeding 80 mm/day. Record observations on Annex 8 checklist.

Warning Sign Observed	Risk Level	Immediate Action
Cracks in road surface or shoulder	HIGH	Stop traffic; notify TID/DoLI; call engineer
Fresh soil or rock debris on road	HIGH	Clear debris; install erosion net; engineer review
Springs or seepage emerging on slope	HIGH	Install drain; halt bioengineering; engineer review
Tilted or leaning trees on slope	MODERATE	Check for slope creep; increase monitoring frequency
Vegetation die-back or browning (dry season)	MODERATE	Gap-fill planting at next monsoon; check drainage
Drain outlets blocked or overflowing	MODERATE	Clear immediately; risk of piping and slope saturation
Bioengineering survival < 40% after monsoon	MODERATE	Redesign species mix; review drainage; replant
Gabion or DSM wall cracking or bulging	HIGH	Structural engineer review; do not plant on wall face
Coir/jute netting detached or torn	LOW	Re-fix with bamboo pins within 2 weeks



Warning Sign Observed	Risk Level	Immediate Action
Gully head advancing upslope	HIGH	Live check dams urgently; call supervisor
River scour approaching road toe	CRITICAL	Structural protection ASAP; evacuate if needed
Heavy rainfall > 100 mm in 24 hours	HIGH	Post-event inspection of all monitored slopes within 48 hr

Chart 8.4 Bioengineering Strength Development Timeline

Use this to set realistic expectations for vegetation effectiveness and plan when civil structures can be scaled back.

Phase	Time After Planting	Vegetation Status	Slope Protection Level	Action Required
Phase 0	0–3 months	Bare / establishment	None — critical period	Coir netting + drainage ESSENTIAL; no planting alone
Phase 1	3–12 months	Pioneer grasses established	Surface erosion control (20–40%)	Maintain drainage; gap-fill; monitor survival
Phase 2	1–2 years	Grasses dense; shrubs emerging	Shallow reinforcement (40–60%)	Civil structures still providing primary support
Phase 3	2–4 years	Shrubs mature; trees establishing	Medium reinforcement (60–75%)	Civil structures become supplementary
Phase 4	4–7 years	Trees >3 m; full multi-storey cover	Deep reinforcement (75–90%)	Routine maintenance only; monitoring continues
Phase 5	7+ years	Mature woodland structure	Full reinforcement + ecosystem services	Annual inspection; note species succession

Civil engineering structures must maintain slope stability during Phases 0–2 (0–2 years). Never remove structural support before vegetation reaches Phase 3.

Source: Adapted from DoR (1999), DRSP records, and Mercy Corps Nepal slope disaster mitigation training materials.



