Government of Nepal
Ministry of Physical Planning and Works
Department of Roads

Road Maintenance and Development Project

Institutional Strengthening Component

IDA Credit No. 3293-NEP

ROADSIDE GEOTECHNICAL PROBLEMS: A PRACTICAL GUIDE TO THEIR SOLUTION

Kathmandu,
June 2007

DHV Consultants B. V.
in association with
CMS Nepal (P) Ltd. and ITECO Nepal (P) Ltd.

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Foreword

The present document “Roadside Geotechncial Problems: A Practical Guide to their Solution” is the outcome of the Institutional Strengthening Component of the Road Maintenance and Development Project for strengthening of the Geo-Environmental and Social Unit (GESU). As the document is prepared through intensive efforts by geo-technical specialists from the DHV-CMS-ITECO consortium and DoR’s Committee Members devoted to GESU strengthening, I believe that the document will fulfill the long-felt need for a comprehensive geotechncial guide for the use by DoR Divisions and the GESU itself.

The existing geotechnical practice in Nepal was often dependent on the choice of the specialists from different countries who used the codes, standards and guidelines of their preference. This situation reflects non-uniformity of the geotechnical practices within the Department of Roads. The present guide which is the result of intensive reviews and familiarization with the needs at the DoR's divisional level will bring uniformity in the assessment, investigation, design and implementation of geotechnical solutions in Nepal. In addition two comprehensive software packages, SLIDE for soil slop stability analysis and SWEDGE for rock slope stability have been purchased by the DoR to support the application of these guidelines.

I take this opportunity to thank the Consultants and Committee Members for their sincere efforts in creating this guide and I advise the engineers at the Divisions to apply these guidelines consistently in their works.

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Tulsi Prasad Sitaula
Director General
Department of Roads

Kathmandu, June 2007

Acknowledgements

The strengthening of Geo-environmental and Social Unit (GESU) within the Department of Roads was among the tasks to be performed in the framework of Institutional Strengthening Component (ISC) under Road Maintenance and Development Project. DoR had entrusted DHV Consultants in association with Consolidated Management Services (CMS) and ITECO Nepal to undertake the assignment.

The task of preparation of the present guide was undertaken in close consultation with the DoR's Committee designated for the purpose under the direct coordination of the Chief of Geo-environmental Unit. About 2 person months of International Geotechnical Consultant and about 5 person months of Domestic Geotechnical Consultant were involved in the assignment under the ISC Consultant's team.

During the assignment, the specialist team had also carried out field visits to a sample of DoR Divisions to familiarize with the requirement and expectations at the Division level. The outcomes from each stage of work were presented to the designated Committee on periodic basis. After submission of the draft guide, it was presented to wider DoR audience in a workshop and comments and suggestions were obtained from the Committee Members which were highly useful in finalizing this guide. Apart from this, two comprehensive standard software: SLIDE for soil slope stability analysis and SWEDGE for rock slope stability were recommended for purchase for the future use of GESU.

We wish to acknowledge the DoR Committee Members, Division level engineers and in particular, Chiefs of the Geo-environmental Unit whose cooperation was invaluable in producing the guide in the present form.

Wishing for successful implementation of the guide and software, we remain.

John de Bresser
Team Leader
Institutional Strengthening Component, RMDP

Kathmandu, June 2007

Roadside Geotechnical Problems:
A Practical Guide to their Solution

Part I: Main Text

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Annexes:

Road-side Geotechnical Problems: A Practical Guide to their Solution

1 Objectives and Overall Approach

1.1 Objectives

The principal objective of this practical guide is to provide engineers at DoR's Division Road Offices and road practitioners with practical guidance on how to deal with geotechnical problems that affect roads under their jurisdictions. This guide addresses the need to involve at an early stage, when required, Department of Road (DOR) officials and engineers and in particular those from the Geo-environmental and Social Unit (GESU).

A large volume of literature currently exists in Nepal on geotechnical problems, principally slope-related, in the form of scientific papers, technical reports and guidelines as indicated in **Table 1**. There is also a significant body of professional engineers, engineering geologists and geologists within Nepal with experience in working with road-related slope stability or landslide issues.

Table 1 Principal Existing Geotechnical Guidance Documents

Document	**Summary**
Landslide Risk Assessment in the Rural Access Sector – Scott Wilson; 2004	Summarises procedures on the assessment of landslide risk, with an emphasis on the remote sensing and mapping of geomorphological and geological issues. Targeted principally at general planning and route alignment for engineering geologist and rural road engineers.
Guide to Road Slope Protection Works – GESU/DOR; 2003	Provides guidance and proposals for the general ongoing management of roadside slopes both at DoR's Division Road Offices (DRO) and GESU level. Does not specifically target road side problems and their solution.
Overseas Road Note 16 – TRL; 1997	Summarises the general geological and geotechnical background related to construction of road in mountainous regions. It provides useful guidelines on possible engineering options for design and protection of slopes. It is insufficiently focussed on problem solution to be of practical use by the engineers at DRO level.
Mountain Risk Engineering Handbook – ICIMOD; 1991	The comprehensive document (in 2 volumes) provides extensive information on all aspects of road engineering in mountainous terrain. However, because of its very size and breadth of detail it is difficult to use as a working guide by the engineers at DRO level.

Between them these manuals or guides contain comprehensive advice on geotechnical engineering in Nepal. However, in the context of the practical approach to problem solution, they have drawbacks in that they cover a very wide range of scenarios such as general landslide hazard, route selection, roadside monitoring, roadside asset management and slope maintenance. None of them deals directly and exclusively with appropriate actions following the occurrence of specific road-side problems, particularly at DRO level.

In contrast, the Bio-engineering handbooks that have been adopted by the GESU/DoR have proved to be very effective in providing practical guidance to engineers at DRO level and GESU. These documents do however concentrate on bioengineering solutions only to treat roadside slope stability problems. One of the objectives of this geotechnical guide is to complement these successful handbooks by strengthening links between engineering and bioengineering solutions and emphasise the decision making processes required to identify the most appropriate and sustainable solutions

This document aims to provide concise guidance on what action to take following a roadside problem event, in particular on

- Problem definition
- Appropriate information collection
- Decisions and actions required in the light of the recovered information
- Summary information on appropriate procedures
- Where to access more detailed guidance
- Selection of standard geotechnical engineering options

This guide is not intended to increase the already large and diverse body of technical knowledge; it is intended rather as a series of signposts to enable practising engineers to access information appropriate to their requirements. It does this within an overall framework intended to guide engineers through a series of stages and procedures towards effective and appropriate decisions related to the geotechnical problems that they face.

1.2 Overall Approach

The overall approach of this guide is to provide road engineers, particularly at DRO level, with a decision making framework within which they can work and select appropriate procedures, make knowledge-based decisions and eventually identify one or more options either to solve the problem or to define further actions required.

As this guide is aimed primarily at DRO level actions, it is appropriate to recognise that some geotechnical problems cannot be effectively dealt with at this level without additional support, either budgetary or technical, from the GESU or DoR. This additional support option is therefore contained within the decision framework. It should be emphasised that an organised logical manner for reaching decisions could be a significant factor in aiding appropriate DoR decisions on support. **Figure 1** outlines the key elements of the overall approach.

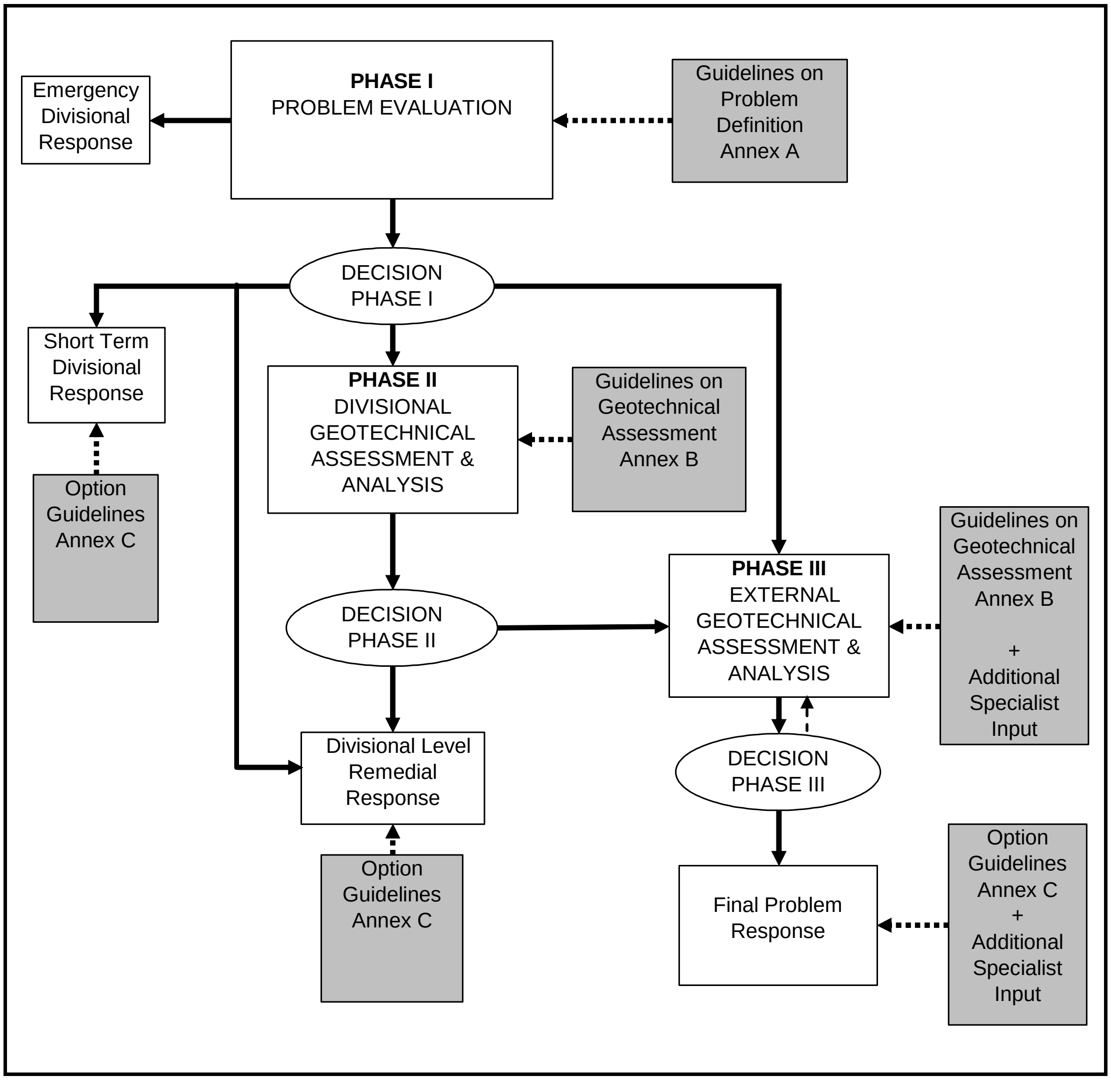
The framework is based around three fundamental actions that are required to be taken by engineers in dealing with roadside problems. These are;

1. Defining the problem,
2. Assessing and analysing the problem, and
3. Identifying available engineering solutions or options.

Each of these steps may, depending on the nature of the problem faced, require a number of actions which must be satisfactorily completed before any subsequent activity can be implemented.

Procedures relating to each these steps are discussed in the following sections with the related procedural detail contained in the associated Annexes.

Figure 1 Overall Approach Framework



The role of GESU in the overall approach framework will be:

- Phase I – providing initial orientation to the DRO level engineers,
- Phase II – overseeing of the DRO level geotechnical assessments and analyses, as required by the DROs, and
- Phase III – managing geotechnical assessments, analyses and designs using either internal GESU resources or external consultants and providing monitoring and quality assurance support to the DROs during the implementation of geotechnical solutions.

2 Phase I Activities and Outcomes

2.1 Objectives

The main objectives of Phase I are as follows:

1. Identify the nature of the problem,
2. Identify immediate response requirements,
3. Make preliminary assessments of hazard and risk,
4. Decide if any short term remedial measures can be initiated,
5. Decide if additional work is required, and
6. Define the nature of any additional work.

The principal activities comprise two levels field information collection together with their corresponding decisions. These are:

1. Initial problem identification
2. Problem definition

2.2 Initial Problem Identification

A problem identification data sheet (A1) has been provided in Annex A to allow definition of the nature of any roadside problem, not only to initiate appropriate assessment and to conceive remedial measures, but to also to identify any immediate road-opening or temporary stabilisation measures that are appropriate and which will prevent the problem from worsening further. This sheet has been designed for use by DRO overseers. Site photographs and sketches are important aspects of this initial data gathering process.

Key decisions are taken based on this initial inspection and a decision pro-forma (Sheet A1.2) should be used to guide and document these decisions. This decision making process should be signed by the responsible DRO level engineer.

2.3 Problem Definition

One crucial outcome from the initial site definition concerns what, if any, additional information is immediately required from the site. Under such condition, next level of inspection should be undertaken by the appropriate DRO level engineer.

The nature of this information will be a function of problem type and hence a number of problem definition sheets have been provided in Annex A. These are as described in **Table 2**.

Table 2 Problem Definition Sheets

Sheet	Title	Application
A2	Slope Instability	Evaluation of roadside problems primarily caused by natural or man-made slope instability.
A3	Erosion Damage	Evaluation of roadside problems primarily related to erosion damage to natural slopes or earthworks.

A4	Pavement Damage	Evaluation of damage to the road carriageway and shoulders.
A5	Structure Problem	Evaluation of roadside problems primarily related to the failure or potential failure of slope stabilisation measures

In some instances it may be necessary to record data from more than one sheet. It is essential that the information on these sheets is as accurate as possible. In particular the following should be noted:

1. The Engineer should thoroughly walkover the site. In the case of a landslide for example it is essential to examine, where safety permits, the condition of the natural ground above or below the immediate failure for signs of further potential movement.
2. Field enquiries should be made on any local knowledge regarding the problem, including for example changes in cultivation or vegetation.
3. Measurements and sketches should be as accurate as practicable. The data may be required as input to geotechnical analyses. Available equipment such as clinometers, ranging poles, compasses, handheld GPS and measuring tapes should be used where feasible.
4. Photographs should be relevant and should be used as backup to the sheets to illustrate significant features. They should include where possible either a scale for close-up views or a figure or vehicle in wider views.

2.4 Assessment and Decisions

As a result of the initial problem identification enough information should have been gathered to enable key initial decisions to be made regarding the following:

1. The significance of the problem
2. Immediate road clearing actions
3. Immediate problem control actions
4. Immediate risk-to-life minimization actions
5. The need for further problem specific information

Initial decisions should be made with the assistance of the problem definition decision sheet A1. This sheet provides guidance on decisions and indicates appropriate actions and options to be adopted based on the ticking of appropriate boxes.

Decisions at a second level within Phase I are based on information obtained from problem assessment sheets A2 to A5. Each of these sheets has accompanying decision and action sheets which should be used to reach key decisions and to recommend appropriate actions.

Enough information should be gathered and assessed during Phase I to enable essential actions or decisions to be taken on the following:

1. Immediate road clearance and remedial works,
2. Short to medium term remedial solutions within the DRO’s capacity,
3. Decision on whether Phase II investigations are required at DRO level,
4. Appropriate cost estimates or budget requirements for works outside the ARMP, and

5. Decision on whether Phase III investigation and design programme is urgently required to be managed either at DRO level or through the GESU.

3 Phase II Activities and Outcomes

3.1 Activities and Objectives

Phase II is concerned largely with undertaking standard field, laboratory and analytical investigations aimed at identifying and designing remedial measures to be implemented at DRO level. If investigation and analysis indicates that the identified problem, or zones within the problem, require specialist input then this requirement should be defined.

The clear objectives of this phase are therefore:

1. To undertake investigations recommended in Phase I,
2. To identify and design of remedial or control measures appropriate to the identified problem, and
3. If necessary, to define and cost any further investigations that may require specialist input outside the existing capability of the DRO.

3.2 Investigation Planning

The fundamental objective of a site investigation is to obtain data for the design and construction of the remedial works. The specific objectives of a site investigation can vary depending on the size and nature of the roadside problem and the complexity of the ground conditions. A logical and structured approach to the site investigation is therefore essential to obtain appropriate information for the design of remedial or control works.

The investigation needs to be planned to meet the following general criteria:

1. Data to be sufficient for an economic and appropriate design to the level of engineering details required,
2. Data to be consistent with the analytical methods available and proposed to be used, and
3. Data collection to be relevant to the types of soil or rock found on the site.

Many investigations are undertaken without due consideration to their planning and suffer from recovering irrelevant data and wasting resources. Every investigation should be planned to comply with the following basic steps.

1. Review of available information including the geotechnical/geological site model,
2. Identification of required geotechnical information,
3. Identification of budget and time constraints,
4. Selection of the most appropriate procedures based on 1-3 above, and
5. Programme the procedures to allow a logical feedback of data into the investigation.

3.3 Investigation Procedures

Available standard investigation procedures are summarised in Annex B under the following general groups:

1. Existing Data Compilation,
2. Risk Assessment,
3. Site Surface Data Collection,
4. Site Sub-surface Data Collection,
5. Laboratory Testing,
6. Soil and Rock Characterisation,
7. Slope Stability Analysis,
8. Slope analysis Software Selection,
9. Construction Material Study, and
10. Route Alignment Selection.

Their likely application within the framework of roadside problem solution is shown in **Table 3**.

Existing Data Compilation

Frequently termed as "Desk Study", this activity should form the basis for any problem investigation. In some cases, this activity may be limited to identifying any existing files or notes on the problem area, including reviewing information gathered under Phase I. For larger problems, the collection and review of existing data, is an essential pre-requisite for the cost-effectiveness of any subsequent investigations. Annex B1 summarises key aspects of existing data gathering. Included under this general heading is guidance on remote sensing and air photo interpretation procedures. It is unlikely that Phase II works under the direct control of DRO budgets will utilise remote sensing and air photo interpretation techniques other than examination of the air photographs.

Table 3 Application of Annex B Procedures

Code	Procedures	Activities	Phase I	Phase II	Phase III
B1	Desk Study	Document Review	●	●	●
		Remote Sensing			●
		Air Photo Interpretation			●
B2	Hazard & Risk	Initial Risk Assessment	●	●	
		Detailed Risk Assessment			●
B3	Surface Data Collection	Geotechnical Mapping		●	●
		Soil & Rock Description	●	●	●
		Soil / Rock Mass Assessment			●
		Discontinuity Data Collection			●
B4	Subsurface Data Collection	Pitting and Trenching		●	●
		Core Drilling			●

		Geophysics			●
		In-situ Testing	●	●	●
B5	Laboratory Testing	Laboratory Test Management		●	●
		Soil Testing		●	●
		Rock Testing		●	●
B6	Soil & Rock Characterization	Soil & Rock Material Parameters		●	●
		Soil & Rock Mass Parameters		●	●
		Appropriate Parameter Selection		●	●
B7	Slope Stability Analysis	Analysis Selection		●	●
		Factors of Safety		●	●
		Standard Charts		●	●
		Detailed Stability Analysis			●
B8	Slope Stability Software Selection	Soil Stability Software			●
		Rock Stability Software			●
B9	Material Study	Construction Materials		●	●
B10	Alignment Study	Route Alignment Selection			●

Risk Assessment

Some form of risk assessment is an essential element of any roadside problem evaluation and the following are relevant definitions:

> **Susceptibility** – those areas most likely to be the locations of existing and future geotechnical failures. Susceptibility is usually expressed in relative terms (high, medium or low) and therefore can have no absolute value.
>
> **Hazard** – the likelihood of any given area being affected by a problem over a given period of time. Slope instability hazard is dependent on problem location, size and travel distance and frequency or probability of occurrence. Hazard therefore describes the potential to cause damage.
>
> **Consequence** – the extent of damage likely to be suffered by infrastructure, land use and people as a result of a geotechnical failure.
>
> **Risk** – the total potential loss resulting from a geotechnical failure or event and is commonly assessed as being a product of a hazard and its consequence.

There is a significant body of literature concerned with the assessment of hazard and risk in geotechnical engineering, much of it beyond standard DRO requirements, for assessing roadside geotechnical problems. A simple matrix approach, based on that included in the Guide to Road Slope Protection Works (GESU/DoR, 2003) is recommended in Annex B2.1 for Phase I activities. A similar matrix approach may be similarly used in Phase II, although the more detailed information will enable greater definition of the hazard and consequence criteria.

Other more detailed approaches may be required for large scale problems and route realignments, such as Landslide Risk Assessment methods presented in Scott Wilson (2004), more appropriately dealt with under Phase III programmes. Annex B2.2 summarises these more detailed procedures.

Site Surface Data Collection

Surface data collection essentially involves the observation and recording of visible geotechnical related features relatively quickly and without the use of costly equipment. It is a cost effective process and is an essential component of all roadside problem investigations, both as an information source for problem assessment and as a step to the effective management of further more detailed assessments.

Annex B.3 outlines standard surface investigation procedures that are commonly used to collect geotechnical and geological data. Some of these procedures, such as soil and rock description, are basic geotechnical tools for use in other related activities. The usefulness of other procedures at DRO level may vary depending on the experience of individual engineers. It may be, appropriate for DRO engineers to consider contracting in expertise in, for example, geotechnical or geological mapping within a Phase II investigation.

Site Subsurface Data

Subsurface investigations require use of equipment to gain information below the ground surface. The equipment and techniques are relatively expensive and therefore these investigations should be carefully planned and controlled to yield the maximum amount of relevant information possible. The parameters usually required to be determined from a landslide ground investigation include the following:

1. The depth to in-situ rock,
2. The geotechnical characteristics of the overlying materials,
3. The presence of any weak layers that may influence the location of failure surfaces,
4. The groundwater profile and soil moisture condition, and
5. The depth and configuration of slip or shear surfaces.

Some of the procedures for subsurface data collection outlined in Annex B.4 involve significant costs that are likely to be outside DRO budgets for Phase II evaluations. However, test pitting or trenching and simple in-situ testing such Dynamic Cone Penetration or Mackintosh probing can be usefully employed in appropriate situations. It is important to note that the use of test pits or trenching within landslide areas must be carefully evaluated from a safety aspect before being adopted. There are occasions when knowledge of the depth to rock is sufficient, for example.

1. Determination of founding depths in rock for retaining walls, and
2. Determination of the maximum likely depth of failure assuming that failure has occurred in overburden, or along the rock-overburden interface.

Geophysical exploration consists of making indirect measurements from the ground surface or in boreholes to obtain subsurface information. Geologic and geotechnical information is obtained through analysis or interpretation of these measurements. Boreholes or other subsurface explorations are required to calibrate geophysical measurements.

Laboratory Testing

Annex B.5 provides guidance on laboratory testing for both soils and rocks and also on some elements of construction material evaluation. It outlines key aspects in the design and undertaking of laboratory programmes. Particular attention should be paid on the selection of appropriate tests and the need for effective quality control throughout the testing, reporting and analysis process. Testing programmes vary greatly in size and scope depending on the type of the roadside problem. Testing should not be commissioned on an arbitrary or ad hoc basis but should be part of a rationally designed programme. Clear objectives should be identified and test procedures and test programmes should be designed with these considerations in mind.

Soil and Rock Characterisation

The appropriate assessment of soil and rock characteristics is crucial to solving geotechnical roadside problems. The characterisation of the relevant soil or rock mass, as opposed to their constituent materials, is of importance in problems concerned with slope instability and related structures. The distinction between material and mass behaviour is closely related to the influence of discontinuities. In general, most soil is considered to behave as a continuous medium, although it is recognized that the soil is composed of discrete particles. An exception to this is the behaviour of some residual soils that contain relict fabric and structure. For these materials, the engineer must be careful to distinguish between the behaviour of the intact material and that of a “blocky” discontinuous matrix since the overall behaviour of residual soil is often influenced by the discontinuities rather than by the intact “blocks”. The behaviour of rock can be considered to be an extreme example of this; if the rock has discontinuities then the rock mass behaviour will almost always be governed by the behaviour of the discontinuities. Therefore, the orientation and characteristics of the discontinuities, as well as the behaviour of the material within the discontinuities is critical to assessing the rock mass.

Annex B.6 provides guidance on the assessment of the geotechnical characteristics of the soil or rock types that are influencing the roadside problem, which is an essential element in any investigation. In many geotechnical environments within Nepal, the selection of appropriate parameters such as c and ϕ for geotechnical analysis is difficult and great care may be required in assessing the representability and suitability of laboratory values. Particularly in Phase II programmes, it may be more suitable to utilise parameters either extrapolated from index testing, or from back analysis of similar problems

Slope Stability Analysis

The procedures for stability analysis are usually considered separately for soil slopes and rock slopes. The former are commonly analysed by limit equilibrium methods of the soil mass and the latter by a combination of kinematic possibility and limit equilibrium methods with an emphasis on discontinuity behaviour.

Methods involving stress-strain analysis and finite element methods are not considered within the scope of this guide.

Phase I or Phase II analyses are likely to be limited to computations related to standard remedial designs with possible use of standard slope charts and tables. Even these cases, however, the use of an appropriate factor of safety (FoS) is important and Annex B.7 provides assistance with FoS selection as well as on standard stability charts. This Annex also provides guidance on the selection of methods for soil and rock slope stability analysis.

Slope Analysis Software Selection

There is currently a wide range of computer software available for use in the analysis of soil slopes, rock slopes and related retaining structures. Their relative usefulness in the Nepalese context is very much a function of their adaptability to the particular geotechnical management requirements of the DoR. A search has been conducted on the capabilities of available soil and rock stability software and key parameters compared on the spreadsheets included in Annex B8. Based on this information and on consultations with the DoR, the following programmes are recommended:

For soil slope stability: **SLIDE (version 5)**; by Rocscience @ US$1495 – single user

For rock slope stability: **SWEDGE (version 5)**; by Rocscience @ US$995 – single user

An additional discontinuity survey analysis programme such as **DIPS** may also be required.

Construction Materials Study

The nature, engineering characteristics and location/availability of construction materials are essential aspects of the road design and construction. The adoption of an appropriate design approach carries with it a recognition that established criteria for road materials need to be looked at closely in terms of actual engineering purpose within individual road environment. Detailed specifications to ensure these requirements are generally defined in terms of properties such as grading, compacted strength and plasticity. Natural construction materials are used to satisfy a range of general need within a road environment, namely

- As fill materials,
- Within pavement layers,
- As a surfacing medium,
- As concrete aggregate,
- As filter mediums,
- As masonry or gabion fill, and
- As material for maintenance purpose.

It is becoming increasingly recognised that a key objective in sustainable road construction is to best match the available material to its road task and its local environment. Construction costs of the upper pavement layers are typically about 40 percent of the total road construction cost and it is clear that, the identification and characterisation of available road construction materials is an important stage in the selection of a road design and the following are seen as crucial points with respect to the ability of a material to carry out its assigned task within a road pavement:

- Knowledge of the key engineering properties of the material,

- The task required of the processing of the material,
- The governing road environment, and
- Probable future alterations to the road environment.

Annex B9 summarise some key issues regarding the selection and use of natural construction materials within the Nepalese geotechnical environment.

Route Alignment Selection

It is unusual within the Nepal's geomorphological and geotechnical environment for radical realignment of a route to be a practical solution to roadside geotechnical problems. In some cases, however, it is both desirable and possible to make minor horizontal or vertical alignment adjustments to either avoid or limit the impact of a slope or erosion problem. In particular some specific problems caused by river bank erosion can be avoided by limited alignment shift within an existing corridor. There may, however, be may be rare occasions where a radical shift of alignment can be considered; for example, to shift sections of a major highway away from an area of persistent problem such as the run-out toes of debris flows at the Siwalik-Terrai interface.

Although the assessment of entirely new road alignments would normally be outside the scope of work undertaken by DRO level engineers some summary guidelines on the stages and procedures for activity are included in this document as Annex B10.

3.4 Decisions and Outcomes from Phase II

Outcomes from Phase II should include decisions on the following:

1. Selection of remedial/protection works appropriate to the roadside problem, and
2. Decisions on the need for Phase III work.

If it is decided that a Phase III programme is necessary, either for further investigation or for the application of identified remedial works, then its requirements must be defined and outline costs prepared. A justification for additional work outside the scope of the DRO should be established on the basis of the Phase I and Phase II information.

4 Phase III Activities and Outcomes

4.1 Activities

A Phase III programme can comprise one or more of the following general activities outside the standard DRO procedures or budget capability:

1. Detailed or specialist site investigations,
2. Specialist analysis of acquired data, and
3. Selection and design of remedial measures.

The need for this programme should be defined in the previous phase of work together with a clear statement of objectives. Descriptions of procedures likely to be required in Phase III programmes are also included within Annex B.

4.2 Management of Phase III Activities

Phase III programmes and their activities are likely to be managed and technically controlled in one of the following general scenarios:

1. The DRO retains control and responsibility for the work which is contracted-out to specialists, or
2. The DoR, possibly through the GESU, takes over the management of the programme and the contract-out the investigation and design work, with the DRO providing liaison and support facilities.

In either event there is an essential requirement for the clear establishment of technical management and quality assurance responsibilities for the whole of the programme. This responsibility should be carried forward through to the construction and supervision of any remedial measures.

In the above cases where geotechnical work is being undertaken by outside specialists then the procedure outlines contained in Annex B should be used as guidance to the DRO or GESU on technical supervision and quality assurance of the contracted works.

The third option for additional works is where total responsibility of the road and associated remedial works is taken over by the DoR Head Office This is likely to occur only in the event of very large and complex geotechnical engineering problems that are having, or likely to have a national impact. This scenario is not directly dealt with in this document.

4.3 Quality Assurance

Quality assurance has to be a fundamental issue in the management of geotechnical investigations, if cost effective solutions or proposals for dealing with roadside problems, are to be identified. Quality assurance has a particular importance where investigation, analysis or design is being undertaken by contracted specialists. In this case the designated DRO or GESU engineer should assume an active quality control role with regards to outputs from the contracted specialists.

Key issues to be considered are:

1. Reliability of existing data presented by the specialist;
2. Reliability and accuracy of new field data. This will involve the quality assessment of appropriate procedures and their competent application and supervision;
3. Reliability and accuracy of laboratory data. This will involve quality control issues such as laboratory accreditation; appropriate test methods, laboratory management;
4. Reliability of analysis and design. This will involve quality control issues such as the selection of appropriate analytical procedures, and the rejection of unreliable, or inappropriate data;

5. Computer Software. The use of computer based analytical methods should be sanctioned only if it is possible to demonstrate that they are appropriate and that quality control is possible to cross-check key results; and
6. The overall professional competence of the specialist.

4.4 Outcomes

The outcome from a Phase III programme should be one of the following:

1. A definitive final methodology aimed at providing a satisfactory engineering solution for the identified problem with a satisfactory and agreed design life, or
2. A definitive methodology for containing and monitoring the identified problem so as to allow satisfactory serviceability of the affected road.

5 Engineering Options

5.1 Introduction

The general approach for solving geotechnical problems related to slope instability and erosion can be considered as falling into one of following broad groups:

1. Problem avoidance,
2. Reduction of driving force,
3. Internal strength enhancement,
4. External constraint,
5. Slope protection,
6. Debris control, and
7. Bank protection.

A range of general geotechnical engineering options exist that can be related to each of the above approaches and to the type of slope problem. **Table 4** provides initial guidance on this relationship and on the most appropriate general solutions to investigate.

In general terms, the solutions will include one or more of the following:

1. Available low-cost engineering options .Annex C provides more detailed design information on the most common geotechnical solutions available to DRO level engineers.
2. Bio-engineering options. The existing DoR Roadside Bio-engineering Reference Manual and Site Handbook provide advice and guidance on these solutions.
3. Options not immediately available at DRO level. These will require specialist geotechnical and engineering input both for design and construction.

Table 4 Matrix of Geotechncial Problems and Solution Options

A. Problem Avoidance	B. Reduction of Driving Force	C. Increase of Internal Strength	D. External Restraint	E. Slope Protection	F. Debris Control	B. Bank Protection	General Options	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**	◊	◊	◊							♦

B, C, D – Primary Slope Stabilization Measures
A, E, F, G – Slope Protection / Control Measures
• - Applicable Solution

♦ - Principal Option to be Considered for Solution of the Problem
◊ - Secondary Option
Bold Probably within DRO's Capability

5.2 Design

The design process to provide engineering solutions to roadside geotechnical problems is generally considered to involve four stages:

1. Consideration of possible general options to satisfy the requirements,
2. Preliminary outline designs for the identified options,
3. Selection of an optimum solution based on comparison of costs, effectiveness, availability of expertise or technology, and environmental impact, and
4. Developing detailed design for the optimum solution.

In the particular case of roadside problems being dealt with by DRO level engineers the following procedure, based on the above, is suggested once the nature of the problem has been identified, assessed and analysed.

1. Identify a general approach (**Table 4**);

2. List general options likely to meet the problem needs;
3. From list (2) identify as a first option any appropriate standard methods within the DRO's design capability;
4. Draw up detailed solutions using as guides Annex C together with associated references and, if required, the Roadside Bio-engineering Reference Manual and Site Handbook;
5. Identify engineering options outside the existing DRO's standard designs that will require additional analytical and design work; and
6. Request support through GESU for item identified under (5).

6 Review of Existing Geotechnical Practices in Nepal

6.1 Road Development Status

The history of road development in Nepal initiated with the first motorable road construction in the Kathmandu Valley in 1924 which was followed by a 42 km long all weather gravel road linking Amlekhganj with Bhimphedi. The Tribhuwan Rajpath (115 km), the first long distance motorable road linking Kathmandu with the Terai was constructed during 1953-1956. The later half of the twentieth century witnessed a considerable expansion of road network with assistance from bilateral agencies like China, India, USSR, USA, UK, Switzerland and multilateral agencies like ADB and WB. The country has developed more than 20,000 km of road network including strategic and rural roads.

6.2 Geotechnical Measures

During the initial road development period, the environmental and geotechnical aspects were not addressed. Soon after roads construction in the mountainous terrain, the problems of slope instability became evident. The awareness on the need of geotechnical and environmental aspects were reflected in the development Dharan-Dhankuta and Lamosangu-Jiri roads.

Dharan-Dhankuta road under the assistance of UK marked the beginning of environment-friendly road design and construction practices in Nepal. Extensive researches, studies and experimentation were conducted during the road development on bio-engineering and geotechnical slope stabilization measures. The measures included various bio-engineering solutions such as brush layer, grass plantation, tree/shrub plantation, wattle fences, brushwood check dams, hedge layers, jute netting, brush matting etc. and geotechnical solutions such as retaining walls, rock bolts, soil nails, subsurface drains, check dams, cascades, trap walls etc. Extensive use of light and flexible gabion structures were applied in road side structures.

Similarly, Lamosangu-Jiri road under the assistance of Switzerland pioneered in environment-friendly road construction practices in fragile mountainous terrain. The bio-engineering, drainage and geotechnical measures were extensively used along the road combined with labour-intensive road construction practices. Within the road, Charnawati Rehabilitation Project is considered as a milestone in extensive use of innovative geotechnical slope stabilization measures. The geotechnical measures designed and implemented in the Charnawati valley include French drains of various types and patterns, drilled horizontal drains (up to 45m), rock bolts, passive ground anchors (up to 20m long 32mm diameter anchor steel with f_y ~ 1000 N/mm^2), diversion catch drains, composite check dams, composite cascades, composite chutes, composite spurs, concrete armoured block protection at river bed in combination with extensive drainage and bioengineering measures. The anchors used were passive anchor bars without polythene sheathing. The anchor tendons with sheathing or active cable tendons are not yet implemented in roadside anchoring in Nepal. The theory and practice of slope stability analysis was implemented in the project. The design and construction of concrete armoured blocks was derived from the extensive model studies performed in VAW Zurich.

Similar geotechnical and bio-engineering solutions were later replicated in other road corridors such as Arniko highway, Thankot-Naubise road, Prithvi highway, Narayanghat-Mugling road, Bhainse-Hetauda road, Malekhu-Dhadingbesi road, Butwal-Narayanghat road, Hetauda-Narayanghat road etc. with varying degree of success. In addition to the replication of successful measures from Dharan-Dhankuta and Lamosangu-Jiri roads, further innovative geotechnical solutions applied in the roads included various forms of composite revetment structures, various types of spurs with face block protection, launching aprons with composite frames or articulated concrete blocks, boulder riprap, boulder armouring using interconnected boulders, rock fall netting, inverted buttress walls etc.

For the slope stabilization and gully control works, gabion work (boxes, mattresses, sacks or bolsters) are extensively used due to its flexible and free draining capabilities instead of rigid masonry and concrete structures. Gabions are used as walls, check dams, trap walls, mattresses or even drains. For filter purpose, extensive use of geotextile is made instead of graded filter due to difficulty of transport at landslide slope. Other forms of walls such as concrete crib walls are rarely used. Recently, geogrid material as reinforced earth has been extensively used in Sindhuli-Banepa road.

6.3 Geotechnical and Hazard Mapping

Simple form of engineering geological mapping was implemented during the Dharan-Dhankuta and Lamosangu-Jiri roads. A more extensive mapping exercise was initiated during the Mountain Risk Engineering Project undertaken by the ICIMOD which resulted in a set of comprehensive Mountain Risk Engineering Handbook in 1991. The document recommended developing a series of mapping including topographic map, slope map, aspect map, engineering geological map, morpho-structural map, land use map and eventually hazard map. Apart from field based mapping, further initiatives were undertaken in Arniko highway rehabilitation project to apply air photo interpretation to develop larger scale (1:10,000) orthophoto and contoured maps as the base map for further land use, engineering geology and hazard mapping. More recently, a DfID study undertaken by Scott Wilson has recommended use of latest satellite imageries in addition to air photo to prepare base map. Recent efforts are directed towards digital processes to develop and implement hazard mapping.

6.4 Landslide Investigation

In consideration of the multi-disciplinary nature of the landslides, efforts were initiated to combine related expertise in the investigation, design and implementation of landslide stabilization measures. Apart from field reconnaissance, photographic illustration and engineering geological mapping, further investigations such as geophysical exploration, core drilling, instrumentation and monitoring, field and laboratory testing are also applied considering the merit of a particular case.

The subsurface geophysical exploration includes resistivity survey, seismic refraction sounding, seismic reflection sounding, electrical resistivity tomography (ERT), ground penetrating radar (GPR) etc. The measures are applied in complex landslides and underground works with varying successes. For roadside problems, the ERT and seismic refraction sounding are the most useful geophysical exploration methods. The geophysical findings should however be used with caution, particularly if not confirmed by core drillings and in-situ testing.

The core drilling is routinely followed in foundation exploration for medium and major bridges. The procedure can be equally applicable to landslide studies and foundation investigations of high retaining walls. The procedure was applied in a number of active landslides along Lamosangu-Jiri road, Arniko highway and Thankot-naubise road. The bore hole logs were referenced while deciding on the depth of foundation or bearing strata, fixed anchor zone for anchors installation and aquifer location for piezometers and horizontal drains.

The practice of geotechnical instrumentation is still innovative in roadside slope stabilization in Nepal. A range of geotechnical instrumentation such as standpipe piezometers, discharge meters, rain gauge, rain intensity meter, rod extensometers, anchor tension gauges etc. were installed and measured in various stabilization works in Charnawati valley of Lamosangu-Jiri road. Similarly, standpipe piezometers were installed and monitored in landslides in Arniko highway. The installation and monitoring of inclinometers and tilt meters are not yet practised in roadside slope management in Nepal.

Monitoring of various parameters is crucial to assess the effectiveness of the applied measures in the landslides, drains, walls and check dams. Instrumental monitoring of the levels and positions of the monitoring points were extensively carried out at Charnawati area and Arniko highway. The monitoring results provided useful hints on the status of stabilization or impending dangers. The monitoring exercise included movement monitoring, subsidence monitoring, cracks monitoring, stress monitoring, stage or discharge monitoring, water table / piezometric monitoring etc.

In the recent road design and construction projects, basic field testing such as trial pitting, DCP testing, material sampling etc. have become routine practice for road pavement investigation. The tests are performed following appropriate ASTM or AASHTO specifications. Similarly, laboratory testing for USCS classification, gradation, LAA, AIV, compaction, CBR etc. are also routinely performed. For slope stability purpose, testing for soil strength parameters (c and ϕ), unit weights (γ_d, γ and γ_{sat}), unconfined compression, triaxial, point load, joint friction etc. are also performed as per discretion of the geotechnical expert. DoR has established laboratories at Division Road Offices to carry out routine materials and quality control testing. However, the DRO level laboratories are not sufficiently equipped for geotechnical testing for slope stability and foundation analysis and design.

6.5 Pavement Investigation

The pavement investigation generally consists of pavement materials testing as well as characterization of subgrade, sub base and base material through field and laboratory testing. The testing equipment such as Benkelman beam transient deflection measurement, roughness measurement with bump integrator and dynamic cone penetration testing are customarily used. More advanced equipment such as falling weight deflectometer is not yet applied; instead, Benkelman beam in combination with high speed camera was used for deflection bowl measurement in the current Road Network Development Project to back analyze elastic moduli of multiple pavement layers. Accordingly, pavement design is generally based on CBR values. More sophisticated pavement design method based on elastic moduli of layers is applied in recent projects which require deflection bowl measurement techniques both during investigation and quality control (static or dynamic moduli) of each pavement layer.

6.6 Stability Analysis

Preliminary slope stability analysis was practised in assessing stability of abutment slope in suspension bridges using simple infinite slope or simple slope models. The slope stability is indirectly represented in the form of slope hazard rating specified for feasibility level study of road alignments. For more detailed slope stability analysis, Hoek & Bray charts were recommended and used by geotechnical practitioners.

The use of computerized analytical tools for stability analysis was initiated from Charnawati rehabilitation project where DOS-based LARIX BS software (German version) was extensively used. Later, geotechnical experts from different institutes applied software of their choice such as SB-SLOPE, STABL, FLAC, DIPS etc. Recently, there has been a breakthrough in the software capabilities, versatilities and speed. Latest version of SLIDE, for example, offers most capabilities for soil slope stability analysis including windows compatibility, non-circular slip surface, effective stress analysis, back analysis, sensitivity / parametric analysis, graphic interface etc. With the advance of user-friendly software, the analysis part has become mechanical but it demands for a sound judgement of geotechnical engineering to obtain information and to eliminate uncertainties on subsoil layers, water table and pressure, soil strength parameters, possible slip surface, pre-sliding condition etc.

Apart from standard slope stability analysis software, different modules such as RETAIN (for design of retaining wall), SAST (stability analysis of talus slope), BAST (back analysis of talus slope), FEAP (finite element analysis program), SAP (structural analysis program) etc. were also in practice for analysis and design of different components.

For hazard mapping purpose, a DOS-based software SHIVAD was extensively used for Second Roads Improvement Project (SRIP) and Hazard Assessment in Sunkoshi-Bhotekoshi Water Catchment Areas (HMWA). The recent trend is to use GIS-based hazard mapping module.

6.7 Codes of Practice

During the early development of roads, the DoR had generally adopted codes of practice and standards of the respective bilateral donor agencies such as BS, ASTM, AASHTO, TRL, DIN, SIA, IRC, Chinese and USSR codes and standards. With the introduction of Nepal Road Standards and DoR Standard Designs, more uniformity was accomplished in the design and construction of roadside structures. As a part of institutional strengthening of the DoR, a series of guidelines such as Guide to Road Slope Protection Work, Roadside Bio-engineering (reference manual and site handbook), Environmental Management Guidelines, Reference Manual for Environmental and Social Aspects of Integrated Road Development, Traffic Safety Manuals, Guideline for Inspection and Maintenance of Bridges etc. are prepared and adopted. The present guide intends to complement the existing set of standards and codes.

7 Review of International Standards, Codes and Guidelines

A large number of international standards and codes were reviewed during the preparation of the present guide. The relevant extracts from those standards are appropriately incorporated in the assessment sheets, investigation procedures and solution options. The list of the reviewed documents is included in the bibliography section, Annex D and key references sited elsewhere.

ASTM: The agency has an extensive set of publication related to material testing which are frequently referred in Annex B of the present guide. The standards are the most referred documents for laboratory and field testing in road sector in Nepal.

AASHTO: The publications of the agency relevant to geotechnical engineering include: R013-03-UL: Standard Recommended Practice for Conducting Geotechnical Subsurface Investigations; R022-97-UL Standard Recommended Practice for Decommissioning Geotechnical Exploratory Boreholes, T306-98-UL Standard Method of Test for Progressing Auger Borings for Geotechnical Explorations etc. Apart from geotechnical core areas, the agency has an extensive publication on the design of road and bridges including all sorts of off-road works.

GCO: Hong Kong Geotechnical Control Office has an extensive set of codes, standards and guidelines on various aspects of geotechnical engineering field. The list of such documents is frequently referred in the present guide which includes: Guide to Rock and Soil Descriptions. Geoguide 3; Guide to Slope Maintenance; Geoguide 3; Guide to Site Investigation. Geoguide 2; Highway Slope Manual; GeoGuide 3: Guide to rock and soil descriptions etc. The Geoguides provides as the most comprehensive literature on the geotechnical engineering and is widely in use in Asia including Nepal.

ASCE: The agency publishes extensive literature on geotechnical engineering for practical as well as research purposes. The publication Journal of Geotechnical and Geo-environmental Engineering is the most notable publication.

The relevant recommendations of the above standards, codes and guidelines are appropriately incorporated in assessment sheets, procedures and solutions included in this guide.

8 Areas for Improvement

Based on the above review of the existing geotechnical practices and guidelines, the following aspects require improvements:

- The geotechnical assessment practice in Nepal is generally weak and requires development of appropriate assessment sheets and strengthening of practices,
- The geotechnical procedures recommended in the existing geotechnical references are complex and extensive and require simplification, and
- The choice of geotechnical measures for solution of roadside problems is not uniform and often dependent on individual’s experience and judgement and therefore, it requires standardization.

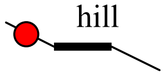
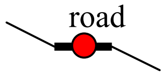
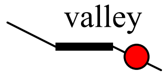
The Annexes A, B and C are specifically designed to address the areas of improvement as noted above. The main text, Annex A and Annex C of this guide is intended for direct use of DRO level engineers. The procedures laid in Annex B serve as reference material to the DRO and GESU engineers to facilitate them to control the quality of the investigation and testing which are outsourced to the consultants.

Road-side Geotechnical Problems
A Practical Guide to their Solution

Part II: Guideline Annexes

Annex A: Geotechnical Problem Definition

Data Sheet A1.1: Site Definition Sheet 1/2

Road name:	Site Ref ID:
Road link: Chainage (km + m):	hill  road  valley 
Geographical coordinates: Lat .º Long .º	Side of road: left ☐ right ☐ Size: L= .... m B= .... m H= .... m
Traffic disruption: high ☐ low ☐ no ☐ Traffic blockage duration: .... days/yr Average daily traffic (ADT): .... vpd	Rainfall No rain for ___ days Raining for ___ days Recent heavy rain ☐:

Preliminary Problem Identification Routine(R); Moderate(M); Severe (S)				**Impacts**		
	R	M	S	On Road	Actual	Risk
Soil-rock fall				None		
Earth-debris flow				Road edge only		
Shallow slide				1 lane		
Deep-seated slide				Most of 2 lanes		
Surface/gully erosion				Whole road		
River erosion/undercutting				Earthworks		
Pavement failure				Culverts		
Structure failure				Bridge		
Drainage blocked						
					Above Rd	Below Rd
				Risk to Life		
				Risk to Buildings		

Problem History Year of original problem________________ Date of current failure/problem :__________ Brief summary:	Existing vegetation types: Tropical ☐ Deciduous ☐ Coniferous ☐ Shrubs ☐ Grasses ☐ None ☐ Land use: Barren ☐ Cultivated ☐ Forest ☐ Built up ☐ Quarry ☐
	Hydrology Dry ☐ Surface springs ☐ Sheet flood ☐ Adjacent river ☐

Previous or Existing Engineering Solutions

	Date		Date
Surface-drainage		Anchors/bolts	
Sub-surface drainage		Catch fence	
Breast wall [_______________]		Pavement overlay/patching	
Retaining wall [_____________]		Bridge repair	
Anchored wall		Culvert repair	
Check dam [________________]			
Bio-engineering			

Road division:	Inspection date:
Location:	Inspected by:
District:	Checked by:

Data Sheet A1.1: Site Definition Sheet 2

Road name:	Site Ref ID

Sketches
Slope Plan   **Slope Profile**
Photograph References

FormA1.2: Problem Identification Decisions 1/1

Road name	**Site Ref ID**
Issue	**Decisions**
A. Immediate or Emergency Engineering Control	1. Clear debris off the road ☐ 2. Remove loose or overhanging material ☐ 3.Divert water off road ☐ 4.Divert water away from the problem area ☐ 5.Place stabilising earth works ☐ 6.Place temporary control structures (gabions, masonry walls) ☐
	7.Others (specify)
B Short Term Engineering	1.Not required ☐ 2. Repair existing structures ☐ 3. Reconstruct the damaged works ☐ 4. Construct new works (use Annex C) ☐
	5.Others (specify)
C Long Term Engineering	Engineering response requires design input. Engineering Definition Surveys 1.Topographic Survey ☐ 2.Engineering Geological Survey ☐ 3. Failure Assessment ☐ 4. Engineering Design ☐
	6.Others (specify)
Mandatory Actions: Further site work **essential** if the following are ticked “YES”: A5; A6; B4 In addition further site work may be advisable if the following are ticked “YES” A2; A4; B3	
Decisions Agreed By	**Date**
Comment	

Data Sheet A2.1: Slope Problems Sheet 1/4

Road Link:	Chainage (km + m):	Slope Ref ID:

Failure Type

I Fall or Topple	II Shallow Translational Slide	III Rotational slide	
a. Soil/earth ☐ b. Rock ☐	a. Soil ☐ b. Rock ☐	a. Soil ☐ b. Rock ☐	
IV Flow	V Slope Creep	VI Erosion a. Rill ☐ b. Gully ☐ c. Toe cutting ☐	VII Complex Types

Failure Geometry

Failure orientation (facing)	(deg)
Length of failed slope L1	(m):
Length of runout L2	(m)
Height of failure H1	(m)
Height above road H2	(m)
Height of backscar H3	(m)
Height below road H4	(m)
Slope above crest A1	(deg)
Failed slope angle A2	(deg):
Debris angle A3	(deg)
Backscar angle A4	(deg)
Slope below failureA5	(deg)
Max failure width W1	(m)
Max debris width W2	(m)
Runout width W3	(m)
Estimated failure depth D1	(m)
Estimated thickness of debris D2	(m)
X-Section: Convex ☐Concave ☐ Straight ☐	
Height above failure to ridge	(m)

Failure Condition

Tension crack:
Absent ☐ On failure ☐
Head of failure ☐ Above failure ☐

Failure activity: Mass movement ☐ Secondary ☐ Dormant ☐

Toe condition: Eroding ☐ Intact ☐

Instability: Above road ☐ Below road ☐

Hydrology: Well drained/Dry ☐ Seepage flow ☐ Active spring flow ☐ Monsoon saturation ☐

Failure surface condition: Intact ☐
Secondary failure ☐ Erosion ☐
Tension Cracks ☐ Springs ☐

Geomorphology- Geology

Landform

Zone 1: High altitude glacial-periglacial ☐ Zone 2: Rock face and associated debris slope☐
Zone 3: Degraded mid-slope, ancient valley floor ☐ Zone 4: Unstable lower slope ☐
Zone 5: Valley floor ☐
Natural slope angles____________________ Similar failures in the area Yes☐ No☐

Geological Zone

Terai Quaternaries.☐ Siwaliks ☐ Lower Himalayan Zone ☐ Higher Himalayan Zone☐

Bedrock

RgI:	Igneous	1.Coarse ☐	2. Medium ☐	3. Fine ☐
RgM	Metamorphic	1. Coarse ☐	2. Medium ☐	3. Fine ☐
RgS	Sedimentary	1. Coarse ☐	2. Medium ☐	3. Fine ☐
RgB	Bedded	Types______________________________		

Soil Types

Alluvium ☐ Colluvium ☐ Residual ☐ Talus ☐ Glacial till ☐ Fill Material ☐

Data Sheet A2.1: Slope Problems Sheet 2/4

Geotechnical Environment

Failure in:
Rock ☐ Soil ☐ Soil-rock☐

Failed Material
Blocky ☐ C-F. Debris ☐ F. Debris ☐

Separate Detailed Description Sheets
Rock mass ☐
Soil mass ☐
Joint survey ☐

General Rock Condition
Weathering
- fresh ☐
- slightly weathered ☐
- moderately weathered ☐
- highly weathered ☐
- completely weathered ☐

General Rock mass condition:
- Intact or massive ☐
- blocky / very blocky ☐
- blocky/ disturbed ☐
- disintegrated ☐

General intact rock strength very weak☐
weak☐ mod. weak☐ mod. strong☐
strong☐ very strong☐

Discontinuity Types Bedding (B) ☐
Joints(J) ☐ Foliation (F)
Faults
Orientation____________________
Condition______________________

Discontinuities	Dip (deg)	Dip Direction (deg)	Persistence (m)	Spacing (m)	Dilation	Infilling	Roughness
F0							
B							
J1							
J2							
J3							
FP							

Additional Visual Descriptions (Rock)

General Soil Condition
Classification

In Situ	Debris
GW ☐ GP ☐ GM ☐ GC ☐ SW ☐ SP ☐ SM ☐ SC ☐ CL ☐ MH ☐ CH ☐ OL ☐ OH ☐ Pt ☐ Boulders: ....% Fine soil: ....% Matrix:gravel ☐ sand ☐ silt ☐ clay ☐ peat ☐	GW ☐ GP ☐ GM ☐ GC ☐ SW ☐ SP ☐ SM ☐ SC ☐ CL ☐ MH ☐ CH ☐ OL ☐ OH ☐ Pt ☐ Boulders: ....% Fine soil: ....% Matrix:gravel ☐ sand ☐ silt ☐ clay ☐ peat ☐

Soil Strength

In situ`	Debris
Very Soft☐ Soft☐ Firm☐ Stiff☐ Very Stiff☐ Hard☐	Very Soft☐ Soft☐ Firm☐ Stiff☐ Very Stiff☐ Hard☐

Additional Visual Descriptions (In situ)

Additional Visual Descriptions (Debris)

Slope Failure Triggered by
Rainfall ☐ Slope Erosion ☐
Cultivation ☐ Vegetation removal ☐
Over-steepening ☐ Road construction ☐
Quarrying ☐ Drainage failure ☐
Stress relief ☐ Rock degradation ☐
Seismic event
Others (specify)____________________

Data Sheet A2.1: Slope Problems Sheet 3/4

Engineering Environment

Bio-engineering work: Percentage area covered: …… %

Trees ☐ Shrubs ☐ Grass ☐ Associated others ______________________________

Engineering work: Length covered: ____________________________.

General Option	Type/Description
Earthwork	
Surface Drainage	
Sub-surface Drainage	
Breast/Retaining Wall	
Revetment Wall	
Check Dams	
Tied Wall	
Piled Wall	
Buttress	
Anchors-Bolts	
Catch Works	
Surface Protection	

Summary of Condition

S. No	Type of measure	Dimension (L x B x H)	Condition
1	…………………………	…….x………..x………	…………….
2	…………………………	…….x………..x………	…………….
3	…………………………	…….x………..x………	…………….
4	…………………………	…….x………..x………	…………….
5	…………………………	…….x………..x………	…………….
6	…………………………	…….x………..x………	…………….
7	…………………………	…….x………..x………	…………….

Comments:

In Situ Testing (undertaken –U; recommended- R)

Point load ☐ Schmidt hammer ☐ Vane shear ☐ Penetrometer ☐ DCP ☐

Samples Taken:

Number Taken

Small disturbed ☐ Large disturbed ☐ Undisturbed ☐ Intact Rock ☐

Photograph References

Data Sheet A2.1: Slope Problems Sheet 4/4

Road name:	Site Ref ID

Sketches

Engineer	Date

Sheet A2.2: Slope Definition- Decisions 1/1

Road name:	**Site Ref ID**

Issue	**Decisions**
A Immediate Action Review	1.Road clearance – further action required ☐ 2.Further emergency problem control ☐ 3.Ammend immediate risk control actions ☐ 4. Revise short term engineering actions ☐
B Geotechnical Assessment	1.Geological/Geotechnical model established ☐ 2.Failure mode established ☐ 3. Failure boundaries defined ☐ 4.Failure cause and trigger mechanism identified☐ 5. Failure active ☐ 6. Failure likely to reactivate in next monsoon ☐
C Preliminary Risk Assessment	1. Hazard: 1.Large ☐ II. Medium ☐ III. Small ☐ 2. Consequence a. High☐ b. Medium ☐ c. Low ☐ 3 Risk _______________ 4. Hazard-risk assessment satisfactory ☐
D Strategic Options	1.Problem Avoidance ☐ 2.Reduce driving force ☐ 3.Increase internal strength ☐ 4.Apply external restraint ☐ 5.Erosion control ☐ 6.Debris control ☐
E Division Remedial Response	1.No further action required ☐ 2.Extend existing measures ☐ 3.Additional DRO standard options ☐ 4.Non-standard measures identified ☐ 5.Other measures required (specify) ☐
F Budget Assessment	1.Solution within Division ☐ 2.Budget request defined engineering works ☐ 3.Budget request for DRO controlled technical/engineering services ☐ 4.Budget request for specialist technical/engineering services ☐
G Stability Analysis	1.Rock discontinuity ☐ 2.Rock circular ☐ 3.Soil preliminary ☐ 4.Soil Detailed ☐ 5.Engineering Structure ☐
H Further Site Investigations	1. Desk study ☐ 2. Topographic survey ☐ 3.Remote sensing ☐ 4.Geotechnical mapping ☐ 5.Sub-surface investigation ☐ 6.Geophysics ☐ 7.Laboratory testing ☐ 8.In situ testing ☐ 9. Others (specify) ☐

Decisions Agreed By	**Date**

Sheet A2.3: Slope Definition – Actions 1/3

A: Immediate Action Review

A1 √: implement further road clearing (see Sheet A1)
X: No action except monitoring

A2 √: see sheet A1
X: No action except monitoring

A3 √: see sheet A1
X: No action except monitoring

A4 √: Review requirement options based on Slope Assessment data
X: No action except monitoring

B. Geotechnical Assessment

B1 √. Use model in hazard and stabilisation assessment and as input to analysis
X. Further investigation required– see Guideline Section Annex B

B2 √. Use in stability analysis and engineering option selection
X. Further assessment required – initially by detailed walkover

B3 √. Use in assessment of hazard scale and engineering option assessment
X. Further assessment required – initially by detailed walkover; possible use of RS

B4 √ Use in assessing effectiveness of available options
X. Further site work required – essential for appropriate stabilisation work assessment

B5 √ Immediate actions not effective; emergency action if high hazard/risk.
X. Monitor

B6 √ Plan stabilisation measures. Advise GESU if high risk outside DRO budget.
X. Monitor

C. Preliminary Risk Assessment

C1-C2 Use Risk Assessment Matrix to identify preliminary risk C3

C3	Ia,Ib,IIa:	Probably require budget/ technical support through GESU
	Ic,IIb,IIc, IIIa,IIb:	Probable DRO action within ARMP
	IIIc.	Routine.