ANNEX 9 CULVERTS: CALCULATIONS AND NOMOGRAPHS

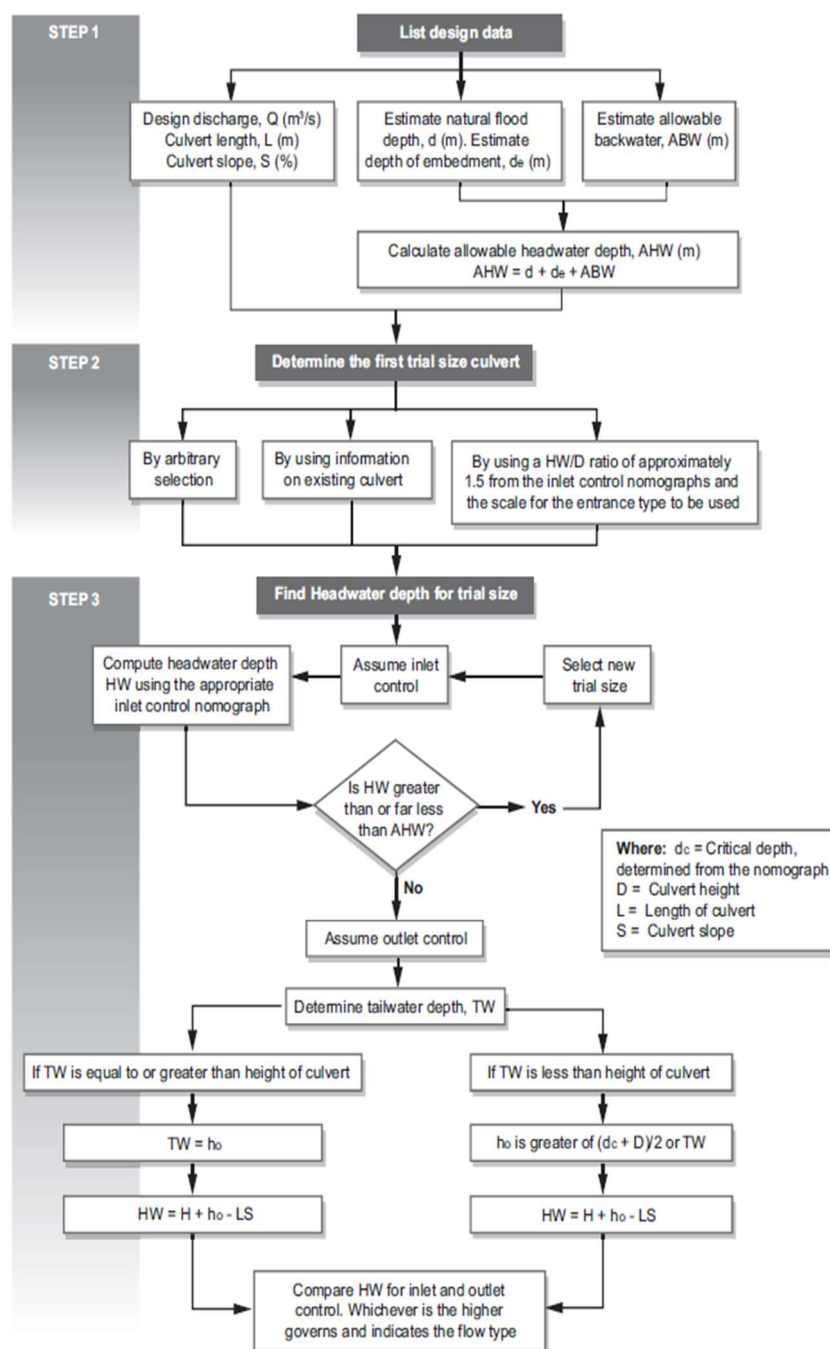


Figure A9.1: Flow chart for estimation of flow capacities of culverts

A simple and systematic procedure used for selection of a culvert size is the use of culvert nomographs.

The culvert opening is estimated using the nomographs for:

- concrete pipes, and
- concrete box culverts.



A simple flow chart for estimating the size of culverts and flow velocity is as shown in **Figure A9.1** and **Figure A9.2**. This approach uses a trial-and-error method as well as the nomographs for inlet control computations.

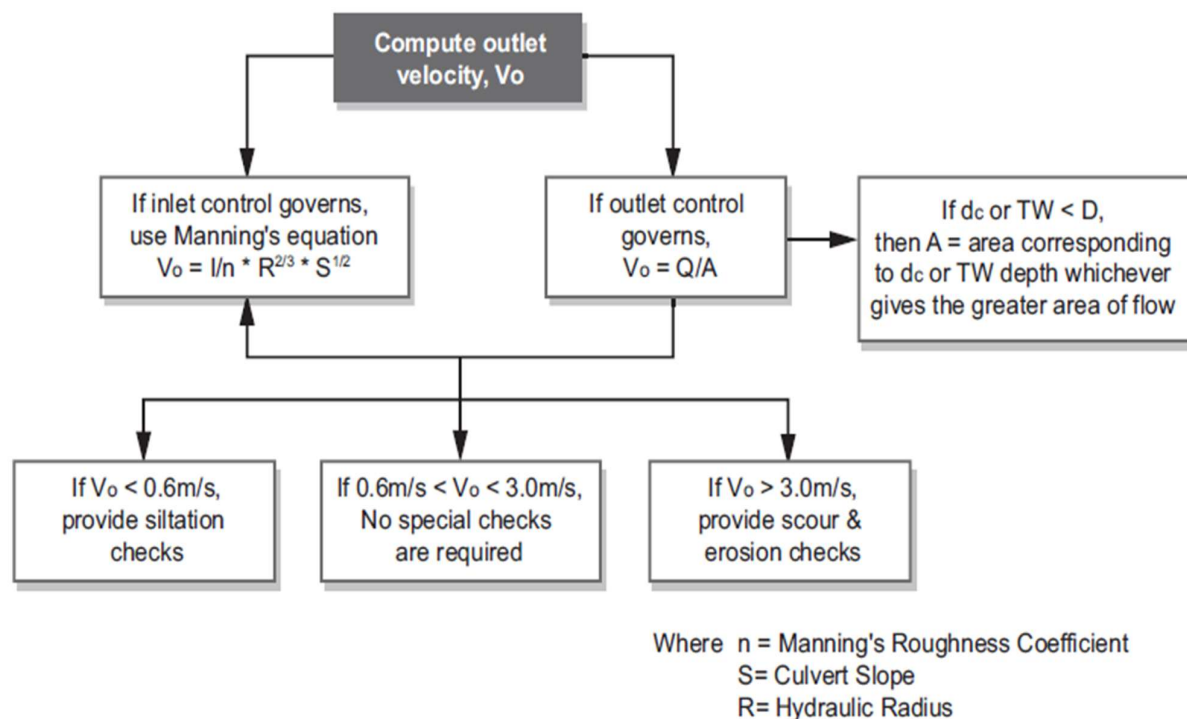


Figure A9.2: Flow chart for estimation of flow velocity

The calculation table for the steps in flow chart is shown in **Table A9-1** and **Table A9-2** below.

Table A9-1: Culvert Design Table-1

Station	DESIGN DATA							CULVERT DATA				
	Q m^3/s	d m	d _e m	AHW m	Skew No.	L m	S m/m	Description	D or B x D m	N	Q/N m^3/s	A m^2
1	2	3	4	5	6	7	8	9	10	11	12	13

Table A9- 2: Culvert Design Table-2

INLET CONTROL				CULVERT DATA								
Q/NB $m^3/s/m$	HW/D	HW m	K _e	H m	d _c m	(d _c + D)/2 m	TW m/m	h _o m	LS m	HW m	Governing HW m	Velocity V _o m/s
14	15	16	17	18	19	20	21	22	23	24	25	26



Design Data

Col. 1: Enter culvert station/location

Col. 2: Enter design discharge, Q (m^3/s)

Col. 3: Enter flood depth in natural channel, d , usually based on field observation

Col. 4: Enter depth of culvert invert below streambed, d_e

Col. 5: Allowable Headwater Depth (AHW) = Col. 3 + Col. 4 + Allowable Backwater Depth (ABW)

Col. 6: Skew Number

Col. 7: Culvert length, allowing for skew (if any)

Col. 8: Culvert slope

Culvert Data

Col. 9: Description of trial culvert

Col. 10: Enter trial size of culvert [diameter of pipe culvert (D) or $B \times D$ for rectangular culvert]

Col. 11: Number of barrels, N

Col. 12: Enter Col. 2 $\div$ Col. 11

Col. 13: Area, A per barrel

Inlet Control

Col. 14: Enter Q/NB for box culvert only

Col. 15: HW/ D from inlet control charts (**Figure A9-3** and **Figure A9-6**).

Col. 16: HW for inlet control = $D \times$ Column 15. If HW is greater or significantly less than AHW, try other size until HW is acceptable before going on to outlet control calculation.

Outlet Control

Col. 17: Entrance loss coefficient from **Table A9-3**.

Col. 18: Head, H obtained from **Figure A9-4** and **Figure A9-7**.

Col. 19: Critical depth d_c , from **Figure A9-5** and **Figure A9-8**.

Col. 20: Calculate and enter $(d_c + D)/2$.

Col. 21: Tailwater depth TW = Col. 3 + Col. 4.

Col. 22: h_o = the larger of $(d_c + D)/2$ and TW i.e. larger of Col. 20 and Col. 21.

Col. 23: LS = culvert length $\times$ culvert slope i.e. Col. 7 $\times$ Col. 8.

Col. 24: Headwater depth, HW = Col. 18 + Col. 22 – Col. 23. If HW is negative, enter zero.

Controlling HW

Col. 25: Enter governing HW i.e. larger of Col. 16 and Col. 24.

If outlet control governs and $HW > AHW$, repeat from Col. 10 with larger sizes until HW is equal to or slightly less than AHW.



If HW is equal to or slightly less than AHW, size is acceptable. Go to next step.

Outlet Velocity

Col. 26: If downstream conditions are such that the culvert outflow may cause a significant erosion or sedimentation problem, calculate V_o for inlet or outlet control, whichever is governing, and enter in Col. 26.

Special erosion control measures

Special erosion control measures are necessary when field investigations show that a channel is degrading. These measures are also required if the culvert outflow velocity poses a significant risk of environmental damage, erosion, or sedimentation.

Figure A9-3 is used to determine headwater depth (HW) of a pipe culvert. The steps are as follows:

- Determine the pipe diameter (D) and design discharge (Q) on the scales.
- Join the values of D and Q with a straight line. Extend the line to meet scale (1).
- From the point on scale (1) draw a horizontal line to meet scale (2) and scale (3).
- Depending on the entrance type as described on the chart, the value of H_e/D is equal to the value on either scale (1) or scale (2) or scale (3).
- H_e which is the headwater depth (HW) is equal to D, multiplied by the value on the scale line.

Figure A9-4 is used to determine head (H) of pipe culverts flowing full. The steps are as follows:

- Determine the length (L) of culvert on the scale depending on the entrance loss K_e and diameter (D) of the pipe culvert.
- Join the two points with a straight line to cross the turning line.
- Determine the design discharge (Q) on the scale at the extreme left. Join the discharge and the point of crossing on the turning line with a straight line. Extend the line to meet the head scale on the extreme right.
- Determine the value on the head scale which is equal to the head (H) of pipe culverts flowing full.