C4 √. No further action. Use in budget/plan justification
X. Further investigation – see Guidelines Annex B

Sheet A2.3: Slope Definition – Actions 2/3

D. Strategic Options

D1 √. Realignment or remove problem – see Options Matrix

D2 √. See general options B on Options Matrix

D3 √ Key issue probably drainage - see general options C on Options Matrix

D4 √. Breast or retaining walls most likely option - see general options D on Options Matrix

D5 √ Bio-engineering a likely option - see general options E on Options Matrix

D6 √ Catch fencing, netting; bio-engineering likely options - see general options F on Options Matrix

E. Division Remedial Response

E1 √. Monitoring

E2 √. Only after assessing these measures meet strategic and risk requirements

E3 √ Use standard DRO designs only after assessing these measures meet requirements

E4 √. Probable request for budget or technical advice through GESU

E5 √. Detailed site investigation required

F. Budget Assessment

F1 √. Mobilise stabilisation through appropriate works orders

F2 √. Prepare detailed cost estimate. Request support through GESU

F3 √. Prepare outline cost estimate and ToR for services and submit through GESU

F4 √.Prepare outline of requirements and budget estimate and submit through GESU

G. Stability Analysis

G1 √. Use standard planar, wedge, toppling procedures (Annex B7). A discontinuity survey may be required (Annex B3).

G2 √ Use standard charts (Annex B7) with appropriate ground water condition and a range of likely C Ø values in sensitivity analysis.

G3 √. Use appropriate standard charts (Annex B7)

G4 √. Forward necessary slope details and parameters to GESU for appropriate software utilisation

G5 √ Use available design guides for standard DRO options otherwise forward necessary details and parameters to GESU for appropriate software utilisation

Sheet A2.3: Slope Definition – Actions 3/3

H. Further Site Investigations

H1	√. Define requirements and mobilise DRO topographic survey team
H2	√. Collate all relevant data at DRO level and utilise procedures in Annex B1.
H3	√. Define requirements and utilise procedures in Annex B1.
H4	√. Define requirements and utilise procedures in Annex B3.
H5	√. Define requirements and utilise procedures in Annex B4
H6	√. Define requirements and utilise procedures in Annex B4
H7	√. Define requirements and utilise procedures in Annex B5
H8	√. Define requirements and utilise procedures in Annex B4
H9	√. Define requirements

Data Sheet A3.1: Erosion Problem 1/3

Road Link:	Chainage (km + m):	Slope ID:

Slope Definition

Slope angle ___(deg) Slope Plan _______ Slope Section__________Slope height ____(m)

Hydrology Well drained/Dry ☐ Seepage flow ☐ Active spring flow ☐ Saturation ☐

Vegetation cover: Tree ___ %, Shrub___ %, Grass___%, Barren___%

Cultivation: Type __________________ Cover___%,

Slope material: Rock ☐ Collvium ☐ Alluvium ☐ Residual ☐ Talus ☐

Earthfill ☐ Rockfill ☐ Glacial till ☐ Failure Debris ☐

Problem	Sheet/Rill erosion ☐	Gully erosion ☐	River scour ☐

Sheet/Rill Erosion

Hazard: Severe (>40 % of slope area) ☐ Moderate (10%-40%) ☐ Minor (<10%) ☐

Rill depth (D) ___(m) Rill spacing (S)___(m) Rill width (W)___(m)Rill bed slope____(deg)

Gully Erosion

Single gully ☐ Multiple ☐ Branching ☐

Gully width (Top W1)_____(m); Gully width (Bottom W2)_____(m)

Gully depth (D1)________(m) Gully side slope(A1)____(deg)

Gully bed slope (A2)____(deg)

Gully curvature: sharp ☐ moderate ☐ straight ☐ Curvature control: rock ☐ soil ☐ Tension cracks at banks: yes ☐ no ☐ Rock outcrop at bed: yes ☐ no ☐

Flow: perennial ☐ torrential ☐ dry ☐

River Scour

Flood level width of river______ (m) Water level width of river_______ (m):

Height of road above river bed H1_____(m) Height of road above flood H2_______(m)

Height of erosion H3_____(m) Maximum ersosion width_____(m)

Scour depth_____(m) Erosion face angle________(deg)

River plan at erosion Concave ☐ Straight ☐ Convex ☐

Erosion status: Stable ☐ Minor activity ☐ Significant activity ☐

Hazard potential Low ☐ Moderate ☐ High ☐

GLOF potential: Low ☐ Medium ☐ High ☐

Geomorphology- Geology

Landform Zone

Zone 1: High altitude glacial-periglacial ☐ Zone 2: Rock face and associated debris slope☐

Zone 3: Degraded mid-slope, ancient valley floor ☐ Zone 4: Unstable lower slope ☐

Zone 5: Valley floor ☐ Similar failures in the area Yes☐ No☐

Geological Zone

Terai Quaternaries.☐ Siwaliks ☐ Lower Himalayan Zone ☐ Higher Himalayan Zone☐

Bedrock

RgI: Igneous 1.Coarse ☐ 2. Medium ☐ 3. Fine ☐

RgM Metamorphic 1. Coarse ☐ 2. Medium ☐ 3. Fine ☐

RgS Sedimentary 1. Coarse ☐ 2. Medium ☐ 3. Fine ☐

RgB Bedded Types_______________________________

Data Sheet A3.1: Erosion Problem 2/3

Engineering Environment

Bio-engineering work: Percentage area covered: …… %

Trees ☐ Shrubs ☐ Grass ☐ Associated others ______________________________

Engineering work: Length covered: ____________________________.

General Option	Type/Description
Earthwork	
Surface Drainage	
Sub-surface Drainage	
Breast/Retaining Wall	
Revetment Wall	
Check Dams	
Tied Wall	
Piled Wall	
Buttress	
Anchors-Bolts	
Catch Works	
Surface Protection	

Structure Condition

S. No	Type of measure	Dimension (L x B x H)	Condition
1	....	.......x...........x.........	....
2	....	.......x...........x.........	....
3	....	.......x...........x.........	....
4	....	.......x...........x.........	....
5	....	.......x...........x.........	....
6	....	.......x...........x.........	....
7	....	.......x...........x.........	....

Comments:

Drainage Condition	Exist	Good	Blocked	Slight Damage	Major Damage
Roadside drain	☐				
Cascade drain	☐				
Berm drain	☐				
Horizontal drain	☐				
French drain	☐				

In Situ Testing (undertaken –**U**; recommended- **R**)

Point load ☐ Schmidt hammer ☐ Vane shear ☐ Penetrometer ☐ DCP ☐

Samples Taken:

Number Taken

Small disturbed ☐ Large disturbed ☐ Undisturbed ☐ Intact Rock☐

Photograph References

Data Sheet A3.1: Erosion Problem 3/3

Road name:	Site Ref ID

Sketches

Engineer	Date

Sheet A3.2: Erosion Definition- Decisions 1/1

Road name:	**Site Ref ID**

Issue	**Decisions**
A Immediate Action Review	1.Road clearance – further action required □ 2.Further emergency control required □ 3.Immediate risk control actions required □ 4. Short term engineering actions – revision required □
B Geotechnical Assessment	1.Geological/Geotechnical model established □ 2. Erosion mode established □ 3. Failure and erosion boundaries defined □ 4.Erosion cause identified □ 5. Erosion active □ moderately active □ dormant □ 6. Erosion likely to reactivate during next monsoon □
C Preliminary Risk Assessment	1. Hazard: 1.High □ II. Medium □ III. Low □ 2. Consequence a. Major □ b. Medium □ c. Slight □ 3 Risk High □ Moderate □ Slight □ (Refer Procedure Sheet B2.1 in Annex B) 4. Hazard-risk assessment satisfactory □
D Strategic Options	1.Problem Avoidance □ 2.Slope protection □ 3.Debris control □ 4.Bank Protection □
E Division Remedial Response	1.No further action □ 2.Extend existing measures □ 3.Additional DRO standard options □ 4.Non-standard measures identified □ 5.Undefined measures required □
F Budget Assessment	1.Solution within Division □ 2.Budget request defined engineering works □ 3.Budget request for DRO controlled technical/engineering services □ 4.Budget request for specialist technical/engineering services □
G Stability Analysis	1.Erosion is causing or likely to cause slope stability problems □
H Further Site Investigations	1. Desk study □ 2. Topographic survey □ 3.Remote sensing □ 4.Geotechnical mapping □ 5.Sub-surface investigation □ 6.Geophysics □ 7.Laboratory testing □ 8.In situ testing □ 9. Others (specify) □

Decisions Agreed By	**Date**

Sheet A3.3: Erosion Definition- Actions 1/2

A: Immediate Action Review

A1 √: implement further road clearing (see Sheet A1)
X: No action except monitoring

A2 √: see sheet A1
X: No action except monitoring

A3 √: see sheet A1
X: No action except monitoring

A4 √: Review requirement options based on Slope Assessment data
X: No action except monitoring

B. Geotechnical Assessment

B1 √. Use model to assess erosion remedial measures
X. Further investigation required– see Guideline Section Annex B

B2 √. Use for engineering option selection
X. Further assessment required – initially by detailed walkover

B3 √. Use in assessment of hazard scale and engineering option assessment
X. Further assessment required –detailed walkover; possible use of RS or API

B4 √ Use in assessing effectiveness of available options
X. Further site work required – essential for appropriate stabilisation work assessment

B5 √ Immediate actions not effective; emergency action if high hazard/risk.
X. Monitor

B6 √ Plan stabilisation measures. Advise GESU if high risk outside DRO budget.
X. Monitor

C. Preliminary Risk Assessment

C1-C2 Use Risk Assessment Matrix to identify preliminary risk C3

C3	Ia,Ib,IIa:	Probably require budget/ technical support through GESU
	Ic,IIb,IIc, IIIa,IIb:	Probable DRO action
	IIIc.	Routine.

C4 √. No further action. Use in budget/plan justification
X. Further investigation – see Guidelines Annex B

Sheet A3.3: Erosion Definition- Actions 2/2

D. Strategic Options

D1 √. Realignment or remove problem – see general option A in Options Matrix

D2 √. Bio-engineering a likely option See general options E on Options Matrix

D3 √ Bio-engineering a likely option See general options F on Options Matrix

D4 √. See general options D on Options Matrix may also involve stability issues

E. Division Remedial Response

E1 √. Monitoring

E2 √. Only after assessing these measures meet strategic and risk requirements

E3 √ Use standard DRO designs only after assessing these measures meet requirements

E4 √. Probable request for budget or technical advice through GESU

E5 √. Site investigation required.

F. Budget Assessment

F1 √. Mobilise stabilisation through appropriate works orders

F2 √. Prepare detailed cost estimate. Request support through GESU

F3 √. Prepare outline cost estimate and ToR for services and submit through GESU

F4 √.Prepare outline of requirements and budget estimate and submit through GESU

G. Stability Analysis:

G1 √.Use Slope Problem assessment and remedial procedures.

H. Further Site Investigations

H1 √. Define requirements and mobilise DRO topographic survey team

H2 √. Collate all relevant data at DRO level and utilise procedures in Annex B1.

H3 √. Define requirements and utilise procedures in Annex B1.

H4 √. Define requirements and utilise procedures in Annex B3.

H5 √. Define requirements and utilise procedures in Annex B4

H6 √. Define requirements and utilise procedures in Annex B4

H7 √. Define requirements and utilise procedures in Annex B5

H8 √. Define requirements and utilise procedures in Annex B4

H9 √. Define requirements

Data Sheet A4.1: Pavement Problem Sheet 1/2

Road Link:	Chainage (km) From To :	Site ID:

Pavement Geometry

Carriageway width____ (m)		Shoulder width_____(m)		
Crossfall (L)___(%)		Crossfall (R)________(%)		Gradient______(%)
Horiz. alignment	Straight ☐	Curve ☐		Sharp bend ☐
Vert. alignmnet	Flat ☐	Gradient ☐	Hill crest ☐	Hill bottom ☐
Cross section	Flat ☐	Fill ☐	Cut ☐	Cut-fill ☐

Pavement design

	Thickness	Material	Comment
Surfacing			
Roadbase			
Subbase			

Pavement Damage

Surface damage	Slight ☐	Moderate ☐	Severe ☐	
Depression	Slight ☐	Moderate ☐	Severe ☐	
Pavement failure	Shoulder ☐	1 Lane ☐	2 Lane ☐	Total ☐
Other				

General Condition	**1**	**2**	**3**	**4**	**5**	**Comments**
Cracks						**1** No cracks, **2** Single **3** >1 not connected, **4** >1 connected, **5** Interconnected (crocodile)
Crack Type						**1** No cracks, **2** Longitudinal **3** Transverse, **4** Block, **5** Parabolic
Ruts						**1** None, **2** <15mm **3** 15-50mm, **4** >50mm
Potholes						**1** None, **2** <2 / 20m road **3** 2-5 / 20m road, **4** >5 / 20m road
Patches						**1** None, **2** <2 / 20m road **3** 2-5 / 20m road, **4** >5 / 20m road
Corrugations						**1** None, **2** <15mm **3** 15-50mm, **4** >50mm
Stripping Extent						1 None, 2 <10% area **3** 10-50% area, **4** >50% area

Deterioration

Normal ☐ Currently active ☐ Potential increase ☐

Deterioration consequences:____

Damage causes

Downslope failure ☐	Uplsope failure ☐	Bank erosion ☐	Structure failure ☐
Sub-grade failure ☐	Materials problem ☐	Drainage failure ☐	

Data Sheet A4.1: Pavement Problem Sheet 2/2

Road Link:	Chainage (km) From To :	Site ID:

Cross Section

Condition Sketch

Scale	Drain (L)	Shoulder (L)	Carriageway Left	Carraigeway Right	Shoulder (R)	Drain (R)

Engineer	Date

Sheet A4.2: Pavement Problem Definition- Decisions 1/1

Road name:	**Site Ref ID**

Issue	**Decisions**
A Immediate Action Review	1.Road clearance – further action required □ 2.Further emergency problem control □ 3.Ammend immediate risk control actions □ 4. Revise short term engineering actions □
B Geotechnical Assessment	1. Failure/deterioration mode established □ 2 Failure boundaries defined □ 3. Failure cause identified□ 4. Failure active □ 5. Failure likely to reactivate in next monsoon □
C Preliminary Risk Assessment	1. Hazard: 1.Large □ II. Medium □ III. Small □ 2. Consequence a. High□ b. Medium □ c. Low □ 3 Risk _______________ 4. Hazard-risk assessment satisfactory □
D Strategic Options	1.Problem avoidance □ 2.Treat as a Slope Problem □ 3.Debris control □ 4.Bank Protection □ 5. Pavement repair □
E Division Remedial Response	1.No further action □ 2.Extend existing measures □ 3.Additional DRO standard options □ 4.Non-standard measures identified □ 5.Undefined measures required □
F Budget Assessment	1.Solution within Division □ 2.Budget request defined engineering works □ 3.Budget request for DRO controlled technical/engineering services □ 4.Budget request for specialist technical/engineering services □
G Analysis	1.Failure has been caused by slope stability problems □ 2 Failure has been cause by erosion problem □ 3 failure has been caused by structural problem □
H Further Site Investigations	1.Desk study □ 2.Pavement condition survey □ 3.Sub-surface investigation □ 4.Laboratory testing □ 5.In situ testing □ 6 Other □

Decisions Agreed By	**Date**

Sheet A4.3: Pavement Problem Definition – Actions 1/2

A: Immediate Action Review

A1 √: implement further road clearing (see Sheet A1)
X: No action except monitoring

A2 √: see sheet A1
X: No action except monitoring

A3 √: see sheet A1
X: No action except monitoring

A4 √: Review requirement options based on Slope Assessment data
X: No action except monitoring

B. Geotechnical Assessment

B1 √. Use for solution selection and engineering options
X. Further assessment required

B2 √. Use in assessment of hazard scale and engineering option assessment
X. Further assessment required – initially by detailed walkover.

B3 √ Use in assessing effectiveness of available options
X. Further site work required – essential for appropriate remedial work assessment

B4 √ Immediate actions not effective; emergency action if high hazard/risk.
X. Monitor

B5 √ Plan stabilisation measures. Advise GESU if high risk outside DRO budget.
X. Monitor

C. Preliminary Risk Assessment

C1-C2 Use Risk Assessment Matrix to identify preliminary risk C3

C3	Ia,Ib,IIa:	Probably require budget/ technical support through GESU
	Ic,IIb,IIc, IIIa,IIb:	Probable DRO action within ARMP
	IIIc.	Routine.

C4 √. No further action. Use in budget/plan justification
X. Further investigation – see Guidelines Annex B

Sheet A4.3: Pavement Problem Definition – Actions 2/2

D. Strategic Options

D1 √. Realignment– see general option A in Options Matrix

D2 √. Bio-engineering a likely option See general options E on Options Matrix

D3 √ Bio-engineering a likely option See general options F on Options Matrix

D4 √.Solution should also involve bank erosion problem issues.

D5 √. Solution should also involve slope problem issues.

E. Division Remedial Response

E1 √. Monitoring

E2 √. Only after assessing these measures meet strategic and risk requirements

E3 √ Use standard DRO designs only after assessing these measures meet requirements

E4 √. Probable request for budget or technical advice through GESU

E5 √. Site investigation required.

F. Budget Assessment

F1 √. Mobilise stabilisation through appropriate works orders

F2 √. Prepare detailed cost estimate. Request support through GESU

F3 √. Prepare outline cost estimate and ToR for services and submit through GESU

F4 √.Prepare outline of requirements and budget estimate and submit through GESU

G. Stability Analysis:

G1 √.Use Slope Problem assessment and remedial procedures.

G2 √.Use Erosion Problem assessment and remedial procedures.

G3 √.Use Structural assessment and remedial procedures.

H. Further Site Investigations

H1 √. Collate all relevant data at DRO level and utilise procedures in Annex B1.

H2 √. Use standard procedures as per MRE manual or TRL ORN 16

H3 √. Define requirements and utilise procedures in Annex B4.

H4 √. Define requirements and utilise procedures in Annex B5.

H5 √. Define requirements and utilise procedures in Annex B4

H6 √. Define requirements

SHEET A5.1: Structural Problems Sheet 1/2

Road Link:	Chainage (km + m):	Site ID:

Geometry	Length of failed Structure (m):	Width at toe (m):
	General slope angle (deg):	Width at top (m):

Applied measures	Bioengineering work	Percentage area covered: …… %
	Trees ☐ Shrubs ☐ Grass ☐ Others ☐ ………………………………	
	Engineering work	Significance of damage: ☐ Plan area of damage: ☐ Percentage area covered: …….%

……………………………………………………………………………

S. No	Type of measure	Dimension (L x B x H)	Condition
1	………………………	…….x………..x………	…………….
2	………………………	…….x………..x………	…………….
3	………………………	…….x………..x………	…………….
4	………………………	…….x………..x………	…………….
5	………………………	…….x………..x………	…………….
6	………………………	…….x………..x………	…………….
7	………………………	…….x………..x………	…………….
8	………………………	…….x………..x………	…………….

For each distressed wall, fill in **Checklist for Distressed Retaining Walls**.

Coments:

Applied Drainage

Drainage type	Good condition	Needs clearing	Needs repair	Not present
Roadside drains				
Cascade drains				
Berm drains				
Catch drains				
Horizontal drains				
French drains				
Culvert chainage ……… + ………				
Culvert inlet				
Culvert outlet				
Culvert wingwalls				
Culvert passageway				

Hydrological condition	Seepage at slope face: Yes ☐ No ☐
	Natural surface runoff: Yes ☐ No ☐
	Ponding water nearby: Yes ☐ No ☐

Comments:

Pavement	Cracks: Yes ☐ No ☐	Cause: Pavement ☐ Slope failure ☐
	Cracks sealed: Yes ☐ No ☐	Depression: Yes ☐ No ☐
Shoulder	Shoulder cracks: Yes ☐ No ☐	Shoulder depression: Yes ☐ No ☐

In Situ Testing (undertaken –U; recommended- R)

Point load ☐ Schmidt hammer ☐ Vane shear ☐ Penetrometer ☐ DCP ☐

Samples: -Number Taken

Small disturbed	☐	Large disturbed	☐
Undisturbed	☐	Intact Rock	☐

SHEET A5.1: Structural Problems Sheet 2/2

CHECKLIST FOR DISTRESSED RETAINING WALLS						
General	Chainage	Wall type	Ref. No.		Logged by	Date
Geometry	Exposed height over distressed length (m)		Maximum		Minimum	Critical
	Plan shape of distressed length		Convex		Concave	Straight
	Filling stone material		Available		N/A	Haulage dist
	Culvert or causeway present ?		No		Yes	Type
	Total length of distressed section (m):					
Distresses	Crest cracks	No.	Max hor disp (mm)	Cumulative (mm)	Max ver disp (mm)	Cumulative (mm)
	Face cracks	No.	Max width (mm)	Average angle from horizontal (º)	Other face damage ?	
	Bulges	In plan?	Max (mm)	In section?	Max (mm)	Height (m)
	Tilting	Significant ?	Crest with respect to toe	Sub vertical	Near vertical	Overhang
	Monitoring results?	Available?	Start date	Movement	Stopped	Continuing
Others	Previous seepage signs?	Yes	No	Seepage through wall	Yes	No
	Probable foundation material		Slope angle below wall (º)	Signs of distress in ground below toe	Yes	No
REMARKS:						
CRITICAL CROSS SECTION		Referred drawing No.				

Sketch Plan		
L	CL	R

Sheet A5.2: Structural Problems – Decisions 1/1

Road name:	**Site Ref ID:**

Issue	**Decisions**
A Immediate Action Review	1.Road clearance – further action required ☐ 2.Further emergency problem control ☐ 3.Ammend immediate risk control actions ☐ 4. Revise short term engineering actions ☐
B Geotechnical Assessment	1.Geological/Geotechnical model established ☐ 2.Failure mode established ☐ 3. Failure boundaries defined ☐ 4.Failure cause and trigger mechanism identified☐ 5. Failure active ☐ 6. Failure likely to reactivate in next monsoon ☐
C Preliminary Risk Assessment	1. Hazard: 1.Large ☐ II. Medium ☐ III. Small ☐ 2. Consequence a. Large ☐ b. Medium ☐ c. Slight ☐ 3 Risk ________________ (Refer Procedure Sheet B2.1) 4. Hazard-risk assessment satisfactory ☐
D Strategic Options	1.Problem Avoidance ☐ 2.Reduce driving force ☐ 3.Repair existing structure ☐ 4.Construct new structure ☐
E Division Remedial Response by Division	1.No further action ☐ 2.Extend existing measures ☐ 3.Additional DRO standard options ☐ 4.Non-standard measures identified ☐ 5.Other measures required ☐
F Budget Assessment	1.Solution within Division ☐ 2.Budget request for defined engineering works ☐ 3.Budget request for technical/engineering services by DRO ☐ 4.Budget request for specialist technical/engineering services ☐
G Analysis	1.Failure has been caused by slope stability problems ☐ 2 Failure has been cause by erosion problem ☐ 3.Engineering structure analysis is required ☐
H Further Site Investigations	1. Desk study ☐ 2. Topographic survey ☐ 3.Geotechnical mapping ☐ 4.Sub-surface investigation ☐ 5. Laboratory testing ☐ 6.In situ testing ☐ 7. Other ☐

Decisions Agreed By	**Date**

Sheet A5.3: Structural Problems - Actions 1/2

A: Immediate Action Review

A1 √: implement further road clearing (see Sheet A1)
X: No action except monitoring

A2 √: see sheet A1
X: No action except monitoring

A3 √: see sheet A1
X: No action except monitoring

A4 √: Review requirement options based on Slope Assessment data
X: No action except monitoring

B. Geotechnical Assessment

B1 √. Use model in hazard and stabilisation assessment and as input to analysis
X. Further investigation required– see Guideline Section Annex B

B2 √. Use in stability analysis and engineering option selection
X. Further assessment required – initially by detailed walkover

B3 √. Use in assessment of hazard scale and engineering option assessment
X. Further assessment required – initially by detailed walkover; possible use of RS

B4 √ Use in assessing effectiveness of available options
X. Further site work required – essential for appropriate stabilisation work assessment

B5 √ Immediate actions not effective; emergency action if high hazard/risk.
X. Monitor

B6 √ Plan stabilisation measures. Advise GESU if high risk outside DRO budget.
X. Monitor

C. Preliminary Risk Assessment

C1-C2 Use Risk Assessment Matrix to identify preliminary risk C3

C3	Ia,Ib,IIa:	Probably require budget/ technical support through GESU
	Ic,IIb,IIc, IIIa,IIb:	Probable DRO action
	IIIc.	Routine.

C4 √. No further action. Use in budget/plan justification
X. Further investigation – see Guidelines Annex B

Sheet A5.3: Structural Problems - Actions 2/2

D. Strategic Options

D1 √. Realignment or remove problem – see Options Matrix

D2 √. See general options B on Options Matrix

D3 √ Use standard DoR procedures

D4 √. Assess possible options – use Option Matrix and Annex C

E. Division Remedial Response

E1 √. Monitoring

E2 √. Only after assessing these measures meet strategic and risk requirements

E3 √ Use standard DRO designs only after assessing these measures meet requirements

E4 √. Probable request for budget or technical advice through GESU

E5 √. Site investigation required

F. Budget Assessment

F1 √. Mobilise stabilisation through appropriate works orders

F2 √. Prepare detailed cost estimate. Request support through GESU

F3 √. Prepare outline cost estimate and ToR for outsourcing services and submit to GESU

F4 √.Prepare outline of requirements and budget estimate and submit to GESU

G. Stability Analysis

G1 √. Use Slope Problem assessment and remedial procedures.

G2 √. Use Erosion Problem assessment and remedial procedures.

G3 √.Use standard structural assessment procedures

H. Further Site Investigations

H1 √. Define requirements and mobilise DRO topographic survey team

H2 √. Collate all relevant data at DRO level and utilise procedures in Annex B1.

H3 √. Define requirements and utilise procedures in Annex B3.

H4 √. Define requirements and utilise procedures in Annex B4.

H5 √. Define requirements and utilise procedures in Annex B5

H6 √. Define requirements and utilise procedures in Annex B4

H7 √. Define requirements

Site Data Sheet A1: Site Definition

Road name and road link: Use standard accepted names.

Chainage: Include chainage of the problem area.

Site ref ID: Unique reference number (road link designation / chainage at middle of site)

Co-ordinates: Include only when possible with GPS.

Section: Indicate size and location of problem with respect to the road.

Traffic: Estimate actual disruption and how long blockage will last. Obtain data on daily traffic flow.

Rainfall: Based on local knowledge. Obtain from nearest rainfall station.

Preliminary problem identification: Tick identified problems using the following guide:

Routine: Problem likely to be solved under routine maintenance budget and procedures. Drains and berms filled by slide material.

Moderate: Problem will require input from DRO engineers before solution identified. Slide material deposited at road.

Severe: Problem likely to require significant investigation and design input. A part of road formation is taken by slide affecting traffic flow.

Problem history: Based on any previous known problems at this site from DRO or DOR documents.

Impacts: Tick relevant "actual" column and also any additional or potential risk related to the

problem in the "risk" column.

Vegetation: General types, for example: trees (tropical, deciduous or coniferous); grass; shrubs.

Land use: For example: - barren, cultivated, forest, built up or quarry etc.

Hydrology: Tick appropriate box for current condition.

Previous or existing engineering solutions: Enter year of any engineering or bio-engineering construction.

Sketches: Both section and plan to show key features. Include a rough scale.

Photograph references: Include enough information to identify the photographs.

Site Data Sheet A2: Slope Problem

Location: Use the same identification references as used on the **Sheet A1**.

Failure Type: Tick the appropriate boxes. If there is a complex slide tick more then one box and under VII list the appropriate type e.g. IIa, VIb etc. This classification is the standard used in most existing slope manuals; see **Figure 1**.

Failure geometry: This detail is required for any possible stability analysis as well as back analysis. See **Figure 2** for guidance. In some cases, a best estimation will be required. The geometry should be plotted to the scale and Cartesian coordinates of key points should be noted for input to the appropriate slope stability model.

Failure Condition: Tick the appropriate boxes.

NOTE: For both failure geometry and failure condition it is essential that the engineer walks extensively over the site.

Landform: Tick the appropriate general geomorphological zone – see **Figure 3** for guidance.

Note also the general natural slope angle in the vicinity of the problem slope and whether or not there are similar failures.

Geological zone: Tick the appropriate general geological environment.

Bedrock: This a estimation of general bedrock type, If the bedrock is interbedded sandstone and mudstone for example, tick the appropriate boxes and **also** under **RgB** list RgS1 and RgS3 .

Soil Types: Tick the appropriate boxes.

Failure in / failed material: Tick appropriate boxes

Separate detailed sheets: Tick if required

General Rock condition: Only to be filled out if the failure took place in **rock.**

Weathering: This is an estimation of the weathering condition of the rock in which the failure took place. See **Table 2** for guidance.

Rock mass condition: This is an estimation of the mass condition of the rock in which the failure took place.

Intact rock strength: This is an estimation of the strength of the rock in which the failure took place. See **Table 1** for guidance.

Discontinuity types: Tick appropriate box to indicate types present in the rock mass in which the failure took place.

Faults: Note orientation of faults that influence the failure.

Discontinuities: To be filled out as indicted in the example below only if the discontinuities have a influence, or potential influence on the failure:

Discontinuities	Dip (deg)	Dip Direction (deg)	Persistence (m)	Spacing (m)	Dilation	Infilling	Roughness
F0							
B							
J1							
J2							
J3							
Failure plane							

Additional visual description: Additional notes on the rock type.

General Soil Condition: Only to be filled out if the failure took place in **Soil**

Classification: Distinguish between the condition and nature of the soil in situ and the soil in the failed mass debris. Tick the appropriate boxes using the following Unified Soil Classification System and the strength guide in **Table 1**.

Additional visual description: additional notes on the soil types.

Slope Failure Triggers: Identify one or more triggers for the failure.

Bio-engineering work: Tick appropriate box or boxes for existing bio-engineering work carried out at the failure site

Engineering work: Identify and list the existing engineering works carried out at the failure site

Summary of condition: Supply detail on the dimensions and condition of engineering works at the failure, eg Intact; damaged, failed.

In situ testing: Mark **U** (undertaken) or **R** (recommended) in the appropriate boxes.

Samples taken: Note the number of samples taken at the site

Photograph references: Include enough information to identify the photographs.

Sketches: Both section and plan in enough detail to define the site together in conjunction with the slope geometry data and photographs. Include a rough scale.

Site Data Sheet A3: Erosion Problem

Location: Use the same identification references as used on the **Sheet A1**

Slope definition: Fill in the appropriate spaces or tick boxes to define the nature of the slope affected by the erosion problem

Problem: Tick appropriate box; see **Figure 1** for guidance.

Sheet / rill erosion: Tick appropriate boxes and fill in data on rill dimensions, see **Figure 4** for guidance. Dimensions should be average for the affected slope

Gully erosion: Tick appropriate boxes and fill in data using **Figure 5** for guidance. Dimensions should be average for the affected slope.

River scour: Tick appropriate boxes and fill in data using **Figure 6** for guidance.

Landform: Tick the appropriate general geomorphological zone – see **Figure 3** for guidance.

Note also the general natural slope angle in the vicinity of the problem slope and whether or not there are similar failures.

Geological zone: Tick the appropriate general geological environment

Bedrock: This a estimation of general bedrock type, If the bedrock is interbedded sandstonefand mudstone for example, tick the appropriate boxes and **also** under RgB list RgS1 and and RgS3

Bio-engineering work. Tick appropriate box or boxes for existing bio-engineering work carried out at the failure site

Engineering work: Identify and list the existing engineering works carried out at the failure site

Summary of condition: Supply detail on the dimensions and condition of engineering works at the failure, eg Intact; damaged, failed.

Drainage condition: Particular attention needs to be paid to drainage, particularly with respect to rill and gully erosion. Make an assessment of the condition of existing drainage under the given headings

In situ testing: Mark **U** (undertaken) or **R** (recommended) in the appropriate boxes.

Samples taken: Note the number of samples taken at the site

Photograph references: Include enough information to identify the photographs.

Sketches: Both section and plan in enough detail to define the site together with the slope geometry and photographs. Include a rough scale

Site Data Sheet A4: Pavement Problem

Location: Use the same identification references as used on the **Sheet A1**

Pavement geometry: This should define the character of the pavement length containing the problem. Fill in required data or tick the appropriate boxes.

Pavement design: This section summarises the pavement composition above sub-grade. A general description is sufficient under “material” ; eg “Crushed alluvium aggregate” or “Stone Chip Seal” etc.

Pavement damage: This is a general assessment of the damage to the pavement in the area in question. Surface damage includes cracking and deterioration not resulting from normal traffic induced deterioration. “Pavement failure” is the total failure of part or all of the pavement. See **Figure 7** for examples

General condition: This summarises the general background condition of the pavement in the region of the failure but not confined specifically to the failed area. See **Table 3** and **Figure 8** for guidance.

Deterioration: Tick appropriate box to give an indication of the potential problem and its consequence.

Damage causes: tick appropriate box

Sketches: Both section and plan. The plan should detail the nature and extent of the damage.

Photograph references: Include enough information to identify the photographs.

Table A1 Soil and Rock Strength Estimations

Key	Description	Field Test	Shear Strength (kN/ms)
	Soil		
S1	Very soft soil	Easily moulded with fingers	<20
S2	Soft soil	Easily penetrated by thumb. Moulds with light finger pressure	20-40
S3	Firm soil	Penetrated by thumb. Moulded with strong finger pressure. Cut with spade	40-75
S4	Stiff soil	Indented by thumb. Cannot be moulded with fingers. Requires hand pick for excavation	75-150
S5	Very stiff to hard soil	Indented by thumbnail. 15mm penetration by knife. Difficult to excavate with hand pick	150-600
	Rock		**Compressive Strength (MN/m2)**
R1	Very weak rock	Easily broken by hand. Penetrated to about 5mm with knife.	0.6-1.25
R2	Weak rock	Broken by leaning on sample with a hammer. No penetration with knife. Scratched with thumbnail	1.25-5.0
R3	Moderately weak rock	Broken in hand with a hammer. Scratched with a knife.	5.0-12.5
R4	Moderately strong rock	Broken against solid object with hammer	12.5-50
R5	Strong rock	Many blows of a hammer to fracture sample	50-200
R6	Very strong rock	Sample can only be chipped with hammer	>200

Table A2 Rock Weathering Descriptions

Term	Description	Grade
Fresh	No visible sign of rock material weathering.	I
Slightly weathered	Discolouration of rock material and discontinuity surfaces	II
Moderately weathered	Less than half of the rock material is decomposed or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework or as corestones	III
Highly weathered	More than half of the rock material is decomposed or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework or as corestones	IV
Completely weathered	All of the rock material is decomposed or disintegrated to a soil. The original mass structure is intact	V
Residual soil	All the material is converted to a soil. The mass structure and material fabric are destroyed	VI

Table A3 Pavement Failure Modes

Failure Mode	Code	Criteria
Overall Condition	1	No visible defects. As built condition
	2	A few minor defects
	3	Isolated moderate defects – patching
	4	Significant defects – overlay
	5	Severe defects – total road rehabilitation
Cracks	1	No cracks
	2	Single
	3	> 1 not connected
	4	> 1 connected
	5	Interconnected (crocodile)
Ruts	1	None
	2	<15mm
	3	15-50mm
	4	> 50mm
Edge Failures > 150mm	1	None
	2	<10% length
	3	10-50% length
	4	> 50% length
Potholes	1	None
	2	< 2 per 20m road
	3	2-5 per 20m road
	4	>5 per 20m road
Crack Type	1	No cracks
	2	Longitudinal
	3	Transverse
	4	Block
	5	Parabolic

Failure Mode	Code	Criteria
Patches	1	None
	2	< 2 per 20m road
	3	2-5 per 20m road
	4	> 5 per 20m road
Corrugations	1	None
	2	< 15mm
	3	15-50mm
	4	> 50mm
Stripping Extent	1	None
	2	< 10% area
	3	10-50% area
	4	> 50% area
Bleeding	1	None
	2	< 10% area
	3	10-50% area
	4	> 50% area
Surface Texture	1	Smooth – intact sand seal
	2	Slightly coarse – fine aggregate shows
	3	Coarse – chippings dominate

Figure A1: Slope Failure Types

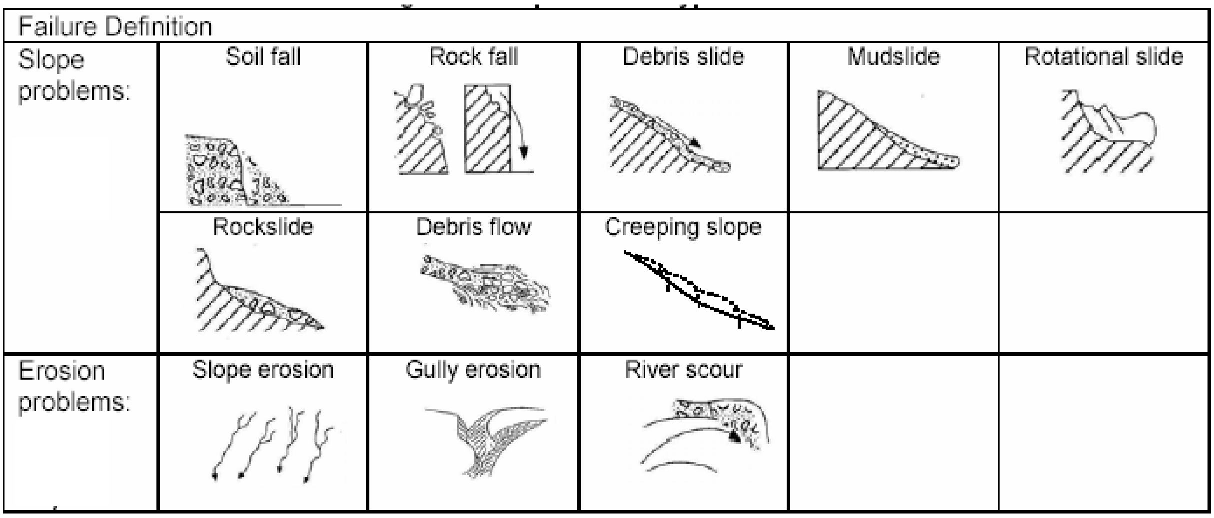


Figure A2: Slope Geometry Dimensions

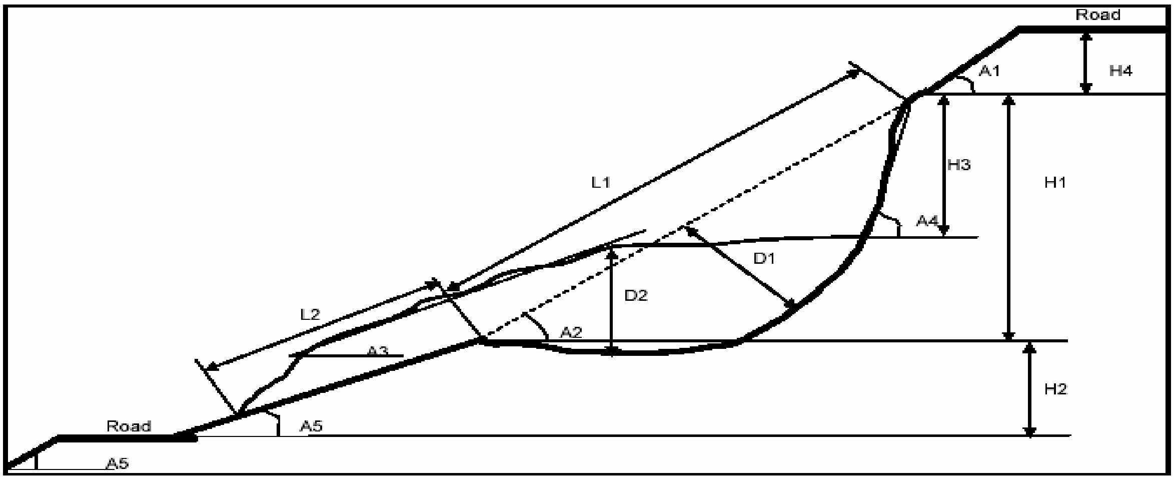


Figure A3: General Geomorphological Zones

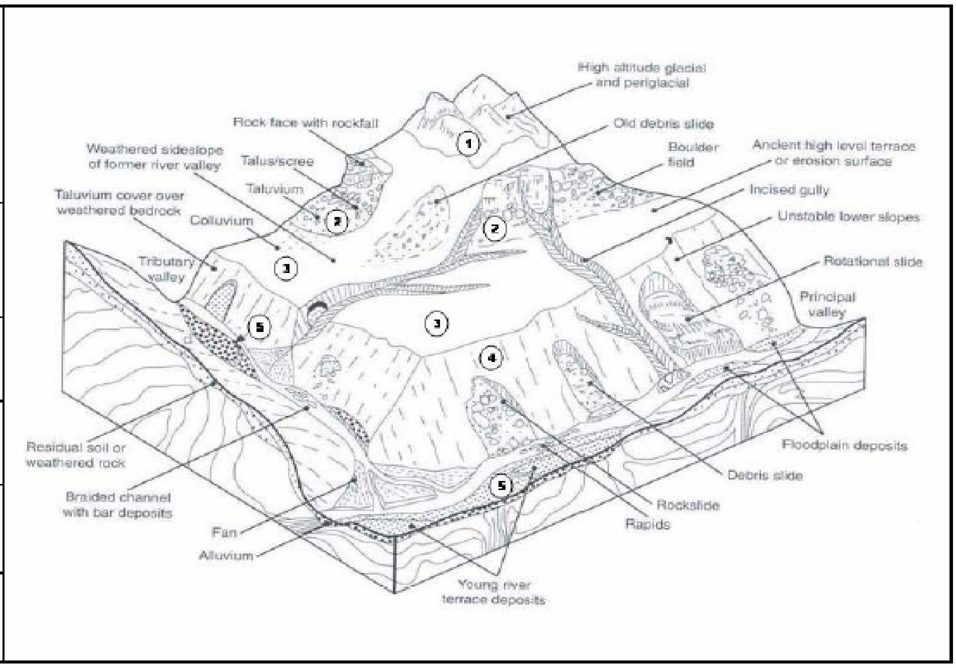
Physiographic region: Landform type:	
Zone 1: High altitude glacial and periglacial	
Zone 2: Free rock face and associated debris slope	
Zone 3: Degraded mid-slope and ancient valley floor	
Zone 4: Unstable lower slope	
Zone 5: Valley floor	

Figure A4: Rill Dimensions

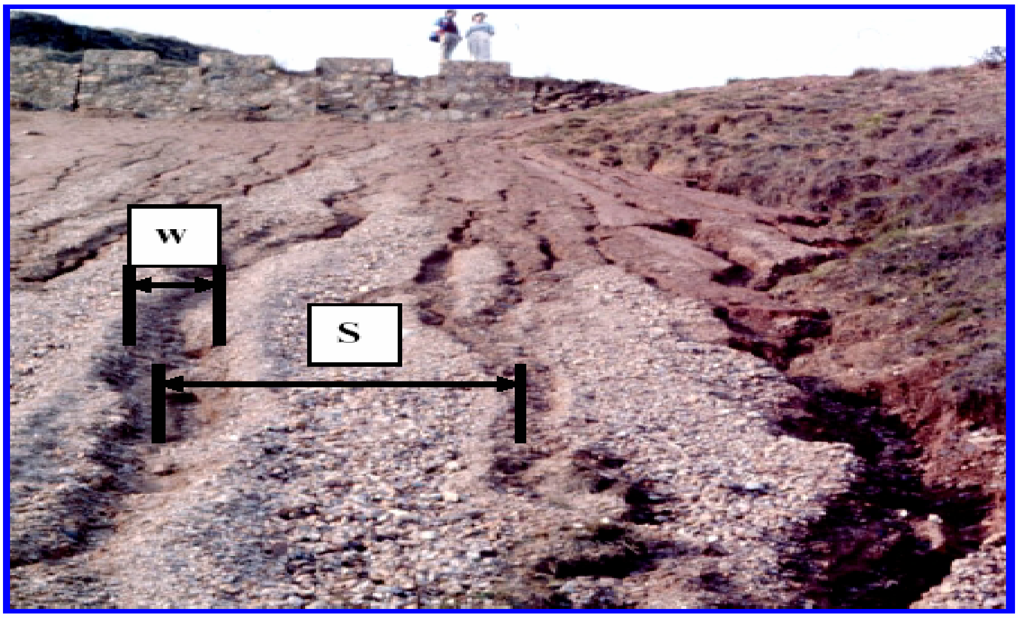


Figure A5: Gully Dimensions

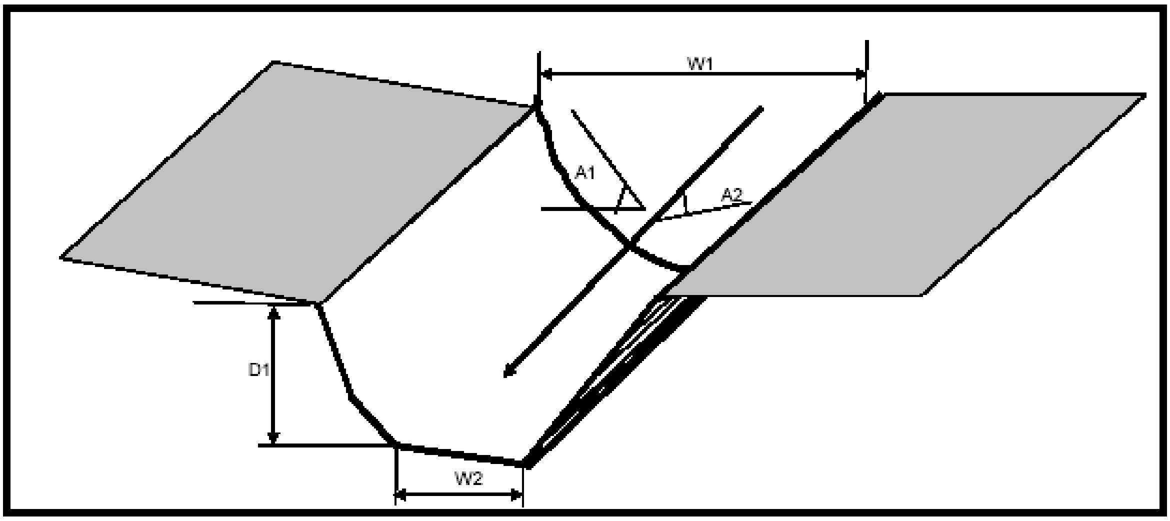


Figure A6: River Scour Dimensions

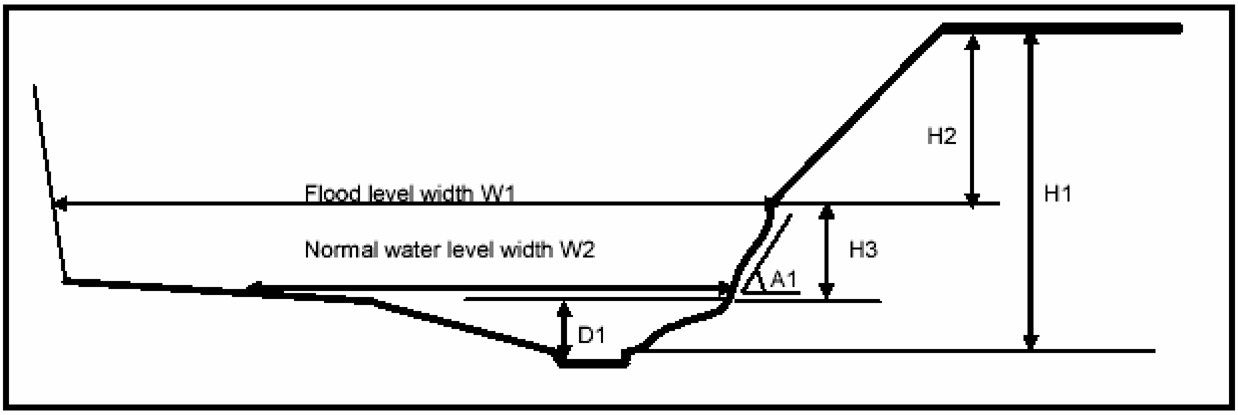


Figure A7: Pavement Damage

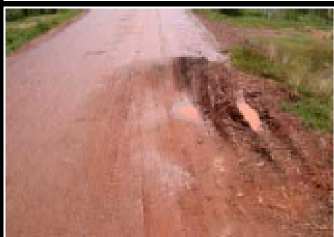
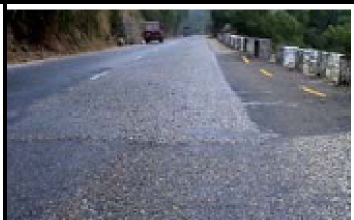
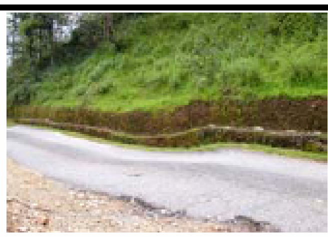
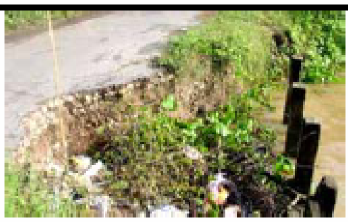
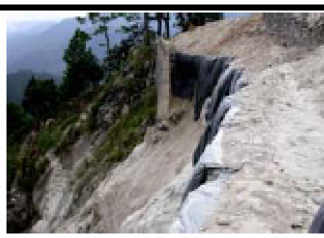
	Slight	Moderate	Severe
Surface Damage			
Depression			
Carriageway Failure			

Figure A8: Pavement Crack Type

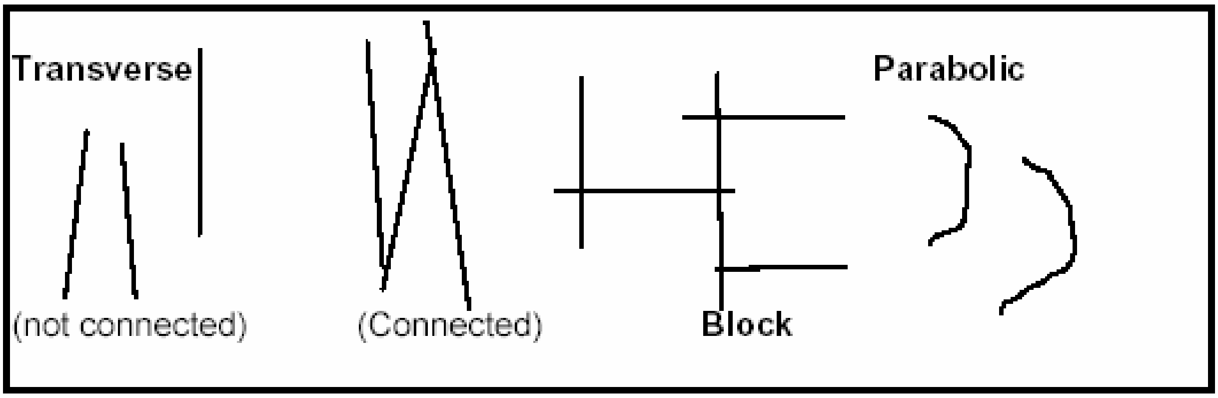


Figure A9: Cut and Fill Dimensions

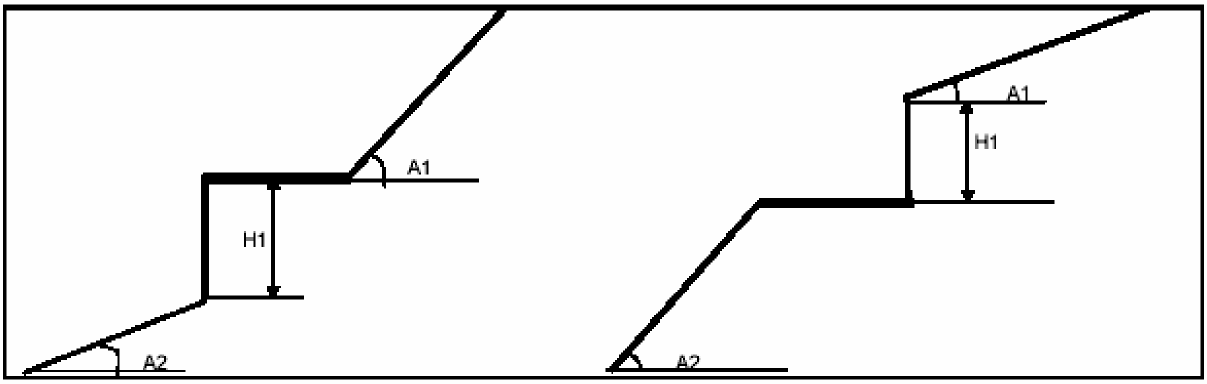
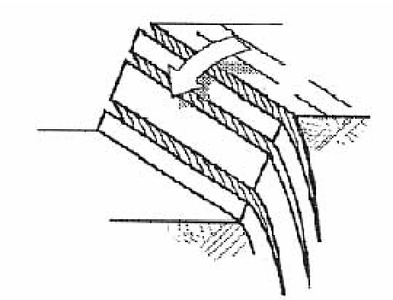


Figure A10: Failures Illustrations

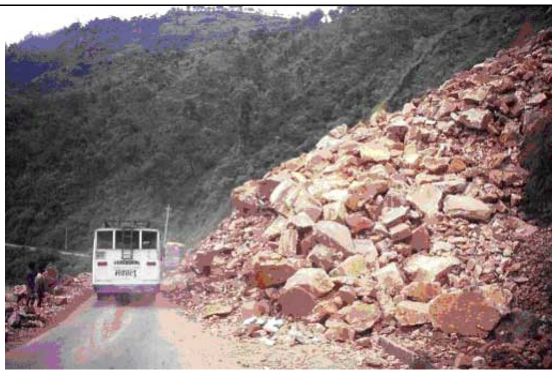
Rock Fall



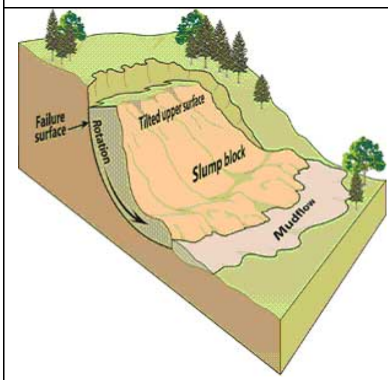
Toppling Failure Schematic

Toppling Failure

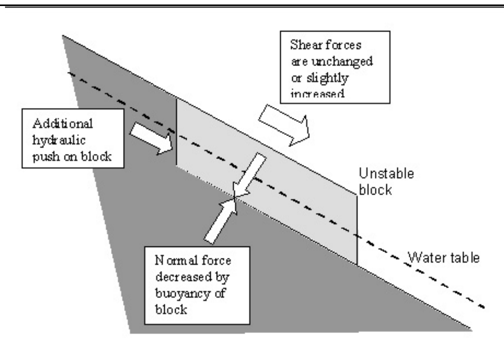
Translational Slide in Rock



Rock Slide Debris

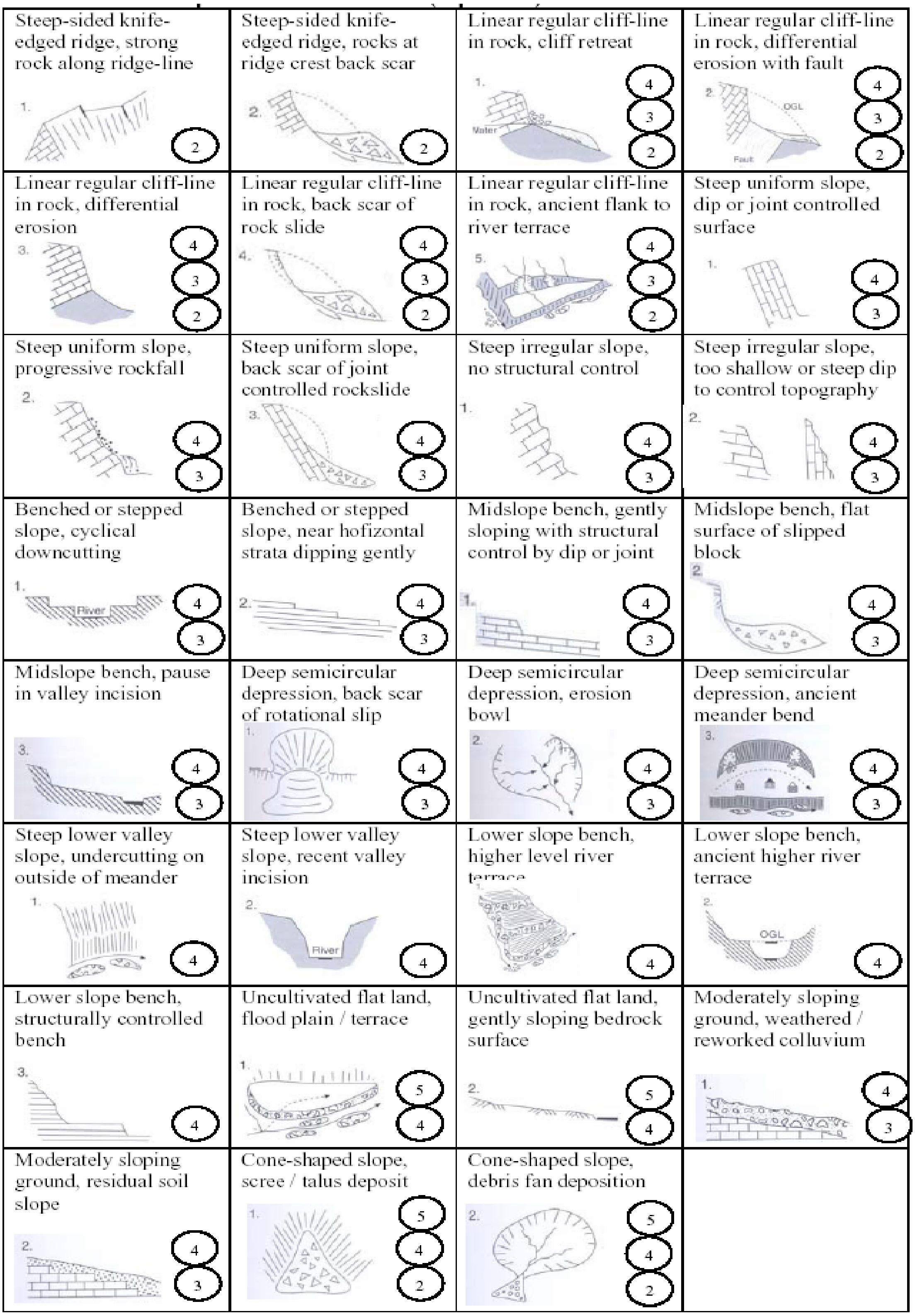


Translation Slide in Soil



Rock Block Sliding Mechanism

Figure A11: Nepal Landforms Sheet



Source: TRL Road Note 16

Note: The zone numbers correspond to those of **Figure 3**.

Road-side Geotechnical Problems
A Practical Guide to their Solution

Part II: Guideline Annexes

Annex B: Geotechnical Assessment Procedures

Procedure Sheet. B1.1 Document Review

Procedure

The aim of a document review is to collect available information relating to the identified geotechnical problem and to incorporate this into the solution process. Problem specific data should be gathered under the following general headings:

General site characteristics

For example

Geomorphology	Rainfall ,	Seismic risk
Geology	Catchment areas	Flood data

Site engineering characteristics

For example:

Engineering history	Previous problems	Traffic
Construction details	Road design	

Geotechnical characteristics

For example

Laboratory tests	Soil-rock properties	Previous analyses, if any
Previous investigation data		

Potential solutions

For example

Previous works	Available solutions	Costs

The Initial step should be to identify an existing department files and technical notes on the problem area held at the DRO or by the GESU. Other likely sources of relevant information are:

Technical reports	Maintenance records
Construction records	Site maps
Geological maps	Topographic maps
Relevant manuals/guides	Government records(climate/hydrology)
University departments	Technical papers

Key References

British Standards 1981. Code of Practice for Site Investigations. BS5930. .British Standards Institution

GEO 1996. Guide to Site Investigation. Geoguide 2. Hong Kong Government

GEO 2000 Highway Slope Manual. Geotechnical Engineering Office, Civil Engineering Department, Hong Kong

Lawrence C., Byard R.1993.Terrain Evaluation Manual TRL State of Art Review 7

Procedure Sheet. B1.2 **Remote Sensing and Aerial Photograph Interpretation**

Procedure Summary

Techniques in which the ground is examined and assessed using images or data collected from the air or space are known collectively as remote sensing and relate to mainly vertical air photo and satellite imagery. They can provide extremely useful data and offer considerable advantages for the mapping of large landslide problems and their geotechnical and geomorphological environments. Remote sensing has particular usefulness in the selection of route alignments in conjunction with terrain evaluation procedures. The Landslide Risk Assessment manual discusses remote sensing in detail and its uses are summarised as

Landslide detection:	Hazard Factor mapping:
Land use interpretation and classification:	Vulnerability assessment:
Landslide monitoring	Terrain evaluation

DRO engineers are unlikely to be directly involved in satellite imagery work, however it is possible that in some large instability or erosion problems could involve them in the use of aerial photo interpretation. The LRA manual describes aaerial photograph interpretation as an extremely useful multi-purpose technique for identifying and evaluating route corridor options, that in particular it can provide information on the following factors:

- Topography (cliffs, river terraces, steep slopes, gullies and streams);
- Landslide mapping (source and run out areas, interpretation of mechanisms and causes by comparison with other terrain factors);
- Erosion mapping (slope and river bank erosion);
- Broad distinction between rock outcrop, residual soil, colluvium and alluvium
- Structural orientations;
- Land use; and
- Rate of change in drainage patterns, erosion and landslide. (By interpretation of successive photography).

Aerial photographs are usually taken vertically, in a strip of overlapping views (called a “run”) commonly at scales of 1:30,000 - 1:50,000. When two adjacent photographs are viewed in a viewing stereoscope, the terrain can be seen as a three dimensional model. Aerial photographs when used in conjunction with geological and soils maps form an excellent tool for obtaining general site information, particularly in difficult access sites. They are best used in conjunction with topographic and geological maps to help build up a complete engineering or terrain picture. A disadvantage is that the scale of the picture is not consistent so measurements taken off the photograph are only approximate.

For more complete reference on remote sensing and aerial photograph interpretation, reference should be made to TRL Road Note 16 and Landslide Risk Assessment in the Rural Access Sector.

Key References

Deoja B. et al (eds)1991.Mountain Risk Enginering Handbook. ICIMOD, Kathmandu, Nepal.

Lawrence C., Byard R.1993 Terrain Evaluation Manual. TRL State of Art Review 7.

Scott Wilson Kirkpatrick (2004) Landslide Risk Assessment in the Rural Access Sector. DFID-DoR Manual. Chapter 2

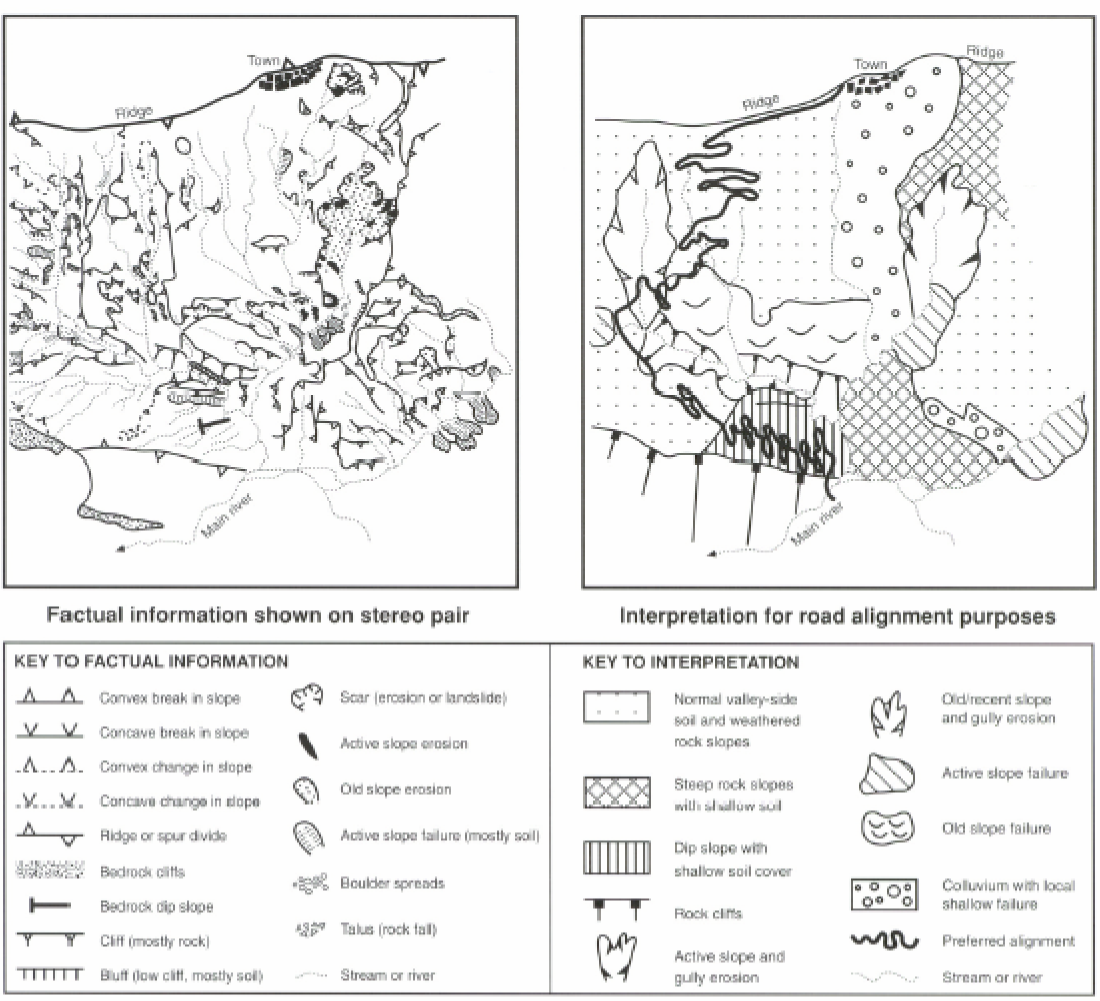


Figure B1.2.1 Aerial Photograph Interpretation of Road Alignment Study

(Source: TRL Road Note 16)

Procedure Sheet. B2.1 Initial Hazard and Risk Assessment

Procedure

A simple and straightforward assessment of hazard and consequent risk is essential at an early stage in the assessment of an actual roadside problem as part of its solution strategy. The following matrix approach is recommended, in which three levels of hazard are compared against the consequences of the hazard occurring, as shown below:

	Hazard		
Consequence	I-High	II – Medium	III. Low
Major a	Ia	IIa	IIIa
Medium b	Ib	IIb	IIIb
Slight c	Ic	IIc	IIIc

The problem **risk** may then be semi-quantitatively considered as **Hazard x Consequence** and related to the general DRO approach to the problem, as follows:.

Risk	**DRO Action**
High: Ia; Ib; IIa	Likely to require DoR/GESU investigation and/or design input
Moderate: Ic; IIb;IIc;IIIa;IIIb	Likely to handled by DRO engineers; although specific cases may require budget support
Slight IIIc	Routine

Precise definitions of hazard may be modified and become more detailed depending on the scale and phase of investigations, but the accompanying Table B2.1.1 provides some guidance. Consequences may be considered in terms of one or more of: socio-economics; risk to life; engineering cost or political impact.

More detailed approaches to hazard and risk, more closely allied to the requirements of planning or route alignment are outlined in Annex B2.2.

Key References

Deoja B. et al (eds)1991.Mountain Risk Engineering Handbook. ICIMOD, Kathmandu, Nepal.

Scott Wilson Kirkpatrick (2004) Landslide Risk Assessment in the Rural Access Sector. DFID-DoR Manual. Chapter 3 & Appendix 2

Table B2.1.1 Guideline for Hazard Types and Hazard Groups

	Hazard Groups		
Hazard Type	**High I**	**Medium II**	**Low III**
Slope Instability	Large failure or area of instability. Likelihood of continuing recurring problem	Moderate slip or slides failure. Indications of larger potential problem	Minor slip or some minor instability indications. Isolated rock fall or soil slips
Erosion	Serious erosion problems having current and ongoing impact on road	Significant erosion impacting on road	Minor erosion not directly impacting on road
Pavement	Complete failure	Partial failure of carriageway	Minor failures eg potholing, undulations. Failure not impacting or likely to impact on traffic
Structure	Complete failure of significant structures directly impacting on road	Failure of individual or some small structures	Signs of distress in structure. etc

Table B2.1.2 Guideline for Consequences

	Consequences		
Categories	**Major a**	**Medium b**	**Slight c**
Conditions	The road formation may fail at a significant length creating a condition of total road blockage without major intervention. Major investment likely to reinstate road formation	A part of road formation may fail creating difficulty in vehicular flow. One way operation with adequate traffic safety may reinstate services.	Debris may be deposited at road formation or road shoulder may fail. Two way operation of traffic can be promptly managed after clearing of slide debris.

Procedure Sheet. B2.2 Detailed Hazard and Risk Assessment

Summary

Both the Landslide Risk Assessment and Mountain Engineering Handbook documents include procedures for the assessment of hazard and risk relating to landslides occurring within a particular area rather than dealing with specific existing problems. This approach should be adopted when considering lengths of existing alignment or for investigation into new alignments. Their general approach is based on rating of key impacting factors. These factors can either be summed or used to produce hazard and risk maps. This latter approach is also outlined in Overseas Road Note 16 (TRL 1997). In the case of the Mountain Engineering Handbook the key factors are:

Rock slopes

Rock structure	Relief	Hydrogeology	Drainage
Rock type	Weathering	Faulting/folding	Land use

Soil slopes

Slope angle	Relief	Water content	Drainage
Soil type	Soil thickness	Land use	Faulting/folding

Each factor is given a score depending its status and the probability of an event (slide, flow or gully erosion) is ranked from low to very high based on the total factor score. (see Mountain Risk Engineering Handbook Tables 23.2 -23.4)

The LRA document recognised that although a large number of factors can influence landslide occurrence they are often difficult to reliably investigate and analyze even on a slope by-slope basis, and therefore the prospect of incorporating them effectively into desk study-based landslide susceptibility mapping is extremely limited. The LRA approach was therefore to evaluate the impact of a wide range of factors on existing slides and identify a limited number of key factors having a significant influence. The result was firstly a two-fold scheme based on Rock Type and Slope Angle and a secondly a four-fold scheme including in addition Structural Orientation and Terrain. The latter is only practical if remote sensing resources were available. The two-fold and four-fold schemes are reported as being successful in accounting for mapped landslide distributions. The two-fold scheme can be applied early on in rural access corridor planning, while the four-fold scheme is intended for more detailed analysis, perhaps once a corridor is chosen or when comparisons need to be made between corridor alternatives. Thus the two-fold scheme is more applicable to regional or district planning, while the four-fold scheme has a greater engineering application. Both schemes are described in Appendix 3.to the LRA document

Key References

Deoja B. et al (eds)1991.Mountain Risk Engineering Handbook. ICIMOD, Kathmandu, Nepal.

Scott Wilson Kirkpatrick (2004) Landslide Risk Assessment in the Rural Access Sector. DFID-DoR Manual. Chapter 3 and Appendix 3

TRL 1997 Principles of Low Cost Road Engineering in Mountainous Regions, ORN 16 Transport Research Laboratory, Crowthorne, UK

Procedure Sheet. B3.1 Engineering Geological or Geotechnical Mapping

Engineering geological mapping is the visual portrayal of an area or site in terms of its engineering parameters, which may or may not be coincident with its geological boundaries. Its aim should be to produce a map or plan on which units are defined by engineering properties or behaviour and whose limits are determined by changes in the physical or mechanic properties of the materials. It should document surface conditions to provide a basis for projecting surface conditions and to assist the engineer in understanding key factors that must be accommodated in designing problem solutions. For the case of individual problems, such as landslides, the most common application of mapping is to divide the site up into individual units of similar character in order to apply relevant and specific engineering solutions, as was undertaken at the Jogimara Landslide (SWK, 1994)

Engineering geological mapping must characterise the site in terms that are meaningful to the engineer. The production of an engineering geological map or plan that will work will require the input of a specialist engineering geologist or geotechnical engineer. The DRO, GESU or whoever is commissioning the work should clearly define the mapping requirements within a Terms of Reference including the extent of the mapping; its objective, the scale required; and the contents of the map

The extent of the mapping should be sufficient to cover not only the immediate problem but also the likely zone of influence. For example when mapping a landslide the areas susceptible to further failure upslope and the potential run-out zones down-slope may have to be included.

In terms of specific roadside problems mapping should be large scale - 1: 1000 - 1:500 or even larger depending on the site. Mapping suitable for route realignments may be of the order of 1:10,000. Typical examples of engineering logical and geotechnical mapping are included in the Mountain Engineering Handbook. A check list for items to be included in a mapping ToR is presented below.

For more detailed engineering geological and geotechnical mapping, reference should be made to TRL Road Note 16 and Landslide Risk Assessment in the Rural Access Sector.

Engineering Geological Mapping Check List

General

Objectives	Scale	Extent	Cross-sections

Detail (a function of the problem requirements)

Soil types	Rock types	Soil/rock boundaries
Slope angles	Bedding	Faults/folds
Geotechnical properties		Instability dimensions
Geotechnical units	Terrain units	Vegetation
Failure boundaries	Debris boundaries	Tension cracks
Erosion boundaries	Streams	Springs/seepages
Drainage	Structures	River beds
Flood limits	Topographic Contours	Roads
Hazard units	Breaks of slope	Quarries

Key References

Deoja B. et al (eds)1991.Mountain Risk Engineering Handbook. ICIMOD, Kathmandu, Nepal.

Anon1972. The preparation of maps and plans in terms of engineering geology.QJEG, 5, 293-381

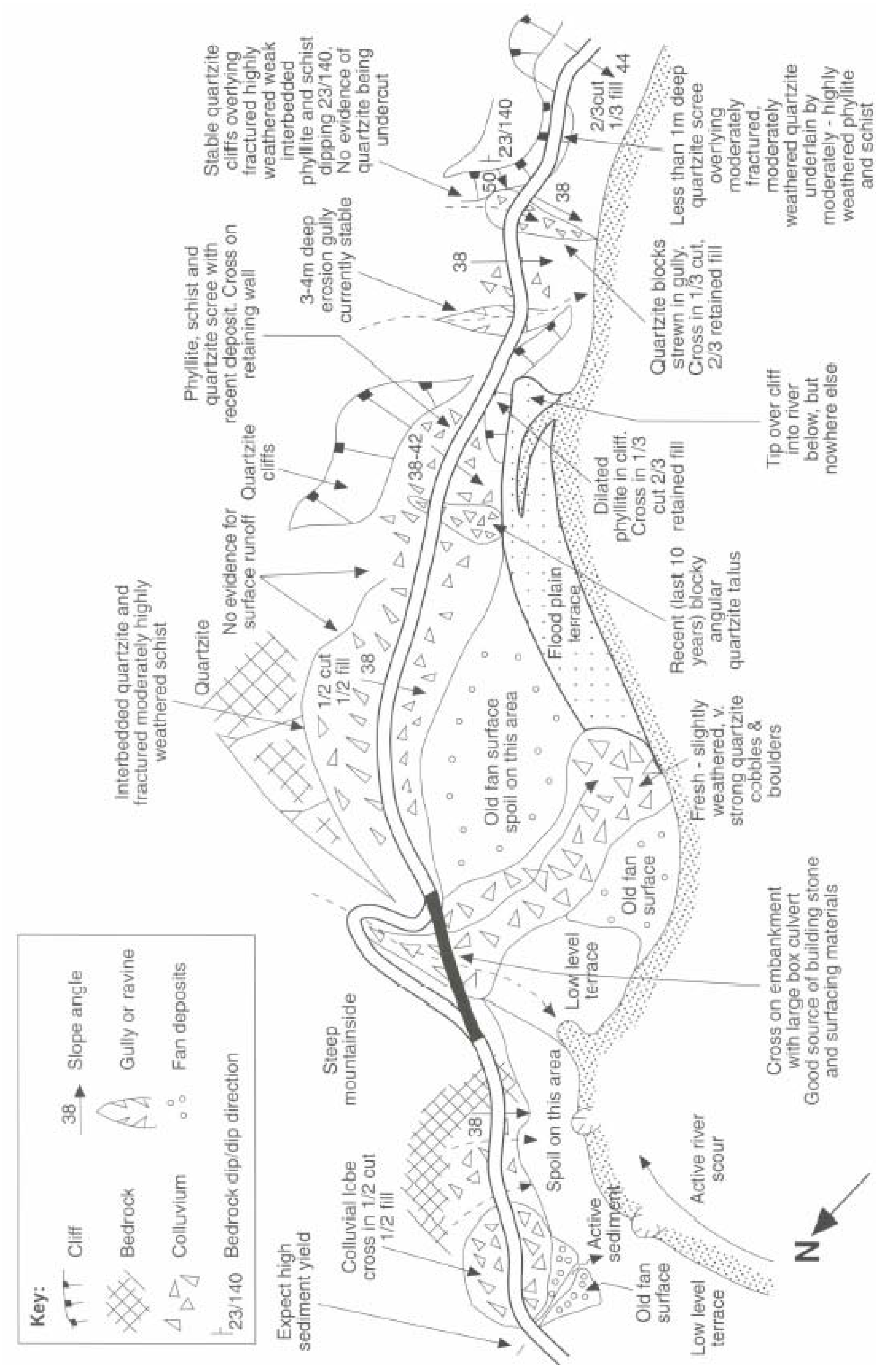


Figure B.3.1.1 Engineering Geological Map for Road Alignment Study

(Source: TRL Road Note 16)

Procedure Sheet. B3.2	**Soil and Rock Classification- Description**

It may be sufficient to classify the main soil and rock types by means of the check-boxes as shown on Data Forms A2-A5. However in cases where geotechnical problems require more detailed examination it will be necessary to describe the relevant soils and rock in a systematic and standards format, The section and table below provide guidance in this procedure.

Description Check Lists

The following items are a basic check list for soil description

Moisture state	Dry; moist; wet; saturated.
Colour	Use colour chart if available - main colours Table B3.2.1
Strength	Table B3.2.2
Fabric-Texture	Particle size; B3.2.3; Shape B3.2.4
Plasticity	Table B3.2.5:
Mineralogy	eg quartzitic; calcareous
SOIL TYPE	Table B3.2..6

Other engineering terms

The following items are a basic check list for rock description

Colour	Use colour chart if available **-** main colours Table B3.2.1
Grain size	Table B3.2..3
Texture-Fabric	Particle shape Table B3.4; Bedding Table B3.2..7
Weathering state	Table B3.2.8

Subsidiary characteristics (eg calcareous)

Estimated strength	Table B3.2.2
ROCK NAME	General rock type Table B3.2.9

Other engineering terms

Key References

British Standards 1981. Code of Practice for Site Investigations. BS5930. British Standards Institution

GCO.1988.Guide to Rock and Soil Descriptions. Geoguide 3. Hong Kong Government

Geological Society (UK) 1977. The description of rock masses for engineering purposes: Working Party Report.QJEG.

Colour value			Chroma		Hue
1	light	a	pinkish	A	pink
2	medium	b	reddish	B	red
3	dark	c	yellowish	C	yellow
		d	brownish	D	brown
		e	olive	E	olive
		f	greenish	F	green
		g	blueish	G	blue
		h	greyish	H	grey
				I	White
				J	Black

Table B3.2.1 Main Colour Descriptions

Key	Description	Field Test	Shear Strength (kN/m^2)
	Soil		
S1	Very soft	Easily moulded with fingers	<20
S2	Soft	Easily penetrated by thumb. Moulds with light finger pressure	20-40
S3	Firm	Penetrated by thumb. Moulded with strong finger pressure. Cut with spade	40-75
S4	Stiff	Indented by thumb. Cannot be moulded with fingers. Requires hand pick for excavation	75-150
S5	Very stiff to hard	Indented by thumbnail. 15mm penetration by knife. Difficult to excavate with hand pick	150-600
	Rock		**Compressive Strength (MN/m^2)**
R1	Very weak	Easily broken by hand. Penetrated to about 5mm with knife.	0.6-1.25
R2	Weak	Sample broken by leaning with a hammer. No penetration with knife. Scratched by thumbnail	1.25-5.0
R3	Moderately weak	Broken in hand with a hammer. Scratched with a knife.	5.0-12.5
R4	Moderately strong	Broken against solid object with hammer	12.5-50
R5	Strong rock	Many blows of a hammer to fracture sample	50-200
R6	Very strong	Sample can only be chipped with hammer	>200

Table B3.2.2 Soil-Rock Strength

Size Limits (mm)	Description
>60	Very coarse grain (cobble-boulder)
60-2.00	Coarse grain (gravel)
2.0-0.006	Medium grain (sand)
0.006-0.006	Fine grain (silt)
<0.006	Very fine grain (fine silt-clay)

Table B3.2.3 Particle Size Definition

Shape	Description
Angularity	Angular
	Sub-angular
	Sub-rounded
	Rounded
Form	Equidimensional
	Flat
	Elongated
	Flat and elongated
	Irregular
Surface Texture	Rough
	Smooth

Table B3.2.4 Particle Shape

Term	Definition
Non-plastic	A roll 40mm long and 6mm thick cannot be formed
Slightly plastic	A roll 40mm long and 6mm thick can be formed and will support its own weight. One 4mm thick will not.
Moderately plastic	A roll 40mm long and 4mm thick can be formed and will support its own weight. One 2mm thick will not
Very plastic	A roll 40mm long and 2mm thick can be formed and will support its own weight

Table B3.2.5 Plasticity

<table>
<tr><td rowspan="8">Coarse grained soils
> 50% visible by naked eye</td><td rowspan="4">Gravelly soils
> 50% material above 6mm size</td><td rowspan="2">Clean gravel
No dirt stain in wet palm</td><td>Well graded gravel
Wide grain size range</td><td>GW</td></tr>
<tr><td>Poorly graded gravel
Narrow grain size range</td><td>GP</td></tr>
<tr><td rowspan="2">Dirty gravel
Leaves dirt stain in wet palm</td><td>Silty gravel
Non-plastic fines</td><td>GM</td></tr>
<tr><td>Clayey gravel
Plastic fines</td><td>GC</td></tr>
<tr><td rowspan="4">Sandy soils
> 50% material below 6mm size</td><td rowspan="2">Clean sand
No dirt stain in wet palm</td><td>Well graded sand
Wide grain size range</td><td>SW</td></tr>
<tr><td>Poorly graded sand
Narrow grain size range</td><td>SP</td></tr>
<tr><td rowspan="2">Dirty sand
Leaves dirt stain in wet palm</td><td>Silty sand
Non-plastic fines</td><td>SM</td></tr>
<tr><td>Clayey sand
Plastic fines</td><td>SC</td></tr>
</table>

<table>
<tr><td rowspan="7">Fine grained soils
> 50% not visible by naked eye</td><td>Tests</td><td>Odour</td><td>Dry strength</td><td>Dilantancy</td><td>Toughness</td><td>Ribbon</td><td>Appearance</td><td></td></tr>
<tr><td rowspan="3">Silts and Clays
low LL</td><td>none</td><td>low</td><td>rapid</td><td>low to none</td><td>none</td><td>dull</td><td>ML</td></tr>
<tr><td>none</td><td>medium to high</td><td>medium to slow</td><td>medium</td><td>weak</td><td>slight to shiny</td><td>CL</td></tr>
<tr><td>Pronounced organic</td><td>medium</td><td>slow to none</td><td>low (spongy)</td><td>none</td><td>dull to slight</td><td>MH</td></tr>
<tr><td rowspan="3">Silts and Clays
high LL</td><td>none</td><td>medium</td><td>very slow to none</td><td>medium to high</td><td>weak to strong</td><td>slight</td><td>CH</td></tr>
<tr><td>none</td><td>very high</td><td>none</td><td>high</td><td>strong</td><td>shiny</td><td>OL</td></tr>
<tr><td>Pronounced organic</td><td>high</td><td>none</td><td>low to medium (spongy)</td><td>weak</td><td>dull to slight</td><td>OH</td></tr>
<tr><td>Highly organic soils</td><td colspan="7">Readily identified by colour, odour, spongy feel and fibrous structure</td><td>Pt</td></tr>
</table>

Table B3.2.6 Field Identification of Soils

Spacing (m)	Definition
>2.0	Very widely spaced
2.0-0.6	Widely spaced
0.6-0.2	Medium spaced
0.2-0.06	Closely spaced
0.06-0.02	Very closely spaced
<0.02	Extremely closely speced

Table B3.2.7 Bedding Spacing

Term	Description	Grade
Fresh	No visible sign of rock material weathering.	**I**
Slightly weathered	Discolouration of rock material and discontinuity surfaces	**II**
Moderately weathered	Less than half of the rock material is decomposed or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework or as corestones	**III**
Highly weathered	More than half of the rock material is decomposed or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework or as corestones	**IV**
Completely weathered	All of the rock material is decomposed or disintegrated to a soil. The original mass structure is intact	**V**
Residual soil	All the material is converted to a soil. The mass structure and material fabric are destroyed	**VI**

Table B3.2.8 Weathering State

Table B3.2.9 Rock Types -Igneous

Field relations	Texture	Grain size	Acid	Intermediate	Basic	Ultra basic
			Light coloured rocks	Light/dark coloured rocks	Dark coloured rocks	Dark coloured rocks
Intrusive		Very coarse grained 60 mm	Rock consists of very large and often well developed crystals of quartz, feldspar, mica and frequently rare minerals PEGMATITE			
	Crystalline	Coarse grained 2 mm	At least 50% of the rock is coarse grained enough to allow individual minerals to be identified.			Rock is coarse grained and dark in colour (dull green to black) with a granular texture. It contains olivine and augite in abundance but no feldspars. PERIDOTITE
			Rocks is light coloured with an equigranular texture *majority of grains approximately the same size) and contains >20% quartz with feldspar in abundance. GRANITE	Rock may be medium to dark in colour with a more or less equigranular texture and contains <20% quartz with feldspar and hornblende in abundance DIORITE	Rock is dark coloured and often greenish with abundant plagioclase (about 60%) and augite together with some olivine. The rock usually feels dense. GABBRO	
		Medium grained 0.06 mm	At least 50% of the rock is medium grained. Crystal outlines are generally visible with the aid of a hand lens but individual minerals may be difficult to identify.			Rock is greyish green to black with a splintery fracture when broken and generally feels soapy or waxy to the touch. It is often criss-crossed by veins of fibrous minerals and/or banded. SERPENTINITE
			Rock is similar in appearance to granite but the crystals are generally much smaller MICRO-GRANITE	Rock is similar in appearance to diorite but the crystals are generally much smaller MICRO-DIORITE	Rock is dark coloured and often greenish with a granular texture. Individual minerals may be difficult to identify. The rock usually feels dense. DOLERITE	
Extrusive	Crystalline/Glassy	Fine grained	At least 50% of the rock is fine grained. Outlines of crystals are not usually visible even with the aid of a hand lens. All rocks in this category may be vesicular.			
			Rock is light coloured (often pale reddish brown or pinkish grey) and may be banded. RHYOLITE Rock is light coloured with a very low specific gravity and highly vesicular PUMICE	Rock is medium to dark in colour (shades of grey, purple, brown, or green) and frequently porphyritic ANDESITE	Rock is black when fresh and becomes red or green when weathered. The rock is often vesicular and/or amygdaloidal. BASALT	
	Glassy	Glassy	Rock is glassy and contains few or not phenocrysts. It is often black in colour and has a characteristic vitreous lustre and conchoidal fracture. OBSIDIAN Rock is glassy and contains few or no phenocrysts. It may be black, brown or grey in colour with a characteristic dull or waxy lustre. PITCHSTONE			

Table B3.2.10 Rock Types –Sedimentary

Group Usual structure			Detrital sediments Bedded	
Grain size		Composition and texture		
			Quartz, rock fragments, feldspar, and other minerals	At least 50% of the rock is composed of carbonate minerals (rocks usual react with dilute HCI).
Granular	Coarse grained 2 mm	Rudaceous	Rock is composed of more or less rounded grains in a finer grained matrix CONGLOMERATE Rock is composed of angular or sub-angular grains in a finer grained matrix BRECCIA	CALCI-RUDITE
Granular	Medium-grained 0.60 mm	arenaceous	Rock is composed of: (i) mainly mineral and rock fragments SANDSTONE (ii) 95% quartz. The voids between the grains may be empty or filled with chemical cement. QUARTZ SANDSTONE (iii) 75% quartz and rock fragments and up to 25% feldspar (grains commonly angular). The voids may be empty or filled with chemical cement. ARKOSE (iv) 75% quartz and rock fragments together with 15% ÷ fine detrital material AGRILLACEOUS SANDSTONE	CALCI-ARENITE
Smooth	Fine-grained 0.002 mm	Argillaceous	Rock is composed of at least 50% fine-grained particles and feels slightly rough to the touch. SILTSTON	CALCI-SILTITE
Smooth	Fine-grained 0.002 mm	Argillaceous	Rock is homogeneous and fine-grained. Feels slightly rough to smooth to the touch. MUDSTON	
Smooth	Fine-grained 0.002 mm	Argillaceous	Rock has same appearance and feels as mudstone but reacts with dilute HCI. CALCAREOU MUDSTON	CHALK (Bioclastic)
Smooth	Very fine grained	Argillaceous	Rock is composed of at least 50% very fine-grained particles and feels smooth to the touch. CLAYSTON	CALCI-LUTITE
Smooth	Very fine grained	Argillaceous	Rock is finely laminated and or fissile. It may be fine or very fine grained SHAL	

Table B3.2.11 Rock Types - Metamorphic

Fabric Grain size	Foliated	Massive
Coarse-grained	Rock appears to be a complex intermix of metamorphic schists and gneisses and granular igneous rock. Foliations tend to be irregular and are best seen in field exposure: MIGMATITE	Rock contains randomly orientated mineral grains (fine-to coarse-grained). Foliation, if present, is poorly developed. This rock type is essentially a product of thermal metamorphism associated with igneous intrusions and is generally stronger than the parent rock. HORNFELS
	Rock contains abundant quartz and/or feldspar. Often the rock consists of alternating layers of light coloured quartz and/or feldspar with layers of dark coloured biotite and hornblende. Foliation is often best seen in field exposures: GNEISS	Rock contains more than 50% calcite (reacts violently with dilute HCl), is generally light in colour with a granular texture MARBLE
2 mm Medium-grained	Rock consists mainly of large platey crystals of mica, showing distinct subparallel or parallel preferred orientation. Foliation is well developed and often undulose: SCHIST	If the major constituents is dolomite instead of calcite (dolomite does not react immediately with dilute HCl), then the rock is termed a: DOLOMITIC MARBLE
	Rock consists of medium- to fine grained platey, prismatic or needle-like minerals with a preferred orientation. Foliation often slightly nodulose due to isolated larger crystals which give rise to a spotted appearance: PHYLLITE	Rock is medium to coarse-grained with a granular texture and is often banded. This rock type is associated with regional metamorphism: GRANULITE
0.06 mm Fine-grained	Rock consists of very fine grains (individual grains cannot be recognized in hand specimen) with a preferred orientation such that the rock splits easily into thin plates: SLATE	Rock consists mainly of quartz (96%) grains which are generally randomly orientated giving rise to a granular texture: QUARTZITE (METAQUARTZITE)

Procedure Sheet. B3.3 Soil-Rock Mass Assessment

For many soil and rock problems it may be necessary to describe and classify materials at a mass or zonal scale. Formal rock mass classifications can be a useful tool for the purpose of dividing a relevant rock mass, such as a landslide, into zones of similar engineering behaviour. These classifications incorporate information on the strength of the intact rock material, the spacing, number and surface properties of the structural discontinuities as well as allowances for the influence of subsurface groundwater, and the orientation of dominant discontinuities.

Although originally developed for use in underground rock engineering projects such as tunnels and power station caverns, rock mass classification systems have proved to be very useful practical engineering tools for classifying rock masses in general. They not only provide a starting point for assessment or subdivision of a problem mass but also help to focus engineers on the appropriate examination of the properties of the rock mass in a very systematic manner. Informed engineering judgments can be made as a result of the familiarity and understanding gained from this systematic study.

Typical of these classifications is Rock Mass Rating (*RMR*) system originally published by Bieniawski in 1974 and which over the years has been successively refined as more case records have been examined to its current form (Bieniawski,1989).The following six parameters are used to classify a rock mass using the *RMR* system:

1. Uniaxial compressive strength of rock material.
2. Rock Quality Designation (*RQD*).
3. Spacing of discontinuities.
4. Condition of discontinuities.
5. Groundwater conditions.

6. Orientation of discontinuities.

In applying this classification system, the rock mass is divided into a number of structural regions and each region is classified separately. The boundaries of the structural regions usually coincide with a major structural feature such as a fault or with a change in rock type. In some cases, significant changes in discontinuity spacing or characteristics, within the same rock type, may necessitate the division of the rock mass into a number of small structural regions. The Rock Mass Rating system is presented in Table B3.3.1 and gives the ratings for each of the six parameters listed above. These ratings are summed to give a value of *RMR*. Rock Quality Designation is an important input to RMR system and a fuller description of this is presented in Table B3.3.2.and Figure 3.3.1, A worked RMR example is presented in Table B3.3.3

Key References

Bieniawski Z.T. 1989. Engineering Rock Mass Classifications. Wiley, New York. 251 pages.

Deere, D.U. 1989. Rock quality designation (RQD) after 20 years. U.S. Army Corps of Engineers Contract Report GL-89-1. Vicksburg, MS: Waterways Experimental Station.

Deoja B. et al (eds)1991. Mountain Risk Engineering Handbook. ICIMOD, Kathmandu, Nepal.

Palmström, A. 1982. The volumetric joint count - a useful and simple measure of the degree of rock jointing. Proc. 4th congr. Int. Assn Engng Geol., Delhi 5, 221-228.

Table B3.3.1 Bieniawski RMR System

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values						
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 – 10 MPa	2 – 4 MPa	1 – 2 MPa	For this low range – uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250 MPa	100 – 250 MPa	50 – 100 MPa	25-50 MPa	5 – 25 MPa	1 – 5 MPa	<1 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core Quality RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities		> 2 m	0.6 – 2 m	200 – 600 mm	60 – 200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (see E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 -25	25 – 125	> 125		
		(Joint water press)/(Major principal σ)	0	< 0.1	0.1 – 0.2	0.2 – 0.5	> 0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Rating	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	IV
Average stand up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 – 400	200 – 300	100 – 200	< 100
Friction angle of rock mass (deg)	>45	35-45	25-35	15-25	<15

E. GUIDELINES FOR CLASSIFICATION DISCONTINUITY CONDITIONS

Discontinuity length (persistence) Rating	<1 m 6	1 – 3 m 4	3 – 10 m 2	10 – 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1-1.0 mm 4	1-5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Rating	Unweathered 5	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip – Dip 45 90^0	Drive with dip – Dip 20 - 45^0	Dip 45 - 90^0	Dip 20 - 45^0
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip – Dip $45\text{-}90^0$	Drive against dip – Dip $20\text{-}45^0$	Dip 0-20 – Irrespective of strike	
Fair	Unfavourable	Fair	

Table B3.3.2 An Example of RMR Rating

A rock slope is composed of weathered granite with a dominant joint set dipping at a fair orientation. Index testing and logging of diamond drilled core give typical Point-load strength index values of 8 MPa and average *RQD* values of 70%. The slightly rough and slightly weathered joints with a separation of < 1 mm, are spaced at 300 mm. Conditions are anticipated to be wet. The *RMR* value is determined as follows :

Table Item	*Value Rating*
1 Point load index 8 MPa	12
2 *RQD* 70%	13
3 Spacing of discontinuities 300 mm	10
4 Condition of discontinuities Note 1	22
.5 Groundwater Wet	7
Adjustment for joint orientation Note 2	-25
Total RMR	**39**
	Class IV Poor Rock
	Mass Cohesion 100-200 KPa
	Mass Friction 15-25^0

Table B3.3.3 Definitions of RQD

The Rock Quality Designation index (*RQD*) was developed by to provide a quantitative estimate of rock mass quality from drill core logs. *RQD* is defined as the percentage of intact core pieces longer than 100 mm in the total length of core. The core should be at least NW size (54.7 mm in diameter) and should be drilled with a double-tube core barrel.

RQD is a directionally dependent parameter and its value may change significantly, depending upon the borehole orientation. When using diamond drill core, care must be taken to ensure that fractures, which have been caused by handling or the drilling process, are identified and ignored when determining the value of *RQD*. *RQD* is intended to represent the rock mass quality in situ.

Palmström (1982) suggested that, when no core is available but discontinuity traces are visible in surface exposures or exploration adits, the *RQD* may be estimated from the number of discontinuities per unit volume. The suggested relationship for clay-free rock masses is:

$RQD = 115 - 3.3\, Jv$,

where *Jv* is the sum of the number of joints per unit length for all joint (discontinuity) sets known as the volumetric joint count. The use of the volumetric joint count can be quite useful in reducing directional dependence of *RQD.* The correct procedures for measurement of the length of core pieces and the calculation of *RQD* are summarised in Figure B3.3.1. below

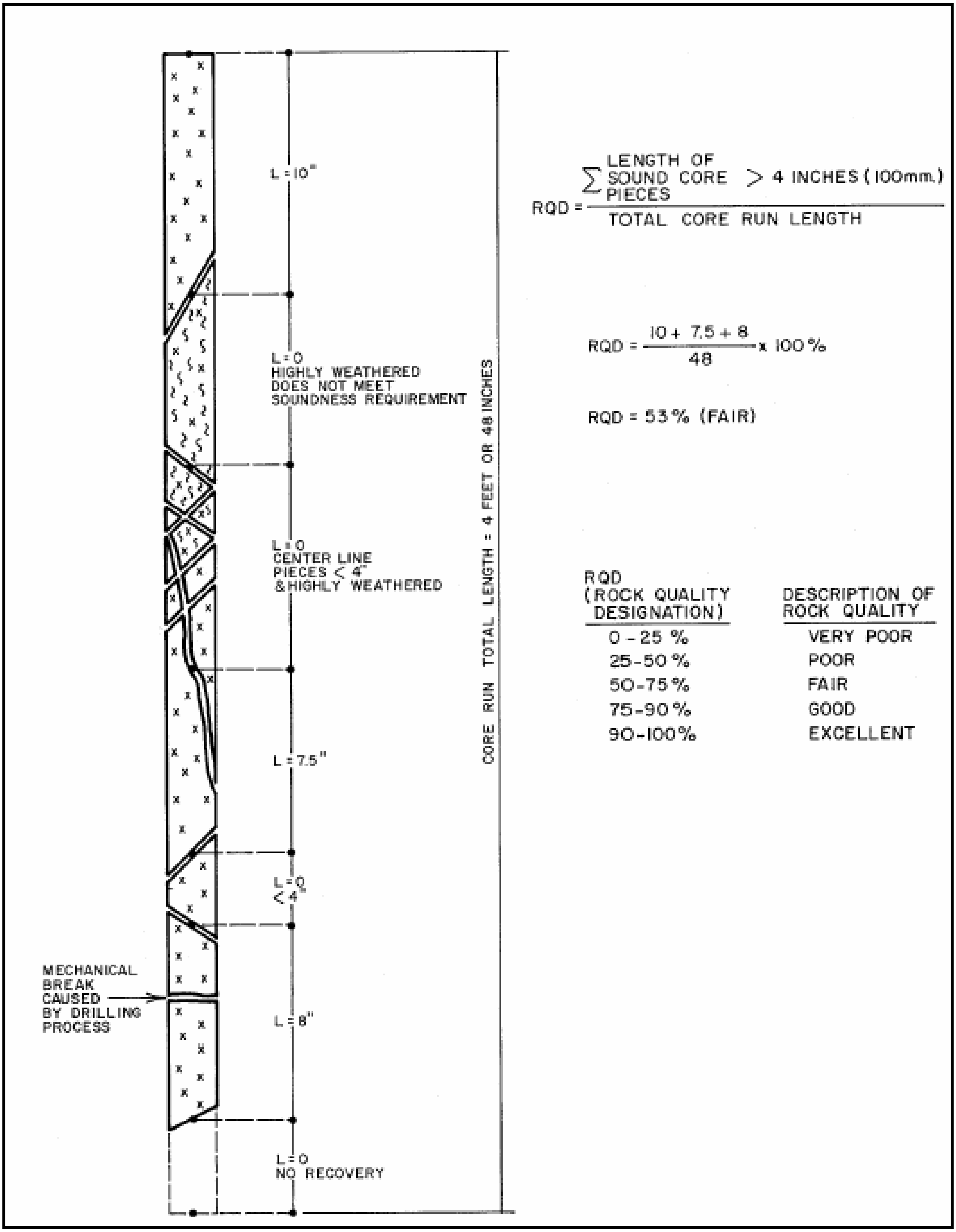


Figure B3.3.1 Schematic Representation of RQD

Procedure Sheet. B3.4 Discontinuity Surveys

In the surface assessment of rock masses it may be necessary acquire more detailed information on the nature and condition of discontinuities than that collected for the Slope Problem sheet. This procedure is likely to be required only for Phase 3 investigations and should be undertaken only by a suitably experienced geologist or geotechnical engineer. Such a survey involves the collection of information on the nature, orientation and condition of discontinuities as exposed on the surface of rock mass.

Typical information which should be collected would include:

1.Discontinuity type: fault; joint; bedding plane; shear plane

2 .Orientation: dip and dip direction/strike

3. Spacing/location; in detailed surveys the location along a scan-line is used to give this data

4 Persistence; the length of the discontinuity in exposure

5. Aperture; spacing between discontinuity walls

6. Infill: type of infill to discontinuity –if any

7. Roughness: roughness of discontinuity faces

Items 1 and 2 may be utilised to ascertain discontinuity patterns and these may be analysed and used as input into rock mass failure analyses. Items 3 to 7 supply information on the geotechnical condition of the discontinuities and hence the selection of suitable C and Ø vales for analysis.

Discontinuity surveying by scan line involves the logging of all discontinuities that cut a line or tape laid across a rock mass exposure. A survey should as far as possible be comprise a number of scan lines laid in an orthogonal pattern in order to get a statistically valid sample.

Orientation data from scan line surveys may be analysed using standard stereographic projection procedures to give summary patterns, Figure B3.4.1

Scan Line Survey Technique

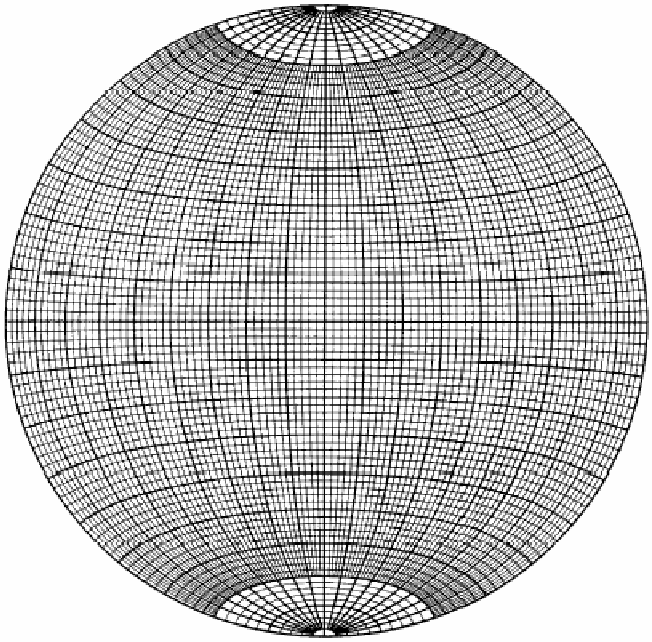
Discontinuity data can be collected using detail scan line survey methods. The detail line survey method provides spatial control necessary to accurately portray and analyze site discontinuities. Each geologic feature that intercepts a usually linear traverse is recorded. The traverse can be a 30m tape placed across an outcrop. In all cases, the alignment of the traverse and the location of both ends of the traverse should be determined. The mapper moves along the line and records everything. Feature locations are projected along strike to the tape and the distance is recorded. Regardless of the survey method, the mapper must obtain a minimum of 60 discontinuity measurements per rock type for confidence in subsequent analyses.

The orientation of a discontinuity can be recorded either as a strike azimuth and dip magnitude, preferably using the right-hand rule, or as a dip azimuth and magnitude. According to the right-hand rule, the strike azimuth is always to the left of the dip direction. The selected recording method should be used consistently throughout the survey. In order to compensate for line bias, a sufficient number of line surveys at a sufficient variety of orientations should be conducted to ensure that discontinuities of any orientation are intersected by at least one survey at an angle of at least 30 degrees. Common practice is to perform two surveys at nearly right angles or three surveys at radial angles of 120 degrees. True discontinuity spacing and trace lengths can be obtained by correcting the bias produced by line surveys.

All discontinuities should be recorded regardless of subtlety, continuity, or other property. Data collection should be systematic practicable and accessible or easily measurable discontinuities should not be preferentially measured. Consistency and completeness are best maintained if all measurements are taken by the same mapper and data are recorded on a form that prompts the mapper for the necessary descriptors. A form minimizes the probability of descriptor omission and facilitates plotting on an equal area projection, commonly the Schmidt net or entering data for subsequent analysis.

Computer programs are available that plot discontinuities in a variety of projections and perform a variety of analyses. Whether the plot format is the equal area projection (Schmidt net) or equal angle projection (Wulff net), evaluation of the plotted data requires an understanding of the method of data collection, form of presentation, and any data bias corrections.

Different rock types in the same structural terrain can have different discontinuity properties and patterns, and the host rock for each discontinuity should be recorded. This could be an important factor for understanding subsequent evaluations of tunneling conditions, rock slopes, or the in-situ stress field in underground openings. Figure 7-2 is a form that can be used to record the data in an abbreviated or coded format. Recording these data will provide the necessary information for determining RMR and Q.



Equatorial Equal Area Net (Schmidt Net)

Key References

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International Society for Rock Mechanics. 1981. Rock characterisation, testing and monitoring - ISRM suggested methods. Oxford: Pergamon.

Matheson C.D.1988. The collection and use of field discontinuity data in rock slope design. TRL Report

Figure B3.4.1 Stereographic Plot of Discontinuities Using DIPS Programme

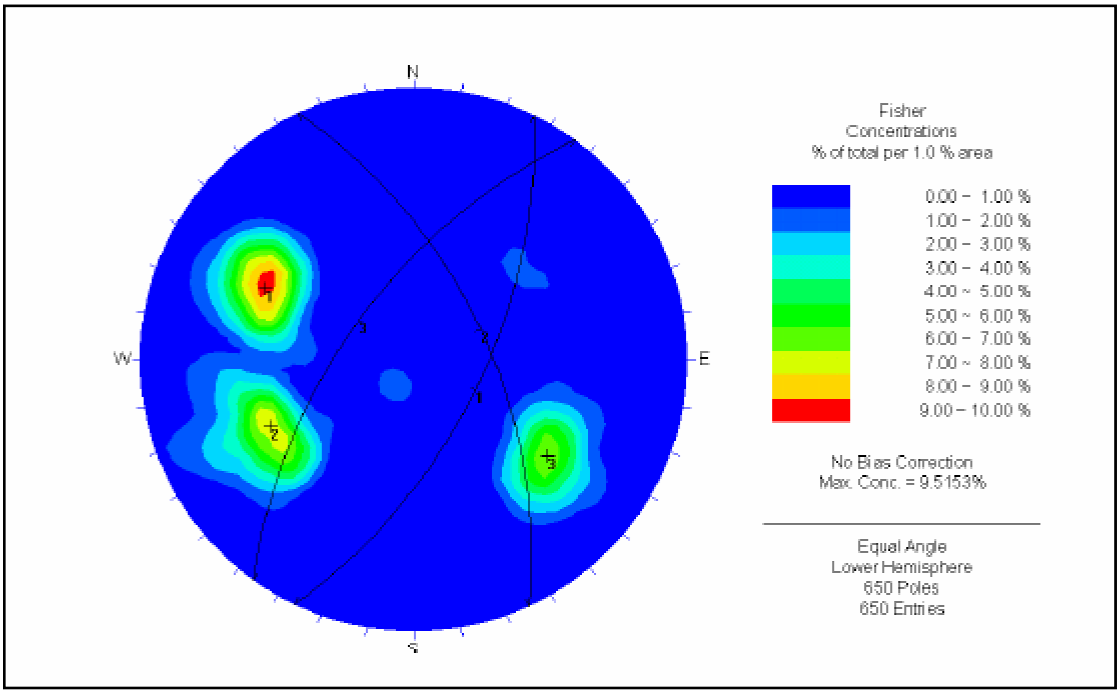

Figure 3.4.2 Discontinuity Scan Line Survey Data Sheet

DISCONTINUITY LOG

Project: ______________________ Sheet ____ of ____

Date: ____________

Feature: ______________________ Location: ______________________ Recorded by: ____________

Traverse Id.	Northing (start)	Easting (start)	Elevation (start)	Trend	Plunge	Traverse Length	Tl. No. Obs.	Recording Method:
								☐ Strike Azimuth and Dip Magnitude * ☐ Dip Azimuth and Dip Magnitude ☐ Feet ☐ Meters

Number	Distance	Rock	Azimuth	Dip	C	E	R	M	H	W	O	T	HL	Notes and Comments

Continuity
- C1 <3 ft. (<1 m)
- C2 3-10 ft (1-3 m)
- C3 10-30 ft (3-10 m)
- C4 30-100 ft (10-30 m)
- C5 >100 ft (>30 m)

Ends
- E0 No ends visible
- E1 One end visible
- E2 Both ends visible

Roughness
- R1 Stepped
- R2 Rough
- R3 Moderately rough
- R4 Slightly rough
- R5 Smooth
- R6 Polished

Moisture
- M1 Dry, not possible
- M2 Dry, no evidence
- M3 Dry, some evidence
- M4 Damp, no free water
- M5 Wet, some drops
- M6 Cont. flow, low pres.
- M7 Cont. flow, high pres.

Wall Hardness
- H1 Extremely hard
- H2 Very hard
- H3 Hard
- H4 Moderately hard
- H5 Moderately soft
- H6 Soft
- H7 Very soft

Wall Weathering
- W1 Fresh
- W2 Slightly weathered to fresh
- W3 Slightly weathered
- W4 Moderately to slightly weathered
- W5 Moderately weathered
- W6 Intensely to moderately weathered
- W7 Intense. weathered
- W8 Very intensely weathered
- W9 Decomposed

Openness
- O0 Tight
- O1 <0.003 ft (<1 mm)
- O2 0.003-0.01 ft (1-3 mm)
- O3 0.01-0.03 ft (3-10 mm)
- O4 0.03-0.1 ft (10-30 mm)
- O5 >0.1 ft (>30 mm)

Thickness
- T0 None
- T1 <0.003 ft (<1 mm)
- T2 0.003-0.01 ft (1-3 mm)
- T3 0.01-0.03 ft (3-10 mm)
- T4 0.03-0.1 ft (10-30 mm)
- T5 >0.1 ft (>30 mm)

Healing
- HL0 completely, to strength of wall rock
- HL2 >50%, or weaker than wall rock
- HL3 <50%
- HL5 No induration

* Dip magnitude follows right-hand rule

Discontinuity Log 14HL
Version 1.0

Procedure Sheet. B4.1 **Trial Pits and Trenches**

Summary

Trial pits or trenches may be excavated by either hand digging or machine excavation. Shallow trial pits provide a cheap method of examining near-surface deposits in situ, but the cost increases dramatically with depth, because of the need to provide side-support. Trial pits and trenches can provide an excellent opportunity to obtain very detailed information on strength, stratification, pre-existing shear surfaces, and discontinuities in soil and very weak rock materials. High quality undisturbed samples can be taken from trial pits. Table B4.1.1 summarises sample types commonly recovered from trial pits

However, trials, pits in landslide materials are potentially dangerous due to collapsing pit walls, this is particularly so for hand-dug operations. Machine-dug trial pits are the preferred method of shallow excavation as long as access can be provided safely Safety is key issue with trial pits and trenches do not enter trenches or pits more than 1 m deep without either supporting the sides or battering back the sides. Even so, if a pit is dug and remains stable without support, a quick means of exit such as a ladder should always be provided.

In clayey soil or fine grained very weak rock materials it is sometimes possible to identify shear planes. Undisturbed sampling of shear planes is usually only possible in exceptional cases but visual examination of their location, nature, condition, and orientation can provide valuable information for stability analysis. In granular soils. It is more common to find zones of disturbance that represent the zones of sliding or shear.

Trial pits, once excavated need to be logged according to recognised procedures involved layer thicknesses and orientations and material descriptions, as outlined in Annex B3.2 .

Shallow pits are particularly useful when investigating the causes of pavement surface problems. Pits excavated into and thro the pavement layers provide the means to check on individual pavement layer thicknesses, sample their material components and undertake in situ strength testing on individual layers.