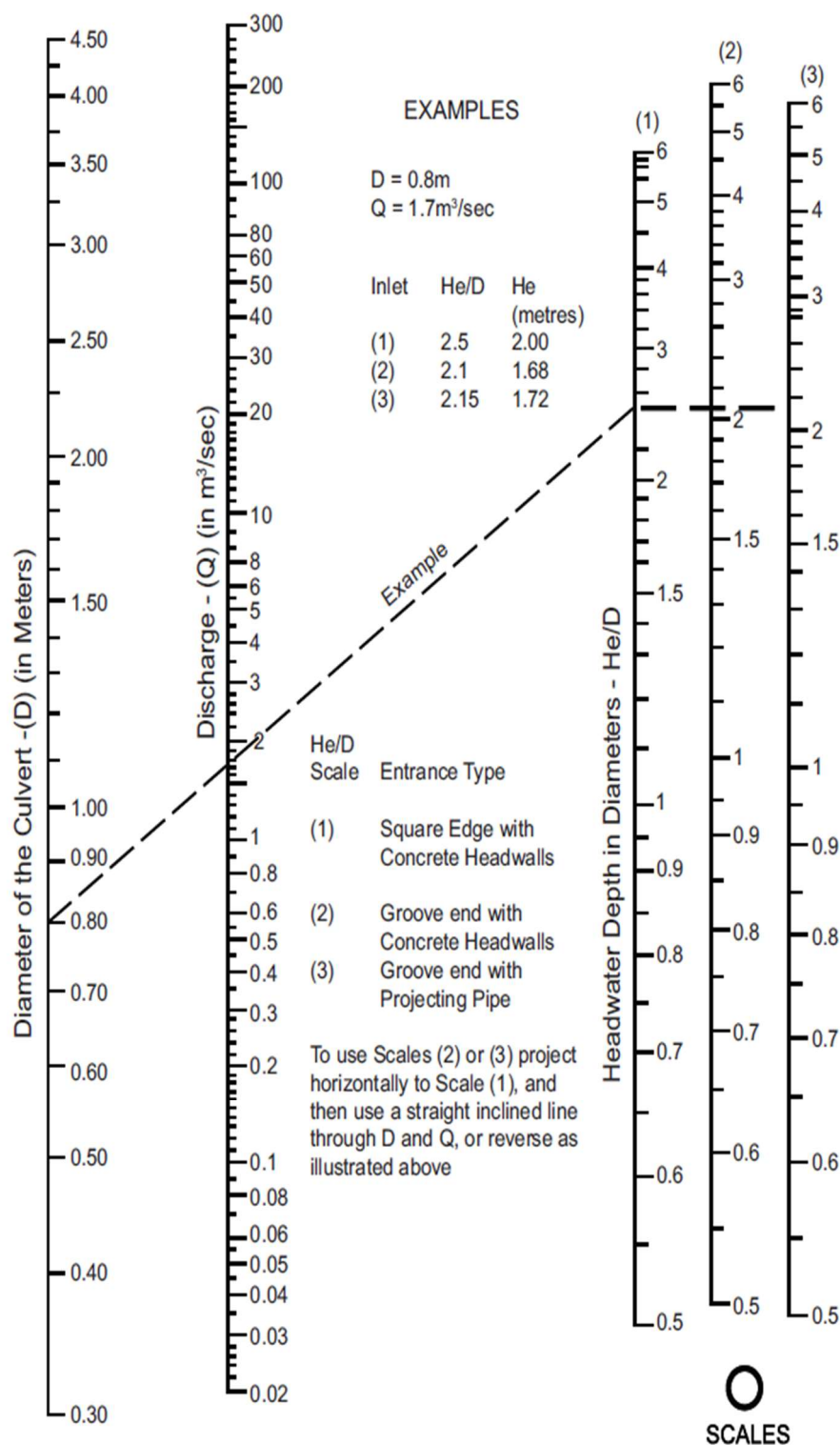


Figure A9-3: Headwater depth and capacity for concrete pipe culverts with inlet control

(Adopted from Chart 1A, FHWA, 2012)

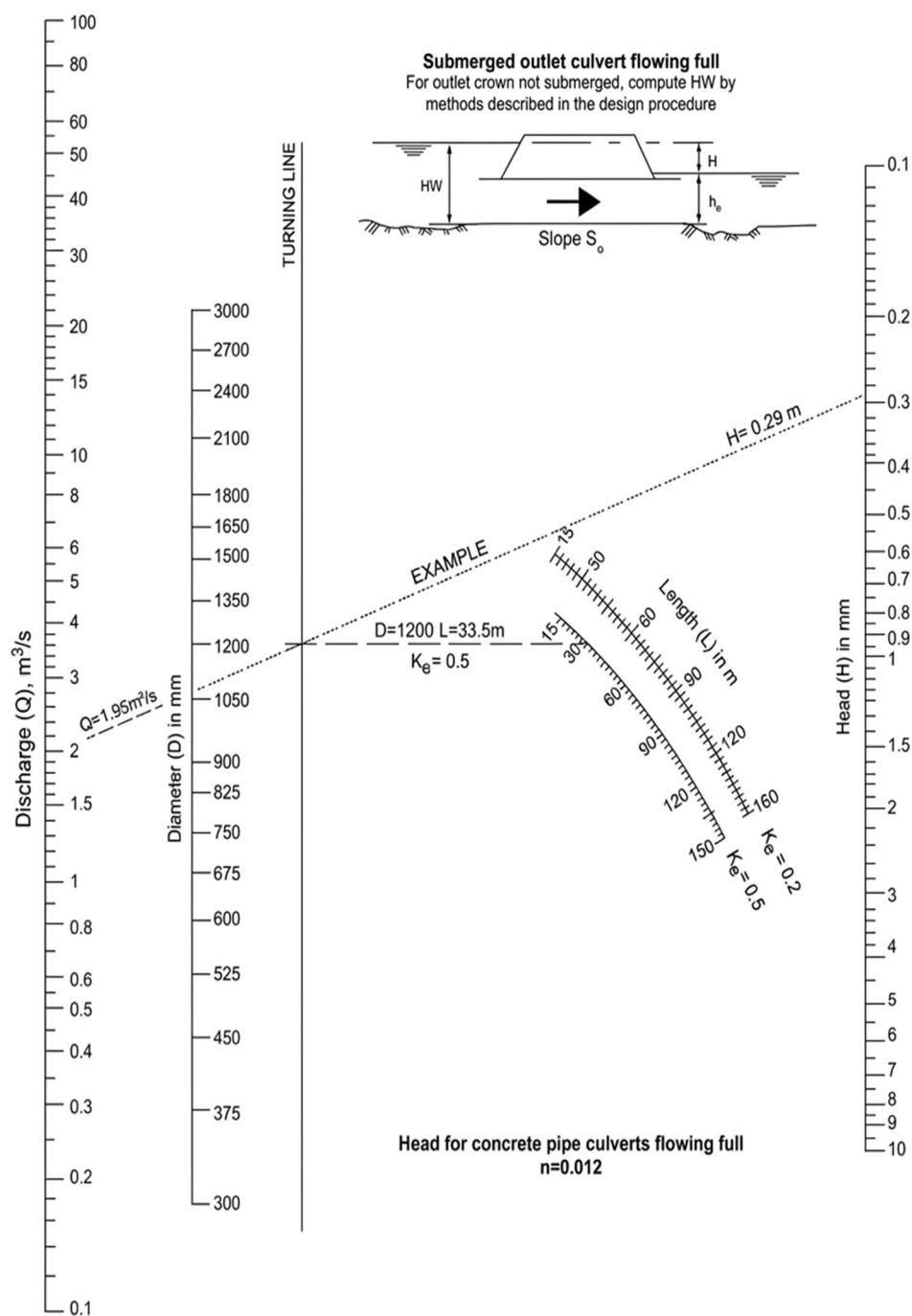


Figure A9-4: Head for concrete pipe flowing full, $n = 0.012$

(Adapted from Chart 5A, FHWA, 2012)

Figure A9-5 is used to determine critical depth (d_c) for pipe culverts. The steps are as follows:

- Determine the design discharge (Q) and size of pipe culvert.
- Draw a vertical line from the discharge value on the horizontal axis to intersect the value of the pipe size.
- From the intersection point, draw a horizontal line to meet the vertical axis.
- The value on the vertical axis is the critical depth (d_c) for the pipe culvert.