Trial pits can also extensively and effectively used in the exploration for and assessment of borrow pit and gravel resources

Key References

British Standards ,1981. Code of Practice for Site Investigations. BS5930. British Standards Institution

GEO. 1996. Guide to Site Investigation. Geoguide 2. Hong Kong Government.

TRL, 1999. Overseas Road Note 18. A guide to the pavement evaluation and maintenance of bitumen-surfaced roads in tropical and sub-tropical countries. Transport Research Laboratory, UK

Turner A K & McGuffey. 1996. Organization of investigation process. Turner & Schuster: Landslides; Investigation and Mitigation, Special Report 247, TRB, Washington

Table B4.1.1 Sampling Methods from Trial Pits

Sample Type	Usage and Comment
Large Disturbed	Used to obtain the large quantities of all-in test material required for tests such as coarse particle size distribution, and compaction-CBR testing.
Small Disturbed	Samples suitable for moisture content profiling and index testing
Carved and Waxed Block/Tube	One of the few methods of gaining a true undisturbed high quality sample even in fabric-sensitive materials. Can be used for examination and assessment of fissure or shear plane orientations. Time consuming and great care required from experienced technicians. Can suffer from disturbance due to stress relief
Small Push-in Tubes	Small thin-wall tubes (20-30mm) pushed into exposures or walls of test pits can give moderate quality samples for visual and mineralogical examination. Requires extreme care in order to be effective in sampling sensitive fabric.
Nail Sampling Method	Form of surface block sampling using nails closely spaced in a circle to extract an undisturbed sample; suitable for loose sandy residual soil.

Procedure Sheet. B4.2 Sub-Surface Boring / Drilling

Summary

Sub-surface boring or drilling should be undertaken for one or more of the following reasons

1. Define geologic stratigraphy and structure.
2. Obtain samples for index testing.
3. Obtain ground water data.
4. Perform in situ tests.
5. Obtain samples to determine engineering properties.
6. Install instrumentation.
7. Establish foundation elevations for structures.
8. Determine the engineering characteristics of existing structures.

Boreholes may be sunk by a number of percussion, or rotary drilling methods. The techniques employed should be chosen to take into account the type and condition of material involved. Special precautions and care should be taken in attempting to recover undisturbed samples in sensitive soils or those whose fabric is of geotechnical significance. In some locations options may be restricted by economic or access constraints. Non cored boring methods generally only take restricted samples, perhaps at every metre or so of depth. Rotary coring normally attempts to recover continuous core, but cannot give a guide to lateral variability, and gives only restricted information on discontinuity patterns in the rock

Table B4.2.1 summarises the most common boring and drilling techniques and Table B4.2.2 summarises common sampling procedures. Materials recovered need to be logged according to recognised procedures involved layer thicknesses and orientations and material descriptions. A check list of information be logged in given in Table B4.2.3.

Drilling can be difficult and costly in coarse debris landslide deposits. In addition the complexity of the ground usually makes interpretation difficult. The presence of boulders slows drilling progress and can lead to spurious interpretations of depth to rock when large boulders are encountered. Core recoverability can be very low and consequently the value of drilling operations, unless they are undertaken to prove the depth to rock head alone, needs to be taken into consideration before they are scheduled.

Non cored probing is increasingly being used as a cheap alternative to boring. and drilling. It is used as a qualitative guide to the variation of ground conditions, and is particularly valuable for profiling. The techniques used are often fast, and are generally cheaper than boring and drilling, but they cannot be used to obtain samples or to install instruments.

Key References

British Standards ,1981. Code of Practice for Site Investigations. BS5930. British Standards Institution

GEO. 1996. Guide to Site Investigation. Geoguide 2. Hong Kong Government.

Turner A K & McGuffey. 1996. Organization of investigation process. Turner & Schuster: Landslides; Investigation and Mitigation, Special Report 247, TRB, Washington

Weltman A.J. & Head 1983. Site Investigation Manual. CIRIA Spec. Pub. 25

Table B4.2.1 Summary of Boring-Drilling Procedures

Method	Description	Usage	Limitations and Comment
Auger Boring	Dry hole drilled with hand or power auger. Auger borings can be made using hand, helical, barrel, hollow stem, or bucket augers. Split-tube samplers can be used with hollow stem augers.	In soil and soft rock; to identify geologic units and water content above water table Provide disturbed samples in fine soil or very weak rock materials that are suitable for determining soil type, Atterberg limits, and other index properties .	Soil and rock stratification destroyed; sample mixed with water below the water table. Augering cannot be used in coarse gravel, cobble of bouldery materials, except when some specially equipped large diameter bucket augers can be employed. .,
Wash Boring	Wash boring. Light chopping and strong jetting of soil; cuttings removed by circulating fluid and discharged into settling tub.	Soft to stiff cohesive materials and fine to coarse granular soils. Used to identify material boundaries and for very disturbed sampling	Should not be used in boreholes above water table or where samples are desired for anything other than general identification.
Light Percussion Boring	Percussion boring: holes 150-200mm in dia are progressed in clays by percussive chopping action and in granular soils by a shell or bailer with a clack valve to retain the sampled material.	Drive borings provide disturbed samples that contain all soil constituents, generally retain natural stratification, and can supply data on penetration resistance. Can be used to recover open tube or piston samples	Percussive action can cause significant disturbance at the base of the hole in laminated clays or granular materials below the water table.
Rock Core Drilling	Usually double or triple tube core barrels with an outer tube with diamond (or tungsten carbide) bit on lower end rotated to cut annular hole in rock; core protected by stationary inner tube ;cuttings flushed upward by drill fluid	Used to recover continuous or near continuous samples in rock materials as cores 22 to 100 mm diameter and as long as 3 m, depending on rock soundness. Standard coring size is commonly 54 mm diameter. The use of larger-diameter core barrels in soft, weak, or fractured strata can improve core recovery and provides a statistically better size sample for laboratory testing.	The percent of core recovered depends on fractures, rock variability, equipment, and driller skill. Core lost in fracture or variable rock; blockage prevents drilling in badly fractured rock. Dip of bedding and joint evident but not strike Core recovery in zones of weak or intensely fractured rock is particularly important because these zones are typically the critical areas The advantages of larger cores must be weighed against their higher costs.

Table B4.2.2 Summary of Boring-Drilling Sample Types

Technique	Application
1. Coring -Double barrel -Triple barrel	Double tube barrels adequate for sampling of competent rock-like materials. The use of core liners may extend their use in some more weathered zones. Triple tube barrels recommended as being significantly better and capable of recovering soil-like material. The erosion and disturbance of recovered material very much influenced by the drilling method and in particular the flushing medium.
2. Mazier, Pitcher, Denison	Systems of sampling using in conjunction with rotary coring that allows a sampling tube to be extended in weaker materials. Potentially useful in mixed soil-rock conditions as well as a semi-continuous method in uniformly weak beds. Expensive and requires experienced drill operators. Unlikely to give true undisturbed samples in sensitive layers. Not suitable for loose cohesionless soils.
3. Driven Large Tube	Traditional undisturbed sampling method in firm to stiff sedimentary soils and some weak rocks. Usually dynamically driven eg percussive boring. Inexpensive and rapid. Recovery aided by core catcher at base. High area ratio and friction on inside of tube produces significant disturbance in fabric dominated and sensitive materials
4. Pushed Thin Wall Tube (Shelby)	Can recover good samples in non-sensitive soft to firm fine cohesive soils. Simple driven equipment (75-200mm) but with much lower area ratio than (3 Some friction disturbance in sensitive materials. Not recommended for hard or granular materials.
5. Piston Tube	Capable of recovering high quality undisturbed samples, generally 50-100mm. Good sample recovery and accurate control on sample depth. Slow expensive operation that requires experienced operators/technicians Generally only possible to use in soft to firm materials not containing coarse material.

Table B4.2.3 Checklist of Information from Boring/Drilling

Action by	Information	Operation
From Boring-Drilling Crew	Size/type of core barrel	B
	Diameter of Casing	B D
	Size/type of core bit	D
	Depths of casing	B D
	Depth/time for each core run	D
	Sample depths	B
	Water table depths	B D
	SPT locations	B (D)
	Other in situ test locations	B D
	Length of core run	D
	Total core recovery	D
	General material description	B D
	Water returns (water flush)	D
	Loss of flushing medium	D
	Piezometer installation details	B D
	Voids	B D
Logged by Geotechnical Engineer or Geologist	Total core recovery (TCR)	D
	Solid core recovery (SCR)	D
	Driven tube recovery	B
	Rock quality designation (RQD)- (See B3.3)	D
	Individual material descriptions (see B3.2)	B D
	Faults/joints	D
	Bedding/laminations	D
	Core testing (point load; slaking)	D
	In situ test results	B D
	Core photographs	D
	Sample numbering	B D

B: Percussive boring **D: Rotary Drilling**

Procedure Sheet. B4.3 Geophysics

Summary

Geophysical techniques can contribute very greatly to the process of ground investigation by allowing an assessment, in qualitative terms, of the lateral variability of the near-surface materials beneath a site. Geophysical techniques can also be used for vertical profiling, where the objective is to determine the junctions between the different beds of soil or rock. Geophysical methods can be very useful at providing information on the location of specific targets, and investigating the variability of the ground, but their results are often more qualitative than is preferred by design engineers.

Geophysics is a specialist activity requiring expert advice on its suitability, application and interpretation. Its successful application depends on its suitability for a specific problem, such depth to rockhead. Used in the wrong context geophysics can give misleading results.

Geophysical methods are of greatest value when performed early in the investigation program in combination with limited subsurface exploration. They are appropriate for a rapid location and correlation of geologic features such as stratigraphy, lithology, discontinuities, ground water, and the in situ measurement of elastic moduli and densities. The cost of geophysical explorations is generally low compared with the cost of core borings or test pits, and considerable savings may be achieved by judicious use of these methods. Six major geophysical exploration methods are seismic, electrical resistivity, sonic, magnetic, radar, and gravity. Of these, the seismic and electrical resistivity methods have found the most practical application to the engineering problems. Table B4.3.1 summerises these procedures.

Non-intrusive seismic refraction surveys are being increasingly used in landslide investigations. While they offer some potential, they are reliant on there being a distinct variation in the seismic velocity of the soil/rock layers present in a slope Failure surfaces that occur within colluvium for instance are unlikely to be identified from these surveys

Geophysical sectioning is carried out to provide cross-sections of the ground, generally to give details of beds and layers. It is potentially useful when there are marked contrasts in the properties of the ground (as between the stiffness and strength of clay and rock), and the investigation is targeted at finding the position of a geometrically complex interface. In addition, these techniques can allow extrapolation of borehole data to areas of the site which have not been the subject of borehole investigation.

If borehole or other records are available then the information should be used to refine the interpretation of the geophysical output. In most cases geophysicists will require a reasonable knowledge of the ground conditions in order to optimize the geophysical test method, and the withholding of available data will only jeopardize the success of a survey..

General References

British Standards 1981. Code of Practice for Site Investigations. BS5930. British Standards Institution.

Weltman A.J. & Head 1983. Site Investigation Manual.CIRIA Spec. Pub. 25

US Army Corps of Engineers, 2001. Geotechnical Investigations. Report EM 1110-1-1804. (Section 4.11)

Table B4.3.1 Summary of Geophysical Techniques Used in Geotechnical Investigations

Method	Description	Application	Limitations
Seismic Refraction	A shock wave produced by either mechanical or explosive means and the primary waves are monitored at equally spaced geophone stations. An analysis of the time-distance relationship of the refracted first arrivals leads to calculation of depths of layers within the tested mass.	Gives delineation of depths to mass interfaces at depths of up to 30-40m. Compressional wave velocities can be used to give indications of soil-rock mass quality. Dynamic modulii may also be derived.	Cannot detect weaker (slower velocity) layers beneath stronger (higher velocity) layers. Requires boreholes for correlation. More expensive than resistivity surveys. Cannot be used adjacent to busy roads or in urban areas where background “noise” will

			interfere with data acquisition.
Cross-hole; Down-hole Seismics	As per seismic refraction but with energy sources and geophones placed in boreholes	Vertical and cross-profiling of lithological units.	Requires one or more boreholes and more expensive back-up equipments than seismic refraction.
Electrical Resistivity	Variations in electrical resitivity differences between soil & -rock types are utilised to identify boundaries in soil-rock masses. Resitivity is measured by passing small electric currents passed between 4 electrodes placed in the ground. In the “Wenner” configuration four equidistant electrodes are progressed along traverses. In the “Shlumberger” configuration the outer electrode separation is gradually increased about a fixed central point	Can identify simple stratigraphical boundaries. Relatively low cost, suited to shallow investigations. Can be used to investigate large areas economically compared with boreholes.	Accuracy for depth prediction may only be +/- 20%. Requires correlation with boreholes, particularly with respect to position of the water table. The same geotechnical materials above and below water-table will give different resistivity results. Complex stratification can cause serious inaccuracies.
Ground Penetrating Radar	Electromagnetic energy is pulsed into the ground which reflects of boundaries and is measured at surface.	Has particular application sin assessing pavement thicknesses in road condition surveys	Expensive. Not effective below water table or in clay materials. Shallow penetration only (<10m)

Procedure Sheet. B4.4 In Situ Testing

In situ tests are often the best means for determining the engineering properties of subsurface materials and, in some cases, may be the only way to obtain meaningful results. In most cases sampling produces at least some disturbance with consequent impact on the quality of subsequent laboratory test results. This impact can be greatly reduced by the appropriate use of a variety of geotechnical in situ testing techniques. The lessened degree of sample disturbance, particularly associated with stress relief, together with a frequently larger tested volume of material, means that in situ testing can yield more truly representative geotechnical parameters.

The following types of ground conditions are examples of those where *in situ* testing is either essential or desirable.

1. Very soft or sensitive clays. Good quality samples are hard to obtain

2. Stoney soils. These soils are almost impossible to sample effectively, because the stones damage both the cutting shoe and the soil as a sampler is driven. Such materials may be tested in situ either using dynamic penetration testing, or geophysical techniques.

3. Sands and gravels. Sand sampling is possible, but tends to be expensive, and to yield relatively highly disturbed samples. Therefore in situ testing is commonly used in granular soils. Typically, testing is carried out using penetration testing or when accurate values of compressibility are required, then plate testing may be used.

4. Weak, fissile or fractured rock. The strength and compressibility of fractured rock is controlled by the discontinuities and usually require rotary coring if they are to be sampled, but even when this can be carried out successfully it can only provide samples from which the intact (rather than the mass) properties may be determined. Typical in situ testing techniques used in weak near-surface rocks include penetration testing, plate loading testing, field geophysical techniques, and pressuremeter testing. In situ rock tests are performed to determine in situ stresses and deformation properties (moduli) of the jointed rock mass, shear strength of jointed rock masses or critically weak seams within the rock mass, and residual stresses along discontinuities or weak seams in the rock mass. The orientations of discontinuities or soil fabric relative to the stress model to be analysed need to be carefully considered when assessing results

Table B4.4.1 summarises the more commonly employed large scale in situ test procedures. Table B4.4.2 summarises some hand-operated in situ procedures.

Key References

Bell F.G., Cripps J.C. 1990. Field testing methods for engineering geological investigations IN Field Testing in Engineering Geology (ed F.G. Bell et al), Geol. Soc. Eng Geol. Spec. Pub. No. 6

British Standards ,1981. Code of Practice for Site Investigations. BS5930. British Standards Institution

British Standards 1990. BS 1377: Methods of Test for Soil for Civil Engineering. British Standards Institution

Sabatini P J et al 2002. Evaluation of Soil and Rock. FWHA report no. IF-02-034. US dept. Transport, Washington.

Weltman A.J. & Head 1983. Site Investigation Manual. CIRIA Spec. Pub. 25

Table B4.4.1 Large Scale In Situ Testing Procedures

Technique	Description	Usage and Comment
Standard Penetration Test	Standard blow counts from the dynamic penetration of granular and weak rock materials and, less commonly, clayey materials. The blow count (or "N" value) can be empirically related to material strengths and empirical estimations of C and Ø. A disturbed sample can be recovered if the split tube is used rather then the solid cone.	Simple, robust and low cost combination of sample plus test. Discontinuous sampling and testing. "N" values may require correction for overburden effects. Can be very sensitive to poor operator technique. Care needed in interpretation in sands and silts below the water table. Used extensively in conjunction with wash boring or percussive boring operations, can also be used batten core runs in very-weak rock materials.
Static Cone Penetration Test (Dutch Cone) Light 2-10 tonne Truck mounted 20 tonne Piezocone	The general procedure involves the forcing of a conical probe into the soil by jacking via extendable rods. The force required to advance sleeved cone is measured at 200mm intervals to obtain a profile of total and frictional resistance. The Piezocone similar but with the addition of a transducer and porous filter element to measure porewater pressures.	No sampling. Continuous record with minimal disturbance. Piezocone will give pore water pressure figures. Access may be problem unless using smaller machines. Progress 50-100m/day. Existing geotechnical correlations may require reinterpretation. Of limited use in materials with indurated layers or corestones which may cause significant damage to machinery
Pressuremeter Pre-bored (PBP) Self Boring (SBP)	The pressure required to expand a cylindrical membrane against the test section is recorded together with corresponding radial strain. For the PBP a borehole is carefully drilled and prepared prior to testing	Good tests for lateral deformation characteristics. Costly procedure requiring expert application.. PBP needs careful hole operation. Can give good soil-rock mass information. Requires good calibration techniques. Disturbance can be caused by advancement of the SBP.
Shear Vane:	Measurement of in situ shear strength of clays up to stiff consistency, either in a borehole or to a limited depth by specially designed stand-alone equipment. Remoulded shear strength may also be obtained.	Rapid directly available undrained shear strength in clays – partial drainage in silty or fissured materials can give misleading results.. Some correlation with laboratory measurements may be necessary. Requires experienced operators. Gives horizontal shear strength only.
Large In Situ Shear Box	Direct measurement of in situ shear strength usually in excavated platform or test pit	Requires careful preparation of test sample. Reasonable measure of material variability; minimum disturbance information generally only obtainable in vertical direction Time consuming and expensive
Large Plate Bearing Test	Measurement of elastic modulus and bearing capacity of soils and weak rock by direct application of load either in a test pit or possibly at base of large diameter borehole	Reasonable measure of material variability; minimum disturbance information generally only obtainable in vertical direction Time consuming and expensive. Equipment not readily available .

Table B4.4.2 Hand Operated In Situ Testing Procedures

Technique *	Description
Hand Held Shear vane	Small hand held shear vanes may be pushed into the walls or floors of trial pits to obtain approximate undrained shear strengths in clayey materials. Useful for gaining initial strength anistropy
Hand Held Penetrometer	Small hand held probes may be pushed into the walls or floors of trial pits to obtain very approximate undrained shear strengths in clayey materials.
Schmidt Hammer	Hand held Schmidt hammers originally developed for concrete testing may be used to gain an estimation of rock compressive strength in the field. The results need correlation with approximate densities on standard charts or figures to obtain strength values (Poole R.W. & Farmer,1980)
Manual Dynamic Cone Penetration (DCP) Testing	Cheap and easy to use probe developed for testing sub-grade strengths of pavement. Can be correlated to CBR%. Limited depth penetration (1.20m). Semi-continuous. No sampling.. (TRL, 199)
Point Load Test	Testing as per laboratory procedure (Annex B5.2) However the equipment is portable, and tests can be carried out quickly and inexpensively in the field.to obtain compressive strength values. (Broch E. & Franklin J.A.1972)

***** The equipment may be arranged from DoR's Central Laboratory or Institute of Engineering.

Procedure Sheet. B5.1 Laboratory Test Management

An appropriate test programme specification should include a logical selection of procedures that in addition to the nature of the problem to be addressed should be a function of material type, sample quality, laboratory capability and budget-time constraints. Prior to initiating the project-specific laboratory testing program, the engineer should review the recovered samples and confirm the testing that needs to be conducted (i.e., type, number, and required test parameters).
Table B5.1.1 and B5.1.2 summarize sample quality requirements for typical roadside problems. Table B5 1.2 sample size requirements for common test procedures

In addition to issues relating to the material type and its proposed utilisation, a well designed testing programme, needs to take a number of other key issues into consideration, namely:

- Economic and time-related constraints
- The ability of laboratories to undertake specific tests
- The requirement for specialist laboratories or equipment
- The requirement for a preliminary testing programme
- Standards to be adopted
- The need for sub-sampling
- Testing sequences (some procedures may be dependant on material properties)

The quality of testing programme depends upon the procedures in place to assure that tests are conducted in correctly, in an appropriate and controlled environment and utilise suitable equipment that is mechanically sound and calibrated correctly. The condition of test equipment and the competence levels of the laboratory staff are crucial in this regard. Quality assurance procedures should be identified and adhered to. From experience, issues that that can cause difficulty include:

Sample misplacement: Responsibility for samples, from when they were taken in the field until they are finally disposed of, needs to clearly identified

Repeatability and reproducibility: Tests on duplicate samples should be used as control checks, particularly if several laboratories are being used.

'Black-box' computer programmes: Some of the more sophisticated soils procedures, e.g. triaxial or oedometer tests may have computer control for testing by software that analyses and reports results. The validity of these programmes requires checking.

Non-Standard procedures: If any non-standard, or modified, procedures are being used this needs to be clearly stated on any test procedure and data record sheets

This procedure may not be directly applicable to the current capacity of the DRO's laboratories; however, the principles should be adhered to.

Key References

British Standards 1981. Code of Practice for Site Investigations. BS5930. British Standards Institution.

British Standards 1990. BS 1377: Methods of Test for Soil for Civil Engineering
British Standards Institution

Clayton C.R.I. 1986. Sample disturbance and BS5930.IN Site Investigation Practice: Assessing BS 5930, (ed. A B Hawkins), Eng. Geol. Spec. Pub. No.2

Table B5.1.1 Sample Quality Classes

Quality	Application
Class 1	Index tests, moisture content, grading, density and remoulded strength, undisturbed strength, consolidation and deformation.
Class 2	Index tests, moisture content, grading, density and remoulded strength in some clays
Class 3	Index tests, moisture content
Class 4	Index tests
Class 5	Strata identification only

Table B5.1.2 Sample Quality Classes Related to sample Type and Materials

Sample Procedure	**Maximum Quality Per Material Type**			**Comment**
	A	**B**	**C**	
Wash Returns	5	5	5	Material boundaries only
SPT Tube	N	3	4	Split for fabric/structure examination
Open thin wall sampler	N	1	2-3	Much more disturbance if driven rather than pushed
Single tube core	4	5	5	Not recommended
Double tube core	2	4	4	Large core size and liner recommended
Triple tube core	1	2	3	The minimum used in sensitive soils
Mazier/Pitcher	1	1	2-3	May be expensive
Bulk (Pit)	4	4	4	Opportunity for large samples
Block (Pit)	1	1	1	Or from good exposure
Small Tube (Pit)	3	3	3	Moisture content and mineralogy analysis in some materials

A: Weak rock; **B:** Non fabric sensitive soil; **C** Fabric sensitive soil

Table B5.1.3 Sample Quantity Requirements

Test Procedure	**Minimum Sample Required**		
	Fine	**Medium**	**Coarse**
Moisture Content	0.05kg	0.35kg	4.00kg
Liquid Limit (Cone /Casagrande))	0.50kg	1.00kg	2.00kg
Liquid Limit (one point Cone)	0.10kg	0.20kg	0.40kg
Plastic Limit	0.05kg	0.10kg	0.20kg
Shrinkage Limit	0.50kg	1.00kg	2.00kg
Linear Shrinkage	0.50kg	0.80kg	1.50kg
Particle Size (BS1377: Sieve)	0.15kg	2.50kg	17.00kg
Particle Size (BS1377: Hydrometer)	0.25kg		
Particle Density (Gas jar)	0.30kg	0.60kg	0.60kg
Compaction (BS Light, 1L mould)		25.0 kg	
Compaction (BS Light, CBR mould)		80.0 kg	
Compaction (BS Heavy, 1L mould)		25.0 kg	
Compaction (BS Heavy, CBR mould)		80.0 kg	
Compaction (Vibration))		80.0 kg	
Chemical Tests (pH Value, Sulphate,Organic Matter,Carbon & Chloride Content)	150g	600g	350g
Point Load Test	10 No. identical samples		
Schmidt Hammer Test (Lab.)	20 No. tests on each sample		
Aggregate Crushing Value (ACV)		2.00kg	
Aggregate Impact Value (AIV)		2.00kg	
Los Angeles Abrasion (LAA)		5.00-10.00kg	
Slake Durability	10 No. lumps @ 40-50g each		
AAV	24 No. Aggregate particles		
PSV	4 x 35-40 No. Aggregate patches		

Table B5.1.4 Check list of Information Required for Sample Submission to Laboratory

1	Laboratory name & address
2	Sample reference number
3	Project/Job number
4	Location reference
5	Very brief sample description
6	Tests required + any special instructions
7	Required test results from above
8	Date of samplpe submission
9	Name of Engineer

Procedure Sheet. B5.2 Laboratory Soil and Rock Testing

In general, soil and rock are tested in order to assess its variability and in order to obtain parameters for particular geotechnical calculations. In the majority of cases no single test procedure will satisfy problem requirements and a battery of test procedures will be needed. Initially classification and index tests carried out to allow the soil on a site to be divided into groups should ideally be scheduled for an initial phase of testing. Ideally, subsequent more expensive behaviour tests are then best carried out on soil which is thought to be representative of each group as defined by the results of classification tests.

Assignment of tests must take careful account of the quality of samples available (see Tables B5.1.1 and B5.1.2) Disturbed samples will largely be used for soil classification and index testing. And undisturbed samples will largely be used for behavioural testing. Some behavioural testing may be undertaken on remoulded or re-compacted samples depending on the needs of the project

Classification and index tests have an important role to play in reducing the costs and increasing the cost-effectiveness of the more sophisticated laboratory testing as well as providing an indicator of general engineering behaviour. Together with detailed sample description, classification tests allow the soils on a site to be divided into a limited number of arbitrary groups, each of which is estimated to contain materials of similar geotechnical properties. Subsequent more expensive and time-consuming tests carried out to determine geotechnical parameters for design purposes may then be made on limited numbers of samples which are selected to be representative of the soil group in question.

Behaviour testing programmes should be designed so that they as accurately as possible model the ground conditions and problem impacts to investigated. For example the range of confining and shearing pressures for soil strength testing must be related to actual overburden conditions – the shearing behaviour of some materials at low confining pressures (shallow slide conditions) is very different from that at moderate or high pressures.

Tables B5.2.1 summarises soil index testing procedures A range of derived indices based primarily on grading and plasticity are used to characterise unbound granular materials and soils. These are listed and defined in Table B5.2.2. Table B5.2.3 summarises soil behaviour tests

Because of the frequently distinct differences between rock material and rock mass properties, laboratory testing rock for foundation or slope problems is generally focussed on compressive strength which is used in conjunction with empirical rules relating to RQD, discontinuity condition, discontinuity orientation and groundwater for mass characterisation.

In contrast the assessments of material-oriented issues such as erodabilty or construction aggregate suitability are firmly based on laboratory testing of rock samples.

Rock aggregate laboratory testing in particular is a vital component of any construction materials investigation. Table B5.2.4 summarises the main laboratory test procedures for rock. Final “on the site” quality and subsequent performance of construction materials can be very dependant on the process of winning, processing, hauling and placement in addition to the stresses induced by the working environment (eg traffic). Hence there is a need to select a range of laboratory testing procedures that can attempt to simulate field conditions.

Whilst the detailed chemical composition of materials may be normally of limited interest for road engineers the presence of some constituents can be of great significance. These include: organic matter; sulphates; chlorides; and carbonates. Table B5.2.5 summarises commonly used tests.

The majority of geotechnical laboratory tests are governed by strict procedures that, in the main, have been originally derived from British (BS) or American (ASTM / AASHTO) procedures and where these apply, the methods of testing and reporting should be strictly adhered to.

Key References

ASTM, Standard Test Methods for Classification of Soils for Engineering. Purposes (D2487-85) Annual Book of Standards.

Brand E.W. & Phillipson. 1985. Sampling and Testing of Residual Soils. Scorpion Press, Hong Kong

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Sabatini P J et al 2002. Evaluation of Soil and Rock. FWHA report no. IF-02-034. US dept. Transport, Washington.

Smith and Collis (eds), 1993. Aggregates: Sand, Gravel and Crushed Rock Aggregates for Construction (2nd Edition). Geological Society, UK.

US Army Corps of Engineers, 2001. Geotechnical Investigations. Report EM 1110-1-1804. (Sections 5,6)

Table B5.2.1 Soil Classification and Index Test Tests

Physical Condition and Index Tests	Standard Procedures		Advantages of Test	Disadvantages and Factors to be Aware of.
	BS	ASTM		
Moisture Content	1377: 2:,3.1	D2216	Simple and widely commonly accepted test.	Misleadingly high moisture contents in halloysitic and allophane rich soils
Liquid Limit (WL)	1377:2,:4.3-6	`D4318	Well established soil index and classification test	Influence of >425μm particles; moisture condition and mixing time. Correlations between procedures require caution.
Plastic Limit (Wp)	1377:2,:5.3	D4318	Well established soil index test. Plasticity index (Ip = W_L-Wp) used as a key defining parameter in many specifications	Influence of >425μm particles; moisture condition and mixing time. Poor reproducibility and repeatability
Shrinkage Limit (Ws)	1377:2, 6.3	D427 & D4943	Yields index information on volume change potential	Initially intended for undisturbed samples although remoulded material can be used.
Linear Shrinkage (Ls)	1377:2,:6.5		Can give an estimate of Ip for soils where W_L and Ws are difficult to obtain .Better repeatability and reproducibility than plasticity test.	Established relationships between Ls . and Ip may not hold true for some tropical soils.
Particle Size Distribution	1377:9:2.3-5 812:103,1	D422	Simple and widely accepted test incorporating both sieving and sedimentation. A fundamental soil classification tool and as index to other properties	Interpretation problems with aggregated particles or weak clasts. Requires particle density values. Different maximum sand size between BS (2mm) and ASTM (4mm).
Soil Particle Density	1377:2, 8.2	D854	Required for use in analysis of other parameters (e.g. psd, compaction)	Some soils influenced by drying temperature Potential confusion between density definitions.
Bulk Density	1377:2	C29 & C29M	Required for use stability analysis. May be undisturbed or remoulded -compacted	Bulk density may be arrived at by a variety of procedures. Some soils influenced by drying temperature

Table B5.2.2 Commonly Used Derived Grading Indices

Index	Definition
Plasticity Modulus	PI x % material passing 0.425mm sieve
Plasticity Product	PI x % material passing 0.075mm sieve
Shrinkage Product	Bar Linear Shrinkage Limit x % material passing).425mm sieve
Grading Coefficient	(% passing 26.5mm – %passing 2.00mm) x (% passing 4.74mm)/100
Uniformity Coefficient (U)	D_{60}/D_{10} The ratio of the 60% particle size to the 10% particle size

Table B5.2.3 Soil Engineering Behaviour Tests

Soil Engineering Behavior Tests	Standard Procedure		Advantages of Using Test	Disadvantages and Factors to be Aware of.
	BS	ASTM		
Swell Pressure	1377:5,:4.3	D4546	Undertaken on undisturbed or compacted material to determine pressure to minimise swell.	Only measures swelling pressure. Soil or fine aggregate only. To measure swell amount use BS 1377:5, 4.4
Collapse	1377:5,:4.5	D4546	Gives good indication of potential for fabric collapse.	Preferable to model site compaction-moisture conditions, eg flooding at project load. Disturbance problems in sensitive fabric materials.
Consolidation (oedometer)	1377:5, 3	D2435	Consolidation characteristics of as-compacted soil-fill or on undisturbed sub-grade samples	Disturbance problems in sensitive materials. Allows vertical drainage only, unrealistic in some structured materials.

Pinhole Test	1377:5, 6.2	D4647	Lab assessment of soil dispersion and erodability.	Based on empirical evaluation of material performance, mainly in temperate materials.
Crumb Test	1377:5, 6.3		Lab assessment of soil dispersion and erodability	Based on empirical evaluation of material performance, mainly in temperate materials
Compaction	1377:4, 3.3-7	D698 & D1557	Simple test. Basis of control on site compaction of fill and pavement materials	Zero air voids a function of particle density- highly variable in tropical soils. Be aware of differing " laboratory and site compactive efforts.
CBR	1377:4, 7	D1883	Quick and simple to perform. A convenient and widely established test for defining material suitability for road construction and subsequent quality control.	An empirical test only. Correlations with other parameters may be material-specific. Dependant on transient soil moisture-density-void ratio conditions. 3 test points are recommended
Triaxial: UU (soil)	1377:7, 8-9	D2850	Unconsolidated Undrained Short term fill analysis and cut-slope during construction. Models rapid application of shearing load	Not strictly applicable for non-saturated conditions or for non-cohesive materials.
Triaxial: CU (soil)	1377:7	D4767	Consolidated Undrained (with pore pressure measurement).Enables long term effective stress analysis of slopes.	Sophisticated test requiring careful supervision of experienced staff.
Triaxial: CD (soil)	1377:7		Consolidated Drained. Enables long-term effective stress analysis of fill slopes	Time consuming and sophisticated test requiring careful supervision of experienced staff
Unconfined Compressive Strength (Soil)	1377:7, 2	D2166	Quick and straightforward method of obtaining undrained shear strength.	Material needs to be intact, cohesive and at least stiff in consistency. Results may be conservative.
Direct Shear	1377	D3080	Shear strength of recompacted or undisturbed materials. Peak and residual strength parameters	Lack of drainage control makes undrained strength values unreliable
Vane Shear (Lab)	1377:7, 3	D4648	Rapid method for obtaining undrained shear strength. Can be used in compaction or CBR moulds.	Only of use for soft saturated clays with no coarse particles. Small sample tested.

B5.2.4 Rock and Aggregate Tests

Physical Condition Tests	Standard Procedures		Advantages of Test	Disadvantages and Factors to be Aware of.
	BS	ASTM		
Moisture Content	812:109	D2216	Simple and widely accepted test.	Misleadingly high moisture contents in halloysitic and allophane rich soils.
Water Absorption	812:109	C127 & C128	Simple test with correlations established with bitumen bound material design	Variability in multi-clast type deposits
Sand Equivalent Value		D2419	A rapid site-lab means of determining relative fines content	Dispersion problem in agglomerated minerals. Relative proportions only
Aggregate Grading (Sieve) Aggregate Sedimentation	812:103,1 812:103,1	C136 & C117	Simple and widely accepted test for defining aggregate size distribution.	Differing usage of "coarse" and "Fine" between BS 812 and 1377. Wet sieve unless little or no fines.
Flakiness Index (If) Elongation Index (Ie)	812:105, 1 812:105, 2	D4791	Standard gauge methods of ascertaining particle shape. Parameters incorporated into coarse aggregate specifications	BS Flakiness test (105.1) easier to undertake than Elongation Index 105.2). Use restricted to coarse aggregate only.
Angularity Number	812:105		Rapid indirect method of estimating gravel roundness based on relative voids content.	Can only be valid for strong aggregate particles, adequate enough to resist tamping blows without any degradation.
Surface Condition	812		Means of indirectly assessing frictional and bitumen adhesive properties of c aggregate.	Subjective assessment only.
Aggregate Particle Density (Bulk particle or Relative Density)	812:2	C127/128	Required in bitumen bound granular material design calculations	In aggregate the procedure will give an "apparent" rather than an "absolute" value. Not directly correlatable with soil particle density
Bulk Density	1377:2	C29 & C29M		
Point Load Strength	[ISRM]	D5731	Simple test with portable equipment. Correlates with UCS. Also usable in the field	Sensitive to changes in moisture condition and surface crushing. Requires identical samples (10 min.). Correlations with compressive strength vary with different materials. Needs careful correlation when testing weak (<25MPa) material.

Table B5.2.4 Rock and Aggregate Tests (Continued)

Simulation Tests	Standard Procedure		Advantages of Using Test	Disadvantages and Factors to be Aware of.
	BS	ASTM		
Unconfined Compressive Strength (rock)	[ISRM]	D2938	Straightforward test for measure strength of intact rock samples	Requires regular (core) shaped samples. Sensitive to changes in sample moisture condition, orientation and preparation
Strength-Deformation (rock)	[ISRM]	D3148	Similar procedure to UCS to measure elastic modulii and Poisson's ratio	As for UCS
Aggregate Impact Value (AIV)	812: 112		Simple test with inexpensive portable equipment giving a basic index parameter for aggregates	Flakiness, elongation can influence results as well as base-floor condition. Tests limited grading. Measures breakdown below 2.36mm only
Aggregate Crushing Value (ACV)	812:110		Gives basic index parameter for aggregates commonly used in specifications.	Flakiness, elongation can influence results as well as base-floor condition. Tests limited grading. Measures breakdown below 2.36mm

				only. Requires compression test machine.
10% Fines Aggregate Crushing Tests	812: 111		Modification of ACV test, more generally used, particularly for weaker materials.	As for ACV
Sulphate Soundness	BS 812: 121	C88	Assesses aggregate durability as a response to repeated crystallization and rehydration stresses. Incorporated in many specifications	Time consuming. Poor repeatability and reproducibility unless great care taken over procedures.
Slake Durability	[ISRM]	D4644	Simple assessment of durability of rock-like material.	Not generally used a suitability parameter in specifications. Fragile materials require careful handling
Los Angeles Abrasion (LAA)		C131/535	Standard combined impact and rolling abrasion test. Commonly used as a specification parameter	For aggregate <37.5mm. Tests a specified grading only. Measures breakdown in terms of material passing 1.68 mm sieve only
Accelerating Polishing Test	812:114	E303	Means of assessing the tendency for aggregate to polish.	Difficult and time-consuming test not normally carried out in standard laboratories. Selected aggregate pieces only.
Aggregate –Bitumen Adhesion		D1664	Tests for assessing adhesion of bitumen to aggregate in water	Observational test only. Takes account of stripping only and not prior coating difficulties.
Aggregate Abrasion Value (AAV)	812: 113		Means of assessing surface wear in surfacing aggregates.	Selected aggregate pieces only.

Table B5.2.5 Soil and Aggregate Chemical Tests

Chemical Tests	Standard Procedure		Advantages of Using Test	Disadvantages and Factors to be Aware of.	Alternative/Modified Tests
	BS	ASTM			
pH	1377:3, 9	E70	BS.Electrometric: Standard method, accurate to 0.1pH.	Requires regular cross-checking against buffer solutions	Use of Indicator papers - simple and quick, approximate values only Colourmetric method requires comparison with standard charts
Sulphate Content	1377:3, 5.2-5.5		Total sulphate in soils, including water- soluble calcium sulphate. Accurate if performed with care.	If measured sulphate content is >0.5% the water soluble sulphates should also be measured	Water soluble sulphate in soil and sulphates in water also by gravimetric (1377:3, 5.6) and ion exchange(1377:3, 5.5) methods.
Organic Content	1377:3, 3	C40	BS dichromate oxidation method. Accurate and suitable for all soils. Fairly rapid test.,	Presence of chlorides influences results, a correction can be applied.	Peroxide oxidation - used to eliminate organic matter for PSD testing
Carbonate Content	1377:3, 6.3	D4373	BS Rapid titration for carbonate content greater than 10%, has 1% accuracy.	Not suitable for carbonate content <10%. ASTM utilises gas pressure method	Gravimetric 1377 3:6.4. Used for hardened concrete. D4373 solubility in HCL. Calcimeter: simple, quick - approximate but adequate for most engineering purposes
Chloride Content	1377:3, 7.2-7.3	D1411	BS Silver nitrate method. Designed for concrete aggregate testing purposes	Titration process requires proper chemical facilities	Water Soluble: 1377 3:7.2; 812.117 BS Acid Soluble: 3:7.3. D1411, Calcium and magnesium chloride in graded aggregate.
Loss on Ignition (LOI)	1377:3, 4		Destroys all organic matter. Applicable for sandy soils containing little or no clay	High temperature may break down water of crystallisation in some minerals and give misleading results.	

Procedure Sheet. B6.1 Soil and Rock Parameters

The identification and utilisation of appropriate parameters is central to most geotechnical investigations as inputs to one or more of the following:

1. Classification of soil-rock materials and masses
2. As indicators of engineering behaviour
3. As a direct input to geotechnical analyses
4. As indicators of potential problem materials

Geotechnical parameters may be obtained by one or more of the following:

1. Index laboratory testing
2. Behaviour laboratory testing
3. Existing documents (desk study)
4. Observation of in situ soil rock behaviour

Key parameter selection criteria:

- Soil material or soil mass
- Effective stress or total stress
- Rock material or rock mass

Essential inputs from field observation – back analysis and engineering judgement

The following Tables provide guidance on parameter selection:

Table B6.1.1 Parameter requirements

Table B6.1.2 Laboratory Criteria for Unified Soil Classification System (USCS)

Table B6.1.3 Unit Weights and Friction Angles of Transported Soils

Table B6.1.4 Soil Classes and Estimated Strength Properties

Table B6.1.5 Estimate of Friction Angle from Sieve Analysis

Key References

Deoja B. et al (eds) 1991. Mountain Risk Engineering Handbook, ICIMOD, Kathmandu, Nepal

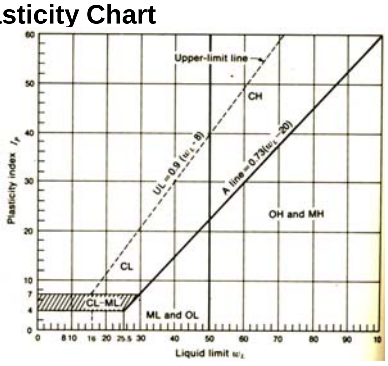
GEO 1996. Guide to Site Investigation. Geoguide 2. Hong Kong Government

GEO 2000 Highway Slope Manual. Geotechnical Engineering Office, Civil Engineering Department, Hong Kong

Table B6.1.1 Soil-Rock Parameter Requirements

Likely Parameters	Geotechnical Issues					
	Soil Slope Stability	Rock Slope Stability	Slope Erosion	Fill Structures	Retaining Walls	Pavement Materials
Atterberg Limits	●		●	●	●	●
Moisture Content	●			●	●	●
Grading	●		●	●	●	●
Soil Cohesion	●			●	●	
Soil Friction	●			●	●	
Compaction – CBR				●		●
Unit Weight	●	●		●	●	●
Oedometer – Consolidation				●	●	
Swell / Collapse Index			●	●		
Erodability	●	●	●	●		
Slake Test	●	●	●			●
SPT N Value		●			●	
Compressive Strength (Rock)		●				●
Rock Modulus		●				
Discontinuity Strength		●				
Discontinuity Orientations		●				
Ground Water Table	●	●		●		
Pore Pressure	●	●				
Aggregate Strength						●
Aggregate Durability						●
Aggregate Shape						●
Chemical Tests						●
Organic Content				●		●

Table B6.1.2 Laboratory Criteria for Unified Soil Classification System (USCS)

<table>
<tr><td rowspan="8">Coarse grained soils
> 50% passing no. 300 sieve</td><td rowspan="4">Gravelly soils
> 50% retained in sieve no. 4</td><td rowspan="2">< 5% passes sieve no. 200</td><td rowspan="4">Borderline cases require dual symbols (GW-GC)</td><td colspan="2">Well graded gravel
$c_u>4$ and $1<c_c<3$</td><td>GW</td></tr>
<tr><td colspan="2">Poorly graded gravel
$c_u<4$ and $c_c<1$ or $c_c>3$</td><td>GP</td></tr>
<tr><td rowspan="2">> 12% passes sieve no. 200</td><td rowspan="2">Above 'A' line and 4<PI<7, require dual symbols (GC-GM)</td><td>Clayey gravel
Below 'A' line or PI<4</td><td>GM</td></tr>
<tr><td>Silty gravel
Above 'A' line and PI>7</td><td>GC</td></tr>
<tr><td rowspan="4">Sandy soils
> 50% passes sieve no. 4</td><td rowspan="2">< 5% passes sieve no. 200</td><td rowspan="4">Borderline cases require dual symbols (SW-SC)</td><td colspan="2">Well graded sand
$c_u>4$ and $1<c_c<3$</td><td>SW</td></tr>
<tr><td colspan="2">Poorly graded sand
$c_u<4$ and $c_c<1$ or $c_c>3$</td><td>SP</td></tr>
<tr><td rowspan="2">> 12% passes sieve no. 200</td><td rowspan="2">Above 'A' line and 4<PI<7, require dual symbols (SC-SM)</td><td>Silty sand
Below 'A' line or PI<4</td><td>SM</td></tr>
<tr><td>Clayey sand
Above 'A' line and PI>7</td><td>SC</td></tr>
<tr><td rowspan="6">Fine grained soils
> 50% passing seieve no. 200</td><td rowspan="3">Silts and Clays
low LL</td><td colspan="3" rowspan="5">Plasticity Chart

</td><td>Inorganic silt, slight plasticity</td><td>ML</td></tr>
<tr><td>Inorganic clays, low to medium plasticity</td><td>CL</td></tr>
<tr><td>Inorganic silt, high plasticity</td><td>MH</td></tr>
<tr><td rowspan="3">Silts and Clays
high LL</td><td>Inorganic clays, high plasticity</td><td>CH</td></tr>
<tr><td>Organic silts or silt-clays, low plasticity</td><td>OL</td></tr>
<tr><td colspan="3">Below 'A' line and
LL (oven dry) / LL (air dry) < 0.75</td><td>Organic clays, medium to high plasticity</td><td>OH</td></tr>
<tr><td colspan="2">Highly organic soils</td><td colspan="3"></td><td>Peat or highly organic soils</td><td>Pt</td></tr>
</table>

Notes:

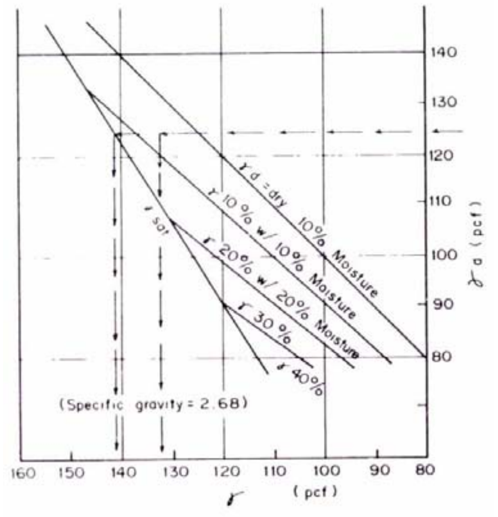
Coefficient of uniformity, $c_u = d_{60} / d_{10}$

Coefficient of curvature, $c_c = (d_{30})^2 / d_{10} \times d_{60}$

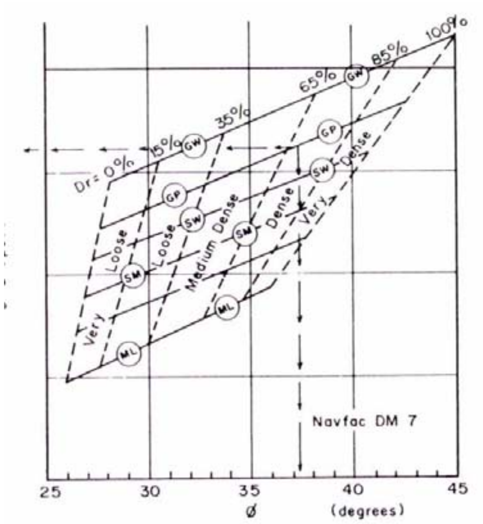
Source: Adapted from Mountain Risk Engineering Handbook

Table B6.1.3 Unit Weights and Friction Angles of Transported Soils

Dry versus bulk unit weight



Dry unit weight versus friction angle



Field test with no. 4 rebar	**Relative Density**
	100%
Can be driven only a **few inches** with 5lb hammer	
	90%
Can be driven only **one foot** with 5lb hammer	
	70%
Easily driven with 5lb hammer	
	50%
Easily pushed by hand	

Steps for friction angles and unit weights:

1. Unified soil classification system
2. Field determination of relative density
3. Determination of friction angle from abscissa
4. Determination of dry unit weight from ordinate
5. Determination of moisture content
6. Determination of bulk and saturated unit weights

Source: Mountain Risk Engineering Handbook

Table B6.1.4 Soil Classes and Estimated Strength Properties

Group	Classification	Unit weight (t/m³)		Friction angle (°)		Cohesion (t/m²)	
GW	Clean gravel, well graded	2.00	± 0.25	40	± 5	0	
GP	Clean gravel, poorly graded	1.90	± 0.30	38	± 6	0	
GM	Silty gravel, little fines	2.10	± 0.25	36	± 4	0	
GC	Clayey gravel, little fines	2.05	± 0.20	34	± 4	0	
GM-ML	Silty gravel, many fines	2.15	± 0.25	35	± 5	0	
GM-GC	Silty to clayey gravel	2.19	± 0.20	33	± 3	0.2	± 0.2
GC-CL	Clayey gravel, many fines	2.10	± 0.20	29	± 4	0.3	± 0.3
GC-CH	Clayey gravel, with high plastic fines	1.95	± 0.20	28	± 4	0.4	± 0.4
SW	Clean sand, well graded	1.96	± 0.20	38	± 5	0	
SP	Clean sand, poorly graded	1.85	± 0.25	36	± 6	0	
SM	Silty sand, little fines	2.00	± 0.25	34	± 3	0	
SC	Clayey sand, little fines	1.96	± 0.20	32	± 4	0	
SM-ML	Silty sand, many fines	2.00	± 0.20	34	± 3	0	
SM-SC	Silty to clayey sand	2.10	± 0.20	31	± 3	0.5	± 0.5
SC-CL	Clayey sand, many fines	2.05	± 0.20	28	± 4	0.5	± 0.5
SC-CH	Clayey sand, with high plastic fines	1.85	± 0.20	27	± 3	1.0	± 1.0
ML	Silt	1.90	± 0.25	33	± 4	0	
CL-ML	Silt to clayey silt	2.10	± 0.15	30	± 4	1.5	± 1.0
CL	Clayey silt	2.00	± 0.15	27	± 4	2.0	± 1.0
CH	Clay	1.75	± 0.15	22	± 4	2.5	± 1.0
OL	Organic clayey silt	1.20	± 0.15	25	± 4	1.0	± 0.5
OH	Organic clay	1.56	± 0.15	22	± 4	1.0	± 0.5
MH	Inorganic silt with high compressibility elastic silt	1.56	± 0.15	24	± 6	0.5	± 0.5

Source: Adapted from Krahenbuhl and Wagner 1983

Table B6.1.5 Estimate of Friction Angle from Sieve Analysis

Friction angle without correction				
Grain size range	**Fraction weight (%)**	**Divider**	**Parameters**	**Quotient (°)**
< 0.002 mm	18%	7	A	2.6
0.002 mm - 0.01 mm	10%	5	B	2.0
0.01 mm – 0.2 mm	25%	3	C	8.3
0.2 mm – 60 mm	15%	2.5	D_1	6.0
> 60 mm	32%	2.5	D_2	12.8
Total	**∑ = 100%**			**∑ = 31.7 °**
Corrections on friction angle				
Property	Criteria			Correction (±)
Grain shape	+ 1° for sharp angular grains ± 0° for medium angular grains - 3° for rounded grains			+ 1
Distribution curve	- 3° for poor gradation (or uniform size) ± 0° for medium gradation + 6° for well distributed grain sizes			- 3
Compactness of soil	- 6° for loose layer of soil ± 0° for medium loose layer of soil + 6° for compact layer of soil			+ 0
Corrected effective friction angle				**ϕ_{eff} = 29.7 °**

Source: Dhawan and Brinch Hansen

Formula: ϕ_0 = A + B + C + D
where,

ϕ_0 = friction angle without correction
A = 1/7 x [fraction weight (%) of grains < 0.002 mm]
B = 1/5 x [fraction weight (%) of grains between 0.002 mm and 0.01 mm]
C = 1/3 x [fraction weight (%) of grains between 0.01 mm and 0.2 mm]
D = 1/2.5 x [fraction weight (%) of grains between 0.2 mm and 60 mm + fraction weight of grains > 60 mm]

Corrections: $\phi_{effective} = \phi_0 + \phi_1 + \phi_2 + \phi_3$
where,

ϕ_1 = correction of grain shape
ϕ_2 = corretion for form of distribution curve
ϕ_3 = corretion for compactness of soil

Procedure Sheet. B7.1 Slope Analysis Selection

Analysis of slopes in Nepal is largely undertaken using Limit Equilibrium methods rather than the more realistic but more complex deformation analytical procedures. The latter are not discussed in this document. The conventional limit equilibrium methods of soil slope stability analysis used in geotechnical practice investigate the equilibrium of a soil mass tending to move down slope under the influence of gravity. A comparison is made between forces, moments, or stresses tending to cause instability of the mass, and those that resist instability. Two-dimensional (2-D) sections are analyzed and plane strain conditions are assumed. These methods assume that the shear strengths of the materials along the potential failure surface are governed by linear (Mohr-Coulomb)

Limit equilibrium analyses assume the factor of safety is the same along the entire slip surface. A value of factor of safety greater than 1.0 indicates that capacity exceeds demand and that the slope will be stable with respect to sliding along the assumed particular slip surface analyzed. A value of factor of safety less than 1.0 indicates that the slope will be unstable.

Table B7.1.1 Analysis procedure.

Factual criteria for analysis

1. The aerial extent of the landslide;
2. The depth of the landslide;
3. The mechanism of failure;
4. The current rate of failure;
5. The location of the proposed alignment, both vertically and horizontally in relation to the geometry of the landslide;
6. The profile of the groundwater regime and how this varies with rainfall.

Analytical criteria for analysis

1. The existing factor of safety of the landslide;
2. The effects of road earthworks (cuts and fills) on the factor of safety of the landslide;
3. The predicted effects of remedial measures (earthworks, drainage and retaining walls) on the final factor of safety;
4. The stability of individual engineering facets, such as cut slopes, fills and retaining walls when located on or close to the landslide in terms of temporary and permanent excavation stability, bearing capacities and foundation stability.

A slope analysis requires the following parameters to be defined:

1. The depth and configuration of the failure surface in the slope section;
2. The strength and density of soil/rock materials and the configuration of any soil/rock layers;
3. The groundwater table and/or soil moisture condition;
4. An accurate cross-section for analysis

Back analysis

Analysis is undertaken of the slope to determine the condition of the slope at the time when failure took place. A factor of safety of 1.0 is assumed and, if the pre-failure topography can be reasonably surveyed, then the unknown parameters are reduced to:

- The failure surface location;
- The strength parameters;
- The water condition (assuming seismic acceleration is not a factor).

Table 7.1.1 Slope Stability Analysis Procedure

Step	Activities
Data preparation	• Plot slope cross section in graph paper in scale of 1:100 or 1:200 • Fix new origin at lower left corner of the cross section so that all points will have positive coordinates • Obtain new coordinates of all key points and interface points
Data input	• Enter topography with point coordinates along the surface • Enter soil interfaces with point coordinates along the interface • Enter potential water table with point coordinates • Define any limiting surfaces beyond which analysis does not extend
Material properties	• For each soil and rock layers input unit weight, friction angle and cohesion • Enter water unit weight • Enter properties of structure if present within the slope
Analysis	• Fix either center point or surface from which potential slip surface passes • Grid of centers may be provided to search on surface with minimum FoS • Aternatively, exit and entry point limits may be prescribed for searching minimum FoS
Design option	• Enter design options in the soil layers • Reanalyse for minimum FoS • If satisfactory FoS is not achieved, modify the design and reanalyze until satisfactory FoS is achieved
Back analysis	• For obtaining insitu soil properties, the slope may be back analysed • Apply most likely pre-failure condition for back analysis
Sensitivity analysis	• Vary water table according to possible drainage solutions and reanalyze the slope • Vary support forces and reanalyze the slope
Report	• Report surface that yield minimum FoS before treatment • Report critical surface with reasonable FoS for designed measures

Note: For detailed procedure on slope stability analysis, reference should be made to the software documentation as the procedure is often software dependent.

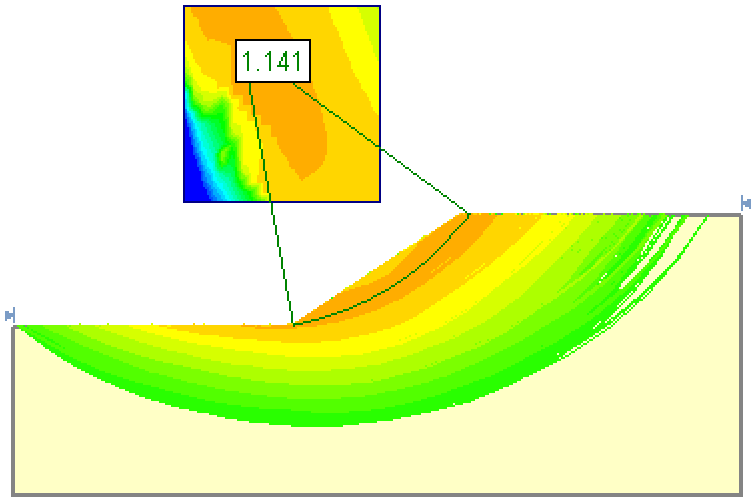


Figure 7.1.1 Simple Slope with Slip Surfaces and Grid of Centers

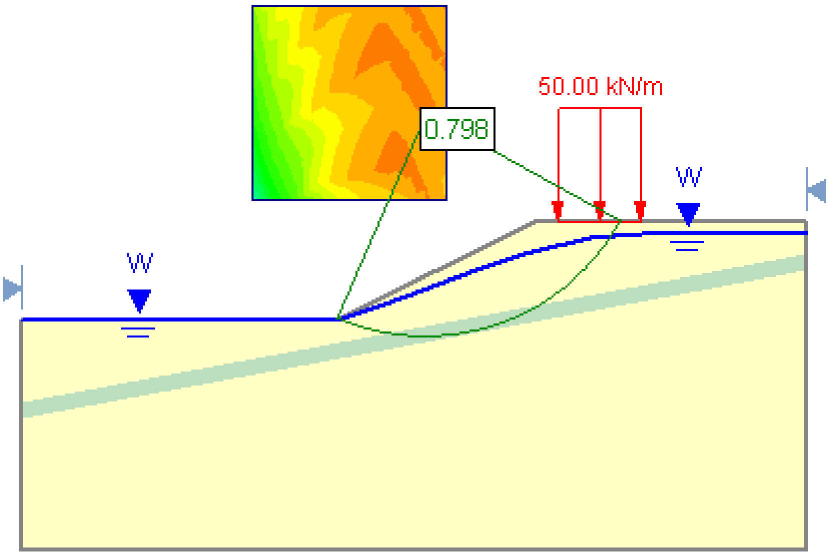


Figure 7.1.2 Analysis Showing Water Table and Loads

Procedure Sheet. B7.2 Factors of Safety

Summary

The Factor of Safety (FoS) is a concept in Civil Engineering largely linked with limit equilibrium methods of analysis, and is closely associated with the methods of analysis and the selection of material parameters used in the analysis. For example, a different FoS may be considered if a mean value of cohesion is selected as opposed to a lower bound one. Additional care need to be taken where new methods of analysis are being employed or non-standard or problem materials are being assessed. The FoS should also be selected with a view to the risk (or consequences) of failure.

The Hong Kong Geotechnical Manual for Slopes (GCO) contains detailed recommended Factors of Safety for both new and existing slopes based on a 10 year return period rainfall and the consequences of failure. These values, which are summarised in Table B7.2.1, were derived for condition in Hong Kong but give some guidance for use elsewhere. Higher or lower Factors of Safety might be warranted in particular situations in respect of economic loss.

Apart from the use of general factors of safety there is an option to use partial Factors of Safety for external loads and material properties. For example Lumb (1970) indicates the effectiveness of the use of a FoS of between 1.50 and 1.63 on cohesion combined with a FoS of 1.07 and 1.15 for coefficient of friction.

Table B7.2.1 Hong Kong GCO recommendations on FoS

Table B7.2.1 Hong Kong GCO FoS Recommendations

	Risk to Life Category		
Economic Risk Category	1	2	3
A	1.4	1.4	1.4
B	1.4	1.2	1.2
C	1.4	1.2	>1.0

Notes

Factors of safety for a 10 year rainfall return period

These FoS are minimum values.

Risk to Life Categories

Typical Examples of Risk to Life	Category
Slopes affecting roads with very heavy vehicle traffic (>12000 ADT)	1
Slopes affecting roads with moderate to heavy vehicle traffic (1200-12000 ADT)	2
Slopes affecting roads with very low to low vehicle traffic (<1200 ADT)	3

Economic Risk Categories

Typical Examples of Economic Risk	Category
Slopes affecting urban or rural trunk roads or road with strategic importance	A
Slopes affecting secondary roads	B
Slopes affecting rural feeder roads	C

Procedure Sheet. B7.3 Standard Stability Charts

Stability charts may be effectively utilised under defined circumstances for slope analysis.

Table B7.3.1 Criteria for using Stability Charts

Key Stability Charts:

- Taylor
- Bishop and Morgenstern
- Hoek and Bray

Figure B7.3.1 to B7.3.5 – Hoek & Bray slope stability charts

Key References

Table B7.3.1 Criteria for using Stability Charts

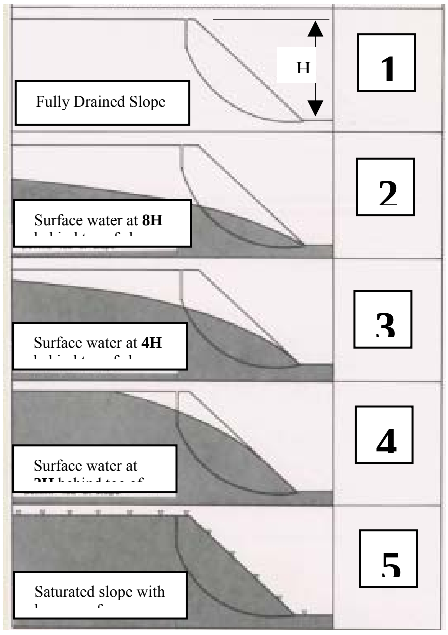
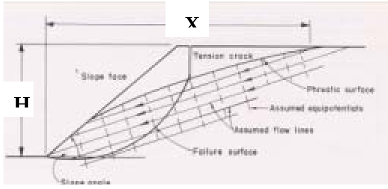
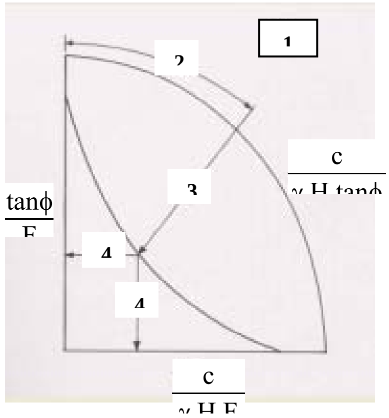


Chart Number



Ground Water Condition



Charts Using Procedure

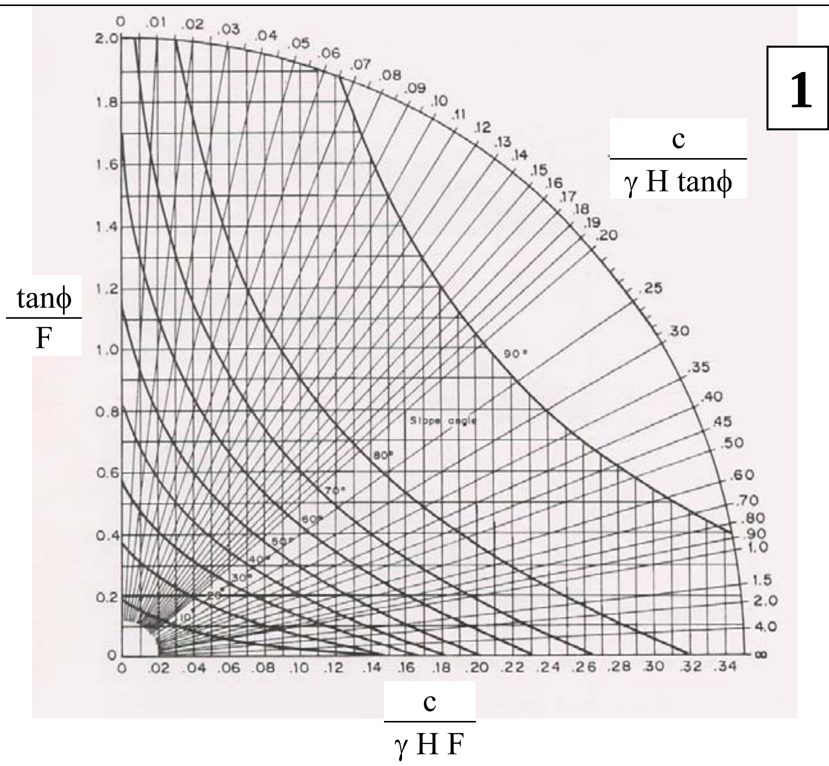


Figure 7.3.1 Stability Chart No. 1

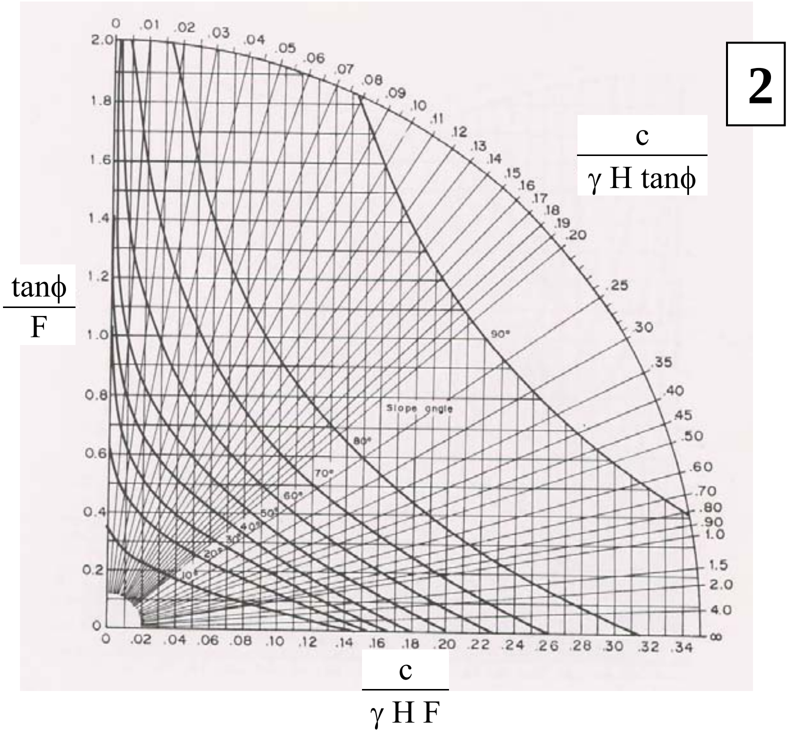


Figure 7.3.2 Stability Chart No. 2

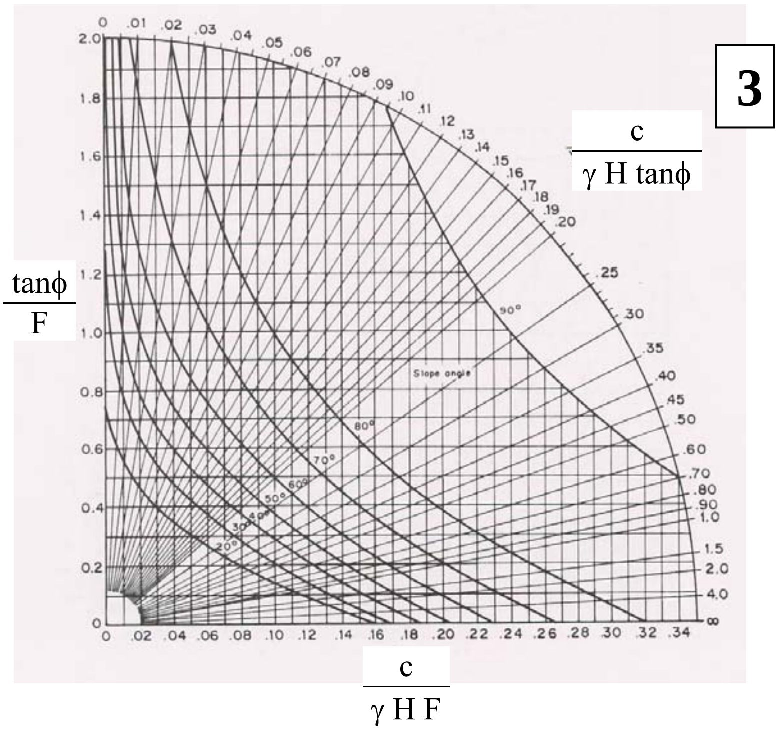


Figure 7.3.3 Stability Chart No. 3

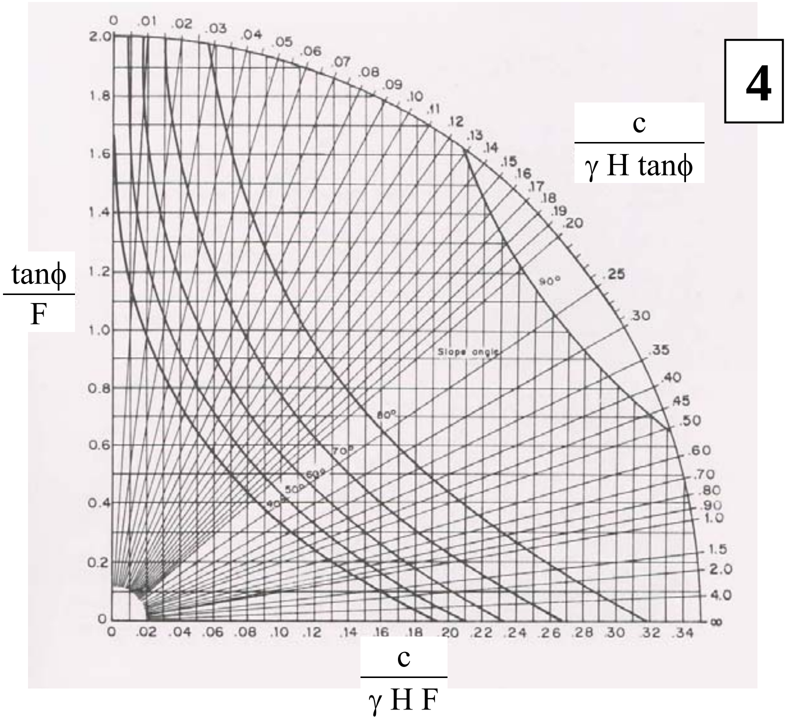


Figure 7.3.4 Stability Chart No. 4

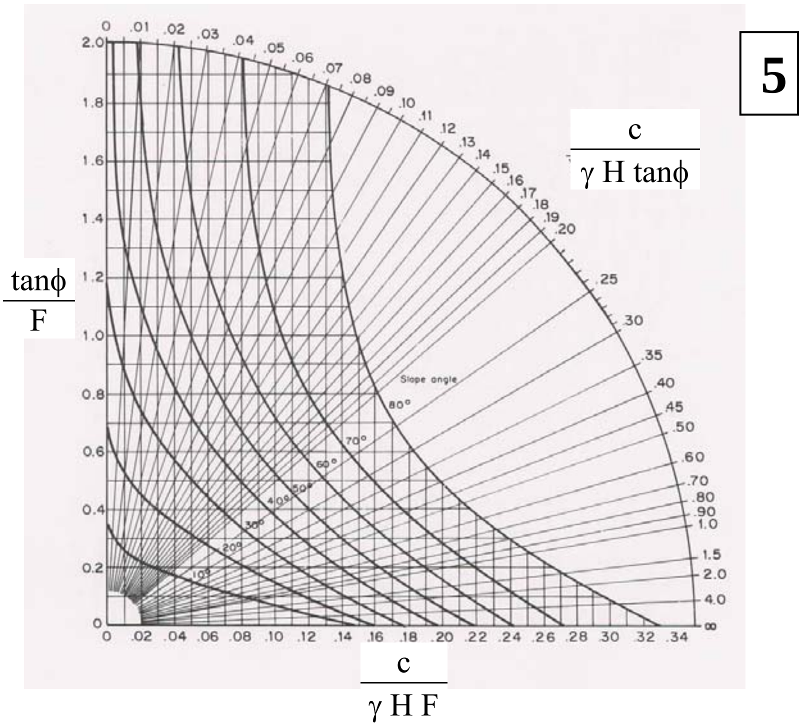


Figure 7.3.5 Stability Chart No. 5

Procedure Sheet. B7.4 Detailed Stability Analysis

The most common detailed methods for limit equilibrium analyses are methods of slices. In these methods the soil mass above the assumed slip surface is divided into vertical slices for purposes of convenience in analysis. Several different methods of slices have been developed. These methods may result in different values of factor of safety because: (a) the various methods employ different assumptions to make the problem statically determinate, and (b) some of the methods do not satisfy all conditions of equilibrium.

Some methods of slope stability analysis (e.g., Spencer's) are more rigorous and should be favored for detailed evaluation of final designs. Some methods (e.g., Spencer's, Modified Swedish, and the Wedge) can be used to analyze noncircular slip surfaces. Some methods (e.g., the Ordinary Method of Slices, the Simplified Bishop, the Modified Swedish, and the Wedge) can be used without the aid of a computer and are therefore convenient for independently checking results obtained using computer programs. Also, when these latter methods are implemented in software, they execute extremely fast and are useful where very large numbers of trial slip surfaces are to be analyzed. The various methods covered in this Annex are summarized in Table B7.3.1This Table can be helpful in selecting a suitable method for analysis

Table B7.3.1 Comparison of Features of Limit Equilibrium Methods

Methods / **Features**	Ordinary Method of Slices	Bishop's Simplified Method	Spencer's Method	Modified Swedish method	Wedge Method	Infinite Slope Method
Accuracy		●	●			●
Plane Slip Surface Parallel to Slope Face						●
Circular Slip Surface	●	●	●	●		
Wedge Failure Mechanism			●	●	●	
Non-circular Slip Surfaces			●	●		
Suitable for Hand Calculation	●	●		●	●	●

Procedure Sheet. B8.1 Slope Stability Software

Summary

Many slope stability analyses are capable of being performed using computer programs. Selection and verification of suitable software for slope stability analysis is of prime importance. It is essential that the software used for analysis be tested and verified.

Tables B8.1.1 and B8.1.2 summarise information on the capabilities of a range of soil and rock stability software programmes from which the following programmes are recommended

For soil slope stability: **SLIDE (version 5)**; by Rocscience @ US$1495 – single user
For rock slope stability: **SWEDGE (version 5)**; by Rocscience @ US$995 – single user

Key factors in the selection of these programmes for use in the Nepal geotechnical environment were as follows:

<u>Soil Slope Programmes</u>

- Compatibility with current Windows systems
- Non-circular failure analysis capability
- Multiple layer analysis
- Incorporation of tension cracks
- Allows effective stress analysis
- Back analysis capability
- General flexibility
- Ease of input and output (graphic)

<u>Rock Slope Programmes</u>

- Compatibility with current Windows systems
- Plane and wedge failure analysis
- Allows variable ground water conditions
- Incorporation tension cracks
- Sensitivity analysis capability
- Back analysis capability
- Anchoring analysis
- General flexibility
- Ease of input and output (graphic)

In addition it is likely that a specialist discontinuity survey programme such as **DIPS** may also be desirable in order to analyse data recovered from discontinuity surveys for rock slope assessment.

Additional information on SLIDE, SWEDGE and DIPS are attached to this Annex.

Table B8.1.1 Slope Stability Software- Soil

Software	Publisher	Platform	Category	Cost	Worksheet Input	Graphical Input	FOS Output	Grid of Circles	Tension Crack	Back Analysis	Sensitivity Analysis	Non-circular Slip	3D Analysis	Hydrology	Vegetation	Effective Stress	Bearing Capacity	Earth Pressure	Multiple Soil Strata	Seismic Analysis	Reinforced Earth	Anchor Analysis
CADS Re-Slope	CADS Computer and Design Services Ltd	Win95/98, WinNT, Win2000, WinXP	Commercial		●	●	●	●	●											●	●	●
CHASM	Bristol Innovations Software Sales Ltd	Win3x, Win95/98, WinNT, UNIX	Commercial	UNIX £3000 Windows £1250				●				●		●	●				●			
CLARA-W	Hungr Geotechnical Research, Inc.	Win95/98, WinNT, Win2000, WinXP	Commercial	US$1900		●	●		●			●	●							●		
DC-Slope	DC-Software Doster & Christmann GmbH	Win95/98, WinNT, Win2000, WinXP	Commercial	Euro 1450		●	●												●	●		●
DLISA	Rocky Mountain Research Station	DOS	Free				●															
ESAU	SINTEF Civil and Environmental Engineering	DOS, UNIX, HP	Commercial	Norwegian Kroner 8000												●	●	●				
FLAC/Slope	ITASCA Consulting Group, Inc.	Win95/98, WinNT, Win2000	Commercial	US$1,250		●	●					●							●	●	●	●
Galena	Clover Technology	Win95/98, WinNT, Win2000, WinXP	Commercial	US$1290		●	●	●	●	●									●			
GEOSLOPE	GEOCOMP Corporation	DOS	Commercial	Ver 5.0 US$970. Ver 5.1 US$1950	●		●	●											●		●	
GEOSTAB	GEOS Ingenieurs Conseils SA (France)	Win95/98, WinNT	Commercial	Euro 3,812			●					●							●	●	●	●
GeoStar	GeoTechnica, 3G, s.r.o.	DOS	Commercial	US$500, US$1000 with support	●	●	●	●				●							●			
Geo-Tec B	Interstudio S.r.l.	Win95/98, WinNT, Win2000, Mac, PowerMac	Commercial	US$499		●	●	●				●							●	●		
GFA2D	He, Stanley Z	DOS, Win3x, Win95/98	Free				●									●			●	●		●
GGU-SLICE	ivilserve GmbH	Win95/98, WinNT, Win2000	Commercial	Euro 145		●	●															
GGU-STABILITY	Civilserve GmbH	Win95/98, WinNT, Win2000	Commercial	Euro 2350			●					●				●	●	●	●		●	●
GSlope	Mitre Software Corp	Win3x, Win95/98	Commercial	US$895		●	●	●				●				●			●		●	●
GSTABL7	Annapolis Engineering Software	Win3x, Win95/98, WinNT	Commercial	US$1,200+US$320 for add. copy			●					●				●		●	●		●	●
I.L.A	Geo&soft International	Win95/98, WinNT	Commercial	US$450			●					●				●		●		●	●	●
LISA	Rocky Mountain Research Station	DOS	Free				●															
MStab	GeoDelft (Netherlands)	Win95/98, WinNT, Win2000	Commercial	Euro 2, 500	●		●	●	●			●				●		●	●	●	●	
PCSTABL 6	Purdue University	DOS	Commercial	US$690			●	●	●			●							●	●	●	●
REAME2004	University of Kentucky	Win95/98, WinNT, Win2000, WinXP	Commercial	US$550		●	●	●				●	●			●			●	●	●	●

Table B8.1.1 Slope Stability Software- Soil (continued)

Software	Publisher	Platform	Category	Cost	Worksheet Input	Graphical Input	FOS Output	Grid of Circles	Tension Crack	Back Analysis	Sensitivity Analysis	Non-circular Slip	3D Analysis	Hydrology	Vegetation	Effective Stress	Bearing Capacity	Earth Pressure	Multiple Soil Strata	Seismic Analysis	Reinforced Earth	Anchor Analysis
Sarma		DOS	Shareware	US Dollars 50			•															
SHALSTAB	University of California (Berkeley)	Win95/98, WinNT, Win2000, WinXP, ArcView	Free			•	•							•								
Slide	Rocscience Inc	Win95/98, WinNT, Win2000, WinXP	Commercial	US$1,495 (Canadian Dollars 2,195)		•	•	•		•	•	•		•		•			•		•	•
SLIP	CADS Computer and Design Services Ltd	DOS	Commercial	£895			•	•											•			
SLOPBG	Prokon Software Consultants (Pty) Ltd	Win95/98, WinNT, Win2000	Commercial	US$420			•												•	•	•	•
Slope (ejgeSoft)	ejgeSoft	Win3x, Win95/98	Commercial	US$161 + Manual free			•	•			•	•										
Slope (GeoStru)	GeoStru Software S.a.s.	Win95/98, WinNT, Win2000, WinXP	Commercial	Euro 300	•		•	•		•		•							•	•	•	•
Slope (Oasys)	Oasys Limited	DOS, Win95/98, WinNT	Commercial	£1,300			•	•				•				•			•	•		
SLOPE 12	Geosolve	Win95/98, WinNT, Win2000, WinXP	Commercial	£1,250		•	•	•				•					•	•	•			
Slope 2000	Hong Kong Polytechnic University	Win95/98, WinNT, Win2000, WinXP, Linux	Commercial	US$640 to 1,280			•	•				•	•						•	•		•
SLOPE 8R	Virginia Tech (Civil Engineering)	DOS	Commercial	US$100			•					•										
SLOPE STABILITY	FINE Ltd	Win95/98, WinNT, Win2000, WinXP	Commercial	Euro 395			•					•							•	•		•
SLOPE-W Basic Edition	GEO-SLOPE International Ltd.	Win95/98, WinNT, Win2000, WinXP	Commercial	US$995			•		•			•							•	•		
Slope-W	GEO-SLOPE International Ltd.	Win95/98, WinNT, Win2000, WinXP	Commercial	US$3,495		•	•	•	•			•				•			•	•	•	•
SLOPNC	Prokon Software Consultants (Pty) Ltd	Win95/98, WinNT, Win2000	Commercial	US$420			•	•	•										•	•	•	•
Stabl for Windows	Purdue University	Win95/98, WinNT, Win2000	Commercial	US$980			•	•				•						•	•	•	•	•
STABLE	M Z Associates	DOS, Win3x, Win95/98, WinNT, Win2000, WinXP	Commercial	£850 + £275 annual support (opt.)		•	•	•	•										•		•	
STABLEPRO-Windows	Ensoft Inc	Win3x, Win95/98	Commercial	US$400 + Stabl4 or Stabl5			•	•				•						•	•	•	•	•
STB	Verruijt, Arnold	Win95/98, WinNT, Win2000, WinXP	Free				•												•			
STEDwin 2.6	Annapolis Engineering Software	Win3x, Win95/98, WinNT	Commercial	US$300 + PCStabl4 to PCStabl6	•		•	•				•						•	•	•	•	•
SVAH	SSK	Win95/98, Win2000	Commercial	Euro 400		•	•												•	•	•	•
SWASE	University of Kentucky	DOS	Commercial	US$250			•															
TALREN 4	TERRASOL	Win95/98, WinNT, Win2000, WinXP	Commercial	Euro 4,500		•	•	•	•			•				•			•	•	•	•
TSLOPE	TAGAsoft Ltd	Web/Java, Java client, server calculation.	Commercial	US$50 per week		•	•	•	•			•				•			•	•	•	•
TSLOPE3	TAGAsoft Ltd	DOS, UNIX	Commercial	US$3,000			•	•				•	•						•	•	•	•
TSTAB	TAGAsoft Ltd	DOS, UNIX	Commercial	US$500		•	•	•	•							•			•		•	•
UTEXAS3	Shinoak Software	DOS	Commercial	US$1,200 + GRAPHIC3 US$1,200		•	•	•	•			•				•			•	•	•	•
WinStabl	University of Wisconsin-Madison	Win3x, Win95/98, WinNT, Win2000, WinXP	Shareware	Minimum donation US$300 + Stabl6	•		•	•				•						•	•	•	•	•
XSLOPE for Windows	University of Sydney	Win3x, Win95/98	Commercial	Australian Dollars 1,100			•	•				•				•			•	•		
XSTABL	Interactive Software Designs, Inc.	DOS	Commercial				•	•				•				•		•	•			

Table B8.1.2 Slope Stability Software- Rock

Software	Publisher	Platform	Category	Cost	Worksheet Input	Graphical Input	FOS Output	Graphical Output	Text Output	Tension Crack	Water Pressure	Back Analysis	Sensitivity Analysis	3D Analysis	Rock Fall Analysis	Plane Failure Analysis	Wedge Analysis	Seismic Analysis	Anchor Analysis	Probabilistic Analysis	Deterministic Analysis	Speed	Movement	Trajectory	Overhang
ACCECALC	Geo&soft International	Win95/98, WinNT	Commercial	US$300			•		•									•				•	•		
CLU_STAR	Geo&soft International	Win95/98, WinNT	Commercial	US$450		•	•		•										•						
EzSlide	University of Manitoba	Win95/98, WinNT, Win2000	Freeware				•						•							•					
GeoRock (GeoStru)	GeoStru Software S.a.s.	Win95/98, WinNT, Win2000, WinXP	Commercial	Euro300		•	•	•	•													•	•	•	
GeoSlide / ProSlide	University of Manitoba	DOS	Freeware				•										•								
Kbslope	PanTechnica Corporation	Win95/98, WinNT, Win2000	Commercial	US$700 single, US$1050 network			•				•			•			•		•						
Plane Failure Analysis	Southern Illinois University	Win95/98, WinNT	Freeware				•									•			•						
RocFall	Rocscience Inc	Win95/98, WinNT, Win2000	Commercial	US$695				•	•			•			•										
Rock Stability	FINE Ltd	Win95/98, WinNT, Win2000, WinXP	Commercial	Euro295			•	•			•					•			•						
ROCK3D	Geo&soft International	Win95/98, WinNT	Commercial	US$900			•		•					•											•
ROCKPACK III	Radford University	Win95/98, WinNT, Win2000, WinXP	Commercial	US$875	•	•	•	•			•				•	•	•		•						
ROCKPF	ARQ Associates, Prokon Software Consultants (Pty) Ltd	Win95/98, WinNT, Win2000	Commercial	US$300			•			•						•		•	•	•					
RocPlane	Rocscience Inc	Win95/98, WinNT, Win2000	Commercial	US$495			•	•		•	•		•			•	•	•	•	•	•				
ROTOMAP	Geo&soft International	Win95/98, WinNT	Commercial	US$900			•	•	•			•			•					•					
SLOPEPACK		DOS	Commercial	US$50			•				•				•	•	•								
SWARS	GEOCOMP Corporation	DOS	Commercial	US$800			•				•					•	•	•	•						
Swedge	Rocscience Inc	Win95/98, WinNT, Win2000	Commercial	US$995		•	•	•		•	•					•	•	•	•	•	•				•
WEDGE	ARQ Associates, Prokon Software Consultants (Pty) Ltd	Win95/98, WinNT, Win2000	Commercial	US$600			•				•						•		•	•	•				
Wedge Failure Analysis	Southern Illinois University	Win95/98, WinNT	Freeware			•	•	•								•	•		•						

Procedure Sheet. B8.2 Slope Stability Software Usage

Although limit equilibrium slope stability software programmes can provide a rapid and effective means of analysing slope failure models they should be used bearing key issues. These issues together with some recommended precautions are discussed below::

1. The software must analyse a failure geometry that reasonably reflects the actual in situ model. An understanding of the possible modes of failure is crucial to the successful application of a classical method of analysis. This is particularly important profiles where the mode of failure is governed by geological factors and where discontinuities are the determining cause of slope failure in these materials. Failures of colluvium over bedrock or failures in residual soil-rock materials most frequently occur along the surfaces dictated by structure. In such cases circular arc failures do not generally occur and shallow non-circular failure analysis would be appropriate
2. The analytical programme being used must be compatible with the critical elements of the slope problem to be investigated, for example drainage condition, loading condition, or layering of materials within the soil-rock mass.
3. Appropriate key shear strength and pore water parameters demanded as programme input must be capable of being supplied by the geotechnical engineer. There is a significant problem in many in situ masses in obtaining the high quality undisturbed samples required for obtaining truly representative values of c' and ϕ'. Software programmes cannot distinguish between appropriate or non appropriate parameters and output "answers" can be produced that may appear misleadingly attractive to an inexperienced engineer. Pore pressure distribution, in particular is critical to the most analytical processes, together with the impact of degree of saturation on soil shear strength and behaviour.
4. In cases where doubts exist about the representability of parameters it is appropriate to undertake a sensitivity analysis to see what the effects of variations of key parameters have on the end product FoS. The back analysis of similar existing failures can also be an important issue in these cases.
5. A sample parallel analysis not using the main software procedures should be undertaken, if possible by hand or spreadsheet methods. If this is not possible then a **sample parallel check using another programme** is recommended. In the case of analysis being undertaken by outside agencies these should always be cross checked by the same programme and if possible sample-checked by other means.
6. The programme output should be checked to ensure that results are reasonable and consistent. Important items to check include the weights of slices, shear strength properties, and pore water pressures at the bottoms of slices. The user should be able to determine if the critical slip surface is going through the material it should. For automatic searches, the output should designate the most critical slip surface, as well as what other slip surfaces were analysed during the search. Checking this information thoroughly will allow the user to determine that the problem being analysed was properly entered into the computer and the software is correctly analysing the problem.
7. To verify that data are input correctly, a cross section of the problem being analysed should be drawn to scale and include all the required data. The input data should be checked against the drawing to ensure the data in the input file are correct. Examining graphical displays generated from input data is an effective method of checking data input.

Procedure Sheet. B9 Construction Materials

Summary

One of the most common reasons for construction costs to escalate, once construction has started and material sources fully explored, are that the materials are found to be deficient in quality or quantity. This leads to expensive delays whilst new sources are investigated or the road is redesigned to take account of the actual materials available. (TRL, 2005) Material investigation therefore often require an extensive programme of site and laboratory testing, especially if the materials are of marginal quality or occur only in small quantities, see Annex B5 for laboratory procedures.

Traditionally materials are selected on their ability to perform defined engineering tasks in a road. The ability of the material to perform these tasks is normally assessed by their compliance, or non-compliance, with construction material specifications. Standard specifications and guidelines for using granular materials, such as those in set out in Overseas Road Note 31 (TRL, 1993), need to be of a general nature. Theoretically these guidelines and other specifications refer to the material as it is finally compacted/laid on the road. The relative quality and in-service performance characteristics of road pavement materials are largely determined by six fundamental properties (Table B9.1) required for the following main tasks

- Common embankment fill
- Capping layer (imported subgrade)
- Sub-base and road-base aggregate
- Road surfacing aggregate
- Aggregates for structural concrete
- Filter/drainage material
- Special requirements (e.g. rock-fill for gabion baskets).

Mica is present in a large proportion of the higher grade schists and gneisses of the Himalayas and to the natural aggregates derived from them. The presence of mica in fine aggregates can adversely affect the workability of concrete, and the addition of water to increase workability will only lead to a reduction in strength. The quantity of mica can controlled by careful selection of the source material.

If the project is in an area where good quality construction materials are scarce or unavailable, alternate solutions that make use of the local materials should be considered to avoid long and expensive haulage For example consideration should be given to,

- Modifying the design requirements
- Modifying the material (e.g. lime or cement stabilization)
- Material processing (e.g. crushing and screening)
- Innovative use of non-standard materials (particularly for low traffic volume projects).
- Using a central quarry of good quality aggregate and budget for increased haulage costs
- Blending materials to achieve a material that is within specification

The materials investigations should take into account any future needs of the road. This is particularly important in the case of gravel roads where re-gravelling is normally needed every few years to replace material lost from the surface. Sources of good material could be depleted with the result that haul distances and costs will increase. Furthermore, good quality material may be required at a later stage in the road's life when the standard needs to be improved to meet increased traffic demands.

Tables B9.2 to B9.6 summaries characteristics and defects of typical construction material groups found in Nepal (modified from data in Cook et al , 2001)

Key References

Cook J R, et al, 2001. Promoting the Use of Marginal Materials. TRL Ltd Research Report 205/2001 (R6887) for DFID, UK

Fookes P G & Marsh A H, 1985. Some characteristics of construction materials in the low to moderate metamorphic grade rocks of the Lower Himalayas of East Nepal. 2: Engineering characteristics. Proc Inst. Civil Eng., Vol 70, 139-162.

Smith M R & Collis L (eds), 1993. Aggregates – Sand Gravel and Crushed Rock Aggregates for Construction Purposes. Geological Society Engineering Geology Special Publication No 9 .(2nd Edition) Published by the Geological Society London.

TRL 1993. A guide to the structural design of bitumen surfaced roads in tropical and sub-tropical countries. Overseas Road Note 31

TRL, 2005. Overseas Road Note 5: A guide to road, project appraisal. Chapter 5- Geotechnics. Transport Research Laboratory, UK

Table B9.1 Key Engineering Road Materials Factors to be Investigated

Key Engineering Factor	Material Requirements
Strength	Aggregate particles need to be load resistant to any loads imposed during construction and the design life of the pavement.
Mechanical Stability	The aggregate as a placed layer must have a mass mechanical interlocking stability sufficient to resist loads imposed during construction and the design life of the pavement.
Durability	Aggregate particles need to be resistant to mineralogical change and to physical breakdown due to any wetting and drying cycles imposed during construction or pavement design life
Haul Distance	Reserves must be within physically and economically feasible haulage distance.
Placeability	Material must be capable of being placed and compacted by the available plant.
Environmental Impact	Material reserves must be capable of being won and hauled within any governing environmental impact regulations.

Table B9.2 Review of Materials: Hard Rocks

Material Types	Material Description	Typical Defects	Potential Pavement Construction & Performance
FOLIATED METAMORPHIC ROCKS : Common Types: • Slate • Phyllite • Schist • Gneiss • Amphibolite	Strong massive to closely jointed STRONG ROCKS, which may produce poorly graded materials on crushing comprising a significant proportion of flaky and elongate particles.	• POOR PARTICLE SHAPE. High proportion of flaky particles (If > 40%) in roadbase materials will lead to poor particle interlock, compaction difficulties and relatively low *in situ* dry densities. • HIGH MICA CONTENT. High content of micaceous minerals can lead to difficulties with compaction in the laboratory and on site. May also affect liquid limit determination and unrealistically high PI's that bear little relationship to field performance.	Materials with poor particle shape tend not to satisfy laboratory CBR 80% required for "standard" roadbase materials. May be satisfactory for lower standard roadbase design such as CBR 50 or CBR 40% for low volume sealed roads Can be improved by mechanical stabilisation – blending with well shaped angular materials designed to improve particle interlock, reduce voids and produce a smooth curve within the desired grading envelope. De-densification of compacted layers can occur due to presence of excess mica, particularly when using vibratory compaction equipment.
CRYSTALLINE IGNEOUS ROCKS Special Group: (fine to medium grained) Basic Igneous Rocks i.e.: • Basalt • Dolerite • Gabbro	Strong massive to closely jointed STRONG ROCKS which can typically be processed by crushing and screening to produce desirable grading.	• DECAY IN-SERVICE DUE TO MINERAL ALERTATION. Apparently sound strong rock aggregate may deteriorate (decompose) rapidly after processing and in the road pavement to produce plastic fines. .	Provided that secondary mineralisation is not significantly developed then these hard rocks will produce good quality crushed roadbase, sub-base and sealing aggregate. Susceptible materials can however deteriorate during pavement design-life and even while stockpiling.

Table B9.3 Review of Materials: Weak Rocks

Material Types	Material Description	Typical Defect	Potential Pavement Construction & Performance
MARLS AND WEAK LIMESTONES	Inherently weak calcium carbonate dominated rocks that produce silty and/or clayey angular GRAVEL	• POOR “AS DUG” GRADING • VERY LOW PARTICLE STRENGTH – inherently weak. • AGGREGATE DETERIORATION Some materials may decompose in–service to produce plastic fines	Selected low plasticity deposits may supply roadbase materials (soaked CBR 40-60%) for low volume sealed roads.
WEAK VOLCANIC AGGLOMERATES AND BRECCIAS	May comprise poorly consolidated (rippable) deposits that when excavated produce variably graded silty sandy angular to sub angular GRAVEL and COBBLES with some boulders	• POOR “AS DUG” GRADING. Frequently gap graded with a high proportion of oversize material • HIGH VARIABILITY WITHIN OUTCROP. Often interbedded with finer ash deposits , which may have high PI. Near surface deposits may be weathered but with well cemented HARD ROCK appearing at depth. • UNSOUND STONE CONTENT. Rippable materials may have undergone significant weathering and basaltic clasts (inclusions) may be subject to secondary mineralisation.	Rarely suitable for use in pavement construction without some processing to reduce oversize content and improve grading. Cobble and boulder size fragments are typically strong and may be difficult to treat with a grid roller.. Screening alone is likely to be wasteful hence use of quarry crushing and processing is likely to be required. Basaltic materials may incur problems with decay in service due to secondary mineralisation, although none reported.
WEAK CONGLOMERATES	Weakly cemented rock comprising sand and pebbles that typically produces moderately to well graded silty SAND and rounded to subangular GRAVEL with a variable proportion of cobbles	• POOR PARTICLE SHAPE. Rounded particles have poor interlocking properties, hence “as dug” conglomerate deposits will tend to be difficult to compact and produce low dry densities. • VARIABLE UNSOUND STONE CONTENT. Conglomerate gravels can comprise a mix of rock types and may contain a significant proportion of weak or weathered particles. • HIGH PLASTICITY FINES. Some conglomerates may be interbedded with argillaceous beds or have a fine grained matrix that decay to produce high plasticity fines.	Conglomerate gravels will typically require crushing and screening in order to satisfy “standard” roadbase specification requirements. Roadbase materials may be supplied from well graded or simply screened (i.e. grizzly) subrounded to subangular deposits . Crushed gravels for use in bituminous surfacing should be investigated to determine their unsound (weathered and inherently weak) stone content and adhesion characteristics.
WEAK SANDSTONES	Weakly cemented rock predominantly comprising sand size particles Usually dominated by quartz although feldspar also encountered	• LOW PARTICLE STRENGTH. • POOR AGGREGATE DURABILITY. Particularly associated with argillaceous (clayey) sandstones. • POOR “AS DUG”GRADING • HIGH PERMEABILITY and loss of strength on saturation. • HIGH PI in material when feldspars decay to kaolin	Selected deposits may supply roadbase .materials for low volume sealed roads in low rainfall areas e.g. those exhibiting high un-soaked CBR values (60- - >100%) but poor soaked CBRs.
WEAK VOLCANIC TUFFS	Weakly cemented rock comprising silt and sand size particles sometimes with gravel size inclusions.	• LOW PARTICLE STRENGTH. Often associated with poor cementation and low density. • POOR “AS DUG”GRADING • AGGREGATE DETERIORATION. Some materials may decompose in the road pavements to produce silty fines.	Little reported construction experience. May have characteristics similar to weak sandstones.

Table B9.4 Review of Materials: Weathered or Highly Fractured Rock

Material Types	Material Description	Typical Defect	Potential Pavement Construction & Performance
FRACTURED/ WEATHERED (RIPPABLE) LIMESTONES	Fractured and weathered rock forming clayey slightly sandy angular GRAVEL and cobbles	• HIGH PI CARBONATE FINES. Typically associated with weathering along joints and fractures • POOR "AS DUG" GRADING with variable proportion of oversize • DIFFICULT TO CRUSH with traditional equipment due to clogging. Use of grid roller or mobile hammer mill may be appropriate.	Well graded (suitably processed) clayey materials typically provide high soaked CBR strengths of (60 – 80%). Can supply roadbase aggregates for low volume sealed roads.
ARGILLACEOUS MATERIALS • Shale • Siltstone • Mudstone	Fine grained weak rocks that may be fissile. Typically produce silty to clayey weak angular or platy GRAVEL	• LOW PARTICLE STRENGTH. Inherently weak rock types • AGGREGATE DETERIORATION. Will tend to "slake" after extraction and in the road to produce plastic fines. • POOR GRADING • POOR SHAPE	Some materials may be suitable for use as sub-base in roads up to medium traffic in well drained dry conditions. Will tend to soften rapidly in wet conditions.
WEATHERED ROCKS	Many partially weathered rock types (whether sedimentary, igneous or metamorphic) may produce sandy GRAVEL materials. Fracture spacing and or bedding planes facilitate extraction of well graded materials by dozer ripping.	• VARIABILITY WITHIN OUTCROP. Expect considerable and sometimes unpredictable lateral and horizontal variation in aggregate quality. • PRESENCE OF DELETERIOUS SECONDARY MINERALS • LOW PARTICLE STRENGTH. • POOR "AS DUG" GRADING • HIGH PLASTICITY FINES	Some rippable partially weathered and fractured rock types can supply roadbase material for low volume roads. Aggregate quality will vary according to degree of alteration (i.e. depth below ground). Selection and mixing during extraction may be critical to obtaining a satisfactory material. A wider range of weathered rock types will be suitable for supply of sub-base and selected subgrade aggregates.

Table B9.5 Review of Materials: Transported soils and Gravels

Material Types	Material Description	Typical Defect	Potential Pavement Construction & Performance
ALLUVIAL SAND DEPOSITS	Typically silty non plastic to low plasticity SAND deposits	• UNIFORMITY OF PARTICLE SIZE. Poor performance in pavement layers is associated with sand deposits comprising a high proportion of single size particles • POOR PARTICLE SHAPE. Angular particles provide good interlock and improved engineering properties	Well graded unstabilised materials may be suitable for sub-base construction.. Cement treated materials can form roadbase, but cement stabilised sands can exhibit shrinkage cracking. .
ALLUVIAL CLAYEY SAND DEPOSITS	Clayey (low to moderate PI) silty SAND	• POOR GRADING. By definition these deposits lack gravel size fraction. Materials with good engineering properties will usually have a wide range of fine grained particle sizes. • POOR PARTICLE SHAPE. Angular particles provide good interlock and improved engineering properties • MODERATE PI FINES. Performance is related to the PIs but more significantly related to the volumetric stability	Un-stabilised materials have been used for roadbase construction for very low volume sealed roads in low rainfall areas (< 500 mm/year) If cement stabilisation is considered for more highly trafficked roads these are prone to cracking and therefore preferred use is in sub-base beneath an un-stabilised roadbase.
COLLUVIAL DEPOSITS • Colluvial Fan Deposits • Scree Deposits (Talus) • Landslide Debris	Typically coarse angular SAND and GRAVEL deposits with a variable cobble and boulder content in a matrix of silty sand or sandy clay	• POOR GRADING. .Usually gap graded with a high proportion of oversize material. • VARIABILITY WITHIN THE DEPOSIT. Colluvial deposits frequently comprise a variable mix of rock types. • HIGH PI FINES. Performance is significantly affected by PI	The character of these deposits is dependent on the nature of the parent rocks and terrain.
ALLUVIAL GRAVEL DEPOSITS • River Bed Deposits • River Terrace Deposits • Alluvial Fan Deposits	Typically moderately to well graded silty SAND and rounded to subangular GRAVEL with a variable proportion of cobbles and boulders.	• POOR PARTICLE SHAPE. Rounded particles have poor interlocking properties, hence “as dug” alluvial deposits tend to be difficult to compact and produce low dry densities. • VARIABLE UNSOUND STONE CONTENT. Alluvial deposits comprise a mix of rock types that reflect the geology of the drainage catchment. Alluvial gravels may contain a significant proportion of unsound aggregate fractions. • HIGH PLASTICITY FINES. Some alluvial deposits, particularly terrace deposits, may contain an excess of plastic fines. Either inherent from *in situ* weathering of gravel particles.	Alluvial gravels typically require crushing and screening in order to satisfy “standard” roadbase specification requirements. Crushed gravels for use in bituminous surfacing should be investigated to determine their unsound stone content and adhesion characteristics. Use of the sodium sulphate or magnesium soundness test is recommended in conjunction with standard strength testing (ie ACV ,LAA) Presence of unsound basalt particles may require mineralogical analysis

Table B9.6 Review of Materials: Residual Soils and Gravels

Material Types	Material Description	Typical Defect	Potential Pavement Construction & Performance
RESIDUAL CLAYEY SAND DEPOSITS	Clayey (low to mod PI) silty SAND	• POOR GRADING. By definition these deposits lack gravel size fraction. Materials with good engineering properties will usually have a wide range of fine grained particle sizes. • POOR PARTICLE SHAPE. Angular particles provide good interlock and improved engineering properties	Un-stabilised materials have been used as roadbase for low volume and very low volume sealed roads. Problems have been encountered with cement improved/ stabilised lateritic clayey sands. Careful evaluation is required if stabilisation is considered.
RESIDUAL GRAVEL DEPOSITS • Quartz Gravels • Weathered Granite/Gneiss gravels • Other residual gravelly soils	Variably graded typically clayey sandy angular to subangular GRAVEL	• POOR GRADING. These deposits tend to be variably graded within the exploitable horizon and are frequently gap graded. • HIGH PLASTICITY FINES. *In situ* weathering can lead to mineralogical decay that produces plastic fines. • HIGH UNSOUND STONE CONTENT. High proportion of partially weathered particles can be present as these deposits have not been subjected to sorting by water.	"As dug" residual gravel deposits will rarely be suitable for standard roadbase construction, due to inherent variability in terms of grading , particle strength and plasticity. However, this group of deposits has been widely used as a source of aggregate for lime or cement improved/stabilised roadbase material..

Procedure Sheet. B10 Route Alignment Studies

For new road alignment projects geotechnical investigations are used to select and compare alternative routes for the road and then to provide design and cost information on a wide range of factors for the selected route. In difficult geotechnical environments such as, remote mountainous terrains, geotechnical investigations need to be comprehensive. Identifying the ideal route will be crucial and relatively sophisticated techniques of aerial photography and remote sensing will often be required (SWK, 2003).

Route alignment studies are an iterative process and, particularly for major routes surveys, should ideally be in the following stages:

1. Identification of possible corridor(s) (Planning stage)
2. Comparison of corridors and alignments (Pre-Feasibility Stage))
3. Assessment of selected alignment for initial design (Feasibility Stage)

Investigations then move from route alignment studies into the detailed engineering investigation and design phases which are not covered in this note.

As the project proceeds through the stages, geotechnical information is collected at greater levels of detail. (Figure B10.1) It is essential that key geotechnical problems or constraints are identified at the planning or pre-feasibility stages in order that they may be either (a) avoided by route selection or (b) so that later work can be focused on providing suitable engineering solutions to them. Essentially a geological or geotechnical ‘model’ is built up and the staged refinement of the ‘model’ should be the central theme of the geotechnical investigation process Table B10.1 presents a Geotechnical Difficulty Rating (GDR) system for classifying potential alignments either for comparing alternatives or for identifying crucial areas for focused investigations.

Route location consists of selecting the best compromise between ‘demand’ factors and the ‘geotechnical environment’. Demand factors determine the areas to be served by the road and the standard (or class) of the road, the geotechnical environment influences the engineering cost. The principal road alignment issues governed by the geotechnical environment are discussed in Table B10.2

In the Nepal geotechnical environments landslide mapping and slope stability assessments must form an integral component of the desk study and field-based assessments .In particular the following should be addressed:

1. The distribution of colluvium
2. The distribution of clayey residual soil on steep slopes
3. where groundwater is high or where surface soils saturate;
4. The location of existing landslide features

Procedures for undertaking route alignment studies are summarised in Annexes B1-B5. Key reporting activities are summarised in Table B10.3

Key References

Fookes P.G., Sweeney 1985. Geological and geotechnical engineering aspects of low-cost roads in mountainous terrain. Eng. Geol.

GEO .2000. Highway Slope Manual. Geotechnical Engineering Office, Civil Engineering Department, Hong Kong

Scott Wilson Kirkpatrick (2004) Landslide Risk Assessment in the Rural Access Sector. DFID-DoR Manual. Chapters 2,& 5

TRL, 2005. Overseas Road Note 5: A guide to road, project appraisal. Chapter 5- Geotechnics. Transport Research Laboratory, UK

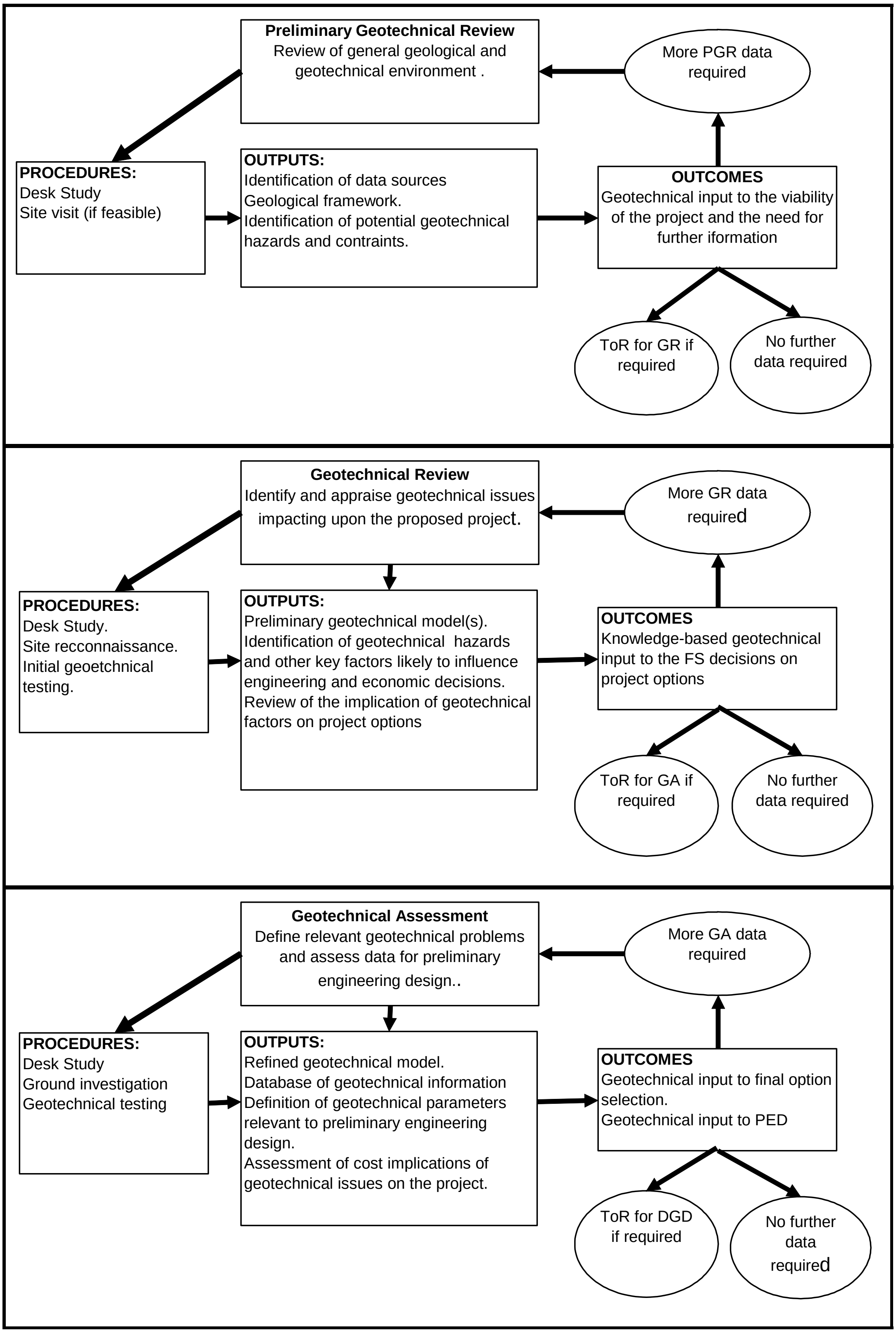


Figure B10.1 Geotechnical Activities Related to Stages of Alignment Selection and Design

Table B10.1 Key Issues in Route Alignment Studies

Key Issues	**Comment**
Need for structures	One of the first factors to consider in selecting the route of the road is the need for major structures such as bridges, large culverts and tunnels. The very high cost of such a structure can be reduced by locating it at the most favourable point within the route corridor 'Nodal points' such as this must be identified at an early stage because they will have a significant effect on the cost of the whole project
Impact of natural or man-made hazards	The occurrence of natural or man-made hazards can have major cost implications for road projects and adjustments to the alignment may be economically justified to avoid or reduce their impacts. Typical hazards to be aware of are: ▪ Natural slope instability ▪ Seismic activity ▪ Volcanic activity ▪ Quarrying. Hazards such as these must be identified early in the development of the project. If major hazards are uncovered only at a late stage or, worse, during construction, the costs of the project will increase substantially
Subgrade conditions	To carry out the structural design of the road pavement) it is necessary to predict the strength of the subgrade soil under the road after the road has been constructed. Particular attention needs to be given to defining areas of expansive or erodable soils which may have significant impact not only on road construction and but also on future maintenance costs
Surface and sub-surface drainage, including erosion	Drainage is vital to the successful performance of a road. Understanding the interaction of hydrology with the proposed structures such as cuttings and embankments, and designing them accordingly, is very much the role of the geotechnical engineer and must be investigated as part of the alignment studies Allied with drainage is the problem of erosion. Depending on soil type, climate and site conditions, the need for anti-erosion measures should be included in the alignment investigations.
Materials used in construction	Sources of road-building materials have to be identified within an economic haulage distance and they must be available in sufficient quantity and of sufficient quality for the purposes intended. Previous experience in the area may assist with this but a survey is usually essential. Annex B9 contains guidance on construction materials issues
Earthworks (the volume and stability of cuttings and embankments	Earthworks always form a significant part of the cost of road construction; even a simple road in flat terrain involves the excavation of ditches and the formation of a small embankment. The cost of earthworks becomes a dominant cost item in areas of steep terrain and the early phase of the geotechnical investigation has an important role to play in the selection of suitable routes to minimize costs. An important consideration for earthworks, especially in steep terrain or areas where there is evidence of former landslide activity, is that construction work could upset a delicate natural equilibrium. A particular difficulty in steep terrain is the disposal of excess material (spoil), therefore every effort should be made to balance the cut and fill.

Table B10.2 A Geotechnical Difficulty Rating (GDR) System

GDR No.	GDR DEFINITION	GDR DESCRIPTION
1	No geotechnical difficulty	No further geotechnical input required beyond standard design advice. No special geotechnical measures required for construction.
2	Very low problem area	Some further minor geotechnical input required at final design and construction stages to confirm geotechnical assumptions. Standard geotechnical precautions may be required within typical designs.
3	Low problem area.	Some further geotechnical input required to provide data for design confirmation. Some limited input at construction stage. Standard geotechnical preventative measures required.
4	Moderate problem area	Geotechnical input required to define extent of problem and provide final design data. Problems likely to be overcome at construction stage by means of standard geotechnical remedial and preventative processes without significant delay.
5	Moderately severe problem area	Geotechnical input required to establish geotechnical parameters and solutions for problems that have potential to cause delay or increase cost.
6	Severe problem area	Geotechnical input required to establish detailed nature and extent of problem. Construction solutions likely to involve significant geotechnical measures with likelihood of delay and cost penalty
7	Major problem area.	Major input required into problem definition and solution. Specialist advice recommended. Several alternative solutions may have to be examined, including minor shifts of horizontal and vertical alignment. Solutions likely to impose significant delay and cost penalties which are not yet definable in detail.
8	Geotechnical obstacle	Feasibility of alignment compromised. Solutions likely to include significant shift of alignment.