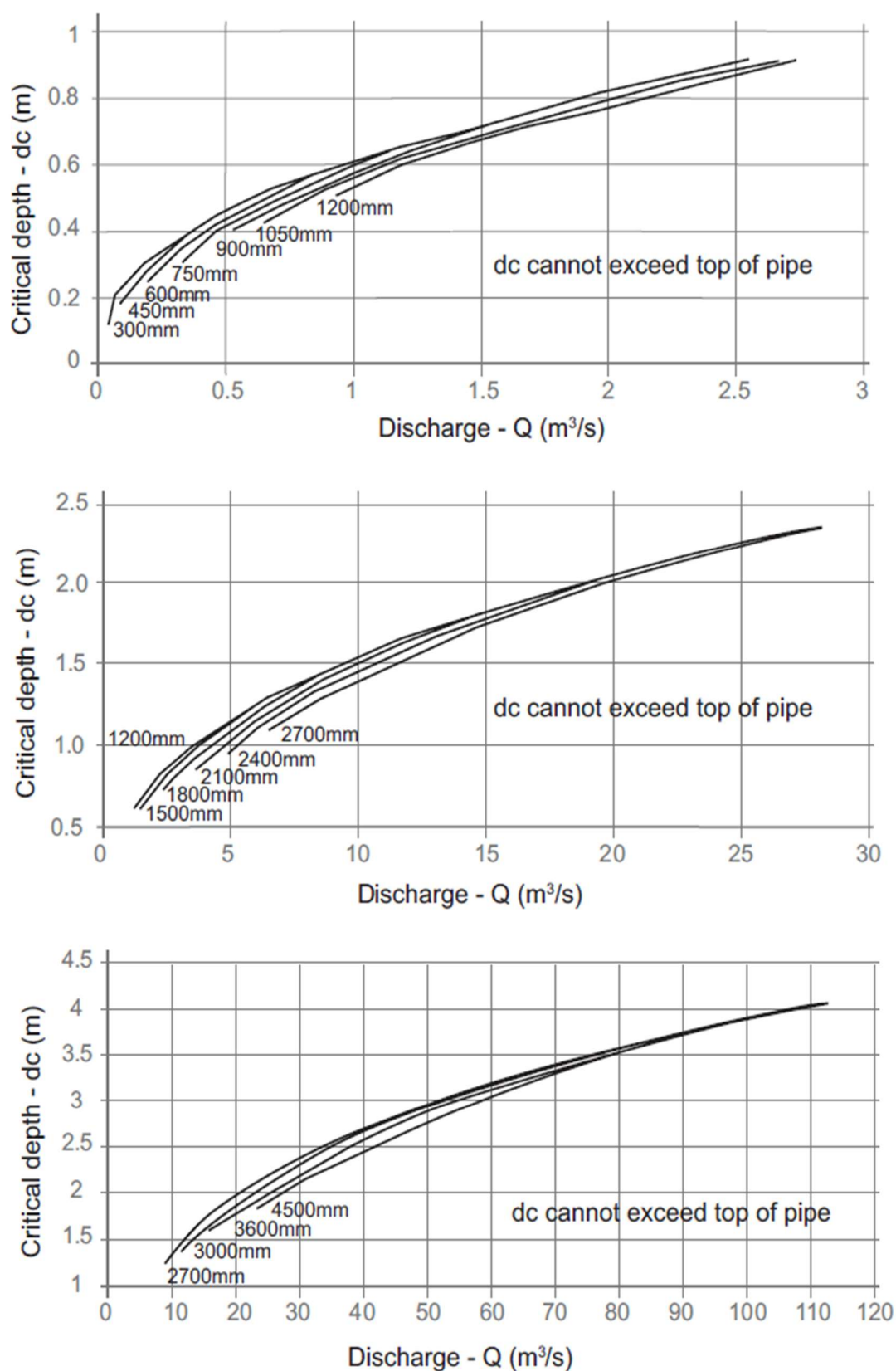


Figure A9-5: Critical Depth (d_c) for circular pipes

(Adapted from Chart 4A, FHWA, 2012)



Figure A9-6 is used to determine headwater depth (HW) of box culverts. The steps are as follows:

- Determine the height of box (D) and ratio of design discharge (Q) to width (B) of box i.e. Q/B .
- Join the values of D and Q/B with a straight line. Extend the line to meet scale (1).
- From the point on scale (1) draw a horizontal line to meet scale (2) and scale (3). Depending on the wingwall type as described on the chart.
- The value of H_e/D is equal to the value on either scale (1) or scale (2) or scale (3).
- H_e which is the headwater depth (HW) is equal to D multiplied by the value on the scale line.

Figure A9-7 is used to determine head (H) of box culverts flowing full. The steps are as follows:

- Determine the length (L) of culvert on the scale depending on the entrance loss K_e
- Determine cross-sectional area or dimensions of the box culvert.
- Join the two points with a straight line to cross the turning line.
- Determine the design discharge (Q).
- Join the discharge point on the scale (extreme left) and the point of crossing on the turning line with a straight line.
- Extend the line to meet the head scale on the extreme right and determine the value which is equal to the head (H) of pipe culverts flowing full.

Figure A9-8 is used to determine critical depth (d_c) for box culverts. The steps are as follows:

- Determine the ratio of design discharge (Q) to width of box culvert (B) i.e. Q/B .
- Draw a vertical line from the value of Q/B on the horizontal axis to meet the graph.
- From the intersection point, draw, a horizontal line to meet the vertical axis.
- The value on the vertical axis is the critical depth (d_c) for the box culvert.