Table B10.3: Typical geotechnical reporting requirements

Item	Preliminary Geotechnical Review	Geotechnical Review	Geotechnical Assessment
A clear statement of the geological setting and geotechnical environment(s)	**P**	✓	✓
Descriptions of anticipated geotechnical hazards, including earthquake hazard	**P**	✓	✓
Definitions of the geotechnical character of the soils and rocks likely to be encountered	**P**	✓	✓
Summaries of the soil-rock geotechnical properties		✓	✓
Borehole and test pit logs		✓[1]	✓
A schematic geological profile		**P**	✓
An Index-Properties profile		**P**	✓
Geotechnical profiles and sections		**P**	✓
Details of geotechnical design relating to earthwork and structure (with plans and sections)			✓[1]
Description of design methods used and typical calculations			✓[1]
Definition of geotechnical design assumptions			✓[1]
Definition of construction materials sources, including volumes and quality			✓
Construction recommendations			✓
Monitoring recommendations			✓

P = Preliminary ✓[1] = If appropriate

Road-side Geotechnical Problems
A Practical Guide to their Solution

Part II: Guideline Annexes
Annex C: Standard Geotechnical Solutions

List of Tables

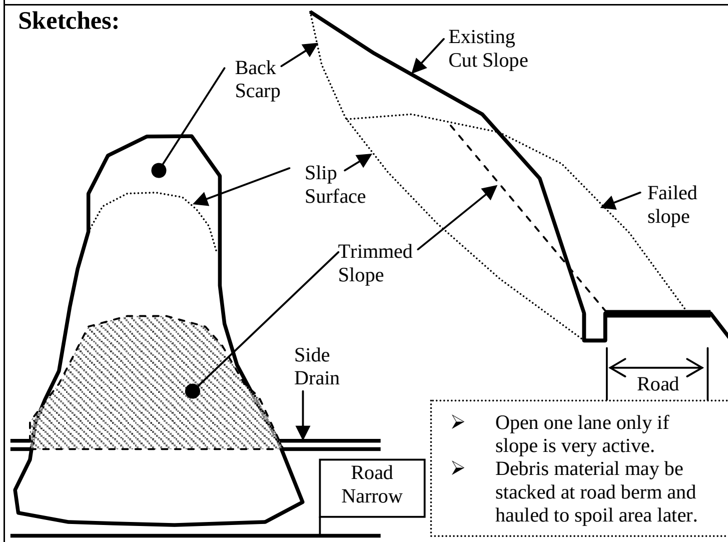
C1 Removal

Name of Measure:

C1.1 Removal

Symbol:

Sketches:



Purpose / Function:

- Open road for traffic flow
- Reinstate drainage function
- Reduce surcharge load on valley side retaining walls and critical slopes

Limitations:

- May require urgent works before removal
- May accelerate movement of silde mass

Design Considerations:

- Consider single lane clearing as an emergency work
- Install road signs on either side to warn on impending dangers due to landslide or rock falls
- Engage flagmen on either end to guide traffic
- Construct essential retaining wall and safety for safety of traffic
- Avoid spoil tipping of material. Material may be shifted at road berm and hauled to designated spoil area later
- Consider collection and convey of seepage water from the slide area
- Consider use of temporary trap walls and fences depending on site specific requirement

Specifications:

- Shift material to road berms temporarily
- Side casting to be prohibited
- Install traffic warning signs on either end
- Designate suitable spoil areea and haul material to those spoil areas

Reference:

Mountain Risk Engineering Handbook Part II

Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

Guide to Slope Protection

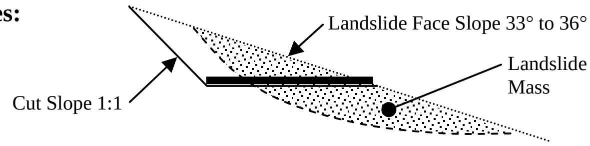
C2 Realignment

Name of Measure:

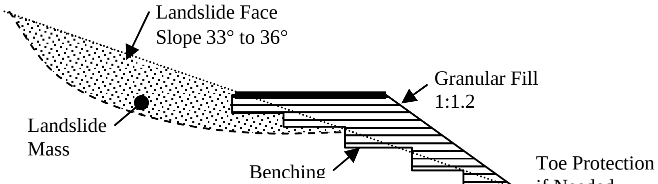
C2.1 Realignment

Symbol:

Sketches:



Alignment across Top of Landslide



Alignment across Toe of Landslide

Purpose / Function:

- Ensures better stability of road
- Avoids high hazard and risk
- Minimizes total cost
- Complements other stability measures
- Ensures better serviceability

Limitations:

- Very limited possibility at sharp ridge and steep terrain

Design Considerations:

- Realign road at highly critical stretches to more stable zone
- Determine stable road corridor from historical record
- Avoid valuable farmland, forest and protected areas
- Avoid areas with seepage and stability problems
- Avoid relignment on landside areas
- Use digital terrain model (DTM) and geomorphological maps developed from detailed field survey
- Adopt balanced cut-fill at slopes < 30°
- Adopt standard gradient, formation width, extra widening and set back distances as per standards at slopes < 30°
- Adopt lower geometric standards for steeper (> 30°) terrain and critical slope condition
- Apply lower geometric standards at steeper (> 30°) terrain and critical slope condition
- Design cut slope as per soil / rock condition and cut height
- Assess preliminary stability from field observation and Hoek and Bray stability charts
- Apply generic cut slope based on geomorphological units
- Where investigation dictates otherwise, design site specific cut slopes
- At critical spots, execute comprehensive investigation plan including core drilling, trial pitting and laboratory testing
- Prepare conceptual stabilization design of landslide or potentially problematic spots during feasibility study
- For unstable slope, identify cause of failure, depths and movement and mitigation options
- Integrate cross drainage and road side drains in slope protection work
- Identify safe spoil disposal areas during design stage
- Carry out landslide hazard and risk assessment at feasibility study
- For detailed slope stability calculations, use stability software

Specifications:

- Adopt suitable geometric standard
- Geometric standards may be lowered at critical spots

Reference:

Mountain Risk Engineering Handbook Part II

Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

Refer to cut and fill slope design guidelines

Table C2.1 Instability Problems Associated with Terrain Features

Facet	Features of Facet	Typical Stability Problems
Ridge top	Rounded relief	• Deeply weathered soils likely • Some erosion potential • Landslides possible
	Sharp relief	• Rock outcrop possible • Costly and difficult rock excavation • Landslides unlikely
	Irregular relief	• Difficult alignment along ridge top • Landsldies possible
	Asymmetric relief	• Joint controlled slopes govern stability of alignment and cut slope • Landslides possible
	Ridge lines generally	• May be subject to intense rainfall • May be affected by seismicity • Landslides possible
Valley side	Slope > 40º	• Probably underlain by rock • High construction cost / low maintenance cost • Landslides unlikely
	Slope 25° - 35°	• Colluvium or landslide material • Landslides likely
	Continouls rock slopes with constant dip	• Joint sets may control long-term stabilty • May be problematic in excavation or foundation • Rock slides possible
	Large embayments	• Either erosional or formed by landslides • Secondary landslides possible
	Large areas of paddy fields	• Drainage problems likely • May be colluvial in origin • Potentially unstable
	Rounded spurs	• Probably formed in residual soil • Generally stable
	Elongated midslope benches	• Either ancient river terraces ro rock benches • Stable or easy for road construction • Landsldies unlikely
	Forest / jungle areas	• Possibly areas of wet ground • Steep slopes require high cuts and walls • Landslides possible
Valley floor	Steep forested slopes forming margines of river	• Possibly actively unstable • Very difficult for road alignment • Landslide likely
	Steep forested slopes behind river terrace	• Possibly old periodically active instability • Landsldies likely

Table C2.2 Suggested Cross Sections at Unstable Sections

Slope Condition	Cross Section	Explanation
Alignment across top of landslide	Full cut	• Reduces driving force
Alignment across toe of landslide	Full fill	• Increases resisting force
Alignment on steep colluvial slope	Mostly full cut	• Slope too steep for fill slope • Foundation for retaining walls uncertain
Alignment on joint-controlled slope	Cut / retaining wall	• Some cutting may be possible • If foundation is stable, mostly retaining wall option is preferable
Alignment on rock cliffs	Cut / retaining wall	• Cutting is usually only option with retaining walls across gullies and rock clefts
Alignment on lower valley side slope	Cut / mostly retaining wall	• Walls depend on foundation stability
Alignment on or adjacent to ridge top	Full cut / minor retaining wall	• Full cut as the cut height is low

Table C2.3 Soil Slope Stabilization Techniques

Approach	Technique	Location	Limitation
Avoid problem	Realign road	Where feasible	• High cost • May create similar problems • Slow to implement
	Removal	Small quantity and shallow depth	• Only feasible for minor, shallow slips • May create further instability
	Bridging	Mainly at re-entrants	• High cost • Slow to implement • Requires confidence that re-entrant margins are not prone to further instability
	Catch wall	Mainly steep slopes in weathered rock where space is available at toe	• Must be capable of containing slop debris • Slip may become more extensive upslope
Reduce driving forces	Regrade slope	On slope where reduction in cut slope angle is feasible	• Unlikely to be feasible in steep terrain • Surface will need erosion protection
	Drain surface	Where needed	• Will only reduce surface infiltration • Combine with other techniques
	Drain subsurface	where water table is above the slip surface	• More effective where sliding mass is relatively permeable
Increase resisting forces by application of an external force	Retaining / breast walls	Where needed	• Moderate cost • Must be founded below slip surface • Combine with other techniques
	Toe berm	Where space is available	• Usually requires significant space at toe
	Ground anchors	For slope stability, used to increase FoS of slopes	• High cost • Specialist installation equipment needed • Potential corrosion / monitoring problems • Yet to be tested in Nepal context
Increase resisting forces by increasing internal strength	Subsurface Drain	Where water table is above slip surface	• More effective when sliding mass is moderately permeable
	Soil nailing	to steepen cut slope angle e.g., for road widening	• High cost • Specialist installation equipment needed • Applicable to non-failed slopes mostly
	Bio-engineering	Where slip surface is very shallow (< 1m)	• Not suitable for steep slopes and deep-seated failures • Planting mix must include deep and strong-rooted shrubs

Illustrative Examples

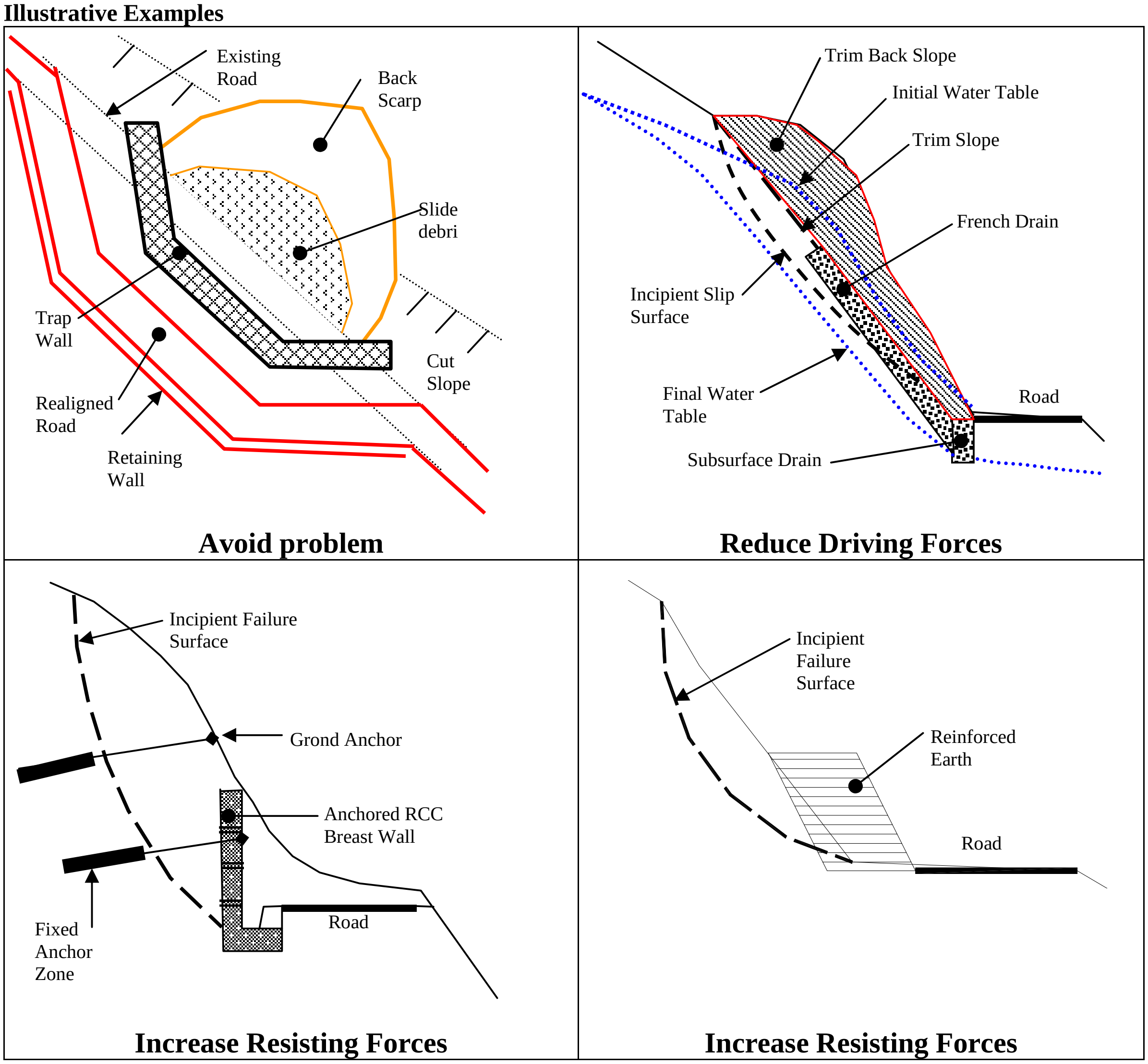
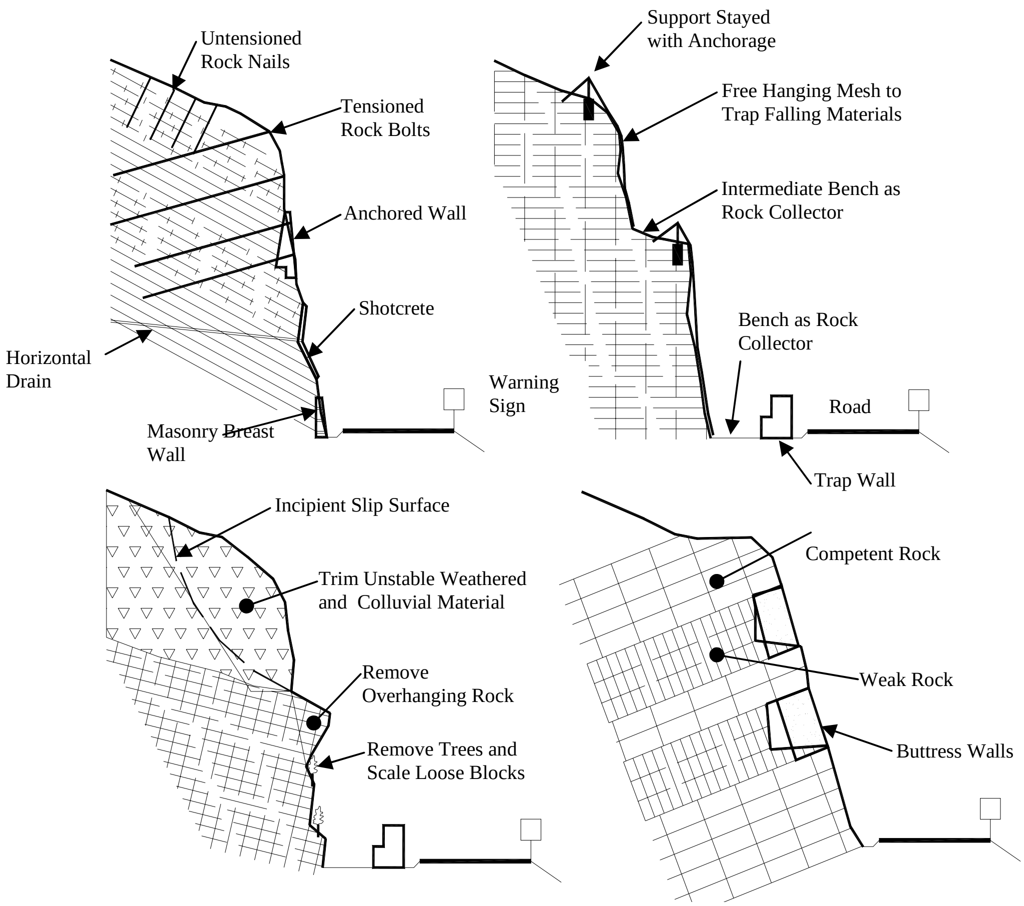
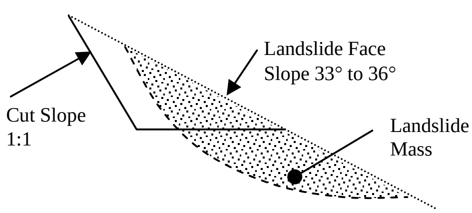


Table C2.4 Rock Slope Stabilization Techniques

Approach	Technique	Location	Limitation
Stabilization / reinforcement	Rock bolts	Any potentially unstable blocks that can be bolted and tensioned back to stable material	• High cost • Special equipment required • Long term corrosion / creep problems
	Dowels	Any potentially unstable block that can be kept in place by passive dowel	• Use usually restricted to blocks 1m to 2m thick
	Tie-back walls	Where multiple rock bolting is required to provide load spread	• Same as for rock bolting
	Shotcrete	Closely fractured or degradable rock face	• Special equipment required
	Buttresses	Cavity on rock face	• Potential access problems
Stabilization / removal	Regrading	Instability at crest of rock face	• Potential access problems • Difficult in very steep terrain
	Trimming	Overhangs / steep slopes	• Controlled blasting techniques required
	Scaling	Loose rock on surface	• Labor-intensive • Potential access and safety problems
Protection	Catch ditch	Base of slope where space permits	• Shape of ditch dependent on height and slope fo rock face
	Mesh	Loose / weak rock on surface	• Will not retain major blocks • Good anchorage required at top of face
	Barrier	Base of slope where space permits	• Needs to be robust to halt movement onto road
	Shelter	Base of high unstable face where other measures not feasible	• Very high cost
	Tunnel	If relocation is the only solution	• Very high cost • Yet to be tried in Nepal

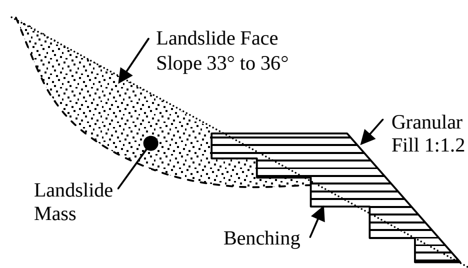
Illustrative Examples





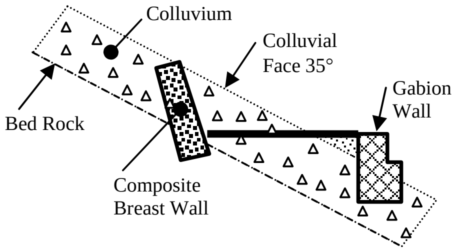
Alignment across Top of Landslide

(Gradient to be adjusted on either end)

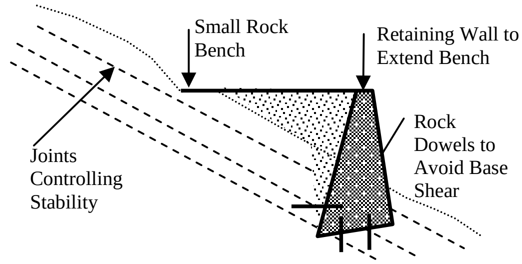


Alignment across Toe of Landslide

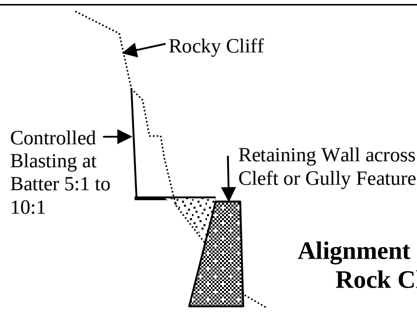
(Toe protection to be provided if necessary)



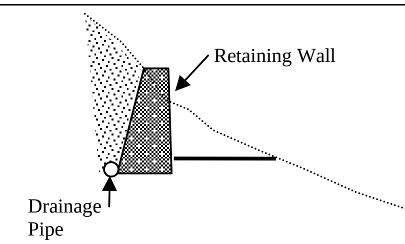
Alignment on Steep Colluvial Slope



Alignment across Joint Controlled Slope

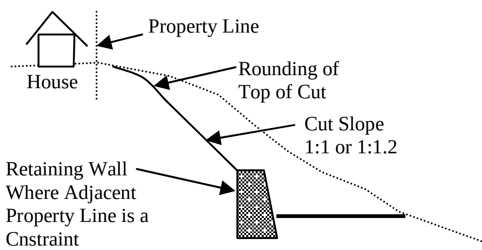


Alignment across Rock Cliff

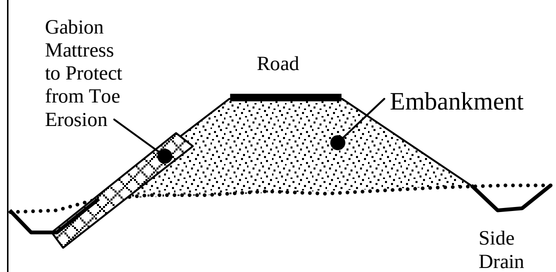


Alignment across Lower Valley Side Slope

(Precaution to be taken to keep the pipe short so that it can be cleaned)

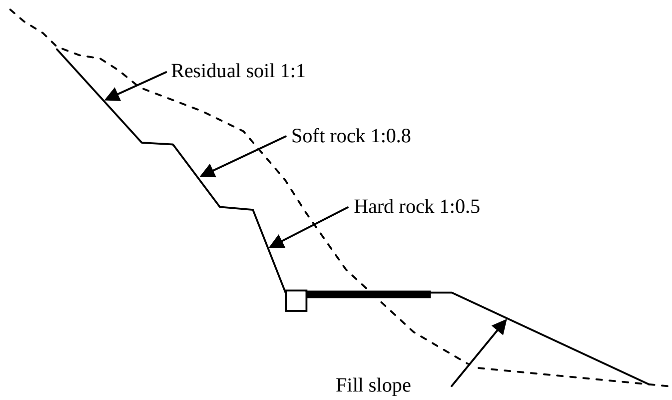


Alignment on or adjacent to Ridge Top



Alignment on Alluvial Terrace

C3 Earthwork

Name of Measure: ***C3.1 Cutting***	**Symbol:**
Sketches:  	**Purpose / Function:** • Reduce driving force **Limitations:** • Limited to right of way
Design Considerations: • Cut slope and length based on geological / hydro-geological conditions and soil parameters. • Cut slope ranges generally from 1V:0.3H to 1V:1.5H. • Surface water management is essential in erosive sandy soil such as decomposed granite, pit sand or terrace gravel. • Cut slope in soft rocks such as mudstone and tuff with low degree of solidification destabilizes due to weak internal shear strength and stress release. • Avoid retaining walls > 8 m height • Stability of fissured rock slope is governed by the degree of fissure development and their distribution. • Cutting work should be made during dry season. • Final cut slope should be treated with drainage, slope protection works and bioengineering. • Erosion and instabilities should be prevented at the toe of the slope. • Where cut slope is steeper than standard gradient, walls and resisting structures should be provided.	**Specifications:** • Cut / removal of soil / rock at upper / head part of slide • Fill / loading of soil / rock at lower / toe part of slide **Reference:** Mountain Risk Engineering Handbook Part II Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice Guide to Slope Protection

Standard Design

Table C3.1 Detailed Design Guidelines for Cut Slopes

Height / Hazard	< 15 m	15-30 m	> 30 m
Low	Follow standard design tables and figures from MREH	Follow standard design tables adn figures from MREH and Hoek & Bray charts Provide breast wall to limit net cut height to 15 m Provide bioengineering measures in soils	Special investigation, slope stability analysis (manual or computerized)
Medium	Follow standard design tables adn figures from MREH and Hoek & Bray charts Provide breast wall to limit net cut height to 8 m Provide engineering and bioengineering erosion control measures in cut slope and beyond	Special investigation, slope stability analysis (manual or computerized)	-
High	Special investigation, slope stability analysis (manual or computerized) Provide landslide and erosion control in cut slope and beyond	-	-

Legend:

Green	Simple case
Yellow	Medium case
Orange	Complex case

Table C3.2 Preliminary Cut Slope Gradients (V:H) for cut height < 15 m

Soil classification		**Cut height (m)**		
		< 5 m	**5-10 m**	**10-15 m**
Hard rock		1:0.3 – 1:0.8		
Soft rock		1:0.5 – 1:1.2		
Sand	Loose, poorly graded	1:1.5		
Sandy soil	Dense or well graded	1:0.8 – 1:1.0	1:1.0 – 1:1.2	-
	Loose	1:1.0 – 1:1.2	1:1.2 – 1:1.5	-
Sandy soil, mixed with gravel or rock	Dense, well graded	1:0.8 – 1:1.2		1:1.0 – 1:1.2
	Loose, poorly graded	1:1.0 – 1:1.2		1:1.2 – 1:1.5
Cohesive soil		1:0.8 – 1:1.2		-
Cohesive soil, Mixed with rock or cobbles		1:1.0 – 1:1.2	1:1.2 – 1:1.5	-

Source: Guide to Slope Protection

Table C3.3 Stable Slope Angle for Sand and Gravel with Nonplastic Fines

Soil no.	**Description**	**Max slope gradient (H:V)**			
		Low GWT		**High GWT**	
		Dense	**Loose**	**Dense**	**Loose**
1	Sandy gravel (**GW**, **GP**) SPT 25-60 blows/ft	0.85:1	1.5:1	3:1	1.3:1
2	Sand, angular grains well-graded (**SW**) SPT 20-50 blows/ft	1:1	1.6:1	3.2:1	2:1
3	Silty gravel (**GM**), uniform sand (**SP**), silty sand (**SM**) SPT 5-25 blows/ft	1.5:1	2:1	4:	3:1

Source: Mountain Risk Engineering Handbook

For maximum unsupported height of steepest slope of cuts for

- coarse grained soils with plastic fines under high and low GWT and
- fine grained soils with dense layer at bottom and at great depth

reference must be made to MREH

Table C3.4 Average Slope Angles for Bed Rock Excavation for Plane of Weakness Dipping < 30°

Type	**Description**	**Maximum slope gradient (H:V)**
Igneous	granite, trap, basalt, tuff	¼:1 to ½:1

Sedimentary	Massive sandstone and limestone Interbedded standstone, shale and limestone Massive calystone and siltstone	¼:1 to ½:1 ½:1 to ¾:1 ¾:1 to 1:1
Metamorphic	Gneiss, schist and marble Slate Serpentine	¼:1 to ½:1 ¼:1 to ¾:1 Special investigation

Source: Mountain Risk Engineering Handbook

Table C3.5 Cut Slope Gradients for Soil Slopes

Soil Type	Water Table	Cut Slope Gradient (V:H) for Cut Height		
		0-3 m	4-6 m	7-10 m
Clayey silt (transported)	low medium high	1.5 1.3 1.0	1.0 1.0 0.8	0.8 0.5 NA
Silts	low medium high	1.0 1.0 1.0	≤ 0.8 ≤ 0.8 0.8	≤ 0.8 ≤ 0.8 NA
Coarse-grained colluvium	low medium high	1.0 1.0 1.0	1.0 1.0 0.8	0.8 ≤ 0.8 NA
Silty clay (residual)	low medium high	1.5 1.2 1.0	1.5 1.2 1.0	1.0 1.0 NA

Source: Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

Table C3.6 Cut Slope for Rock Mass without Structural Control

Rock Mass Description	Group	Discontinuity Roughness			
		Very Rough fresh unweathered surfaces	**Rough** slightly weathered, iron stained surfaces	**Smooth** moderately weathereda dn altered surfaces	**Slickensided** highly weathered surfaces with compact coatings or filings fo angular fragments
Intact or Massive massive insitu rock mases with very few and widely spaced discontinuities		Discontinuity-controlled failures			
Blocky / Very Blocky interlocked undistrubed to partially distrubed rock mass with multifaceted angular blocks formed by three orthogonal discontinuity sets	**G1/G2**	60°-65°	60°-65°	50°-60°	45°-50°
	G3/G4	50°-60°	50°-60°	45°-50°	40°-45°
Blocky/ Disturbed folded and/or faulted with angular blocks formed by many interseting discontinuity sets	**G1/G2**	45°-50°	45°-50°	40°-45°	40°-45°
	G3/G4	40°-45°	40°-45°	35°-40°	35°-40°
Disintegrated poorly interlocked, heavily broken rock mass with a mixture of antular and subrounded rock pieces	**G3/G4**	35°-40°	35°-40°	35°-40°	35°-40°

Source: Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

Rock type groups:

G1 = Geniss, granite, granodiorite
G2 = Quartzite, Diorite, Gabbro
G3 = Sandstone, Breccia, Hornfels, Rhyolite, Andesite, Basalt, Tuff
G4 = Siltstone, Mudstone, Schist, Slate, Phyllite

Table C3.7 Cut Slope for Rock Mass with Structural Control

Rock Type Group	Discontinuity dipping out of slope > 30°		Discontinuity dipping out of slope < 30°		Discontinuity dipping into slope	
	Closed	**Infilled**	**Closed**	**Infilled**	**Closed**	**Infilled**
G1	65°-80°	40°-45°	80°-85°	45°-50°	80°-85°	80°-85°
G2	60°-75°	40°-45°	70°-80°	45°-50°	75°-85°	75°-85°
G3	60°-70°	40°-45°	70°-75°	45°-50°	75°-80°	75°-80°
G4	55°-70°	40°-45°	65°-75°	45°-50°	70°-80°	70°-80°

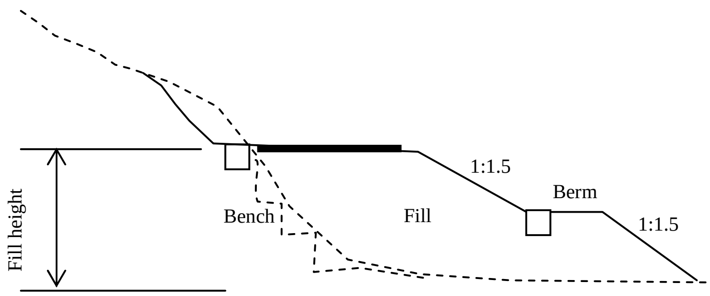
Source: Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

Name of Measure:

C3.2 Filling

Symbol:

Sketches:



Purpose / Function:

- Counteract the driving force

Limitations:

- Limited to right of way
- Proper compaction needed
- Toe protection may be necessary

Design Considerations:

- Soil properties to be obtained from field tests and laboratory tests such as index (USCS classification), strength (CBR and unconfined compressive strength) and deformation (oedometer, triaxial) characteristics
- Stability analysis essential for embankment height > 5m
- Existing natural ground should be capable to safely withstand additional load due to fill (stability, bearing pressure and settlement)
- Fill slope gradient dependent on characteristics of fill material
- For high fill, 1-2 m wide berms are recommended every 5-7 m vertical interval with perper berm drainage
- Management of surface and subsurface water essential for high embankments
- Drainage, surface protection and bioengineering essential to increase stability against effects of rainfall and infiltration
- Lower geometric standards in critical areas with proper warning signs

Specifications:

- Cut / removal of soil / rock at upper / head part of slide
- Fill / loading of soil / rock at lower / toe part of slide

Reference:

Mountain Risk Engineering Handbook Part II

Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

Guide to Slope Protection

Standard Design:

Table C3.8 Recommended Cut Slope Gradient

Fill materials	**< 5 m**	**5-10 m**	**10-15 m**	**15-20 m**
Well graded sand, gravels, and sand or slit mixed with gravels	1:1.5 – 1:1.8		1:1.8 – 1:2.0	
Poorly graded sand	1:1.8 – 1:2.0			
Rock masses (including muck)	1:1.5 – 1:1.8		1:1.8 – 1:2.0	
Sandy soils, hard clayey soil and hard clay	1:1.5 – 1:1.8	1:1.8 – 1:2.0	-	-
Soft clayey soils	1:1.8 – 1:2.0	-	-	-

Source: Guide to Slope Protection

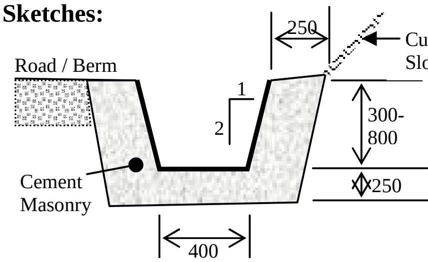
C4 Surface Drainage

Name of Measure:

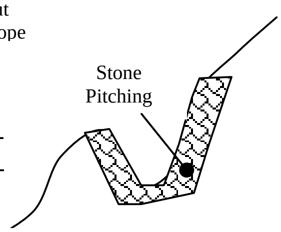
C4.1 Surface Drains

Symbol:

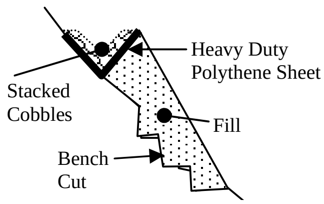
Sketches:



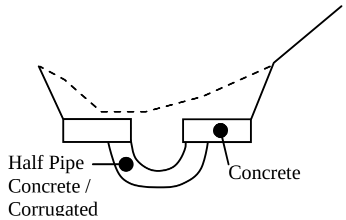
CEMENT MASONRY DRAIN



STONE PITCHED DRAIN



POLYTHENE LINED DRAIN



HALF PIPE DRAIN

Purpose / Function:

- Collect surface water from springs and rainfall
- Safely discharge collected water to nearest natural channel
- Reduce driving force
- Increase resisting force
- Reduce pore pressure
- Reduce infiltration

Limitations:

- Failure of catch drain may trigger slope erosions

Design Considerations:

- Implement as an immediate measure in landslides pior to investigation and stability analysis
- Ensure proper collection of surface water to ditch and avoid infiltration of collected water
- Locate drains at slope depressions with proper lining and gradient (dry stone lining not recommended)
- Delineate catchment areas for each drain and compute design runoff based on rainfall intensity, catchment area and characteristics of surface
- Design drain size for design discharge of 10 year return period in low hazard zone and 25 year return period for critical areas
- Outslope road formation for bitumin sealed road for design speed < 30 km/hr and gradient < 5% requires no side drain
- In wet area, use surface-cum-subsurface channels
- Standard methods: rational formula, US soil conservation service curve number method, California culvert practice for estimating discharge
- Use Manning's equation with standard coefficients for different materials for computation of open channel flow with uniform section
- Ensure safe velocity in channels (loose clay or fine sand up to 0.5 m/s, coarse sand 0.50-1.00 m/s, fine gravel, sandy or silty clay 1.00-1.50 m/s, Coarse gravel, rocky soil 1.50-2.50 m/s and boulders, rock 2.50-5.00 m/s)
- Provide inspection chambers at junctions of drains
- In unstable slope provide anchored blocks to fix drains

Specifications:

- Types of drains: catch drain, berm drain, toe drain, drainage channel, cascades etc.
- Forms of drains: U-shaped gutter, reinforced concrete, corrugated half pipe drain, grouted rip rap
-

Reference:

For anchors refer to ground anchors

Mountain Risk Engineering Handbook Part II

Guide to Slope Protection

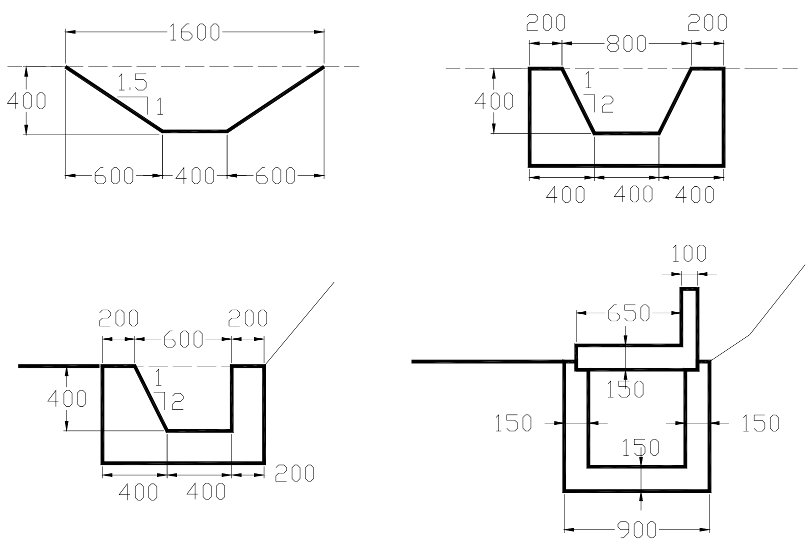
Standard Design

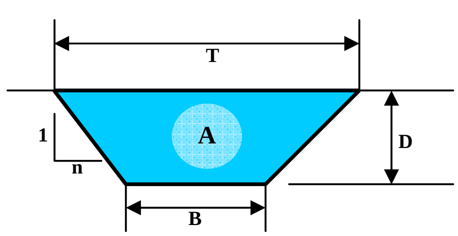
Table C4.1 Roughness Coefficients and Limiting Velocities

Bed materials		Roughness coefficients 'n'	Limiting velocity (m/s)
Sand, silt (unbound)		0.022-0.025	0.3
Loam, fine gravel		0.022-0.025	0.9
Stiff clay		0.018-0.022	1.2
Good grass cover	Easily eroded soil	0.025-0.030	0.9
	Other soil	0.025-0.030	1.5
Coarse gravel		0.030-0.035	1.5
Rock	Smooth	0.035-0.040	-
	Jagged	0.040-0.045	-
	Soft	-	2.5
	Hard	-	5.5
Masonry		0.025-0.030	-
Concrete		0.015-0.020	-

Source: Guide to Slope Protection and Mountain Risk Engineering Handbook

Illustrative Examples





Formula for Trapezoidal Channel

$T = B + 2\,n\,D$

$A = D\,(B + T) / 2$

$P = B + 2\,(1 + n^2)^{1/2}\,D$

$R = A / P$

$V = 1/\eta\;A\;R^{2/3}\,S^{1/2}$

$Q = V\,A$

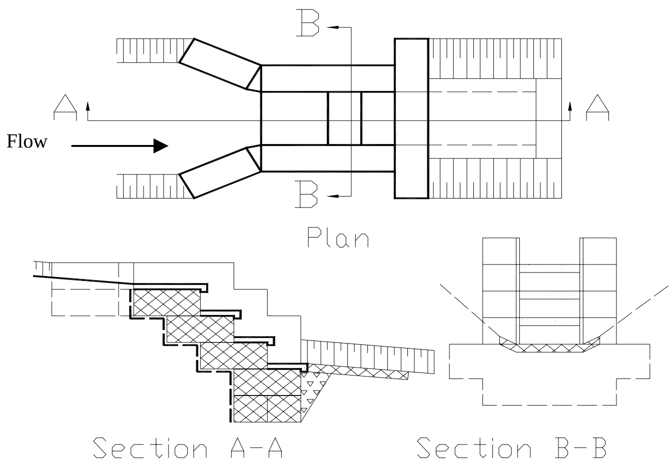
For B = 0.5 m, D = 0.3 m, n = 1.5, S = 1.0% and η = 0.0225,
T = 1.4 m, A = 0.285 m^2, P = 1.58 m, R = 0.18 m,
V = 0.40 m/s and Q = 0.115 m^3/s

Name of Measure:

C4.2 Cascade Structure

Symbol:

Sketches:



Purpose / Function:

- Dissipate surplus kinetic energy of flowing water through sudden vertical drop
- Reduce velocity of flow
- Prevent eroson in bed and bank
- Improve stability of stream bed slope

Limitations:

- Gabion wires fail due to coarse bed load
- Concrete or cement masonry cascades not suitable where flexibility is desirable
-

Design Considerations:

- Suitable where discharge is low
- Suitable for steep erodible gully that may trigger toe failure of potentially unstable slope
- Usually applied at inlets and outlets of cross drainage structures
- Layout dictated by site condition
- Where coarse bed load is expected gabion cascades should be protected with wire protection
- Drop rise and width to suit to the gradient of gully and discharge
- Tread shall be larger than rise to allow for dissipation of energy at each tread
- Stilling basin with water cushin should be created at each tread either with raised crest or with inward inclination of tread (10-15%)
- Ensure proper embedding at top and good foundation at bottom of the cascade
- Apron of boulder rip rap should be provided at outfall of cascade to dissipate surplus energy and to protect cascade structure from scour
- Follow bottom to top construction sequence
- 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
- For relatively good foundation condition, cement masonry cascade is recommended
- For relatively weak foundation condition and where flexibility is required, gabion cascades are suitable
- Gabion cascades should be lined with outward sloping treads

Specifications:

- Material options: gabion, concrete or cement masonry

Reference:

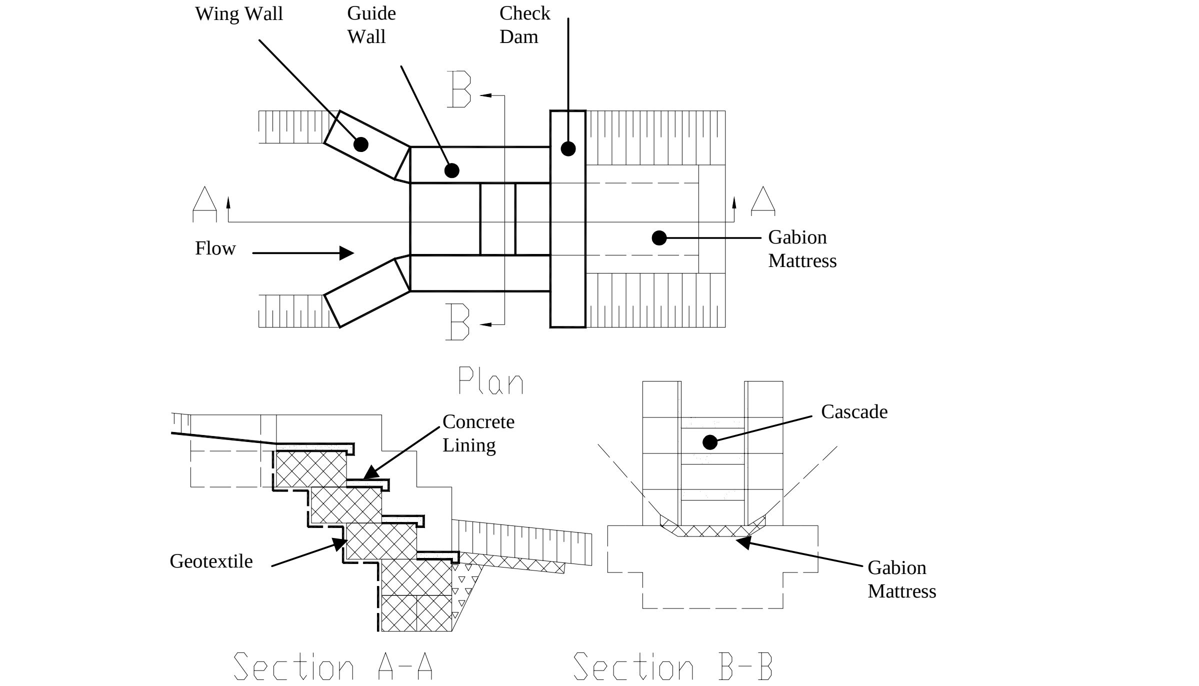
Mountain Risk Engineering Handbook Part II

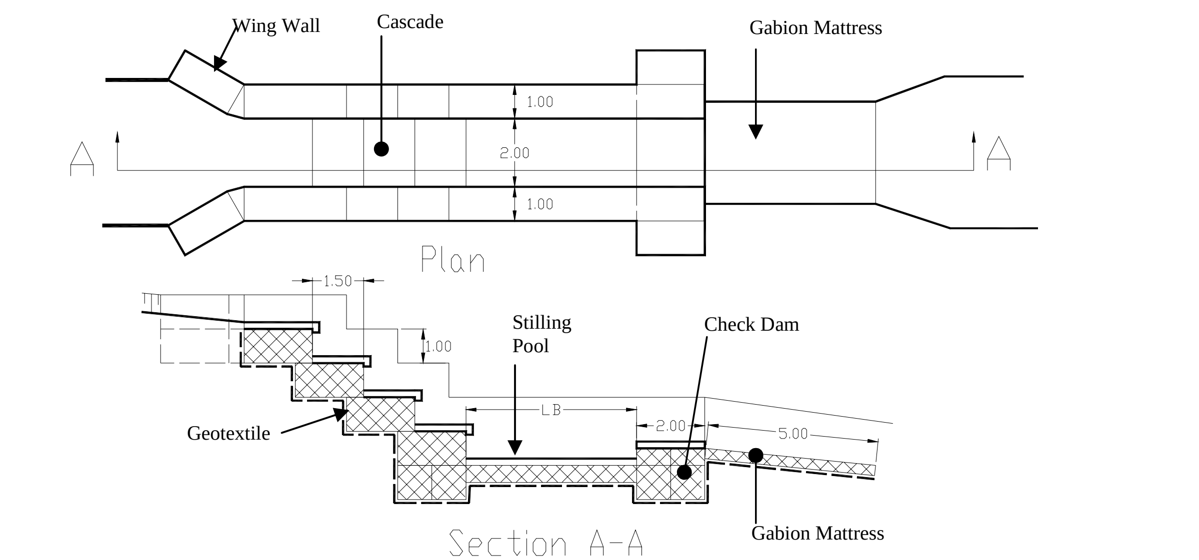
MACCAFERRI Guidelines for Gully Control Works

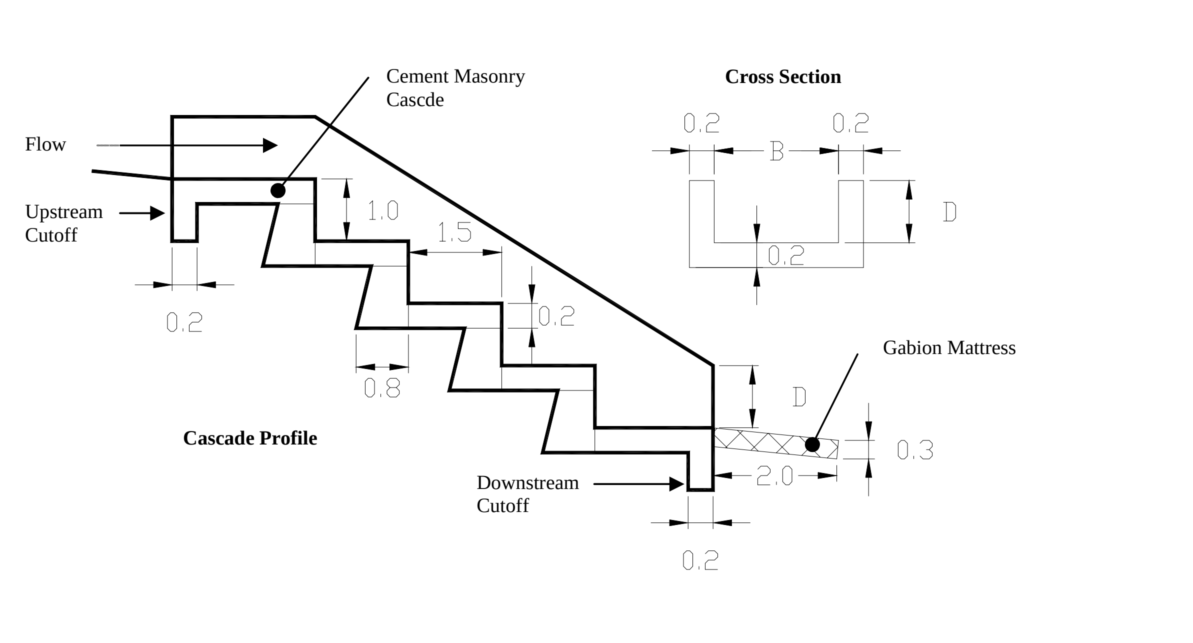
Sabo Technical Centre: Design of Sabo Dam

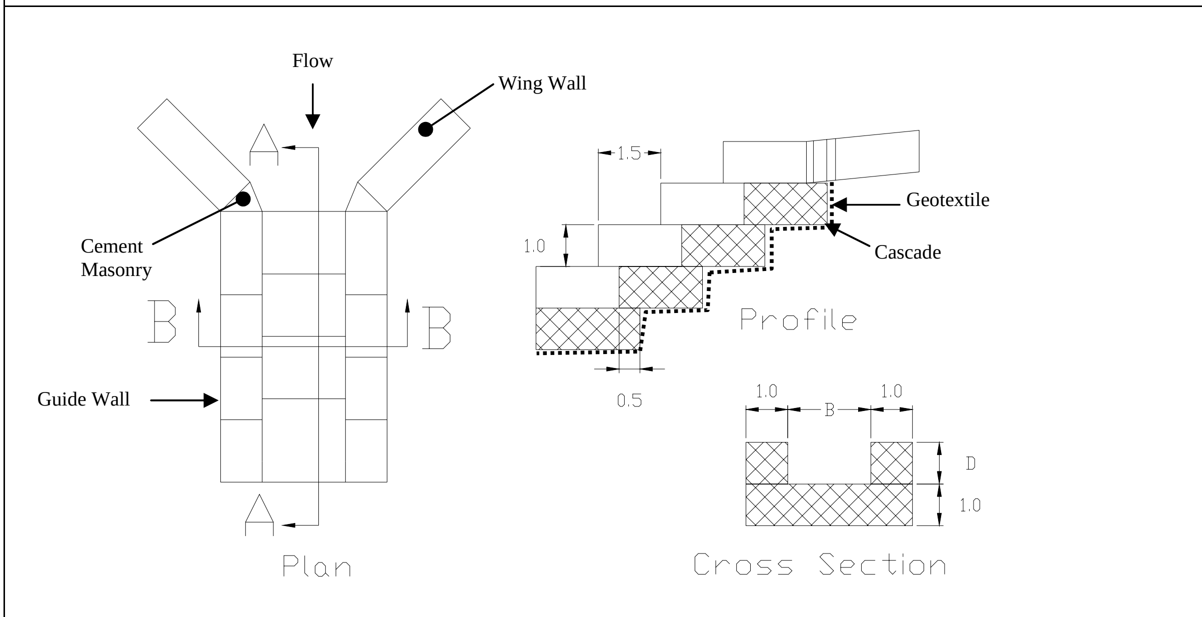
Guide to Slope Protection

Illustrative Examples

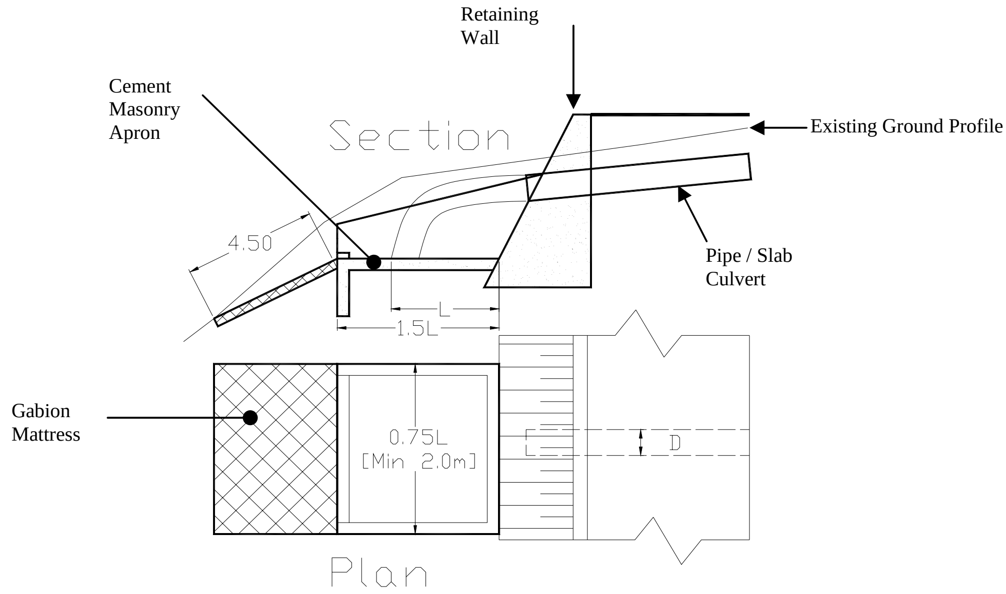


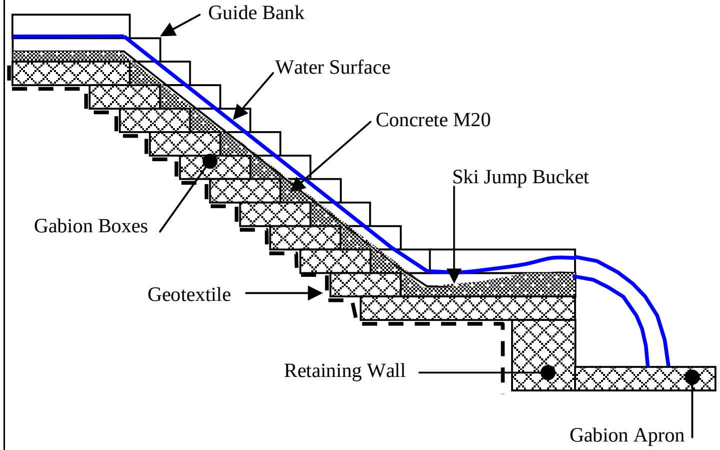






Gabion Cascade


Retaining Wall
Cement Masonry Apron
Section
Existing Ground Profile
4.50
Pipe / Slab Culvert
L
1.5L
Gabion Mattress
0.75L
[Min 2.0m]
D
Plan

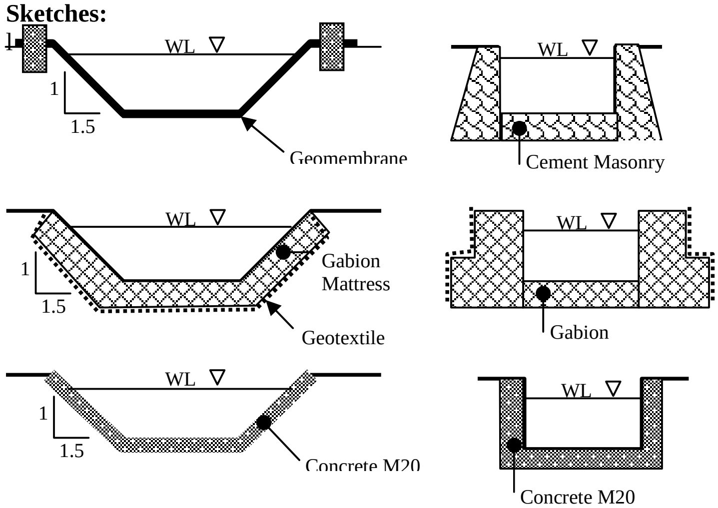
Name of Measure: ***C4.3 Chute Structure***	**Symbol:**
Sketches:  	**Purpose / Function:** • Convey flow within lined steep channel • Prevent eroson in bed and bank • Improve stability of stream bed slope • Dissipate surplus kinetic energy of water by stilling pool , ski jump bucket, roller bucket, chute blocks or impact baffle **Limitations:** • Unprotected gabion wires fail due to coarse bed load • Inside lining should be RCC • Free board should be high to accommodate turbulent flow
Design Considerations: • Suitable where discharge is low • Suitable for steep erodible gully that may trigger toe failure of potentially unstable slope • Usually applied at spillway profiles • Layout dictated by site condition • Where 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 subseqent separation • Chute width and depth according to design discharge • Ensure proper embedding at top and good foundation at bottom of the chute • Apron of boulder rip rap should be provided at outfall of cascade to dissipate surplus energy and to protect cascade structure from scour • Follow bottom to top construction sequence • Provide weep hole, filter material and filter fabric to drain out water trapped within chute structure • For relatively good foundation condition, cement masonry chute structure with concrete lining at flow section • For relatively weak foundation condition and where flexibility is required, gabion cascades with concrete lining at flow section • Proper structural / geotechnical design is required. (Avoid rule of thumb dimensioning)	**Specifications:** • Material options: gabion, concrete or cement masonry **Reference:** Mountain Risk Engineering Handbook Part II Guide to Slope Protection

Name of Measure:

C4.4 Channel Lining

Symbol:

Sketches:



Purpose / Function:

- Reduce risk of scour of bed
- Roughen and strengthen stream bed
- Resist scouring process
- Prevents bank slope failures (lateral erosion)

Limitations:

- Not applicable for steep channel gradient
- Downstream gully bed in high risk due to increased water velocity

Design Considerations:

- Transition from lined channel to unlined natural channel should be integral part of design
- For low discharge and velocity, vegetative structures like live check dams, fascines or bamboo/shrub plantation are used
- For relatively low discharge, dry stone rip rap or concrete grouted rip rap are used
- For high discharge and velocity, gabions, boulders or concrete blocks are suitable
- For better stabilty, dish shaped or bowl shaped lining is desirable
- Lining should minimally extend up to design high flood level
- To prevent lateral eroison of embankment, lining should be extended beyond design high flood level with minimum free board of 0.3 m

Specifications:

- Lining or reinforcement work dependent on nature of gully and design discharge
- Lininng material options: boulders, stones, concrete blocks, gabions and vegetative structures

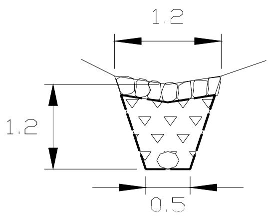
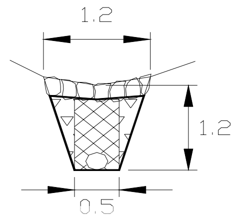
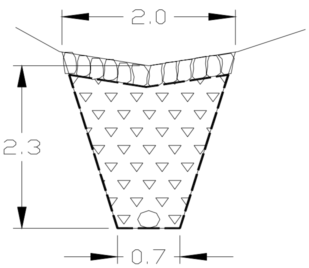
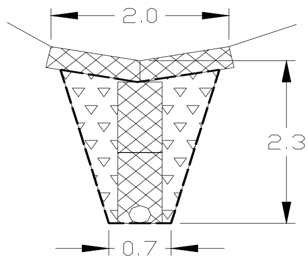
Reference:

Mountain Risk Engineering Handbook Part II

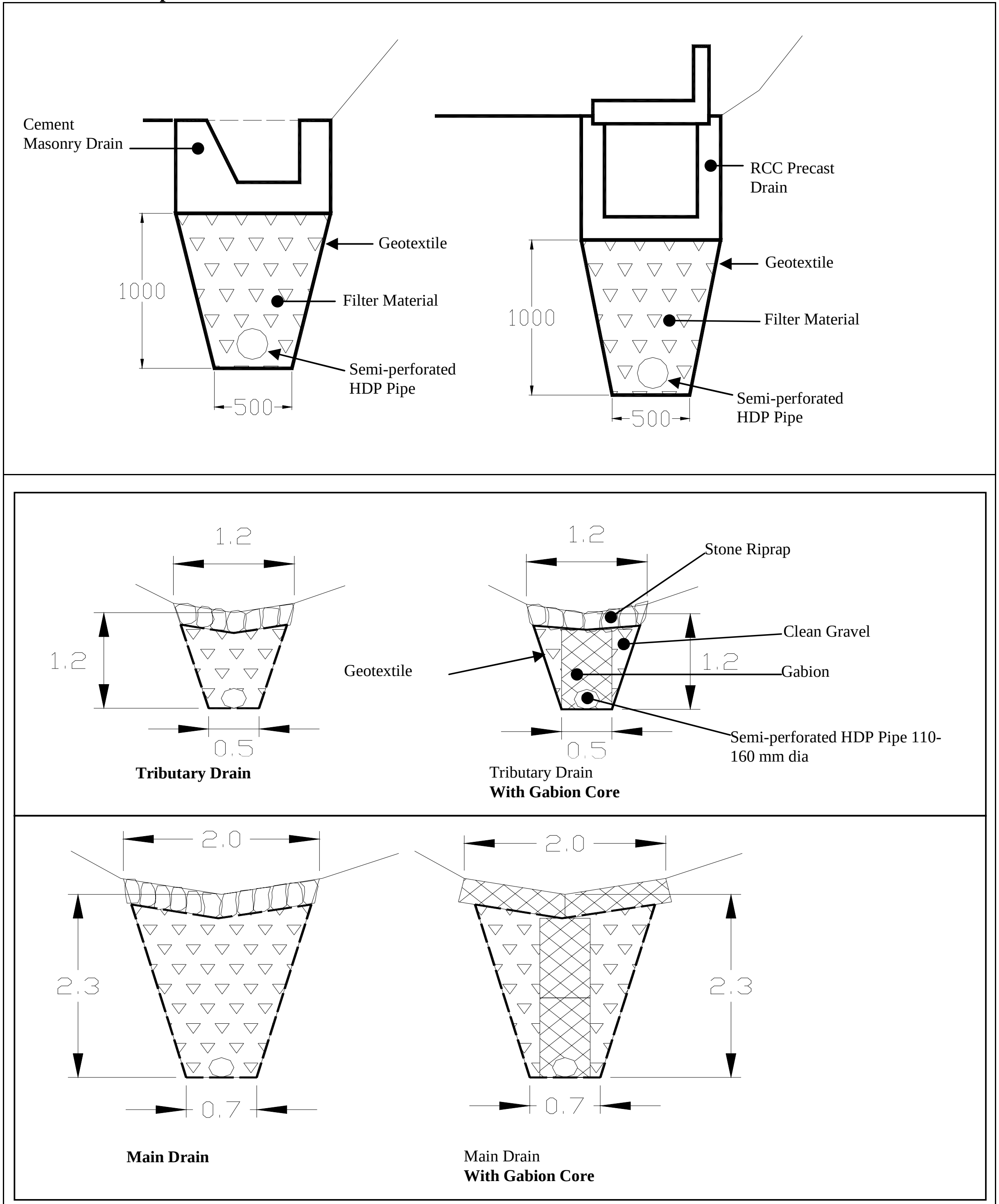
MACCAFERRI Guidelines for Channel Lining Works

Guide to Slope Protection

C5 Subsurface Drainage

Name of Measure: ***C5.1 French Drains***	**Symbol:**
Sketches:  Tributary Drain  Tributary Drain **With Gabion Core**  Main Drain  Main Drain **With Gabion Core**	**Purpose / Function:** • Intercept and drain out near-surface water • Reduce driving force • Reduce seepage force • Reduce weight of unstable soil mass • Decrease pore pressure • Partly drains surface runoff • Control shallow failure **Limitations:** • Cannot drain out deep water table • Maintenance is problematic.
Design Considerations: • Carry out geological and geophysical investigation to determine whether the instability is caused due to high seepage • Locate network of French drains along natural depressions • Network consists of tributaries and main drains in herring bone or parallel pattern • French drains can be modified to drain out both surface and near-surface water for effective drainage • Delineate sub-catchments of each French drain • Design capacity of French drains considering sub-catchment area, rainfall intensity and infiltration rate • Design size of HDP pipe considering ground water discharge • Provide inspection / maintenance outlets at intervals of 20 m • Use geomembrane (impervious) at bottom of trrench to reduce seepage of collected water • In unstable and moving slopes, the french drains may require anchored blocks to fix in place • At toe of French drains, support walls and outlet channels should be provided	**Specifications:** • Depth normally from 1 to 3m • Materials: main part with gravel, dry packing, riprap or gabion with semi-perforated HDP pipe in filter material, soil interface lined with geotextile at sides and geomembrane at bottom channel **Reference:** For anchors refer ground anchors Mountain Risk Engineering Handbook Part II Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice Guide to Slope Protection

Illustrative Examples



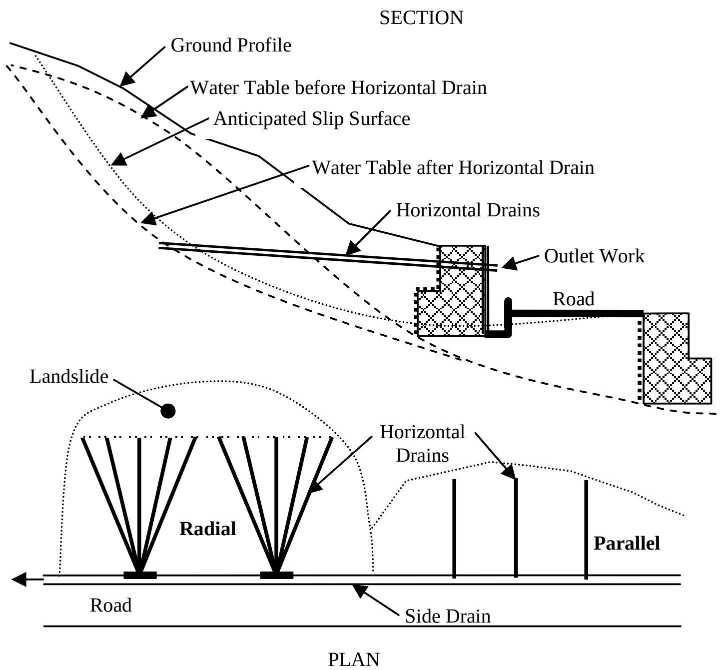
French Drains

Name of Measure:

C5.2 Horizontal Drains

Symbol:

Sketches:



Purpose / Function:

- Lowers perched water table
- Reduce driving force
- Reduce seepage force
- Reduce weight of unstable soil mass
- Increase resisting shear strength
- Decrease pore pressure

Limitations:

- High cost
- Requires special equipment
- Requires special expertise
- Requires extensive soil exploration
- Hence found limited use in Nepalese roads

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
- Deep ground water (> 5m) can be drained out using horizontal drains
- Options: horizontal drilled drains, drainage wells, drainage tunnels or thier combination
- Most effective method fo 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 concreet) 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

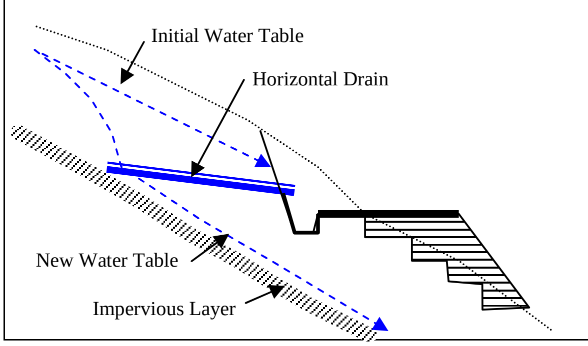
Specifications:

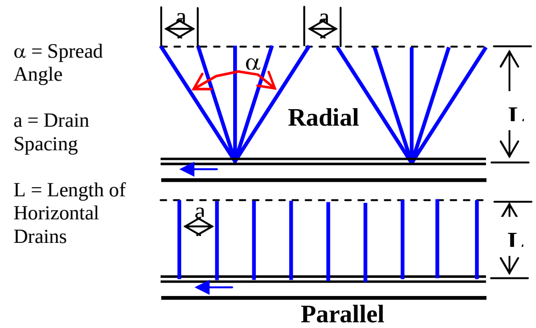
- Length 20-30 m with bore hole sizes 50-100 mm, 5-10º upslope, semi-perforated pipe 50-63 mm dia (perforation with 3-5 mm dia holes at 10-15 mm distance in zigzag pattern) wrapped in highly permeable geotextile
- Layout in parallel or radial (fan) pattern with up to 7 drains at a point
- Monitor discharges from each drain after installation

Reference:

Mountain Risk Engineering Handbook Part II
Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice
Guide to Slope Protection

Illustrative Examples





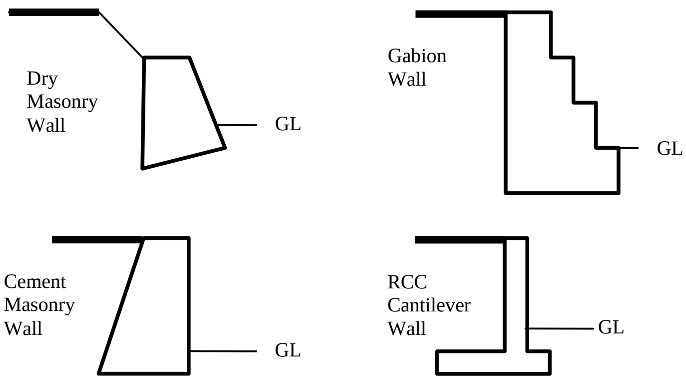
C6 Retaining and Breast Walls

Name of Measure:

C6.1 Wall Structures

Symbol:

Sketches:



Purpose / Function:

- Retaining embankment and surcharge
- Supporting toe of slope
- Supporting cut slope
- Preventing small-scale shallow collapse
- Prevent erosion or collapse at toe of large scale slope failure
- Help stabilize landslides
- Supporting other slope protection works

Limitations:

- Cannot stabilize large landslide
- Backfilling is not proper

Design Considerations:

- Generally on the valley side of road
- Strongly recommended at toe of failed slope
- Breast walls support cut slope directly without any backfill
- In large-scale landslide, systematic slope stability analysis should be carried out to design suitable stabilizing measure
- Design steps: evaluation of loads and pressures (dead load, surcharge, earth pressure, buoyancy, live load, water pressure, earthquake, impact etc.) and analysis of structure to withstand them
- Dead load calculated using standard densities of materials
- Live load calculated either by using standard codes or based on available data and experience
- Earth pressure is estimated using either empirical or theoretical analysis method
- Use active earth pressure from back fill using Rankine, Coulomb or Log Spiral theories
- Select trial wall section (back battered instead of front batter)
- Fix backfill geometry and classification
- Determine surcharge intensity
- Determine water table information
- Determine earth pressure coefficients and bearing capacity
- Check for stability against base sliding (FoS >1.5 static, >1.0 dynamic)
- Check for stability against overturning (FoS > 2.0 static, > 1.5 dynamic)
- Check for stability against bearing capacity of foundation (maximum base pressure < allowable bearing capacity for static and < 1.25 times allowable bearing capacity for dynamic case)
- Check overall stability of the wall and slope (FoS > 1.5 static and > 1.0 dynamic)

Specifications:

- Wall types: gravity, semi gravity, tieback, reinforced earth
- Earthwork and structures should be in a single stage to permit use of surplus cut material in backfill and embankment

• Determine allowable bearing capacity through in-situ loading tests or from soil exploration • Follow an iterative procedure to satisfy all conditions • For gravity type retaining wall, assume top width 0.35 to 0.70 m, base width 0.5 to 0.7 times wall height • For semi gravity or cantilever type, assume web thickness 0.35 m and base thicknesses 0.50 m, base length 0.5 to 0.7 times wall height • Avoid series of retaining walls one above another in steep slope • In sandy soil check for differential settlement • In dry walls ensure proper bonding and bedding of stones • Backfill should avoid unsuitable materials that may result in high seepage pressure • Ensure graded filter layer behind weep holes • Provide toe protection where water flow is anticipated	**Reference:** Mountain Risk Engineering Handbook Part II Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice Geoguide 1: Guide to Retaining Wall Design AASHTO Standard Specifications for Highway Bridges

Table C6.1 Allowable Bearing Pressures of Soils

Bearing material	**Compactness**	**Allowable bearing capacity (t/m^2)**
Well-graded mixture of fine sand and coarse-grained soil, glacial till, hardpan, boulder clay (**GW-GC, GC, SC**)	Very compact	100
Gravel, gravel-sand mixture, boulder-gravel mixture (**GW, GP, SW, SP**)	Very compact Medium to compact Loose	80 60 40
Coarse to medium sand, sand with little gravel (**SW, SP**)	Very compact Medium to compact Loose	40 30 30
Fine to medium sand, silty or clayey medium to coarse sand (**SW, SM, SC**)	Very compact Medium to compact Loose	30 25 15
Fine sand, silty or clayey medium to fine sand (**SP, SM, SC**)	Very compact Medium to compact Loose	30 20 15
Homogenous inorganic clay, sandy or silty clay (**CL, CH**)	Very stiff to hard Medium to stiff Soft	40 20 5
Inorganic silt, sandy or clayey silt, varied silt-clay-fine sand (**ML, MH**)	Very stiff to hard Medium to stiff Soft	30 15 5

Source: Mountain Risk Engineering Handbook

Table C6.2 Friction angle and unit weight of compacted materials

Group	Soil type	SPT range	Dry unit weight kN/m^3	Effective friction angle °
GW	Well-graded clean gravels, gravel-sand mix		20-21.5	>38
GP	Poorly-graded clean gravels, gravel-sand mix		18.5-20	>37
GM	Silty gravels, poorly-graded gravels-sand silt		19-21.5	>34
GC	Clayey gravel, poorly-graded gravel-sand clay		17.5-21	>31
SW	Well-graded clean sands, gravelly sand		16-19	38
SP	Poorly-graded clean sand, sand-gravel mix		16-19	37
SM	Silt sands, poorly graded sand-silt mix		17.5-20	34

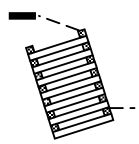
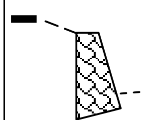
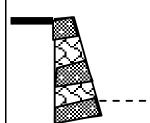
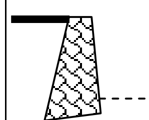
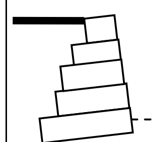
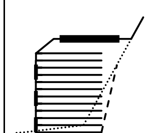
Source: Mountain Risk Engineering Handbook

Table C6.3 Unit weight of wall materials

Type of wall	Unit weight of masonry (kN/m^3)			
	Brick	**Granite**	**Limestone**	**Sandstone**
Dry masonry	13.8	18.8	17.4	15.3
Gabion masonry	12.8	18.8	17.4	15.3
Cement masonry	17.9	24.4	26.6	19.9

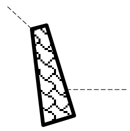
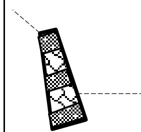
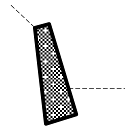
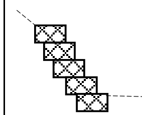
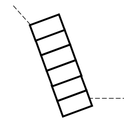
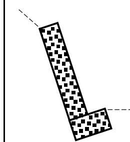
Source: Mountain Risk Engineering Handbook

Table C6.4 Typical Design of Retaining Walls

Types	**RCC Crib**	**Dry Masonry**	**Banded Masonry**	**Cement Masonry**	**Gabion Masonry**	**Reinforced Earth**
Schematic						
Top width (m)	1.2	0.6–1.0	0.6–1.0	0.5–1.0	1.0	4.0 or 0.7–0.8H
Base width	0.4–0.6H	0.5-0.7H	0.6–0.65H	0.5–0.65H	0.6–0.75H	4.0 or 0.7–0.8H
Front batter (V:H)	4:1	3:1	varies	10:1	6:1–4:1	3:1
Back batter (V:H)	4:1	vertical	vertical	varies	varies	3:1
Foundation dip (V:H)	1:4	1:3	1:3	1:10–1:6	1:6–1:4	horizontal
Foundation depth (m)	0.5–1.0	0.5	0.5–1.0	0.5–1.0	0.5	0.5
Height range (m)	4.0–12.0	1.0–4.0	4.0–8.0	1.0–10.0	1.0–6.0	3.0–12.0
Fill slope angle (°)	< 30°	< 30°	< 20°	35°-60°	35°-60°	< 35°

Source: Adapted from MREH

Table C6.5 Typical Design of Breast Walls

Types	Dry Masonry	Banded Masonry	Cement Masonry	Gabion	Drum Wall	Concrete
Schematic						
Top width (m)	0.5	0.5	0.5	2.0	1.0	0.5
Base width	0.3-0.35H	0.23H	0.25H	2.0	1.0	0.25H
Front batter (V:H)	varies	varies	varies	varies	varies	varies
Back batter (V:H)	3:1-5:1	3:1	3:1	3:1-5:1	3:1	3:1
Foundation dip (V:H)	1:3-1:5	1:3	1:3	1:5	1:3	1:3
Foundation depth (m)	0.5	0.5	0.5	0.5–1.0	0.25	0.5
Height range (m)	3.0–6.0	3.0–6.0	1.0–8.0	1.0–6.0	1.0–2.2	1.0–12.0
Hill slope angle (°)	35°-60°	35°-60°	35°-70°	35°-60°	15°-35°	35°-70°

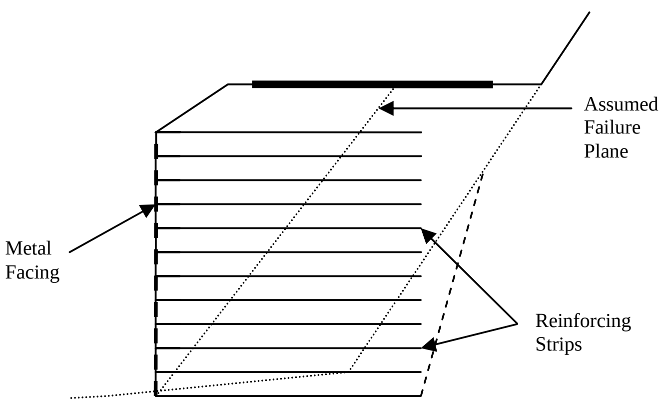
Source: Adapted from MREH

Name of Measure:

C6.2 Reinforced Earth

Symbol:

Sketches:



Purpose / Function:

- Retaining backfill
- Supporting cut slope

Limitations:

- Steel reinforcing strips susceptible for corrosion
- Very steep batters require formwork during construction

Design Considerations:

- External check such as overall stability, base sliding, overturning and bearing pressure same as that for gravity structure
- Internal stability should be checked for possibility of failures within the reinforced earth
- Used where embankment requires substantial cohesive strength
- Geogrid is the suitable reinforcing material
- Steel reinforcing strips are susceptible to corrosion
- Manufacturer's standard design charts should be followed for various design parameters
- Length of reinforcement about 0.8 to 0.8 times wall height
- Spacing between reinforcement grids from 20 to 100 cm in multiples of lift of compaction layer
- Practical front slope 3V:1H
- Gravel drainage layers should be placed at potentially wet areas to intercept seepage
- Ensure high level of compaction with heavy equipment
- Provide compaction at foundation to 93% modified proctor value

Specifications:

- Material options: geogrid, geotextile, gabion mesh or steel reinforcing strips

Reference:

Mountain Risk Engineering Handbook Part II

Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

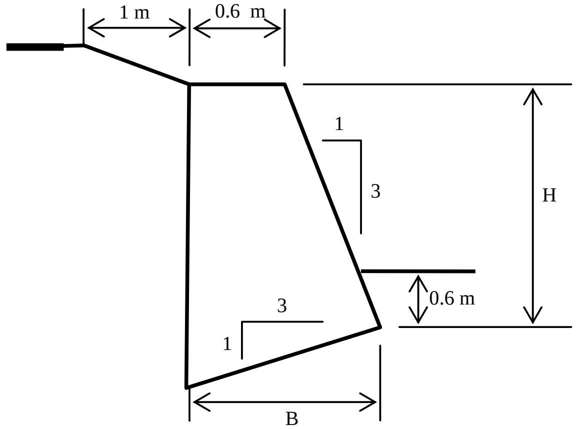
Guide to Slope Protection

Name of Measure:

C6.3 Dry Masonry Walls

Symbol:

Sketches:



Purpose / Function:

- Retaining backfill
- Supporting cut slope

Limitations:

- Limited to 4m in height
- Skilled mason, suitable stones and bonding of stones with key stones required
- Special care needed during constructigon, otherwise, it becomes sone fill, not masonry

Design Considerations:

- 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 1 times wall height
- For foundation in muddy condition provide stone soling at foundation

Specifications:

- Bond stones at least 45 cm in length and reasonable shaped are required at 0.6 m intervals of wall surface
- Proper lapping of stone in each course

Reference:

Mountain Risk Engineering Handbook Part II
Landslide Risk Assessment in the Rural Sector
Guide to Slope Protection

Table C6.6 Results from Analysis of Dry Masonry Wall

Wall Height (m)	Top Width (m)	Base Width (m)	Foundation Inclination (°)	Friction Angle (°)	Toe Pressure (t/m^2)
1.0	0.6	0.93	18.4	30	2.1
2.0	0.6	1.23	18.4	30	5.6
3.0	0.6	1.60	18.4	30	9.1
4.0	0.6	1.93	18.4	30	13.0

Notes:

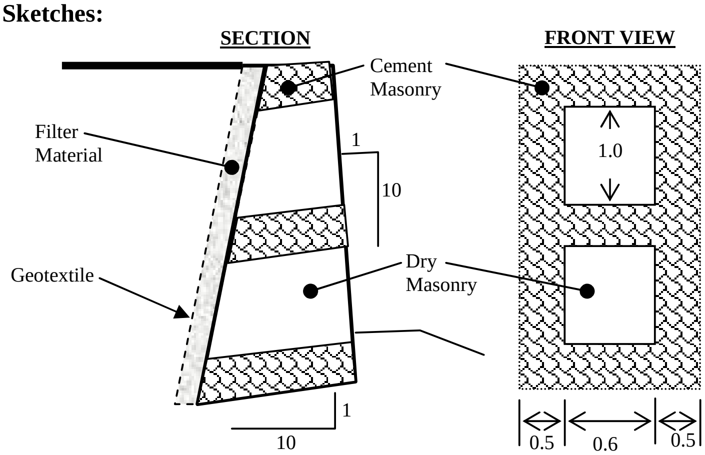
1. Assumptions: fixed front batter = 1:3, wall friction angle = $2\phi/3$, level fill, good drainage, soil unit weight 1.7 t/m^3, wall unit weight 1.65 t/m^3, surcharge load = 1.7 t/m^2 and lateral friction factor = 0.6.
2. The walls are adequately safe against overturning (FoS>2.0) and base slidig (FoS>1/5).
3. Walls up to 3m height may be designed on the basis of this table.
4. Other types of walls should be considered for height higher than 3m, either for full height, or for part of wall below 3m from the top of wall.

Name of Measure:

C6.4 Composite Masonry Walls

Symbol:

Sketches:



Purpose / Function:

- Retaining backfill
- Supporting cut slope
- Draining seepage water efficiently

Limitations:

- The wall is rigid and brittle
- Not suitable for unstable / moving foundations
- Limit height to 6 m for standard design

Design Considerations:

- 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
- Stronger than dry masonry but weaker than cement masonry walls
- 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 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 muddy condition at foundation, provide stone soling prior to blinding concrete
- For weak subsoils, reinforced concrete footing is required
- Ensure compaction at foundation at least 93% modified proctor value
- Vertical construction joints are required for walls > 10 m long
- At unstable area, spacing of joints should be reduced to 6m.
- Economical than cement masonry but takes longer time for construction

Specifications:

- Good quality stone
- Cement mortar of specified grade
- Types: random rubble masonry, coursed rubble masonry or ashlar masonry

Reference:

Mountain Risk Engineering Handbook Part II

Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

Guide to Slope Protection

Table C6.7 Results from Analysis of Composite Masonry Wall

Wall Height (m)	Top Width (m)	Base Width (m)	Foundation Inclination (°)	Friction Angle (°)	Toe Pressure (t/m^2)	
					Front Battered	Back Battered
3.0	0.6	1.8	1:10	30	5.0	14.6
4.0	0.6	2.4	1:10	30	11.3	18.4
5.0	0.6	3.0	1:10	30	16.5	22.0
6.0	0.6	3.6	1:10	30	21.3	25.6
7.0	0.6	4.2	1:10	30	25.8	29.1
8.0	0.6	4.8	1:10	30	30.2	32.6
9.0	0.6	5.4	1:10	30	34.5	36.0
10.0	0.6	6.0	1:10	30	38.7	39.5

Notes:

- Assumptions: minimum front batter = 1:10, wall friction angle = $2\phi/3$, level fill, good drainage, soil unit weight 1.7 t/m^3, wall unit weight 2.0 t/m^3, surcharge traffic load = 1.7 t/m^2 and lateral friction factor = 0.6.
- The walls are adequately safe against overturning (FoS>2.0) and base slidig (FoS>1/5).
- Walls up to 3m height may be designed with rule of thumb and walls with heights 4m to 6m may be designed on the basis of this table.
- Walls higher than 6m require foundation investigation for bearing capacity and overall stability.
- Where bearing capacity is low, provide extra toe and heel projections (0.75m thick and 0.50m long)

Table C6.8 Results from Analysis of Composite Masonry Breast Wall

Wall Height (m)	Top Width (m)	Base Width (m)	Foundation Inclination (°)	Friction Angle (°)	Toe Pressure (t/m^2)
1.0	0.5	0.5	1:4	36	1.7
2.0	0.5	0.9	1:4	36	9.7
3.0	0.5	1.5	1:4	36	15.5
4.0	0.5	1.5	1:4	36	22.1
5.0	0.5	2.6	1:4	36	27.0
6.0	0.5	3.1	1:4	36	33.5

Notes:

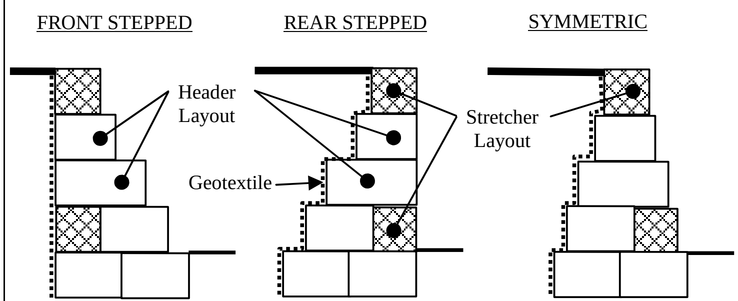
- Assumptions: minimum front batter = 1:4, wall friction angle = $2\phi/3$, level fill, good drainage, soil unit weight 1.9 t/m^3, wall unit weight 2.2 t/m^3, no surcharge load and lateral friction factor = 0.6.
- The walls are adequately safe against overturning (FoS>2.0) and base slidig (FoS>1/5).
- Walls up to 3m height may be designed with rule of thumb and walls with heights 4m to 6m may be designed on the basis of this table.
- Where bearing capacity is low, provide extra toe projection (0.75m thick and 0.50m long).
- The foundation pad of breast wall may be integrated with road side drain.

Name of Measure:

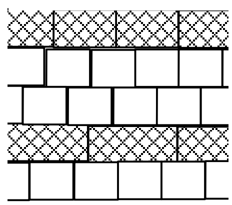
C6.5 Gabion Walls

Symbol:

Sketches:



FRONT VIEW



Vertical joints of gabin boxes to be staggered as much as possible

Normal box sizes: 2x1x1 and 1.5x1x1

Purpose / Function:

- Retaining backfill
- Supporting cut slope

Limitations:

- Breaking of wires by abrassion of bed load
- Corrosion of wires
- Relatively short life
- Height limit 8 m
- Proper stone filling inside gabion crates is a problem

Design Considerations:

- Designed as gravity structure
- Light density (about 70% of cement masonry)
- Larger section required compared to cement masonry wall
- Accommodates settlements and deformations without rupture
- Flexible nature makes it suitable in weak foundations and unstable / creeping slopes
- Allows free drainage through the wall
- In wet areas, either graded filter or geotextile is recommended at back face
- Outlet drain should be provided from the lowest point of gabion wall
- Ensure that heel drainage discharge can be visually inspected at outlet to catch pits
- Can be constructed in short sections (2 or 3 m) and therefore suitable for construction in unstable areas
- When used in river or cascades, the flow surface up to deisgn high flood level should be lined either with concrete 10-15 cm thick or shotcrete
- Use rule of thumb up to 3 m height, standard designs up to 6 m height and standard program for height > 6 m
- Limit height to 8 m
- Joints across cross section should be staggered
- Joints along length should be staggered where possible
- No need of blinding concrete at foundation
- At muddy and weak foundation, either stone soling or graded gravel layer with 93% modified proctor should be ensured

Specifications:

- GI wire with heavy coating
- Good quality stone > 10 cm size
- Bracing wires about 4 per m^2
- Selvedge wire 7 or 8 SWG, netting wire 10 SWG and binding wire 12 SWG
- Tight packing of stone

Reference:

MACCAFERRI Guidelines should be followed for design and construction of gabion structures

Mountain Risk Engineering Handbook Part II

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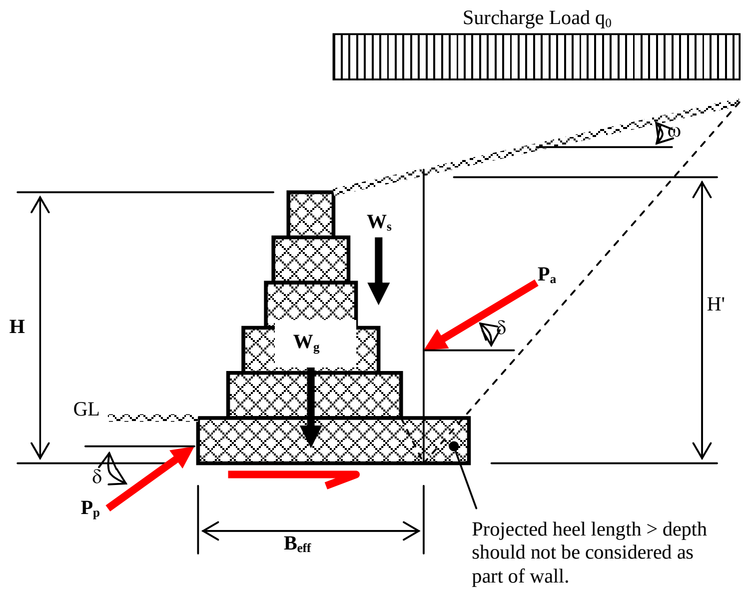
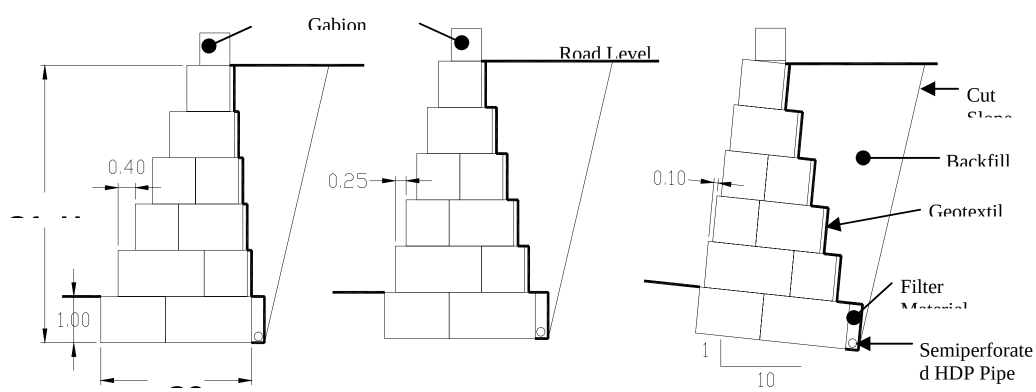
Guide to Slope Protection

Illustrative Examples

GABION WALL LOADING

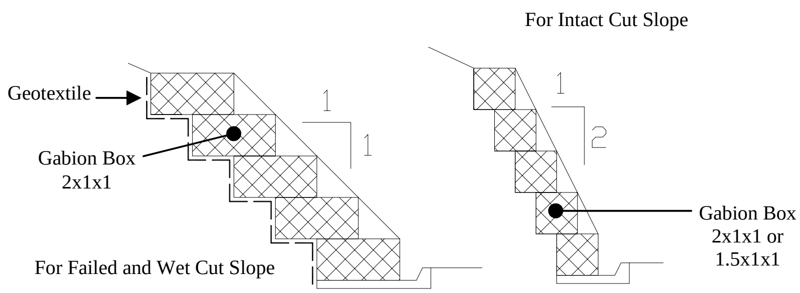
Based on MACCAFERRI Guidelines





Front Stepped **Symmetric** **Rear Stepped**

Gabion Walls



Gabion Breast Walls

Table C6.9 Results from Analysis of Gabion Wall

Wall Height (m)	Top Width (m)	Base Width (m)	Foundation Inclination (°)	Friction Angle (°)	Toe Pressure (t/m^2)	
					Front Stepped	Rear Stepped
3.0	1.0	2.0	1:10	30	-	7.7
4.0	1.0	2.5	1:10	30	-	10.7
5.0	1.0	3.0	1:10	30	4.7	13.7
6.0	1.0	3.5	1:10	30	9.4	16.7
7.0	1.0	4.0	1:10	30	13.8	19.55
8.0	1.0	4.5	1:10	30	18.2	22.4
9.0	1.0	5.0	1:10	30	22.5	25.3
10.0	1.0	5.5	1:10	30	26.7	28.1

Notes:

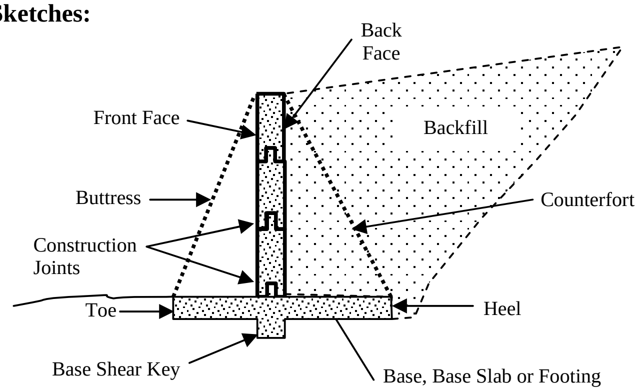
- Assumptions: minimum front batter = 1:5, wall friction angle = ϕ, level fill, good drainage, soil unit weight 1.7 t/m^3, wall unit weight 1.65 t/m^3, surcharge traffic load = 1.7 t/m^2 and lateral friction factor = tanϕ.
- The walls are adequately safe against overturning (FoS>2.0) and base slidig (FoS>1/5).
- Walls up to 3m height may be designed with rule of thumb.
- Walls with heights 4m to 6m may be designed on the basis of this table adjusting for width of foundation layer depending on bearing capacity.
- Walls higher than 6m require special investigation for bearing capacity and overall stability.
- Where bearing capacity is low, provide extra toe and heel projections (1.00m thick and 0.50m long).

Name of Measure:

C6.6 Cantilever Walls

Symbol:

Sketches:



Cantilever Wall Elements

Purpose / Function:

- Retaining backfill
- Supporting cut slope

Limitations:

- The wall is rigid
- Not suitable for unstable / moving foundations
- Not be suitable for wet colluvial slope

Design Considerations:

- 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
- For foundation at muddy layer, stone soling must be provided prior to blinding concrete
- For weak foundation either provide graded gravel layer 30 cm with 93% modified proctor or RCC mat to distribute soil pressure in wider strip
- For drainage, weep holes (75-100 mm in size) at 2-3 m^2 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
- Consider earth pressure at virtual back of wall i.e., vertical from end of heel
- Consider surcharge and weight of soil between web and virtual back of wall
- Where shear key is used, consider contribution of weight of soil below footing in sliding stability
- Only 50% of passive resistance should be considered

Specifications:

- Cement concrete of specified grade
- Types: L-shape, inverted-T, with or without shear key

Reference:

Guide to Retaining Wall Design, GEOGUIDE 1, Geotechnical Control Office, Hong Kong

Standard Specifications for Highway Bridges, AASHTO, 1996

Illustrative Examples

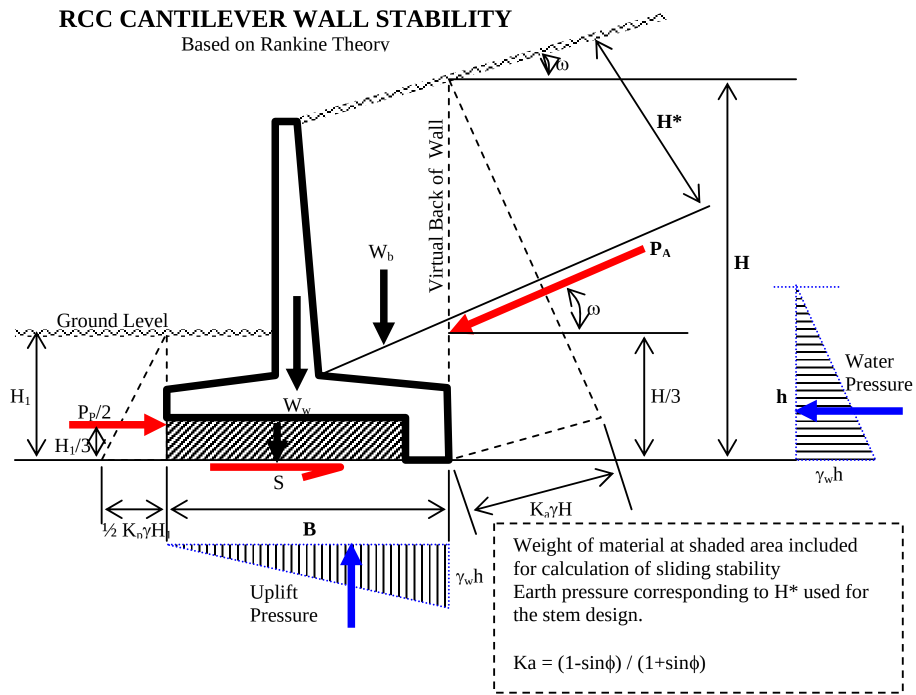


Table C6.10 Results from Analysis of RCC Wall

Wall Height (m)	Base Width (m)	Toe Length (m)	Heel Length (m)	Web Thickness (m)	Friction Angle (°)	Toe Pressure (t/m^2)
5.00	2.50	0	2.00	0.50	30	21.2
	2.50	1.00	1.00	0.50	30	11.0
6.00	3.00	0	2.50	0.50	30	24.5
	3.00	1.25	1.25	0.50	30	11.9
7.00	3.50	0	3.00	0.50	30	27.7
	3.50	1.50	1.50	0.50	30	12.7
8.00	3.50	0	3.00	0.50	30	36.2
	4.00	1.75	1.75	0.50	30	13.6
9.00	4.00	0	3.50	0.50	30	39.0
	4.50	2.00	2.00	0.50	30	14.4
10.00	4.50	0	4.00	0.50	30	41.8
	5.00	2.25	2.25	0.50	30	15.2

Notes:

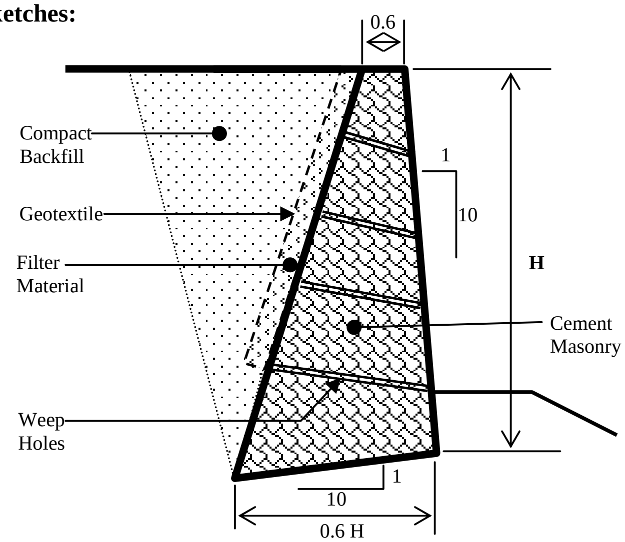
- Assumptions: web and foundation thickness = 0.50m, wall friction angle (at virtual back of wall) = ϕ, level fill, good drainage, soil unit weight 1.07 t/m^3, wall unit weight 2.50 t/m^3, surcharge traffic load = 1.0 t/m^2 and lateral friction factor = 0.45.
- The walls are adequately safe against overturning (FoS>2.0) and base slidig (FoS>1/5).
- Walls with heights 5m to 8m may be designed on the basis of this table adjusting for lengths of heel and toe depending on bearing capacity.
- Walls higher than 6m require special investigation for bearing capacity and overall stability.
- Where bearing capacity is low, adopt symmetric section and provide extra toe and heel lengths.
- Where base sliding is critical provide shear key at heel side.
- Normal dimensions with 25% toe length and 75% heel length may be adopted, however, the analysis should be repeated.
- Rankine formula may be used for analysis for surcharged backfill slope, provided the earth pressure direction is kept parallel to the surcharged angle.
- The width of base slab and web may be constant as long as the desired moment of resistance is achieved at the critical base and web sections.

Name of Measure:

C6.7 Cement Masonry Walls

Symbol:

Sketches:



Purpose / Function:

- Retaining backfill
- Supporting cut slope

Limitations:

- The wall is rigid and brittle
- Not suitable for unstable / moving foundations
- Impermeable structure may not be suitable for wet colluvial slope

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 m^2 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
- At unstable area, spacing of joints should be reduced to 6m.

Specifications:

- Good quality stone
- Cement mortar of specified grade
- Types: random rubble masonry, coursed rubble masonry or ashlar masonry

Reference:

Mountain Risk Engineering Handbook Part II

Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

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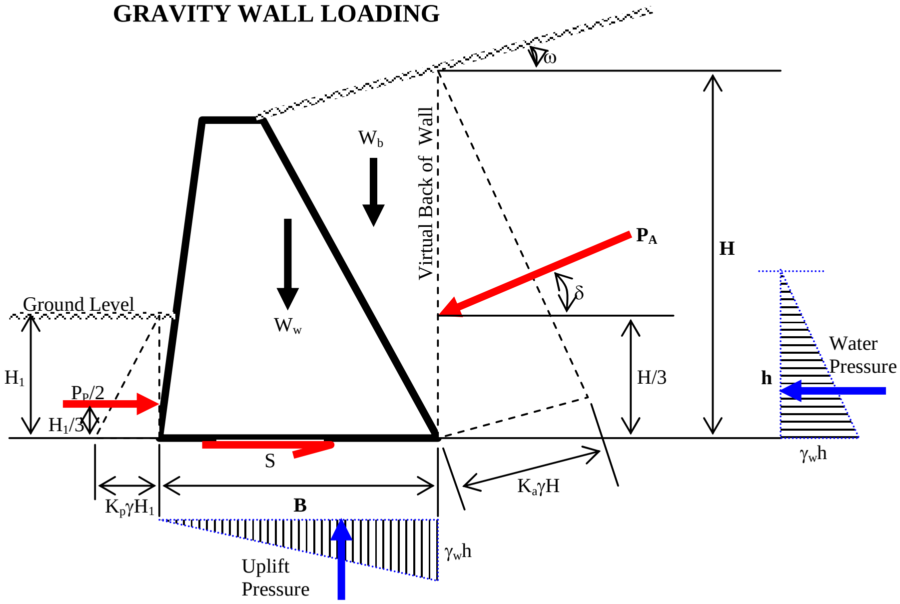
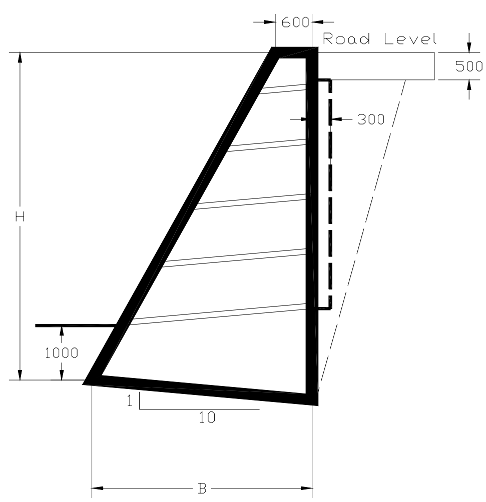
GRAVITY WALL LOADING



Rankine Theory
Ka = (1-sinϕ) / (1+sinϕ)
δ = ω

Coulomb Theory
$K_a = \sin^2(\beta+\phi) / \sin^2\beta / \sin(\beta-\delta) / [1+(\sin(\phi+\delta)\sin(\phi-\omega) / \sin(\beta-\delta) / \sin(\beta+\omega))^{1/2}]^2$
δ = ϕ for gabion - soil interface
= 2ϕ/3 for cement masonry - soil interface
= ϕ/2 for cement concrete - soil interface

Note: Both Rankine and Coulomb theories may be used for smooth soil-structure interface and low surcharged backfills (< 15°). However, for steep surcharged backfill and rough soil-structure interface, Coulomb theory provides more representative earth pressure.



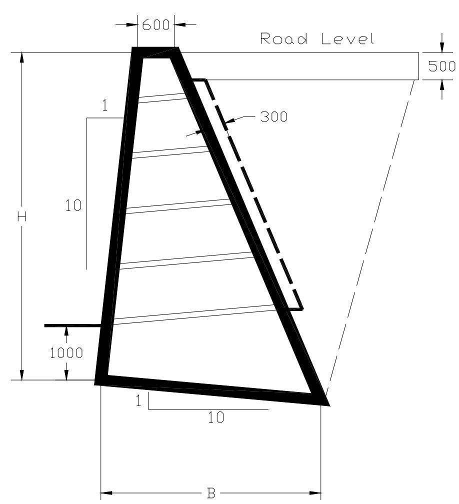


Table C6.11 Results from Analysis of Cement Masonry Wall

Wall Height (m)	Top Width (m)	Base Width (m)	Foundation Inclination (°)	Friction Angle (°)	Toe Pressure (t/m^2)	
					Front Battered	Back Battered
3.0	0.6	1.8	1:10	30	4.9	15.1
4.0	0.6	2.4	1:10	30	11.5	19.1
5.0	0.6	3.0	1:10	30	17.1	22.9
6.0	0.6	3.6	1:10	30	22.1	26.7
7.0	0.6	4.2	1:10	30	26.9	30.4
8.0	0.6	4.8	1:10	30	31.5	34.0
9.0	0.6	5.4	1:10	30	36.0	37.6
10.0	0.6	6.0	1:10	30	40.5	41.3

Notes:

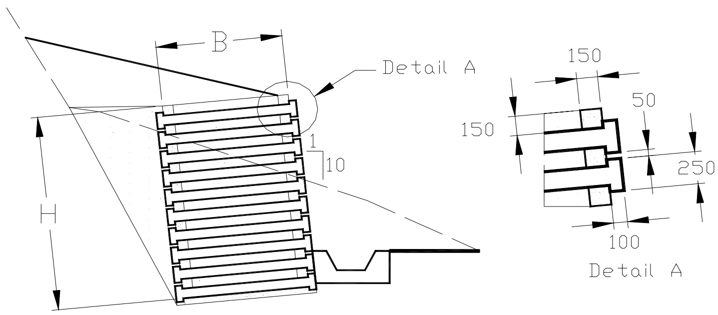
- Assumed: minimum front batter = 1:10, wall friction angle = 2ϕ/3, level fill, good drainage, soil unit weight 1.7 t/m^3, wall unit weight 2.2 t/m^3, surcharge load = 1.7 t/m^2 and lateral friction factor = 0.6.
- The walls are adequately safe against overturning (FoS>2.0) and base slidig (FoS>1/5).
- Walls up to 3m height may be designed with rule of thumb and walls with heights 4m to 6m may be designed on the basis of this table.
- Walls higher than 6m require foundation investigation for bearing capacity and overall stability.
- Where bearing capacity is low, provide extra toe and heel projection (0.75m thick and 0.50m long).