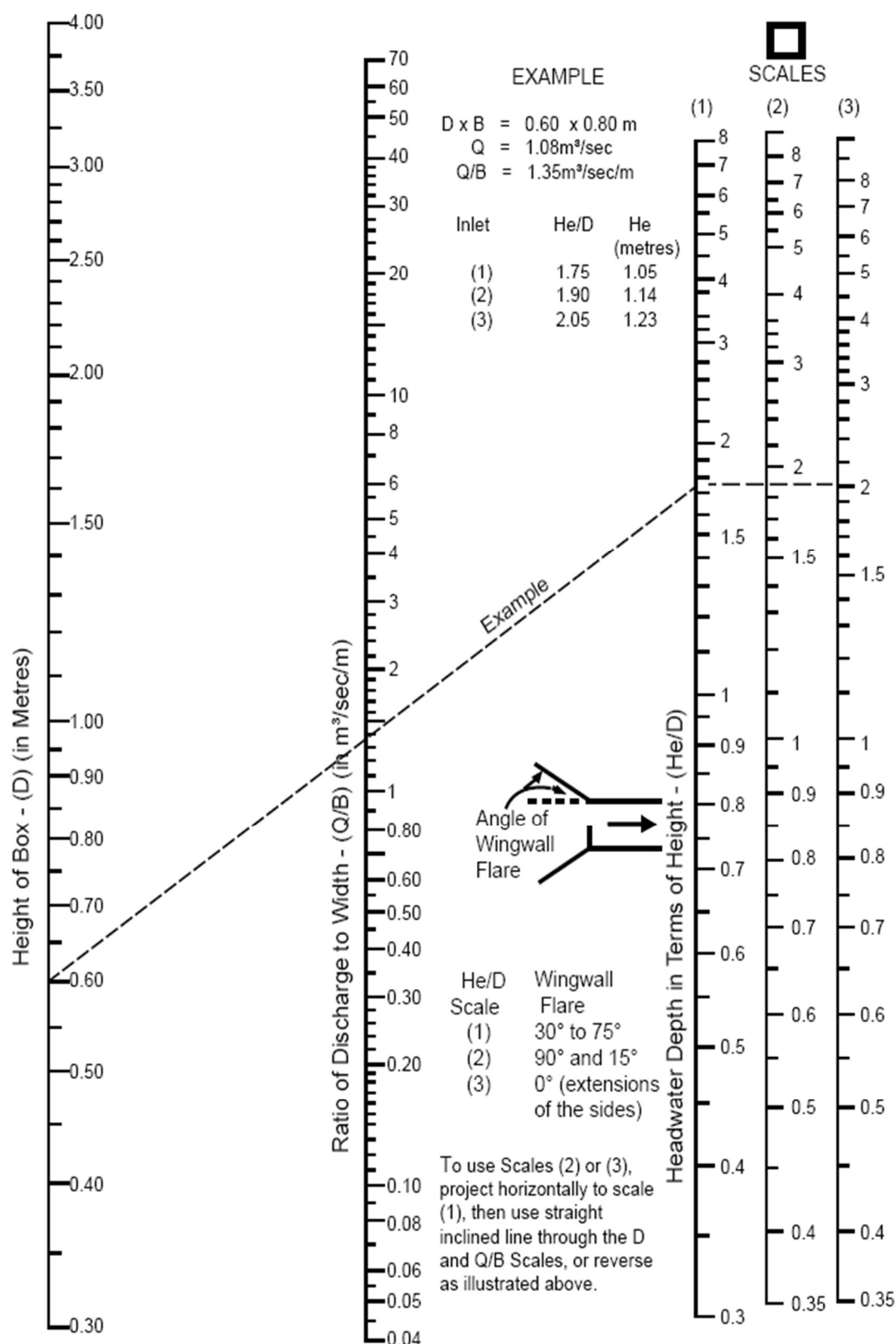


Figure A9-6: Headwater depth and capacity for concrete box culverts with inlet control

(Adapted from Chart 8A, FHWA, 2012)

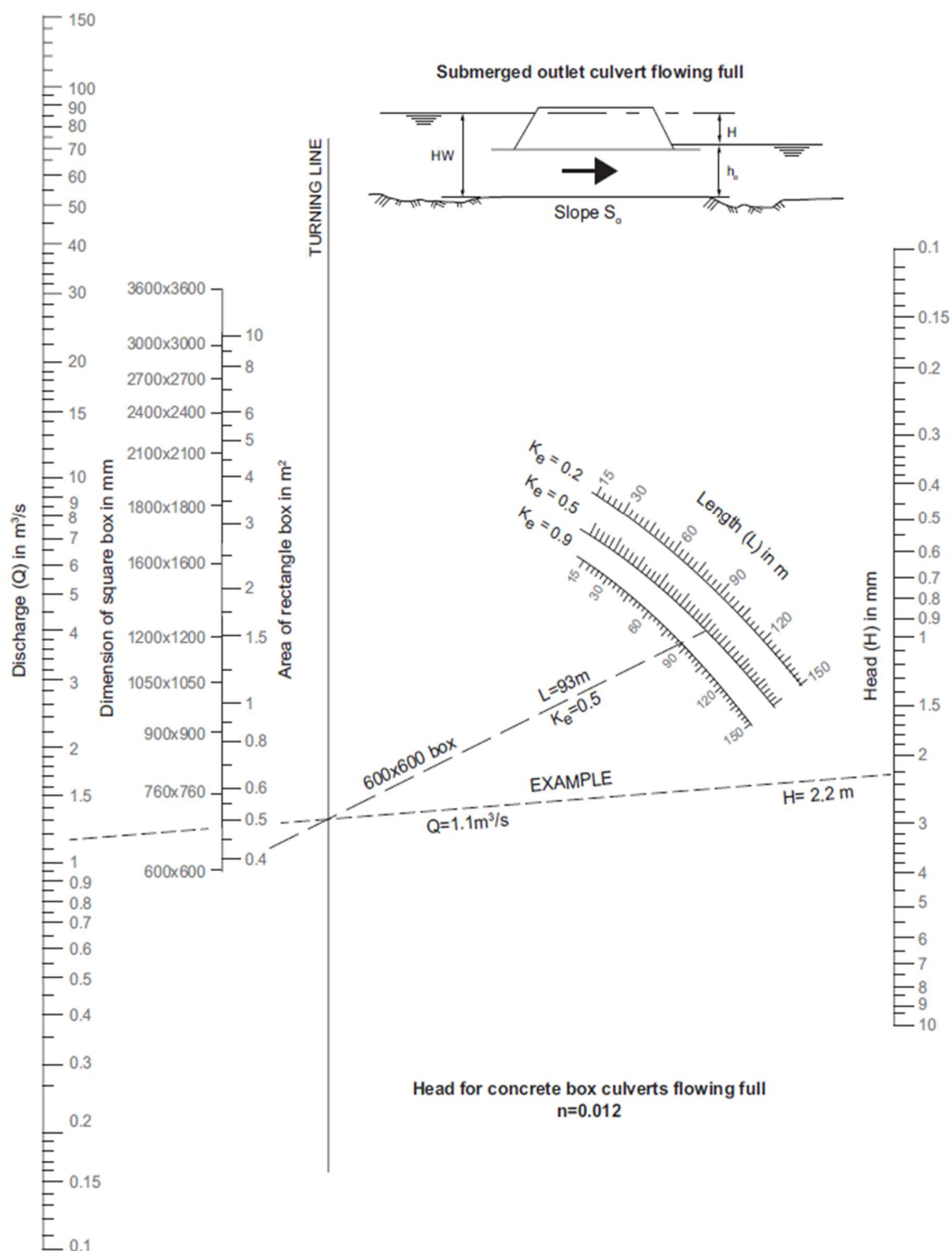


Figure A9-7: Head for box culvert flowing full, $n = 0.012$

(Adapted from Chart 15A, FHWA, 2012)

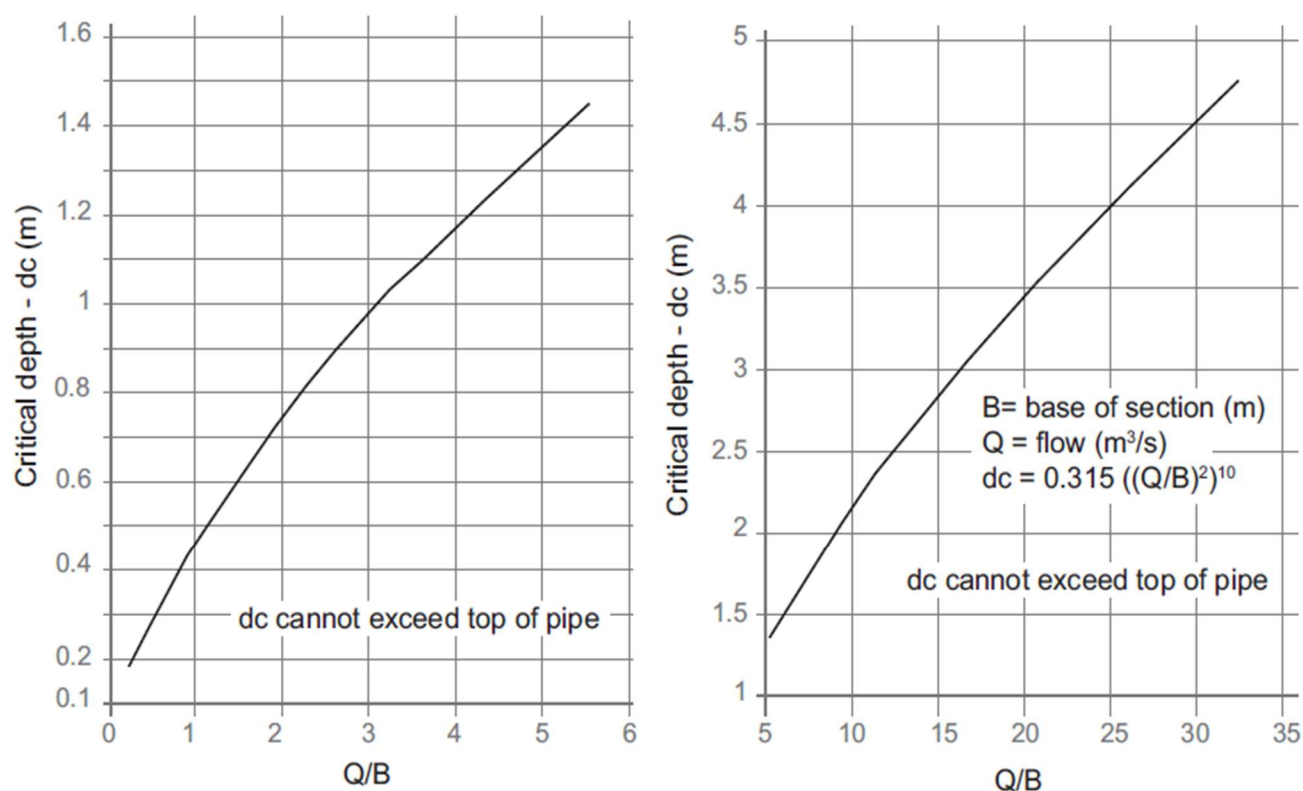


Figure A9-8: Critical Depth (d_c) for rectangular section

(Adapted from Chart 14A, FHWA, 2012)

Table **A9-3** provides the value of coefficient (K_e) to apply to the velocity head for determining head loss at the entrance to a culvert operating under outlet control.