Name of Measure:

C6.8 Crib Walls

Symbol:

Sketches:



Typical Crib Wall

Purpose / Function:

- Retaining backfill
- Supporting cut slope

Limitations:

- Joints not fixed, segmental elements
- Standard design to be limited to 8 m height

Design Considerations:

- Entire unit behaves as a gravity wall
- Can resist some differential settlement and deformation
- Stringers designed as simply supported beams
- Earth pressure behind the wall same as that for gravity wall
- Stability calculation should include failure surface above the toe of the wall
- Check for base sliding same as that for gravity wall
- Check for over turning should exclude weight of soil within the crib wall
- Soil inside the crib wall may not work as integral part of wall
- Apply standard design for height up to 8 m

Specifications:

- Material options: timber, precast reinforced concreete or prefabricated steel
- Core fill with granular material

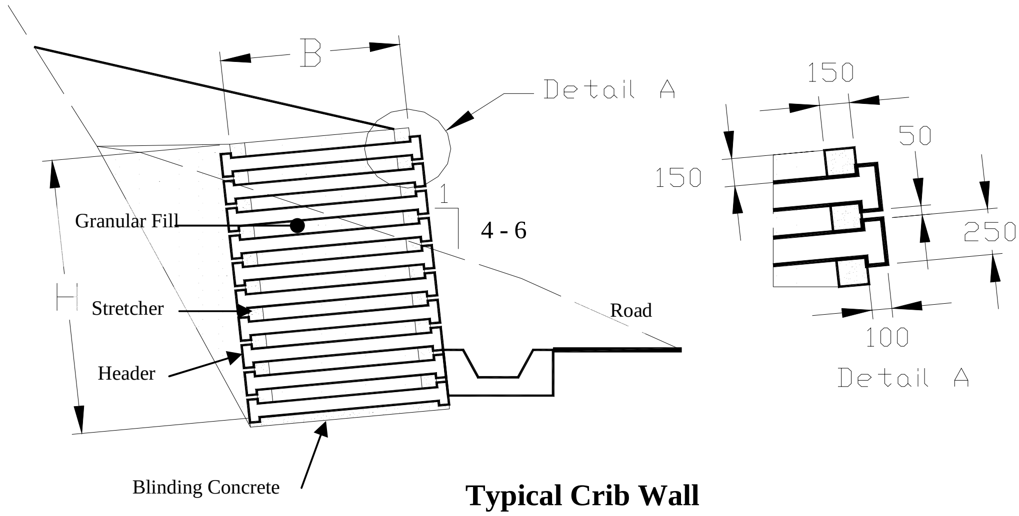
Reference:

Mountain Risk Engineering Handbook Part II

Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

Guide to Slope Protection

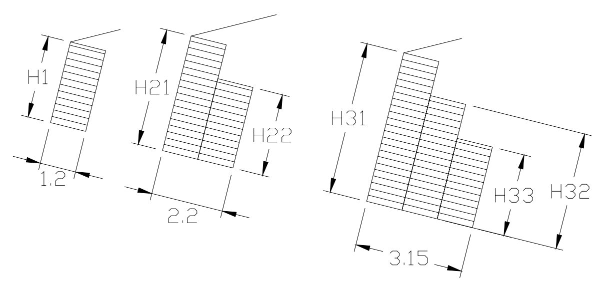
Geoguide 1: Guide to Retaining Wall Design

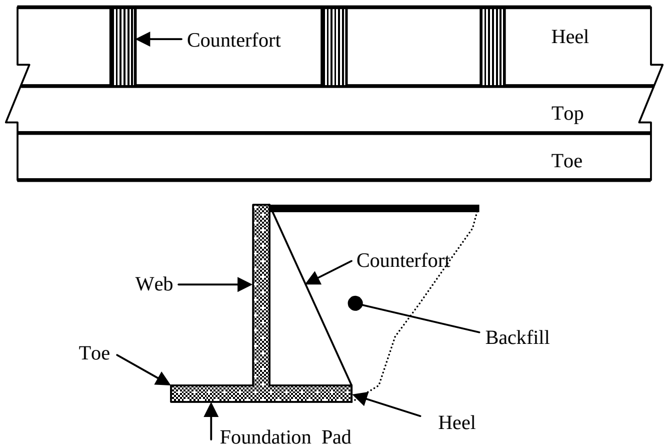


Typical Crib Wall

Table C6. 12 Crib Wall Design Guidelines

Type	**Hmax** (m)	**B** (m)	**Assumptions**: ϕ=30°, c=0, δ=20°, γ_s=1.95 t/m^3, γ_w=1.55 t/m^3, front batter = 1:4, live load = 0.6m of soil, $F_{sliding}$ = 1.50, $F_{overturning}$ = 2.0, surcharge fill angle = 0.
H1	**3.00**	**1.20**	
H21	**5.50**	**2.20**	
H22	**4.00**		
H31	**8.30**	**3.15**	
H32	**7.20**		
H33	**5.30**		



<table>
<tr><td>Name of Measure:
C6.9 Buttressed or Counterfort Walls</td><td>Symbol:</td></tr>
<tr><td>Sketches:


RCC Counterfort Retaining Wall</td><td>Purpose / Function:
Retaining backfill
Supporting cut slope
Limitations:
The wall is rigid
Not suitable for unstable / moving foundations
Not be suitable for wet colluvial slope</td></tr>
<tr><td>Design Considerations:
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 (5 cm) of blinding concrete is required
For drainage, weep holes (75-100 mm in size) at 2-3 m^2 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
Consider earth pressure at virtual back of wall i.e., vertical from end of heel
Consider surcharge and weight of soil between web and virtual back of wall
Where shear key is used, consider contribution of weight of soil below footing in sliding stability
Only 50% of passive resistance should be considered
Design counterforts as T-beams
Design buttresses as rectangular beams</td><td>Specifications:
Cement concrete of specified grade
Types: counterfort or buttressed walls
Reference:
Guide to Retaining Wall Design, GEOGUIDE 1, Geotechnical Control Office, Hong Kong

Standard Specifications for Highway Bridges, AASHTO, 1996</td></tr>
</table>

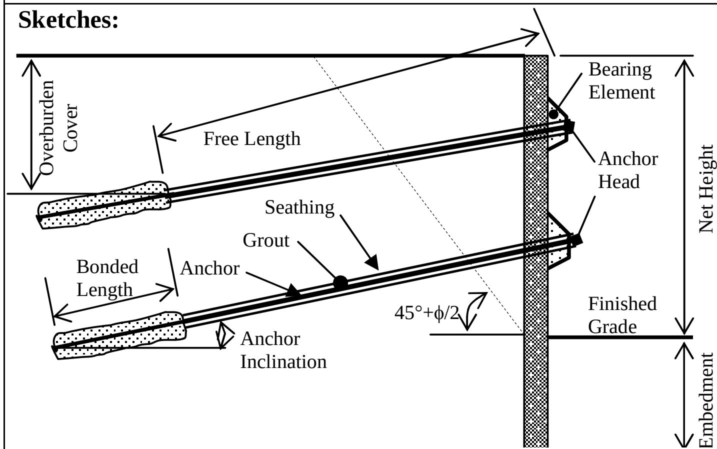
C7 Tied-back Walls

Name of Measure:

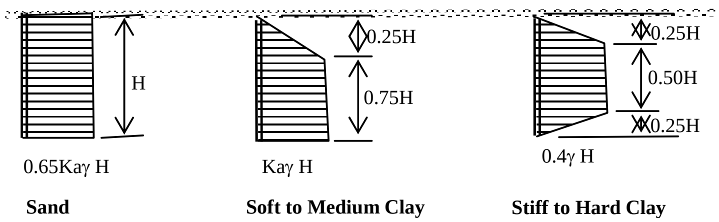
C7.1 Anchored Walls

Symbol:

Sketches:



Earth Pressure on Anchored Walls with two or more Levels of Anchors



Purpose / Function:

- Retaining backfill
- Supporting cut slope

Limitations:

- Wall height generally limited to 4 m
- Ensuring full grout and grout quality is critical

Design Considerations:

- External check such as overall stability, base sliding, overturning and bearing pressure same as that for general wall structure
- Used where earth pressure cannot be transferred entirely in the foundation
- Wall panels are designed as beams resting on column strips
- Each wall panel supports a uniform load equal to total earth pressure in the panel
- Ties are anchored to the rock or firm soil by cement grout
- Bond strength: 50 (stiff clay) to 150 kN/m^2 (hard rock)
- Untensioned anchors develop tension due to outward movement of wall during compaction of embankment
- The wall may be composite with gabion wall with concrete anchored strips as buttresses
- For foundation in soil, provide a blinding layer of lean concrete (5 cm)
- For foundation in muddy condition, provide stone soling prior to blinding concrete
- For very weak soil formation, provide RCC mat foundation to distribute vertical load in wider strip
- Ensure compaction of foundation to at least 93% modified proctor value

Specifications:

- Anchor tendon: high yield strength bar or cable strands
- Wall structure: RCC or composite RCC and gabion

Reference:

Mountain Risk Engineering Handbook Part II

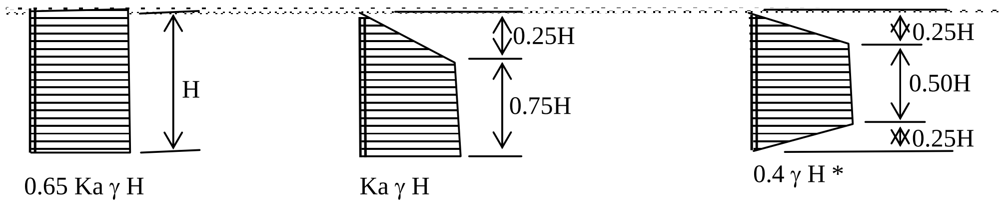
Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

AASHTO Standard Specifications for Highway Bridges

Guide to Slope Protection

Apparent Earth Pressure Distribution

Earth Pressure on Anchored Walls with two or more Levels of Anchors

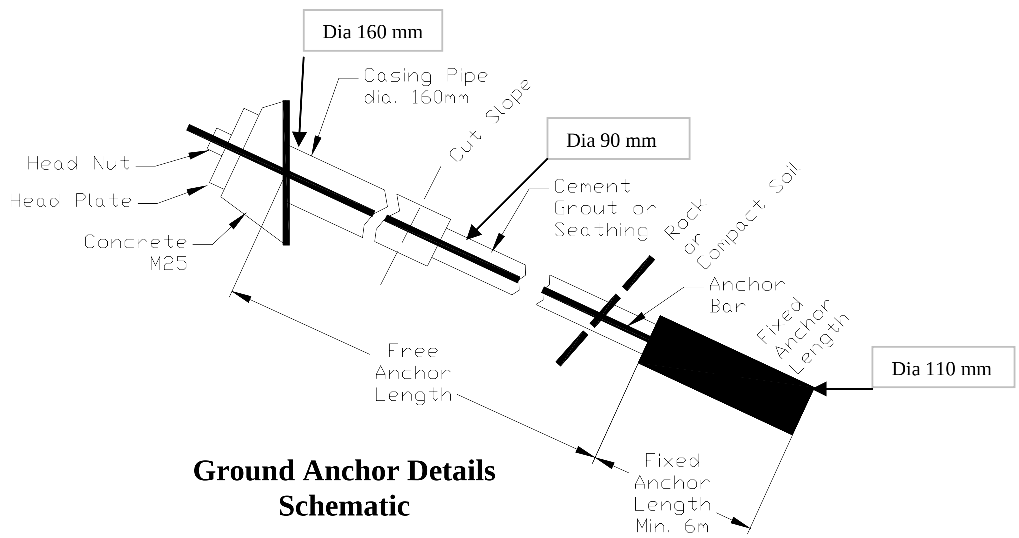


Sand (or permanent walls in clay)

Soft to Medium Clay $q_u = 2.5$ to $10\ t/m^2$

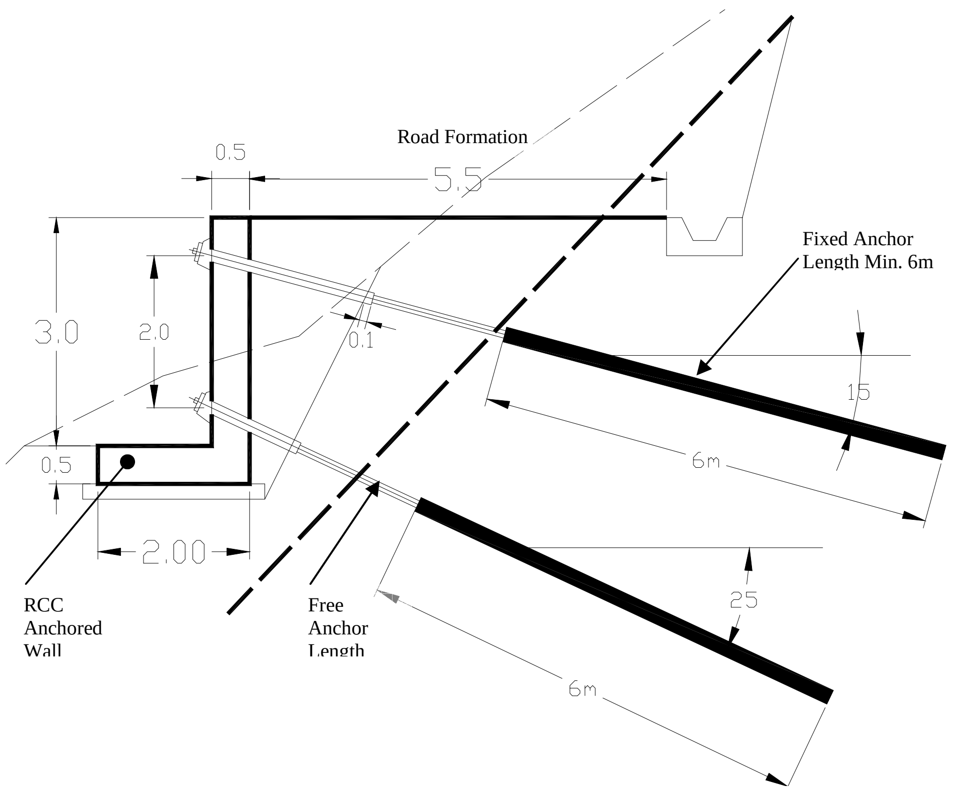
Stiff to Hard Clay $q_u > 10\ t/m^2$

1. $K_a = \tan^2(45-\phi/2)$ for **sand**
2. $K_a = 1 - m(2\ q_u / \gamma H) \geq 0.25$ for **clays** where, m = 1 for overconsolidated clays, m = 0.4 for normally consolidated clay
3. Coefficient 0.4 for long term and 0.2 to 0.4 for short term conditions
4. Surcharge and water pressures must be added
5. Last two diagrams not valid for permanent walls or walls where water table lies above bottom of excavation



Ground Anchor Details Schematic

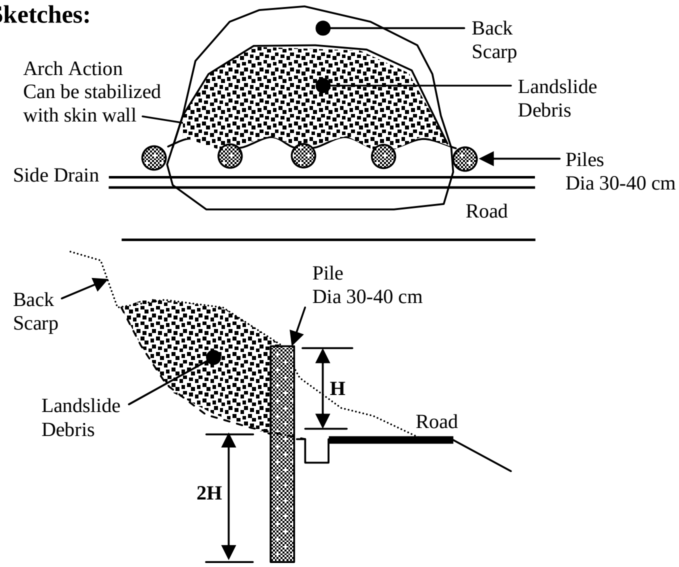
Illustrative Examples



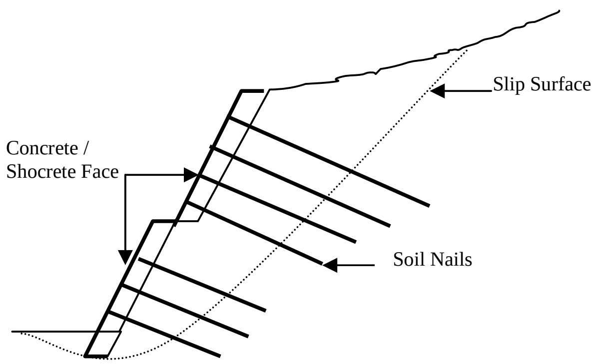
Anchored Wall Details

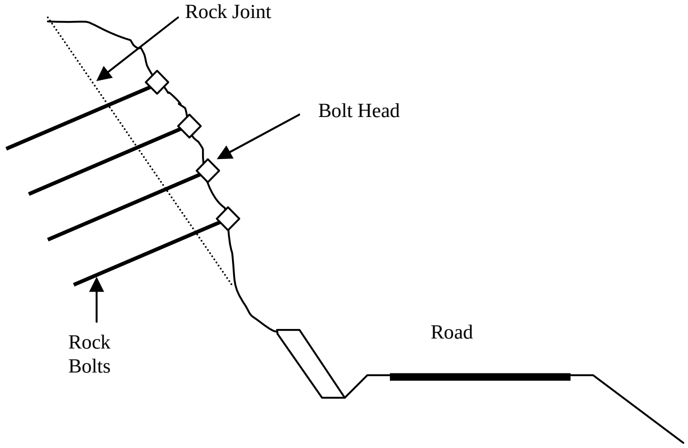
Note: For soils, the direction of anchors is as shown in the above sketches. However, for anchors on rocks, the direction should be as far as possible perpendicular to the bedding or jointing critical to slope instability.

C8 Piles

Name of Measure: ***C8.1 Pile Work***	**Symbol:**
Sketches: 	**Purpose / Function:** • Increase resistance against sliding by bending and shear strength **Limitations:** • Competent bed rock to withstand moving soil mass is essential • Unsuitable for creeping speed of more than 1mm per day • Old technology used by frames / bamboo poles • Construction in active slide is difficult
Design Considerations: • Designed to work individually • Shearing piles installed at compressive zone (toe part) • Bending piles are installed at tensile zone (head part) • Driven piles: H-section steel pile, sheet pile, reinforced concrete pile, steel pipe pile driven with pile driving machine • Inserted piles: H-section steel pile, sheet pile, reinforced concrete pile, steel pipe pile placed in prebored hole and concreted and cement grouted • Cast-in-situ pile: borehole up to bed rock, RCC construction in-situ • Check maximum bending moment • Ensure no cracking by shear force or bending • Check maximum deflection: should not cause creacks in surrounding soil • Check that landslide mass between piles must not slide down: keep spacing less than 2 m for piles of 30 to 40 cm dia. • To check passive failure, install piles at lower part of slide	**Specifications:** • Design should take bending and compression • At least two-thirds should be embedded below ground surface **Reference:** Mountain Risk Engineering Handbook Part II Guide to Slope Protection

C9 Anchors and Bolts

Name of Measure: ***C9.1 Soil Nails***	**Symbol:**
Sketches: 	**Purpose / Function:** • Stabilize small-scale unstable soil slopes • Reinforce embankments • Increase shearing strength • Reduce tension in unstable slope **Limitations:** • High cost • Requires special equipment • Requires special expertise • Uses imported materials • Not suitable in loose sandy soils and soft clay • Less commonly used in Nepal
Design Considerations: • Slender steel nails inserted into soil layer • Soil nail types: flexible nails (inserted through drillling, grouting and absorb tension), stiff nailing (directly inserted withouth grout and take shear, bending and some tension in slope) • For safer design, assume that all nails take only tension • Stability analysis simlar to that of an anchored slope • Effective in firm, dense and low-plasticity soils • Not suitable in loose sandy soil and soft clay • Normally 1 soil nail per 1 to 6 m^2 of soile surface combined with shotcrete / concrete facing • Standard nail sizes: 12 to 32 mm diameter, length < 5m	**Specifications:** • Nails shall conform to appropriate specification of steel • Grouting shall be with neat cement grout **Reference:** Mountain Risk Engineering Handbook Part II Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice Guide to Slope Protection

<table>
<tr><td>Name of Measure:
C9.2 Rock Bolts</td><td>Symbol:</td></tr>
<tr><td rowspan="2">Sketches:

</td><td>Purpose / Function:
• Reduce driving force</td></tr>
<tr><td>Limitations:
• Limited to right of way
• Construction uphill is difficult</td></tr>
<tr><td rowspan="2">Design Considerations:
• Usually with bar tendons
• Protect from plane failure or wedge failure in rock mass
• Forms monolithic mosaic joining unstable part to stable rock mass
• No structural work required except anchor head that fits to the rock face</td><td>Specifications:
• Process: drilling inclined hole, placing bar tendon, grouting with cement, placing and fitting anchor head</td></tr>
<tr><td>Reference:

Mountain Risk Engineering Handbook Part II

Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

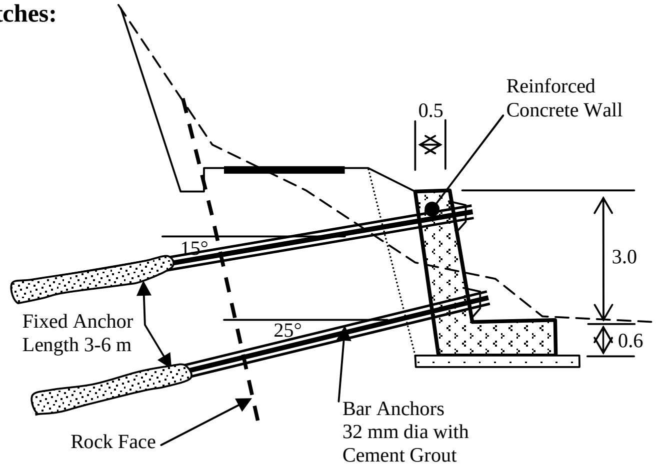
Guide to Slope Protection</td></tr>
</table>

Name of Measure:

C9.3 Ground Anchors

Symbol:

Sketches:



Purpose / Function:

- Transfer load to firm strata
- Increase stabilizing force
- Prevent collapse or rock falls
- Connect unstable part to stable bedrock or firm soil

Limitations:

- High cost
- Requires special equipment
- Requires special expertise
- Requires foreign materials

Design Considerations:

- Three types: rock bolting, earth / rock anchor, rock anchor
- Ground anchor types: friction type, bearing type or combination
- Friction type transfers active pressure only through skin friction developed at grout surface which depends on contact surface area, consolidation and rock / soil characteristics
- Bearing type mobilizes passive earth resistance due to under reams or expanded end at root zone which depends on bearing area, consolidation and rock / soil characteristics
- Ground anchors are combined with light walls of piles
- Light walls transfer active earth pressure to anchor and take up compressive force exerted on it
- Information needed: soil / rock characteristics, joints , strengths fo various strata, water table
- Design must be continuously updated basd on actual drilling bore logs and photographic views druing construction
- Usually inclined downward for gravity flow of grout
- Where pressure grouting with rubber gasket is possible, anchor may be inclined upward
- Desirable grouting pressure 0.2 N/m^2 per meter overburden
- Working load of 25 mm anchor bar 250 kN
- Anchor pull out test: at least 3 or more than 5% of total number of anchors loading up to 1.3 times working load
- Formula: $T=\pi DL\tau$, where T is ultimate tension, D is diameter of bar, L is fixed anchor length and τ is shear resistance between anchor system and soil mass in fixed anchor zone (normally 1500-2500 kN/m^2 for hard rock, 500-1500 N/m^2 for soft of weathered rock)

Specifications:

- Entire process of anchor installation should be supervised
- High yield steel bars, fy=830 to 1030 N/mm^2, continuously threaded complete with couplings, end plate, head assembly, centralizers, grouting pipe slots

Reference:

Mountain Risk Engineering Handbook Part II

Guide to Slope Protection

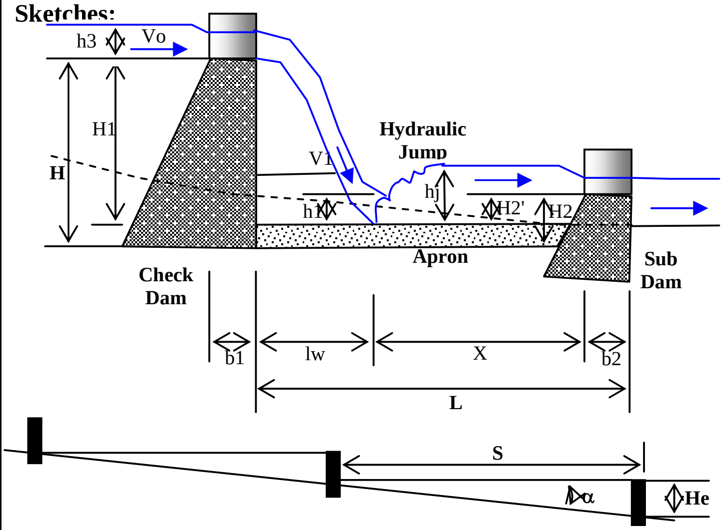
C10 Check Dams

Name of Measure:

C10.1 Check Dams

Symbol:

Sketches:



Purpose / Function:

- Prevent erosion at bed and banks
- Retard and guide debris flow
- Reduce damage by debris flow
- Reduce flow velocity
- Improve bed slope stability
- Capture and retain sediment
- Improve bank stability

Limitations:

- Narrow gorge, good foundation and keying possibility are rare

Design Considerations:

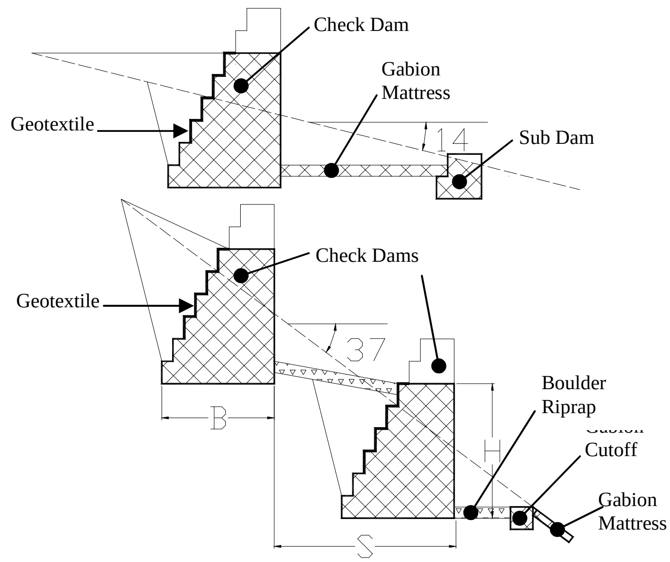
- Location and size determined according to purpose
- Dam height depends on bed slope, dam spacing, sediment discharge and purpose (depositing or stabilizing)
- For depositing purpose, widely spaced high check dams are used
- For stabilizing purpose, closely spaced low heigh check dams are used
- Spacing $\mathbf{S=H_e /KG \cos\alpha}$, where H_e is effective dam height, G is $\tan\alpha$, α is bed slope and K is constant specific to gully varying from 0.3 to 0.5
- Dam should be located in stable ground or narrow gorge with good foundation and lateral keying possibilities with wider upstream section
- For dam height > 15 m, bearing capacity and permeability of foundation rock essential
- Foundation treatment required where dam foundation is weak
- Checks for bearing pressure, settlement and base sliding should be considered
- Arching with concave surface downstream increases check dam strength
- At fragile bank conditions, bank revetment and side walls are required at upstream and downstream of check dam
- For high check dams with large discharge, suitable apron structure with inverted filters is required at stilling pool
- Discharge over check dam is calculated at broad-creseted weir
- Foundation depth and length of apron are dependent on discharge, discharge, drop height and bed materials

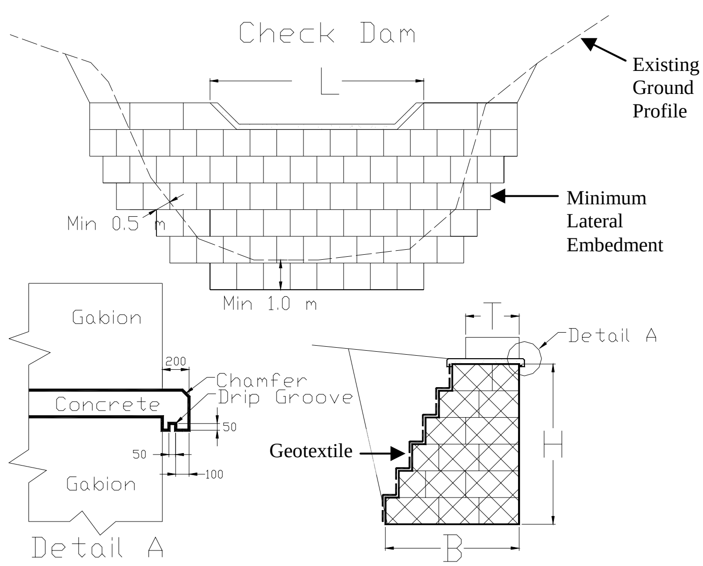
Specifications:

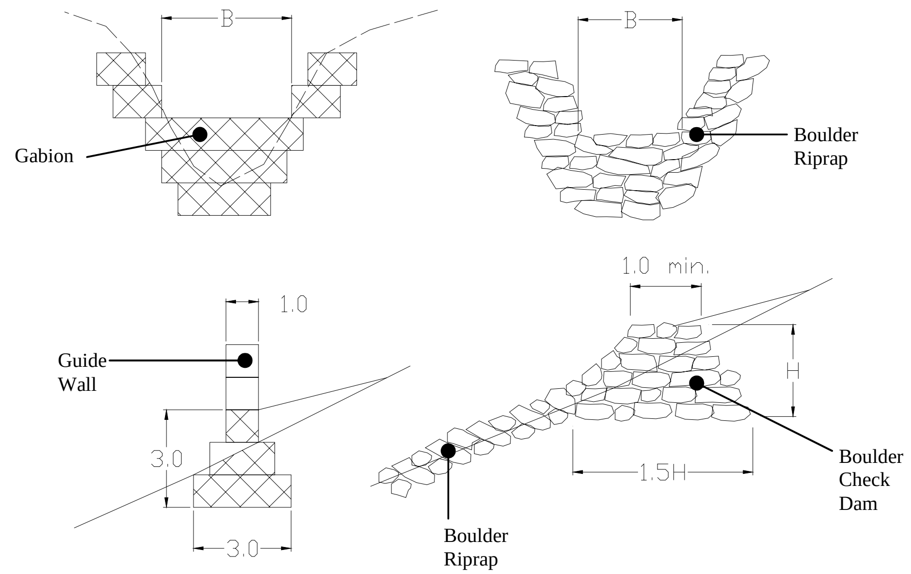
- Material options: gabions, cement masonry, concrete, reinforced concrete, steel / timber crib
- Dam location in stable ground

Reference:

Illustrative Examples






B
B
Gabion
Boulder
Riprap
1.0 min.
1.0
Guide
Wall
H
3.0
1.5H
3.0
Boulder
Check
Dam
Boulder
Riprap

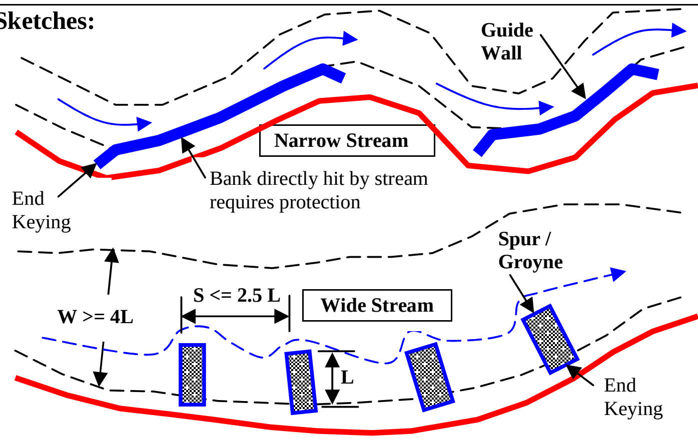
C11 Bank Protection Work

Name of Measure:

C11.1 Bank Protection

Symbol:

Sketches:



Purpose / Function:

- Protect erodible bank
- Help retain toe of road embankment
- Protect from further bank cutting

Limitations:

- Rock armouring requires special equipment and skill
- Precast concrete blocks require special lifting equipment and skill
- Rivers in hills have high velocity of flow
- :Yet to be tested / documented in Nepal context

Design Considerations:

- No traditional formula for assessing hydraulic characteristics and determining of local scour for young streams
- Gabion spurs or revetments in young rivers develop early breakage of wires
- Gabion or masonry launching aprons are ineffective due to early breakage of wires or loss of stones
- Provide cement masonry revetments with foundation below scour depth with
  - reinforced concrete facing up to annual flood level
  - cement masonry up to 5 year flood level and
  - gabion wall / mattresses up to 20 year flood level
- Upstream and downstream ends of the revetments should be properly keyed
- Local flow velocity may be assemed as 2V where V is average velocity of flow of river
- Where revetments are placed above scour depth, provide launching aprons with
  - flexibly connected concrete frames with boulder/gabion infill should be provided for flow velocity up to 3 m/s
  - flexibly connected precast concrete blocks or boulders of sizes appropriate for flow velocity
  - graded boulder / concrete block / tetrapole riprap
- Avoid using isolated big boulders or CABs
- Avoid use of massive gabion or stone masonry structure for emergency and short-term measure
- Align new roads at least 60 m above water level to avoid expensive river training works
- Model studies are advised before application of massive protection works
- For rivers in plains, gravel / cobble spurs with block lining at all exposed face may be suitable

Specifications:

- Guide wall should not encroach river flow.
- Series of spurs is required to effectively protect bank.
- Spacing between spurs should be limited to 2.5 times spur length
- Spur length shoud be limited to 25% of stream width

Reference:

Mountain Risk Engineering Handbook Part II

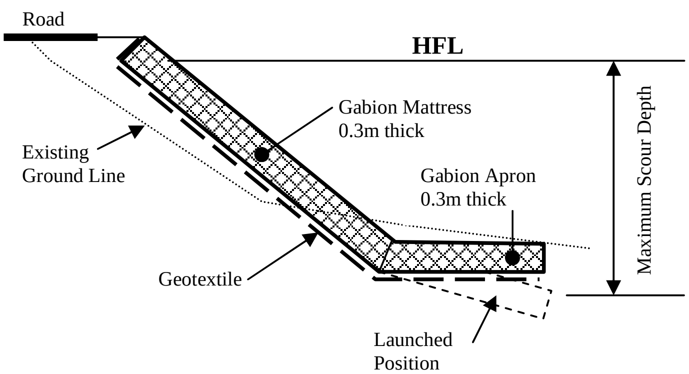
Guide to Slope Protection

Name of Measure:

C11.2 Revetment

Symbol:

Sketches:



Purpose / Function:

- Safeguard erodible bank
- Help retain toe of road embankment
- Protect from further bank cuttinng

Limitations:

- Foundation excavation and dewatering is cumbersome
- Possibility of bank destabilization during foundation construction

Design Considerations:

- Gabion spurs or revetments in young rivers develop early breakage of wires
- Compute flood levels of 1, 5 and 20 year return periods or estimate from the observation of flood marks at banks
- Compute local scour depth from traditional formulae or estimate from the observation of deepest thalweg profile
- The revetment section could be in the form of lining work, breast wall or retaining wall depending on the space availability
- Provide cement masonry revetments in mountain stream with foundation below scour depth with
  - reinforced concrete facing up to annual flood level
  - cement masonry up to 5 year flood level and
  - gabion wall / mattresses up to 20 year flood level
- Upstream and downstream ends of the revetments should be properly keyed to the firm banks
- Local flow velocity may be assemed as 2V where V is average velocity of flow of river
- Where revetments are placed above scour depth, provide launching aprons with
  - flexibly connected concrete frames with boulder/gabion infilled panels should be provided for flow velocity up to 3 m/s
  - flexibly connected precast concrete blocks or boulders of sizes appropriate for flow velocity
  - graded boulder / concrete block / tetrapole riprap
- For rivers in plains, gravel / cobble spurs with block lining at all exposed face may be suitable
- For the design of revetment structure consider submergence effect during high flows, draw down effect when flood rapidly decreases, earth pressure etc.
- For streams in plains, gabion revetments, concrete framed gabion infilled revetments or articulated concrete blocks or panels could be adopted

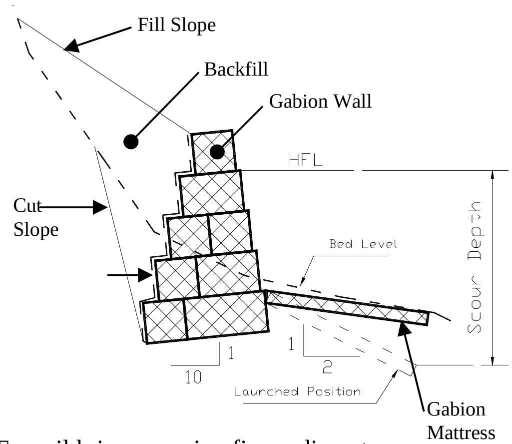
Specifications:

- Material options: concrete, cement masonry, gabion, concrete blocks/panels
- Design life minimum 20 years
- Provide weep holes with proper filter fabric and filter material behind spur to avoid leaching out of fines due to recurring drawdowns

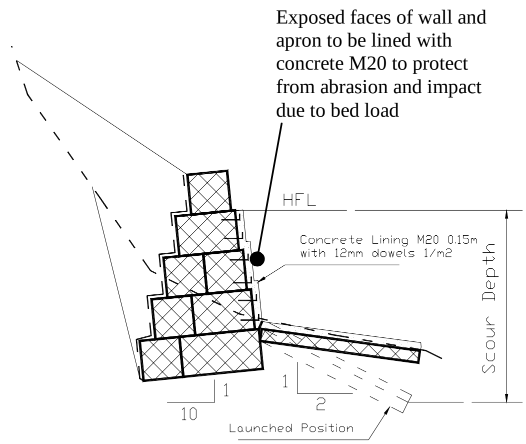
Reference:

Mountain Risk Engineering Handbook Part II

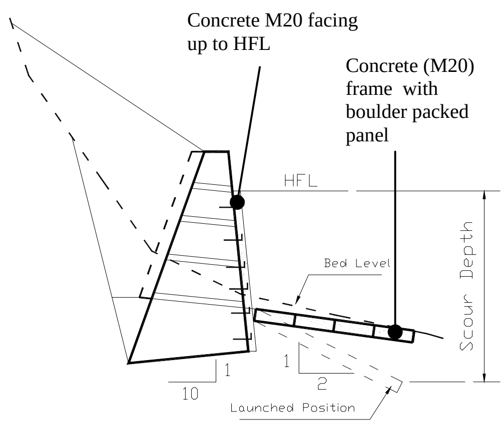
Guide to Slope Protection



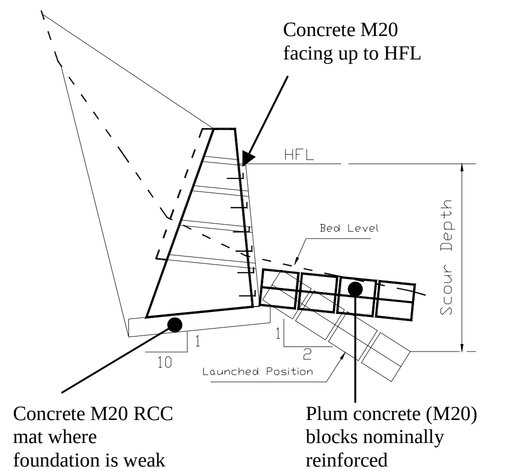
For mild river carrying fine sediment



For alluvial river carrying gravel and cobbles as bed load



For mountain stream with water velocity less than 3 m/s



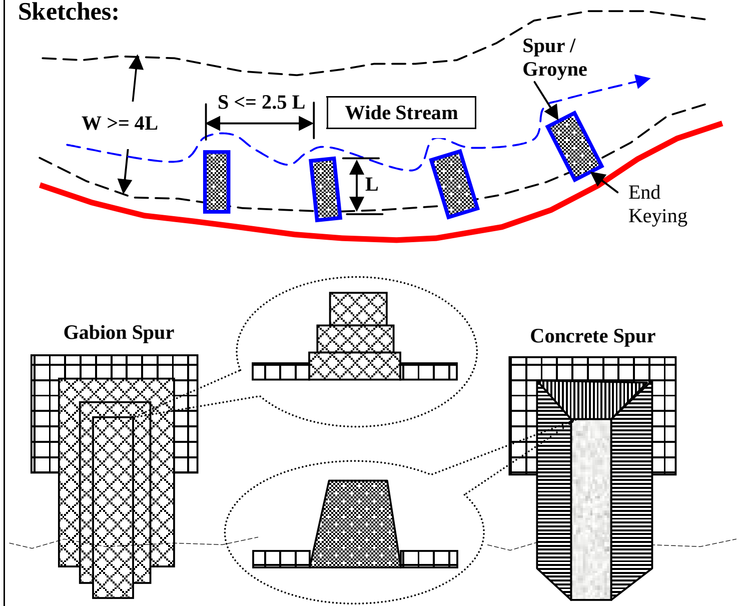
For mountain stream with water velocity 3-6 m/s
Due attention to be paid in quality control in plum concrete

Name of Measure:

C11.3 Spurs / Groynes

Symbol:

Sketches:



Purpose / Function:

- Protect erodible river bank
- Divert flow away from bank
- Induces deposition at downstream side

Limitations:

- Narrow width of mountain streams does not permit use of spurs
- Scour around spur head is high
- Spur head is most vulnerable
- May affect other bank or downstream works adversely

Design Considerations:

- Suitable in wide river beds
- Usually in series, isolated spurs have limited effect
- Length of spur should be no more than 25% of width of river
- Distance between spurs should be no more than 2.5 times length
- Scour around spur head is maximum and hence spur head should be better founded or protected with wider launching apron on all three sides
- Top of spur should be above HFL of 5 year return period. Occasional overflow during higher floods may be permitted
- Design of spur section must consider hydrostatic pressure due to difference in water level at upstream and downstream, hydraulic impact of flowing water
- Local scour depth computation at spur head should consider constricted river width
- Where coarse sediment or debris abrassion is anticipated, the exposed faces of spur must be lined with Concrete or concreted panels.
- For boulder reaches of streams, spur body must be protected with concrete panels

Specifications:

- Instead of isolated spurs, a group of spurs should be provided at spacing not exceeding 2.5 times exposed length of spur.
- Spur head is the most critical and hence propoer launching apron shoud be provided around spur head.

Reference:

Mountain Risk Engineering Handbook Part II

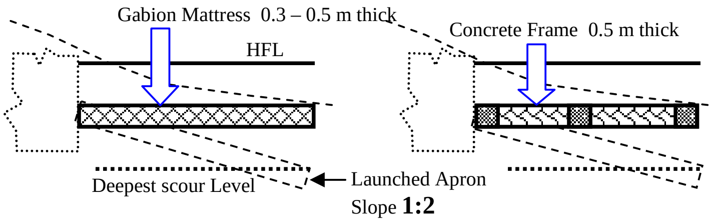
Guide to Slope Protection

Name of Measure:

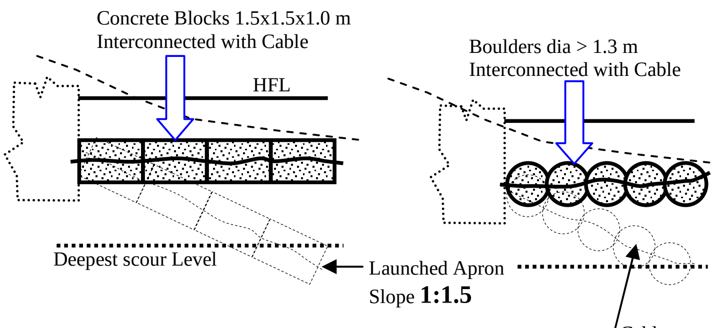
C11.4 Launching Aprons

Symbol:

Sketches:



For Water Velocity < 3 m/s



For Water Velocity 3 - 6 m/s

Design Considerations:

- Foundation of main structure must be embedded at least 1 m below top of launching apron
- Compute maximum general scour using
    - traditional Lacey's formulae or
    - estimate from field observation of deepest (thalweg) level or
    - from hydrological study of nearby bridge site
- Determine local scour depth below apron level
- Determine minimum length of launching apron as $\sqrt{5} \times d_s$
- Determine local flow velocity $V_l = 2V$
- Determine suitable block diameter as per local flow velocity $d = 0.04 \times V_l^2$ where Vl in m/s and d in m
- Fix connection / placement details
- For local flow velocity < 3 m/s, gabion or concrete frame apron with gabion infilled panels may be suitable
- For local flow velocity > 3 m/s, concrete blocks, armoured boulders or concrete armoured blocks may be required
- Introduce roughness elements in smooth surfaced launching aprons
- Where heavy bed load with coarse sediment or debris, the exposed surface of launching apron should be provided with flexible lining

Purpose / Function:

- Protect main structure from scour
- Adjusts to bed level change

Limitations:

- Armoured concrete blocks and boulders require special equipment
- High cost for fast flowing streams in mountain reaches

Specifications:

- Material options: gabion, boulder riprap, concret frame with gabion infilled panels, concrete blocks, tetrapoles, armour boulder etc.
- Connections should be flexibly connected to accommodate movements / deformations

Reference:

Mountain Risk Engineering Handbook Part II

Guide to Slope Protection

Table C11.1 Size of Boulders for Riprap Works

Local Velocity (m/s)	Diameter of Isolated Boulder (m)	Diameter of Interconnected Boulders (m)	Local Velocity (m/s)	Diameter of Isolated Boulder (m)	Diameter of Interconnected Boulders (m)
0.5	0.01	0.01	5.5	1.21	0.91
1.0	0.04	0.03	6.0	1.44	1.08
1.5	0.09	0.07	6.5	1.69	1.27
2.0	0.16	0.12	7.0	1.96	1.47
2.5	0.25	0.19	7.5	2.25	1.69
3.0	0.36	0.27	8.0	2.56	1.92
3.5	0.49	0.37	8.5	2.89	2.17
4.0	0.64	0.48	9.0	3.24	2.43
4.5	0.81	0.61	9.5	3.61	2.71
5.0	1.00	0.75	10.0	4.00	3.00

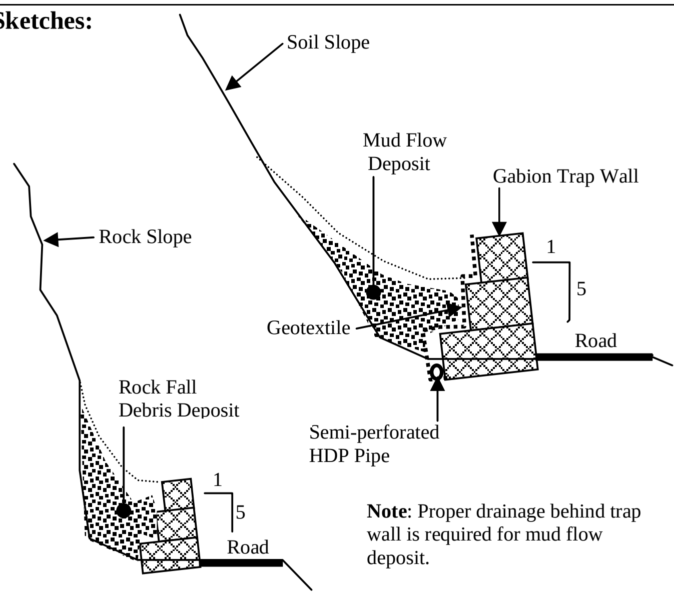
C12 Catchworks

Name of Measure:

C12.1 Trap Walls

Symbol:

Sketches:



Purpose / Function:

- Contains slide / fall debris material
- Helps improve traffic safety
- Allows time to haul debris material to spoil areas
- Successfully used in Jogimara landslide, Dhading, Prithvi Rajmarg

Limitations:

- Not applicable at narrow road stretches
- Brittle wall structure not suitable

Design Considerations:

- Design wall to retain anticipated debris material
- Provide access track to allow equipment for clearing
- Provide cushioning at the top and back face to protect wall structure
- Provide free draining material at heel where mud retention is planned.

Specifications:

- Adequate space is required for retention
- Height should be enough to safeguard vehicles

Reference:

Mountain Risk Engineering Handbook Part II

Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

Guide to Slope Protection

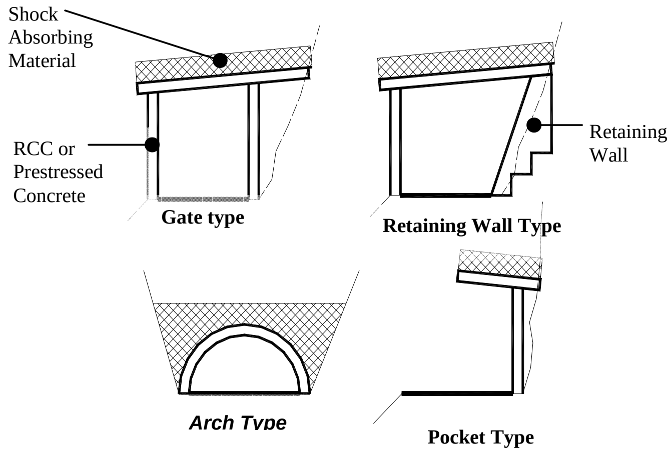
Refer guidelines for design of retaining wall section

Name of Measure:

C12.2 Rock Sheds

Symbol:

Sketches:



Rock Sheds

Purpose / Function:

- Contains slide / fall debris material
- Helps improve traffic safety
- Allows time to haul debris material to spoil areas

Limitations:

- Not applicable at narrow road stretches
- Not applicable for mud flows
- Yet to be tried in Nepal context but cout be interesting

Design Considerations:

- Design fence to retain anticipated debris material
- Provide access track to allow equipment for clearing
- Provide wire mesh at the back face to protect fence elements

Specifications:

- Sufficient head room should be provided for vehicles
- Structural design should take into account of surcharge load and possible impacts / abrasion

Reference:

Mountain Risk Engineering Handbook Part II

Landslide Risk Assessment in the Rural Sector: Guideline on Best Practice

Guide to Slope Protection

Refer guidelines for design of retaining wall section

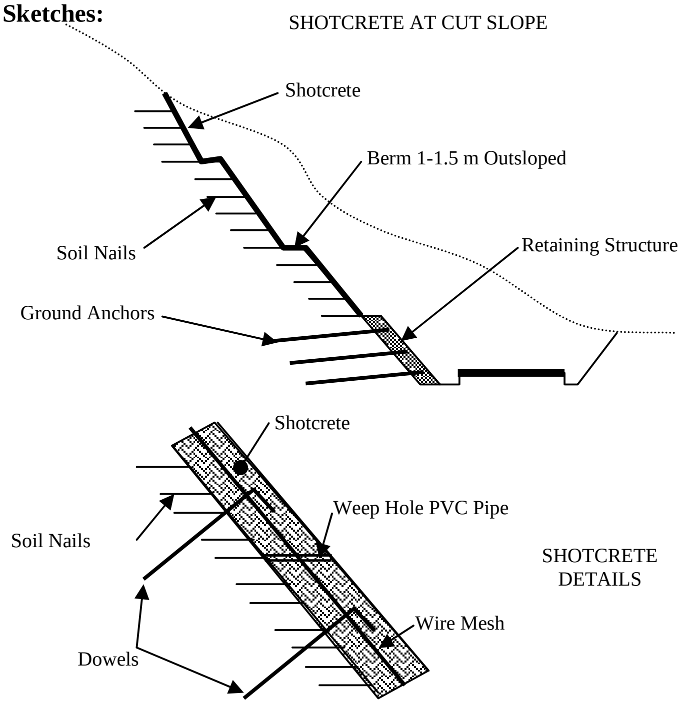
C13 Surface Protection Work

Name of Measure:

C13.1 Shotcrete Work

Symbol:

Sketches:



Purpose / Function:

- Prevent external weathering and erosion of rock surface
- Reduce risk of rock falls and shallow slope failures in highly weathered and heavily jointed rocks

Limitations:

- May be counter-productive where seepage and springs exist
- Requires special pneumatic pressure equipment
- Requires special skill
- Vegetative structures cannot be applied
- Does not reduce earth pressure at slope

Design Considerations:

- Thickness of shotcrete determined considering slope condition and weathering condition
- Standard thickness 8-10 cm for mortar and 10-20 cm for concrete
- Cement mortar shotcrete is considered short-term solution
- Permanent shotcrete may require reinforcement mesh and rock bolts / soil nails @ 1-2 per m^2
- Spraying methods: dry spraying and wet spraying (commonly used)
- Clean surface with compressed air and spray shotcrete from top to bottom
- Embed top of shotcrete in firm ground
- Provide weep holes with pipes at least 1 in 2-4 m^2
- Ensure sufficient drainage of springs or seepage prior to spraying of shotcrete in wet areas

Specifications:

- Suitable for steep slopes of highly weathered ro heavily fractured rocks
- Material: cement mortar (1:3 or 1:4) w/c ratio 45%-50% or concrete (1:3:1 or 1:5:2) with w/c ratio 40%-45%
- Reinforcement options: welded-wire mesh or steel fibre mixed concrete
- Bolts / nails fully encased in shotcrete

Reference:

Mountain Risk Engineering Handbook Part II

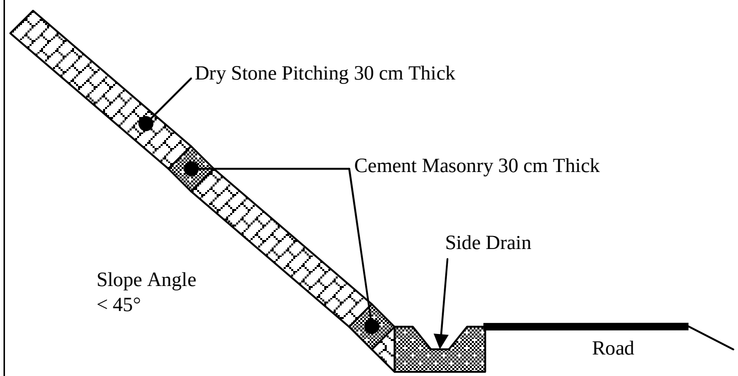
Guide to Slope Protection

Name of Measure:

C13.2 Pitching Work

Symbol:

Sketches:



Purpose / Function:

- Prevent slope erosion and external weathering action
- Reduce risk of shallow cut slope failures

Limitations:

- Limited to right of way
- Good workmanship is required for pitching works

Design Considerations:

- Applicable in slope < 45º in non-cohesive sediments, mudstone and collapsible clayey soils
- A layer of graded filter or geotextilefilter should be placed underneath pitching works where seepage and springs are encountered
- In-situ concrete pitching used in fractured rock slope with possibility of stripping
- For steeper rock slopes, shotcrete with reinforcement mesh and rock bolts is required
- Proper cleaning of surface prior to concreting is essential to avoid gaps between slope surface and concrete
- Thickness of pitching depend on slope gradient and purpose

Specifications:

- Materials: stone, boulder, concrete block or concrete

Reference:

Refer shotcrete and rock bolts for treatment of steeper rock slopes
Refer to Table for standard pitching works

Mountain Risk Engineering Handbook Part II

Guide to Slope Protection

Standard Design:

Table C13. 1 Standard Pitching Works

Type of pitching	Pitching thickness (m)	Slope gradient (V:H)	Height (m)	Geological condition
Stone / boulder	0.25 – 0.35	1:1.0 – 1:1.2	<5.0	Sediments talus cone, mudstone and collapsible clayey soils
	< 0.25	1:1.2 – 1:1.5		
Concrete block	0.25 – 0.35	1:1.0 – 1:1.15	< 3.0	
	0.14 – 0.18	1:1.5 – 1:1.8		
Concrete	< 0.20	< 1:0.5		For large steep slopes of bed rock with fractured joints
Reinforced concrete	< 0.20	> 1:0.5		

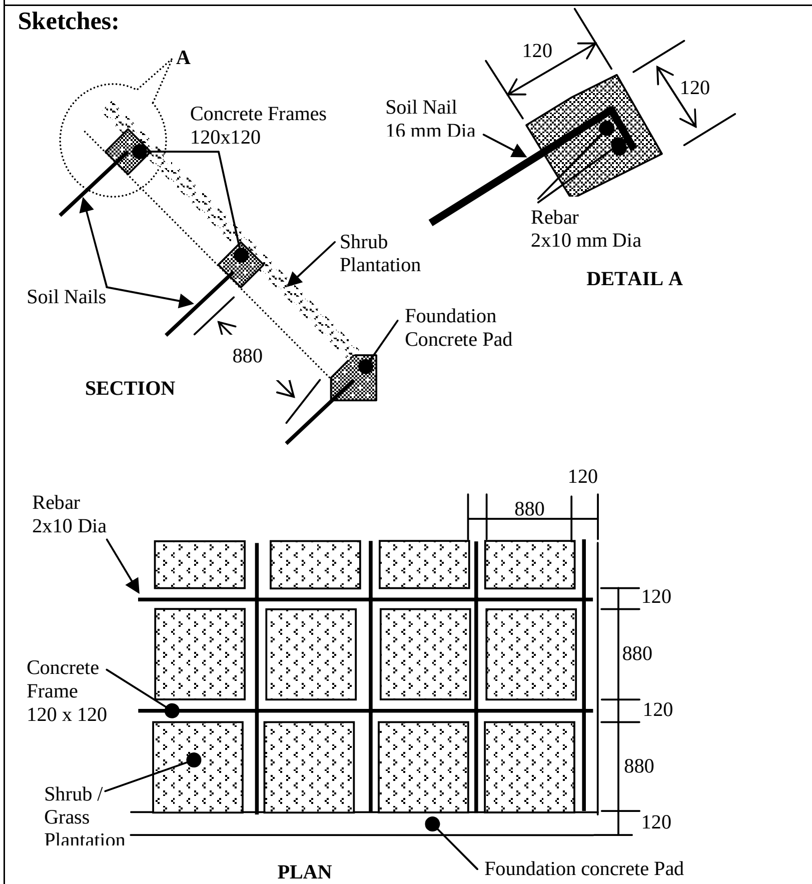
Source: Guide to Slope Protection

Name of Measure:

C13.3 Frame Work

Symbol:

Sketches:



Purpose / Function:

- Prevent surface weathering, scouring and erosion
- Control shallow slope failures

Limitations:

- Not suitable for steeper slopes
- Not designed to resist active earth pressure of unstable slopes
- Greenary and aesthetic is adversely affected

Design Considerations:

- Suitable for slope gradient less than 1:0.8 where vegetation alone cannot check slope failure
- Provides some resistance due to concrete crib, cast-in-situ concree or cement masonry works
- Materials: frame with concrete crib work, cast-in-situ concrete or cement masonry and panels with stone, boulder, concrete pitching, shotcrete or vegetation
- Commonly used on large slopes of highly weathered or fractured rocks with spring water where falling of slope material cannont be fixed with shotcrete work
- Concrete block frame work used in slopes < 1:0.8 (V:H) and where vegetation is not suitable
- Cast-in-situ concrete frame works used where stability of slope with block frame works is questionable in long term

Specifications:

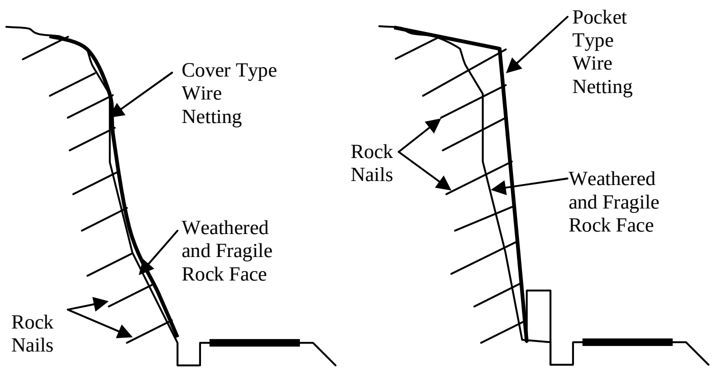
- Frame sizes: 120x120 to 500x500 mm @ 2-5 m intervals partially embedded in slope
- Frame joints to be anchored with steel anchor rod 25 mm dia, 50-100 cm long

Reference:

Mountain Risk Engineering Handbook Part II

Guide to Slope Protection

<table>
<tr>
<td>Name of Measure:
C13.4 Wire Netting</td>
<td>Symbol:</td>
</tr>
<tr>
<td rowspan="2">Sketches:



COVER TYPE WIRE NETTING POCKET TYPE WIRE NETTING</td>
<td>Purpose / Function:

Prevent rock fall from weatherd and highly jointed rock surface
Protect traffic from possible rock falls
Stop stones to reach the road traffic zone
Absorb impact energy of falling rocks
</td>
</tr>
<tr>
<td>Limitations:

Require anchoring points at top and withih the slope
Requires special skill for installation
</td>
</tr>
<tr>
<td rowspan="2">Design Considerations:

Cover type netting restrains rock fall through tension in the net and friction between rock and ground
Pocket type netting catches falling stones between slope and net and energy of falling stone is absorbed by the net
Size of net depends on slope surface condition and size of rock fall
Wire net diameter should be capable fo resitng its own weight and weight of falling stone
Net anchors should have enough strength and stability to withstand dead load and live load due to falling rocks
For pocket type netting, kinetic energy of falling stones are considered which should be absorbed by net and anchors.
Absorbable strength of net should be higher than possible energy of falling stone
Regular inspection and removal fo the fallen stones should be carried out recurrently
Where rock fall netting is not possible, rockshed, tunnelling and rock barrier structure / fence should be provided
Design of rock shed / barrier / fence depend upon the resistance for the falling stone energy and its impact on the structure
Rock shed materials: reinforced concrete, prestressed concrete ans steel
Rock shed types: gate type, arch type, retainign wall type, pocket type
Rock shed cushion: minimum 90 cm thick sand or other shock absorbing material
</td>
<td>Specifications:

Materials: wire rope, galvanized wire
Methods: cover type rock fall prevention net and pocket type rock fall prevention net

</td>
</tr>
<tr>
<td>Reference:

Mountain Risk Engineering Handbook Part II

Guide to Slope Protection</td>
</tr>
</table>

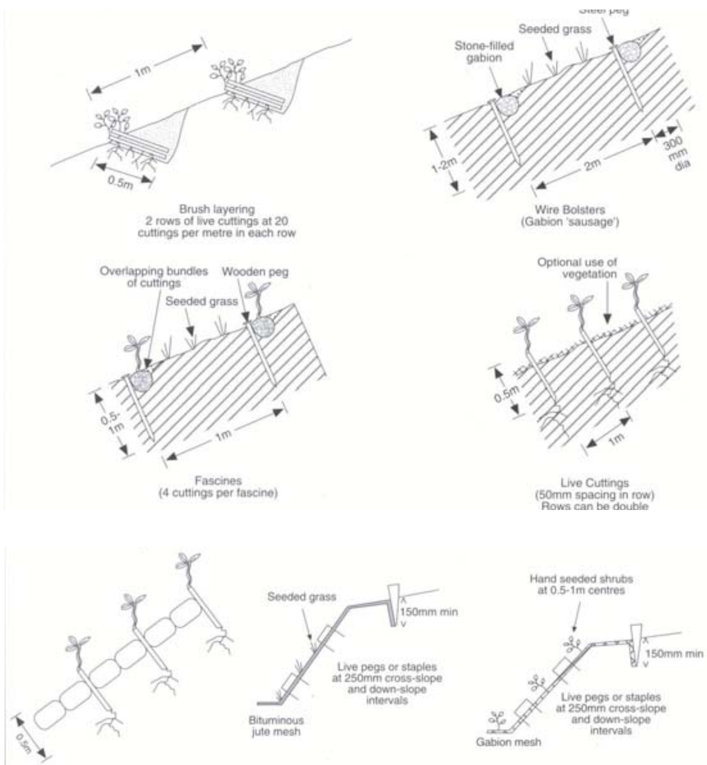
C14 Bioengineering

Name of Measure:

C14.1 Bioengineering

Symbol:

Sketches:



Purpose / Function:

- Protect slope from erosion in bare slopes
- Reduces possibility of shallow seated instabilities
- Catch eroding materials moving down the slope
- Armoru slope against surface erosion from runoff and rainsplash
- Reinforce soil by providing network of roots increasing soil resistance
- Anchr surfae material extending roots through potential failure plane into firmer strata below
- Support soil mass by buttressing and arching
- Drain excess water from soil mass

Limitations:

- Limited to right of way
- Unstable bares slopes with potential of frequent slope failures are unsuitable for bioengineering

Design Considerations:

- Reference should be made to **Roadside Bio-engineering Site Hand Book** and **Reference Manual**
- Can be applied alone in marginally stable bare slope or embankment slope
- Can be applied in combination with other civil engineering measures such as drainage, structures or surface protection works

Specifications:

- Separate Roadside Bio-engineering Site Hand Book and Reference Manual should be referred

Reference:

Roadside Bio-engineering Site Hand Book and Reference Manual

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