The entrance head loss (h_e) is given by

$$h_e = K_e * \frac{V^2}{2g}$$

Table A9-3: Entrance loss coefficients

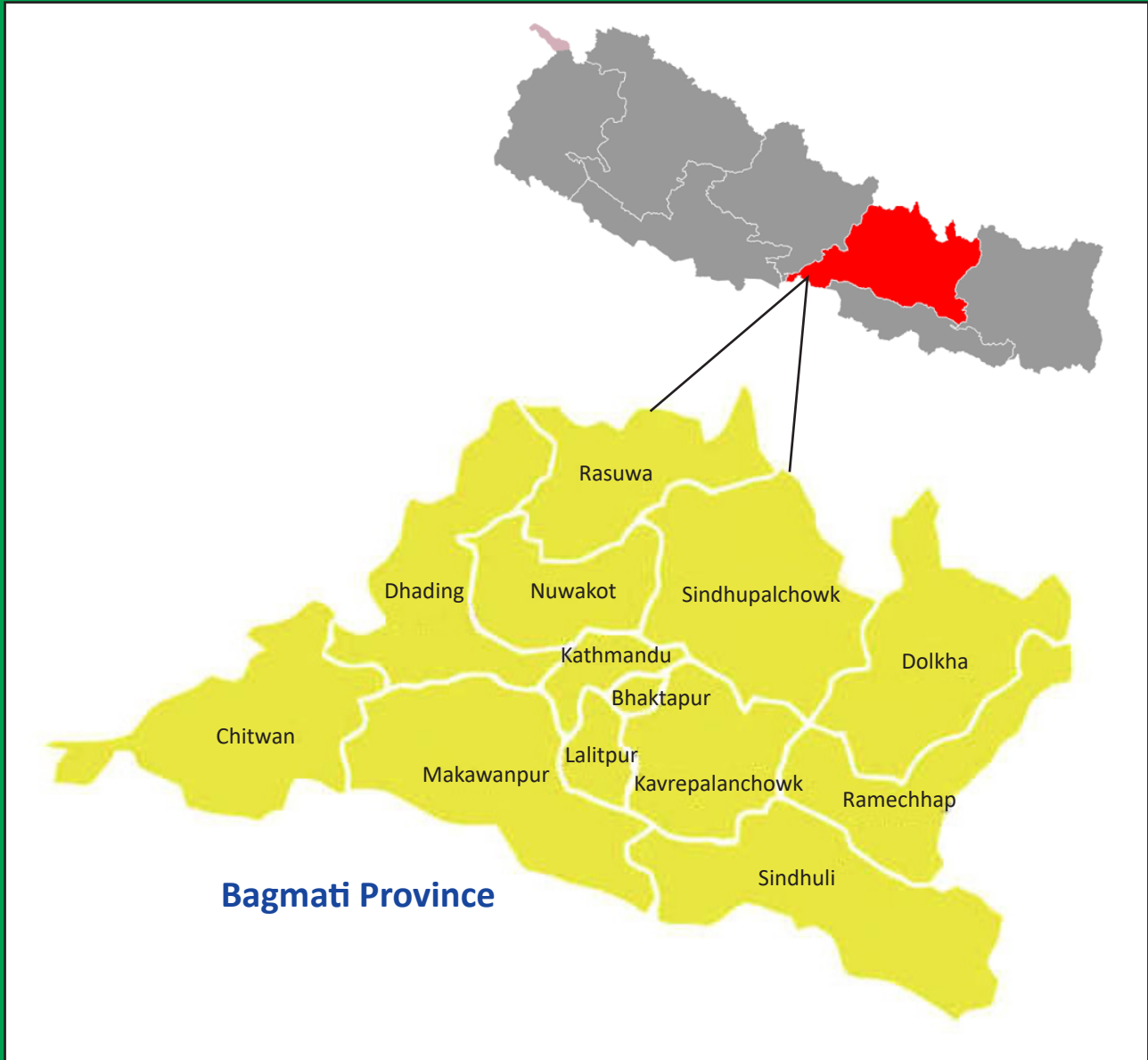
Type of Barrel and Inlet	K_e
Pipe (Concrete)	
Projecting from fill, socket end	0.2
Projecting from fill, square cut end	0.5
Headwall and Wingwall	
Socket end of pipe	0.2



Square edge	0.5
Rounded (radius = 1/12 D)	0.2
Mitred to conform to fill slope	0.7
End-Section conforming to fill slope (standard pre-cast)	0.5
Bevelled edges, 33.7° or 45° bevels	0.2
Side-tapered or slope-tapered inlets	0.2
Box, Reinforced Concrete	
Headwall	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrel dimension, or bevelled edges on 3 sides	0.2
Wingwalls at 30° to 75° to barrel	
Square-edges crown	0.4
Crown edge rounded to radius of 1/12 barrel dimension, or bevelled top edge	0.2
Wingwalls at 10° to 25° to barrel	
Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side-tapered or slope-tapered inlet	0.2
Projecting	
Square-edged	0.7*
Bevelled edges, 33.7° or 45° bevels	0.2*

*Estimated

(Source: Refer to Greenville County, South Carolina: Storm Water Management Design Manual, January 2013)



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